UNIVERSITÁ DEGLI STUDI "ROMA TRE"

FACOLTÀ DI LETTERE E FILOSOFIA

DOTTORATO DI RICERCA IN
FILOSOFIA E TEORIE DELLE SCIENZE UMANE
XXI CICLO

TESI DI DOTTORATO

**PRELUDES TO ONTIC STRUCTURAL REALISM
- Eddington and Weyl –
a Theoretic Route from General Relativity to Quantum Mechanics
through the Theory of Groups**

DOTTORANDA:
MIRIAM COMETTO

DIRETTORE DI TESI:
Chiar.mo prof. MAURO DORATO

COORDINATORE DEL DOTTORATO:
Chiar.mo prof. PAOLO D'ANGELO

ANNO ACCADEMICO 2008 - 2009

Amore e Vita voglio cantare..

ai miei genitori
Paolo e Mariana

INDICE

INTRODUZIONE

Una profonda alleanza tra fisica e geometria: è questa una delle caratteristiche comuni nella ricerca dell' astronomo A.S.Eddington e del matematico H.Weyl. Dall'emergere di questo intimo legame tra le due discipline, Eddington formulò una delle prime tesi strutturaliste in filosofia della scienza, ponendosi tra i referenti storici di una controverso filone interpretativo sullo statuto della conoscenza scientifica, ripreso recentemente dai sostenitori del *RSO* all'interno del dibattito sul realismo scientifico. L'oggetto della nostra ricerca è il percorso teorico che dalla riflessione epistemologica di Eddington conduce ai recenti sviluppi strutturalisti in seno a tale dibattito sulla portata epistemica, semantica e/o ontologica delle teorie scientifiche.

Tale percorso trova un fondamentale nutrimento nel profondo connubio tra scienze matematiche e fisiche testimoniato dal pensiero di Hermann Weyl e dall'opera che questi, insieme a E. Wigner, portò avanti intorno agli anni '30, sulla 'traduzione' della teoria dei gruppi di trasformazione nella Meccanica Quantistica . Difatti la prospettiva di Eddington manifesta una singolare caratterizzazione, dal momento che la struttura-universo investigata dalla fisica è per lui "*the structure of the kind investigated in the mathematical group theory*" (Eddington 1939:147).

Dall'opera di questi autori emerge una profonda riflessione sul linguaggio delle fondamentali teorie scientifiche del Novecento, Relatività e Meccanica Quantistica, i cui esiti concettuali si rivelano assai fruttuosi per una più ampia comprensione dei requisiti necessari ad una metafisica idonea per la scienza contemporanea.

Nell'introdurre il lavoro si cercherà, nelle pagine seguenti, di fornire un quadro unitario del perché sia auspicabile e in parte necessario riscoprire quelli che sono da considerare i 'padri fondatori' di una prospettiva recentemente recuperata. Questo obiettivo non può essere tuttavia perseguito senza una previa, sia pur breve, introduzione al *RSO*. Essa metterà in luce da un lato le motivazioni che alimentano la pretesa di costituire una genuina e necessaria alternativa alle posizioni realiste, dall'altro le principali difficoltà che questa posizione incontra, in particolare nel produrre una soddisfacente definizione della nozione chiave di *struttura*.

Sulla base di queste due direttrici la ricerca si volge, con intenti differenti, all'opera di A.S.Eddington, B.Russell ed H.Weyl nella convinzione che la sistematicità con la quale questi autori affrontano le questioni epistemologiche portando alla luce i nodi concettuali soggiacenti, si riveli molto utile per la chiarificazione delle problematiche centrali nelle recenti posizioni. Anche quando sono autori di formazione scientifica, ritengono che la riflessione filosofica dia compimento al loro lavoro scientifico. E curiosamente tale elaborazione origina, in ciascuno dei casi presentati, dalla rivoluzione operata dalla teoria della Relatività di A. Einstein. Dalle loro riflessioni appaiono con chiarezza i motivi per cui la teoria della Relatività e la Meccanica Quantistica suggeriscano un approccio strutturalista, motivando implicitamente il rinnovato interesse della filosofia della scienza per gli aspetti strutturali della conoscenza scientifica, caratteristico degli ultimi decenni. L'aspetto forse più significativo per la genesi del questo punto di vista risiede nel sodalizio crescente tra gli sviluppi del pensiero matematico, in particolare geometrico, e quelli del pensiero fisico. Lo studio condotto rivela difatti una riflessione affatto isolata, e nondimeno privata della dovuta risonanza, generata da una profonda analisi concettuale delle nozioni fondamentali coinvolte nelle teorie scientifiche considerate.

Ripercorrere il cammino aperto da questi autori ha senz'altro il pregio di presentare all'attenzione del lettore un pensiero vivo, profondo e articolato, che riflette su se stesso, su ciò che gli sta di fronte e sui propri strumenti ermeneutici ed epistemologici con l'acume e la profondità propri di grandi menti scientifiche (qualora matematiche, qualora fisiche, qualora filosofiche). E in questa riflessione elabora una tesi epistemologica forte che si

nutre degli esiti della ricerca fisico-matematica per la comprensione di due nozioni fondamentali, quali la nozione di spazio e soprattutto la nozione di oggetto.

Per comprenderne la capacità dialogica rispetto al dibattito attuale, occorre in primo luogo presentare, sia pur a grandi linee, i nodi centrali di tale dibattito. Il *Realismo Strutturale* è un approccio alla conoscenza scientifica che focalizza l'attenzione su (*a*) la rete di relazioni esistenti fra oggetti fisici e sintetizzata dalle teorie scientifiche attraverso le equazioni (realismo strutturale epistemico) e/o (*b*) la rete di relazioni e relata costituenti la struttura fisica/trama della realtà in cui le relazioni acquisiscono un primato rispetto ai relata stessi (RSO). Esso nasce come tesi epistemica (*a*) per rispondere ad alcune difficoltà che il realismo incontra nel dar conto dei radicali mutamenti ontologici caratteristici del cambiamento teorico (Laudan, 1981: la storia della scienza è un cimitero di teorie –ed ontologie- abbandonate). Come posizione sullo status della conoscenza umana, il realismo strutturale pone i limiti di ciò che possiamo conoscere in alcuni *aspetti strutturali* della realtà. In altre parole, l'apparato formale delle teorie scientifiche avrebbe la capacità di 'sintetizzare' le relazioni fondamentali tra le entità del mondo fisico: l'approccio epistemico, come specificato in una serie di saggi di John Worrall ed Ellie Zahar, pubblicati a partire dal 1989, accetta di essere realista su tali aspetti strutturali, rinunciando ad avanzare tesi sull'ontologia di riferimento. Si traccia così il percorso della continuità scientifica nel solco di quelle strutture matematiche che risultano suscettibili di essere rintracciate nel passaggio da una teoria precedente ad una successiva. L'ottimismo epistemico nei confronti delle teorie è bilanciato da un agnosticismo rispetto all'ontologia delle teorie stesse, che rimarrebbe preclusa alla nostra conoscenza. L'esempio paradigmatico di tale continuità è fornito, secondo questi autori, dalle equazioni di Fresnel per la riflessione e rifrazione della luce, che sono perfettamente derivabili nel contesto della teoria elettromagnetica di Maxwell, sebbene il quadro ontologico di riferimento sia radicalmente cambiato. In contrasto con l'agnosticismo degli strutturalisti epistemici, le posizioni ontiche avanzano pretese esattamente sulla ontologia delle teorie scientifiche, proponendo un'ontologia di strutture.

Il problema dell'oggetto fisico e il RSO

Le motivazioni fondamentali delle posizioni ontiche di realismo strutturale risiedono nella sottodeterminazione metafisica che caratterizza la Meccanica Quantistica laddove

possiamo adottare una metafisica di particelle individuali come pure una metafisica priva di individui: ci troviamo così di fronte ad una teoria compatibile con due metafisiche di tipo differente (cfr. Teller, 1998; French and Krause, 2006).

In questo ambito si riflette dunque una difficoltà legata allo statuto problematico degli oggetti microfisici: la definizione, costituzione e caratterizzazione cambia dal mondo classico a quello quantistico. Le entità fisiche del mondo classico sono 'individui' dotati di ben definite proprietà, alcune delle quali indipendenti dal resto del mondo (proprietà intrinseche). Tali entità sono addirittura definite in base alle proprietà che possiedono e soprattutto sono distinte sulla base di esse, obbedendo in tal modo al principio di identità degli indiscernibili (PII) formulato da Leibniz e chiaramente espresso nel carteggio con Clarke: gli indiscernibili sono identici (sono lo stesso oggetto), dunque due individui diversi avranno almeno una proprietà che li distingue (la loro posizione nello spazio e nel tempo).

Gli oggetti quantistici possiedono invece delle caratteristiche peculiari, derivabili da una teoria che di per sé fornisce delle distribuzioni di probabilità relative a certi risultati di misura. *Dai principi* di questa teoria, emergono alcune caratteristiche:

1) per il principio di indeterminazione la posizione e la quantità di moto (e dunque velocità) di una particella quantistica non possono essere identificate simultaneamente;

2) il formalismo della Meccanica Quantistica è fatto di vettori di stato del tipo $|\Psi\rangle$, la cui interpretazione è controversa: la modalità standard di considerarli è formulata nell'interpretazione di Copenhagen (interpretazione realista) secondo cui ciascun vettore è riferito ad un oggetto in senso macroscopico(individuale), ossia ad un singolo elettrone, ad esempio, in un ciclotrone; da ciò deriva che due particelle descritte da vettori di stato identici sono considerate identiche, violando PII.

3) l'evoluzione dello stato quantistico segue strani percorsi perché ha la possibilità di "separarsi": negli esperimenti sull'interferenza, un neutrone che attraversa un interferometro (a neutroni) è come se si separasse seguendo due cammini differenti e producendo così un fenomeno di interferenza in contrasto con il dato empirico immediato (l'impressione sullo schermo) che invece suggerisce che esso percorra solo uno dei due possibili cammini.

4) abbiamo l'*entanglement*, come prodotto di qualsiasi interazione: sistemi di particelle interagenti sono in uno stato di sovrapposizione e dopo una

loro interazione non è più possibile assegnare loro vettori di stato separati. Le correlazioni tra i 2 sottosistemi di $|\Psi\rangle$ non sono di tipo classico.

Interpretazioni alternative di queste situazioni peculiari della Meccanica Quantistica si sono mosse nella direzione di non considerare gli stati come riferiti ad individui, bensì ad insiemi di oggetti microscopici[1], laddove per insiemi si intende un numero infinito o almeno molto elevato di oggetti microscopici preparati identicamente, come può essere un fascio di elettroni preparati in un ciclotrone, in modo da consentire la stabilità delle frequenze relative dei risultati di misura al variare del numero di oggetti. In ogni caso ci si trova tuttavia di fronte ad oggetti fisici identici ma distinti, dunque a violazioni del principio al quale si lega, a torto o a ragione, la nozione di "individualità" nel mondo macroscopico.

Il primo ambito su cui si ripercuote, ed emerge, la particolarità dell'oggetto quantistico rispetto a quello classico è la statistica: il dominio classico ed il dominio quantistico obbediscono infatti a due statistiche di tipo differente, nel primo caso quella di Maxwell-Boltzmann (a differenti permutazioni degli oggetti corrispondono differenti arrangiamenti dei sistemi, risultanti nella statistica), nel secondo caso le due statistiche di Fermi-Dirac e Bose-Einstein (a differenti permutazioni corrisponde lo stesso arrangiamento) valide per le particelle identiche. Non potendo entrare in questa sede nel merito del dibattito sull'interpretazione di queste statistiche accennerò semplicemente al fatto che in taluni casi (cfr. Saunders, 2006) è forse possibile implementare una nozione di discernibilità 'debole', nel qual caso le uniche particelle quantistiche genuinamente identiche sarebbero i bosoni elementari(fotoni, bosoni gluonici -W e Z- e bosoni Higgs), ossia non aventi una struttura interna di tipo fermionico. Queste considerazioni fanno parte del dibattito, ma in senso generale in statistica quantistica sembrano esistere particelle indistinguibili ma non identiche e questo viola il principio di identità degli indiscernibili, problematizza la nozione di individualità, il principio di individuazione e la stessa possibilità di etichettare le particelle, manifestando la necessità di una formulazione del principio di individuazione/individualità che sia adatto per la Meccanica Quantistica. La violazione di PII non elimina di per sé la possibilità di declinare un principio di individualità, ma necessita una revisione del criterio (Teller 1998; French and Redhead 1988). In questo senso tra le opzioni proposte figura da un lato il ritorno a principi che trascendono

---

[1] In ogni caso l' interpretazione olistica sembrerebbe preferibile sia perché più rispondente al tipo di formalismo utilizzato, che fornisce informazioni su distribuzioni probabilistiche, sia perché il confronto tra quantità teoriche (ricavate dal formalismo) e risultati di misure individuali non ha senso per la caratteristica non-ripetibilità delle misure individuali (De Muynck, 2007).

l'insieme di proprietà (si parla di *trascendental individuality, haecceitas, primitive thisness*), da un altro lato il tentativo di ristabilire una forma di distinguibilità, e dunque di PII, sulla base della pluralità numerica o di certe proprietà irriflessive (è il caso della *contextual discernibility* di Saunders). Tra le ipotesi interpretative avanzate per dar conto delle peculiarità sopra esposte figura la tesi che suggerisce di non considerare affatto le entità microfisiche come particelle individuali. In particolare la tesi forte del RSO à la French e Ladyman rifiuta ogni tentativo di implementare una nozione di individualità in quanto essa violerebbe l'invarianza per permutazioni caratteristica della Meccanica Quantistica (cfr. French e Ladyman, forthcoming) .

La problematicità di questi oggetti e la sottodeterminazione metafisica costituiscono un terreno di scontro tra sostenitori del realismo e sostenitori dell'antirealismo e per questi ultimi (vedi Van Fraassen) costituisce un motivo in più per abbandonare ogni pretesa metafisica e contentarsi di un approccio strumentalista. La sfida per i realisti consiste dunque nel fornire una ontologia risolutiva e la soluzione strutturalista adotta una ontologia di strutture, in base alle relazioni emergenti dalle descrizioni fisiche. In Meccanica Quantistica ciò significa considerare *those group theoretic invariants described in terms of the relevant symmetry principles* (French, 2006:172). L'idea di fondo è quella di considerare le descrizioni fornite dalle teorie fisiche e provare a derivare una ontologia conseguente. Questo passaggio, è fondamentale: il RSO porta avanti una metafisica basata su relazioni (o proprietà relazionali non sopravvenienti) e strutture (dove una struttura è definita come un insieme di relazioni tra relata privi di individualità) in contrasto con una metafisica tradizionale di oggetti individuali e proprietà intrinseche.

Il risultato è una posizione che imposta la predicazione stessa (il modo in cui parliamo degli oggetti, riflettente il modo in cui essi sono) in maniera differente: cambia l'impostazione e perciò stesso cambia l'ontologia. La fotografia della realtà fornita dal RSO è quella di una struttura fisica descritta attraverso leggi dinamiche e quantità invarianti rispondenti a certi principi di simmetria di carattere gruppale, una realtà composita di reti di relazioni, rappresentate nelle leggi fondamentali[2]. Le proprietà tradizionalmente fondamentali della materia sono concepite anch'esse come il risultato delle interazioni fondamentali e sono riconcettualizzate, o meglio si suggerisce[3] che vadano riconcettualizzate, sulla base di queste relazioni piuttosto che dei loro relata. Si vuole in

---

[2] le leggi rappresentano uno status quo di relazioni esistenti = descrivono delle relazioni
[3] Questo è uno dei problemi del RSO di French e Ladyman: fornire, al di là del suggerimento, una chiara definizione di come la riconcettualizzazione debba essere fattivamente operata.

questo modo concludere che il peso ontologico sia tutto spostato sulle relazioni, mentre i relata sono meri segnaposto, o meglio sono i nodi, punti di intersezione, nella rete di relazioni. Ciò che tiene insieme suddette relazioni non sono relata individuali dotati di proprietà, bensì i principi di simmetria che rappresentano gli invarianti: nei termini di questi invarianti si descrivono i nodi della struttura . I nodi sembrano quasi emergere, con le caratteristiche che consideriamo loro proprie (spin, massa e carica), al termine del processo di comprensione dell'ontologia strutturale di riferimento data da una certa lettura del linguaggio usato nelle descrizioni. Questa caratterizzazione suscita non poche perplessità: non si capisce in che modo avvenga il passaggio dalle descrizioni all'ontologia e la perplessità deriva dal fatto che sembra essere in atto una ontologizzazione delle descrizioni (riprendendo alcune suggestioni di Born, French sostiene che le particelle elementari siano "*ontologically nothing more than sets of invariance*" [2000:103]). La forte commistione tra il momento epistemico e il momento ontologico richiama le posizioni dei primi strutturalisti, nel qual caso è motivato da una vicinanza più o meno esplicita con i temi kantiani. I primi strutturalisti hanno un atteggiamento fortemente costruttivo: l'ontologia è costruita a partire dall'epistemologia. Non si vuole negare la possibilità di scegliere un tale percorso anche per le attuali posizioni, ma si vuole tenere presente il fatto che esse si prefiggono di assumere una tesi realista in merito all'ontologia, una tesi sul 'ciò che esiste nel mondo' in base alle nostre descrizioni. Ontologizzare tale descrizioni sembra un modo troppo forte di implementare il realismo. D'altra parte, nella sua riflessione sul linguaggio gruppale il RSO si presenterebbe come candidato ideale per dar conto di un carattere peculiare della fisica contemporanea, quali sono le invarianze per permutazioni e le simmetrie che si presentano sia in Relatività generale (invarianza per diffeomorfismi) che in Meccanica Quantistica (invarianza per permutazioni che motiva le peculiarità della statistica quantistica rispetto alla statistica classica). Questa impostazione richiede tuttavia un'ampia argomentazione del fatto che:

    1)   il passaggio dalle descrizioni alla realtà fisica sia immediato;

    2)   una descrizione di tipo gruppale debba essere evidenza della natura relazionale della metafisica di riferimento;

    3)   le relazioni abbiano una priorità sui relata, i quali acquisiscono le proprie caratteristiche in virtù della struttura di relazioni in cui sono inseriti;

4)   la riconcettualizzazione strutturale degli oggetti comporti, nella forma più radicale di RSO, una eliminazione degli individui dall'apparato ontologico della Meccanica Quantistica.

Ciascuno dei punti sopraelencati rappresenta una assunzione tutt'altro che banale e tutt'altro che implicita, come invece sembrerebbe emergere dalla letteratura sul RSO, nel fatto che le descrizioni utilizzano il linguaggio della teoria dei gruppi. Tuttavia la problematicità degli oggetti quantistici e l'emergere di quel linguaggio sono anch'essi due elementi di portata rilevante nel momento in cui si conducano delle considerazioni di tipo ontologico sulle teorie scientifiche fondamentali. Un elemento che ha contribuito a spostare la nostra attenzione dal dibattito attuale alle sue origini storiche risiede nel fatto che le questioni menzionate (1-4) non sono limitate alla riflessione piuttosto specifica, per quanto cruciale, sulla posizione in merito all'individualità/non individualità degli oggetti quantistici. Bensì esse rimandano ad un approccio all'ontologia che vuole essere complessivo. La sottodeterminazione metafisica della Meccanica Quantistica è *una* motivazione per adottare un impianto metafisico differente da quello tradizionale e coinvolgente tutta la riflessione ontologica. Si sono pertanto ricercate le ulteriori possibili motivazioni all'origine dell'epistemologia strutturalista e ciò ha condotto a confrontarsi con il pensiero degli autori considerati nel presente lavoro[4]. L'epistemologia strutturalista muove i suoi primi passi all'inizio del novecento, in conseguenza della riflessione sulla teoria della Relatività. Tale riflessione manifesta la genesi in parte geometrica degli aspetti relazionali della costituzione degli oggetti. D'altra parte i suoi primi portavoce manifestavano una certa impostazione kantiana, caratterizzata dall'interesse costante per le categorie concettuali all'opera, in senso anche performativo, nella fruizione stessa della teoria di Einstein e, successivamente, nell'approccio alla Meccanica Quantistica. Come mettere in accordo questa riflessione, con l'approccio realista delle recenti riflessioni? Mossi da questo interrogativo si è pertanto approfondita l'analisi trovando un punto di fuga per le riflessioni realiste in quello che riteniamo essere l'aspetto forse più significativo per la genesi dello strutturalismo: il

---

[4] Come riferimento esplicito del RSO, il nostro lavoro si concentra sulla figura di Eddington, un autore lasciato un po' nell'ombra dal pensiero contemporaneo. Tuttavia non possiamo esimerci dal menzionare l'altro grande, e più approfondito, padre fondatore dell'epistemologia strutturalista, Ernst Cassirer. Come sottolineano gli stessi Ladyman e French: "*The metaphysics of physics is explored in the works of Cassirer and Eddington…In both cases their structuralism was significantly informed by their reflections on the foundations of General Relativity; in both cases they emphasised group theory as representing the sense of structure they had in mind…in both cases they can hardly be described as realists…*"(French and Ladyman, forthcoming: 1). Il legame tra la filosofia di Cassirer ed il RSO è stato indagato da French (2001) e French e Cei (2006).

sodalizio crescente tra gli sviluppi del pensiero matematico, in particolare geometrico, e quelli del pensiero fisico. Dallo studio su tale connessione emerge quel particolare sguardo sulla realtà fisica in cui l'elemento di rivoluzione è costituito da un mutamento della logica soggiacente alla predicazione degli oggetti fisici. In questo senso l'approccio concettuale di un autore come A.S. Eddington si ritrova effettivamente nelle riflessioni attuali sullo strutturalismo in una forma *mediata* dalla riflessione sul linguaggio della teoria dei gruppi usato nelle teorie scientifiche. Nell'accettare la validità di tale approccio la tesi intende sostenere una forma moderata di realismo strutturale motivata, nella quale si pone l'accento sulla necessità di una metafisica strutturale non eliminativa.

I quattro capitoli che compongono il corpo della tesi sviluppano un percorso teorico che muove dalla riflessione di Eddington vagliando la possibilità di considerare la posizione di questo autore come un fondamento per le posizioni strutturaliste. L'elemento principale che motiva una genuina paternità di Eddington anche nei confronti delle posizioni realiste è dato dal delineare una forma di olismo strutturale ontologico. In tal senso al di là degli aspetti kantiani della sua epistemologia ci interessa l'approccio concettuale che emerge dalla sua analisi delle teorie scientifiche come rifiuto di una metafisica individualista. Questo approccio, superate le difficoltà legate al possibile contenuto di una tesi strutturalista, può essere riconciliato con una prospettiva realista : tale l'obiettivo dei capitoli conclusivi, dove l'attenzione si sposta sul lavoro di Weyl. La sua riflessione ha infatti il pregio di mostrare il "fisicamente significativo" del tipo di descrizioni utilizzate sia in Relatività che in Meccanica Quantistica.

Nel prosieguo della presente introduzione si presenterà un quadro delle tematiche trattate singolarmente nei 4 capitoli centrali e nelle conclusioni della tesi.

Primo Capitolo - Eddington's Philosophy of Science

Lo strutturalismo in Eddington è il risultato di un approccio epistemologico alla scienza che egli stesso qualifica come *soggettivismo selettivo* o *strutturalismo*. Un elemento fondamentale delle tesi eddingtoniane è costituito dal fatto che esse sono limitate in due direzioni: in primo luogo si limitano alla fisica, in secondo si limitano all'ambito specifico della fisica post-relativistica.

In questo senso si evince una prima differenza con l'approccio in ambito realista, che si presenta piuttosto come un approccio alla conoscenza scientifica in senso lato e tende ad allargarsi oltre il dominio della scienza strettamente positiva. Se da un lato il primo punto di vista rischia di generare un riduzionismo troppo forte al dominio fisico, il secondo punto di vista ha il problema di dar conto del fatto che a seconda del tipo di disciplina (fisica, chimica, biologica, sociale, economica) cui lo si voglia applicare esso può mutare radicalmente e richiedere una nozione di individuo incompatibile con l'eliminativismo adottato a livello fondamentale.

I due appellativi sopraccitati non sono strettamente sovrapponibili, individuando bensì due diversi momenti della riflessione del nostro autore: un momento epistemologico fortemente idealista (trascendentale) guida in maniera generale l'approccio alla scienza fisica, che secondo Eddington è una epistemologia scientifica; un secondo momento eminentemente strutturalista guida in maniera particolare l'interpretazione delle teorie contemporanee, con un enfasi sulla teoria della Relatività generale. Una comprensione del rapporto tra i due momenti è fondamentale nel confronto con il dibattito contemporaneo, nel quale il primo momento è messo da parte in favore di una prospettiva realista. In questo senso i due momenti devono essere relativamente indipendenti, nel senso che la tesi strutturalista non deve necessitare di un sfondo kantiano o neokantiano. D'altro canto lo strutturalismo in Eddington, la sua tesi che la fisica *contemporanea* generi una visione strutturale della conoscenza e della realtà, è effettivamente derivante da quel tipo di epistemologia. Da questo intimo collegamento fra i due momenti dell'analisi, nasce la necessità di suddividere il confronto con il nostro autore in due capitoli. Il primo capitolo più espressamente dedicato ad una comprensione globale della sua visione epistemologia. Il secondo dedicato ad una disamina del momento strutturalista come direttamente discendente dall'analisi della teoria scientifica .

La filosofia della scienza è per il nostro autore un'indagine del come la scienza proceda ed una spiegazione dei suoi metodi. In questo si declina la tesi che la conoscenza empirica possa essere ottenuta attraverso un'analisi degli strumenti metodologici e delle categorie di pensiero in essa coinvolti. Da ciò deriva per un verso l'attenzione per le procedure di misurazione, per l'altro il carattere marcatamente aprioristico, secondo una direttrice in primo luogo temporale. L'apriorità della conoscenza scientifica è intesa come

possibilità di derivarne le conclusioni *prima* di una effettiva osservazione. Ponendo l'enfasi ora sull'uno ora sull'altro di questi due aspetti della conoscenza la critica ha sviluppato due immagini quasi incompatibili di un Eddington operazionista e di un Eddinton idealista à la Berkeley (cfr. Dingle, 1954; Lovejoy, 1930). Nel mostrare i limiti dell'una e dell'altra estremizzazione del pensiero del nostro autore si cercherà di porre in giusta luce quegli elementi teorici attraverso cui l'analisi delle teorie scientifiche è effettivamente impostata. Infine, dalle precedenti riflessioni emergerà che i due aspetti dell'epistemologia eddingtoniana vadano piuttosto concepiti come due momenti di un unicum le cui suggestioni sono spiccatamente kantiane, in modo tale da mostrare il percorso che porta Eddington all'affermazione del *soggettivismo selettivo*. Una volta chiarito ciò che la sua filosofia della scienza non è si perviene dunque ad una analisi di ciò che essa sia, declinando il contenuto delle due denominazioni ad essa associate, *selective subjectivism* e *structuralism*. Eddington sostiene che le generalizzazioni della fisica possano essere raggiunte per via epistemologica, intendendo con questo termine l'analisi delle categorie di pensiero e degli strumenti metodologici soggiacenti e strutturanti le nostre osservazioni. Tale analisi ci fornisce una comprensione delle *forme* in cui gli oggetti si possono presentare alla nostra conoscenza, ossia per essere oggetti possibili della nostra conoscenza. Nell'analisi delle categorie di pensiero si situa la riflessione sui concetti di analisi e di sostanza. Nell'analisi degli strumenti metodologici, la riflessione sui principi guida della pratica scientifica. In Relatività generale, per esempio, la regola o il principio guida che informa tutto il procedere è la richiesta che la conoscenza fisica, basata sulla misurazione di quantità fisiche, in primo luogo lunghezze e durate, sia formulata in modo da tener conto delle misurazioni possibili di una sempre più ampia classe di osservatori.

Le due etichette di soggettivismo e strutturalismo si possono dunque situare come rispettivamente una riflessione sul carattere aprioristico della conoscenza ed una riflessione sulla sua formulazione matematica . Il passaggio tra i due momenti si ha nel concetto di struttura . Lo strutturalismo è infatti una lettura delle teorie scientifiche in cui uno spazio consistente è lasciato ancora una volta all'apparato concettuale ereditato dal soggettivismo. Ad esso si affianca tuttavia un punto di vista operativo, che considera nella fattispecie l'apparato matematico della teoria . Di fatto lo strutturalismo porta avanti quanto ha guadagnato dall'approccio olistico in un dominio specifico della conoscenza umana, la fisica. Perché dunque strutturalismo, piuttosto che *olismo*? Perché l'approccio olistico si

salda con la riflessione sulle strutture geometriche emergenti dalla RG e fisicamente significanti. Eddington *incontra* un mondo geometrico. Questo motiva l'associazione della qualifica strutturale della conoscenza fisica con la sua caratterizzazione simbolica. Gli strumenti metodologici considerati sono: le procedure in base a regole con sui tali simboli sono raggiunti ed i simboli stessi attraverso cui le quantità fisiche sono rappresentate. Questi ultimi costituiscono il limite della nostra conoscenza, in quanto riassumono l'informazione massima disponibile su certe condizioni definite e assolute del mondo. Essi sono l'unico modo in cui acquisiamo conoscenza delle quantità fisiche. Con questa impostazione dell'approccio strutturale in collegamento con l'epistemologia di sfondo simil-kantiana si chiude il primo capitolo come introduzione al secondo nel quale la prospettiva strutturalista è analizzata più nel dettaglio in connessione con la teoria della Relatività generale.

Capitolo Secondo – Eddington's structuralism: the route from General Relativity

Il dominio primo da cui emerge lo strutturalismo è la lettura della la Relatività, nella quale il concetto di conoscenza fisica è concepita come relativa principalmente alla *struttura* del mondo esterno, piuttosto che alla sua *sostanza*, dove con struttura si intende un complesso di relazioni e di relata, di cui la sostanza in quanto materia costituisce solo un elemento parziale: la materia non è che una fra milioni di relazioni, più evidente agli occhi della nostra mente. Dunque l'intento di Eddington è quello di ridurre l'analisi dei fenomeni alla loro espressione in termini di relazioni, intervalli, e relata, eventi o punti-evento, indistinguibili (*Mathematical Theory of Relativity*, 1923: 4).

In primo luogo dunque la struttura-mondo che conosciamo è quella ottenuta come sintesi di tutti gli aspetti misurabili degli oggetti di un mondo assoluto, rappresentata nel continuum quadridimensionale di Minkowsky, che ne manifesta un aspetto intrinseco: la quadridimensionalità. L'immagine/indagine ontologica prende le mosse da eventi puntuali indistinguibili e privi di caratteristiche se non quella di essere punti-evento del continuum quadridimensionale, ossia elementi di una struttura concepita come complesso di relazioni. Tra di essi sussiste una relazione quantitativa primaria, l'intervallo, e dal confronto tra tutte le relazioni tra punti della varietà quadridimensionale emerge una regola di connessione che esprime una qualità intrinseca del mondo ed è misurata dai coefficienti del tensore

metrico ($g_{\mu\nu}$). Operando su questi coefficienti Eddington ottiene il tensore di Einstein ed introduce le equazioni del campo. Tali equazioni non sono tanto leggi che collegano i punti, ma sono *condizioni* definite ed assolute del mondo. Ad esse si associano le nostre percezioni, o forse meglio sarebbe dire concettualizzazioni, di materia e di assenza di materia (vuoto) che corrispondono a due momenti caratteristici del peculiare strumento utilizzato, il tensore (annullamento ed equivalenza altri oggetti esprimenti caratteristiche fisiche). In che senso le equazioni del campo sono condizioni del mondo? Nel senso che esse indicano i parametri di connessione unici in cui i fatti fisici accadono e si mostrano: la Relatività non ci fornisce tanto delle leggi derivate dalle proprietà di certi punti, quanto piuttosto i parametri di interrelazione e le dinamiche (di metrica e materia) che sono condizioni di esistenza del mondo e che fondano (in senso kantiano) il modo in cui possiamo comprendere le nostre stesse percezioni, ciò che chiamiamo materia e ciò che chiamiamo assenza di materia.

Le differenti configurazioni risultanti $G_{\mu\nu} = 0$ o $G_{\mu\nu} = K_{\mu\nu}$ (nella forma estesa $G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G = 0$ e $G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G = -8\pi T_{\mu\nu}$) sono diverse possibilità fisiche, in cui $K_{\mu\nu}$ rappresenta un insieme di relazioni piuttosto che di oggetti. Ciò che la mente fa è dotare di qualità vivide(vive, colorate) certe proprietà strutturali selezionate del mondo.

Il mondo fisico non è strettamente dipendente dalla mente: esso si compone di una unità sintetica quadridimensionale che non è rappresentabile *nello* spazio e *nel* tempo in quanto separati, bensì ad un livello superiore. Il modo in cui la nostra conoscenza del mondo si sviluppa a partire da questa qualità intrinseca del mondo è attraverso la sintesi data dal *'no one in particular' point of view*. Le risultanti della sintesi sono l'intervallo spaziotemporale o altri oggetti geometrici invarianti rispetto agli specifici gruppi di trasformazione che collegano i sistemi di riferimento concepibili. Così si conosce il mondo come struttura geometrica. Dice Eddington: non siamo partiti in questa analisi con l'obiettivo di derivare un mondo geometrico; abbiamo analizzato la teoria e questo è ciò che abbiamo ottenuto, un mondo geometrico. D'altro canto nella teoria della Relatività si mettono in primo piano alcune particolarità del rapporto tra geometria e fisica, giacchè se da un lato attraverso le equazioni del campo riceviamo informazioni sul come le caratteristiche geometriche dello spaziotempo influenzano i campi di materia, dall'altro otteniamo anche informazioni sul come la materia stessa influenza le caratteristiche geometriche. Si potrebbe usare la suggestiva espressione di Wheeler e dire che laddove la metrica dice alla materia come muoversi, la materia stessa dice alla metrica come curvarsi.

Questa caratterizzazione, data dalla profonda alleanza tra geometria e fisica, si sviluppa in Eddington con l'idea che quello che si individua in Relatività sia un *pattern of interrelatedness*, potremmo dire un tessuto complessivo delle relazioni. Queste relazioni portano con sé i relata in maniera inscindibile, non come individui (intesi come base costruttiva delle relazioni in quanto separabili da tutto il resto e dotati di proprietà intrinseche), bensì come nodi esistenti all'interno della rete di relazioni. A questo punto si specifica la natura della rapporto tra relazioni e relata, che sono dati insieme, come un pacchetto. Come non ci sono relazioni senza relata, non ci sono relata senza relazioni, pertanto i relata stessi non sono scindibili dalla struttura in cui sono inseriti e non ha senso parlare delle proprietà da essi possedute intrinsecamente, dove per intrinsecamente si intenda indipendentemente da tutto il resto. Per quanto siffatta visione del rapporto sia meno radicale rispetto a quanto espresso nella forma eliminativista del RSO, bisogna comunque notare che è già in atto una rivoluzione concettuale laddove l'ontologia tradizionale assume come primitive gli individui, mentre qui la primitiva è una relazione fondamentale tra elementi indistinguibili: l'intervallo. Il punto di vista sviluppato è genuinamente olistico e la teoria della Relatività si presenta come il dominio primo in cui l'approccio strutturale si sviluppa e in cui trova una sua comprensione è attuabile. In ogni caso se pure si è aperta la via per una prospettiva olistica (e strutturalista), il cammino verso la prospettiva realista non è ancora compiuto, principalmente a causa del soggettivismo soggiacente.

Capitolo Terzo – Eddington, Russell and "Newman's Problem"

La prima obiezione filosofica con la quale la posizione di Eddington si deve confrontare è mossa da Braithwaite l'anno successivo alla pubblicazione di *The Nature of the Physical World* : la rappresentazione fornita da Eddington rischia di essere vuota, se non si specificano le relazioni della struttura-mondo nei loro aspetti qualitativi e dunque, secondo Braithwaite, extra-strutturali. Questa obiezione ricalca una ben più famosa obiezione mossa dal prof. M.H.A.Newman (1928) al prof. B.Russell e citata nella letteratura come "*Newman's problem*". Il terzo capitolo si concentrerà dunque sul confronto tra le due prospettive di Eddington e Russell, mettendone in luce le fondamentali differenze in ragione delle quali le due posizioni pur simili si presentano diversamente equipaggiate al vaglio della obiezione di Newman. L'argomento è tanto più interessante se si tiene conto del fatto che i due autori

sono collegati con il dibattito recente sullo strutturalismo secondo due cammini differenti: Russell è ripreso da posizioni epistemiche, Eddington da posizioni ontiche. I due approcci condividono la linea di fondo di un'enfasi sulle relazioni, ma non le motivazioni né il dominio e i modi di applicazione.

La prima parte del capitolo è dedicata ad una disamina della tesi strutturalista di Russell, che fornisca le basi per un confronto tra i due autori. Essa fu introdotta in parte nella *Introduction to Mathematical Philosophy* del 1919, ma compiutamente sviluppata poi nell' *Analysis of Matter* (1927). Secondo Russell l'unica conoscenza ottenibile del mondo esterno è una conoscenza di tipo strutturale che ci impedisce di attingerne le caratteristiche intrinseche del mondo esterno, quelle che egli chiama 'qualities', ma ci fornisce informazioni sulla sua struttura, intesa come rete di relazioni tra eventi.

Il capitolo propone la tesi secondo la quale il fallimento dello strutturalismo in Russell non è dovuto alla dottrina della struttura di per sé, cioè al fatto che si avanzi una prospettiva strutturalista, quanto piuttosto ad alcuni aspetti soggiacenti dell'epistemologia russelliana, in particolare una dicotomia di fondo tra la struttura della realtà e la sua natura, il riduzionismo logico, la prospettiva atomistica. Fondamentalmente Russell sviluppa una tesi sul modo in cui le nostre teorie rappresentano la realtà: ci sarebbe una somiglianza (isomorfismo) tra la struttura delle nostre percezioni e la struttura dei loro stimoli. In particolare la motivazione di Russell è difendere il *monismo neutrale* attraverso una *teoria causale della percezione*, rispondendo fra l'altro all'esigenza di sviluppare un opportuno raccordo tra le evidenze empiriche e la crescente astrattezza della fisica. I due fondamentali postulati della sua teoria causale della percezione sono la *continuità causale* e il postulato di *somiglianza strutturale* tra percezioni e stimoli. E' quest'ultima nozione il centro dell'obiezione del prof. Newman: essa, che dovrebbe caratterizzare sostanzialmente la nostra conoscenza del mondo, in realtà la riduce ad una conoscenza della cardinalità dei sistemi fisici e quello che poteva esserne il contenuto significante ne rimane escluso. Inoltre, seppure le strutture logiche catturano qualcosa di architetturale nel mondo, avremmo, nella visione di Russell, troppi modelli per rappresentarle.

Gli esiti dell'analisi sulla tesi strutturalista di Russell conducono a due conlusioni: da un lato esistono per le attuali posizioni epistemiche possibili vie di fuga dall'obiezione di Newman, vie di fuga che d'altro canto implicano un abbandono della formulazione strettamente russelliana(J.Saatsi and J.Meelia, 2005, Votsis, 2003); dall'altro lato lo

strutturalismo di Eddington manifesta una attenzione per il significato fisico degli strumenti matematici utilizzati che lo dota di una fondamentale apertura contenutistica, proprio per la motivazione epistemologica soggiacente e per il modo in cui la struttura è rappresentata.

A questo proposito si vaglia, nella seconda parte del capitolo il riferimento di Eddington alla natura gruppale del concetto di struttura. In particolare si considerano le obiezioni di Braithwaite, mostrando che fondamentalmente i due autori si muovono su due terreni diversi. In primo luogo in Eddington la *group-structure* è una forma di pensiero attraverso cui 'leggere' le equazioni; in secondo luogo, se anche fosse intesa à la Russell, l'applicazione della teoria dei gruppi assegnerebbe alla struttura una tale serie di vincoli fisici in termini di conservazione di energia, impulso, momento angolare e via dicendo, da avere una ricaduta immediata in termini di contenuto. Dunque la possibilità di resistere all'obiezione di vacuità contenutistica risiede nell'epistemologia adottata, nella concezione stessa di struttura e nel rapporto tra relazioni e relata. Ciò che Russell, secondo lo stesso Eddington, perde di vista è proprio la natura gruppale delle strutture fisiche. Il punto centrale è che l'ingresso di proprietà di tipo geometrico svolge un ruolo fondamentale nella comprensione stessa del rapporto tra relata e relazioni. D'altro canto l'idea di Eddington non riguarda tanto la conoscibilità o meno degli aspetti intrinseci della realtà, quanto piuttosto che ciò che abbiamo sempre considerato come aspetti intrinseci delle entità non sono strettamente parlando indipendenti dal resto del mondo. Sebbene la motivazione sia eminentemente concettuale, la sua riflessione apre comunque un terreno per ulteriori sviluppi, nel quale il RSO può trovare fruttuose sementi. In questo senso si può considerare il punto di vista di Eddington come genuinamente anticipatore delle attuali posizioni. In particolare il tipo di analisi da lui condotta sulle condizioni di accessibilità dell'universo fisico e l'accento sul linguaggio matematico utilizzato nello specifico delle teorie scientifiche sono associabili con le ragioni che in ambito più recente motivano la riconcettualizzazione strutturale degli oggetti fisici.

Capitolo Quarto – From geometry to quantum: the rising of group theoretic language and ontology

Nella sua attenzione per la concettualizzazione della struttura-mondo, Eddington non si sofferma sul dettaglio di tale caratterizzazione, pur utilizzando come esempio la descrizione dello spin dell'elettrone.

Inoltre, un elemento problematico nel confronto tra lo strutturalismo di primo novecento à la Eddington e il RSO risiede nel fatto che nel primo caso ci riferiamo ad un autore di impostazione kantiana, latente o manifesta, mentre nel secondo caso abbiamo una riflessione che vuole porsi come forma di realismo, accettandone dunque la tesi metafisica e in qualche forma almeno una delle due fra la tesi semantica e la tesi epistemica. Occorre dunque poter esulare dal carattere performativo delle descrizioni fisiche e far sedimentare, se possibile, l'impostazione predicativa in una posizione che sia realista. Il IV capitolo muove dalla persuasione che un momento importante di questo passaggio risieda nel riferimento alla caratterizzazione 'gruppale' delle proprietà quantomeccaniche, che il RSO mantiene come caratterista rilevante nelle sue considerazioni. Nel RSO questo elemento è tanto più fondamentale quanto più esso si situa alla radice dell'approccio eliminativo nei confronti dei relata delle strutture considerate come fondamentali. Dunque, pur mantenendo uno sguardo al lavoro di Eddington, nel quarto capitolo si prende in esame un aspetto apparentemente estraneo alla sua indagine e tuttavia ad essa ricollegabile. In altre parole vedremo in che termini possa essere considerata la caratterizzazione 'gruppale' della Meccanica Quantistica: come si ricollega l'uso della teoria dei gruppi con il modo in cui possiamo designare una ontologia per la teoria?

Le due linee guida al vaglio del quarto capitolo sono:

1) la rilevanza dello studio sullo spazio come generativo dell'approccio gruppale

2) l'idea che l'applicazione della teoria dei gruppi in Meccanica Quantistica possa effettivamente rappresentare un passo in avanti verso il realismo strutturale rispetto alla prospettiva di Eddington. E' questo un passaggio cruciale nella discussione, per via dell'interpretazione che la posizione realista offre della teoria dei gruppi.

Seguendo queste due direttrici il capitolo di divide in due parti, focalizzandosi in primo luogo sul collegamento/slittamento nell'applicazione della teoria dei gruppi dalle teorie sullo spazio alla Meccanica Quantistica. Tale passaggio sarà presentato attraverso l'intenso lavoro condotto da H.Weyl dapprima sul problema dello spazio, attraverso l'evoluzione dall'idea di congruenza a quella di trasformazione, e sulle simmetrie che lo caratterizzano, in seguito sulla relazione tra le invarianze dei gruppi di trasformazione e la Meccanica Quantistica. E' infatti nelle riflessioni sulla concettualizzazione dello spazio e sui fondamenti della geometria che il linguaggio dei gruppi appare in primo luogo come

significativo. All'interno di tali studi emerge inoltre un progressivo mutamento nel carattere della predicazione. Questo stesso mutamento sembra essere una delle caratteristiche che, attraverso la nozione di gruppo, si trasmette dalla concezione dello spazio(tempo) alla costituzione degli oggetti.

Le motivazioni che ci spingono a veicolare la trattazione attraverso l'opera di Weyl sono molteplici: in primo luogo la sua pubblicazione di *Quantenmechanik und Gruppentheorie* (1928) associata alla persuasione di aver raggiunto, attraverso tale studio, una comprensione più profonda della natura reale delle cose; poi la possibilità di riscontrare nel suo lavoro alcuni tratti comuni con la visione di Eddington pur non essendo un neokantiano; l'attenta riflessione sullo spazio e sui fondamenti della geometria che culmina nell'idea che la geometria consegua in ambito fisico la sua piena validità; la possibilità di evidenziare in modo molto chiaro nell'analisi del concetto di spazio un percorso teorico che va da Riemann ad Einstein analizzando l'intima connessione tra spazio, tempo e materia che permette di saldare le riflessioni strutturaliste su geometria/fisica con un approccio più marcatamente realista. Infine, ciò che emerge nel lavoro di Weyl non è tanto un tentativo di dissolvere gli oggetti in strutture matematiche, fattore al centro delle critiche di RSO, quanto il tentativo di comprendere l'appropriatezza di certo linguaggio utilizzato nelle teorie scientifiche in riferimento all'ontologia soggiacente.

La seconda parte del capitolo è dedicata nel dettaglio alla proposta del RSO di adottare una ontologia di strutture sulla base delle relazioni emergenti dalle descrizioni fisiche. Questo è il passaggio fondamentale dal momento che RSO propone una metafisica di relazioni e strutture a differenza della metafisica realista tradizionale focalizzata su individui e proprietà (intrinseche). Poiché il principale case study del RSO è la trattazione dello spin, si vaglia l'effettiva possibilità di una adozione strutturale di tale proprietà, esplorandone la legittimità anche attraverso il parere contrario di M. Morrison (2007).

Conclusioni – Relazioni, Relata e strutturalismo moderato.

Le posizioni strutturaliste formulate agli inizi del novecento manifestano la ricerca di un'immagine alquanto unitaria dell'indagine scientifica, attraverso l'analisi della costituzione degli oggetti fisici e dello spazio. La riflessione neokantiana sulla filosofia della scienza, tipica dei primi strutturalisti, Eddington e Cassirer ai quali il RSO si ricollega, conduce ad una revisione della nozione di oggetto, manifesta sia nel lavoro di Eddington sia nell'

epistemologia di Ernst Cassirer in maniera più ampia. Il motivo per cui lo strutturalismo ontico è interessato a questi autori sono le interpretazioni della Meccanica Quantistica e l'idea che le condizioni di accessibilità siano condizioni di esistenza del mondo fisico. Eppure non si può tralasciare il fatto che tali interpretazioni scaturiscano in ambo i casi dalla soggiacente impostazione filosofica e d'altro canto si originino da riflessioni sulla Relatività, da riflessioni sulla nozione di sostanza, da riflessioni sulla capacità rappresentativa della geometria. L'idea di non considerare le proprietà come 'possedute' da oggetti, quantomeno nel senso di oggetti esistenti indipendentemente da esse, è un elemento teoretico fondamentale delle posizioni strutturaliste in tutte le loro manifestazioni. Pur essendoci focalizzati sul lavoro di Eddington, non si può fare a meno di menzionare la prospettiva di Cassirer in proposito: secondo Cassirer, la manifestazione costante di una certa relazione non è una ragione sufficiente per inferire la presenza di una *portatore*, contrariamente all'impostazione meccanicistica in base alla quale tutti i fenomeni sono riconducibili a fenomeni del moto e questi a loro volta necessitavano la presenza di siffatti *portatori*. In questo nuovo senso egli stesso riconcettualizza ad esempio la carica dell'elettrone, come relazione costante priva di un costante 'carrier'.

In conclusione del lavoro si considerano le conseguenze metafisiche suggerite dall'approccio strutturalista, per la Meccanica Quantistica e le problematiche ad esso correlate. La prospettiva 'gruppale' esaminata nel capitolo precedente viene confrontata in primo luogo con la natura delle proprietà coinvolte nelle descrizioni quantistiche nel tentativo di sostenere che si tratti di proprietà puramente relazionali. In secondo luogo si analizza il rapporto tra questa riconcettualizzazione relazionale delle proprietà e la nozione di individualità/identità. La posizione di Eddington nei confronti di proprietà e relazioni ammette una sorta di codeterminazione costante tra relazioni e relata. Prescindendo momentaneamente dall'aspetto idealista e considerando unicamente la sua forma di strutturalismo, ci troviamo di fronte ad una assunzione meno forte rispetto alla forma eliminativista di realismo strutturale (French e Ladyman). E tuttavia la visione di Eddington costituisce già un distacco rispetto al realismo standard.

Una serie di problemi restano aperti per lo strutturalismo ontico eliminativo. In primo luogo, da parte strutturalista si rende necessaria un dettaglio di come le proprietà tradizionali della fisica vadano effettivamente riconcettualizzate: come vanno intese strutturalmente massa, carica, spin? Dove e come si originano all'interno della struttura le differenziazioni che le nostre stesse leggi fisiche individuano? Come la massa o lo spin

acquisiscono la loro quantità caratteristica? Non si vuol sostenere che non sia possibile una tale visione, ma il RSO manca attualmente di una precisa delucidazione di come queste associazioni possano essere comprese. Sulla base dei principi di simmetria dei sistemi fisici otteniamo certi invarianti per trasformazioni gruppali. Attraverso di essi si formula una struttura di tipi naturali in cui le tradizionali particelle appaiono come fermioni o bosoni in base alla rappresentazione del gruppo di permutazioni e come, ad esempio, elettroni in base alle proprietà associate con la rappresentazione irriducibile del gruppo di Poincarè (massa e spin). In questa prospettiva la distinzione fermione/bosone è considerata come la fondamentale distinzione all'interno della struttura stessa. D'altro canto si può dubitare che tale caratterizzazione sia effettivamente indipendente dagli elementi, particelle, campi o altro, il cui peso anche euristico sembra difficile da eliminare. Tanto più si rivela plausibile in questo senso un ritorno all'idea Eddingtoniana di struttura-gruppo, nella quale i relata non sono completamente in dismissione. Infine la stessa possibilità di descrivere i nodi della struttura ne implica l'esistenza (attuale o potenziale) all'interno della struttura stessa . L'effettiva rilevanza della teoria dei gruppi come linguaggio significante nelle teorie contemporanee e la capacità della visione strutturalista di fornire un chiaro approccio alla Relatività generale nel suo profondo legame con le proprietà fondamentali dello spaziotempo e della materia (nei termini di un tessuto di determinazione) rendono il dibattito sull'approccio strutturalista un interessante campo di ricerca .

La non-individualità delle particelle, sia pure intese come campi, non genera automaticamente l'idea che esse non abbiano alcun peso ontologico nella struttura. In questa prospettiva l'approccio à la Eddington già permette un indebolimento del peso ontologico dei relata, piuttosto che una loro eliminazione, e il corrispondente aumento di valore delle relazioni. Esso può essere associato a forme più moderate di realismo strutturale, come quella presentata da M. Esfeld (Esfeld 2003, 2004; Esfeld e Lam, 2006).

CHAPTER ONE

Eddington's Philosophy of Science

§1.1. Introduction

The following section explores the growth and development of the thesis that physical knowledge is essentially structural through the work of A.S.Eddington[5]. Particular attention will be paid to the metaphysical consequences of this thesis through the relationship between relations and relata in a structure. Eddington believes that structures are always an indivisible package that give priority to the relations rather than to the single elements. He believes that the best expression of this doctrine is the Group Theory. In both physics and mathematics Group Theory plays a significant role within the extraordinary theoretical evolution which accompanied the rising of the theory of Relativity and of Quantum Mechanics. Such a theoretical evolution constitutes the effective nourishment of the early positions in structuralism, which aim to become the expression of changes in the conceptualization of space, of physical objects, and of the object of knowledge. Structuralism in Eddington is the outcome of an epistemological approach to science. In order to Structuralism, one must first understand Eddington's epistemology. The present chapter presents Eddington's philosophy of science.

The way Eddington proceeded in presenting his epistemology exposed him to several criticisms and misunderstanding. His view was mistaken as Operationalist, or extreme idealism, linking him to Berkeley's position. The possibility of placing Eddington within the Operationalist domain will be denied. Though the observational procedures have a

---

[5] Arthur Stanley Eddington was both one of the *most distinguished astrophysicist of his time* (see Chandrasekhar (1983): p.1) and one of the most important interpreters of Relativity, especially in Great Britain, also making fundamental experimental confirmations of General Relativity previsions. In 1919 he was in the team which planned, organized and made the two expeditions, in Brazil and West Africa, which found observational confirmations of the gravitational effects of the Sun on trajectories of light coming from Hyades, through the solar eclipse of 29 may 1919. He has been Plumian Professor of Astronomy at the University of Cambridge from 1913 to 1944, and Director of the Cambridge Observatory as well, from 1914 to1944. Hence he came to philosophy from the exact sciences. Nevertheless, where his enormous contributions to physics and mainly astronomy is widely recognized, the philosophical analysis he drew as a consequence of his theoretical work of renowned physician and astronomer, met often a more general reproach from the side of philosophical community, rather than an acceptance.

fundamental place within his view, the very way he conceives physical practice brings him out of the Operationalist realm. The idealistic or phenomenalistic tinges of his work feels the influence of the wider tradition of his countrymen, Berkeley, Locke, Hume, Price, Russell. Comparing Eddington's view with the philosophy of G. Berkeley, we will see that the tension between the subjective and the objective features of our knowledge of the world cannot be reduced to Berkeley's maxim *esse est percipi*. The tension tries to find a solution in a synthesis of the two features, where both would be considered. The success of such an attempt is at times dubious, but Eddington tries to provide the elements to achieve it. His view is sometimes ambiguous, lending itself to several misunderstandings.

Many physicists and mathematicians put their efforts to clarify and set in a right light the work of this author, Whittaker, Chandrasekhar, Kilmister, Yolton, among the others. Once some semantic difficulties of Eddington's philosophical writings have been overcome, and the doctrine of structure has been plainly situated, the possibilities of a dialogue between Eddington's structuralism and other points of view will manifest themselves. In particular the outcomes of his research constitutes an important conceptual resource within the perspective of the ontic structural realism recently developed by S.French and J.Ladyman.

A further important issue in the understanding of the idealistic tinge of Eddington's perspective is the connection with the kantian view, especially concerning the role which Eddington assigns to the mind in selecting, then privileging, certain fundamental patterns in the structure of the world. Hence, in accounting for the role of mind into the scientific knowledge, we will consider the possibility of understanding Eddington's 'selective subjectivism' as a form of kantian[6] epistemology.

Given these premises, we will explore Eddington's philosophical works[7], emphasizing those features of his epistemology which have to be considered relevant to recent structuralist views. The main lines of Eddington's approach to the philosophy of science

---

[6] Eddington says (1939): "we do not accept the Kantian label, but as a matter of acknowledgment, it is right to say that Kant anticipated to a remarkable extent the ideas which we are now being impelled by the modern developments of physics"(188-189).

[7] The epistemological interest, thoroughly developed through his latest works, *The Philosophy of Physical Science*(1939) and *Fundamental Theory* (1946), appears already in his firsts and through many other scientific and philosophical works, in which he showed to be aware of the importance of epistemological reflections by the side of exact science.

will be set out in order to: a) avoid the first criticisms to Eddington's view (operationism and idealism/phenomenalism), b) frame the link with kantian suggestions and c) display the elements through which the successive analysis of Relativity theory and of Quantum Mechanics could be framed.

§1.2. Eddington's philosophy of science

Eddington discussed the philosophical principles associated with the developments of contemporary physics in a cycle of lessons delivered in Cambridge in 1938, which were later published under the title of *Philosophy of Physical Science*. Previously in *The Nature of Physical World* or *New Pathways in Science*, he had mainly talked from the starting point of physical theories, finding applications to the philosophy of science. In 1938 his approach was the opposite: he presented the philosophy of physics, finding applications in science. Moreover, his aim was not so much the presentation of "philosophy of science according to Eddington". Rather, he wanted to inquire into the philosophical presuppositions which exist in science. The starting point was the idea that there exist a corpus of notions and concepts which are *authoritative* in physics, and which lead, guide and drive what is accepted in physics. A philosophy of science underlying physics exists and is followed by any person which practises physics, hence accepting that practice. According to Eddington scientific practice, methods of knowledge, justification of theories and their confirmation, are informed by philosophy.

In the first place, "philosophy of science" is an inquiry into the nature of the knowledge of the physical universe, the knowledge gained through the methods of physics. In Eddington's work this inquiry is developed through both an investigation of how science proceeds and an analysis of the scientific methods, and it is meant to extract those ideas which guide scientific practice.

In a summary way physical knowledge is given by the alliance between theory and observation, the second always representing the leading test-bed of the first. The possibility of specifying a procedure of observation is the first epistemological principle traced by Eddington: any item of scientific knowledge must be an assertion about what the outcome

of a specific procedure of observation is or would be. Accordingly, this should make scientific knowledge an hypothetic-observational discipline and should let it produce generalizations which are the laws of nature and which manifest the knowledge we have in any occasion, provided the right procedures have been made.

Accoriding to Eddington there are two ways to formulate these generalizations:

- Empirically: generalizing from observations.
- Epistemologically: analysing the employed methodological tools and categories of thought. This method formulates generalizations that are more reliable than empirical generalizations. They present the unique way through which objects can ever enter our knowledge, so as to be possible objects of our knowledge.

The latter way characterizes a new method of physics. Both General Relativity and Quantum Mechanics are its outcomes. Within the epistemological perspective the analysis of equipments, and procedures of observation is put forward.

The very possibility of analysing the process of observation in order to gain information about what and how we know, characterizes such a knowledge as *a priori* for it is precedent (not successive) to the very observations. Strictly speaking the object of scientific epistemology is not so much *what* we know in the first place, rather *how* we know. The characters of *what* we know in physics will be deductable from *how* we know it. Eddington establishes a hierarchy according to which the way we know, through a corpus of concrete observational instruments, observational procedures, principle guiding the procedures and so on, is relevant to the understanding of both the characters of physical objects, and to the very reason why we find those characters. Eddington puts the physical knowledge itself, not so much the physical world, under examination. He aims to find the leading criteria of our approach to the physical world and to understand the physical world through an understanding of the criteria of such an approach. Eddington requires criteria to evaluate the outcome of our observations. Thus the question he addresses to both General Relativity and Quantum Mechanics in the end is, "What are you telling us about?". The answer is *relations*, for General Relativity, and *probabilities* in Quantum Mechanics.

Scientific epistemology serves then as an observation of the observers, in order to understand what they are really observing through the analysis of their very observational procedures.

§ 1.2.1. Is it Operationalism?

Initially the insistence on the observational processes and the statements about the nature of physical quantities and measurements were read as a subscription to Operationalism (Dingle, 1954; Yolton, 1960). Indeed the father of this view, P.W.Bridgman, indicated the search for a link between scientific concepts and experimental measures as the most relevant methodological outcome of Einstein's work. In reflecting on the philosophical implications of the new physics Bridgman developed an analysis of the scientific concepts as determined through a definite set of *operations*: a concept is synonymous to the corresponding set of operations.

The paradigmatic example of such a new way of considering scientific concepts is Einstein's analysis of the concept of Simultaneity: indeed in special Relativity, Simultaneity is analyzed drawing considerations on the operations through which two events are described as simultaneous.

The defining operations are concrete procedures when we deal with physical concepts such as *length*; they are mental when we deal with mental concepts, for example all mathematical concepts. as 'mental concepts'). Even length cannot be just an abstract concept but depends on the physical operation of measuring segments.

Emphasizing the operative character of physical concepts, Bridgman wanted to avoid the opposite way of defining them, through assumed properties: the latter are the typical way through which concepts like the Newtonian *absolute time*, absolute, true and mathematical, per sé, are defined. These concepts would make of physics a completely abstract discipline, removed from reality. Hence Bridgman seems to be led by an empiricist attitude: those concepts which cannot be measured through a set of operations must be avoided as devoid of meaning. On the other hand, he mitigates the empiricist attitude by involving the *mental concepts*, for instance the mathematical concept of continuity, and by recognising the approximate character of empirical knowledge, given by the minimal uncertainty which characterizes measurements. All the same, he admits the possibility of a

mixture between physical concepts and mental concepts. His thesis was rather to provide a definition of physical experience in terms of actual physical experience.

Bridgman did not want to found a philosophical school, but Operationalism greatly influenced his philosophical reflection, especially with respect to the empiricist and reductionist attitude. Though Bridgman did not pursue the reduction of physics to its experimental branch, this Operationalist perspective was perceived as a drastic reduction of the meaning of scientific concepts, pretty much exhausting them through sets of operations. Inasmuch as Eddington was compared with the Operationalist account, he was compared with this perspective.

The fundamental risk underlying physical theories is the progressive dismissal of the link with the world[8]. This would also lead to a view in which physical quantities, represented by symbols within equations, would have no connection to a knowledge of the external world: physics would became "*a description of the relations existing between the results of certain operations which you performed*" (Dingle 1954: 12).

Eddington shares with Bridgman the way explanation is meant and the very reasons which invite the analysis of concepts. Indeed Bridgman's perspective involves the general thesis that it is possible to analyze nature through correlations. Such a thesis finds a correlative within Eddington's approach, as well as the interest toward the way the new physics involved a change in the fundamental concepts of our descriptive constructions. The Operationalist emphasis on the role of physical experience in grounding the scientific definitions seems to be common to any approach of science. Who would ever deny that science relies on measurements, observations? Indeed these features are found into Eddinton's approach.

On the other hand, in comparing Eddington with the Operationalist perspective, he must be compared with the abovementioned reductionist interpretation of Operationalism.

The identification is due to some passages of Eddington's work, the most representative of which is the introduction of *Mathematical theory of Relativity*. In it he says that "*a physical quantity is defined by the series of operations and calculations of which it is the result*" (1923: 3). He remarks several times on the indispensability of measurement/observations.

---

[8] Bridgman did not deny the link with the underlying world. Nevertheless, since it is not our aim to inquiry into Bridgman's view, we will compare Eddington with the common view on operationalism, which involves such a stance.

The need to specify the procedures of observation is fundamental because any item of scientific knowledge must be an assertion about what the outcome of a specific procedure of observation is or would be. On the other hand, the fundamental feature of Eddington's investigation on scientific knowledge concerns the analysis of scientific methods in order to extract those assumptions which guide procedures of observation. In other words, scientific practice is led by epistemological assumptions which are not strictly speaking Operationalist.

Eddington manifests the need to deal with both the methodological assumptions and the epistemological character of physics. As Yolton (1960) notes, at the methodological level science establishes correlations between experiences which can be measured, weighted, and manipulated. It is a matter of *pointer readings*. In addition to the experimental feature, Eddington's approach leads back the attention to the theoretical route which guides the correlations. Accordingly he pursues an analysis of the procedures of observations in order to make some leading principles emerge.

Far from his having a reductionistic attitude, his inquiry leads back the procedures of measurement to an intellectual/theoretical apparatus. Thus Eddington's view shows some characteristics which do not fit with an Operationalist.

Firstly, though related with the experimental side of physics and with the manipulations on mathematical elements, some concepts such as that of analysis, that of structure and that of existence, and principles such as the principle of blank sheet are not *reducible* to experimental physics and manipulative mathematics. Moreover one of the central themes of the Eddington's *Fundamental Theory* (1946) is that " *All the quantitative propositions of physics, that is the exact values of pure numbers that are constants of science, may be deduced by logical reasoning from qualitative assertions, without making any use of quantitative data derived from observation".* In the *fifth Arthur Stanley Eddington Memorial Lecture*, Sir E.Whittaker extensively notes that Eddington assigns to theoretical physics an authority and a priority in unifying, explicating and pursuing the scientific progress which exceeds the experimental physics. Whittaker links it to the Leibnitzian idea of a subordination of quantities to qualities. The priority of theoretical physics is due to the fact that it provides *qualitative* concepts and principles, such as the concept of *displacement of current* or *wave front,* and principles such as the indetermination principle, the principle of minimal action, etc., which constitute the pillars of the scientific building.

Secondly, Eddington introduces the apparently Operationalist approach within the domain of General Relativity, where the concept of measurement assumes a peculiar meaning which we will see later.

Thirdly the mentioned establishment of correlations between physically measurable experiences suitably places the observer within the picture of knowledge, rather than reducing scientific concepts to operative meanings. Yolton expresses it as the need to "*place the source of the process of object discrimination in basic factors within the observer*"(Yolton 1960: 41). The *object discrimination* alludes to the process through which we distinguish things and their features, assigning them qualities and quantities. To place it within the observer is the counter part of the relativistic standpoint of General Relativity.

Placing the observer inside the system of knowledge implies the introduction of categories such as simplicity[9], truth, and "beauty". These are genuine and determining features of human thought and scientific practice: they prevent Eddington's absorption within the Operationalist group.

Moreover, one of the main points of Operationalism is the abandon the view that physics provides us with a knowledge of the nature of the world (see Dingle). Operationalism places a sharp distinction between the unknowable nature of the world and its knowable structure. This distinction is the main target of the criticism against structural positions[10]. Such a distinction is partly findable in Eddington's account. Nevertheless, with respect to the determination of physical knowledge, the external world has in fact a weight which is independent from the particular observer's point of view.

There is no doubt that the relationship between subjective and objective is continuously at stake in Eddington's work and this goes together with his characterization of what is scientific knowledge. More than once, he insists that one of the features which distinguishes XXth century physics from the previous centuries is its aiming at knowing a knowledge rather than a thing.

Knowing a physical *thing* usually means to know its characters (dimensions, associated physical quantities, other properties). Accordingly knowing a physical *knowledge* means knowing its characters

---

[9] as an example "*simplicity is taken as a demand for reduction*"(Yolton, 1960:2).
[10] See also Kilmister (1994) for the distinction within Eddington's position. Further criticism on such a distinction relates to the recent reading of Poincarè's and Russell's by the side of epistemic structural position (for the debate see Worrall, Cao, Psillos, Saatsi and Meelia and Saatsi).

The acquired knowledge is a knowledge of spatiotemporal relations, in Relativity, and a knowledge of probabilities of obtaining certain outcomes through performing certain measurements, in Quantum Mechanics. In this sense we understand the way our generalizations and observations and measurements arise.

Thus Eddington claims that the new physics is a scientific epistemology, and motivates the *inferential* character of our knowledge of physical objects. The latter feature could appear banal, though it is not. When he affirms that "*familiar objects which we infer are as much inferential as a remote star inferred from an image..*"(1934: 92) he is saying more than the simple fact that we have an indirect knowledge of objects. The *intrinsic* characteristics of particular objects derive on the immediate knowledge provided by the theories. But the immediate knowledge mainly enable the derivation of *extrinsic* properties.

As a matter of fact the relations are epistemically prior to the properties and the individuals. Strictly speaking the number of properties which could be considered as *intrinsic* diminishes.

Hence the apparently banal inferential character of knowledge, introduces some conceptually fundamental possibilities into Eddington's philosophy:

> 1)   the possibility of accounting for *invariances* without immediately referring to individual objects
> 2)   the possibility of a variation in the way the predication of objects is driven
> 3)   the possibility of focusing on the epistemic conditions
> 4)   the possibility of endorsing an holistic approach to Knowledge

Such four possibilities are very important in order to understand the development of structuralism and the link with the ontic structural realism. Tatter aims to reconceptualize of objects in structural terms and shares some features outlined in those possibilities, a different interpretation of invariance, a different hierarchy of predication, the pursuing of the identity between epistemic conditions and existence's conditions, and an holistic approach to reality.

Going back to the knowledge of the characters of our *knowledge*, Eddington finds proof of such a feature precisely in General Relativity as well as in Quantum Mechanics[11]. There we appreciate some characters of *our knowledge* of the physical universe, From them characters we derive information on the physical universe itself. Though the knowledge of objects is then mediated via the characters of our knowledge, human beings, the objective features of the universe are not completely expunged. An example of the way Eddington balances the objective and the subjective, as knowledge dependent features, appear clearly in Eddington's treatment of Relativity. Every time we want to individuate actual quantities, or better their values, we turn to a frame of reference, hence to a particular observer's point of view. This does not make the discovered features less real, but makes them just cognitive components, rather than exhausted objects, of the world. They are just relative features of an absolute universe. An immediate question arises concerning the fact that a characteristic of the theory of Relativity is the invariance of Lorentz transformations, namely the fact that the same transformations are valid for all the systems of reference. Such an invariance explicitly seems to overcome the particular observers' points of view. Eddington accounts for it in terms of a "no-one in particular point of view": it summarizes the invariant features of the different frames of reference. It constitutes a synthesis of the different observers' perspective. The equations which we reach through the no-on-in-relativistic point of view are invariant. They impose a form to the possible quantities reachable as outcomes of our measurements. On the other hand, those represent a piece of human knowledge. The synthesis between the different perspectives is operated by a subject*s*.

In the end the aim of Eddington's approach is neither the reduction of knowledge in the name of an operative principle, nor the achievement of a purely objective knowledge: he rather emphasizes the non-existence of any purely objective knowledge of the physical world achievable through the methods of physics. There is an unavoidable element of subjectivity deep inside the very methods of science, even in Lorentz transformations.

---

[11] Analysing the method of quantum theory, Eddington summarizes it as proceeding "*by a direct analysis of knowledge of a system, instead of by an analysis of the system itself*" (1939:53)

§ 1.2.2. Is it Idealism?

In addition to being misinterpreted as Operationalist, Eddington's view has been attached to Berkeley's idealism. The following section will defend the thesis that inasfar as Berkeley's idealism is accounted for, Eddington's views differ from it. The differences between the two positions come from the motivation and the derived consequences of the endorsement of an idealistic option. In order to evaluate them, we will consider the comparison according to the following six points:

a)   The subjective character of knowledge and the constructive aspect of knowledge with respect to its objects

b)   The criticism against material substances

c)   The focus on concepts

d)   The status of mathematics and physics

e)   The religious view

The most general idealistic thesis (GIT) which constitutes the common ground for a comparison between Berkeley and Eddington is that:

GIT: *knowledge is subjective in character, and depends on the mind.*

There is no need to discuss the reality of external world, since Eddington and Berkeley both admit it in some sense. The issue concerns the way it enters into our knowledge. The first difference between the two thesis concerns the domain under scrutiny: in Berkeley's view GIT is a thesis concerning all human knowledge, whereas in Eddington the domain is smaller, because he deals only with that part of human knowledge which concerns science, physical knowledge.

Of course GIT also puts Berkeley, and Eddington, in the same path of Kant. It is useful to remark Cassirer's view that Berkeley genuinely anticipated Kant in affirming that the truth of our knowledge is not to be found in the accordance with the "things in themselves"(Cassirer 1952: 332). But both Kant's and Eddington's views do not stop there.

In particular, Eddington sees the subjectivity of physical knowledge as depending on the fact that it is a human enterprise. Knowledge has such and such characters because it is structured by human beings. We are the thinkers and feelers of what we think and feel. Hence our sensory and intellectual apparatus matters in the definition of our physical knowledge of the world. This is what leads Eddington to focus on the frames of thought, constitutive and revisable, and on the instruments through which the world is inquired.

On the contrary, the evolution of Berkeley's thought will cause a revolution in the role that senses play in the cognitive enterprise. Finally senses and experience become the pure appearances and the truth lies into pure intellectual ideas. In such a way the fundamental reality to be inquired become an over-empirical reality.

Furthermore the purpose of Berkeley's idealism is a criticism[12] of his contemporary thought, mainly directed against the lockean theory of the abstracted ideas, according to which we would be able to form general ideas through abstraction. The issue is that according to Berkeley (1) the mind cannot sharply separate qualities which are intimately connected (2) all the entities (included the ideas) are clearly determined and individual. Thus we always think in a precise way: a triangle is an isosceles or a scalene triangle, it is coloured in some way, it is big or small, we cannot have 'pure' representations as lacking of all their empirical characterizations.

Then he inquiries into two problems of perception[13], namely the representing ability of general (not abstracted) ideas and the identity between perceptions and objects: 1- how is it possible that a particular perception has a representative ability far beyond its direct function? 2 - how is it possible that perceptions, which are something internal to us, *become*[14] objects, which are something external? (*New Theory of Vision*) Inquiring into the justification of such two passages (internal perceptions - external existence) he develops

---

[12] We are not interested in following the development of Berkeley's thought (though it somehow will be accounted through the explanation of his thesis). We are rather interested in his specific thesis.

[13] In *An Essay toward a new theory of vision* the problem is formulated starting from the notion of *space*: space is a necessary term of representation, but it is not immediately perceived. Hence the distance between objects, which is necessary to their sensory structure, is not an object of sensory impression. Space is then an unobservable element mixed with the visible world. It is unperceivable though perceived.

[14] The very way the question is proposed spoils the discussion discussion since the issue is not how the perceptions *correspond* to objects, rather how they *become* objects. The perceptions are the ontological starting point.
In some sense this is the successive stage of he discussion is the one which will lead B.Russell's theory of perception: we start from perceptions and we try to make them agree with the available mathematical constructions. The reality does not enter the picture since anything is played within the domain of the representations. Nonetheless Russell supposes the external world as the cause of such representations, in order to avoid Berkeley's idealistic monism.

the strongly idealistic thesis that the true objects of vision do not exist outside the spirit[15], namely they are not the copy of any external objects: our perceptions regard objects but we only perceive ideas, hence objects are ideas.

He wants to understand how a particular perception signifies something different from itself, then going beyond its proper content, i.e. how it could be taken to generalize something else. In Berkeley generality is not abstraction. He dislikes abstraction as the possibility of eliminating the empirical features of our sensations. Generality is rather a nexus of signification which enables a particular idea to be the sign of the other similar idea (arising from the same species: for instance a given straight line could be taken as the exemplar of other particular ideas). Thus words are centres of aggregation of particular ideas of the same species.

Led by the research of an understanding of perceptions his view progressively departs from the empirical level focusing only on ideas, since we perceives ideas. Hence he provides a new understanding of what experience is and a new principle of what reality is: the material substances are reduced to the immaterial perceptions (immaterial substances), which on their turn will lost their intrinsic unity. Thus Berkeley will need to put the foundations of a comprehension of the all variety of sensations in the presence of a superior intellect. Ultimately it is God's presence which grounds the unity of our perceptions, which become nothing but signs of a divine language which refer to things only at a secondary level.

Berkeley's theory of concepts and of substance will be the clue of Cassirer's criticism which emphasizes the development form a sensualistic basis toward a spiritualistic metaphysics.

In some sense, since the very 'I' become a bundle of changing ideas, the very spiritual substance as well as the material becomes an empty word.

These are certainly not the conclusions which Eddington reaches. Then in order to better understand the difference with Eddington we have to better understand **a)** *the constructive aspect of knowledge with respect to its objects* and **b)** *the criticism against material substances.*

---

[15] Locke assigned the objects and to perception to two spheres of the real' s realm: sensation is the realm of external existence; reflection is the realm of internal existence. Berkeley rejects the distinction and proposes a idealistic monism.

In Berkeley we have a complete creation of the objects by the spirit. To tell the truth, Berkeley's aim was to make human knowledge stable (as well as establishing the immortality of the soul and the divine providence), looking for the deep understanding of the book of nature beyond the appearances and beyond the common sense. In such a sense his anti-mechanistic view looked for the first causes of phenomena and it is paradoxical that he was considered as the father of a sceptic view. On the other hand in looking for those causes he puts human knowledge under criticism and the very evaluation of the role played by the senses changed radically. His theory of perceptions finally is a theory of the way the objects of our sensations are entirely created from the ideas. In such a sense he pursues an antimaterialistic view as the rejection of the materialistic realism, according to which the material substances are causes of the ideas: the material substances do not exist, namely mind-independent things do not *exist*. The nucleus of the immaterialistic outlook is thus a principle of reality: *esse est percipi vel percipere* (Phylosophical Works p.290). It affects the all reality which does not divide into material and spiritual substances (Descartes), rather it divides into perceiving beings and perceived objects. The immaterialistic principle of reality produces the idealistic principle: since esse est percipi, any idea, passion and sensation has not any existence external to the perceiving. Moreover perception has a representative function with respect to the all empirical structure.

Eddington has a less ambitious point of view. He does in effect both emphasize the constructive role of mind and criticizes *matter*. In the first place the mind-dependence has an epistemic character: the knowledge we reach of physical objects (since he is dealing just with physical knowledge) is not a mind independent one. Such an assumption does not make them unknowable at all nor un-existent apart from our knowledge. They rather are *relatively* knowable. Physical knowledge tells us the way they are knowable to us.

On the other hand the very structural knowledge obeys some constraints which are provided by some features of the world (the four-dimensionality of the universe, a law of atomicity which he plugs into the structure, and so on): the reached knowledge *thus* (due to such a link with the world) expresses the possible physical conditions of the universe which we know. There still is the object half-way in the interplay of knowledge.

Berkeley wanted to reject Locke's idea that 1) the *sensible objects*, i.e. the objects of our perceptions, have an existence distinct from their being perceived from the understanding and 2) that their character as independent from us could be abstracted according to the

distinction between primary qualities and secondary qualities[16]. Such a view is then a form of representative realism grounded on abstract ideas: to imagine something which is distinct from the subject is to abstract it.

The criticism of Berkeley is that even the abstractive power does not go beyond the possibilities of a real existence within the perception, hence it is impossible to distinguish something from its sensation/perception: in other word abstraction is linked to the perceptive things. Sensible objects are the objects of our perceptions.

Eddington's view is quite sympathetic with the mind-dependence of the objects' characterization: as mentioned he sustains that the subjective element is unavoidable from *physical* knowledge. On the other hand in his view we cannot find the criticism of abstraction which Berkeley pursues: Eddington rather assigns to abstraction a great role in the individuation of the patterns of interrelatedness which constitute the focus object of our knowledge. According to him the physical world[17] is not only built, but it is also abstracted and given.

Locke assigned our sensations to an external existence and the reflection to an internal existence and said that the latter *resemble* the former. Berkeley rejected such a representative realism with its distinction: the true objects of vision do not exist outside the spirit, hence they are not the *copy* of external objects. Physical objects obtain a proper reality only through the judgement since the judgement is the locus where the connection among sensible data happens. With respect to Berkeley, Eddington's view will be on the same foot of Locke's view[18], where the reality of objects cannot be abandoned since it

---

[16] Berkeley rejects the division between primary and secondary qualities, since it reduces the latter to the former: such a reduction according to him make an abstraction a metaphysical reality. In criticizing the abstract concept, as a peculiar mental reality isolated from consciousness, he aims to reach pure perceptions. Finally, in criticizing abstract concepts he also critics the attribution of 'existence' to them, since existence must be limited to individual determinations.

On the contrary abstract concepts has a value just because of an ability of the spirit, which gets the all particular characteristics and the all similar representations in a unique representation, a unique sight → the cognitive substratum is provided by the representative ability of mind, not only fom the content of the representation.

In order to reach the 'empirical' world of things (= a representation of an order of phenomena rued according to rules and then objective) the extension and the colour (I and II qualities) are both immediately known and given as states of the subject.

[17] Moreover, Eddington deals with a physics which strictly speaking brings us far beyond our perception. The objects which he deals with are not just the sensible objects.

[18] According to Cassirer, Locke bounds knowledge to a world of sensations and reflections but he still ought to mantain an aimed- unreachable limit in the knowledge of absolute objects: without the external reality the very variety and the content of our sensations would disappear. Hence the external world cannot be *deduced*

grounds sensations. Eddington's motivation is an inquiry into the characters of physical knowledge, through the analysis of the available scientific theories[19].

Concerning the criticism of *matter* Eddington is against the view that substance, that is *matter*, is the brick /distinctive feature of the universe. This does not mean that the *existence* of everything should be reducible to immaterial perceptions.

The criticism of matter which Berkeley proposes in *Treatise concerning the principles of human knowledge* is the criticism of a mind(spirit)-independent substance or of a substratum of the qualities[20] of bodies. Accordingly he substitutes the terminology of 'bodies' with a terminology of 'perceptions' (as immaterial terms). The perspective is slightly different between the two authors: Berkeley criticizes matter as substance as opposite to mind-stuff. Eddington criticizes substance as matter as a peculiar way of regarding reality privileging a particular partition into it. But the reality maintains its status of being, at least partly, the source of our physical representations.

Berkeley's criticism of substance brings him to the establishment of a theological principle of unification and explanation and to defend a instrumentalist view of physics and mathematics.

Eddington's criticism of substance gradually brings him to the holistic view and to the structuralist approach.

To tell the truth, in Berkeley's view the reality does not cease to be when we do not observe it. Rather the things we do not observe maintain a sort of expectation, thus remaining within the consciousness: the crucial point is that the all human experience is in the consciousness and the dependence from mind is absolute. According to his *idealistic doctrine* the contents of our knowledge are the aggregate of our spiritual experiences. Hence the central node is not so much what is knowledge, rather what is experience and existence.

---

from experience, it must rather be its unaccessible source. Berkeley strongly denies such a view: physical objects obtain a proper reality only through the judgement since the judgement is the locus where the connection among sensible data happens.

[19] Though Eddington suggests a connection with a theory of perception it is not his main topic, nor the structural outlook is completely extensible to it.

[20] Berkeley is also a critic of the distinction between primary and secondary qualities, holding in both Locke and Galileo. According to the separation, the natural science aims to represent the primary qualities. Berkeley rejects the distinction and affirms that the reality of perceptions id due to their existence within perceiving minds. Thus it is also possible to account for the identity between perceptions and object of knowledge: indeed the object of knowledge are derived from the very perceptions.

Existence is bound to experience and experience is perceptions, hence ideas. From the "pure experience" he derives reality in its *conceptual determination.*

That is why Cassirer notes that Berkeley's criticism on abstract concepts truly focuses on the concept of existence. And it is a fundamental feature since according to Cassirer the concept of existence contains (and exhausts) the all metaphysics of the gnoseological question.

Thus **c)** *the focus on concepts* serves a different target in Berkeley and Eddington: Berkeley is accounting for perceptions and elaborates a new principle of reality (existence); Eddington is inquiring into the leading principle which direct our knowledge and curiously he will deal with the concept of existence *so far as* it matters in physical knowledge. Eddington does not provide any principle of existence, he just inquires to what extent it enters the domain of physical knowledge. As we saw in the previous paragraph the analysis of the concepts is the real focus of Eddington's work. This is the further difference between Eddington and Berkeley. The former does not hold that the human experience is all in the consciousness. It is in life, consciousness and spirit(PPS 69).

In Berkeley's view the pervasive character of consciousness induces a new determination of the reality of natural object (which is entirely built by human mind – under the warranty of the goodness of God) [21]. As mentioned Berkeley does not want to deny the existence of sensible things, rather to understand the meaning of "existence" within our experience: what is *to us* the existence of something? This is sympathetic with Eddington's approach in physics: what is *to physical knowledge* the existence of something? According to Berkeley the existence of something is a stable and connected representative content., hence it exists only and everything we can represent to ourselves. According to Eddington the existence of something into our physical knowledge is just its entering, occupying a node, into the structure which we are physically knowing.

In Berkeley's account the issue arises as to the boundary line between fantasy and reality: in which sense should we say that the 'unicorn', which has a representative content in our mind, does not exist? Nevertheless, according to him, the distinction between tales

---

[21] A further common feature of the idealistic view is that there is not a single domain of sensibility (senses) which is prior to the other with respect to the problem of objectivity: any sphere of sensible impression cannot refer to a reality which is not in relation with the consciousness (simply because there is not such a reality to be reached, not there is such a reference to be aimed) (Cassirer p.323).

and reality consists precisely in the fact that reality manifests stableness and connection in a regular way, not tales (*arbitraria e fugace*).

The very science is finally a description of phenomena in terms of their coexistence and regularity. It does not regard ultimate causes. The understanding of a phenomena implies its fitting within the previous knowledge.

Berkeley's view on **d)** *the status of mathematics and physics* is famously presented as a paradigm of the instrumentalist positions (think, for instance, of Popper's criticism of Berkeley's instrumentalism in his *Conjectures and Confutations*). His idealism lets to save the phenomena, showing, according to him, the vainness of a research of underlying hidden causes. (affirming the useless of mathematical models in physics): mathematical concept are just hypothesis and abstractions which we use to describe (summarize) the world of phenomena.

Though accepting Descartes' view (*Diottrica*)that it is not the eye that sees, rather the spirit, Berkeley rejects anything which does not fall under the domain of consciousness.

On such a footstep he both rejects the idea that we can evaluate the relationships between things according to some geometrico-mathematical principles[22] (as in Descartes) since they are external to man and criticizes the representational theory of perception.

A different view is present in Eddington: in the first place such a sharp separation between eye and spirit is not possible, rather the contribution of both is necessary to knowledge, both sensible and intellectual apparatus (equipment); in the second place the relationships between things are precisely inquired through geometrical characters and principles so that he reaches a geometrical view of the world. Moreover the geometrical features of modern physics indicate the bridge toward the complex of sensations which share, according to him, a group structure.

Berkeley's rejection of the *resemblance* depend on the fact that if we divide things in directly perceived (ideas) and indirectly perceived, we ought to reduce the latter to the former. The idea of a resemblance between ideas and things is misleading: we only could link ideas, schemes. We cannot compare models and reality, since the latter is ungraspable in principle and any knowledge grounded on such a postulate of correspondence is in

---

[22] The idea that man sees through geometry is a naïve conceptual realism: it cannot be the lever of the consciousness.

principle falsified. Pursuing such a view of knowledge as a resemblance between ideas and things devoid empirical knowledge of value, opposing to it a false ideal: "*..essi tolgono ogni valore alla nostra conoscenza empirica, contrapponendo ad essa un ideale falso e irraggiungibile. Chi vede la realtà della rappresentazione nel fatto che essa riproduca qualcosa di non rappresentabile, chi fa così dipendere la valutazione di ciò che è immediatamente conosciuto da qualcosa senz'altro in conoscibile, costui ha già scardinato in tal modo la conoscenza.*" (Cassirer 333).

Finally in Berkeley's idealism the weight of the theological point of view (**f**) is fundamental.

Bodily substances are not to be taken as the causes and the groundings of our perceptions; the genuine meaning of the laws of nature is rather the constant order of sensible perceptions, which is linked to the act of the Creator and to his relationships with minds.

The very connection of phenomena is not due to a causal nexus, rather to a process of signification, since the experience is the language of the Creator of Nature. As the first the grammar of such a language must be learnt, but the real interesting content is finally the meaning of the language, rather than the grammatical elements. The sensations are then sensible *signs* which enable our movements within experience. They are signs not within the human language, rather within the language of the Creator, which is the guarantor/ warranter of the permanence of perceived objects. The Creator is the unitarian basis of reality and the warranter of our perceptions.

Even the cognitive relationship which ground Berkeley's model of explanation could not be understood apart from the relation between the minds and their Creator.

Eddington, though his deep religious experience, does not assign such a paramount role to the theological argument in philosophy of science, nor he wants to belittle the idea of a man *as an element in moral and spiritual order*(PPS 223). In his view there holds an equilibrium between the different ambits of human experience: no-one exclude the other and each one has its own domain. The explanation of phenomena, as an answer to a scientific question, cannot be led back to a theological principle. Nevertheless the knowledge of physical world is only a part of the greater issue concerning human experience: compared to the whole of the human experience the question on what the reality is imply, according to Eddington, a kind of research which is wider than the physical

research and which is engrained within the human spirit (soul). Any man in his life faces such a research, which involves knowledge, faith and truth.

To conclude, Eddington shares with Berkeley some labels: but to a great extent the meaning of such labels differs in the two points of view. So far we approached Eddington's view through a negative path, through saying what it *is not*. In the next section we will approach it in the positive path, through closely analysing how it develops.

§ 1.3. Selective Subjectivism

Eddington's idea is that the philosophy of science is a *selective subjectivism* or *structuralism*. What do the two labels refer to? As mentioned, Eddington claims that generalizations of physics are achievable through an epistemological route: the analysis of methodological tools and categories of thought, which underlie and set observations, provide the unique *forms* in which the objects could ever present to our knowledge, i.e. to be possible objects of our knowledge. The two mentioned labels (selective subjectivism and structuralism) could be respectively placed in terms of a reflection on the aprioristic character of knowledge and a reflection on its mathematical formulation.

In accordance with such a distinction, in the following we will deal with the first feature (and the first label), which leads to a discussion of the relationship between Eddington and the idealistic tradition, in a broad sense, and finally with the kantian outlook.

The reflection on the impact of the specific mathematical formulation of physical knowledge will be delayed for the next chapter, where the relationship between the subjectivist outlook and the structuralist outlook will also be accounted in order to evaluate the relative dependence of the two views. Of course Eddington did not considers them as two separated accounts, rather as two thesis linked to an unique view: nevertheless it is interesting to understand the extent to which the two thesis are mutually dependent, better the extent to which the second is linked to the first, in order to evaluate the possibilities of involving the structuralism within a realistic account.

§ 1.3.1 Kantian links - which place for the subject?

As mentioned in the previous sections, the physical knowledge, which always takes the form of a description of the world, manifests an aprioristic character in two sense. In the first place, looking at the process of observation it is possible to achieve fundamental information about what and how we know *before* the effective observation: some characters of knowledge emerge before an actual observation, though not being independent from a plan of observation. In such a respect the aprioristic feature is due to a temporal priority. Secondly the way we set our observations induces the possible forms of our knowledge and thus the derivable forms of the objects of nature within such a knowledge. The very existence of an aprioristic character in knowledge manifests, according to Eddington, the fact that knowledge itself is not completely objective and motivates the search for the role of mind, of observers, i.e. of subjective elements, into it.

This is the road which drove Eddington to qualify his[23] philosophy as *selective subjectivism*: it is the idea that, though there are some proper knowable features of the World (as its four-dimensionality), the relevant patterns of our knowledge are subjective, i.e. dependent on a selective activity of the human mind. This view immediately recalls kantian suggestions, as well as the very analysis of the categories of thought underlying the building of our knowledge of the world.

In the previous chapters we saw two different attempts to read Eddington's epistemology in terms of an operationalist account and an idealistic account à la Berkeley. As we saw, both the reading are unable to fulfil the whole of Eddington's view, accounting for it only to a partial extent. In the present section we will inquiry the thesis that his epistemology should be better understood within a (neo)kantian reading. It is basically the proposal of T. Ryckman (2006), which considers the selective subjectivism *and* the structuralism as the locus for a kantian approach to scientific knowledge.

---

[23] Strictly speaking he does not want to elaborate just another point of view on science. He thinks to be elucidating some theoretical feature which do act in science. By the way he speaks of *his own* philosophy of science since he thinks that any such a synthesis requires an acceptance of responsibility.

In order to clarify the selective role of the mind in characterizing our knowledge of the world, Eddington proposes an analogy (though he does not consider it as exhaustive) with an ichthyologist which wants to infer conclusions on the population of the sea (the world) through an analysis of the fishes he caught with his net (the observable elements). In particular he obtains two generalizations concerning the size of the fishes (minimum two inches long) and some of their properties (their having gills). In the example it appears that the better way to reach a complete evaluation of the ichthyologist's knowledge is to engage considerations on the net, rather than to the caught fishes. In such a way he also realizes the limits of his knowledge, depending on the amplitude of the meshes of the net which drives the possible expectation on the size of the caught fishes. Then, dropping the analogy, he concludes that "*if we take observation as the basis of physical science, and insist that its assertions must be verifiable by observation, we impose a selective test on the knowledge which is admitted as physical. The selection is subjective, because it depends on the sensory and intellectual equipment which is our means of acquiring observational knowledge. It is to such subjectively-selected knowledge, and to the universe which it is formulated to describe, that the generalisations of physics the so-called laws of nature apply*"(1939: 17). The general idea is that the knowledge provided from physics is the outcome of a subjective selection of some features of the world. As mentioned the selection is due to the characteristics of the knowing subject (i.e. sensory and intellectual apparatus) hence it is subjective. Our physical descriptions are formulated through that selection, defining an image, an universe to which effectively the laws of nature apply. The natural answer arises: Is there anything genuinely knowable in the world then? Is there any objective knowledge we can acquire? Of course the answer to such questions depends on what we think *knowable* means. Indeed Eddington is depicting the knowledge which he thinks to be the genuine knowledge of physics. We acquire knowledge. But knowledge has *always* the specific character of being knowledge *of* someone. It is misleading and rather naïve, in his view, to think that any inference in science ought to be based on the presupposition of a pre-existent, objective and mind-independent datum. Eddington's view on experience is peremptory: "*The data furnished by individual experience are clearly subjective, and it is ultimately from these data that the scientific conception of the universe is derived for what we term "collective experience" is a synthesis of individual experiences. It would seem almost axiomatic that an ultimate datum is necessarily subjective*"(1934: 294).

On the other hand, such a view does not aim to an individualistic/solipsistic perspective. He rejects any attempt to derive a solipsistic outlook. The possibility of

avoiding it rests on the comprehensive view on knowledge which Eddington draws in the conclusive parts of his epistemological works (1928, 1936, 1939). Beside the structural knowledge of physics, human knowledge also involves a direct knowledge (of own feelings) and a sympathetic knowledge(with other people experience). In other words scientific knowledge is just a part of the whole cognitive building, which has anthropologic roots, rather than epistemologic ones. We might say that knowledge is a human activity and that it is hinged on experience (then on a subject-object interference): its constitution and characters depend, with respect to the subject, on the way it *is* in the multifaceted experience as a human being (not only as an individual)[24].

Eddington does not deepen such an idea, he just presents an overall view in the conclusions of both *The philosophy of physical science* and *The nature of physical world* and in the epilogue of *New pathways in science*. Anyway it is clear that he does not conceive the subjectivism as a form of solipsistic individualism. Even when he remarks on the importance of individual observers in breaking the symmetries of the universe with their observations (i.e. with their frames of reference) he always emphasizes that the relative gained knowledge is not merely imaginative nor less worth to be studied, since mind selects characters on an underlying background. But the relevance is on the fact that it is a *selection*. As mentioned, physical knowledge grounds on experience and experience is an interference of subject and object, the subject having a half-sharing in such an interference. From the subjective side, the interference is selective rather than creative[25]. Thus in some sense, Eddington seems to be posing some limits to any procrustean action of mind. Unfortunately he is far from being clear on such point. Through some passages (emphasizing the limits of the mind's action) it seems that we cannot put into the world something that was not there.

In qualifying the physical world, that is the world described by the equations of physics, Eddington assigns to it three features:

1)   it abstracted "*by the mind of the scientist from a more comprehensive reality*" (1934: 292);

2)   it is constructed "*by the mind from relations and relata*"(*ib.*)

3)   it is given "*as embedded in a background reality*"(*ib.*).

---

[24] The emphasis on the anthropologic basis of human (global) knowledge might also be the source of a difference with the kantian perspective.

[25] The difference between the creation and the selection becomes minimal as much as we enter the microscopic domain.

What is given is, for instance, the spatiotemporal structure as a four-dimensional continuum[26].

The equations of physics, which obviously are abstractions, effectively describe a world which is embedded in a background reality external to the knowing subjects: nevertheless such descriptions do construct the physical world, through *a putting together of associations to which the mind is sensitive* (*ib.* 293).

On the other hand, mostly of his remarks on the categories of thought leading physical descriptions insist on the fact that there is not strictly speaking any *necessity* for us to recognise that patterns out of our cognitive activity: i.e. the selection gets back something which we put ourselves into the object. Nevertheless, though most of the law of nature are dependent on the categories of though we employ, there are some *laws of Nature* (capital "N") which genuinely pertain to the world independently on us, for instance a law of atomicity.

Eddington assigns to the subject a weight which is paramount in both *The Philosophy of Physical Science* and in *Space Time and Gravitation* and it is weaker in *New Pathways in Science*[27]. Yolton rightly commented that he *strives* to place the observer, since indeed he constantly insists on the impossibility to conceive a completely objective knowledge. On the other hand, if the knowledge is always subjective, what about the *objective reality*? What about the objective world? Eddington answers the question in considering criticisms on the role of mind, coming from the neorealist perspective of W.T. Stace and C.E.M.Joad (*New Pathways in Science*). He thus discusses the objective reality of, say, electrons and atoms, assuming first of all a certain difficulty in defining the 'objectively real'. The subjective selectivism aims to an explanation of *the relation of atoms and electrons to the data of human experience.* To a great extent anything that is in relation with experience could considered "real". The issue is the definition of the term: for sure, whilst the definition would imply the complete independence from the mind, the 'being in relation with experience' would hardly be a warranty that the distinguished characters assigned to atoms and electrons would be classified as "objectively real". On the other hand, Eddington remarks that the scientific

---

[26] Kant considers space and time as pure a priori intuitions through which *we* analyze phenomena, having no correspondence in the world a part from the knowing subject. Eddington's view is different.
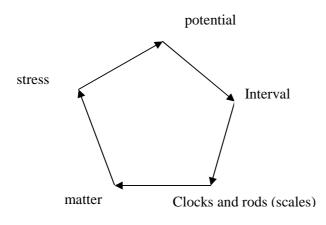
[27] Even such a distinction must be taken as just indicative. The works in between the three mentioned also present a non definitive position.
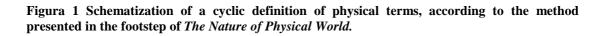
status of those entities also undergo somewhat uncertainty because of the quantum theory and this very fact obviously impacts their philosophical status (the way we want to consider them). In such respect "*The effect of wave mechanics (especially as developed by Dirac) is to make the separation of the subjective and objective elements in human experience more indefinite. Relativity theory revealed an unsuspected subjective element in classical physics and cleared it away; wave mechanics has revealed a further subjective element; but its procedure is to let it stay and adopt methods suitable for treating a partially subjective world. So far as I can see, we find ourselves unable to reach by physical methods a purely objective world, and it would seem to follow that all the entities of physics have the partial subjectivity of the world to which they belong though, of course, they are not purely subjective*"(1934: 292).

The selection is linked to a constructive moment. But it is unthinkable without the resting two features of the world (abstracted and given). Thus physical knowledge is not a merely constructive enterprise. The constructive feature is expressed in the constitutive role of the frames of though, which build physical knowledge and determine the unique forms through objects could present to our knowledge. How does the selection happen? As mentioned, Eddington does not want to make knowledge relative to individuals, nor he wants to attribute reality to something which do not exist. Ryckman claims that a great role in Eddington's view is played by a *cyclic reasoning* , which he introduces in *The Nature of Physical World* and poses again in *New Pathways in Science*. Eddington poses physics to define its own terms through a cyclic *method*. For instance he considers the term 'potentials'. They are some quantities introduced into Einstein's law derived through mathematical manipulations on other fundamental quantities called 'intervals'. On their turn intervals are measurable relations between events, we measure them through clocks and rods[28], rightly used according to instructions. Clocks and rods are strip of matter. But what is matter? Avoiding the notion of substance, Eddington defines matter within the domain of mechanics as *the embodiment of three related physical quantities, mass (or energy), momentum and stress*. Finally the cycle closes when Eddington presents the *far-reaching achievements of Einstein's theory that it has given an exact answer to the question. They are rather formidable looking expressions containing the potentials and their first and second order derivatives with respect to the coordinates*" (NPW 262). The cyclic method is schematized as follows[29]:

---

[28] Eddington rather mentioned rods and "scales".

[29] Eddington adds an arrow going out of the cycle in correspondence to 'matter'. The arrow points to a someone Mister X which represents the observer. He finally decides what do not matter a definition as it is *known*. Another arrow link Mr. X to a '?' which indicates the 'known' matter.

potential

stress

Interval

matter

Clocks and rods (scales)

Figura 1 Schematization of a cyclic definition of physical terms, according to the method presented in the footstep of *The Nature of Physical World.*

The cyclic method is reposed in *New Pathways in Science* concerning the inferences through which physics account for everyday experience. Eddington discusses a criticism from Mr.Joad on the circularity of the proposed inferential route: we *infer* entities (for instance atoms and quanta) starting from daily observations (of course through an inferential process); on the other hand those entities ground the descriptions through which we construct the physical world in which they are suggested to live.

Observations ⟶ Entities

Physical World ⟵ Descriptions

Figura 2 – Schematization of the cyclic method applied to the scientific inference.

Ryckman takes the cyclic method (he says the *cyclic reasoning*) to manifest the transcendental character of reasoning, thus reflecting the kantian perspective. In this way also Eddington's demand for a synthetic conception of measurements is accounted for. The synthetic conception of measurements, which basically involves the invariant formulation of the interval, produces a supposed impersonal objective reality. But such a synthesis is achieved only if the performing rules (deductively given to us) are properly carried out. Those rules also set the way our instruments must be built. In other words, we

build our measurement apparatus according to some rules; we derive conclusions (particular measurements); we abstract generalizations to which we attach a legend of objectivity in the standard sense of mind-independence. Finally from the generalizations we get back the very rules. Indeed they are the same rules according to which we built the instruments.

Figura 3 – The *cyclic reasoning* according to Ryckman (2005 §7. 5. 3)

Those rules are given to us deductively according to the mind's selective activity: in this, Ryckman accounts for the several passages in which Eddington emphasizes that we just get back from nature what we ourselves put into it. In the conclusions of *The Relativity Theory of Electrons and Protons* Eddington poses such a mind-dependence of knowledge as necessary character of our attempt to understand the complexity of the world: we start to understand it through a *sieve* and finally we comprehend what we ourselves put into the world to comprehend it.

On the other hand, whereas the selective aspect emphasizes the constructed character of physical world, the remaining two features which Eddington attaches to it (*abstracted* and *given*) cannot be set aside. The assertion that mind cloaks with vivid qualities some pre-existent causal structure weakens the feared solipsistic risk, which is implied into the

subjectivist points of view. In such a sense the selection (on the ground of a previous structure) could involve a correspondence to some intrinsic characters of the world, as it will be with the four-dimensional character of the world, in General Relativity. Such a possibility is often remarked from Eddington despite Ryckman's account of the cyclic reasoning.

By the way, the selection effectively happens and directs knowledge[30]. In such a respect Eddington's view suitable fits with the reflections which recently drove the reconsidering of Kant and of logical positivism with respect to the role of philosophy in science (see Friedman [1992], Friedman [2002] and DiSalle[2001]). The focus of such a reconsideration is mainly a clarification of the role of philosophy in science in the understanding of the theory changes. But the interesting point, with respect to Eddington's view, is the suggestion that the crucial node is the understanding of the ongoing conceptual changes. Indeed it manifests the idea that the root of the scientific progress are highly engrained with the development of some fundamental concepts. In such a sense, according to DiSalle (2001), the work of Einstein is paradigmatic in developing a new understanding of the electromagnetism through a progressive and open dialogue with the previous *conceptual* paradigm. Eddington's reading of the work of Einstein also focuses on the conceptual elaboration, in a slightly different sense. In order to understand it we will delineate the two chief thesis of selectivism concerning the *intellectual* equipment:

> (a)   Some frames of thought underlie the expression of our physical knowledge.
>
> (b)   It is partially possible to *emancipate* from a frame of thought *as soon as we realise that it is only a frame of thought and not an objective truth we are accepting* (1939: p.121)

According to Eddington, the inquiry into the intellectual equipment through which we approach the world of physics elucidates those "forms of thought" or "frames of

---

[30] According to such a view Eddington rejects naive realism, materialism and mechanistic conceptions of phenomena as they fail in addressing such an essential feature as the consciousness of experience. He also sees in the new physics a reconciliation between life and theoretical knowledge: especially in the indeterministic characterization of physical universe. Paradoxically such an indeterminism reaches the status of the more objective approach to science, as Eddington says that is " *something which a reasonable man might almost believe*" (Eddington 1934:91).

thought"[31] within which physical knowledge is fitted, for instance the concept of substance, the idea of the separability of space and time, the concept of analysis. Through the study of the intellectual equipment it is possible to foresee some characteristic of our feature knowledge, which could be discovered *a posteriori* in the laboratories.

Considering the first thesis

(a)   Some frames of thought underlie the expression of our physical knowledge.

Eddington does not care to clearly justify it. He rather provides examples, as the influencing frame of thought grounded on to the distinction between space and time. Such a distinction is not to be found in nature. Yet it underlies the discovery of a lot of laws and properties which are taken to pertain to natural objects and which are comprised into the Lorentz transformations. As known, Lorentz transformations are invariant with respect to the systems of reference. In such respect they are meant to overcome the particularity of the observer's frame of reference. On the other hand they generalize properties which are ascribed on the basis of a distinction which does not exist in nature. In such a respect, according to Eddington, the greatness of the theory of Relativity is exactly the fact that it enable us to *go through* the frame of thought which made us separating space and time: in doing this it does not disregard laws, properties and scientific conclusions we reached through that previous frame. It just makes us recognise which are the usual forms of our thought, thus making us independent from them: "*we use them, but we are not deceived by them*"(*ib.*118).

In some sense even Lorentz transformations maintain the subjective elements since they are generalizations of laws and properties which were ascribed to objects according to a reference frame[32]. On the other hand, through Einstein's work, we are now able to recognise the such a frame-dependence: in such a sense we still use the previous reached laws *but we are not deceived by them*. A further example is the law of the increasing of mass with velocity: such a law naturally arises, he says, from a frame in which a we separate space and time from their original four-fold unity. When we analyze how mass changes with

---

[31] On a closer view, Eddington distinguishes between forms of thought and frames of thought, the latter being a more elaborate occurrence of the former. For instance, a form of thought is the concept of substance, a frame of thought is represented by the concept of *analysis*.

[32] Such a view is clearly expressed also in *The Relativity theory of electrons and protons* (1936).

respect to the changing velocity, we basically discover again the relation between the temporal dimension and the velocity's vector, once the former has been separated from the four-fold unity.

Hence the revolutionary role of the theory of Relativity consisted precisely in making manifest the features of a frame of thought: Relativity did not discarded the previous frame, since indeed many of its scientific conclusions are still used, rather it made us looking "through" the latter.

Such a view is clearly a rejection of naïve realism. But also could confound a realistic point of view according to which Lorentz transformations are taken as truly general and invariant formulations referring to some *intrinsic* feature of the world. The equation 'invariant = objective = intrinsic feature of the world = intrinsic feature of natural objects' is in fact an assumption of the realist positions (see Castellani [1994], [1998]). Eddington does not deny the generalizing power of those transformations, nor the relevance of their character of *invariance*. He rather links the generalizing power to an intellectual reflection on the system of analysis. In such a sense he separates the wider validity of the new invariant transformations with respect to the old transformations, from the direct correspondence with intrinsic properties.

On the other hand he maintains that what is discovered is not merely illusive, nor 'unreal'. He maintains a *relative* character of the reached conclusions as the distinctive feature of its being the fruit of human knowledge, always and unavoidably a *relative* knowledge of an *absolute* universe. This is not meant to make human scientific knowledge trivial, nor illusory, nor useless, nor false. On the contrary it becomes in some sense a relative centre of truth, thus maintaining and increasing the relevance and fruitfulness of the inquiry into it. In such a sense the closeness with the kantian perspective does not eliminate the possibility of suitably involving Eddington's approach within a realistic approach.

The thesis (a) introduces the selective role of the knowing-subject, his having a half-way in the experience and consequently a sort of cautiousness in ascribing properties to the world.

The second thesis (b) concerns the possible 'revisability' of the system of analysis:

(b)   It is partially possible to *emancipate* from a frame of thought *as soon as we realise that it is only a frame of thought and not an objective truth we are accepting* (Eddington 1939:p.121)

The frames of thought are revisable, i.e. they could be substituted by new ones. In such a sense, the theory of Relativity manifested an emancipative power, since it enables some frames of thought to be recognised. From the revisability of the frame of thought the science appears opened toward new conceptualizations. Though Eddington's categories of thought are constitutive (since they dictate the possible forms of our knowledge and objects of knowledge) they do not share the absoluteness of kantian forms. For instance, the concept of substance is presented a far influencing and pervasive concept of human thought and yet Eddington analysis dismisses it.

Whittaker emphasizes that the more stable principles in scientific progress are the *negative* principles or principles of impotence, which basically prevent us from doing things[33]. By the way Eddington does not focuses on the negative principles (it is rather an interest of Whittaker to track them within Eddington's work). He rather individuates and analyzes some positive concepts which are fundamental in leading our conceptions: the first and the most influencing one is the concept of analysis[34]. It is the concept of "*a whole as divisible into parts, such that the co-existence of the parts constitutes the existence of the whole.*" (*ib.*118). Why is the concept of analysis so important? Eddington takes it to be in conformity with the 'necessity' of analyze which is typical of physics, i.e. the necessity to account for the variety in terms of simpler elements. Such an apparently simple concept guides science in different ways, since it has been correlated to other concepts:

- The concept of substance.
- The concept of identical structural units – identical parts resembling one another.

Indeed the concepts of analysis involves the reference to *wholes,* complexes, as *sets* of parts. What could significantly change is the conception of *part*. In some sense Eddington distinguishes between a 'right' and a 'mistaking' way of conceiving the wholes, according to

---

[33] The relevance on negative principles is also remarked in recent philosophical debates (see Longo within the bibliography).
[34] Eddington also calls it a 'necessity' of thought

the way *parts* are accounted for. Rightly meant analysis should not involve an individualistic conception of a part as separated from the rest, since the latter is always a member of a 'complete set of parts': its significance is bound up with the system of analysis in which it occurs. The right way to intend 'part' is then as "component"[35].

Apart from the part being a component of a whole, the concept of analysis does not bring a *qualitative* distinction between parts. Thus the effort must be put in setting out another concept which brings qualitative distinctions: the concept of substance. Indeed it introduces a distinction between *positive* and *negative* parts, privileging the positive ones[36] and imposing a restriction to the concept of analysis. Instead the right way to account for the latter is to consider both the positive and the negative components[37].

"Substance" has been so long the main manifest category affecting our sight on the world because of its opposition to emptiness: such a distinction would be due to the preference of mind toward the character of having *positive* qualities and of permanence. The relevance which it acquires with respect to physical knowledge could be better understood as we clarify that Eddington fundamentally identifies *substance* with *matter*. As we will see such two features of the reflection on substance (distinction substance-emptiness and identification substance-matter) constitute a joining point of the two perspective of Eddington's philosophy of science (selective subjectivism and structuralism). By the way 'substance' does not *substantiate* into a system of analysis: it just imposes some constraints, which the theory of Relativity helped to eliminate. The real system of analysis which it did not eliminate, though manifesting it, is still due to the concept of analysis.

The *system* of analysis within which physics approaches phenomena is then linked to the idea of a progressive reduction to simpler and simpler parts: hence the concept of analysis is associated with a further one, according to which physics reaches or aims to reach *identical structural units*, i.e. identical particles resembling each other. Such a

---

[35] Thus the relation part-whole must be thought as component-system

[36] A banal example of substance analysis is the analysis of a barrel: the substance-analysis does not consider the bung-hole as a part of the barrel, since it is something with a 'minus' sign (it is a hole in the wood of the barrel).

[37] The right way to understand the latter in physics is considering the example of the positron, the antiparticle of the electron: "*A positron is a hole from which an electron has been removed; it is a bung-hole which would be evened up with its surroundings if an electron were inserted. But it would be out of the question nowadays to define "part" in such a way that electrons are parts of a physical system but positrons are not.*(1939:121). Another example in such a sense is the light being 'a part' of darkness (since darkness is taken to be the outcome of two interfering light waves). A very similar reflection on the relationship between particles and antiparticles is also expressed in Toraldo di Francia (1998), whose holistic suggestions as also a reference within the recent structural realist literature.

specialization of the concept of analysis justifies, according to Eddington, the common scientific agreement on the products of science: molecules, atoms, electrons, photons and so on. Thus science grounds on an holistic principle (the concept of analysis once substance have been deleted) and paradoxically on a somehow atomistic principle (the concept of identical structural units). They are so strictly fused that when a difference among the components of a whole is found, it is immediately adduced to a difference in the internal structure of those very components, i.e. to the fact that they are not truly the last units.

Once the two categories (analysis and structural units)have been recognized, Eddington starts to 'work' with them in order to place them in a right light. The first objection which might be directed to such a view, in particular to the atomistic principle, is that physics does not deal with units which completely resemble: for instance in considering electrons and protons as units, we are forced to recognize two varieties. On the other hand, such a difference is plainly taken to indicate that physics have not yet reached its target and to pursue farther the research: thus the difference between electrons and protons is taken to be accounted in terms of a diversity in their internal structure. So the apparent dissatisfaction of a reduction to electron and protons manifests the action of the frame of thought which pursues us to instinctively account for the diversity in terms of underlying simpler units[38].

Thus the strongest thesis: the last constituents[39] of the world have the fundamental character of the *sameness*. In so far as the intrinsic nature of the related units is concerned and in so far as an issue on their *nature* enters the aims of physical knowledge, it deals with their *sameness* and nothing more.

Hence the system of analysis which drives science is three-fold:

    i. in the first place, it is characterized by the research of elementary units;

    ii. in the second place, it involves that the simplest elements ground the complex ones;

---

[38] As a matter of fact those simpler units have been discovered, as the quarks.

[39] As we will see in dealing with the metaphysical consequence of the structural thesis, Eddington does not completely deny the individuality of particles, though the accepted meaning is very thin, within the descriptions of physics.

iii. in the third place, the variety arises from the variety of the mutual relations between those units, among themselves, with observers and with other external objects.

(i)condenses the atomistic view; (ii.) is a corollary of the concept of structural units which enables the equation 'elementary units = simplest elements' and (iii.) restates the holistic view of the concept of analysis. Eddington did not formulate the equation of (ii). Nevertheless it seems to us that it is involved in the way (i) and (iii) are presented in the traditional view.

Joining the three features the arising system aims to reach the simplest ultimate elements grounding the all complexity of the world. Such a view has two corollaries: in the first place those parts are taken to be detachable (not distinguishable, but isolated), independent from one another; in the second place, since variety is a challenge for reduction, the ultimate elements must be characterized by *sameness*. The sameness arises from our forcing the physical knowledge within the categories of thought.

The way Eddington works[40] on both the concept of analysis and the concept of structural units seems to basically lever on or enable a change in the mentioned perspective.

The revision concerns precisely the view on units and the equation elementary units=simplest elements. For sure Eddington analyzes the physical enterprise from a perspective which aims to reach the elementary constituents. Indeed General Relativity deals with point-events, devoid of properties (hence of eventual differences), and the variety of the universe arises from their spatiotemporal relations: even when he passes from point-events to the material particles, the properties like mass and charge are accounted through a relation with the general distribution of matter.

On the other hand something has changed with respect to the i+ii+iii view: the target are not any longer the simplest independent units. The search for the ultimate elements was the search for the simplest in terms of which the reduction of the complex could be operated. But 'ultimate' in Eddington's view does not mean 'further un-analyzable', nor independent: Eddington is happy with electrons and protons, though knowing a relative

---

[40] Remember that the thesis (b) of the selectivism allows for the revisability of the frames of thought. In considering the concept of analysis and the concept of structural units Eddington as a matter of fact reformulates them in order to suitably place them within the new epistemology.

difference. He takes them as the first bricks of the relations: why? Why do not their difference bother him? Because he considers even that difference as dependent from their relations with the general structure. In such a sense those units are genuinely taken to be components of a whole, hence un-detachable from it. In such a sense those units are not simple at all, with respect to the relationships they engage.

What is really interesting and what is also fruitful in providing an understanding of the physical world is not the atomistic ideal, which looks for the simplest elements in order to make them the isolated bricks of our knowledge. The real understanding must begin with something rather complex as the relation among rather indistinguishable[41] units, and between them and the background structure (distribution of matter). As constituents and as relationally characterized they are not independent, nor they necessarily are simple. The outcome is that the atomistic approach is subsumed into the holistic one. In Eddington such a possibility will also be a fundamental feature of the structuralist perspective.

This does not prevent us from speaking of electrons and protons and other particles, rather put the research in the right conceptual perspective.

Why did we say that the relation is complex ?

      1)   because it already starts with 2 elements, and truly regards more than two bodies

      2)   because there holds an intimate exchange between dynamics and geometry: the intervals is not *only* a metrical distance. Einstein theory gets Riemann's lesson: the metric derives from the cohesive forces among bodies. Eddington does not mention this link, but he is well aware of the centrality of the relationships between dynamics and geometry both in General Relativity and Quantum Mechanics[42].

---

[41] To be more precise, Eddington says that whilst the aim of the analysis is to separate it must stop short before the ultimate units, since their indistinguishability would confound them thus making the separation vain.

[42] Eddington mentions the link in several passages, starting from the reflection on the theory of Relativity, which must be looked at through the geometry-mechanics 's lens. Concerning the quantum domain the relevance of the link does not change, as he says for instance in *New Pathways in Science*: "*It also follows that in the small-scale systems we cannot separate geometry from dynamics. As soon as we introduce into our picture of the world anything possessing orientation, it automatically begins to spin one way or the other. To say that there is definitely no spin would be to claim an accuracy of knowledge which we have seen to be impossible. The most "restful" system we can contemplate is one equally likely to have any value of the spin up to half a unit in either direction. Knowing then the probability distribution, we can*

3)   Thus the complexity of the reality does not merely rely on simple elements, rather on their mutual relations (first order: individual and their properties; second order: relations and their properties)

4)   The discourse is not different in QM: when Eddington brings into account a particle he always considers also the environment in which it is inserted. The starting point are systems.

Moreover, though simplicity acts as a regulative idea in such a research of the constituents, the final product of the analysis is different from the expectation: indeed, considering General Relativity, the focusing point is a relation, the *interval*, which is invariant and is the new physical measure. It seems that the reduction misses the target. Indeed the search for the elementary units comes up with the fact that the truly explicative/ characterizing element is the relation between such units, rather than the units themselves.

So far, we followed Eddington's reflections on the main categories of thought influencing our path through scientific knowledge. The constitutive feature of the categories of thought (thesis a) and their revisability (thesis b) are the two main features which enable a (neo)kantian understanding of Eddington's selective subjectivism. Such an understanding also gives reasons for those features which motivated the attempt to track an operationalist or a purely idealistic route of Eddington's view. On the other hand within the selective subjectivism the two other characteristics of physical world (abstracted and given) should be accounted for. Though the efforts in emphasizing the mind-dependence of knowledge, the fact that the outcomes of the analysis fit well with reality is not a mind-dependent fact: some features appear which resist the mind-dependence. Yet such very features enter the descriptions of the physical possibilities: in such a sense the subjective element does not delete some knowable intrinsic features of the World, it rather remarks that the two dimensions (subjectivity and objectivity) are not just juxtaposed. That the physical knowledge gets relative, but not less real, features of a richest absolute reality is a growing character of the new physics, where for instance Quantum Mechanics contributed, according to Eddington, to further extend the domain of subjectivity.

compute the average energy of spin of a large number of these restful atoms; in macroscopic physics the average is all that concerns us" (p.106).

Once the kantian link have been established, we endorsed the analysis of the categories of thought, finding that the dismissing of the concept of substance serves the right placing of a more pervasive frame which effectively informs the scientific thought: the concept of analysis. Though the concept of substance has been avoided, the concept of analysis remains, which couples with the concept of structural identical units. From the theoretical point f view those concept respectively represent an holistic outlook and an atomistic outlook. Their analysis according to the outcomes of Relativity ends up with an absorption of the latter within the former to the extent that the parts are un-detachable from the systems, though they still maintain some sort of individuality as relata.

Hence, through the analysis of the conceptual frames and the attempt to suitably re-place them, Eddington progressively reaches the idea that the new physics is a discipline which proceeds through concepts of form rather than through substances[43]. Thus must be considered, for instance, the periodicity of waves of Quantum Mechanics and the curvature of spacetime of General Relativity[44]: "*I do not suggest that either the curvature or the waves are to be taken in a literal objective sense; but the two great theories, in their efforts to reduce what is known about energy to a comprehensible picture, both find what they require in a conception of "form"*(*ib.*) (1939:110). Following what we said in the introduction to the selective subjectivism, the outcomes of the epistemological analysis are those unique forms in which the world could ever present to our knowledge. We also mentioned that Eddington's philosophy of science is twofold: so far the first horn have been considered, concerning the aprioristic character of scientific knowledge; the emphasized relevance of form and the holistic approach enable the bridge to the second horn, proposing a new understanding of our theory's formulation.

The second label which Eddington attaches to his approach in the introduction of *The Philosophy of Physical Science* is *structuralism*. As mentioned, it refers to the reflection of the mathematical formulation of physical knowledge. On the other hand the two moments cannot be completely separated: the passage from the first to the second is made through the analysis of the concept of structure which mediates the holistic approach developed in

---

[43] In such sense it is also possible to understand the affirmation that matter is one of thousands of relations. The criticism against substance, as mentioned is a criticism against the idea that a partial concept would led our understanding of the world.

[44] The periodicity of waves and the curvature of spacetime are the ways energy manifests itself respectively in quantum mechanics and General Relativity (see *The Philosophy of Physical Science*).

the concept of analysis. As we saw, the holistic approach is engrained within selective subjectivism.

On the other hand 1) a *structural holism* does not directly involve any form of antirealism nor relativism. On the contrary it is perfectly compatible with a realistic approach. 2) Eddington does not ever ask why we recognize only that patterns. Maybe it is not a question which interest to structural knowledge, while he wants to deal with structural knowledge.

Structuralism appears as a reading of scientific theories which reruns to a great extent the conceptual apparatus of the selective subjectivism, concerning the *form* which the objects of knowledge acquire. Beside the conceptual view, he thus develops an operative approach, i.e. he considers the mathematical apparatus of the theories, in the first place the apparatus of the general theory of Relativity.

He considers the scientific image of the world, i.e. the total amount of outcomes achieved through the methods of science, and evaluates the nature of the acquired knowledge: it is a knowledge of structures as *a complex of relations and relata*. The conceptual approach is still at work: he basically brings the holistic approach to the specific domain of physical knowledge. In such a sense what is the need for a *structuralism* rather than a simple *holism*? The label is due to the fact that the holistic approach nourishes with a deep reflection on the geometrical structures emerging from General Relativity as physically significant.

Eddington basically meets a geometric world. This feature motivates the structural quality of physical knowledge and the emphasis on its symbolic characterization: physical knowledge is both structural and symbolic.

The methodological instruments under scrutiny are:

     1)   the procedures according to rules which produce/achieve certain symbols

     2)   the very symbols through which physical quantities are represented

Such symbols constitute the limits of our knowledge as they summarize the maximum of the available knowledge concerning certain definite conditions of the world. In such a sense they represent the solely/unique way we get knowledge of physical quantities: "*mathematical symbols represent elements of knowledge, not entities of the external world -*

unobservables cannot be introduced except by deliberate intent as auxiliary quantities in the mathematics. The modern physicist is often reproached for assuming that because he has no knowledge of a thing it is non-existent. But this is a misconception; there is no need to make any assumption about things of which we have no knowledge direct or indirect, since they cannot appear in ananalysis of our knowledge.(PPS 50)

The paramount role that mathematics plays within Eddington's structuralism is both a feature and an issue: indeed the first glance on structure is given from a mathematical perspective. Moreover even the final characterizations is "the structure investigate by the mathematical theory of groups". On the other hand notions as *symbol* and *symbolic nature* are often used without a clear definition.

The structural approach is suitable within the mathematical domain probably because of the very nature of mathematical reasoning which let us deal with entities and relations independently of their, so to say, regional instantiation here or there. This line of abstract reasoning, which privileges the loss of particulars in favour of a gain in generality, was already codified by Euclid in his treatise. Of course the first issue is the way to link the mathematical abstraction to the physical concreteness, unless we endorse a platonic view on mathematics.

From the point of view of the physician Eddington, mathematics provides the symbols through which our physical understanding of the world proceeds to the extent that the very target of physics turns out to be a symbolic world, i.e. a symbolic image of the commonsensical world. The question could then be, what does physics add to the science of numbers which provides us with such symbols? The immediate answer is that physics performs measurements on phenomena and codifies the outcomes in mathematical formula, with the aid of mathematical symbols. In such a way it provides us with an image of the physical universe, the whole of the natural phenomena we observe in a direct or indirect way. But this is just one horn of the answer, which holds for the experimental physics. The other horn holds for a branch of physics which according to Eddington uses a wholly different method: the theoretical physics. In that domain, the general aim being the same (giving an image of the universe we live in and of the knowledge we obtain of it), mathematical symbols[45] are not embedded as outcomes of experiments, rather as outcomes

---

[45] According to Eddington the very communicability of knowledge depends on its mathematical character. An issue is that though insisting on such a character as a symbolic character, then he does not clarify the meaning for 'symbolic'. Nevertheless a point which remains fixed is that symbols must give us informations which let us perform operations.

of some principles arising from intellectual synthesis. Though in physics "*we hardly may do without mathematics*"(1928: 241), the mathematical apparatus is itself reached somehow *in perspective*: the perspective developed starting from some ideas. Basically he is thus affirming that a theory is not (just) empty mathematical formulae[46], since those formulae, embedded in a physical theory, are already the outcomes of an intellectual synthesis full of content. An explicit example of this feature will appear in Relativity, when he will dwell on the use of tensors. At present we shall note that the hint on the role of mathematics is also interesting for what we are going to inquiry in the following, that is the idea that we can predict/infer the outcomes of the observational knowledge through an analysis of methodological tools and categories of thought at works.

Regarding the methodological instruments through which the scientific knowledge proceeds and in fact works, they are basically mathematical symbols, the counterpart of physical quantities. As we consider the incipit of *Space, Time and Gravitation*, we find Eddington saying that '*any physical quantity, such as length, mass, force , etc.. which is not a pure number can only be defined as the result arrived at by conducting a physical experiment according to specified rules*" (1920, p.8). What he is pointing as 'methodological tools' are not so much the specific physical quantities (length, mass, force, etc.) rather 1) the symbols through which the latter are defined and 2) the processes (of conducting a physical experiment) according to specified rules through which the symbols are achieved. Finally he affirms that the symbols through which we represent them constitute both limits of our knowledge and "definite an absolute conditions" of the world (1920a:151). Those symbols represent the unique way in which our knowledge of such physical quantities is achievable and achieved: there is not any other way to embed those quantities into a *physical* knowledge. In such a way the second qualification of physical, structural, knowledge is that it is symbolic: working on physics is dealing with this kind of knowledge, which Eddington distinguishes from another kind, non-symbolic, qualified as 'intimate'. Such a feature reduces the extent of the structuralist thesis only to a part of human knowledge, meant as a greater whole. The whole of knowledge involves then the direct knowledge of our feelings, the sympathetic understanding of our past feeling or of other people's meanings, and the structural knowledge. So far as physics is concerned, we deal with the last one.

---

[46] In this sense he would contradict Hertz's famous assertion about electromagnetic theory: Maxwell's theory is Maxwell's equation. Also, a deep inquiry into the relationship between the mathematical and the physical could bring some items within the debate on the epistemic structural positions.

The frequent insistence on the fact that human mind is the alchemist who somehow transmuted the symbols, dressing them with tangible characters and even with new significances, partly takes us again to the issue of the relationship between subjective and objective characters of the new physics that Eddington is inquiring: from the beginning till the end of his philosophical analysis the subjective side of scientific knowledge appears then as an unavoidable feature. The very categories of subjective and objective are re-situated, in order to account for the fact that it is impossible (and we are unable) to reach a completely objective world through the methods of physics. In some passages the relationship is even unbalanced, toward the subjective dimension. Nevertheless, the entities and properties and magnitudes which physics poses are not purely subjective. The mentioned mathematical character of scientific theories makes them representations of an independent world. And they are good representations. This makes more urgent to understand the second point, i.e. the process according to rules through which the mathematical symbols are reached.

The focused quotations on the status of physical quantities are taken from two works, *Space Time and Gravitation* and *Mathematical Theory of Relativity*: in such works when he speaks of and qualifies measurements, observations and procedures of observations, the perspective is subjected to the *Relativity standpoint*. The Relativity standpoint is the requirement that physical knowledge, which is based on measurements of physical quantities, first of all lengths and durations, "*must be stated in a form that takes into account the possible measurements of wider and wider classes of observers*"(Ryckman, p.184). The observers are actual or conceivable.

Since a subjective quality , i.e. an human element, cannot be avoided from the conception of nature, what we can do is to eliminate any *particular* element, i.e. any reference to *this* or *that* framework. In few words, the frame must be left indeterminate and in this way it is possible to reach an image of the world which is independent of any particular observer, namely the 'no-one-point of view'. The relativistic standpoint seems to be the methodological counterpart of the principle of general covariance: the latter covariance is the principle according to which we should not have privileged coordinates and it is a fundamental requirement for the principle of equivalence, according to which gravitation is accounted in General Relativity in its connection with the special Relativity.

Indeed in a 'local' perspective, through considering the sufficiently small tangent spaces to the minkowskian spacetime, "General Relativity" reduces to special Relativity[47].

Now, the relativistic standpoint as the counterpart of the principle of general covariance, also is what motivates choice of point-like events as the starting point for measurements in Relativity, rather than clocks and rods which are frame dependent. In such sense, the form which our measurements and our experiments take is *ruled* by the Relativity standpoint.

The role of methodological tools finds also a better clarification in association with the afore treated categories of thought, the *ensamble* of those features (forms, notions or principles) which fit the observational knowledge and which emerge through the analysis of our intellectual activity.

§1.4. Conclusions

Our first chapter was meant to provide a general introduction to Eddington's philosophy of science, which is considered an essential starting point to evaluate his works on more technical features of the scientific theories.

The fundamental feature which he assigns to the physical knowledge is its aprioristic character. Through the analysis of our observational procedures some principles emerge which lead:

1)   our standing in front of the world in order to know it (it is a selective approach, linked in the first place to the notion of substance-matter);

2)   our understanding of the object of knowledge due to the understanding of its characters.

Thus we already know how to evaluate the outcome of our observations, even before their recording: it depends on the way we built and set our instruments.

The structuralism emerges from such an epistemic evaluation. Thus it makes sense to ask: what do we know? Eddington's answer is we know relations (at least within the theory of Relativity), we know a structure as a complex of relations among relata. In General

---

[47] Thus the dynamics of gravitational field and the curvature identify with the dynamics of an Euclidean space, holding the Lorentz-Poincarè group of transformations.

Relativity we will know a spatiotemporal structure which is the structure of the *determination* of the relationships between bodies (motions). Thus, when he says that knowledge concerns *forms* it is usually speaking of such patterns of interrelatedness. Sometimes it also refers more specifically to the mathematical symbols as empty forms which we fill with content through linking them to something else (other forms already content-full.

The idealistic tinge of such a point of view is evident and according to the author it *"arose out of mathematical researches on the Relativity theory"* (*New Pathways in Science*, 1928). Therefore he focuses on the 'construction' of things in scientific domain[48]: the world building. Understanding the role of both methodological tools and categories of thought is also useful to understand Eddington's certainty of the outcomes of the expedition of 1919: he was absolutely persuaded with respect to the theory of Relativity and from his analysis of it he was sure of those outcomes very much before the expedition.

Eddington shares with Bridgman, Kant, Cassirer, Einstein and so forth, the emphasis and focus on concepts, through not stopping at Bridgman operationalist approach. He shares with Berkeley, Kant and Cassirer the idea that physical knowledge is subjective, without achieving Berkeley's extremely idealistic perspective. He shares with Kant and Cassirer the idea that some categories of though inform our knowledge of the world and the very constitution of the object of our knowledge, through limiting it to the specific domain of physics. He shares with Cassirer the emphasis on the symbolic knowledge, the predilection toward the pattern of interrelatedness (an holistic outlook), a particular view on the fundamental properties as derivative with respect to an underlying structure, the rejection of the notion of substance, the physical origin of his epistemological view. On the other hand, once again, his reflections are limited to the domain of physics.

All the mentioned feature are in some sense shared with those philosophers, thus manifesting a continuity between Eddington and the idealistic tradition in its different variations. The distinctiveness of his view lies mainly in the way the different features are

---

[48]We see in his work a continuative insistence and trail to take the scientific world as closer as possible to the common sense: science starts from common sense and must not betray it.. that is way he could not accept completely the operationalist account. Whether he succeeded in bringing science and common sense together is a matter of doubts, nevertheless that was his urgency. Nevertheless, in the Gifford lectures and in NPS he stresses the distance between the "two " world (ex. of the two tables) as the "two aspects or two interpretations of one and the same world". Though he often speaks of confirmation of theories by observations, his view as an astronomer is that *"there are no purely observational facts about heavenly bodies"* (Eddington 1933 p.17).

introduced and the weight they have within the economy of Eddington's thought. By the way the most original formulation is the structuralist thesis which links Eddington to the deep development of mathematics and physics. In this sense it emerges the great profundity of a thinker and a scientist which, within his limits, tried to provide a unifying view science through his own scientific experience and through an epistemological analysis.

Eddington manifests the conceptual construction of the objects which enter our descriptions.

The presented framing of the structural approach in his link with the background (neo)kantian epistemology is meant to provide an introduction to the second chapter, which will closely consider the details of the mentioned analysis, mainly in connection with the works on Relativity theory.

Before going further, a remarkable feature of Eddington approach concerns his intended domain: he is dealing with physical knowledge and eventually the related discipline (biophysics, physical chemistry). Nothing more is involved in the structuralist/selectivist approach. He is not providing an omni-comprehensive approach to human knowledge. In such sense he is an anti-reductionist and he does not want to reduce every knowledge to physics. There are other levels of human knowledge and in the end a clear account for "human knowledge" must also involve both direct knowledge (of our feelings) and sympathetic knowledge (with other people feeling, with memories and so on), i.e. must account for a dimension of individual which is eminently anthropological, or sociological, and cannot be reduced to physics.

In his reading it is possible to find some insights which draw it close to Cassirer's epistemology, especially with regard to a certain idea of "object" which they both developed according to the outcomes of Relativity, then finding within the quantum mechanics a confirmation of it. Of course Cassirer's view presents a philosophical insight and baggage which overcomes Eddington's approach. Nevertheless, one of the reason for such a closeness could be the kantian root which Eddington explicitly recognizes and which should be addressed also because of the mentioned relation with recent views which instead are *realist* in attitude. Understanding the weight of what Eddington qualifies as an "idealistic tinge" of his view gives the extent of a possible retrieving of his view in the realist perspective: whether an intrinsic and unavoidable linkage between idealism and

structuralism would appear, the retrieving could be at least difficult. Indeed the realist approach

Anyway, the fact that such a tinge is not endorsed as a starting principle, rather it is unveiled as the final conclusion of a long analytic route, could represent an advantage for the structural realist who could somehow decide to what extent (how far) he wants to follow Eddington's route and where and when to correct it.

"Is it too much to say that mind's search for permanence has created the world of physics? So that the world we perceive around us could ‑scarcely have been other than it is? The last sentence possibly goes too far, but it illustrates the direction in which these views are tending".(Eddington 1920: p.198). Eddington's works show the attempt to conciliate the existent mind-independent world and the *mind-dependent knowledge*, which is a fact. Mind cloaks the geometrical skeleton of the world with measurable physical quantities, according to certain "interpretative patterns", that is, some categories of interpretation: e.g., *matter can scarcely be said to exist apart from mind(1920cp.153)*. The interpretative patterns of mind, its epistemic categories, appears as fundamental in the very definition of physical knowledge. Thus an analysis of the fundamental concepts is provided (in PPS), showing the systematicity of Eddington's approach, i.e. the fact that he approaches the analysis of scientific knowledge minding a general frame of thought (an epistemic key) within which the issues are stated. In order to understand physical knowledge such a frame cannot be set aside.

The mentioned thesis, that our knowledge of physical world is essentially structural, reflects a quite new and peculiar attitude with respect to the status of scientific knowledge, whose traces we surprisingly and with proper differences find through the work of some more noticed contemporary philosophers (B.Russell, M.Schlick, Carnap with some respect). Without entering such differences, we can note two features of such an attitude:

1.   it finds a fruitful application's bank in the reading of Relativity;

2.   it nourishes with a spread criticism of the notion of substance in favour of the emphasis of functional relations among elements of physical systems[49].

---

[49] On a closer sight the various structural thesis contain significant differences according to the way they are embedded within the global frame of each author's thought. An example, particularly interesting for us, of such a differentiated declension of the structural thesis emerges in the comparison between Eddington's and

With respect to Eddington's work, the reading of Relativity is the domain where the notion of structure finds its first, wide and clear definition and it is also the domain where the criticism of the notion of substance appears with strength, in the particular form of the criticism of *matter*. In the next chapter the inquiry into the scientific domain will be deepened by getting into the details of Eddington's philosophy on both the theory of Relativity and the Quantum Mechanics. Basically we will present the way in which the overall outlook of our author is declined within the two domains.

Russell's positions. As we will see the way Eddington accounts for the structure makes his position resist to an objection which on the contrary was fatal to Russell's thesis.

CHAPTER TWO

Eddington's Structuralism: the route from the General Theory of Relativity.

§2.1. Introduction

Sir Arthur S. Eddington was an herald of Relativity. S. Chandrasekhar, who was his student and friend, does not exagerate the conviction of the British scientific community when he mentioned that Eddington was responsible for Einstein's fame both in Britain and crossing the Atlantic. Eddington even led the British astronomers which obtained the observational confirmation of General Relativity in 1919[50], and which had a great impact even on the common people[51]. General Relativity and its confirmation acquired a fundamental importance because of their significance in terms of our understanding of the *universe we live in*, first of all in the physical meaning. In such events, the work of Eddington and many other among both scientists and philosophers aimed to code this new theory and its significance in terms of what time and space *really are*[52]. In his reflections Eddington emphasized a 'relational dimension' both in the way knowledge is constituted, as the interaction between subject and object, and in the way the very object is understood. This relational perspective emerged already from his astronomical studies on the organization of stars, in which he saw the beginning of a new fruitful research on the relationships of those *widely separated individuals* (1926: 120-1). Of course we must be cautious in using the labels:

---

[50] After a consistent work in the field of astronomy, mainly devoted to the study of the internal constitution of stars, Eddington became an expositor and exponent of General Relativity: with his close friend and associate Sir Frank Dyson he organized the 1919 expedition, though some years later Eddington had to say that he was so sure of the truth of GR that he would not have planned the expedition.

[51] Chandrasekhar quotes Rutherford's view on the impact of the confirmation of General Relativity on common people: "*The war had just ended; and the complacency of the Victorian and the Edwardian times had been shattered. The people felt that all their values and all their ideals had lost their bearings. Now, suddenly, they learnt that an astronomical prediction by a German scientist had been confirmed by expeditions to Brazil and West Africa and, indeed, prepared for already during the war, by British astronomers. Astronomy had always appealed to public imagination; and an astronomical discovery, trascendly worldly strife, struck a responsive chord. The meeting of the Royal Society, at which the results of the British expeditions were reported, was headlined in all the British papers: and the typhoon of publicity crossed the Atlantic. From that point on, the American press played Einstein to the maximum.*"(1983: 29)

[52] Of course, as we will see, this revolution in the physical conception of physical space (and time) was prepared or at least accompanied by another precedent revolution happened in the foundation of geometry with the discovering of non-euclidean geometries.

'relational dimension' immediately recalls the leibnitzian positions within the long debate on relationalist and substantivalist on the nature of space and time. Eddington does not endorse a discussion of such positions, nor draw his analysis in order to take his part within the debate. Nevertheless, since the General Relativity appears to him as the rising domain of the structuralist account, the ontological consequences of his view naturally make it enter the debate. The two challenging positions are generally presented as follows:

> i. *substantivalism* as the idea that space and time exist independently from the localized events;
>
> ii. *relationalism* as the idea that space and time are just relations between events and physical bodies[53].

Such two positions concern the nature of space-time and do not directly affect the nature of the objects in it (of any kind: events, material particles and so on).

Eddington's structuralism opens[54] a third view which *enlarges* the considered domain: the analysis of spacetime neither is the analysis of a set of relations arising or imposed on a separated set of objects, nor it is the analysis of a geometrical structure containing and affecting object without being affected. The scrutiny concerns a unique element, the structure-universe, which enters the theory as a whole whose geometrical and dynamical characters are indeed intimately connected. Such a universe is the spatiotemporal 'structure' which the general theory of Relativity inquiries. The equality or the priority, assigned to relations with respect to relata (without the possibility to account for the ones apart from the others) must be understood starting from such a view on how the object of General Relativity marks itself out.

Eddington's position differs from both the substantivalist and the relationalist approach since: 1- space and time cannot be separated from the events localized in them (the relationship is of the kind whole-components): thus for instance matter is not taken to cause an unevenness in the field, matter *is* the unevenness; 2- the ontological and epistemological primacy is not assigned to the physical bodies (differently from the

---

[53]The bibliography on such argument is endless: for a good introduction to the debate as uploaded in Relativity theory and for further bibliographic suggestions see Dorato(2005) Allori, Dorato, Laudisa and Zanghi (2007).

[54] As mentioned Eddington does not enter the specific of the discussion. The way he develops the structural knowledge concerning spacetime and matter suggests a third possible *intermediate* approach between the two main positions. On the other hand the full development of such a view must be looked for only within the recent debate. Indeed the idealistic tinge of Eddington's view induces some difficulties in the plain understanding of the mentioned patterns as patterns of the world.

relationalist account where relations are supervenient on physical bodies[55] – and on their properties - which constitute the ontology of the theory[56]).

With respect to the ontological consequences of Eddington's structuralism, our target in the following chapter will be the meaning that should be attached to his paradigmatic aphorism "*Space is not a lot of points close together; it is a lot of distances interlocked.*"(Eddington 1923: p.10). In looking for it, the sense in which the general theory of Relativity enable an structural ontology will hopefully come into light. In particular the analysis of the theory of Relativity[57] manifests some fundamental geometrical characters of the world. This is one of the main innovations introduced by Einstein's theory: the intimate association between geometry and mechanics (metric and field). In Eddington's work such an association also sustains the structuralist account because of the reflection on group theoretic invariance and symmetry.

In chapter one it has been mentioned that Eddington conceives the structuralist view as the natural reading of the scientific theories according to the holistic perspective due to the selective subjectivism[58]. Uploading the holism with the mathematical apparatus emerging in General Relativity he gains the persuasion that physical knowledge concern *structure* rather than *substance*, where the former is to be meant as a complex of relations and relata within which the material substances represent just a partial (in the sense of a 'part') element. Thus he claims that matter is but one among thousands of relations.

According to this view he attempts to reduce the analysis of phenomena to their expression in terms of relations and relata. The following sections will run this attempt, emphasizing on the one hand the leading principle of his analysis (§2), on the other hand the way the emerging relational perspective matches with the mathematical apparatus of General Relativity(§3) and finally the place that relations and relata occupy in the final picture(§4).

---

[55] In the general relationalist account (see Leibnitz) space and time, as orders of relations, are dependent on the proprieties of the material bodies, hence considered in themselves are just ideal things.

[56] The received view on the background independence of General Relativity is taken to pursue a relationism about spacetime (see Rickles and French 2006) .

[57] Eddington mainly deals with the General theory of Relativity, since he considers it the more general view, also involving the special theory.

[58] On the other hand it ought to be remarked that the route selectivism→structuralism is not univoque: it should rather be meant as a cyclic route, since he also admit that the idealistic tinge of his view arose from the very analysis of General Relativity.

Section §3 will take into account the influence of the subjectivist perspective in the reading of General Relativity, which is an unavoidable feature of Eddington's perspective. On the other hand we will also emphasize those elements which could be considered as relatively independent from the strict kantian tinge and which place Eddington among the precursory of a structural reading of scientific ontology.

§2.2. *The relativistic* standpoint

Eddington's approach, even in the case of technical works, is led by a philosophical outlook[59], i.e. an attention for some elements of analysis or some requirements which are philosophical in character: such is, for example, the endorsement of a "relativistic standpoint", which otherwise would be a truism within the domain of Relativity. In his view the endorsement of the relativistic outlook means looking for "*a picture of the world which shall be a synthesis of what is seen by observers in all sorts of positions, having all sorts of velocity and all sorts of sizes*" (Eddington 1921:31): he wants to start the analysis of space and time from some basis which would be independent of the frame of reference, then suitable for all conceivable observers.

In this sense the synthesis would provide a point of view from 'no one in particular' and it could be considered as a character inherent to the world, because of its relying on an invariance.

Such an approach requires a certain level of generalization which intuitively is the counterpart of a certain level of abstraction. In practise, the frame-independent picture of the world could only be captured intuitively or conceptually: indeed it arises from an abstraction from all the spatiotemporal *sensible* determinations, the determinations linked to the single observers. On the contrary, the requirements of a concrete (not only conceptual) picture imply the introduction of values for physical quantities, the reintroduction of determinations due to practical measurements which are inevitably frame-dependent.

The development of such an approach resembles very much the typical mathematical reasoning in its looking for abstractness. It implies the loss of particular determinations

---

[59] According to Eddington the new physics cannot dispense from philosophical consideration because of its very nature.

balanced by an enormous gain in terms of generality of demonstrable relations[60]. It became useful in order to discover or invent abstract entities and relations and to study them independently of their spatiotemporal locations. On the other hand the mathematical reasoning is not sufficient in the perspective of a physical approach since the issue of physics is to make those abstract entities and relations 'significant'. Eddington is then working on a subtle boundary line. Nevertheless he first of all is looking for the epistemological system underlying the theories, something that requires a generalising effort. He pursues such a topic through the analysis of physical knowledge (via current theories) with an eye to its object and the other eye to its conceptual framework.

The endorsement of the above-mentioned relativistic standpoint has two fundamental consequences: 1) it rules the way the mathematical symbols, which represents physical quantities in Relativity, are achieved and 2) it motivates the choice of point-like events as the basic elements of analysis of the physical world in Relativity.

The common instruments through which spatio-temporal intervals are measured are clocks and rods. But their use presupposes, according to Eddington, the very material that he is looking the foundations for. Hence he looks for the ultimate constituents of the world, as physics knows it, led by the ordinary idea that in order to explain phenomena and to understand relations between the complex objects of ordinary experience they *"must be resolved into simpler elements"* (1920a:145).

The outcome of such a perspective is that the analysis shifts from an 'object' basis (where our instruments are objects, as clocks and rods) toward a 'conceptual' basis. Indeed those simpler elements are inevitably less familiar to us than the complex ones and are given a conceptual and more abstract characterization. The shift obtains a peculiar status for the point-like events which on the one hand become the basis for measurements and on the other hand appear as the simpler elements in which the complex objects of ordinary experience must be resolved, in the domain of Relativity[61].

There is an issue here. Resolving complex objects into point-like events would perhaps make the latter the primitives of our ontology, hence from a philosophical perspective the instruments of our explanations. On the other hand, their being primitives does not make them automatically the fundamental terms of physical statements. Instead,

---

[60] Such a line of research was codified already into Euclide's treatise, where he derives *via* valid logical procedures a great number of theorems from few postulates on entities and their relations.
[61] We will see that later he will considers particles, rather than pointlike events, as the fundamental relata.

Eddington reaches exactly this achievement: the point-like events are both part of the primitive ontology and they are among the fundamental terms of physical statements. On this basis he also develops the purpose of presenting the conceptual architecture lying behind the expressions of physical knowledge. The ending point of such a purpose is the thesis that in physics the inquiry of the world is "*a quest for structure rather than substance. A structure can best be represented as a complex of relations and relata; and in conformity with this we endeavour to reduce the phenomena to their expressions in terms of the relations that we call intervals and the relata that we call* events" (Eddington 1923: p.41)[62].

The fundamental remark is yet that the point-like events are coupled with the fundamental relation which is the interval, the real basis of measurements in Relativity. Indeed in looking for the suitable foundations of measurements Eddington chooses the point-like events rather than clocks and rods, but deepening the analysis he realizes that the effective ground is the relation among them. If we have to define the World as object of our physical knowledge, it is the aggregate of point events and it is four-dimensional. Then the spatiotemporal "interval" between two points is introduced as the fundamental *invariant* measurement, in General Relativity: on the one hand, we have a quantitative relation to which we can assign a numerical value; on the other hand, the measurability of anything implies necessarily the existence of such a relation between some (two or more) constituents of the external world.

Generally speaking the character of invariance makes the interested element suitable for acquiring a label of "objectivity", which science always aims to achieve, followed by the two other labels of "knowableness" and "reality". Basically an invariant is something truly knowable, since it does not change according to the change of frame, it is valid for all the conceivable observers. Effectively, we might say, it was looked for in those terms, exactly in order to be something frame-independent according to the relativistic standpoint. The main conceptual feature is that if we look for a fundamental invariant measure in the Relativity theory, we found a *relation*. The bricks of the cognitive building are not objects, rather relations among them. In this sense the very theory would determine its relevant metaphysics as a metaphysics of relations in the first place. In Eddington's perspective such an achievement lies within an underlying kantian perspective. Nevertheless the idea that the

---

[62] In considering Eddington's approach as a prelude to ontic structural realism it ought to be remarked that a fundamental difference lies in the role and the weight that *relata* have into the structure. The issue will be developed in another section of the present work. At present it is enough to say that the ontic structural realism assigns the ontological weight entirely to the relations.

new physics suggests and supports a metaphysics of relations and structures, rather than a metaphysics of individuals, constitute a distinctive element of the structuralist positions independently of the belonging (kantian or realist). In this respect Eddington's reflection represents a starting point for the recent developments.

§2.2.1 The 'analysis' in General Relativity

Then, looking for something frame-independently knowable Eddington did not find an intrinsic property or an entity, he rather found first of all a relation among points. This will be, to him, one of the more characteristic consequences of Relativity in terms of changing the view on physical knowledge: the physics of Relativity provides us with a knowledge of *relations*, among relata. This is the more relevant as the interval couples together the determinations of distance and duration which are, to Eddington, the most important terms in physics since all the other terms for physical quantities (velocity, acceleration, energy..) depend on them.

From the ontological point of view a first reading of Einstein's theory is usually taken to substitute an ontology of substances with an ontology of events[63]. In Eddington's view the primitives are not only the point-like events, undefinable and un-characterized *a part from* their mutual invariant relations: the primitives are the wholes of the relations and the relata. Thus apparently the underlying ontology is not an ontology of substances, nor merely an ontology of events, nor even an ontology of relations without relata. Though the relation has a paramount weight within the ontological picture, it could not be completely abstracted from the relata: the ontology in this sense is an ontology of structures as *wholes of relations with relata.*

Indistinguishable point-like events *together with* the invariant relations among them: they both conceptually participate in the concept of *analysis*, which we presented in the previous chapter. It frames any our physical analysis with the idea that it always concerns wholes rather than single pieces, aggregates of parts rather than single part, in which the whole is the coexistence of parts. In such a conception it does not make any sense to conceive a part as independent of the *system* in which it is embedded, both conceptually and ontologically.

---

[63]See Dorato(2000): footnote 55 p.222(it.).

The further point is: why should the ontology of substances be abandoned[64]? Eddington rejects an ontology of substances since fundamental physics does not deal any longer with such a notion, rather it deals with *forms*. As we saw in chapter one, in saying 'substance' Eddington is saying ' matter-as-substance' and such an identification mainly refers to the first of the two main characters of a substance: its being *positive*, a positive set of parts, and its being *permanent*. Its being positive is better understandable in connection with the concept of emptiness: thus matter has a positive character with respect to emptiness(naively understood)[65]. The preference for the positive characters of the universe accompanied the natural science with the identification of substance and matter. Even the emphasis on the mind's role in privileging substance refers to the identification of substance with *matter*.

The second character (permanence) flows into the conservation principles. But the first is substituted: indeed modern physics deals with, say, light waves and situations in which interfering light waves give rise to darkness. Positive characters (light) and negative characters (darkness) fit together. The actors in modern theories are sets of both *positive and negative* parts, as in the case of interfering light waves. Hence the new physics needs to rely on a concept with such characteristics. According to Eddington such a concept is the concept of *form*. He takes plainly the notion without deepening so far such a theme which instead contains a tangle of ideas. Yolton (1960) remarks that the idea of the knowableness of forms could be led back to the aristotelian doctrines and to the medieval debate over the nature of the universals. On the other hand Eddington's approach links the employment of the notion to the rejection of the concept of substance. In this respect, the doctrine of structure would enter an empiricist tradition, involving in different ways Ockam, Locke, Hume and reaching Ernst Mach, which eludes the substance through emphasizing the permanent link of certain sensible qualities, the uniformity of certain relations and their functional role. Whilst this would be the case it could represent an obstacle for the endorsement of this perspective within the recent positions, which eventually would risk a consistent 'loss' of realist content. On the other hand Eddington's emphasis on the *forms* is due mainly to his holistic approach and to the criticism of the atomistic approach to

---

[64] Concerning the ontology of events, we should not say that it is abandoned: it is rather completed within the holistic view which takes together events and intervals.

[65] The *positive* character of substance-matter refers to its standing out with respect to 'the rest'. Indeed the main featue to which it is usually opposed is emptiness.

physical knowledge. In *The Philosophy of Physical Science* he affirms the view that the current substitute of substance is energy, since it is conserved, and energy appears in the theory of Relativity as a curvature of space-time, while it appears as a periodicity of waves in Quantum Mechanics, both the last two concepts are, according to him, concepts of form, which indicate as we will see a pattern of interrelatedness of the universe.

§2.3. Structuralism and Subjectivism in General Relativity.

Eddington's treatment of General Relativity covers a number of works:

1. *1920 - Space, Time and Gravitation. An outline of the General Relativity Theory*
2. *1920a* –The meaning of matter and the laws of nature according to the theory of Relativity , *Mind 29,* 145-158
3. *1920b* – The philosophical aspect of the theory of Relativity, *Mind 29*, 415-422
4. *1920c* – Report on the Relativity theory of Gravitation*,* report to the Physical Society of London
5. *1921* – The Relativity of Field and Matter, *Philosophical Magazine* 42, 800-806
6. *1922 – The Theory of Relativity and its Influence to the Scientific Thought*, The Romanes Lectures
7. *1923 –The mathematical theory of Relativity*
8. *1936 - Relativity theory of protons and electrons*

The first philosophical work on Relativity, *Space, Time and Gravitation*, starts with a prologue on "What is geometry?", an hypothetical dialogue between a mathematician, a physicist and a relativist on the role of geometry within human knowledge.

Eddington introduces a first meaning for the relationship between geometry and material laws. Geometry is the domain wherein the properties of space are usually studied (and usually from an Euclidean perspective). But in Relativity 'length' cannot be conceived apart from some *measurement* of length, thus the geometry of physical space, namely the 'natural geometry', becomes the theory of the behaviour of material scales. Every time we experimentally investigate the extensional properties of space, we found extensional relations of matter. The issue is that they are not strictly euclidean. Hence space, as we

know it, must be an abstraction by such material relations. In such way he is suggesting an interdependence between geometrical laws and physical laws, which he attributes already to Poincarè, and further developed emphasizing the narrow link between geometry and physics. We arrive to such a connection by recognising, first of all, that time and space are involved in all our measurements. The fundamental measurement is not just the *spatial* interval, rather the spatiotemporal interval between two point-events in the universe. In addition to the fact that each point event is defined by four coordinates, the practical measurement of a spatiotemporal interval reveals as well a four-dimensionality, through the 'comparison' of two points: indeed it is given by two measures of space (one for each point) associated with two measures of time. Hence the natural geometry of the universe is a four-dimensional geometry.

The difficulty might be that when mathematicians speak of analytic geometry, apparently they are not interested in the *meaning* of the variables *x, y, z ,t*. This is not a problem for the mathematicians, but it is for the physicians (they have to recognize something in, say, the series of Fourier). On the contrary when a relativist speaks about time as a fourth dimension, he has in mind a real meaning: *dimension* is associated with the idea of *order* relations, an order which is *in nature*. Physicists have to "comment" mathematical symbols: the symbolic chain has some interpretation as something which describes what happens in the universe. Thus what physics recognizes is not a single symbol identifying one entities, rather a chain of symbols identifying their relations and order, which will be reconnected with our ordinary experience[66]. The world is for Eddington a whole of entities linked by the four-dimensional order, and this very set is the ground for our perception, as physics told us till now[67].

The first main conclusion of the prologue of *Space, Time and Gravitation* concerns the dependence between geometry and laws of matter, arising from the fact that natural geometry is the theory of the behaviour of physical scales employed in measurements. This is much more important as we mentioned that 'lenght' and 'duration' in Relativity are read

---

[66] In such a way Eddington goes further the epistemic stance of structural realist views and its dichotomy.

[67] This anticipates an important point in Eddington's understanding of physics and philosophy, namely the strict link between our physical knowledge and the theory of perception: perception is a kind of rough physics measurement (mainly because human mind is part of the very structure it is knowing, so basically, it seems, it is itself a structure). And we perceive space and time as they are measured: objects of natural geometry. Nevertheless, we should be cautious in understanding this stance: it seems to be leading to the possibility of a realist correspondence between our knowledge and the known world, but we should wait till the end of the story to understand it properly.

as the most fundamental magnitudes, from which all the others (velocity, energy, acceleration, and so on) depend. As an example, according to such a reading Eddington treats *mass* as a derivative quantity and motivates the very increase of the mass of β particles, the electrons emitted from the nuclei of certain radioactive substances. This phenomenon first found an explanation within the electromagnetic domain: basically Maxwell's equations implied the increasing of mass due to the electrical origin of those particles, though failing in predicting the law of that increasing. Instead Eddington frames the variation within Einstein's method as due to the fact that "*mass is a* relative *quantity, depending by its definition on the relative quantities length and time*" (1922: p.20), hence to the Relativity of frames of reference.

On the other hand, he poses the emphasis on the fact that geometry and mechanics are no longer distinguishable to the extent that mastering the geometry of four-dimensional world is inevitably learning about its mechanics. And through the reached unification of the two branches of mathematical physics (geometry and mechanics) Eddington approaches the problem of gravitation.

General Relativity provides us with a unified picture of our knowledge: within the picture even the study of force fields is reduced to the study of geometry[68] since we speak of the trajectories of material particles (geodesics). Even though the best way of exploring the Spacetime is looking at the motion of material particles, Eddington sustains that the material particle is not any longer the fundamental element, since it has not any meaning by itself: indeed we are rather interested in its field, that is the relation between its geodesic and other geodesics in the universe, and matter could not be thought as disjoined from its field[69]. When Eddington says that *it's all a tangle of relations*, he seems to be suggesting a view of space as field of fields (which are taken to be relations)[70].

Such a pre-eminence of relations sounds difficult since it seems to disagree with experience. The objects encountered in ordinary experience appear as individual relata. They traditionally have both an ontological and epistemological priority with respect to the

---

[68] "*..a field of force is a manifestation of the geometry of space and time*" (Eddington 1922: p.24).
[69] Then in his view the field is a relation between a particle's geodesics and the other particles' geodesics.
[70] Considering the example of the relationship between geodesics and particles, a geodesics is the line of universe of a material particle. A question arises concerning the very particle: should not it be considered as existent by itself, with its 'real and causally efficient properties' (Dorato[2005]: 17)? In such a respect Eddington's approach pursues a reading in which the real and causally efficient properties of particles constitute the counterpart of its belonging to the spacetime.

relations *they* instantiate. As we saw in chapter one, Eddington analyzes such a perspective within the concept of analysis as an atomistic point of view leading science: the idea of structural identical parts lying at the basis of reality, perfectly separated and separable. Though recognising the strength of such a perspective, he develops a different approach according to the holistic view which he assumes from the theory of Relativity: the parts cannot be separated from the whole to which they belong.

He starts from the traditional way theoretical physics achieves its task, according to the idea of structural identical units. Hence he considers the alleged simpler constituents[71] in accordance with the relativistic standpoint: the point-like events[72]. On the other hand, as soon as the analysis goes on, it appears that the relevant role in the description is played by the relations among the point-like events, to begin with the primitive relation of interval.

Thus we have a general formula for the interval, where the different values of the potentials *g* synthesize the metrical properties of the system. Considering potentials and kinds of space, deduced by the interval as averaged properties of small regions, we get a macroscopic value for the very interval defined as

$$ds^2 = g_{11}dx_1^2 + g_{22}dx_2^2 + ... + 2g_{12}dx_1x_2 + ..$$

This formula is a kind of intermediate summary that, according to Eddington, counts only statistically. The important thing is that there are some mathematical properties of a group of values for potentials of the same spacetime, which are not shared by potentials of another eventual spacetime. Such properties are expressed via differential equations.

Each region of the universe requires new measurements to determinate the coefficients of the formula, that is new potentials, and this constitutes the starting point of the *infinite variety of nature* (1920a:148). By considering the gradient of the collective coefficient $g_{\mu\nu}$, that is considering its variation from point to point, and the gradient of the gradient, we obtain some additional characters of the chosen region. Some difficulties arise because the ten potentials $g_{\mu\nu}$ regard not only intrinsic properties of the universe, but also relational properties of our arbitrary frame of reference: they describe not only the kind of existing spacetime (four-dimensional), but also the nature of the used system of reference. In describing different systems, we use peculiar symbols of coordinates, according to the

---

[71] The two outcomes of such the atomistic view are the idea that the unity elements would be the simplest elements and the idea that relations between them depend on their properties.
[72] Successively, in the *Relativity Theory of Electrons and Protons* he will introduce the analysis with respect to the material particles.

different kinds of space involved: an orthogonal system differs from a polar or oblique one as well as from systems of latitude and longitude. The very use of the peculiar kind of symbols anticipates in some way a knowledge of the system. These facts do not tell us that everything is relative, since the relative represents a 'door' in terms of a whole-parts outlook where 'relative' is always 'a part of 'absolute'. Indeed every physical knowledge refers to partitions in space and time: then in order to understand the absolute features of the universe, we must appreciate it by the relative.

The observer constitutes an asymmetry in the universe, introducing the particular *form* of the spatiotemporal mesh. This emphasis on the singularity of the different observers' points of view, then on the primacy of the observer, weakens by the way the absolute features of universe. On the other hand, Relativity tells us that the spatiotemporal interval between two points, is absolute. A contradiction seems to take place: the interval is absolute, the four-dimensionality is an intrinsic feature of the world, but on the other hand there is not any *intrinsic form* of the Universe since our knowledge of nature is grounded on observations. It seems to be contradictory and also counterintuitive: grounding on observations should be the warranty of objectivity! But we must remember that observations imply observers and 'observer' implies a particular perspective, an asymmetry in the general frame of the 'no-one-in-particular'. The individual observer introduces a particular 'system of meshes', i.e. a particular system of space-time determinations. What makes the difference between 'systems of meshes' is the asymmetry created by the reference to an individual observer. In this sense it is possible to see the selective subjectivist 'reading' acting in the analysis of the general theory of Relativity. We mentioned that a guide principle (the relativistic standpoint) leads the way our descriptions are achieved in accordance with all the possible observers. For sure every observation has two components: what is observed and the observer, joined in every description, physical or ordinary, of natural phenomena. The arbitrary partitions of space and time through different observers are not fundamental to nature: nature has its proper different geometry, the quadruple order of events, common to all the observers, which is intrinsic to the external world.

Eddington uses the adjective *intrinsic* with respect to the four-dimensionality of the world and to a sort of law of atomicity which he suitably involves within the holistic outlook, through clarifying the place of relata within the structure. On the other hand his position remains partially ambiguous with respect to the relationship between such intrinsic

(hence we should say 'objective') features of the universe and the subjective character knowledge. Indeed it must be remarked that even the relativistic standpoint is not meant to completely eliminate the subjective element. It apparently *mediates* even such two characters which are intrinsic features of the world.

Eddington affirms that the unity of the four dimensions is in the external world, rather than in the relation between world and subject which builds his proper knowledge of space and time. The *structure* of the world is linked to the spatiotemporal interval / extension (constituted by length and duration)[73], which has an absolute meaning, that is, it is independent of the particular spatial and temporal partition of different observers. But in dealing with the observer the absolute order breaks in the different manifestations of space and time. Hence to a great extent the 'no-one-in particular' point of view seems to be the balancing point between the objective features of the world and an unavoidable asymmetry[74] introduced by the subjective point of view of human observers.

In this sense physical knowledge always maintains the subjective character. Indeed even the perspective of the "no-one-in particular" which eliminates the deflections due to the individual frames of reference, cannot eliminate the *human* characteristic of knowledge[75]. Eddington expresses it in the following way: "*The subjectivity referred to in these lectures is that which arises from the sensory and intellectual equipment of the observer. Without varying this equipment, he can vary in position, velocity and acceleration. Such variations will produce subjective changes in the appearance of the universe to him; in particular the changes depending on his velocity and acceleration are more subtle than was realised in classical theory. Relativity theory allows us to remove (if we wish) the subjective effects of these* personal *characteristics of the observer; but it does not remove the subjective effects of* generic *characteristics common to all "good" observers although it has helped to bring them to light.*"(Eddington 1939: 85-86). In his view, we can abandon the strictly subjective perspective of a particular observer and reach a kind of non-perspective knowledge: but this knowledge is still observational, hence it undergoes the limitations of our sensory and intellectual apparatus. We can consider it as an *absolute* knowledge provided that we do not

---

[73] The theory of Relativity describes the relations of events with respect to our frame of reference and all the terms of elementary physics refer to such relative features of the world. The observer is a system of coordinates, that provides a division in space and time and localizes events.

[74] The observer himself is a four-dimensional object represented basically by his trajectory in the universe and creating the asymmetry.

[75] In such respect Ryckman claims that the relativistic standpoint is the way to put in the transcendental idealism within the scientific perspective: indeed it becomes the way the subjective constitution of the objects enters the physical picture.

take it as *purely objective*, since in his view there is not such a completely independent knowledge[76].

On the other hand the form of the relative features is not arbitrary. There exists a kind of *form*-constraint. It means that it is not the case that everything could be a feature of the universe. The constraint is expressed in the use of the tensorial calculus of Riemann, Christoffel, Ricci and Levi-Civita. Its introduction begins with the $g_{\mu\nu}$ figuring in the fundamental formulation of the interval ds^2 and through the successive introduction[77] of the Levi –Civita connection ($\Gamma_{\mu\nu}^{\gamma}$), of Riemann-Christoffel curvature tensor ($R_{\mu\sigma\nu}^{\rho}$) and its contraction, etc. Tensors define limited number of values for *g*, hence they define some conditions for different states of universe (in the empty space, in the nearness of energy, in the nearness of matter, in the presence of matter, that is with a complete *curvature*, since the presence of a particle in a region of spacetime modifies it in an absolute way). The emphasis on tensors is not casual: tensors are mathematical objects particularly suitable for the representation of physical quantities since they identically vanish in all the frames, i.e. if a tensor vanishes in a system, it vanishes in all the systems. Thus they are the best representation of a physical fact independently on the system (see Whittaker 1951). Eddington remarks that tensors have *"a fixed system of interlocking"*(*ib*.86) so that through assigning them to physical quantities the changing of frame of reference automatically and correctly produces the required change in the physical quantities according to the tensorial interlocking[78].

The duality between absolute and relative features of the universe is to be considered as the duality between the absolute and the relative features of *our knowledge of* the universe. In order to solve it mathematics helps us, by focusing on such symbols, as $B_{\mu\nu\sigma}^{\rho}$ e $G_{\mu\nu}$: they do not express explicitly a *measure* of intrinsic properties of the universe, since "*measuring*" a property involves necessarily a system of reference, though there exist some

---

[76] Moreover, whilst we would decide to look for the purely subjective knowledge, we would be forced to give up all the physical knowledge, laws and constants of nature.

[77] The mathematical analysis of such passage could be found in Eddington (1923) *Mathetical Theory of Relativity*. A fundamental comment on such a procedure is in Ryckman(2005). For a good introduction to the philosophical issue of General Relativity see Dorato(2005).

[78] *"But, after all, this device is only a translation into symbolism … A tensor may be said to symbolise absolute knowledge; but that is because it stands for the subjective knowledge of all possible subjects at once"*(Eddington 1939: 87).

specific quantities which are *invariants* (interval and total curvature). As Eddington specifies *"Things like $g_{\mu\nu}$ and $G_{\mu\nu}$ occupy a position intermediate between qualities of the World and qualities which involve space and time haphazardly"* (1920a: 150 footnote 1). It must be remembered that he his peculiar analysis of the mathematical apparatus is led by a 'reconstructive' attitude: since knowledge has an aprioristic character he analyzes it in order to understand the way the world *is as* an object of such knowledge. In this respect he conceives even Eisntein's field equations, as we will see, as *definitions* and he considers the mathematical objects first of all as empty form: at first sight, considered per sè, $G_{\mu\nu}$ could be taken, he says, as an empty form lacking of content[79]; we do not know *what* exactly is this content, but we nevertheless gave a clear and recognisable meaning to the image, so that we will recognise it every time we will find it. But we can operate in a physically significant way with that symbol in two senses: 1) we can impose that it vanishes; 2) we can say that it equals something else, expressing physical quantities. When we state that a tensor *vanishes* or it is *equal* to another, as the stress-energy tensor, we are denoting an *intrinsic condition* of the universe, independent of the system of coordinates. In such operations the symbol manifests a physical meaning. That is why tensorial equations are interesting, according to him: only referring to them we deduce the hidden features/characters, behind our formulas, pertinent to the *intrinsic state of the universe*. We got two absolute equations: $G_{\mu\nu} = 0$ in the empty space - as devoid of matter; $G_{\mu\nu} = K_{\mu\nu}$ in the space containing matter (where $K_{\mu\nu}$ contains only familiar physical quantities)[80]. So whenever $G_{\mu\nu}$ does not vanish, it implies that we are in a universe which distinguishes between occupied and empty space, where *empty* means devoid of matter. This interpretative move is well stated by Eddington as it is: an interpretative move. Before continuing its analysis we must note that such view is quite heterodox with respect to the current way Einstein's equations are conceived, definitely not as definitions: far from being an empty form the left hand of the

---

[79] This depends, as we will see, on the way he conceive Einstein's equations, as definitions of matter.

[80] In the *Mind* paper (1920a) he particularizes the two formulae so that we have: $G_{\mu\nu} - \dfrac{1}{2} g_{\mu\nu} G = 0$ and

$G_{\mu\nu} - \dfrac{1}{2} g_{\mu\nu} G = -8\pi T_{\mu\nu}$ .The passage from $G_{\mu\nu}$ to the complete formula is well explained in Ryckman's work: he shows the conceptual importance of such an equation, between an empty form and a filled form, as a kind of process of signification, in which the empty form acquires a content and a meaning. In any case it seems that the tensors K or $T_{\mu\nu}$ themselves represent tangles of relations rather than objects and summarize properties as the density of matter or the state of motion of matter in a region.

equations ($G_{\mu v}$) indicates the metrical properties of the continuum. On the other hand, through heterodox, Eddington's view provides once again some relevant features of a structural approach, independently on the idealistic view: in the first place, he enlightens a fundamental feature of the gained descriptions in their individuating some patterns of interrelatedness of the world; secondly, as we will see, he does not dispense from regaining the link between geometry and physic, despite the mentioned definitional role of the equations. In this sense his structuralist perspective provides the possibility to develop a particular way of considering those equations: not as laws governing objects, rather as indicating some physical possibilities through revealing the pattern of interweaving of reality. The way such features could figure within a realist reading of the outcomes of General Relativity will emerge clearly in the fourth chapter of the present work, as we will consider the way the theory emerges from the study of the fundamental properties space.

In Eddington's view the field equations express *conditions* of the world: they indicate the parameters of connection in which physical facts happen and manifest (to our perception). They are the constraints[81]. As mentioned, General Relativity is not taken to express laws arisen from properties of points. Those laws rather express the *patterns of interrelatedness*, linked to the dynamics (of matter and metric), which are the knowable conditions of existence of the world, namely the unique possible physical configurations of the world. The further step concerns perception. Indeed those very conditions are *definitions* of the way in which some states of the universe are revealed in our perceptions, in particular they are definitions of *matter* and *lacking of matter*. This represent a constitutive feature of Eddington's subjectivism. $G_{\mu v} = 0$ and $G_{\mu v} = K_{\mu v}$ are different physical possibilities: but they do not bound the possible behaviour of the substratum of universe per sè. They indicate the way the universe appears in our knowledge. And they define the way some states of the world impress on our perception, mainly because in the case of $G_{\mu v} = K_{\mu v}$ a distinction emerges among empty space and occupied space in our perception(i.e. we recongnize the characters of positivity and permanency which led us to

---

[81] In his *Report on the Theory of Relativity* he even says that: " *Further, taking all possible distributions of permanent gravitational field which <u>can</u> occur in space (in the neighbourhood of, but not containing, matter), we do not exhaust the conceivable variety of functions expressing the g's. There is a general limitation on the g's imposed, not by mathematics, but by Nature which is expressed by the differential equations of the law of gravitation which we are about to seek. The law of gravitation, in fact, expresses certain absolute properties common to all the measured space-times that <u>can under any conditions occur in Nature</u>*"(1921: 25, my underlining).

assign a priority to substances). But physically speaking $G_{\mu v} = 0$ represents a curvature smaller than the first degree and $G_{\mu v} = K_{\mu v}$ represents a modified curvature of the universe whose mass and momentum are components.

When the left-hand side of the equation $G_{\mu v} = ...$ vanishes it denotes a definite and absolute configuration of the of the World: that configuration is then common to any part of the world which is empty of matter. This, according to Eddington, provides us with the *"perception of emptiness"*[82] (1920a:p.151). An objection to such view could be that from the physical point of view it is not empty of radiation(gravitational) but only of matter. On the other hand, as Eddington emphasizes, it corresponds to what we could consider emptiness with respect to the fundamental category of substance-*matter*[83]. When the left-hand side does not vanish the corresponding properties *is perceived as* matter. And it is emphasized because of the mind search for permanence and for the positive characters it assigns to substance. In such view we see some undefined analytical quantities, mathematical symbols, acquiring a "reference" and progressively being identified as something familiar to our experience: we have the opportunity *"to learn what we are talking about"*(*ib.*), that is mind's *perceptions*[84]. The structural (then physical) properties of the world are in the end provided with, say, 'coloured' qualities by the mind. The view could be summarizes in Eddington's words:

"*the world which we have to build from the crude material is the world of perception, and the process of building must depend on the nature of the percipient. Many things may be built out of* $G_{\mu v}$ *, but they will only appear in the perceptual world if the recipient is interested in them. We cannot exclude the consideration of what kind of things are likely to appeal to the percipient. The building process of the mathematical theory must keep step with that process by which the mind of the percipient endows with vivid qualities certain selected structural properties of the world*" (MTR pp.237-238).It is evident the influence of the kantian reading in such an interpretation of Einstein's equations.

---

[82] Strictly speaking we should not speak of 'emptiness' since $G_{\mu v} = 0$ is not empty of radiation (gravitational). On the other hand Eddington's terminology is led by his making 'emptiness' as the opposite of 'substance' and his identification of substance and matter. Since $G_{\mu v} = 0$ expresses the lacking of matter, it is then an 'emptiness'.

[83] Since talking of 'perception of emptiness' sounds a countersense, we could say a conceptualization of emptiness.

[84] Of course the expression "perception of emptiness" is misleading, since being provided with mass we would never *perceive*, strictly speaking, emptiness around us. We should speak of "conceiving" rather than "perceiving".

On the other hand, a remarkable point with respect to the structuralist (broadly meant) reading is that $K_{\mu\nu}$ expresses physical characters not so much as objects or entities causing perturbations, rather as tangle of relations which are constituents of the curvature. Such holistic perspective, which acquire the 'structural' denomination due to the formal instruments it involves, ought to be remarked since in the next chapters we will consider the way a *realist* perspective could take advantage from it. Mass and momentum and other features characterizing material bodies represent some kind of perturbations, some modifications in the components of the curvature of the universe. In this sense we may understand when Eddington says that matter is not an entity producing perturbation in the gravitational field, rather matter *is* that perturbation: *"Matter does not cause an unevenness in the gravitational field; the unevenness of the field* is *matter"*(1920a: 152). Matter is taken as a process: the process (as complex of relations) happening in the locus of perturbation. In such a sense he is explicitly criticising the view of matter as the *substance* which cause perturbations, unevenness, irregularities. *"Matter is but one of a thousand relations between constituents of the World, and it will be our task to show why one particular relation has a special value for the mind"* (1920a:153).[85] Indeed the treatment of General Relativity basically points out the way in which substance arises from the tangles of relations. The *substance* , which our mind uses to recognize as soon as it recognizes some permanency, is nothing more than a particular pattern which mind "loves to trace": indeed it is dealing with a real *substratum*, but the distinctions in such substratum derive from the mind's contribution.

A question could arise about the insistence on the role of the mind. Better, if substance is so constitutive for the world of our perceptions, why should we diminish its importance so much? To answer such a question within Eddington view it must be remembered that the criticism is motivated by the fact that the choice of a permanent substance-matter as primitive of an ontology bears necessarily consequences on the law of gravitation, on the laws of mechanics and on the way ordinary space is conceived. He wants to avoid them because fundamental physics, according to him, has not such primitives. But this is strictly dependent on his identification of substance with matter. Then he reaches the wanted definition of matter *in terms* of constituents and relations, something that we may recognize as a first step toward a structural reconceptualization of ontology. He started from an ontology of pointlike events and reached an ontology of

---

[85] All the same, as example, for light: he does not consider it as an outsider of the electromagnetic field producing oscillation in the electromagnetic force, rather the very oscillations constitute light.

fields through the rules of connection between intervals and the introduction of $G_{\mu\nu}$ from which the field equations are derived. Eddington then points to a definition of what matter is, according to (on the basis) of the elementary features of the theory. Such a definition also reverberates on the fact that our brain is made of matter. The reasoning at the basis of such a methodology is, according to Rickman, a somewhat cyclic reasoning due to the transcendentalist view.

On the other hand, such a view which starts with some clear epistemic assumptions, manifests an evident ontological bearing, which on the one hand introduces Eddington within the debate on the nature of space time and on the other hand introduces him within the debate over the status of scientific theories and knowledge, precisely quite near to the recent structural realist positions. As mentioned the structuralism entered the current debates over scientific knowledge mainly from the side of realist positions, though now the structural tendency found a number of defenders also on the antirealist side. By the way our concern is with the realist family. The epistemic stance emerged as the first, through the work of Worrall, Zahar and others, in order to provide a suitable way of maintaining the realist attitude toward theories though saving them from the frequent antirealist attacks due to the theory change. The chosen strategy to account for the theory change tracked the continuity on those structural features of scientific theories which are preserved through it. This view unavoidably forces to an agnostic attitude toward entities, which just few realists were ready to endorse. Thus a debate on the ontological side of the structural stance emerged. The second line[86] of the structural tendency endorses an *ontic* stance, involving ontologically strong thesis. For the main motivation we will refer to French and Ladyman's view (since they endorsed this line as firsts). Their motivation is the metaphysical underdetermination in QM and they propose a reconceptualization of physical objects in structural terms, recalling some ideas of Eddington and Cassirer's view. They also endorse a strong eliminativist view: ALL THERE EXIST is a structure in which relations are ontologically prior to relata (the slogan is 'relations without relata').

Starting from what we saw about Eddington's work, his concern takes place in an intermediate position with respect to the epistemic/ontic stance. To begin with his position

---

[86] The first defenders of the ontic structural position are James Ladyman and Steven French, which developed the position in his eliminativistic perspective. Beside the first formulation, a number of philosophers started to discuss many issues in philosophy of science within an ontic structural position (see Cei, Esfeld, Lam, Lyre, Saunders).

is evidently epistemic in character as testified by his constant attention toward the epistemological character of physical knowledge, the understanding of his theoretical presuppositions and foundations, and so on. Nevertheless the approach to such a theoretical framework bears fundamental consequences at the ontological level.

The concern about the status of structuralism, whether it should end up into an epistemic or an ontic stance, which Ladyman (1998) poses as the first dilemma with respect to the epistemic structural realism, finds an answer within the work of Eddington: the two levels are both strictly linked and inseparable. On the other hand this answer could be highly taken to reflect the kantian perspective which influence his view. According to Ryckman, which endorses an interpretation of Eddington's view completely focused on the link with the underlying Kantianism, the interconnection between the epistemic and the ontic level is quite naturally due to a cyclic reasoning (Chapter 1§ 2.2.1) which grounds Eddington's approach: the idea of an objective reality and its very characterizations arises from the way the measurement apparatus is built, according to some categories of thought. The mind has a paramount role in determining the ontology because it informs the very way the physical theories, from which the ontology is depicted, are formulated (see Chapter 1).

On the other hand Eddington does not endeavour to develop a completely kantian approach to the theory of Relativity. This also emerges in many situation in which the philosophical notion he uses are far from referring to a clear philosophical position. This is also what makes sometimes misleading, and yet rich of suggestions, his words.

For instance, considering again the primary relation of interval, it is indefinite in nature and the $g_{\mu\nu}$ contain such indefinable element. Accordingly also $G_{\mu\nu}$ has a definite *form* and an indefinite *content*. This would eventually bring Eddington near to the epistemic stance, or to a kantian idea of unknowableness of the nature of things. On the other hand, there is a fundamental feature to be considered: *form*, according to Eddington, exhausts all the physical properties of matter since from the law of curvature of the universe for $G_{\mu\nu}$ we may derive all the mechanical laws of conservation[87], and physical knowledge cannot go

---

[87] Eddington considers also $G_{\mu\nu} = K_{\mu\nu}$ as a dictionary which explain components of curvature with respect to usual terms of mechanics. So we can write it as $G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G = -8\pi T_{\mu\nu}$ and we obtain an interpretative schema in which variables for density of matter and components for velocity appear. The

beyond the form. This is very interesting: form exhausts all the physical properties. In this sense physical structural knowledge in his formality is exhaustive, also regarding the supposed *content* on which the critics of the epistemic stance always lever.

Another feature of physical knowledge emerging from such a view concerns the fundamental significance acquired from mathematical, say, manipulations, because of the idea that forms are physically exhaustive. Such an approach constitutes a revolution with respect to the contemporaneous mathematical thought which was trying to dispense with the meanings. When we speak of form and content we usually think of form as *equations* and content as *physical/concrete features/properties*. In Eddington's account physical properties are already accounted for through the *form*, which both indicate equations and physical properties.

The content matters then at another level of knowledge, what Eddington delineates in the conclusions of *The Philosophy of Physical Science*: brain's matter, in his physical sight is simply *form*, but its reality implies the *content*. What does this mean? It seems to suggest that in some way physics does not exhaust "reality". This does not mean that physics does not touch reality, rather that physics in its insight has limits. It gives an extraordinary knowledge of the world, pretty much precise of the material at work but it seems that to understand reality you need to match it with a knowledge of the *content*, what Eddington's considers a non-metrical or 'intimate' knowledge. What appeared as the *limits* of structuralism rather places it in the wider ambit of human knowledge which is not only the scientific one. In this sense the apparent dichotomy form/content acquires a new sense. The theory of Relativity unifies laws which assured the glorious place of physical knowledge due to their precision and to the exactness of their applications. And this is knowledge of a structural form, not of a content. The content, unknown to physical knowledge, forms the substance of our conscience and flows through all the physical

---

problem is that we usually speak of motion according to the permanent identity of particles. But such an idea, though familiar, is nevertheless a very complex feature of the universe. *"Now the expression* $G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G$ *has a remarkable property known as the property of* conservation. *This property is simply a mathematical identity due to the way in which the expression has been built up from the simpler element* $g_{\mu\nu}$. *It results from this property that,* provided we measure space and time in one of a certain limited number of ways, *matter will be permanent"* (1920a: 153). *Vice versa*, he says, choosing a permanent substance for the world of perceptions brings necessarily the law of gravitation, all the laws of mechanics and the ordinary space and time of experience. The General Relativity turns out to be a theory about the most general *"way in which relations can combine to form permanent substance"* (*ib.* 157). And an important counterpart of such a view is that it is the mind which focuses on permanence and imposed such laws to the *indifferent universe.*

universe. Through it we have a sign of some deep features of the world, not reachable by the methods of physical knowledge.

The reality appreciated by physical methods is the synthesis of all the possible features of nature. Looking for the reality with accepted methods we find a geometrical theory. But we must also remember our limits, which are the limits of our knowledge. And here the structuralist-subjectivist view comes out as Eddington uses the metaphor of a future (5000 d.C.) possible antiquarian inquiry on a past volume containing a huge number of "chess" matches, written in the obscure symbolism of such a strange game. Studying carefully the book, in particular the uniformity of the game, 5000 d.C. – scientists will discover out of doubt moves and rules of the game. But they will never be able to discover the true nature of the true pieces really used to play, of the objects, nor of the chessboard. To the former they will give some arbitrary names, distinguishing them according to their properties which involve their possible moves. With respect to the chessboard they will say something more, since its material and its form is unknown, but the connections of the point and the order relations between them is known. What is the analogy about? According to Eddington our experiments are like registered matches. The rules are the physical laws. Space and time of the observers(frames) are the chessboards, while order relations are absolute relations of order in Spacetime. Pieces are the unobservable entities of physics: electrons, particles, *points*; their properties and moves are maybe their properties and fields of relations (gravitational, electromagnetic, and so on). Our knowledge of the nature of things must be similar to antiquarian knowledge around the nature of pieces: it is a knowledge of their nature as pawn and pieces in the game, not as carved pieces of wood. As carved pieces of wood they may have relations and meaning which transcend (go beyond) any physical image[88].

In the mind's article on the meaning of matter and laws(1920a) the conclusive idea is that *"all the Nature was required to furnish is a four-dimensional aggregate of point-events"*(*ib.*:155) and all the laws are provided by mind's activity. We have a universe of point-events *with* their primary relations[89]. From these we may build an infinite number of secondary relations and more complicate qualities which describe characteristics of the state of universe, but their

---

[88] In this picture we may clearly track the shadow of Duhem, Poincarè, going back directly to Kant.
[89] As seen, the kind of structuralism of Eddington is not the strongest one. Of course he stresses the role of relations and their preminence. Nevertheless he maintains the relata in the picture, though with a lower epistemological weight.

existence is latent, unless someone give them a meaning (as running on one of many possible way in a moorland). The mind is the filter of matter from the insignificant muddle of qualities: it exalts the permanent and ignores the transitory; in this sense he frequently seems to be reading the laws of nature as having their source not in a special mechanism of nature, rather in the activity of mind. Finally he says that as much as physics grows up, mind retakes from nature what mind itself put in: "*we have found a strange foot- print on the shore of the unknown…and Lo! It is our own.*"(Eddington 1920:201).

On the other hand the picture resists the complete mind-dependent reduction just due to two facts: as the first, there are laws, as Eddington himself recognizes, which seem intrinsic to the universe; secondly, human mind, which should be the law giver of the universe, is part of the very aggregate which it informs[90]. *The Nature of Physical World* restricts the idea that all the laws are provided by mind, acknowledging that at present *there are* laws which seems to have their seat in the external world and the most important of them is the law of atomicity, i.e. the quality of universe of distinguishing matter from emptiness and making the first appearing in blocks called atoms or electrons. Where does such discontinuity - which is not bound to matter and energy since Planck discovered the quantum of action - come from? Such an issue further motivates the inquiry into Quantum Mechanics and the attempt to give a structural account of its domain, through involving the atomicity within the holistic perspective.

Summing up, through the works on GR, some fundamental element of Eddington's epistemology appear:

    1)   The relevant role of relations provides the ground for his structuralism, which seems somehow limited, since the physical-structural knowledge, that is metrical knowledge, does not exhaust human knowledge. In some sense it could be taken again as an epistemic form of structuralism. Nevertheless in the attitude toward physical knowledge it constitutes a good starting point in order to understand the Ontic Structural Realist's idea that physical world enters our knowledge in a structural way and that each physical object could be reconceptualized to enter in such a way physical knowledge. In a realist perspective, in which a greater correspondence is supposed to hold between the

---

[90] Basically, in some way, the imprinting of the world is the same as our imprinting.

way we know and the way things are, this opens the door to ontologically understand the world in structural terms.

    2)   Selective subjectivism, which constitutes the second horn of his epistemology, highly recalls kantian themes, showing connections with perception theory. On the other hand the two labels are not completely interchangeable and this feature enable us to consider the structuralist analysis as partly independent. In this respect a realist perspective could find the way to suitably implement the holistic-structuralist approach.

There are almost two other important elements to consider with respect to OSR:

    1)   the paramount importance of geometry;

    2)   the particular way the relata of the spatiotemporal relations are embedded within the structure.

Concerning the first point, we saw that the study of the absolute structure of the *physical* universe grounds on the concept of 'interval between two close events', qua their absolute attribute independent of any system of coordinates. Eddington as a physicist is *"concerned not with the nature of the relation but with the number assigned to express its intensity; and this suggests a graphical representation, leading to a geometrical theory of the world of physics"* (1920: p.187): in such a respect the interval, as well as the other symbols which he introduced, summarizes some *geometrical properties.* On this very basis it is possible to build a geometry of the universe. On the other hand, in dealing with General Relativity, geometry plays a fundamental part, because of the intimate link between geometry and dynamics: "*When we deal with the four-dimensional world we can no longer distinguish between geometry and mechanics. They become the same subject. When we have completely mastered the geometry of the world of events, we shall have inevitably learnt the mechanics of it. That is why Einstein, studying the geometry of the world and discovering that it was strictly non-Euclidean, found that he was at the same time studying the mechanical force of gravitation*" (1922: 23).

The intrinsic four-dimensionality of the world is far from being a trivial feature. Beside this Eddington considers that the trajectories of particles in free motion are geodesics of a curved spacetime, and *geodesic* has an absolute meaning. Now, he says, it is impossible to choose a system such that all the particles of, say, the solar system move in straight line. So the geometry must be non- Euclidean in a gravitational field. Nevertheless, the possibility of geometries is limited, since the trajectories of particles in a gravitational

field must be ruled by a law. Such limitation is absolute, since it concerns the very structure of the universe. The non-euclidean fourdimensionality of the world is finally to be connected with and the intimate link between geometry and mechanics which is the conceptual core of Eddington's reading of General Relativity and its crucial innovation.

In considering the new spatiotemporal model Eddington does not affirming the existence of a manifold of points, as an independent space of points underlying the bodies or a spacetime of point underlying events. Such a view would imply the existence of a separated metrical structure. On the contrary, when he affirms the four-dimensionality to be a feature of the world he just affirms a fact: the world is four-dimensional. As soon as we try to describe it with the ascertain methods of physics we end up with a structure which is both geometrical and dynamical, as a whole. "*Here a wide vista opens before us. We see that two great divisions of mathematical physics, viz. geometry and mechanics, have met in the four-dimensional world*" (*ib.* 23). Such a link does not merely refer to the possibility to *treat* the mechanical problems through the aid of geometrical apparatus/methodologies. They rather refer to the same subject-matter (which is the world) and they cannot be divided any more than the subject of magnetism and electricity: "*It is through this unification of geometry and mechanics that I should like to approach the problem of gravitation, showing that a field of force is a manifestation of the geometry of space and time.*" (*ib.* 24).

Through the study of the relations between point-like events he got an highly interrelated structure which has a geometrical character, it represents the geometry of spacetime, i.e. its curvature. On the other hand the geometrical structure is not disjoined from the material fields. It already appeared in that fundamental passage of the equation among tensors: $G_{\mu\nu} = K_{\mu\nu}$. All the physical processes are strictly linked to the geometrical structure which helps to describe/define their happening. Thus Eddington claims that the structural knowledge exhausts all the physical knowledge is much more weighty. This Structure, i.e. this complex of interrelations among indistinguishable points, bearing physically significant properties as energy, density of matter, impulse, and so on, is diffeomorphic invariant in General Relativity and it is the fundamental element, we may hazard, the real element of General Relativity. In such an understanding, Eddington's reading of General Relativity becomes a powerful weapon for the ontic structural realist approach. The issue is to examine the metaphysical understand of structure: here a difference appears and nevertheless the position maintains his grip on the current debate.

Finally, let us consider back the idea that material particle has not got any meaning in itself rather it has meaning because of its field, which represents the relation of its geodesic with the other geodesics of the universe. It could seem to provide a form of relationalism, rather than a structuralism, as it focuses on a whole of relations and emphasizes the pattern of interrelatedness, leaving the relata, as it seems, somehow apart. The fundamental difference in Eddington's structuralism is that his world-structure is meant to be a whole of relations *and* relata: "*we never denied the existence of absolute characters of the universe with an absolute meaning…geodesics or natural trajectories have such absolute meaning….material particles and geodesics are the absolute structure of the universe*" (1920,199)[91]. It is this feature of the relations and relata which will be considered in the final next section.

§2.4. Relata in the Structure – from General Relativity toward Quantum Mechanics

In 1927 Eddington gave his Gifford Lectures which were recollected and published under the title *The Nature of Physical World* (1928). In these lectures he recalled many features of his epistemology, both rerunning through the theory of Relativity and introducing some elements arising from quantum theory.

In considering the construction of the physical domain *The Nature of Physical World* introduces the doctrine of structure that *The Philosophy of Physical Science* will make explicit. The *world building* introduced in 1928, neither is merely achievable on the ground of relata nor on the ground of relations alone. Relations and relata come together as a package in which "*the one is unthinkable apart from the other*" (1928, 231). This unity and interdependence is the starting-point from which the structure must be conceived. Consequently, the ontological priority of entities, of relata, is downsized. This feature already appeared in what Eddington said concerning material particles in General Relativity; they were not important by themselves, but rather they were important because of the relations between their own geodesics and the other geodesics.

---

[91] Once again Eddington provides a passage where the strictly idealistic tinge of his view is mitigated. Though human mind manifests a sort of privileged channel of structuring the world, its work is always counter-balanced by the independence of the world which does manifest its characters even within our knowledge (though mediated). The question arises why mind recognizes exactly that particular patterns.

Relations and relata are material for building. If one wants to understand our world, going from the simpler elements to the more complex, he has to introduce a sort of "numerical measure" for each element of the world-structure. Within the *world building* Eddington laid on the basis for a study of the diversity, on the ground of a definition of similitude. To begin with he defined each relatum on the basis of a numerical measure of the structure in which it is embedded. Each relatum has a *mark* which is individuated by its coordinates, 4 numbers since the universe is four-dimensional[92]. The mark identifies all its possible relations. The possible combinations of those four numbers provide the numerical coefficients which give a numerical value for each relatum's surrounding structure. The really important ones are 16, whose 10 are *symmetric coefficients*, Einstein's potentials $g_{\mu\nu}$ through which we build geometry and mechanics[93]; the residual 6 are *asymmetric coefficients* through which we build electromagnetism (3 for electric intensity, and 3 for magnetic force)[94].

Then the *mark* is a measure of the relationship between the relatum and the structure in which it is embedded. This provides the building of physical properties from the starting point of structural interlocking. According to the different frame of reference, we then gain the relative values of physical quantities for each relatum. The perspective is fundamental, since Eddington does not give a way of *constituting* relata, neither relations, but rather he shows how to retrieve them from the package in which they are embedded as a whole (see French 2003: 234-236). Given the structure, the embedded relata are discerned.

In the first place the relata existing in the four-dimensional world-structure are individuated in their relation with it. On the other hand, physical knowledge is not merely a

---

[92] It is worth to recall some further considerations concerning the link between geometry and mechanics in General Relativity. As known, the law of gravitation rules a geometrical quantity, the *curvature*, while Newton's law rules a mechanical quantity, the *force*. Geometry traditionally regards space. But in General Relativity space and time could not be divided, hence the theory needs some geometry which accounts for both. The three-dimensional space becomes then a sort of partition of the four-dimensional spacetime. Of course, though space and time are meshed, there is an absolute distinction between space relations and time relations. Nevertheless, according to Eddington, the difference between the two 'geometries' (of space and of time) is not so deep, and mathematicians bridge it using the symbol $\sqrt{-1}$. On the other hand, General Relativity implies an extension of geometry toward the domain of mechanics, and the two disciplines mesh.

[93] The limited number of values for the potentials g (which contribute to individuate some states of the universe) are defined through the use of the tensorial calculus of Riemann, Christoffel, Ricci and Levi-Civita. Tensors have a fundamental role in providing structural knowledge, since they gave, as we saw, *conditions of the world which are at the basis of physical phenomena* (Eddington, 1923: 49).

[94] Eddington's particular investigation of algebraic structures was not well liked to his contemporaries. A good secondary bibliography could be found in French (2003) and Ryckman (2005).

knowledge of the fact that there is a four dimensional aggregate of point events, or of moving particles, though we saw the significance of such a statement (§2). Indeed Eddington emphasized that to understand the structural knowledge was to understand the way we can *particularize* the structure. The particularization is obtainable in Quantum Mechanics[95], focusing on the fact that the structure is *defined and investigated by group theory* (Eddington, 1939: 176). In chapter 3 and 4 we will closely consider both the way the group theory is employed in Eddington's view and the extent to which his approach is useful for the structural realist. Beyond the subjectivist claim, which has to be abandoned within the realist perspective, Eddington's view presents in the first place a conceptual weapon for the structural realist.

The structural holism introduced in the reading of General Relativity fits with the inquiry into the quantum domain. As well as in the case of General Relativity, Eddington is interested in the theoretical impact of quantum theory, beside the formal apparatus (and leading it). The relevant features of its connection with group theory are then analyzed in some latest works, after the *Nature of physical World* (1928): *The philosophy of Physical Science* (1939), 'A discussion on the role of group structure in physical science' (published in 1941, on *Mind* **50**) and *Fundamental Theory*, the posthumous work published by Whittaker in 1946.

Relativity theory told us that we observe *relations*. Quantum theory tells us that we observe *probability*, entering physical theory through Heisenberg's principle as expressed by the mysterious formula $qp - pq = ih/2\pi$ which lies at the root of everything in physical world[96].

According to Schrödinger *p* is an *operator* which corresponds to momentum. It is not a physical quantity, rather a mathematical symbol which let us do some mathematical operations. According to Bohr and Jordan *p* is a *matrix*, that is an infinite number of quantities set in a frame. Finally according to Dirac it is a symbol without numerical interpretation. Eddington takes Dirac's approach and fits it within his view of the relationship between mathematics and physics, suggesting the idea that "*at the very basis of*

---

[95] Understanding the relation between quantum physics and Relativity, which is still today one of the main issues of theoretical physics, is understanding why mind chooses as substantial matter the same quality which Nature provides as some kind of atomicity. (And moreover is to understand in which terms such atomicity must be understood □ it could be understood in structural terms as far as nodes and relations are taken together).

[96] It holds that $i = \sqrt{-1}$, *q* and *p* are coordinates and momentum and $qp \neq pq$.

physical phenomena we reach entities that are not numerically measurable, as many things in our conscience, and the very exact science, grounded on correlation between number-measure and phenomena, is based on such idea. In physics we are interested in a symbolic world and we hardly may do without mathematicians. Instead if we want to discern the lines of Nature out of our mind we must get out of the simply and pure frame of mind in building with mathematics"(Eddington, 1928: 240-241).

This is the interpretation of Dirac's view, which moves from fundamental entities which are not expressible *via* numbers or systems of numbers, and not linked via arithmetical operations. Eddington finds Dirac's equation expressed in terms of *spinors* rather than tensors. Reflecting on such new mathematical symbols and looking for some bridge between Relativity theory and Quantum Mechanics, he considers the problem of particles' indistinguishability, appeared since 1926. The indistinguishability of quantum particles is still the focus of a great debate in philosophy of science, concerning the ontological consequences of the new theory. Basically it is a paradigmatic feature in expressing the oddness of quantum objects with respect to ordinary, classical, ones. The classical objects are individuals furnished with specific properties and distinguished each other, through at least one property (spatiotemporal position). Classical objects obey Leibniz' s principle of *Identity of Indiscernible* (PII). On the other hand, quantum objects possess peculiar characters which makes them violate PII. They share all their supposed intrinsic properties and they obey the principle of indetermination, hence momentum and position cannot be simultaneously identified, providing a clear way to distinguish them. Quantum objects are indiscernible, but not identical. They also manifest an ambiguous behaviour which presents them as both individuals and not-individual according to the situations. They undergo *entanglement* in consequence of any interaction, according to which non-separability holds.

The ambition of structural realist positions is to provide a suitable ontology for Quantum Mechanics[97]. The main motivation for a change of perspective with respect to the ontology of physical theories (from an object-oriented realism to a structures-oriented

---

[97] The analysis of structural realism starts from considering the metaphysical package in terms of which the scientific theories should be understood. Such a package is underdetermined in quantum mechanics by the formalism, since we know individuals according to some restrictions due to the accessibility of their states (indeed we only know what we 'prepared') *and* non-individuals. The ontic structural realism suggests to consider them as non individuals at all and to endorse a metaphysics of structures as suggested by the group-theoretic character of quantum descriptions. In a sense the present section supports, through Eddington's view, the ontic structuralist idea that a focus on relations and patterns of interrelatedness is a suitable way to deal with the current scientific enterprise; on the other hand the consequences that OSR derives from such an idea are not engaged *tout court* (as we will see in chapter five).

one) arises from the mentioned difficulties of quantum mechanical framework as regard to the nature of quantum objects, in particular with issues of individuality or non-individuality of quantum particles. The suggestion is that "*the nature of quantum objects is such that they cannot be conceived as individuals in any of the traditional metaphysical sense*" (French and Ladyman forthcoming). According to the ontic structural realist, the suitable ontology for Quantum Mechanics should be derived from the descriptions of the theory, which represent the conditions of our knowledge. The ontic structural realist wants the conditions of knowledge to be conditions of existence of the world, and the relevant role of the group-theoretic descriptions in Quantum Mechanics becomes a further element which would pursue the structuralist turn.

Eddington did not expressively treat the group-theoretic characterizations of elementary particles, though he focuses on the indistinguishability of particles, which plays a fundamental role in the introduction of group theory as an appropriate language for Quantum Mechanics. On the other hand, in considering the indistinguishability, Eddington already considered the notion of *structure* as a useful concept in order to clarify the complexities and the relevance of the relations holding between physical objects. Hence he is a valid interlocutor of the recent positions.

Eddington enters the issue of indistinguishability through his interpretation of Dirac's view. Yet, where Dirac's equation concerns a single particle, Eddington's considers a second particle as a representation of the "environment". This move fits well with his approach, already showed in the context of Relativity, which presents physical situations always in a genuinely holistic way: "*it is idle to treat in our equations a system supposed to have no interaction with its environment, since the interaction is the only thing about the system which concerns observational physics*"(Eddington, 1936: 129). The indistinguishability of particles is then analysed by Eddington on the basis of what he calls the *principle of blank sheet*. The idea is that our analysis of the understanding of indistinguishability must be driven beginning from a *blank sheet,* rather than an *already scribbled sheet*. The latter would represent a situation in which our analysis would already presuppose the target, the distinguishability. Instead we should write characteristics and measurements, which give us a background in terms of which we can later distinguish phenomena, on a blank sheet. This would let us reach the real source of their distinctions. We start with intrinsically indistinguishable particles, electrons and protons, and spacetime-frame. The difference between proton mass and electron mass, hence their distribution, cannot be differentiated before their identification

at different times. Indeed *mass* implies an operator involving time, $-i\partial/\partial t$. Hence, he says, we cannot use what we traditionally considered as intrinsic physical properties, like mass, to introduce the distinction of particles, since it would be put the cart before the horses[98].

Eddington's aim is to find the source of the distinctions. We only know that electrons interact[99], but we cannot start the description of these interactions by presupposing absolute distinguishability of particles and intrinsic distribution. The fundamental dynamics is "*dynamics of indistinguishable particles…*(where) *the dynamics of distinguishable particles is a practical adaptation to be used when we do not wish to analyse the phenomena so deeply*" (*ib.*: 287). Two remarks must be added to Eddington's view on distinguishability. In the first place he treats the issue as he treated the use of clocks and rods was treated in Relativity: the gained knowledge concerns a relative feature of a deeper absolute. Secondly, since we may track only the statistical behaviour of particles, and we are unable to identify particles at different spatio-temporal locations, it seems that quantum indistinguishability is even observational. Our procedures of observations do not let us distinguish. Since those procedures are elaborated on the basis of our mind's activity of selection, the indistinguishability of particles seems to be partly a consequence of selective subjectivism[100]. The indistinguishability belongs then to a limit which is epistemic in principle. We are *unable* to distinguish them because of our very methodology, "*…our generalizations about their behaviour … describe properties imposed by our procedure of observation..*" (Eddington, 1939: 37). This view on particles and indistinguishability finds a more general framework in what Eddington calls the concept of *identical structural unities* (*ib.*: 146). The frame of thought which guides physics is the search for an analysis of the universe through identical structural unities. The Universe would be a complete whole of identical parts. In analysing matter, contemporary

---

[98] A similar discourse is put forward for charge. It might be objected that particles are distinguishable according to their positive or negative charge. Eddington treats both mass and charge through the introduction of a particular algebra, the *E*-symbols algebra (1936): "*For our physical applications the significance of a matrix is embodied, not so much in its representation as an array of numbers, as in its non-commutative multiplication property… Most, if not all, of the properties of matrices which make them suitable for describing the conditions and activities of the physical universe are also possessed by general symbols endowed with the same non-commutative properties*" (Eddington, 1936: 20). He assigns to each physical system a frame-symbol E_μ , defined over complex numbers. The use of the *E*-symbols is particularly useful to him, since they have not any other property except those provided by the calculus in which they are embedded. Through the calculations of the *E*-symbols the difference in positive and negative charges appears as a difference in the used frame-symbol.

[99] In Eddington's view, the traditionally considered intrinsic characters, for instance the mass itself, are interchanges of energy.

[100] Of course, the epistemological weight of mind's activity strengthens the idealistic features of Eddington's work.

physicists find protons similar to each other, and electrons similar to each other and in such a way, for example, recognize two elementary unities. Hence Eddington asks, 'what does distinguish the first from the second?'. Until the revolution of the theory of Relativity, the difference was looked for in the internal structure of the elements. It indicated that perhaps protons and electrons were not the genuine structural unities of the universe[101]. Such an attitude in the research manifested, according to Eddington, the "right" intuition that difference lies in the structure rather than in the unities by which it is composed. The theory of Relativity indicated a way to modify the underlying frame of thought leading physics, toward and holistic perspective. Then Eddington says that the distinctions between elementary unities should be found in the structure, *" their difference arises in their relations with the general distribution of matter in the universe"*(*ib.*:149). The application of this reading to mass, charge and spin, all the supposed *intrinsic* properties which characterizes different families of particles are determined by the relations of elementary unities with a general distribution. Those properties are derivative on the net of relations whose the structure is made of. In the end, going beyond the atomic concept of analysis, beside the structural identity of ultimate parts of the world, the variety of universe originates from the whole rather than from elements.

Eddington's approach to the indistinguishability of particles suggests a view in which their properties are relational rather than intrinsic. This is a genuinely philosophical thesis which enters plainly within the aforementioned debate on the ontology of Quantum Mechanics.

A question arises concerning the differentiations. If the unit elements are all identical, how is it possible that the structure generates the variety of the universe? The issue clearly concerns the relationship between the net of relations and the relata, and moreover the role which the relata have in the picture. This issue is linked to one of the crucial features of structural positions, dealing with a reversion of the traditional, we might say, *mode of predication*. With 'mode of predication' we mean the way objects of knowledge are defined and characterized, the way they emerge, the role they occupy into our cognitive framework, the way relata and relations "relate to" each others. The way of predication is fundamental in a theory of knowledge and it traditionally has a precise hierarchy. The predicative

---

[101] Eddington's concern on the fact that maybe protons and electrons are not the genuine unities of the universe is farsighted of the successive researches in atomic physics with the elaboration of the Standar Model of Particles.

schema is generally made of unit elements, their intrinsic properties and their relations; its hierarchy expects basic units (relata) with their intrinsic properties, and among them relations are instituted. In the traditional mode relata have an absolute priority with respect to relations. Thus we have, say, electrons and protons identified and distinguished by their intrinsic properties of mass, spin and charge, and *then* establishing relations and grounding laws.

Vice versa in Eddington's view, and in general in the structuralist view, the mode of predication is reverted. The actors are the same: units, properties and relations. The hierarchy changes. Relata do not have any longer the previous priority, rather they are on the same foot of relations, in the softer positions, or even a step below relations[102], then instituting a sort of continuous co-determination.

Such a reversion of the predicative mode in the structuralist points of view is one of the main sources of scepticism with respect to the position, both in the past an the current debates. Such a reversion of the mode of predication is at work in Eddinton's discussion of the indistinguishability of particles. It also underlies his defence of the notion of structure and of the structural approach from the objection of vacuity.

§ 2.4.1 Again on relata

The group-structure concept is fundamental within Eddington's epistemology. Physical knowledge being communicable, it is necessarily structural. The elements of the structure are given just the properties arising from it. Moreover, the ultimate elements of physical structure "*are identified with relations*" (Eddington, 1939: 274). Here is another crucial feature of his picture. Eddington assigns a representation to what he calls the *primitive relation P*, defined as a relation "*capable of being conceived as something whose existence is contingent on the existence of two somethings (called relata), either of which could exist or not*" (*ib*.: 272) and either of which is simple, namely it is not analysable into parts. He does not speak of properties, bundles of properties, and so on. He draws a picture of uncharacterized unities whose only feature is their *existence*. Although 'existence' could be an elusive term in philosophy of science, Eddington recognizes it as a form of thought and provides it with a structural account in terms of a primitive relation. He introduces a structural concept of existence,

---

[102] The second account of relata characterizes the eliminativist structural positions.

with a definite mathematical meaning, represented by an idempotent symbol J (which has two eigenvalues) for which $J^2 = J$. *Existence* is the unique example of a structure of only one element. And Eddington regards the representing ultimate elements with idempotent symbols, as an expression of the thought that all that we can say about an element in a structure, apart from his structural association with other elements, is that it exists (eigenvalue 1) or not (eigenvalue 0). He applies the concept of existence to the physical domain through the E-symbol calculus and says that "*To apply this in physics, we take* J_r *to be an* existence operator *for an entity or condition* e_r. *If* J_r *has the eigenvalue 1,* e_r *is said to exist in the system described by the eigensymbol* U; *if the eigenvalue is 0,* e_r *does not exist in* U" (1936: 308). The primitive relation P is denoted through a *double existence symbol* $P = J_1 \times J_2$, with J_1 and J_2 as the relata. Relation P exists iff J_1 and J_2 both exist; $P = J_1 \times J_2$. All the same, a relation between relations would exist iff the two relations exist, hence it has a quadruple symbol of existence. From this starting point, the target is to reach a structure whose relations of relations would be represented by the same symbols of the very relations, such that we have the possibility of describe them in terms of group-theory. In fact, our knowledge of the external world is a group-structural knowledge and elementary particles from group-structure. The particular group implied in the representation of the fundamental structure of the world, according to Eddington, is the same of the rotation group in six-dimensions.

Each element of the structure, as revealed by experience, has 4 spatiotemporal coordinates. Furthermore being a particle[103], not only a geometrical point, it is revealed at least in relation with another particle, as showed in the double existence symbol. The two remaining dimensions represent respectively the plane of rotation and the kind (positive or negative) of charge. Oddly, the next theoretical step consists in making the structure independent of the existence of singular elements: this is the case of a structure made by a lot of elements. The existential symbol of such a structure must express the independence from singular element. Each element thus obtains a doubled existence symbol, as element of the structure and as independent element. As independent element it is represented by $2J - 1$, where 1 is the representation of its contribution to the structure (this means that in order to eventually consider it as independent element we abstract from its doubled

---

[103] We must note that when Eddington speaks of elementary particles in terms of this abstract algebra which he calls E-algebra, he refers only to protons and electrons.

existence symbol the number which represent its being an element of the structure, conventionally the number 1). In such a way we obtain the symbol for an independent element of a structure $K = 2J - 1$ which has two eigenvalues, 1 for its existence and -1 for its non-existence. The absence of a particle in the structure is not simply a negation, rather it is a hole in the structure. We may note that this view sounds very close to certain interpretations of Dirac's equation with respect to anti-matter (see Toraldo di Francia[1976]: 365-371).

Apart from its occupying or not a place in the structure, all we can say about the particle concerns its relation to the structure: all its magnitudes (mass, charge and spin) are properties which pertain to the particle because of its relations with the universe around it.

Eddington analizes thoroughly the primacy of relation. The fundamental relation is what he calls the *state*, which could be described as occupied or not occupied, and *K* becomes the symbol of occupation. All the physical structures, and in the end the Structure of the universe, may be built according to this way of thinking: *"Firstly…the elements of a structure are assigned no properties other than those arising out of the group or algebra which defines the abstract structure. Secondly, we introduced a form of thought according to which the ultimate elements of physical structure are identified with relations…Thirdly, the definition of a primitive relation is expressed in terms of 'the concept of existence', afterwards extended to the 'concept of independent existence'"*(Eddington, 1941: 274).

He manages an abstract structure as provided by the methods of symbolic algebra (the $J_1 \times J_2$ algebra) and uses it as a mean to represent reality in his holistic perspective. In this way he defines a pattern, a pattern of interrelations within the structure of a group of operations. The obtained abstract structure which repeats indefinitely allows the definition of further entities. In this recursive pattern of structures we find a characteristic of mathematical group-theory which is also(as well) linked to the probabilistic feature of quantum physics: *"… the <u>conception</u> of a system as the product(not the sum) of its parts lends itself to a probability interpretation, since probabilities are multiplicative…"*(*ib*.:268, my underlining). Eddington uses the group-theoretic perspective in a *conceptual* way strengthening the structural-holistic view. In his analysis of the concept of existence the elementary particle, with his legend of individuality, *"is a product of analysis of…group-structure"*(1939: 164) and in this sense it is not ever independent of the latter. On the other hand, we find another foreshadowed crucial element for ontic structural realism. Despite we exported the general

concept of object from the classic to the quantum world, what we only can apprehend *"is the relevant group-theoretic structure, of course, as it is represented in terms of symmetric and antisymmetric state functions"* (French[forthcoming]:14).

The difficulties in seeing how the new epistemological view flows into ordinary physics, depend mainly on the fact that *measurement* must be re -introduced, as the moment in which ordinary quantities of physics come into the picture (Eddington 1939: chapter X). In this final step, the notion of *measurement* goes back to an ordinary meaning, as it is a comparison among the observed relations between entities, and some typical samples. In *Fundamental Theory* (1946), Eddington's posthumous work edited by E.T. Whittaker, we find many passages concerning this theme. The idea of physical science as *"the systematisation of knowledge obtained by measurement"*(1946: 268), must be connected to the structural picture. In order to do this we have to compare measurements to the structure, finally as defined according to the structural concept of existence. In this procedure Eddington follows the inverse path with respect to the beginning of his works. In his first works he went from ordinary physics to the fundamental one, setting a new epistemological approach. The posthumous work goes back to the ordinary physics provided with the analytical weapons gained in the previous path. *"We observe only relative positions and relative velocities; consequently an observable coordinate or momentum always involves two physical entities. A measurement involves four physical entities, two to furnish the observable that is said to be measured and two to furnish the comparison observable used as standard.*(comparison between two given objects and two graduation marks) *…what is measured is something associated with four entities; we shall call this a* measurable. *Entities, observables involving two entities, and measurables involving two observables or four entities, form the rudiment of the structure that we are going to develop …the symbol which we employ to represent the existence-attribute of an entity must therefore be such that its meaning only becomes definite when it is conjoined with another symbol representing the structure contemplated. This reduction of a symbol to an interpretable form by association with another symbol is expressed mathematically as a reduction to an eigenvalue."*(*ib.*: 266). Even the measurable, is then a structural concept. This is remarkable, since later he will identify 'particle', a *'conceptual carrier of variates'*, with 'measurable' or better he refers to measurable as a particle.

He is aware that in this way the issue about the need of distinguishing measurables (now identified as standard particles) reappears, while it is a fundamental tenet of quantum theory that elementary particles are indistinguishable, they have no distinctive identity. Nevertheless, we must remember the perspective he gave to such a distinction under the

principle of the blank sheet: the deep source of distinctions relied there on the dynamics of indistinguishable particles. In the ordinary practise physicists obviously *conceive* electron as distinct. Thus, since the *Fundamental Theory* does not endorse the analytic perspective (simpler towards complex), there is a sense in which those particles are individuals: "*if they are continually exchanging identity, they must be conceived as having an identity to exchange. We are not concerned with any metaphysical conception of identity. Whatever is that is exchanged – whether it is called 'identity' or merely 'suffix' – has to have a structural equivalent…But the fundamental reason for distinguishing measurable is…to provide connectivity*"(*ib.*: 273). Even whilst the solution of the issue of individuality/not individuality of particles would be in favour of the first stance, the defined individuality would serve the 'cause' of the structural connectivity. In this sense it should be rather meant as the expression of the existence of the relata within the structure as a *numerical plurality*. In this sense, in maintaining the relata, Eddington's perspective suggests a moderate structuralist perspective. With the mentioned concession to individuality, the most relevant feature of Eddington's structuralism is that 1)such an individuality is by the way embedded within the structural conception, hence it is a very thin kind of individuality; 2) it is counterbalanced by an elimination of the intrinsicness of fundamental properties.

In a summary way, Eddington provided an approach to physical knowledge which was holistic:"…*The crux of the problem is to supply 'connectivity' to the measures; so that in the theoretical treatment there may be an equivalent for that part of the procedure of measurement which consists in noting the objects and circumstances to which the measures relate*"(*ib.*: 269). Each element, and each stage, of our physical knowledge has a structural meaning. Among the many possible measurements, someones provide a basis for systematisation and unification of our knowledge and Eddington's structuralism selects a set of basic measures to do this, being sure that "*physical science, in its search for systematisation, had already arrived at just the same selection*" (1946: 272). Beside the stressed subjectivist approach, the insistence on the way physical quantities have been built reflects another significant attitude with respect to the inquiry into theoretical physics. In chapter one (§1.2.1) we said that Eddington assigns a priority to the qualitative features of science, rather than to the quantitative ones[104]. From the

---

[104] The leibizian idea that science of quantities is subordinate to the science of *qualities* found its first development within the domain of geometry: Whittaker considers the passage from the metric geometry to the projective geometry, with the consequent abandonment of metric notions of distance and measure. In

experimental point of view, such an attention to qualitative features is chronologically posterior to that for quantities. Nevertheless the former is fundamental in the domain of theoretical physics, which according to Eddington has a different method with respect to the experimental discipline. Theoretical physics uses unifying methods. The main example of this unifying ability of the intellectual analysis is Optics. Indeed in the domain of Optics the first great unification, theoretically significant and experimentally predictive and successful, was provided through Huygens concept of travelling *wave-front*, which brought the superposition principle. What made the 'travelling wave-front' a unifying concept, and what gave it the explicative power, was its intellectual source. Going on, the history of optics and its development in light of Maxwell's work showed crucial turning points in correspondence with conceptual principles. So, Maxwell's ether was already an unification (of many ethers into a single one) due to the concept of *displacement of current*. It constituted first of all an intellectual revolution which later found an experimental confirmation. Hence, Eddington's principle of privileging qualitative and intellectual features in the analysis of knowledge was the end point of a long successful history of theoretical physics. The fundamental characteristic of the intellectual conceptions is that they are able to provide explanations. Furthermore, their richness and their unifying power make them suitable to be extended to other domain of applications. In this sense the progress of theoretical physics would build on the progressive evolution and substitution of current conceptions, qualitative conceptions. Indeed the transitory character of theoretical physics could create an issue of validity for the very Eddington' s principle. In this respect Whittaker (1951) interestingly notes that Eddington remarked some qualitative assertions having a character of permanence. Whittaker calls those assertions the *postulates of impotence*. The only qualitative assertions which are absolutely permanent curiously indicate some negative outcomes of the theoretical research. They are assertions on what cannot be done, they assert what is not possible. Example of this are assertion as: 'the perpetual motion is not possible', 'to set up an electric field in any region of space enclosed by a hollow conductor of any shape and size, by charging the outside conductor is not possible', 'to build a machine capable of converting the heat-energy of surrounding bodies, all at the same temperature as itself, into mechanical energy, is not possible (this grounds the second principle of thermodynamics) (see Whittaker 1951: 18). Among these, there are some

---

fact the concept of order acquires a growing importance, which is a qualitative and more powerful and general concept than the concept of *measure*.

assertions, which ground the research in Relativity and in Quantum Mechanics, which will appear to be particularly interesting to the present work. For instance, the very postulate of Relativity - 'detecting a uniform translatory motion possessed by a system as a whole, obtained by observing phenomena taking place within it, is not possible' – which grounds the relativistic standpoint so fundamental in Eddington's view in the first treatment of the structural perspective. Moreover the very principle of indetermination - 'to establish at the same time position and momentum of a particle is not possible'- which is one of the theoretical basis of Quantum Mechanics making also an issue on the fundamental properties assigned to physical objects and to the very way of conceiving physical objects.

The emphasis on qualitative features finds a wide expression in Eddington's attention toward the constants of nature, especially on the fine-structure constant, to which he dedicates several passages through his all work and in particular the last one, *Fundamental Theory*. Eddington formulates the Fundamental Theory on the basis of the *E-numbers* (16 symbols) through which he builds the aforementioned non-commutative algebra for fundamental physics[105].

§2.5. Conclusions

The previous sections presented Eddington's structural view of the physical theories. In concluding, we will present the path, from Eddington's view toward the recent structuralist positions, which will be followed in the next chapters.

The first remarkable feature is that his philosophy of physical knowledge is achieved on the ground of a wider understanding of human knowledge, within which non-structural features are included. Such a feature must be suitably placed since it seems to be a constant that pretty every structuralist position, whether it likes it or not, faces an objection concerning the relation between structural and non-structural elements of the world. Eddington's conclusive remarks in *The Philosophy of Physical Science*[106], which light up his view

---

[105] It is remarkable that though the interpretation of the E-symbols is problematic, nevertheless S.R.Milner deepened them and obtain the class of the €-tensors which constitutes a new branch of tensorial calculus and Maiorana as well deepened them (they are called Maiorana numbers).

[106] Eddington's view on the relation between structural and non-structural features of knowledge are also presented in his reply to Braithwaite's criticism. Braithwaite (1940) alleged Eddington's structuralism of providing an empty idea of physical knowledge. The objection refresh a famous objection moved by Newman (1928) to Russell's *Analysis of Matter* (1927). The all debate will be addressed in chapter three.

on structures, objects and knowledge, are a good clarification in this respect. Indeed the non-structural features of human knowledge do not concern the physical domain. Physical knowledge *is* in fact structural in his foundations, in its methods and in its objects. Every knowledge we can reach about the physical world is gained in structural terms both because of the way we organize knowledge of it, and because of the way the world in his fundamental features *is*. From Eddington's analytical point of view, the physical world is a world of structures, of *interconnections* between relata, which at the lowest fundamental level become relations themselves, as expressed in terms of the idempotent symbol indicating the relation of existence. One of the peculiar characteristic of Eddington's structuralism, despite the difficulties due to his lack of a philosophical training, is its quite *systematic* point of view. The theoretical work about the outcomes of Relativity and Quantum Mechanics is thus philosophically sustained and substantiated by the conceptual analysis of the main involved notions. Hence, in *The philosophy of physical science* he provides the structural conception of analysis, substance, structure and existence. They summarize the steps of the conceptual revolution at works, which we think to be first of all a revolution in the mode of predication.

In this terms his works contribute to frame the new structural perspective on physical objects, focused on the priority of relations and relational features in the very constitution of both world and scientific knowledge. One of the most relevant features is the introduction of the notion of *group*, and of the group theoretic characterization of the structure, as two means of a fundamental revolution in our theoretical approach to objects and knowledge. Here we find a great intuition of Eddington's work since the group-theoretic characterization of structure is not a trivial operation because of the relevant role that group theory was gaining into the quantum domain in the '20s and '30s. In the next chapter, comparing Eddington's structuralism with Russell's one, Eddington's emphasis on the notion of group will emerge as a fundamental weapon in the issue concerning the content of physical knowledge. First of all we will inquire into the work of B.Russell trying to deepen the differences with Eddington. Those differences contribute to collocate him as a precursor of the ontic structural positions, where Russell led to the epistemic ones.

The group theoretic approach to the structural issues enrich Eddington's analysis which presents fundamental insights on the debate over the ontology of *both* General

Relativity and Quantum Mechanics, thus entering two widest debates in the philosophy of science: the debate over substantialism and relationalism in Relativity and the debate over the ontology of Quantum Mechanics. Eddington's approach to physical knowledge and to physical systems appear as an interesting source of intellectual unity under the banner of a peculiar notion of structure. Structure is as a whole of relations and relata, where the latter might manifest an at least thin sort of individuality, which is *undetachable* from the structure in which they are embedded. Eddington provides a view which is not eliminativistic in the strict sense, nevertheless is evidently attractive and fruitful for the recent development of the structural position.

CHAPTER THREE

Russell, Eddington and "Newman's problem"

§3.1. Introduction

The previous chapters explored the characteristics of Eddington's epistemology and the development of his structuralism. The structural perspective was not his own prerogative. In *The Analysis of Matter* (1927) Bertrand Russell developed the thesis[107] that we could attain only a *structural* knowledge of the physical world, which prevents us from knowing any intrinsic feature of it[108]. This knowledge gives us information on the structure of the world, in terms of relations between events. The lever of Russell's structuralism is the idea that our theories resemble reality up to isomorphism because of a *similarity* between the structure of our perceptions and the one of their stimuli.

In 1928 Russell's thesis underwent the crucial criticism put forth by prof. M.H.A.Newman, and famously mentioned in the literature as 'Newman's problem'. The criticism focused on the notion which was supposed to substantially vehicle our knowledge of the world, the notion of *structural similarity*, which would reduce it to a matter of cardinality.

Rerunning the same argument, Braithwaite criticized Eddington's structuralism one year after the publication of *The Philosophy of Physical Science*(1939). Nevertheless, although the strict similarities between the two thesis, Eddington's structuralism proves to be surprisingly equipped against such an objection.

The aim of the present chapter will be an inquiry into Russell's structuralism, in order to provide the basis for a comparison among the two authors and to evaluate their position with respect to the Newman's problem (and Braithwaite's objection).

The comparison is as much relevant as we consider the recent renewal of the structural tendency within the debate on scientific realism. Within such a renewing of

---

[107] Russell introduced the thesis already in 1919 (*the introduction to mathematical philosophy*) and developed it later, through *The Analysis of Matter* (1927).

[108] Such a view have been also assimilated to some suggestions found in Poincarè and Duhem.

structuralist positions we are indeed presented with two lines, an epistemic one and an ontic one, which differ in both motivations and aims. They indicatively address to Russell's view, and Eddington's view respectively. The apparent similarity between the two breaks in front of 'Newman's problem'. From the differences between their epistemology it is also possible to draw the path which links them to the different stances of the recent structural approaches.

The following sections will:

1. Present Russell's position and the connection between the doctrine of structure and the causal theory of perception.

2. Show the gist of Newman's objection.

3. Consider Eddington's position and the way his structuralism is immune to Newman's problem.

The first section will look at the development of Russell's structural thesis, which is strictly linked to the formulation of a causal theory of perception. Attention will be paid in emphasizing the epistemological difference with Eddington's view. The content of the two thesis is slightly different and yet in a fundamental sense.

Subsequently we will present Newman's objection and some recent discussions over the possibility of tying Russell's suggestions within the epistemic structural realism. Within such a debate, the most clear and fruitful analysis have been developed by Meelia and Saatsi(2006). They effectively provide the epistemic structural realist with a viable way out of the problem. On the other Russell was not properly an epistemic structural realist. In this respect the defence of *his* view against Newman's objection (Votsis, 2003) is rather difficult to be endorsed.

Finally we will consider Braithwaite's objection to Eddington's thesis. Eddington's view proved to be equipped against the argument because of two features: on the one side his specific philosophical point, linked with a kantian approach; on the other side, the very way the structure, i.e. the relationship between relations and relata, is characterized. In his recent work *The Reign of Relativity* , T.Ryckman insists on the fundamental neokantian view lying behind Eddington's work in order to motivate the immunity against Braithwaite's objection.

Instead we will focus on the second feature of Edddington's view with the leading idea that his notion of structure deviates from the original russellian line exactly in his saying that we know *"the structure of the kind investigated in the mathematical group theory"*(Eddington 1939:147). Indeed the reflection on the employed mathematical tools of physical theories, and the way they are considered, provides that statement with a fundamental openness to the content of physical knowledge. This feature of Eddington's view is an important criterion toward the evaluation of the issues linked to the different structuralist positions. Russell's view and Eddington's view accounted for the structural/non-structural relationship in two different ways. Comparing them enables a suitable placement of the "problem of content" also seen in the recent debate.

§3.2. Russell's Structuralism: Structural Postulates and Causal Theory

In a paper of 1977, Michael Bradie delineates the "structural postulates" of Bertrand Russell's philosophy, with the leading idea that Russell's post-1927 view on the nature of knowledge is marked by the continuity of his thought on structure. Bradie tracks a development from *The Analysis of Matter*(1927) to *Human Knowledge* (1948) where such postulates constitute even the basis of the scientific inference. In the end he suggests that Russell's structural analysis *suitably evaluated and articulated* could be a model capable of dealing successfully with the issues of the growing science. The suggested fruitfulness in dealing with the problems of the growing science was among the reasons for the recovery of Russell's view in recent debates on scientific realism. The relevance of his work on structure is also recognized in a critical display by Demopoulos and Friedman (1985), since the *theory of theories* presented by Russell in 1927 highly anticipated further philosophical developments and debates on scientific knowledge. His structural thesis by the way underwent a lot of criticisms mainly because of the concept of similarity of structure, which has a key role within the position. M.H.A. Newman moved the main critic in an article that appeared in *Mind* one year after the publication of *The Analysis of Matter*. Later on, a rich discussion developed on the footsteps of Newman's work until today (McLendon, 1957; Demopoulos and Friedman, 1985; Psillos, 1999; Votsis, 2003; Meelia and Saatsi, 2006).

Russell's structuralism is recalled within the debate on scientific realism, in order to suggest a more restrictive form of realism. It accepts theories as true descriptions of reality though bounding them to the knowledge of the relevant relations among entities whose nature is unknown. This position, which is called *epistemic structural realism*, endorses a form of agnosticism with respect to the entities (we do not know their nature) which is meant to account for both the extreme success of science and the fact that the ontology of scientific theories changes through time with the theories themselves. How is this account achievable? There is in fact a reachable knowledge which motivates the success of science, and manifests itself in our descriptions. The claim is that such a knowledge does not concern the nature of ultimate constituents of the world, and it is not knowledge of entities. Rather, it is knowledge of the structure of the natural world. Theories are true descriptions of such a structure and science through them science maintains a continuity through theory change.

Russell's claim, that we do not know any intrinsic qualities of the world, but rather its structure, fits well with the epistemic structural account. Nevertheless in order to suitably situate Russell with respect to such a position it is necessary to inquire into *his* view, pointing out how the ability of descriptions in mapping out the structure of natural world is therefore accounted for.

Russell developed his structural view in *The Analysis of Matter*[109]. The attention will be also paid to his previous works *The Introduction to Mathematical Philosophy* (1919) and *On the Notion of Order* (1901), since they provide some useful insights into the doctrine of relations. It will be claimed that the failure of Russell's structuralism was not due so much to the doctrine of structure per se, but rather to the following features of the underlying epistemology:

> 1)   An atomistic approach, according to which everything is reducible to the simplest constituents which can be separated from each other and singularly constitute the starting point of analysis. As we saw in chapter 1, this atomistic approach is overcome in Eddington's account through its absorption within the holistic point of view.

---

[109] The main source of our analysis is Russell's *Analysis of Matter*, which will be marked as AM. We sometimes will refer to *Introduction to Mathematical Philosophy* (IMP) and to *Human Knowledge* (HK).

2)   The view of knowledge as entirely reducible to logic: Russell apparently borrows the idea of a reducibility from Whitehead's view. Bradie (1977) and McLendon claim that the logical reductionism prevent Russell's view form involving the empirical content.

3)   The sharp dichotomy between the structure and the nature of the world, which characterizes his bifurcated position.

In some sense the third feature could also de found within Eddington's epistemology. Nevertheless the way the bifurcated position and the doctrine of structure match differs in the two authors. Thus the interesting point is not only the doctrine of structure, rather the global approach to physical knowledge, which Russell developed within *AM*.

The topic of *AM* is to give an account of two issues:

1)   the debate over materialism/idealism;

2)   the growing abstractness of physics;

Russell's structural claim is strictly linked to the answer he gave to such issues. He accounted for them through the endorsement of a *Causal Theory of Perception* introduced in order to support the *neutral monism,* a thesis concerning the 'fundamental stuff' of the world. Precisely, it is a thesis on the 'type' of 'stuff', which could be mental, physical or neither. Though such a debate is not the focus of the present work, it is worth considering since it constitutes Russell's perspective in 1927. The *neutral monism* incorporates two stances: as a *monism* it is a thesis, regarding the ultimate reality, against the dualism between mind-reality and physical-reality, suggesting a unity of the "material" of reality at the fundamental level[110]; as a *neutralism* it should support the idea that such fundamental reality is neither merely mental, nor physical.

The Analysis of Mind (1921) anticipated and presented an extensive view of *neutral monism* in a slightly different way. Russell said: "*The American Realists are partly right, though not wholly, in considering that both mind and matter are composed of a neutral-stuff which, in isolation, is neither mental nor material. I should admit this view as regards sensations: what is heard or seen belongs equally to psychology and to physics.*" (1921: 25-6; my emphasis). Then first of all the neutral

---

[110] Christian Wolff considered as *monists* those philosophers asserting the existence of a unique kind of substance.

monism regards *sensations*: what we hear and see. And also it seems not so much a neutralism rather a mixture-*ism*. Something 'neutral' would *neither* belong to mind nor to matter. *Vice versa* Russell said that what we see and hear belongs to *both*. In this sense it is a mixture. And Russell went further: "*But I should say that images belong only to mental world, while those occurrences (if any) which do not form part of any "experience" belong only to the physical world*"(*ib.*). There *is* in fact something that is only mental and something that is only material: they are respectively images and things which fall out of the experience, then pertaining only to the *physical world*.

Then the 1921's view leads to three possibilities:

- if the fundamental stuff is truly the neutral one, we should say that reality is just *sensations*;

- if we want to enlarge the view, involving everything that falls into the experience, images will come into the picture;

- if we would want to reasonably involve the physical world, we are led back to a *dualism*. In the weaker sense, there are some features of the world which do not enter experience (hence some unknowable features); in the stronger sense physical world itself is something that curiously is not part of *any* experience. The issue is, how should we gain any knowledge of it, if it is out of experience? Moreover the mentioned view of the physical world as excluded from any possibility of experience put physical knowledge into an embarrassing situation, though Russell also said that there exist also *laws* belonging to a physics conceived in such a way (the law of gravitation would be such a kind of physical law).

In 1922, Russell also published a paper in *Mind* answering the criticism raised by the previous work. The paper's title was *Physics and Perception*. There he said that perception has two parts: a core of sensations and a set of images and beliefs raised by our past experience. Through this definition of perception, the first two aforementioned possibilities lead to a view which puts the fundamental 'stuff' into the domain of perceptions. This eventually leads to a form of phenomenalism, bounding human knowledge to perceived phenomena . Only perceptions exist and an object is the connecting point of different observers'

perceptions. An object is a group of data (features), which constitute its biography. An object is "real" just as long as its biography contains at least one perceived datum[111].

On the contrary, *The Analysis of Matter* serves the rejection of any eventual phenomenalism, or any possible suspect of it, in order to overcome the impasse of an out-of-experience physical world: the new view allowes that the knowledge of reality could not be merely perceptive and provides a suitable place for physical knowledge in relation with the perceptive one[112].

The target is to widen the domain of knowledge beyond the perceptions thus accounting in a suitable way for the relation between them and physics. Russell needed an account of the perceptions which fitted well with the new character, highly abstract and counterintuitive, of physics. This account would allow us to appeal to empirical evidence, which traditionally falls under the domain of perceptions. The issue is posed in the following way:

a)   science gains confirmations by empirical evidences;

b)   empirical evidences fall under the domain of perceptions;

c)   we should give a way to go from the growing-in-abstractness domain of science to the concrete domain of our perceptions and *vice versa*.

This is the theme which underlies the whole work. Perceptual knowledge maintains a primacy with respect to the physical, which is basically seen as formal and *purely* structural. Perceptual knowledge, though "scattered", is taken as concrete knowledge whereas physical knowledge is abstract, though systematic. Then the main issue is how to match the two and it is pursued through an inference: analyzing perceptions Russell infers certain mathematical properties of reality.

Such an inference is led by some postulates regarding the connection between perceptions and their stimuli. The very possibility of such an inference testifies the primacy of perceptive knowledge. Nevertheless Russell's 'matching' involves also a different strategy with respect to the very perceptions, led by the aforementioned atomistic approach. The very basis of our world, which we traditionally count as "pieces of matter",

---

[111] This is basically a view translated from Berkeley's "esse est percipi", being is being perceived.
[112] He clearly affirms such an idea already in 1922: what strictly falls out of experience is to be part of the body of hypothesis which provide scientific knowledge.

are seen as logical structures of events: perceptions have a great deal to do precisely with such events, rather than with the "pieces of matter" whose nature is *unknown*[113].

§3.2.1 Structural Postulates of Physical Knowledge

The way Russell accounted for the inference from perceptions to stimuli is theoretically grounded on the postulates analyzed by Bradley(1977). The explicit postulates, famously defined in both *AM* and HK, could be summarized in the postulate of causal continuity and the structural postulate.

> 1)   *Causal continuity* postulates that what we experience (our percepts) is causally related to its stimulus in the external world. Then there is a way, a path, a continuous path, from our perceptions to the stimuli, what also implies the possibility to recognise the identity between our experience and other people experiences.

> 2)   *Structural postulate* postulates that different causes produce different effects. This is the inverse formulation of Weyl-Helmoltz's principle "same causes, same effects". The idea is that from the effects we can get something architectural about their causes, the stimuli[114]. Then the gained knowledge concerns the *structure* of the causes, and causes and their effects are *structurally similar.*

From this basis he basically formulated the thesis that: *at the very end of the causal chain there exists an object which is structurally similar to its effect* (Russell 1940: 232)[115]. Such a statement testifies the development of Russell's thought on perceptions. In 1922 he considered an unnecessary idea the fact that a thing would be causally responsible for the occurrences which produce our perception. The 1927 work introduces a more realistic attitude.

---

[113]Note that he does not want to say that reality is just "spiritual" and that just perceptions exist.

[114] From the structure of the stimuli we would be able to deduce by **correlation** the qualities of events.

[115] The quotation comes from *An Inquiry into Meaning and Thought*(1940), which is successive to *The Analysis of Matter*(1927) and to the Newman's objection (1928). Nevertheless, though Russell abandoned the strong structural thesis after Nemwan's paper, he does not abandoned the whole causal theory of perception. Hence the quoted claim could be taken as genuinely summarizing the outcomes of the two mentioned postulates: we just will clarify the meaning of the *structural similarity* according to *AM*.

Nevertheless, the epistemic dichotomy between percepts and external world, which is a heritage of the original phenomenalism, remains as a tacit posit of the neutral monism. It generates a strong partition between the knowledge of the physical world and the perceptual knowledge. Thus percepts and 'things' of the external world result as two epistemically separated domains. Despite his attempt to eliminate any form of bifurcation theory from his view, a dichotomy reappears as a sort of postulate which creates in a programmatic way a hiatus between the domain of reality and the domain of perceptions.

Paradoxically the causal theory of perception strives to overcome a separation between perceptions and stimuli which Russell himself implicitly posited. He believes that the possibilities of overcoming such a hiatus rely in interpretation, and interpretation has a social origin in the commonality of experience among different perceivers. Nevertheless, the very recognition of a commonality grounds on the causal continuity which then is the main candidate to overcome the epistemic dichotomy.[116] The bridge on the gap is twofold: on the one hand perceptions are taken to be structures of events linked around a point; on the other hand they are defined as part of brain matter.

When Russell mentiones the "external world" he points to *things that are not percepts*: He does not question about the daily knowledge of macroscopic objects we do experience, rather he inquires into knowledge of things we do not perceive, which do not directly fall under our experience, either because they enter other people's experience, or because they are not strictly speaking perceivable. Those are the kind of things that fall under the knowledge provided by current physics. The curious consequence of *The Analysis of Mind*, that the physical world fell out of our experience, is not denied: it is just weakened through the idea that there is a link between our knowledge and such a falling-out-of-experience world.

One of the outcomes of this view is that we have direct knowledge[117] of the 'intrinsic character', 'nature' or 'quality' of percepts. The use of "intrinsic" reverses the common sense. The current way of using the adjective refers it to characters which pertain to objects per se, to things as they *objectively* are independent of anything else. Particularly the intrinsic

---

[116] The issue remains how he conciliate the "structural" with the "causal".
[117] This feature constitutes another step beyond the 1922's view where he said that direct knowledge is not possible.

character are independent of our perceptions, they exist without the perceiving subject[118]. Moreover it is usually associated with the sort of features discovered through physical knowledge. Ascribing the intrinsic nature of properties to perceptions, not to stimuli, is at least an unusual procedure.

Also Russell did not say that stimuli did not have intrinsic features. Rather he claimed that it was possible to *know* only the intrinsic features of perceptions, and not the stimuli's one. In this sense, his view differs from Eddington: Eddington's view lead to the idea that the traditionally considered intrinsic features of the entities are derivative with respect to all the Universe's structure. Even whilst we would be able to separate any independent characters of the entities from our cognitive activity, it would not be an intrinsic character of those entities independently of *the rest*. Indeed there is not strictly speaking any entity independent of the rest[119].

Russell believed that the knowledge of the world of stimuli was achievable through an inference on the ground of the structural postulate, drawing deductions from percepts. The "mirroring" between stimulus and percepts was a structural similarity. The knowledge concerned a structure.

On the other hand, causes pertained to stimuli. In this view the problem arises since there is a veil of appearance between the external world and us. We know our perceptions, whose connections "structurally mirror" causal connections of the world. We should trust on it based on the causal continuity between causes and effects. But our knowledge gained by perceptions in no way tells us about real causations. We just know a net of connections.

The curious thing is also that once physics has given us the structure of stimuli of our perceptions we apparently have to consider it as the *causal* skeleton of the world[120]. We have to be clear on such point: it is a matter of fact that in Russell's view the causal continuity between causes and effects places causality first of all into the domain of stimuli. The way such a causality, which is 'generative' with respect to our representations of the world, fits with the highly formal account of Russell's structuralism is obscure. We do not affirm that it is an impossible fit, but rather that it has not been deepened in Russell's view. We would state it the following way: causality pertains first of all to stimuli, but our knowledge of

---

[118] Strictly speaking in such view we rather should say that there is no way of knowing intrinsic qualities, or we should turn over the all picture and say that the genuine intrinsic properties, better the "proper" properties, are the one that exist even without the perceiving.

[119] Chapter one and two presented Eddington's structural holism.

[120] Newman (1928) also notes that the causal continuity works as 'generating relation'.

them does not concern the causal features; stimuli also are the causes of our perceptions, through a causal chain; the causal chain reaches the retinal nerves from the external objects, and gives perceptions.

A number of questions arise from this view: how should we consider the path from perception to physics? What is the content of our inferences from perceptions to physics? Is the causality of the world reflected within our perceptive knowledge? Is the structure of stimuli, revealed by mathematics, causal or not? And so on.

In order to answer them we ought to understand both Russell's thought on physics and the meaning of the previous mentioned thesis, "*at the very end of the causal chain there exists an object which is structurally similar to its effect*" (Russell 1940: 232). We will devote the next sections to such issues.

§3.2.2 From Perception to Physics: the Causal Theory of Perception

The second part of *AM* looks for the basis of the neutral monism. The first consequence of the presupposed hiatus between different domains of knowledge, physical and perceptual, manifests itself as a dualism between the phenomenal world and the physical. They are conciliated through the idea that the latter is the causal source of the former.

In the history of philosophy, the causal theory of perception had a variety of derivations, but it always involved a concern in the way knowledge was gained and the relation of 'belonging to' which relates effects and causes, or sensible qualities and physical objects. Accordingly, as Price (*Perception* : *66)* stated them:

> 1)   "In the case of all sense-data....'belonging to' simply means being caused by, so that 'M is present to my senses' will be equivalent to 'M causes a sense-datum with which I am acquainted' ".

> 2)   "Perceptual consciousness is fundamentally an inference from effect to cause".

Russell stated it in the same terms: "*Science holds that, when we 'see the sun' there is a process, starting from the sun traversing the space between the sun and the eye, changing its character when it reaches*

the eye, changing its character again in the optic nerve and the brain and finally producing the event which we call 'seeing the sun'. Our knowledge of the sun thus becomes inferential; our direct knowledge is of an event which is, in some sense, 'in us' " (AM:127). The direct knowledge would concern the event "seeing the sun", and not the event "sun" which originates the chain.

In *AM* the fundamental problem between physics and common sense relies on the different metaphysics that science implies. Common sense recognizes as 'object' something that has permanence and that is linked to various sensations. This general idea implies memory and experience and depends on the concept of space as it is formed on the ground of perceived relations between simultaneously seen or touched objects. There are also some correlative relations, which hold between different kinds of perceptions and which we learn because of experience:

> - From our experiences of 'empirical' (not logical) correlations we deduce the entities of our perceptive experience.

> - From such correlations we also deduce the common cause of our perceptions, and not vice versa.

A physical object appears to the common sense as something that is capable of affecting different senses simultaneously. It is a common belief, mainly due to the inter-subjectivity of our perceptions[121], that we perceive objects as they are. In this sense 'substance' is a natural category for common sense, and 'substantial identity' is a concept which characterizes both language, common sense and metaphysics. Russell instead took any traditionally conceived unique substance to be a series of events (occurrences) linked in some relevant way[122].

He approached perception with an epistemological interest, as an implicit condition of empirical science[123], rather than as a mental process. The leading question is similar to Eddington's question, 'what and how do I know about the external world?'. The first observation is that among the abundance of data of our experience we always find temporal relations and often spatial relations. Naturally our experience concerns objects,

---

[121] We have not any difficulty in recognizing a similarity or an identity between what we perceive and what other people tell us they are perceiving: on such a reflection, Russell ascribes an inter-subjective character to our perceptions.
[122] This is maybe an anticipation of the bundle theory of properties.
[123] Another premise of empirical knowledge is that it rises in the very moment of perception and it remains in the memory

but Russell considered them as the outcome of deductions. Perceiving objects is perceiving certain sensible qualities, with the expectation of some others. At the core of these sensible qualities there hold temporal and spatial relations which constitute the primitive basis of our knowledge. 'Matter' which physics and philosophy inquire differs from the material object of common sense, even though they are linked. Hence *AM* does not speak of what we know in terms of the object of common sense, but rather in terms of its sensible/analysable qualities.

The long chain of deductions starting from physiological deduction arrives at scientific laws, basically in the form of differential equation or statistical means. The latter only differ from the former because they refer to groups rather than to individuals. The fundamental deduction which science inherited from common sense is the idea of the permanence of unperceived objects which are grounded in the idea of theoretic[124] entities. Justifying this thesis is one of the fundamental issues of an analysis of matter. The deduction generates the philosophical notion of substance as well as physical notion of matter. It also grounds deductions concerning other people minds and perceptions[125], which basically form the basis of science and also for the causal theory of perception[126].

The central idea of Russell's causal theory of perception is that perceptions have some external causes. Perceptions are not unique and different people do not "see the same thing". They rather see similar things related by a common causal source. Concerning unperceived things which are perceived by other people, the way to accept deductions about them proceeds gradually: In a first stage, we ought to arrange our perceptions in groups on the ground of the supposed object of reference; then, putting apart the object of reference, we focus on correlations between the bunched perceptions. Objects are eliminated and the group[127]of perceptions remains. Also such perceptions, or net of perceptions, are supposed to remains also without a witness. In this way we could speak of a physical object as a group of perceptions, and we explain why two objects distant from each other have the same form and dimension 'in reality'.

---

[124] 'Theoretic' means unperceived and unobservable.
[125] The aforementioned idea of the inter-subjectivity of perception is linked to the idea that the objects, causally responsible for our perceptions, have such a permanent character which is proper of the notion of substance: the receiver beings have a reasonable world of common external causes for their perceptions.
[126] The possibility of accepting the "testimony" of other people is one of the fundamental pillars of science.
[127] He uses the notion of "group": Russell clearly knew the use of such notion in geometry and the use of it by Eddington. So his choice is probably not naïve.

In the second stage we note an analogy between other people's bodies and behaviour, and our body and behaviour: we ascribe to other people's behaviour some stimulus of what we know.

In the third stage unperceived entities appear. We observe constant correlations between A and B, and we deduce A and B in a case in which A is not perceived. Our deduction is not based on universal considerations as "A is always present", rather it is something existentially quantified: "sometimes A exists". And it is grounded on induction[128].

Though such a reasoning regards situations in which there aren't perceiving people, it seems applicable also to unperceived entities, hence unobservable, hence theoretical. The physical object is not only a biography of perceptions: it is the centre around which a group of perceptions coming from different people is ordered. Hence it is not a point, rather a volume[129].

Thus the fundamental elements of Russell's causal theory of perception are:

    - Perceptions are organized around a centre;

    - Perceived things are continuous to the events linked with them and vice versa;

    - There is an analogy between groups and physical objects.

    - Matter is only knowable because of some non-merely-abstract characteristics due to its link with perception.

Perceptions are data for deductions. They do not give direct knowledge of *objects*. Generally speaking, a real object has the characters of a formula, from which we can derive the physical appearances[130] of the objects. Something different happens for unperceived events. According to Russell, we inherited the idea that unperceived causes must be like the Kantian *Ding-an-sich*. In *AM* he denies such a complete unknowability[131]:

---

[128] As well as substance, induction has an important place in common sense's view, so that scientific methodology ought to develop an appropriate notion, in order to avoid false deductions of common sense.
[129] (We see here some kind of group-based-reconceptualization of objects).
[130] distant appearances differ from closer; the firsts are more undetermined and we cannot deduce the latter from them.
[131] The question arises whether he succeeds.

1) we suppose that difference between perceptions implies difference between stimuli (the ratio is 1:1).

2) there exists spatio-temporal contiguity between perceptions and events.

3) we can state a correspondence between external world geometry and perceptions' geometry.

Thus it is possible to find a lot of information, in terms of mathematical properties, about the *structure* of stimuli[132]and because of the difference between perceptions and stimuli, we should retain the structural properties. The final thesis is expressed as follows: with respect to unperceived things we can deduce a lot about their mathematical structure but nothing about their intrinsic qualities (*AM* : 324).

The causal theory of perceptions enables Russell's reconstruction of the notion of physical object and knowledge, along two main lines:

- criticism of the notion of substance

- notions of structure and similarity of structure

The first line associates the views of many authors of the same time. As we saw, a criticism of the substance recurs in Eddington's view, but it is also a proper feature of the wider epistemological tradition including Cassirer, the neo-positivists, Reichenbach and so on.

§3.2.3 Critique of the concept of Substance

At the level of physics, the controversy about the notion of substance concerns the way we want to look at our physical entities, for instance electrons and protons. Even regarding them as substances, furnished with qualities and relations, the issue remains:

---

[132] In saying that we do not know intrinsic qualities of the world, but we know many mathematical properties which will be preserved through theory change, our knowledge would be "just" a second order one. The first order predicates are those predicates which contain individual variables. The second order predicates contain predicate variables. According to Russell's view our knowledge is bounded to the latter. "*Russell claims that we can at most know the second order structure of physical relations but not the relations themselves for we have no epistemic access to them. A consequence of this view is that there is an underdetermination of the first-order physical relations by the abstract structure, since to any such structure correspond infinitely many such relations*"(Votsis 2003:1).

How should we consider 'particles', as entities – permanent pieces of matter-, as events or as anything else?

We speak of particles because physics resolves physical objects as groups of electrons and protons, due to an atomistic prejudice. Russell does not attempt to deny the atomistic point of view, he rather substitutes the *atoms*: electrons and protons are not the primitives of physical world, rather they are logical structures of *events*[133].

The discussion on this point brings a particular definition for the notion of object within a process which goes from material tangible things, which he analyzes as supposed causes of our perceptions, to proofs of unobservable intangible entities which satisfy mathematical equations. In this context he develops a critic of the common view on *matter* as anticipated at the end of *The ABC of Relativity*. The central point concerns avoiding the notion of substance, regarding both tangible and intangible matter. The physical world is a world of events. Even electrons and protons[134] are logical structures of events, namely the spatiotemporal events which identify them – the presence of *m* mass *and* the presence of *c* charge *and* the presence of *s* spin *hic et nunc*. In this respect Russell's view has been named *eventism* and assimilated to the Whitehead analysis. A comparison between the two authors is not the aim of the present work and will bring us farther away from the present discussion. Nevertheless, it is certain that Russell felt the influence of his colleague concerning both the criticism of the notion of matter/substance and the centrality of the *event*[135]. On the other hand, Whitehead presents a theory of perception which rejects any bifurcation of nature in two systems reality. In their different manifestations the theories of bifurcation distinguish between nature as *apprehended* in consciousness and nature as the *cause* of it. We have two realities: the system produced by mind and the entities, for instance the electrons. The bifurcation arises from a difficulty in accounting for the traditional difference between primary qualities and secondary qualities. According to Whitehead, an alike distinction in reality is not what a philosophy of science must look for. He rejected the idea of an apparent nature as opposed to some more true reality. Rather "*there is but one nature, namely the nature which is before us in perceptual knowledge*" (Whitehead 1920: 40). This

---

[133] Any unity of matter is taken to be a causal line, that is a series of events linked through an intrinsic causal law.

[134] The elementary particles considered in AM(1927) are electrons and protons. HK(1951) considers also neutrons and positrons.

[135] In *The Concept of Nature* (1920) Whitehead said that an immediate fact was the "*whole occurrence of nature as an event*".

unitary view, which we will not further develop[136], was surely different from Russell's account.

Russell's ontological picture does not aim to say that objects do not exist because they are mere logical constructions starting from perception. His aim is rather the idea that insofar as they enter our knowledge they enter it as logical structures of events.

According to the causal theory of perception and contrary to the substantialist view, physical objects are deduced as centres of an ordered group of events[137]. The presence of a *substance* at the centre of such groups is just a possibility, not a necessity. It belongs to the field of purely abstract possibilities (Russell 1927: 302-303).

Russell moved from a logicist approach[138], reducing physical knowledge to mathematics and then to logic. Though the emphasis on mathematical symbolism is a common feature also of Eddington's view, the latter did not consider physical knowledge as independent from any possible experience.

Further remarks must be added regarding Russell's idea that physics reveals only the mathematical characters of the 'material' which constitute its object, but not intrinsic characters. *AM* frequently insists on a dichotomy between 'mathematical characteristics' and 'intrinsic features', as if 'mathematical characteristic' couldn't indicate intrinsic. Physical properties are considered structural properties as a consequence of the physical abstractness, also manifested in the growing relevance of higher level mathematics. But what does *structural properties* exactly mean? The thesis refers in this sense to the analysis of relations developed in *The notion of order* and in *Introduction to mathematical philosophy*. The structural properties are indeed those logical properties derived by relations of order. We will consider them later. In the meantime it ought to be remarked that Russell could well consider structural knowledge as a non-empty one since he is convinced that logic is a synthetic discipline, capable of saying something new and not-trivially true about the world.

---

[136] For more details see Whitehead's *Concept of Nature* and *Principles of Human Knowledge* and Carlson (2009).

[137] The idea of a group of events ordered around a centre is not a technical concept. Russell just derives it from the praeminence of the events-oriented doctrine of perceptions.

[138] Russell inherited from Whitehead the idea that the logicist method could be extended from the domain of mathematics to the domain of physics, in order to define physical objects. The basis of the logical construction were first of all the sensory data of perception. Already before the *AM* the basis of the logical construction are the events: " *By 1921 Russell had assigned the role of logical atoms to events, the more neutral, neither decidedly physical nor decidedly mental, elements that fitted nicely with his newly discovered affection for neutral monism. Moreover, he had assigned the role of the objects of direct acquaintance to percepts, those events that occurred within one's head. Despite these shifts, Russell's commitment to the project of logical construction remained firm*"(Votsis 2003: 879).

We mentioned Russell's view as a form of 'eventism' which he inherited from Whitehead, as well as the idea of using logic in order to define physical objects. The consequence of this intuition concerning the extensibility of logical methods to other domains, as the domain of physics, is that the *atoms* of his ontology are the events and everything is reconsidered starting from them. This is, according to Russell, an outcome of the General Theory of Relativity, which enables us to conceive pieces of matter as groups of events. It starts from a four-dimensional multiplicity of "events", not from a temporal series of three-dimensional multiplicity linked by the notion of matter in motion. We have world-lines, i.e. linked events; light-beams constituted of parts. Russell wants to see particles in the same way: electrons as events linked by causal laws.

The principal characteristic that physics assigns to such groups of connected events is the existence of a first order differential law which links the events along a linear path. The chain of events linked by such a differential law is a piece of matter, it basically is a bundle of events. In the end a material unity is a peculiar chain of events, characterized by the existence of an intrinsic causal law (*AM* : 305). In this chain the transition from an event to the other is a possible motion.

Moreover, according to Russell, the non-substantiality of elementary particles emerged also in Quantum Mechanics where electrons and protons dissolved in bundles of radiation. Hence the expression 'persistent unities of matter' lost its previous metaphysical meaning. We do not perceive (even 'perceive') substances: we perceive groups of events[139] belonging to a causal chain. Even speaking of things as groups of states is a very close idea. The characteristic permanence of the old substances remains within the existence of causal intrinsic laws. We track the causal chains with some intrinsic causal unity and assign to it the characteristic of successive states of what we once called 'substance'. Substance as 'a persistent unity underlying any perception' is eliminated, but the causal unity of a causal process remains. The link with the perception theory is due to the fact that perceptions are first of all events of the world, from which everything could be deduced.

It is also notable that Russell did not say that particles were not substances. He just said that it did not matter: no possibility, neither particles as substances nor particles as non substances, could be proved. But this was not a limit, since the group of events possessed all the needed properties. From the perspective of Russell's perception theory, which

---

[139]Such events are now "genus-identified", identified because of some belonging "families" – which finally define objects.

considers physical objects of perception as groups of events, it is desirable that physics would redefine his ontology without the notion of a permanent substance, since it is a dubious concept. Through the causal theory he attempted to impose an ontology of events as the fundamental fruitful ontology of physics, which is a suitable fit with the world of perceptions.

Hence the elimination of the notion of substance is the basis of epistemology, both structuralist and not structuralist. Also, it is a common feature with Eddington's epistemology. On the other hand the latter did not defend an ontology of events. It instead is the outcome of Russell's theory.

After the epistemological framework of Russell's structural thesis has been presented, and some relevant differences with Eddington's epistemology has emerged[140], it is worth introducing Russell's doctrine of structure.

§3.2.4 Structure

As mentioned, according to Russell physical knowledge does not regard the *intrinsic qualities*, but rather the relevant structure. In physics, "*nothing…ever depends on the actual qualities*"(Russell 1927:227). He introduced the notion of structure in order to the analogy between causes and effects which is one of the postulates of his bridge from perception to physics[141]. It is clear that Russell's structuralism is an eminently epistemic thesis, since it concerns the way our theories represent reality. The idea is that they get some architectural features in the world. The technical device which accounts for the relationship between percepts and objects is the *structural similarity*. In order to understand this claim, the present section will analyse the idea of 'having a structure'.

Russell's general definition was that "*to exhibit the structure of an object is to mention its parts and the way they are interrelated*" (HK: 267; AM: 249). Naturally such a definition concerns the internal relations of an object, i.e. the way an object is constituted, and not the

---

[140] With respect to the characteristics of Russell's view, Eddington's view has a non-logicist attitude, a non-atomistic view, and a non-eventist intended ontology.

[141] in such a sense he is speaking of the notion of isomorphism which will be later used concerning the representative power of models.

relations among different objects. On the other hand when Russell said that physical knowledge concerns the structure of stimuli he effectively applied the general notion to the universe of stimuli.

Besides the general notion, McLendon (1955) notes that Russell used 'having a structure' at least in four senses:

1.   Being a complex element. This is a weak sense and it is not the sense used in *AM*, since this is also valid for classes. In this sense, any entity having a plurality of parts, has a structure. The physical universe trivially has a structure since it has a plurality of parts. A structure is a plurality of parts.

2.   Being a whole, having a plurality of distinguished parts *arranged* in a definite way, whose arrangement (the *pattern* of relations) is known "*whatsoever the characteristics of the complex and its relations*" (McLendon, 1955: 80). The different with 1. is in the fact that 1. focuses on any collection of elements. On the contrary 2. focuses on arranged wholes. A structure is an arrangement of parts. In considering the structure of those arranged wholes the attention is neither to the terms, nor to their specific relations, but rather to the way everything is arranged. We should dwell on sense 2. It could seem empty or tautological to say that 'every whole have an arrangement'. It must be remarked that: a) the arrangement is known; b) its possible characteristics are specified through providing the third and fourth sense, according to the kind of relation which characterizes the arrangement. Thus it is obvious that 2. maintains an extreme generality since its specifications are provided in the subsequent senses. Nevertheless it is not the case that 2. is empty nor tautological.

3.   Being a whole, having a plurality of distinguished and arranged parts, whose arrangement is grounded on a non-ordering relation.

4.   Being a whole, having a plurality of distinguished and arranged parts, whose arrangement is grounded on an *ordering* relation. An ordering relation is a relation which has the properties of transitivity, asymmetry and connectedness[142].

---

[142] McLendon uses the word *'connexity'* rather than connectedness.

The way these properties (transitivity, asymmetry and connectedness) are defined is the usual[143]:

- *asymmetry*: $\forall a \forall b (aRb \neq> bRa)$ or $\forall a \forall b (aRb \vee bRa)$

- *transitivity*: $\forall a \forall b \forall c (aRb \,\&\, bRc \rightarrow aRc)$

- *connectedness* (or connexity): given two terms of a class, one of them must be the previous term and the other one must be the successive term. For instance, considering any two integers or any two real numbers, the one is smaller than the other. The same does not hold for the complex numbers.

Why does Russell focus on the arrangement *whatsoever the characteristics of the complex and its relations*? The reason is the focus on the ordering relation. Indeed, according to his doctrine of relation, the *order* of a class does not arise from the nature of the elements nor from their specific relations. It rather arises from the fact that whatsoever the relation, it has the three mentioned properties (asymmetry, transitivity and connectedness).

Note that all the temporal relations but simultaneity, all the relation of magnitude but equality and most of the spatial relations are ordering relations. According to the theory of special Relativity, there holds a partial order rather than a total order. Indeed not all the pairs of events are temporally ordered, but rather just the timelike ones and the light ones.

From these four senses of structure, McLendon generalizes Russell's view: "*any entity whatsoever which has a plurality of parts will have a structure both in the first and second sense and in either the third or the fourth sense*"(1955: 82). More precisely, so far as the physical knowledge is concerned, it deals with the fourth sense.

More thought should be given the idea that a knowledge of an arrangement could provide a genuine knowledge. Putting aside the specifics of Russell's thesis for a while, what does an arrangement count for? In which sense should we be interested in the pattern of relations, rather than on the relata? The significance of the notion of arrangement relies on the difference between the concept of *structure* and the concept of *collection of object*. The former is an ordered set of elements with precise relations, not the second. The most useful examples of such a difference could be taken from the chemistry, considering for instance

---

[143] Russell's requirement for a relation generating an order is that it enable a distinction between the previous and the successive terms. For further details on the doctrine of relations see *The Introduction to Mathematical Philosophy*(1919).

isomers. In the case of isomers different arrangements of the very same atoms (C_2H_6O) produce different chemical substances (for instance the ethyl alcohol and the methyl ether). The structural patterns of those different chemical substances depend on the specific relation between the elements and such a relation is not completely dependent on the particular elements[144]. The example will be considered carefully in the next section as we will deal with the key russellian notion, *structural similarity*. Indeed, the main difficulty with Russell's notion is that it is impossible to make the supposed relevant relation explicit.

In *AM* Russell noted that the notion of structure was only applicable to relations and *systems* of relations, but not to mere collections of objects, i.e. classes. He defined a *class* as a collection of objects univocally identifiable[145]. He noted that we must not only consider the terms of the relations (*relata*), but also the interrelation, the arrangement of the structure. As we will see, Eddington noted that Russell's incurrence into Newman's problem was due to his failing to account for that interrelation.

Russell put forward different kinds of examples for his notion of 'having a structure': skeletons have a structure, made of bones, which in their turn are structures of cells, which are made of molecules, and so on. Moreover, moving on to other physical entities, we may analyse them into structure of events.

On the other hand, Russell's concept of structure suffers from an extreme abstractness, which motivated the emphasis of criticisms on the lack of any knowledge concerning the nature of the constituents, that is not involved in the determination of the structure. This creates a problem concerning the structural content of our knowledge. In order to avoid misunderstanding on this point, it must be stated that, according to Russell, the nature of the constituents does not contribute to the fact that the structure has an order, nor that our perceptions structurally resemble the physical world. This fact does not mean that the character of the structure does not depend on the nature of the constituents. We simply do not know it. Russell is agnostic in this respect.

Furthermore, the *AM* devotes a chapter to the role of the structure's constituents. Structures are described through terms, which themselves may have internal structure and relations. Relata are as fundamental as relations, within the structure. The ultimate known

---

[144] It eventually depends on the *kind* of element (for further details see Krause [2005]).
[145] In such a sense he did not endorse McLendon's first sense, but the generalized view covers the point. This is not important to McLendon, since he tries to demonstrate that all the four senses turn out to be empty.

structural terms are called 'particulars'[146] and they occupy a place in the world because of their properties and their relations with other terms, rather than because of their possible internal structure. A particular corresponds to the intuitive idea of a substance, at least until we find some important structural differences inside it. For instance, once atoms were considered substances; now they are structures of electrons and protons, and they are no longer particulars.

In such respect, Russell's view clearly satisfies the atomistic point of view, which Eddington pointed out as a characteristic frame of scientific thought. As a matter of fact, Eddington overcame that point of view through introducing the structural thesis[147]. On the contrary, Russell endorsed the atomistic perspective without any modification.

The aforementioned claim to the nature of the constituents means that insofar as we can know the structure, that nature does not emerge as a feature of our knowledge. In this sense, that the mirroring between stimuli and perceptions involves just the second-order relations (footnote 26) is quite understandable. Indeed Russell did not speak directly of the 'furniture' of the world (its entities and their properties). He moved from the first order to second order, a characteristic which emerges from the way Russell presents the fundamental notion of his structuralism: the structural similarity.

§3.2.5 Similarity

As mentioned before, the notion of structure is developed in order to allow for the notion of 'similarity of structures', which is the crucial concept within Russell's thesis. Two relations *P* and *Q* are 'similar' when there is a correspondence *f*, which is 1:1 between their fields, such that when two terms are in the relation *P*, two correspondent terms via *f* are in the relation *Q*. If a*P*b then *f*(a)*Q*f(b) and conversely.

The most familiar example regards two series: the structural correlation among two series does not change their order. But, he mentions, the relevance of the similarity of structure goes beyond the simple example of series. For instance it concerns the analogy between a map and a geographic region, or between a record (phonographic) and the music it represents.

---

[146] He used "particulars" relatively only in regard to our knowledge: it is not an absolute metaphysical term.
[147] In chapter one and two we saw that Eddington's structuralism is a form or holism in the first place.

According to the aforementioned definitions of structure, McLendon refers the senses of *similarity of structure*:

> i) Referring to structure as complexity, similarity means "having the same number of components, that is cardinality". This is to be the kind of notion which motivates Newman's objection.

> ii) In the more articulated sense (ordering and non-ordering relations) two structures are similar when they fulfil some conditions:

> 1.   members of the class α are related by relation *P*;
> 2.   members of class β are related by relation *Q*;

1. and 2. ensure that the comparison is between structured classes, namely systems of relations.

> 3.   Between the members of the two classes there is a 1:1 correspondence, namely there is a 1:1 relation *S* which *preserves* the structuring relation *P* in α and *Q* in β

Point 3. is the crucial point of the notion of similarity. *S* is not just any kind of relation. It is a *function*, namely an isomorphism, which preserves the structure. It preserves the logical properties of the system. The preservation means that the field of the relation could be changed without any alteration in the arrangement (structure). Such an idea implies that the elements of the structure are considered indistinguishable with respect to the structure. On the other hand it must be remarked that the simple substitution of elements does not automatically preserve the structure. The two structures must be already similar in order for us to state the similarity : in such a sense, the significance of the notion depend on the underlying epistemology.

This feature is very interesting since Yolton notes that Russell's view is problematic since we cannot have a direct knowledge of the two terms linked via the structural correspondence; hence the analogy can never be verified (Yolton, 1960: 59). On the other hand, we should not need to verify the analogy if the two structures are already similar. In Russell's case the frame of the causal theory of perception serves the scope: it is already

known that perceptions and stimuli are structured in a similar way. Again the example from chemistry is useful: the substitution of the atoms in a chemical substance with similar ones produces the same substance. In this sense there is a fundamental difference between a discipline such as chemistry and one such as mathematics: in mathematics, the substitution of the elements with similar ones does not uniquely provide the same structure. Hence the analogy with mathematics could be misleading. As we will see, in Russell's case this is a crucial feature, as he reduces physics to mathematics and mathematics to logic. In such a reduction he loses the crucial possibility of involving within his picture the empirical features of a discipline like physics.

> 4.   whenever two terms of the first system are related by *P*, two corresponding terms in the second system are related by the relation Q;

Point 4. guarantees that from knowledge about the relation between some terms of the first, we know something about the relation of the other system. Two similarly structured classes share logical properties. That is, similarity is a commonality of logical properties: sharing the same structure or *number-relation* is sharing the class of all relations similar to the given one. This is the same correspondence that lets us *infer* from a geographic map the represented area, from a phonic record the represented music. Requirements 3. and 4. are very similar. On the other hand, the latter is a corollary of 3., concerning the knowableness of the relations, thus enabling inferences from the first domain to the second.

Essentially, Russell affirmed a mapping, a way of correspondence between perceptions and their stimuli, so that through knowing our perceptions we reach a knowledge of the structure of our stimuli. If we have valid deductions from perceptions to their causes, such deductions mainly refer to logical properties. The main example is provided by the case of the physical space and the perceptual space: they are not identical, yet their structural similarity allows for a correspondence which lets us deduce the logical (or mathematical) properties of physical space. Our perceptions are <u>ordered</u> by specific characteristics. The postulates of the causal theory of perception enable that the stimuli as well are ordered according to the same characteristics. In this way we find a nucleus of logical properties. The important point is that logical properties include the expressible

ones in mathematical terms. That is, all the fundamental properties expressed in physical theory.

Such correlations between the perceptual order and the physical order are taken to explain the mathematical nature of our physical knowledge: we cannot deduce from perceptions any non-mathematical properties. Hence, since empirical knowledge arises from perceptions, it must be mathematical. Generally speaking, all deductions from perceptions, namely all scientific deductions, give us only structure. This structure is mathematically expressed[148]. Therefore, the problem does not concern so much the notion of structure, as logical properties having to include all the fundamental properties expressed in physical theory, since they are expressed in mathematical terms. Physics is synthesized in mathematics and mathematics is reduced to logic. A logical notion is taken to exhaust all physical meaning.

In Russell's view logical structures are supposed to obtain some architectural features of the world. The reduction of physics to logic and the idea that the mirroring is a structural correspondence could be questioned.

As we will see in the next section, Russell's view faces two fundamental problems: it enables the existence of too many representing models for the aforementioned architectural features of the world, and it lacks significant content. Both problems are emphasized in Newman's objection. The next sections will show that the reductionist point of view has a significant role in determining them.

§3.4. "Newman's Problem" and the Current Debate

The main issue regarding structural knowledge is the clarification of its *content*: what exactly does it mean that we know the structure of the world? In Russell's view the material which constitutes the objects of physics has some mathematical characteristics. They do not tell us anything about the intrinsic features of the external world. Hence, in which sense do they tell us something significant about it?

---

[148] In particular Russell referred to mathematical logic.

This was basically what M.H.A.Newman noted in his critical notice (1928): the division of knowledge, while fascinating, is useless "unless we are prepared to return to the view that really there is nothing of importance that can be said about the external world. The trouble is the view that nothing but the structure of the external world is known"(Newman, 1928: 144). The point is, what do we gain by knowing that there is a similarity of structure between our perceptions and their stimuli? What are we actually knowing?

§3.4.1 "Newman's Problem"

Newman's article aroused initially no interest till 1985, when a second article by Demopoulos and Friedman revitalized Newman's concern at a time when a renewed debate on structuralism was growing in philosophy of science. At the core, Newman's idea doubts whether Russell's theory is capable of discovering and affirming the truth of at least some proposition in which scientific theories could be interested in, for instance propositions regarding atomism.

According to Newman, Russell's view could be summarized thus:

• "[*t*]*here* is a relation R such that the structure of the external world with reference to R is W" (Newman 1928: 144). In fact, in Russell's words, we do not have to specify the relation R.

Then Newman notes that

• for any aggregate A "*a system of relations between its members can be found having any assigned structure compatible with the cardinal number of A*" (*ib*.140)[149]. This is an explicit theorem of set-theory: every set A determines a structure containing every relation (whatever - *arity*), that is its full structure. On the contrary, it is always possible to find a relation such that the correspondent set has the structure W. Then we do not have the possibility of identify among a variety of relations, the *intended relation* that is the "important" relation which provides us with the unique interpretation of a certain physical domain.

• Russell's claim, though fascinating, does not give us any important information: indeed important statements about the structure are those concerned

---

[149] "*any collection of things can be organized so as to have the structure W, provided there are the right number of them*"(*ib*.: 144)

with the structure *set up* in the considered aggregate of elements "*by a given, definite, relation*"(*ib.*).

Hence, in the end, we could only know that "*the world consists of objects, forming an aggregate whose structure with regard to a certain relation* R *is known, say* W; *but of the relation* R *nothing is known but its existence*"(*ib.*144). Such an assertion merely expresses a trivial property of the world, concerning its cardinality: indeed "*any collection of things can be organised so as to have the structure* W, *provided there are the right number of them*"(*ib.*).

On the other hand, there exist some issues in which science could be interested and which fall outside the structural picture. For example, Newman said, in science we are interested in the existence of atoms or of any microscopic particle as well, which cannot be *perceived*, strictly speaking, nor defined as macroscopic physical object via their 'aspects'. "*The evidence for what is ordinarily called its* (their, ndr.) *existence is as strong as for any other piece of scientific theory*"(*ib.*143). And this must be accounted for. At least through a naïve intuition we *know* that our knowledge of the external world is not trivial in fact[150]: hence our knowledge of unperceived entities should be not purely structural[151].

In the end Russell's notion of structure is so general that:

- the only gained knowledge regards the cardinality of the system;

- it enables a plurality of models (of reality) among which it is impossible to choose the definite (true/real) one. Indeed if we could set up any structure similar to the given one, then any model of the world of stimuli could be provided out of the known structure *W* of our perceptions. We could be provided with a multiplicity of theoretical models for the same physical domain, without the ability to choose the intended one, since the constraints for "being the correct representation of" are so general as tobe trivial.

---

[150]The naïve intuition Newman (and Demopoulos/Friedman) refers to is the intuition that structural properties which our theories postulate are not stipulated, but rather discovered.

[151] "*the observable/unobservable dichotomy is not explicable in terms of the structure/quality division of knowledge whitout giving up the idea that our knowledge of the unobservable parts of the world is discovered rather than stipulated*"(Demopoulos and Friedman, 1985: 630). The idea that our theoretical knowledge is entirely stipulated was diffused in the years immediately before and after *AM*. Perhaps Russell's emphasis on physics as a deductive system might seem in line with the latter view, but we rather should consider *AM* as an attempt to preserve a "non-conventionalist view" in such a sense, taking the dichotomy structure/quality and form/content as reflexive of the theoretical/observational knowledge.

- if our knowledge concerns only structure, we cannot know anything *that is not logically deducible from the mere fact of existence, except ('theoretically') the number of constituting objects*: we know the cardinality of the system plus everything that is logically deducible from the *mere fact of* the existence of the structure.

Two conclusions of Newman's review are very interesting: as to the first, the above problem makes it necessary *"to give up the 'structure/qualities' division of knowledge in its strict form"* (Newman 1928: 147), which in the eye of Demopoulos and Friedman means *"giving up the idea that we do not know the qualities of the unperceived objects"* (Demopoulos and Friedman, 1985: 629)[152]. The second conclusion is that Russell's structuralism collapses his theory on phenomenalism, which is exactly what he wanted to avoid.

Russell answered Newman's criticism in a letter published later (1968) in his autobiography. In the letter he recognizes the truth of Newman's work: *"it was very clear to me, as I read your article, that I had not really intended to say what in fact I did say, that nothing is known about physical world except its structure. I had always assumed spatio-temporal continuity with the world of percepts, that is to say, I had assumed that there might be co-punctuality between percepts and non-percepts, and even that one could pass by a finite number of steps from one event to another compresent with it, from one end of the universe to the other. And co-punctuality I regarded as a relation which might exist among percepts and is itself perceptible"* (*ib.*: 632).

Votsis (2003) notes that in further works Russell did not mention Newman's problem. Nevertheless in *The Human Knowledge* (1948) he stated the structural thesis substantially in the same way. On the other hand, he presented there a view which recalls the idea of the Ramsey-sentence (1929)[153], since *"qualities and relations, if not experienced, can only be known by means of descriptions in which all the constants denote things that are experienced. It follows that a minimum vocabulary for what we experience is a minimum vocabulary for all our knowledge"* (HK: 283). In dealing with the underdetermination of theories he notes that logic *"is concerned with sentences that are true in virtue of their structure, and that always remain true when other words are substituted, so long as the substitution does not destroy significance"* (*ib.*: 269). To him this is

---

[152] In a more recent criticism on Russell's "upward path" to structuralism, Psillos (2000) notes that from the realist point of view the very claim that the world has a formal structure is unexciting: as Newman notes, it follows trivially if we take the world as a set-theoretical entity. The *"much more exciting claim is that such structure corresponds to a definite natural structure"*(Psillos, 2000: 10). Note that on the contrary Votsis(2003) defends the idea that Russell's structural claims are not trivial exactly because they match the structure with concrete systems.

[153] The Ramsey-sentence of a sentence *T* is the sentence *T** formed from *T* by replacing all its theoretical predicates with variable predicates and quantifying them existentially.

true both for language and for physical situation and he brings again the same example as in *AM*: the relevant point is "*to deal with the relation of our perceptual experiences to the external world …Whenever one <u>complex structure</u> causes another, there must be much the same structure in the cause and in the effect, as in the case of the gramophone record and the music. This is plausible if we accept the maxim "same cause, same effects" and its consequence "different effects, different causes". <u>If this principle is regarded as valid, we can infer from a complex of sensations or series of sensations the structure of its physical cause</u>, but nothing more, except that relations of neighbourhood must be preserved* " (*ib.*). The issue is the same for the analysis of matter (physics and perceptions), the postulate of causal continuity is pretty much the same ("same causes/same effects" to justify the inference from the effect's structure to the cause's structure), the thesis is pretty much the same: "*In physics, assuming that our knowledge of the physical world is only of the structure resulting from the empirical known relation of "neighbourhood" in the topological sense, we have immense latitude in the interpretation of our symbols. Every interpretation that preserves the equations and the connection with our perceptive experiences has an equal claim to be regarded as* possibly *the true one, and may be used with equal right by the physicist to clothe the bare bones of his mathematics*" (*ib.*).

An example of such an underdetermination is, according to him, the case of the dualism wave/corpuscle: "*Either hypothesis, therefore, is equally legitimate and neither can be regarded as having superior claim to truth. The reason is that the physical world can have the same structure, and the same relation to experience, on the one hypothesis as on the other.* The point for Russell is that our knowledge of matter derives from perceptions and from their effects on our body[154]: if we take a region without our body inside it, two physical theories expressing the very same conditions at the boundary of the region are empirically indistinguishable. In particular protons and electrons are known only through their external effects, and as long as those effects remain the same we can change at will the theoretical implant without verifiable differences. The issue with physics is not solipsism, rather it concerns deductions about situations of which we can have no direct experience.

Of course such an attitude lays itself open to empiricism, be it constructive, structural or whatever. The objection could point to an investigation of cases in which equations provide us with an, at least minimal, interpretation (see Saatsi, 2006).

---

[154] Russell's intent is not to allow for solipsism, seen as a form of idealism according to which nothing exists but my mind and my mental events.

There are some clear points in which the link between Russell's view and more recent views concerning the status of physical knowledge is evident. In this respect, the analysis of McLendon (1955) provides a fruitful understanding of the problem. After the aforementioned exposition of the way in which Russell developed his notions of structure and structural similarity, McLendon puts forward his proper critics:1) in its *precise logical sense* (1955: 89) the notion is first of all absolutely useless for the purposes of Russell; 2) to make it useful we should impose some empirical limitations on it; 3)even though modified by empirical limitations, the gained concept or concepts would be different from Russell's purely logical concept.

The issue does not concern so much a failure in accounting for the relationship percepts-objects: rather the problem is that the similarity holds equally well between the relevant cases and between trivial cases. The uselessness of Russell's notion to serve the aims he wanted to, starts from the observation that any two classes having the same number of elements, will trivially satisfy the above conditions. McLendon shows it by considering the class A of a dozen cars in a parking, and the class B of a child's building blocks randomly scattered on the floor. Provided that the two classes have the same numbers of elements, they will satisfy the 4 conditions. The members of both the class have some spatial relations with other members of the same class (conditions 1 and 2). There is at least a 1:1 correlation (but even much more) enabling us to relate a member of $\alpha \in A$ with one and only one member $\beta \in B$. The simplest correlation assigns a natural number (different for each member of the same class) from 1 to 12 to each member of each class (condition 3). Finally it is obvious that if a member $\alpha \in A$ has a relation with another $\gamma \in A$, as well there will be a member $\beta \in B$ (the correlative of α) which would have the corresponding relation to another member $\delta \in B$ (condition 4).

As a matter of fact the structural similarity between the two classes does not provide the sufficient informations which would enable a significant distinction. The second observation on the fact that the notion applies to all the possible wholes with the same cardinality, concerns the very "wholes". The point of Newman seems to be that we need to fix/declare the reference of the relation, what would mean going out from the strict purely logical structure, that is out of the mere mathematical equations. The possible options are: going to the non-structural domain (what Newman and Psillos[2000] want) or consider such move as declaring that the "structure" is not the merely formal. The latter

option crashes the distinction structure/nature. Anyway if we consider cases of alleged structural continuity in history of science, which would provide examples of structural knowledge, we see that some kind of interpretation is somehow implied in the very formal account: this could be a step in the direction of McLendon's conclusion that the purely logical notion must be tied up with some empirical constraints[155].

The point of McLendon is: "*the concept, which is intended by Russell to apply descriptively with peculiarity discriminating relevance to cases particularly important for common sense and philosophy, applies equally well to them and to trivial cases. Consequently, it fails to differentiate the important cases from the trivial ones…far from asserting something important, discriminating or informative about them, is to utter a tautology applicable to all similar cases and therefore to all wholes*" (1955: 92). He concludes that knowing that two entities are structurally similar, and one of them has some empirical characteristics, let us infer in fact nothing about specifiable empirical characteristics of the other entity.

The interesting point is that such a failure is not due to the notion of similarity per se: it is rather due to an epistemological choice which prevented Russell from involving the empirical characters within the formulation. In *such* a sense the notion of structural similarity, or isomorphism, becomes useless with respect to the target. It is not able to properly account for representation, modelling.

So far we challenged the 'exhaustive power' of the notion of similarity in providing significant knowledge. The idea that the correspondence holding between the world of perceptions and the external (unobservable) world takes the form of an isomorphism has not been challenged. Nevertheless, leaving aside for a while Russell's concern, there is debate whether the representative virtues of scientific theories should be accounted for in terms of *isomorphism*, especially within the semantic approach to scientific theories[156]. The debate matches with other issues concerning the nature of representation and modelling and covers a number of issues which cannot be addressed in the present work since belonging to a too wide debate. It is out of doubt that the notion of isomorphism has a fundamental role in mathematical modelling. In the first place it does not simply state the

---

[155] Note that Russell admits that we always interpret equations. The issue in his case would be that interpretation falls apparently out of the structural knowledge.

[156] A wide discussion on such theme could be found in the work of Hempel, Carnap and Suppe. The debate has recently been developed, for instance, by Giere, 1988; Hacking, 1983; Suarez, 1999; da Costa and French, 1990 and 2003; Van Fraassen, 2006; Told and Redhead, 2007.

existence of a relation, rather it affirms a precise correspondence that is a *function*, that is, it has a precise mathematical formulation and consequence. The issue is whether the used function exhausts the scope for which it has been introduced. Newman's thesis is that it does not exhaust the scope. We claim that such a failure is not only (and not so much) due to the mentioned correspondence, rather to the underlying reductionism with respect to our descriptions of the world[157].

On the other hand this could not constitute a problem in *any* structural perspective. Once the empirical characteristics are involved within the notion, the epistemic structural thesis could find a suitable formulation. This is the challenging issue of the recent debates within the epistemic structural positions, where the crucial issue is to provide an account for the *realist* side of the structural claim.

§3.4.2 Further Critiques and Recent Debates

The recent debate on the *problem of content* concerning the structural thesis brings the discussion slightly far from the strictly russellian account, as soon as the logicist attitude is abandoned and the empirical features are involved within the picture. Before entering such domain it ought to be mentioned that the non-triviality of Russell's view has been defended by J.Votsis (2003). He says that the criticism on the alleged triviality or falsity of Russell's structuralist view is itself false as it argues on the basis of the myth of the possibility of uniquely pick out physical relations or relata. A structural view would just say that "*there is an* empirically *identified abstract structure that is, of course, instantiated by many concrete structures. One of these concrete structures represents the physical system under consideration (i.e. the system of our observations)*"[158](*ib.*: 886) The point is that we can reach relations between observables both a priori and by empirical investigation. Starting from empirical investigations in the world of perceptions we deduce the abstract structure. The *method* is important, since it is at least

---

[157] Though Russell distinguished between our perceptions and their stimuli (the objects of physical world), our descriptions are bounded to the logical domain: as we saw in the previous sections, he matched an agnostic view of ontology and the idea that objects enter our knowledge as logical structures of events.

cc[158] Hence the idea is: Russell's notion grounds the idea of mathedical analogy, so fundamental for mathematical modelling of reality. Hence the kind of knowledge it gives is not trivial, nor false. The problem is, as Russell himself notes in the reply to Newman, that it is neither unique.

partly empirical and the discovering of certain relations between observables is an empirical matter. Then the informations are not devoid of importance (*ib.*: 887).

Votsis insists that the criticisms against Russell's view are grounded on an illegitimate extrapolation of Russell's notion out of the contest in which it is developed, and on which it is strictly dependent: the causal theory of perception and the relation between physics and geometry, that is the general understanding of non-euclidean geometry, and of GR.

Votsis' defence of the structural similarity is sharable insofar as it concerns the idea that there exist some possibilities to escape the core of Newman's objection. In the following we will present the core of the such possibilities. On the other hand, insofar as the strict russellian view is concerned, Newman's problem holds not so much due to the triviality of the notion of isomorphism, rather to the epistemological reduction to logic. The very intertwining of physics and geometry is taken to warrant the possibility of considering physical world as a logical structure of events.

Before going to Eddington's view, let us add a point on the recent attempt to find a way out of Newman's objection. We mentioned that the debate focuses on the possibility of providing an account for the theoretical content over and above Russell's pure logico-mathematical structure.

Russell's representation failed in indicating the intended model for representing the world, it failed in indicating the content of our knowledge and in involving the empirical features. Thus the endorsement of the structural stance becomes difficult from realist perspective since the former seems to fail in satisfying the expectations of any realist position.

The problem of content is accounted for within the epistemic structural positions through the endorsement of the structural content of a theory as expressed in terms of its Ramsey sentence.

The idea behind the ramseyfication is that the cognitive content of a theory *T* is captured by the sentence *T** formed from *T* by replacing all its theoretical predicates with variable predicates and quantifying them existentially. In other words, we take the theory, eliminate the theoretical predicates, substituting them with predicate variables (as II order's ones) and quantifying them existentially (II order existential quantifier). This means that we

do not quantify on I order individuals (then no entities): the picture regards the II order, then it concerns relations.

Critics of the epistemic structural positions (Ketland, 2004; Demopoulos and Friedman, 1985; Psillos, 1995 and 2000) take the Ramsey sentence to fall into Newman's problem as well as the russellian thesis. J.Ketland' s article *Empirical Adequacy and Ramseyfication* (2004) inquiries whether claiming that T^* is true would be different from simply claiming that T is empirically adequate and his aim is to show that they are the same claim, since the first statement only adds cardinality constraints to the empirical adequacy. In such a sense, the Ramsey sentence would be useless for any realist position.

A brilliant criticism of Ketland's analysis is presented by Meelia and Saatsi (2006), through a focus on two fundamental and non-banal assumptions of Ketland's argument concerning the way he considers the predicates of the theories and the way he considers the quantification of such predicates. Indeed the analysis of any application of the Ramsey sentence starts from some consideration concerning the predicates involved in scientific theories. Ketland divides the language of a theory in three classes of terms: terms for observative relations, terms for mixed relations and terms for theoretical relations (where relations *interpret* extra-logical predicates)[159].

The first assumption concerns Ketlan's idea that the result of ramseyfication would be a deleting of *both* theoretical and mixed predicates. This is a non banal assumption which is not implicit in the structuralist view. There is not any structural point of view which is forced to abandon the mixed predicates (as having mass, being white, being part of and so on).If the claim against the structural engagement with the ramsey sentence is 'T* is too easily true, has no physical content', the structural realist could answer the claim by saying that he has not any problem with the observational content and then he is not forced to eliminates *all* the mixed predicates (' being a part of', 'being located in the region *r*', 'having velocity *v*', 'having energy *E*' and so on..).

---

[159] This means that we have a theory T (t…t, o…o) (→ non logical predicates) on a domain S and we have a model M (D, R…R) for that theory such that R…R are the interpretations of the predicates of T and D is a domain with the same cardinality of S (T-cardinality correct). According to Ketland that is a two-sorted language, whose first order variables are meant to divide in primary variables, which range over observable objects, and secondary variables, ranging over unobservable objects.

The target of ESR is different from Russell's. The former has the specific aim of paying heed to both Laudan's Pessimistic Meta-indaction and the No Miracle Argument. The extension of the domain on which ESR is agnostic is decided from the history of science. So, as Meelia and Saatsi note, "*Whatever the electromagnetic field may really be like, it is still true that it has an energy, that it has a velocity, that observable charged objects located in its path are accelerated, that when passed through a medium it is decelerated*" (2006: 10). Those assertions, expressed in the relevant equations preserved through the theory change, though saying pretty nothing definite on the nature of the ontological framework involved of unobservable objects, could nevertheless be significant in terms of structural content.

Hence the issue with ESR is not so much the lack of content, rather the fact that the available physical content of the (ramseyfied) theories must be suited in order to indicate the nature of the involved properties: natural, qualitative, causal. This involve some restriction of the domain of II order quantification: by higher order predicates or by removing the second Ketland's non-banal assumption.

The second assumption is that the second order quantifiers range over each subset of the first order domain, i.e. that the second order domain is *full*. As well as in the previous case, the structural realist is not constrained to assume such a kind of quantification. Ketland does not consider the difference between a quantification over properties and a quantification over sets: in the first case the domain is restricted (it affects only some predicates and variables), not in the second case. Practically the domain over which the structural realist might want to quantify, saying for instance that 'everything carries energy' or 'have velocity' or 'is made of part', could vary being different according to the theory.

As well as the traditional realist differentiate the considered kinds of entities, so the structural realist could want to differentiate among for properties: intrinsic, extrinsic, observable, unobservable, disjunctive, natural, causal, inert, qualitative or not. "*The physicist who urges that no two space-time points share all their properties is not making a claim that is trivially true…Just as the intended domain of the physicist's first order quantifiers is less than all the objects that there are, so too the intended domain of the physicist's second order quantifiers is less than all the sets of objects that there are*" (Meelia and Saatsi, 2006: 14).

Thus Meelia and Saatsi provide a weapon for the epistemic structural realist to go beyond Newman's problem. The point is that the structural content is not bounded to the pure formal, logical structure. Hence the intentional relations which characterize the

intended relation of a structure could (and must) be formalized in order to enter the structuralist schema. Of course the mentioned analysis implies a weakening of the originally strong dichotomy between a knowable structure and an unknowable nature of the world. The task of the epistemic positions is then to show the nature of the quantifying restriction.

Summarizing, the Newman's problems, which is the problem of content, affect Russell's view not so much because of the use of isomorphism, rather because of the underlying epistemology (dichotomy, though unwitting, atomism and moreover logicism). A possibility to overcome the issue is available for the recent revival of russellian thesis *so far as* it is not taken in its strict formulation (thus in the strict russellian sense). The issue is, in such cases, to provide a sort of 'qualification' of the structure. It interests the *epistemic* structural positions. In such a sense the original position is overcome, and abandoned. It already happens, as mentioned, in Russell's *Human Knowledge.*

As mentioned in the introduction of the present chapter, the ontic structural realism differs from the epistemic one both in motivations and domain: it is a thesis concerning the furniture of the universe. In other words, physical knowledge is structural because there exists only structure. Some intuitions driving such position are mutuated by the epistemology of Eddington. The next sections will be devoted to explore the objection to Eddington's structuralism, the way he answers it and the way from its structuralism toward the recent approaches.

§3.5. Eddington and Braithwaite

In 1940 R.B. Braithwaite published a review on *The Philosophy of Physical Science*, where he criticized Eddington's thesis in different respects. He explicitly recognizes that the core of his objection to the employed notion of structure reruns Newman's objection. In the present section we will enter Braithwaite's concern, emphasizing the connection with Russell/Newman issue, and analyze Eddington's answer in order to understand whether his thesis is effectively immune to Newman's argument.

This point is quite interesting also with respect to the recent attempts to develop an ontic form of structural realism. In the previous section it has been shown that even the epistemic forms of structuralism have some possibility to overcome Newman's problem,

due to the fact that they do not involve the strict reduction to logic involved within Russell's view. We will consider the possibility that those positions which endorse structuralism as an ontological claim would be free from Newman's concern.

In such a respect, Eddington's view provides the ontic structuralist with a conceptual weapon linked to the differences with Russell's view, which could be summarized in two points:

> 1)   Eddington's claim that physical knowledge is structural in character does not deal with a causal theory of perception: he has not a problem of balance between causes and effects, since he defines the gained knowledge in an analytical way, starting from methodological tools and category of though to set out the frame of knowledge. T.Ryckman 's defence (2005) of Eddington's view insists on such a point. The connection with the neokantian perspective presented in the first chapter provides a first sense in which the claim that "*we know the structure of the kind defined and investigated by group theory*"(Eddington, 1939: 176) could be meant.
>
> 2)   Eddington's structure is opened to a particularization, which arises both in GR and QM. In this sense we could get a second, though indirect, sense in which the aforementioned claim on the group-structure could be significant.

Following the path of 1) we will see that Eddington's claim is not epistemologically alike to Russell's one, since the discussion shifts to the analysis of the conceptual frame of thought through which theoretical work in physics shall(o should) be understood. In such a sense, Newman's problem does not hold.

Following the path of 2) the claim (" *we know the structure of the kind…*") will be finally considered as a possible characterization of the structure which does exist, hence being knowable. Even in this case, which somehow widen Eddington's claim, Newman's problem does not hold because any claim on the fact that the structure of the world is group theoretic is not a banal claim concerning the attainable structural knowledge.

With respect to such two paths, Eddington's view is a genuine prelude to the recent ontic position. On the other hand, the ontic structural realism (henceforth OSR) neither

endorse completely Eddington's position, nor it is forced to do it, due to the fact that OSR has been developed as a *realist* position.

§3.5.1 "Newman's problem", again?

In his review on *The Philosophy of Physical Science*, Braithwaite's main point is not the criticism of the structural thesis, which is just an exemplification of Eddington's reasoning. He is rather interested in discussing a view which, true it were, would be absolutely revolutionary: the thesis concerning the a prioristic character of physical knowledge. Just as the laws of arithmetic are implicit in the process of counting, thus the laws of physics are implicit in the process of observing. We devoted the first chapter of the present work to pose such a claim, which indeed manifest an approach to *physical science* which should be better read in terms of a neokantian reading, though restricted. Braithwaite also notes that such a reading of physical knowledge is meant to suitably put physics in its proper place with respect to other forms of knowledge[160]. Of course the apriority does not directly concern the particular propositions asserting the outcomes of certain physical observations and measurements. It directly concerns the specific formulations of natural laws, which by the way comprise a lot of information not completely subjective on the objects surrounding us. For instance "*that most of space is nearly empty, the matter being aggregated in relatively small islands*"(Eddington, 1939: 218) or that light is identical to electromagnetic waves.

For sure the sort of mixturism between objective and subjective features in physical knowledge worries Braithwaite. Indeed in some sense Eddington lets the concept of a prioristic knowledge to have an empirical side: we saw (chapter one) that the first sense of the *apriorism* of knowledge concerns its been prior to actual observation. Such a priority depends on the possibility to analyse the way our instruments are built according to certain categories of thought. Through such an analysis we can deductively derive the characters of our knowledge prior to an actual observation. In this sense *aprioristic* does not mean *non-empirical*, as Eddington emphasizes: "*epistemological or* a priori *knowledge is prior to the carrying out*

---

[160] Braithwaite seems to complain that "*Eddington's apriorism is not intended to magnify the importance of physical laws: on the contrary, he considers that he is "debunking" them..and putting physics in its proper place whence it cannot invade the rightful domains of "life, consciousness, spirit"*"(1940:p.456)

of the observations, but not prior to the development of a plan of observation. As physical knowledge, it is necessarily an assertion of the results of observations imagined to be carried out" (*ib*.: 24). Without an observational experience and/or an intersubjective knowledge we could not attach any meaning to the terms involved in physical knowledge. By the way, whatever the way physical laws are deducible from experience, the fundamental feature of Eddington's epistemology is their aprioristic deduction, the pillar of his view on physics. The main difficulty which Braithwaite finds in examining Eddington's argument on the a priority of knowledge relies in a difficulty to fit the two works which were meant to exhaust it: *The Philosophy of Physical Science* (PPS), which provides indications of how the deduction should be performed, and the *Relativity Theory of Electrons and Protons* (RTEP) which is meant to add details to the deduction. The issue concerns the introduction of the second work, where Eddington apparently affirms the impossibility of such a deduction: (Braithwaite's quotation): "*the theory is purely deductive, being based on epistemological principles and not on physical hypothesis. But it could be not presented in purely deductive form – which would mean, I suppose, that it was treated as an investigation in pure mathematics with a physical* dénouement *in the last chapter*"(RTEP: 5). The difficulty could be solved through considering what Eddington says immediately after the quoted passage (RTEP: 5-6). The theory has not been *treated* in the clear deductive form according to a precise choice of the author which considered essential *to bear in mind the physical applications throughout*. According to such a choice some physical results are often assumed as the starting point, rather than having been reached deductively: they reach the clear deductive form only in the conclusions of the work. What Braithwaite takes to generate a suspect of contradiction is just a methodological choice which serves the clarity in treating a subject as the *Relativity Theory of Electrons and Protons*, from a perspective which is unusual[161].

The central part of the critical review is devoted to analyze both the concept of structure and the structural concept of existence as an example of Eddington's reasoning. The attack is mainly directed against (i) the definition of *structure* according to the employment of the group theory and (ii) the suggested involved dichotomy structure/content which already affected Russell's view.

---

[161] A future which could sound even more strange is the frequent reference to quantum theory within a treatise concerning *The Relativity theory of Electrons and Protons*. Though clarifying that he does not want to draw conclusions from the quantum domain, he cannot prevent from consider, for example, the way some fundamental physical quantities are defined within quantum mechanics.

The issue should be to find the answer to the following question: 'what does it mean that we know the structure of the kind investigated by the group theory?'

For the sake of future clarity it must to be noted that Braithwaite's criticism somehow restates the question and asks 'what do we know when we know a group?'

According to Braithwaite, Eddington conceals that "*the set of elements of a group (call them operations if you like) do not form a group in themselves, but form a group* with respect to *a given mode of combination.. A group, in the mathematical sense, is undefined except when the combining relation is given*" (1940: 412). Hence, knowing a group is knowing its elements and its given combining relation.

A 'group', <u>as defined by Eddington</u>, is a terminable set of operations *P,Q,R,* etc…such that any operation *R changing P* into *Q* is again a member of the group. Braithwaite's point concerns the abstractness of the employed language which defines the group-structure: according to him even Eddington's example of the set of rotations *implicitly assume* the relevant feature, i.e. the mode of combination of the elements in the group (i.e. the fact that the rotation is always successively applied to another rotation).

Braithwaite[162] notes that the set of element *P,Q,R, etc*…forms a group *with respect to* a mode of combination C, if the following holds:

1) combining any two elements of the set through C we obtain another element of the set[163]

2) combination by C is associative (*(PQ)R = P(QR)*)

3) given any two members *P, Q* of the set there is a third one *R* such that combining *P* and *Q* (or *Q* and *P*) by C the outcome is *R*

We should not say that P is *changed* into Q by R: it is rather *combined* with R by means of C. The conclusion of the analysis would be that "*The group-structure which Eddington is talking about must be less abstract than his language leads one to suppose. To say that two sets of things have the same group-structure would be to say nothing of interest unless the mode of combination of both the group had been specified*"(Braithwaite 1940:p.463).

---

[162] We stated Braithwaite's definition. In order to clarity the current definition of group is the following:
A set G is a group, iff the following properties of multiplication hold for any $a,b,c \in G$:

1) (associative properties) $\forall a,b,c \in G$ it holds that $a(bc) = (ab)c$

2) there is a *neutral element* **u**, such that $\forall a \in G \ ua = au = a$

3) $\forall a \in G$ there is an *inverse element* a^{-1} such that $a^{-1}a = aa^{-1} = u$
From these three axioms Braithwaite's 1) and 3) descend.

[163] The set is *closed* with respect to C

When Braithwaite speaks of the two sets of things having the same group-structure he probably refers to the fact that Eddington frequently notes that the rotations in six dimensions, Kummers' quartic surfaces and an elementary particles in an elementary state involving his spin and charge are represented by the same group. On the other hand, Braithwaite evidently refreshes Newman's concern that a structure/content dichotomy is untenable in order to account for a genuine *knowledge* provided by physics, since the content provides the very characterization for the structure.

Once again the debate on the structural thesis apparently relies on the dichotomy between structure and content. Nevertheless, such a dichotomy is stated in Russell under a defined point of view involving the causal theory of perception and the logicist perspective which characterize his account of the deductions of physics from perception.

 On the contrary Eddington's epistemology does not plainly endorse the causal theory, nor he shares the reductionist attitude. Hence the two epistemologies differ in a significant sense. Finally, we will see that his endorsement of the group theoretic characterization is not meant to account for the deductions of physics by the means of Russell's structural similarity between stimuli and perceptions. Moreover, considering Eddington's answer to the criticisms, we will also see that his view does not strictly suffer because of the objection, since the latter fails the target in some relevant sense.

The lever of Eddington's answer is the difference between an *abstract group* and a concrete group and the reason he gave for considering the *abstract* one, rather the concrete one. This two aspects summarize the main difference between Braithwaite's perspective and Eddington's one: the former deals with the concrete realizations of a group, which implies a clear definition of the *names* of the elements; the latter deals with the abstract *form*, where the elements have just the properties assigned by the group[164].

A further crucial feature of the latter's approach must be understood, which both motivates his insistence on *form* and enables difficulties and misunderstandings. Using the abstract notion is precisely what makes the mathematical notion of group "conceptually" useful, according to Eddington, in the philosophy of physics since it indicates a pattern, and it also does not eliminate the defining relation of the group. In such a respect, Braithwaite' s distinction among the nature of the members of a group and the nature of

---

[164] Note that when Eddington refers to the *realisations of a group* he does not mean the technical sense of *representation*: he just refers to the common, in some sense banal, idea of concrete exemplification.

their combining relation is not even possible. Indeed the proper characteristic of the notion of group makes the two (elements and relation)[165] inseparable: *The element is what it is because of its relation to the group structure*(1941: 269). In the first place *this* conception provides exactly one of the interesting and fruitful features of the group-theoretic approach in Eddington's eye. The passage has to be considered in the following way:

> "*Let a,b,c,…be elements of an abstract group whose structure is specified mathematically by equations such as c=ab. Braithwaite, following the pure mathematicians, replaces the symbols a,b,c,…by* $\alpha o, \beta o, \gamma o …$; *so that the equation becomes* $\gamma o = \alpha o \beta o …$*mathematically replaceable by* $\gamma = \alpha o \beta$ *…and points out that by introducing an alternative symbol he can construct a combination* $\alpha : \beta$ *which is not equal to γ ; so that* <u>the group structure</u> *does not apply to* <u>intrinsically</u>…
>
> *Braithwaite's conclusion is —The elements do not form a group apart from their combining relation; therefore we can have no structural knowledge of things like* α, β, γ *- so that's the end of structuralism.*" (Eddington, 1941: 270).

Such an argument does not get the usefulness of the concept of group-structure. But the failing in understanding such a usefulness has also to be found in Russell's account, which just glimpsed the idea of considering an abstract structure. But it was a pattern of entities. The issue is that "*but the elements of group theory make it clear that pure structure is only reached by considering a pattern of interweaving, i.e. a pattern of interrelatedness of relations*"[166] (Eddington 1941: 278). Russell misses completely the notion of group (through he uses it, but not in the same way as Eddington). And Braithwaite misses why it is useful in the abstract sense:

> *The elements do not form a group apart from their combining relation; therefore our structural knowledge is about things like* $\alpha o, \beta o, \gamma o$ *- so that's the beginning of structuralism…the dot is undetachable…*(*ib.* 270)

---

[165] Eddington considers in the first place the conceptual idea behind the notion of group. This is the reason for his mentioning elements and relations, rather than transformations, operations, and composition.
[166] In such a passage Eddington refers to *The Philosophy of Physical Science* pp.137-140.

If we speak about the group-structure $\gamma = \alpha \circ \beta$ we exactly are saying that the elements come together with that specific relation "∘": there is not another way to consider them as elements of the group. Indeed they are *defined* by their role within it. This point is fundamental in order to understand Eddington's interest with respect to the *abstract* group since it is twofold. In the first place the abstract character of the group does eliminate the *name* of the elements, not the internal structure of the group (provided by the combining relation) which has a defined *multiplication table*, expressing the product of the elements on a pairs, its being finite or infinite, its being abelian or not[167], and so on. We saw Braithwaite's concern on the fact that two group are isomorphic only with respect to a given mode of combination. Eddington does not deny it. But there is a fundamental feature of the mathematical theory of groups which must be remarked: according to the relation of isomorphism it is possible to divide the groups into classes such that each group belongs to only one class and each class contains all the isomorphic groups: thus the elements of the same class are isomorphic, the elements of different classes are not. The *common abstract* of the element of a class is the *abstract group*: it is the group as considered through setting aside the nature of the elements and maintaining just the group law. In such a sense Eddington's examples of the rotations in six dimensions, of the Kummers' quartic surfaces and of an elementary particles in an elementary state involving his spin and charge are isomorphic elements of the same class, i.e. the class represented by the same abstract group: they have the same structure which differs from the structure of , say, the rotations in three dimensions.

Braithwaite rather focuses on the concrete group in terms of *realisation*[168] of the group. The notion of isomorphism could be found in Eddington's view just concerning the way different concrete groups belong to the same class, i.e. to the same abstract group: they share their multiplication table. The notion is not developed with Russell's purpose and by the way is far from being trivial (we know that groups differs in significant sense, not only by means of their cardinality, rather exactly by means of their combination).

In the second place, whereas Braithwaite focuses on the group as the object of analysis, Eddington's purpose is "*rescuing out of the mathematical formalism what is for physical*

---

[167] The abelian groups are the groups for which the commutative property holds. Some examples of abelian groups are: the set of rational numbers $\neq 0$, with respect to the operation of product and the set of plane rotations around a given point, with respect to the product of transformation. A non-abelian group is for instance the set of movements in Euclidean plane, with respect to the product of transformations.

[168] The term (realisation) <u>should not</u> be meant as the technical term *representation* of group theory.

purposes the most essential feature of the group <u>*conception*</u> *of structure"*(*ib.*). He is rescuing out the conceptual features of the symbolism[169].

In such two senses there is not such an issue as the fact that the employed notion does not hint on the nature of the combining C.

A crucial feature of the latter's approach must be understood, which both motivates his insistence on *form* and creates difficulties and misunderstandings: using the abstract notion is precisely what makes the mathematical notion of group "conceptually" useful in philosophy of physics. Eddington always speaks of the *form* of knowledge and in such a respect he also analyzes the mathematical symbolism. On the other hand, the reader might find it difficult to operate the passage from such a perspective to the specific/contextual/concrete physical knowledge. An abstractive effort is required in dealing with Eddington's approach.

He suggests that the current understanding of the physical world, as it is provided by current theories, is conceptually assimilable(comparable) with the conceptual frame provided by the mathematical theory of group. He even notes that there is of course a misleading way of reading the mathematical symbolism which detaches the terms from their mode of combination. But it represents particular conceptions which must be understood and linked to the more general abstract conception provided by the abstract group view. Thus the first concern of Eddington's structuralism is epistemological, but not along Russell's view (i.e. according to the idea that perceptive knowledge leads to a partial knowledge of the physical world grant to the causal continuity). He is rather showing the way in which physical thought is structured: in such a sense " *Epistemology does not predict the names that the practical physicist will bestow on the 'elementary particles' when he comes across them in his experience - if he ever does*" (Eddington, 1941: 275) since it shows "*the engrained form of thought with which a physicist approaches his task*". Such an epistemological route both motivates the search of physicists for those very names in the algebraic appearances and Eddington's attempt to properly set the way that *form* must be looked at, hence the way physical objects must be conceived, according to the changing frame. An unsatisfactory element in such a

---

[169]Of course we can find interpretations which separate α from the dot "O". Then the role of an epistemological analysis of physical assertions should enlighten and allow for the fact that we practically refer our knowledge and our language to particular realisations of the structure. In such a sense the discussion on the group-structure is a 'section' of the wider discussion on the concept of analysis and of its holistic interpretation.

view could be represented by the fact that he does not motivate the changing in the frame of thought. He showed that our physical thought is informed by some categories of thought(cfr. Chapter one). He showed how such categories changed from a strictly atomistic account toward an account which is group-theoretic (not strictly deleting the search for ultimate elements, rather placing those elements within the whole). He showed how such a development is deeply inside the revolution operated by the theory of Relativity and the quantum theory. But he did not provide the motivation for such a change.

Of course this was not Eddington's problem because of the kantian tinge of his view. He was perfectly satisfied with the simple idea of an interplay between subjective and objective features of human knowledge and then he went on in inquiring into the subjective side which is the unique available side for human inquire. On the other hand this is a theme which must be accounted within a realist perspective, which is more interested in the *objective* side of the interplay.

It ought to be noted that at this stage Eddington's structural thesis does not yet focus on the group-theoretic characterization of quantum properties, which instead will be the focus of the ontic structural realism. On the other hand, the reflection stands a step before and it is even more important as it provides the guidelines for a reversion of the way physical objects are conceived. In such sense his work could be rightfully considered as a genuine conceptual preliminary to the recent view.

The drawn epistemological route is also fundamental in understanding Eddington's development of the E-algebra (or $J_1 \times J_2$ algebra), whose operators are relations defined through double existence symbols (representing the existence/non-existence of the elements bearing them)[170]. Indeed it is an algebra which satisfies the group-theoretic point of view according to the epistemological principles: the elements of such an algebra (a matric algebra of order 16 over the field of complex numbers) are conceivable as *relations* among relata whose unique properties is the existence/non-existence. The introduction of such an algebra represents the first step through which Eddington develops the idea that even the numerical scheme of physics arises from our forms of thought: thus he tries to formalize the subjectivist approach in physics. The numbers of physics, i.e. our 'measures' physical quantities, are not informative as *numbers*: they are informative "*in conjunction with a*

---

[170] The *E-symbols* algebra is introduced since *The Relativity Theory of Electrons and Protons*(1936).

connectivity which is not describable by numbers"(*ib*. 276). As an example of such a connectivity, which he often referred as a 'pattern of interrelatedness of relations', Eddington presents again the algebra of operators representing rotations acting on rotations, for which the 'pattern of interrelatedness' is manifested in the associated multiplication table.

So far we dealt with the first horn of the theoretic weapon we mentioned in the introduction of the present section. Eddington's structuralism grounds on a fundamentally different epistemology with respect to Russell's view. Furthermore he suggests a conceptual reading of the notion of structure, as a form of thought through which the current work of physics should be read, which differs in purpose from Russell's employment of the structural similarity. Hence it falls out of the domain of appliance of Newman's objection. Moreover, as we saw, Braithwaite's criticism diminishes (if not even 'vanishes') as soon as the meaning of *abstract group* is set clearly.

As the discourse moves toward "forms of thought", the connection with the neokantian perspective presented in the first chapter immediately arises. T.Ryckman 's defence (2005) of Eddington's view insists on such a point. Eddington's interest in the group-structure approaches does not relate to Russell's aims (structural similarity between stimuli and phenomena/perceptions). Ryckman notes that it relates to: the idea that mind can appreciate only relations, the cyclic reasoning and the conception of mathematical equations as *definitions*. A clear example of this is provided by Eddington's analysis of "… *the origin of the fundamental field laws. Eddington's explanation of this origin – mentioning the mind's activity in selectively cloaking the bare skeleton of geometric "world structure" with measurable physical quantities – give expression to a transcendental idealism* updated *by Relativity theory"* (Ryckman, 2005: 184).

In such a respect Newman's objection, revised in Braithwaite's words, does not hold: they are pointing to the representational ability of theories and to the possible content of a representation. Eddington's claim in the first place does not aim to exhaust the content of the representation, since he first of all shows the epistemological route underlying our representations. Beside that, he grants that physical knowledge always happens within a particular frame of reference, with particular measures for our quantities: he wants to provide the suitable understanding of such measures, through showing the frame of thought which leads them o should lead them.

Beside Ryckman's emphasis on the transcendental idealist approach, Eddington's view could generally be taken as a reflection on the mathematical formulation of physical knowledge. Though the mathematical description of physical entities could leave unsatisfied, Eddington aims to reflect on its employment. The usefulness of the mathematical apparatus does not rely on a supposed ability of exhausting the physical description (it is not the scope of mathematics to *exhaust* the physical content): it rather elucidates a *form*, a pattern of interweaving. According to such an approach contemporary physics should be considered as a research on an object (the universe) which manifests the characters of a group-structure: a whole whose parts are not separable and should be meant as α o rather than α.

Once such a first epistemological purpose has been understood, the claim that "*we know the structure of the kind defined and investigated by group theory*"(1939,176) could be compared with, or put along, a second possible purpose concerning the more specific way the world-structure exists and is (thus) knowable.

Let's start with the assertion that one of the philosophical features of General Relativity concerns the fact that: "*whatever the constitution of the external world, we can pick out a four-dimensional aggregate of entities that we may take to be our point-events since these have been left undefined…if we attempt to push the analysis behind the point-events, we are, I think, bound to particularise the structure*" (1920b, p.157).

The challenge is to deepen the understanding of the claim, which so far we just considered as a driving suggestion: which kind of structure is investigated by the group theory with respect to the physical theories considered by Eddington?

> 1) invariances under transformations in General Relativity: certain physical quantities are invariant under certain groups of transformation of coordinates.

> 2) after 1927, the quantum properties. Indeed in 1927 H.Weyl published *Quantenmechanik und Gruppentheorie,* the theory of groups in Quantum Mechanics. The aim was to derive the fundamental relations of Quantum Mechanics starting from the symmetry principles(group theoretic). And Weyl himself thought to have reached a deeper view of the real nature of things, through

the aid of group theory. The relevant symmetries of the microscopic world are expressed in the language of group theory.

Understanding the structural knowledge is then understanding what is to particularize the structure according to such 2 points. We have to compare Eddington's reading of structuralism in General Relativity (GR) and Quantum Mechanics (QM) with such a 'particularization', which by the way involves the outlined epistemological analysis of the group-structure frame. In this case, which in some sense widen Eddington's claim (it widen Eddington's own defence, not Eddington's work), Newman's problem does not hold because any claim on the fact that the structure of the world is group theoretic is not a banal claim concerning the attainable structural knowledge.

The issue of triviality would perhaps affect the first part of the mentioned assertion: *whatever the constitution of the external world, we can pick out a four-dimensional aggregate of entities that we may take to be our point-events since these have been left undefined.* In such a sense, the requirements for picking up the four-dimensional aggregate are very few, since the constitution is unspecified and the entities (in such case the point-events) have been left undefined. But Eddington also affirms the possibility to particularize the structure. Hence we should focus on such a possibility.

In GR the invariance[171] under transformations are comprised in Einstein's field equations, which arise out of the analysis of the fundamental relations in the four-dimensional geometrical world of events: the intervals. In such a respect Eddington's analysis is far from being trivial. The fundamental equations $G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G = 0$ and

$G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G = -8\pi T_{\mu\nu}$ track definitely not trivial conditions. They are *conditions*, for

---

[171]We saw (chapter 2) the distinctive standpoint of the theory of Relativity, i.e. the search for a knowledge which is independent on the system of reference, though not independent of the human knowing subject. In such a sense he manifests again the idealistic approach: even the homogeneity and isotropy (invariance for rotations) of space connected/expressed/arising from the invariance have an aprioristic epistemological character: they arises from epistemological principles (for instance the relativistic one). We only have acquaintance with aspects (by particular points of view) of the world, not with the totality of measures: any correspondence with the four-dimensional real world is only mathematical (mathematical identity which defines matter and emptiness – by the no-one point of view). The mathematical symbolism constitutes the boundary of physical knowledge which is structural in the sense that it indicates the pattern of interconnectivity of the world, not its intrinsic nature, nor the elements as separable from the rest.

instance, for the world involving "matter", whence the world geometry tensor $G_{\mu\nu}$ equals with the *physically manifested* stress-energy tensor $T_{\mu\nu}$ (second equation).

The important feature is that the equality is between the physically manifested tensor *and* the world geometry tensor $G_{\mu\nu}$. It expresses a physical configuration which has the outlined *conceptual* group-structure of a whole where the parts not separable, even conceptually, as we saw that any element of a group-structure should be meant as α o rather than α. The physical content (the concrete realisation if you like) is provided by the right-hand side of the equation. We saw (chapter two) that the subjective selectivism influences very much the way Eddington conceives those equations. He even says that they are *definition* of our perceptions.

On the other hand, the equations indicate the pattern of interrelatedness of the world system, as reached, in Eddington's analysis through operating on the spacetime interval. The bearing of the structural thesis concerns what the field equations represent, i.e. the *conditions* of the world.

Through the work of Relativity he inquiries into the aforementioned complex of relations which arises from the fundamental relativistic relation which is the interval: the characters of the four-dimensional continuum of point-like events, which constitutes the spacetime, come from a series of mathematical procedures which start from a fundamental relation. Thus the idea that GR is a theory providing us with a knowledge of relations, or of a texture of relations.

On the other hand he is aware that in GR he deals with the trajectories of material particles. He is perfectly aware that a complete treatment of Relativity must deal with the motion of material particles, which involves both their geometrical properties and their dynamical properties. The interest for the introduction of material particles within the analysis of Relativity grows throughout Eddington's reflection: in the first works on Relativity (1920a, 1920b, 1921, 1922) the theme is not so much investigated, but already in 1923 (*The mathematical theory of Relativity*) the interest towards electron and protons emerges, finding a clear approach in 1936 (*The Relativity Theory if Electrons and Protons*[172]). The issue arises when *in our survey of nature we encounter the phenomenon of atomicity* which challenge the

---

[172] The mentioned work effectively treats the dynamics of material particles. Nevertheless it ought to be remarked that in speaking of *particle* he means *a conceptual entity whose probability distribution is specified by a wave function* (1936: 8) a conception which differs from the classical understanding of the same term.

continuity emerged within the theory of Relativity. Then the *Relativity theory of electrons and protons* inquiries the dynamics of material particles, remarking the impossibility to dismiss the quantum treatment of the physical quantities associated with them. Hence QM enters the picture[173].

It is both an amazing and surprising fact that he endeavours to put together two theories which are taken to be incompatible to some relevant extents. On the other hand he does not look for a unification through some unique formula, rather for an *harmonization*[174] which he sought within the epistemological approach. A fundamental outcome of his reflection on particles is that "*the fundamental dynamics is dynamics of indistinguishable particles*"(1936: 287). An odd feature with respect to such a treatment is that he does not explicitly mention the group-theoretic characterization of particles in Quantum Mechanics.

The mathematical theory of groups revealed itself as a powerful medium for expressing physical properties of conservation; after Noether's work in 1918 the representation of symmetries are coupled with conservations of properties; in 1927 it is explicitly referred to QM, in order to characterize the properties of quantum particles. Hence we should expect Eddington to insist on such an employment. For sure his main example against the triviality of the employment of an *abstract group* is the example of spin, which has a group theoretic characterization. In some sense it is a difficult example, indeed it is hard to describe electron-spin as an activity or a condition in the external world. In Eddington's words: "*As a statement of what is happening in the external world this amounts to saying that something of inapprehensible nature is doing something incomprehensible*"(1941: 279).

Eddington's idea is:

> 1) Spin's directions can be distinguished one another "*by specifying their components in a set of mutually orthogonal planes*"(*ib.*). This is not a trivial

---

[173] Here is the *incipit* of the *Relativity Theory of Electrons and Protons*: "*In this book I have endeavoured to give a connected account of a series of investigations in the borderland between Relativity theory and quantum theory. It begins where my earlier book,* The Mathematical Theory of Relativity, *leaves off – at the point where in our survey of nature we encounter the phenomenon of atomicity. To our gross senses matter seems continuous, and it has been treated as continuous in the usual theory of Relativity. Experiment has, however, taught us that it is composed of multitudes of units, and the theory is here extended to throw light on the existence and properties of these units*" (1936:v).
[174] The aim for an harmonization directs his approach to quantum mechanics: he considers mainly Dirac's work on the relativistic wave mechanics and his wave equation.

knowledge since not all the physical systems satisfy it (i.e. stress-systems do not satisfy it).

2) better, spin components could be associated with the unit rotations in the planes, which also define their sign.

3) Hence we might say that *"among the characteristic of the electron is something specified by numbers associated with a set of operators whose multiplication table is …(here state the multiplication table)"*(*ib.*).

4) Apparently the claim could seem unsatisfactory because of its abstractness. For sure our understanding of it depends on its association with other characterizations of physical world (i.e. our background understanding). Nevertheless it ought to be noted that through the multiplication table it is possible to say *which* group we are dealing with (i.e. the representation group could be involved as structural knowledge). In this sense the given *abstract group* provides significant information. Moreover *"this form contains all that is actually employed in developing the mathematical theory which traces the consequences of electron-spin"*(*ib.*).

The conclusion of point 4 could raise back the difficult to pass from the mathematical formulation to its physical meaning. A difficulty which could be also raised by the fact that Eddington does not lay down his defence of the structuralist approach by explicitly analysing and/or stressing the overall group-theoretic feature of the main quantum properties, manifested through Weyl's work[175]. On the other hand he does *a)* stress that physical knowledge grounds on mathematics but involves interpretation and *b)* provide in fact the interpretation in structural terms. In the latter respect his interpretation focuses on the starting point of the indistinguishability of particles, already appeared since 1926. Classical physics is accostumed with a treatment of physical objects which is impossible in quantum domain. Classical objects are discernible according to their intrinsic (or state independent) properties and where we are presented with two objects *a* and *b* which share all their properties, it is still possible to distinguish them through their spatiotemporal position (state dependent property). Such kind of discernibility reflects in classical statistics where, considering two sharing-properties-particles *a* and *b* distributed over two boxes 1 and 2, we can imagine four possible cases:

---

[175] As a matter of fact the paramount role he assigns to the group-structure perspective is epistemological.

1)   Both the particles in one box: $\left|1(a)\right\rangle\left|1(b)\right\rangle$

2)   Both the particles in the second box: $\left|2(a)\right\rangle\left|2(b)\right\rangle$

3)   particle *a* in box 1 and particle *b* in box 2: $\left|1(a)\right\rangle\ \left|2(b)\right\rangle$

4)   particle *a* in box 2 and particle *b* in box 1: $\left|2(a)\right\rangle\ \left|1(b)\right\rangle$

In classical statistic, these four possibilities has the same probability: 1/4 .

When we move to the quantum domain a further feature must be added since quantum particles share their state independent properties *and* are indistinguishable according to their state-dependent properties. This reflects in the statistics, as the probabilities of the above configuration is 1/3 for three cases: case 3 and case 4 are indeed considered as the same situation. The fact that 3) and 4) must be treated as one and the same situation manifests the fact that quantum particles are indistinguishable. Classical objects obey Maxwell-Boltzman statistics, where different permutations of objects correspond to different arrangements; quantum objects obey Fermi-Dirac and Bose-Einstein statistics, respectively for fermions and for bosons, where different permutations of objects correspond to the same arrangement[176]. The difference in the statistics is usually taken to indicate that quantum objects have peculiar features and need a different treatment with respect to the classical ones. The indistinguishability of particles in quantum domain has been linked to the debate over their individuality, from which OSR takes its main motivations. We will consider such a debate in the last chapter, since we are at present concerned with Eddington's view of particles' indistinguishability.

He assumes it as a support to the group-structure view of physical world which we should take as a structure of intrinsically indistinguishable particles and spacetime-frame in which what we traditionally considered as intrinsic physical properties, like mass or charge,

---

[176] Though the peculiarity of quantum statistics, Simon Saunders(2006) endorses Quine's distinction between degrees of distinguishability on order to defend the 'weak discernibility' of fermionic particles via their irreflexive relations (since fermionic particles show anti-symmetric relations). It is ground on the existence of an irreflexive relation between fermionic particles, since their superposition state, expressed by $\Psi = \frac{1}{\sqrt{2}}\left|\uparrow\right\rangle_1\left|\downarrow\right\rangle_2 - \frac{1}{\sqrt{2}}\left|\downarrow\right\rangle_1\left|\uparrow\right\rangle_2$ tell us that the outcomes of a measurement would always show a particle   with   spin   up   and   another   with   spin   down.

are not any longer intrinsic:… *the mass of an electron is an interchange of energy with all the other charges in the universe*. It is a relevant point that Eddington treats both charge and mass as interchanges of energy originated in the structure as a whole rather than in the singular elements. In his view particles' indistinguishability indicates that, especially in quantum domain, the structure of the world which our physical knowledge achieves is of the group-theoretic kind in the epistemological sense. In such a sense, the epistemological path from group-view denies the intrinsicness of fundamental properties. This is a further important step with respect to the comparison with OSR since the latter, in its most eliminativist form, pursue the claim even further in denying also the individuality of particles. On the contrary, though Eddington emphasizes the fundamental role of relations, he does not dispense from the relata in his picture, from the very beginning of his reflection in 1920: "*The relations unite the relata; the relata are the meeting points of the relations. The one is unthinkable apart from the other. I do not think that a more general starting-point of structure could be conceived*" (Eddington, 1920a: 230-231). In this sense, when it comes to the physical counterpart of the epistemological view, the idea that "*the elements of structure are assigned no properties other than those arising out of the group or algebra which define the abstract structure*"(1941:274) could indicate definite way to differentiate the structure, enabling the *collating* names according to the group/groups differentiation (for instance, some nodes are characterized via halved values of spin and some others via integer values). In this respect, not any collection of objects can be organized so as to have the world structure as indicated by our fundamental scientific theories.

§3.6. Conclusions

The first part of the above work was meant to show the connection between Russell's view and Eddington's view and overall the differences between the two authors. Considering the crucial objection which Russell's thesis underwent we showed how Newman's problem finds a possible solution within the recent debate: a fundamental turn in the debate is represented by Meelia and Saatsi (2006), which provide a viable way for the epistemic structural positions. By the way the actual debate discusses a step beyond Russell's view which is bounded to the logic reductionism which underlies his perspective. The overall feature which differentiates Eddington's perspective from Russell's one is the

different epistemologies they developed. In this respect Eddington is significantly equipped against Newman/Braithwaite's concern:

- Eddington's notion of structure differs from Russell's one. Our Author characterized his notion through the reference to the mathematical theory of group. Moreover such a characterization covers two paths: an epistemological one, referring to the holistic approach, and a rather semantic one concerning the physical content of the group-theoretic claim, which is far from representing a banal or a trivial claim. In his philosophical works Eddington devotes the main part of the doctrine of structure to discuss the first path.

- In such respects the Newman's problem does not even present to Eddington (if we follow the first path) or does not hold (if we follow the second path): there is not such a problem as "science aims to know more than the mere II order structure".

From his structural thesis and the discussion on the way it should be meant, some interesting features emerged:

1)   the geometrical synthetic[177] view represents the "*real world of physics, arrived at in the recognised way by which physics has always (rightly or wrongly) sought for realty*" (Eddington 1921b,181-183). He unwitting reaches a geometrical theory of the world: "*we did not consciously set out to construct a geometrical theory of the world; we were seeking physical reality by approved methods, and this is what happened*"(*ib.*).

2)   The inseparability between geometry and dynamics constitutes a fundamental feature of General Relativity. And geometry also have a significant role in Quantum Mechanics, due to the use of group-theoretic language.

3)   Looking for the ontology arising from physics the key notion is "group".

4)   The group-theoretic approach should be meant first of all as an epistemological route. It influences the way physical objects should be meant, harmonizing the traditional atomistic approach with an holistic one, as emerged from the development of physical research

5)   Consequently physical properties are to be understood from the starting point of structural interlocking. He is not giving a way of *constituting* relata,

---

[177] *Synthetic* as it arises as a synthesis of all the possible observers' point of view.

rather showing how to retrieve them from the package in which they are embedded as a whole. (French)

6)   In such a framework he develops a structural concept of existence: "*Firstly…the elements of a structure are assigned no properties other than those arising out of the group or algebra which defines the abstract structure. Secondly, we introduced a form of thought according to which the ultimate elements of physical structure are identified with relations* [as emerged from GR]…*Thirdly, the definition of a primitive relation is expressed in terms of 'the concept of existence', afterwards extended to the 'concept of independent existence'*"(Eddington, 1941: 274).

It is quite fascinating to face the work of Eddington from the starting point of our current debates in philosophy of science. Where current debates compulsorily break up over very specific issues due to the developments of physics, the work of the early XXth century epistemologists still offers a quite systematic point of view on what scientific knowledge could represent and, surely, involves. In a wider perspective which significantly relates to the philosophical background, these authors represent a quite interesting sliver in the puzzle of epistemological thought in the early XXth century. It surprisingly turns out to be much more multifaceted than what it seems, and such different facets gain their suitable/right space in the history of human thought as much as they survive in connection with very recent philosophical positions. Such is the case of the so called "Early structuralists", Eddington and Cassirer, and with different outcomes Russell.

On the other hand, our interest toward Eddington's philosophical contribution moved from the approach to the recent debate on structuralism which gave born to the *ontic structural realism* (OSR). The last section serves the purpose, among the others, to show the rightfulness to address Eddington as a genuine conceptual prelude to it. Hence as a final remark some relevant points of the recent position ought to be indicated, which enable the connection: they will be deepened in the next chapters.

In the first place, OSR emerged within an existing debate (realism/antirealism), in the track of 'structuralist tendency' which is broadly characterized as "*a shift in focus away from objects – however they are metaphysically conceived – to the structure in which they are (supposedly) embedded*" (French, 2006b:167). Such a general claim was originally developed as an epistemic thesis (all we know is structure – Worrall's epistemic structural realism) and later

became also an ontic thesis (Ladyman and French) due to some metaphysical issues arising from Quantum Mechanics[178]: the idea is that physical knowledge is structural because *the world is ultimately entirely structural* (French, 2006b: 171). In some sense the claim follows Eddington's and Cassirer's work, where the conditions of accessibility are conditions of existence. The idea seems to be that the way we get information is relevant to understand the way things are. The fact that we know via the group theory must not be a trivial fact, nor an arbitrary one with respect to the way the world is. Thus the reflection of OSR focuses on the group-theoretic characterization of quantum properties and the relevant structure they refer to is group-theoretical. Such an insistence in some sense exceeds Eddington's perspective: we saw that he did not deepen so forth the group-structure discourse with respect to the quantum case, though he considers the spin among his main example; nor he particularly considered the contemporary works on the connections between group-theory and Quantum Mechanics (by Weyl and Wigner). On the other hand the reflections on the content-fullness of the abstract group and overall on its significance as an epistemological way to look at physical world clearly fits well with the OSR's claim: physical objects should be better "*reconceptualized in structural terms*"(*ib*.180). This view implies moving the interest toward relations and assigning them and ontological priority, which turns out in a rather eliminativistic view (the infamous slogan is "relations without relata"). On the other hand the eliminativistic view is not the unique route of the reconceptualization. The crucial challenged point is the so called 'object-oriented view", i.e. the fact that quantum objects are conceptually treated in the same way as macroscopic objects, assigning them some sort of individuality *and* intrinsicness of properties. So far as such a view of objects is the target of the reflection, Eddington's approach could be well taken as a genuine part of the ontic structuralist landscape. Both his reflections on the concept of analysis, on the critique of the substance, on the notion of structure and of existence clearly point out the impossibility to consider intrinsic (as independent from the rest) any feature of physical objects. On the other hand the relata do not lose their place in the structure, at least with respect to their existence. In such a respect Eddington's view differentiate from OSR's eliminativistic account.

Nevertheless the denial of the idea that quantum objects are individuals provided with intrinsic properties opens three possibilities:

---

[178] The main motivation of the OSR is the metaphysical underdetermination of quantum particles.

1)   Quantum objects *neither* are individuals, *nor* they have intrinsic properties;

2)   Quantum objects *are not* individuals *and* they have intrinsic properties;

3)   Quantum objects *are* individuals *and* they have *not* intrinsic properties.

Without considering option 2), which has not counterpart within the debate, the option 1) shall be linked to the eliminativistic account whereas Eddington's view shall be linked to the option 3). With respect to the first stance an issue holds concerning the fact that certain properties (mass, charge and spin) come always together (in what we traditionally call 'electrons', 'protons', and so on)according to particular bunches, i.e. in fixed amounts (*tot* mass, *tot* charge, *tot* spin). With respect to the third stance and issue holds concerning the way individuality should be understood, moreover with respect to the quantum violation of the *Principle of Identity of Indiscernibles*.

Similar issues animate the current debate over the structural positions. By the way in repudiating the definition of *physical object* as "individual with intrinsic nature" what is denied is not *ipso facto* the existence of physical objects, rather the existence of *physical objects as* individual objects with intrinsic nature, with a nature independent on the structure in which they are embedded.

Concerning Eddington's putative fatherhood with respect to OSR, some further point must be added. In the case of OSR there is not such a structure/nature dichotomy which we find in the epistemic stance and which motivated the raise of Newman's concern: OSR is precisely an ontological claim on the nature of reality. In such a sense the link with Eddington's view, which collocates in the half-way between an epistemic and an ontological purpose, must be properly set. OSR takes Eddington's analysis of structure, both in his semantic and epistemological path, without accepting the neokantian tinge of his epistemology. How is such a divorce to be done? On the other hand, the reference to the group theory must be suitably set within the realist perspective, also through providing a clear understanding of its association with other mathematical theories (for instance within the domain of QM it could be associated with different algebras) and of its physical interpretation.

Hence the next chapter will be devoted to deepen the connection between the employment of a so powerful mathematical tool and the way we figure out the ontology of our physical theories: in order to do it the work of Hermann Weyl, another fundamental character of the scientific landscape in the passage between the XIX and the XX century, will come into our analysis. As mentioned, he provided the *translation* of group theory into Quantum Mechanics and his work is particularly interesting from our perspective.

CHAPTER FOUR

From Geometry to Quantum: the rising of Group-Theoretic Language and Ontology.

§4.1. Introduction

In chapter three we considered the way Eddington's structuralism does not suffer the objection of Newman/Braithwaite. His understanding of the group-perspective have been contextually presented, as a conceptual route to structuralism, emphasizing once again an holistic attitude with respect to the ontology of scientific theories. On the other hand chapter 3 closed with an issue concerning the relationship between the group-theoretic approach and its recent employment by ontic structural realism (OSR): what is the group theory useful for? And how does it help the structuralist approach? Such a link will be the focus of the present chapter.

It is remarkable that the development of the group-theory and of its applications, which OSR crucially refers to with respect to Quantum Mechanics, links first of all to the study of certain symmetry principles emerged into an inquiry on the concept of space and of its dimensionality, which characterized in a fundamental sense the transition from the pre-relativistic to the post-relativistic view in physics.

Furthermore, in the previous chapters Eddington's structural thesis have been widely linked to the development of the general theory of Relativity. As a matter of fact the rising of Einstein's theory brought a fundamental reflection on the significance of scientific knowledge in the global sense, since it enabled the rethinking of the fundamental concepts of our doing science which found a counterpart in the second fundamental revolution of the XXth century, the quantum theory. The beginning of the century brought a re-evaluation of all the usual concepts of ordinary physics (and ordinary experience): space, time, matter, physical object, length, measure, and so forth. In this sense Eddington was but one among the leading characters of such a rethinking, and his structuralist reflections were not an isolated and solitary event. We focused on his work since we are interested in

the conceptual preludes to OSR, which also refers to the work of Ernst Cassirer[179]. Both their (Eddington and Cassirer) philosophical reading of scientific knowledge put a great emphasis on the link between the new physical theories and the developments of geometrical thought, as emerged with the formulation of non-euclidean geometries and the focus on geometrical invariants. In such a sense the comprehension of the way a structural perspective arose from the new physics pursues us to consider some features of the debate on the concept of space and the foundations of geometry, which characterized the second half of the XIX century. It is our persuasion that in order to gain (*a*) a wider perspective on the source and the evolution of the structural perspective and (*b*) some useful elements in the evaluation of the shift in the application of the group theory (from Relativity theory to Quantum Mechanics) we have to understand its source in the XIXth century's debate. Then the purpose of the present chapter is to inquiry into such a shift through the work of H.Weyl. He was not a structuralist, neither did he develop any strictly speaking structural thesis (à la Eddington or Russell). On the other hand he carried on some fundamental reflections on the concepts and the structural features of scientific knowledge, both in mathematics and in physics[180], which in 1927 brought to the publication of *The Theory of Groups and Quantum Mechanics*. In this work he affirms the group theory to be the most appropriate language for Quantum Mechanics. His work manifests an attention toward the deep understanding of the formal apparatus of scientific theories which is sympathetic with Eddington's perspective and on the other hand could allow for the expectation of OSR.

Due to the complexity of the theme the present chapter will be divided into two main sections. The first section will deal with Weyl's reflections on the conceptualization of space as a mean for understanding the instruments of our comprehension of space. His work will be a vehicle for our inquiry into a theoretical route which goes from Riemann to Einstein in analysing the properties of space. In spite of Klein's 'divorced view' of geometry as separated from the concrete domain of physics, we will immerge into a

---

[179] For a wide treatment of Cassirer's philosophy see Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer.* Open Court Publishing Company; for further details on the structural conception of objects see Ihmig (1999); for further details on the link between Cassirer and the OSR see Cei and French (2006), French (2001), Ladyman and French (forthcoming).

[180] Both from the strict scientific point of view and from the mathematical-philosophical, Weyl's work manifests a great dept and richness. The present work moves from a, say, selective approach which inevitably will betray such a richness. Hence, whilst the reader would feel the need of further investigation, some useful treatments and bibliographic suggestions could be found, beside the works of Weyl himself, in E.Scholz (ed.), *Hermann Weyl's Raum-Zeit-Materie and a general introduction to his scientific work* (Birkhäuser Verlag, Basel, 2001) and "Weyl's analysis of the 'problem of space' and the origin of gauge structures", *Sci .Context* **17** (1-4)(2004), 165-197.

perspective in which geometry "*attains its fully validity in physics*" (Weyl 1918: 43). In this sense the route Riemann-Einstein is an example of an ontologically significant reading of certain geometrical structures, due to a theoretical reflection on the involved instruments and concepts. In adding such a reflection to the structural outlook à la Eddington a mean for a structural claim could be achieved. The perspective of the analysis does not aim to a 'dissolution of objects into mathematical structure', which always fears the critics of the structural positions (see Cao and Psillos): it rather inquires into a possible understanding of the employed language of certain theories. In this sense it is also relevant that the intimate connection between space/time and matter, which Weyl addresses (1918:xxi) and which the General Relativity widely supports, was surprisingly intuited by Riemann long before its clarification in the work of Einstein. Beside the emerging physical significance of geometry in connection with the laws of motion, also the first fundamental symmetries emerge, i.e. the first physical application of the theory of transformations groups: through the concepts of 'invariance' and 'transformation' the theory of groups proves to be a significant language for physics, enabling the expression of some fundamental properties of space which have a physical counterpart in terms of conservation laws. It also appears as a powerful unifying language (for space time and matter), neither due to a solely formal exercise nor to the establishment of conventions.

The second section will recollect the first to the specific topic of our research, i.e. to the discussion over the structural positions. Accordingly the previous discussion will be compared to

1) The conceptual side of the structural positions, which we found in Eddington's work;

2) The 'substantial' side of the structural positions, i.e. the way the application of the group theory to Quantum Mechanics could in fact represent a step ahead toward OSR with respect to Eddington's view. The issue will be to understand the group-theoretic characterization of quantum properties and to what extent it could be taken to support ontic structural *realist* approach to ontology.

Part I

§4.2. From the raumproblem *to the group-theoretic invariance*

A relevant feature of Weyl's work is the needed rethinking of some fundamental notions of our knowledge of the external world, overall the notion of space. Following his analysis of the concept of space is following the conceptual evolution of geometry from a perspective grounded on *congruence* toward a perspective grounded on *transformation*, culminating in the developments of the transformations *groups*. From these issues he later came to Quantum Mechanics through the study of the groups language and through the work of distinguished scientists such as Emmy Noether, Eugene Wigner and Werner Heisenberg. This process provides some extremely important formal instruments through which the complexity of reality is inquired. In what follows we will focus on three conceptual nuclei:

1. the first one concerns the constitution of the *Raumproblem* as a problem: we will be interested in how the conceptualization of space and its organization (or re-orgnization, since we will consider non-euclidean or post-euclidean points of view) affect our knowledge of the external world and of external objects. According to Weyl the way mathematical and physical quantities are expressed, through scalars, vectors and tensors, points out as well "…*the mathematical constitution of the space in which these quantities exist*"(Weyl 1918: 43). The mathematical properties which emerge are not bounded to the domain of geometry, but they represents something which "*attains its fully validity in physics*"(*ib.*). In such a view, which will be found perfectly in line with the work of B. Riemann, the problem of space emerges not so much as an isolated matter of pure mathematics, rather as an issue deeply interrelated with the very way natural phenomena happen to be.

The aim of this section will be to show the way the study of the problem of space becomes the occasion to deepen the relationship between mathematical and physical knowledge. Weyl's claim that "*As natural phenomena take place in a metrical space this tensor calculus is the natural mathematical instrument for expressing the uniformity underlying them*"(*ib.*)

appears very sympathetic with Eddington's remarks on the significance of the employment of particular mathematical symbols. With respect to such a resemblance, Weyl's approach seems to provide an allowable content for the structural realist insistence on the particular descriptions[181] involved in the current scientific theories: in this sense OSR could find a viable starting point to frame the ontological research.

2.   Once the problem of space has been stated, the second brief nucleus will consider the further development of the notion of *congruence*, grounding Euclidean geometry[182], toward the notion of *transformation[183]*. The reorganization of the geometric system due to Riemann's turn gets ashore to the study of invariances and to the notion of *group*.

This second section will focus on the development of the group-theoretic approach from to the study of space. It is an interlude which is by the way need in order to understand the third section.

3.   Section three will deal with the association between the study of certain spatio-temporal symmetries and certain physical properties, which remarks the reciprocity between the geometrical descriptions and the physical characterization of the world. Within such a reciprocity the group theory finds its first application and concrete significance. Successively it is brought into the quantum domain via the work of Weyl and Wigner.

The aim of the last section will be to delineate the main features of the group-theoretic approach, which according to us is brought from space-time to the quantum

---

[181] Instead of beginning with an already metaphysically framed picture, they want to start from the descriptions in order to draw the picture. An issue could be that our approach to theories cannot be meant as starting from a tabula rasa. On the contrary, previous knowledge always brings its alleged picture. In this respect Eddington's analysis presents a useful sight on the revisability of the frames of thought (chapter 1).

[182] The fundamental *form* grounding Euclidean geometry, the Phytagoras' theorem, was taken as universally valid, thanks to the fact that the Euclidean system is closed – the 'closure' of a set X is the set $\overline{X}$ obtained through imposing a boundary to X - with respect to homothetic transformations. An homothetic transformation is a particular geometrical transformation which enlarges or restricts figures in a plane or in the space without changing the relative ratios of points (their form and orientation). At the very basis of the closure for homothetic transformation there is Euclidean fifth postulate and on this fact rests the constitution of sensorial space.

[183] The development is toward congruent transformation of coordinates and then to transformations. The shift is progressively led to a consideration of the relations between elements.

domain, in terms of : the reciprocity between geometrical and physical descriptions; the focus on relations rather than on the involved specific elements. Once this features will have been addressed it will be possible to broach the discussion over the second part of the chapter, namely the link between the group-theoretic characterization of quantum domain and the OSR's approach.

§4.2.1 The constitution of the Raumproblem

In the incipit of *Space, Time and Matter* Weyl says: "**SPACE** and **time** *are commonly regarded as the* **forms** *of existence in the real world,* **matter** *as its* **substance**. *A definite portion of matter occupies a definite part of space at a definite moment of time. It is in the composite idea of* **motion** *that these three fundamental conceptions enter into intimate relationship*" (Weyl 1921:1). In his perspective the passage from the pre-relativistic toward the relativistic perspective has a crucial conceptual turn in the way space, time and matter are conceived in their interrelation, i.e. in the idea of *motion*[184]. The very causal connection of the world is part of its very nature as an active domain where space/time since now cannot be separated.

According to him, scientific research started from a conception of space, time and matter, as respectively the forms of existence and the substance of the world and grew as the description of what happens in the world in terms of these three notions (the third being the fundamental) with extraordinary outcomes as the building of Euclidean geometry or the formulation of the law of conservation of matter, higher expression of the idea of matter as a substance. Nevertheless classical science apparently concealed the seeds of its evolution: the unshakeable colossus of human science got soon tottering because of its own generative character, through the discovering of unexpected features and new horizons of research. The buds and blossoms of the new research appeared within different disciplines: the notion of *field* (which appeared as a different kind of reality with respect to the traditional matter) and the outcomes of electromagnetic theories; the developments in the field of geometry (due to the discovery of the non-euclidean

---

[184] On the role of the concept of *motion* in geometry and physics between XIX and XX century see Jammer. He also marks a difference with respect to the wide kantian influence on the mathematical and physical thought: Kant's transcendental aesthetic deals with space and time; the concept of motion is not a priori known (see Jammer: 161).

geometries) and the consequent revolution brought by both the theory of Relativity and the development of Quantum Mechanics.

In reflecting about such an evolution the principal interest of Weyl concerns the way the notion of space has been re-organized[185]. Thus he considers the possible interpretations of the concept of space, mainly through the works of Riemann and Hilbert, in mathematics, and through Einstein's Relativity. The latter appears then as the natural conclusion of a process of reconceptualization of space in its connection with time and matter. Weyl's works on the theory of Relativity[186] (1918 and 1923) are indicative in such sense: in his view the theory constitutes a fundamental turn in the human inquiry of the world, as it brought us nearer to the plan underlying phenomena. It somehow "crushed" "*the wall which separated us from truth*" and "*brought us much nearer to grasping the plan that underlies physical happening*"(*ib.*:x). On the other hand the very fact that Einstein achieved *necessarily* and *uniquely* certain equations is due, according to him, to the fact that the scalar curvature has a certain feature in Riemann's space[187].

It ought to be remarked that in his initial (1918) treatment of Relativity he chooses a different view with respect to Einstein, putting an emphasis on the local tangent spaces[188] as the epistemically privileged spaces of ideal observers intuition: the local structure would

---

[185] The analysis of such an issue is to him "..*a good example of the kind of analysis of the <u>modes of existence</u> which is the object of Husserl's phenomenological philosophy… The historical development of the problem of space teaches how difficult it is for us human beings entangled in external reality to reach a definite conclusion.*" (Weyl 1918: 4-5).

[186] Mostly of Weyl's fundamental works appeared between the '20s and '30s . His first reflections on the problem of space, as elaborated in the papers published between 1908-1918[186], basically joined into *Raum, Zeit und Materie* in 1918, re-edited in 1921 in the famous London edition under the title "*Space, Time and Matter*". In the same year he published *Das Kontinuum*. In 1923 he then published *Mathematischen Analyse der Raumproblem* where the pillars of his mathematical enquiries are made precise, then moving to the philosophical analysis. In 1926 he wrote an article for the Handbuch der Philosophie of R.Oldenbourg, which he later revised and published as *Philosophie der Mathematik und Naturwissenschaften*, re-edited in 1949 as *Philosophy of Mathematics and Natural Science* for the Princeton University Press. The work published in the '30s relate to his studies on the intimate relation between geometry and physics in quantum mechanic: in 1928 the first edition of *Gruppentheorie und Quantunmechanik*, famously re-edited in 1931 and translated in English in 1932; also in 1932 there is *The open World* and two years later (1934) *The classical groups: their invariants and representations*. In 1952 *Symmetry* and in 1955 *The structure and representations of continuous groups*.

[187] A Riemannian Space is a space whose properties depend on a quadratic form which expresses the square of the distance among infinitely close point. Such form is called metric form (or fundamental form) and it is defined as $ds^2 = g_{\mu\nu}dx_\mu dx_\nu$.

[188] In order to define a local tangent space we should introduce the notion of differentiable manifold. Broadly speaking a differentiable manifold as an *n*-dimensional set of points *M* provided in any point $P \in M$ of a set of local coordinates whose changing are expressed through certain differentiable functions. According to Dorato (2005: 45) we define intuitively a local tangent space to the point $P \in M$ as the tangent space V_p formed by all the *tangent vectors* to all the curves which pass from *P*. The notion is fundamental in the theory of Relativity since: "*Lo spaziotempo fisico è dunque un* continuum *quadridimensionale di eventi fisici idealmente inestesi che da un punto di vista matematico è rapresentato da una struttura M che solo* localmente, ovvero nell'intorno di ciascun suo punto, *ha le proprietà topologiche e differenziabili di uno spazio euclideo* $\Re^4$ " (Dorato 2005: 43).

be in such sense the fundamental existing structure. In noting that Weyl abandoned the purely local view in his later works after the rising of Quantum Mechanics[189], Howard(2005) questions the very argument for a purely local view: why should the intuition space have such an importance for fundamental physics, such that an epistemic fact (as the alleged correspondence between the local tangent space and the space of intuition) have any implication for the fundamental ontology? A first answer could refer to a rather husserlian perspective in Weyl's firsts work, which pushes him to always recollect the research to the space of intuition as the phenomenal domain. On the other hand, Howard reformulates the issue in terms of an underdetermination thesis: grant the need for scientific theories to account for observations (the 'phenomenal' level), we should/could accept any story (even counter intuitive) which would manifestly be coherent with them. On the other hand, it seems to us that the seek for the correspondence (between the space of ordinary experience and the fundamental physics) is not only a seek for the internal coherence of certain theoretical model, suitable to be linked with observations. Perhaps, it is our persuasion, Weyl receives an urgency which is typically Riemannian: the seek for a non arbitrary geometry. Beside the internal coherence of a theory and its coherence with observations, the theoretical (in Riemann's case the geometrical) model should be non-arbitrarily significant. This seems to be the conceptual topic of the raumproblem[190]. On the other hand, even though a motivation could be recovered in the epistemic privilege of the 'local' perspective, a further issue concerns the plainness of the eventual correspondence between the intuition space and the local tangent space, namely the intuition of ordinary experience and a highly mathematical structure. In a sense it represents an occurrence of the pervading issue of the new physics: the relationship between the growing abstractness of the discipline and our intuitions of the world or our formulations of its ontology[191]. We will find a similar concern in the discussion concerning group theoretic perspective, which will be developed in the II part.

In order to better understand the mentioned route from Riemann to Einstein, on the significance of geometrical research, Riemann's reflection will be accounted for. In his dissertation "On the hypothesis which lie at the basis of geometry"(1854) he generalized the study of surfaces through the introduction of the concept of *n*- dimensional *manifold*.

---

[189] Weyl himself puts a remark on such point in the introduction to the later editions of *Space Time and Matter*.
[190] See Jammer (1953), Longo (2002), Bailly and Longo (2003) and Howard (2005).
[191] In chapter three we saw that such an issue drives the reflections of an author as Bertrand Russell.

He followed Gauss' work on the intrinsic geometrical properties of surfaces, as independent from any alteration/deformation of the surrounding space[192]. Thus, as Weyl clarifies, "*the geometry of a surface deals with the inner measure relations of the surface that belong to it independently of the manner in which it is embedded in space. They are the relations that can be determined by* **measurements carried out on the surface itself**" (1918: 89). Starting from an analysis of the mathematical properties of a manifold of undefined objects (points), both the Euclidean and the Lobachevski/Bolyai's geometries are showed to be special cases of a generalized space[193]. Moreover Riemann showed the possibility to provide an appropriate metric enabling a constant positive curvature space, thus an elliptic space[194].

Since the organization of our perceptual space(Euclidean) is just a limiting case of a multiplicity of possibilities, the distinctive properties of space cannot found an exhaustive definition in terms of Euclidean concepts[195]. If the foundation of geometry, in such sense, is not aprioristic, the properties of space must have a different foundation, which Riemann initially grounds in experience. On the other hand, the more we descend into the microscopic domain the more the possibility to turn to experience diminishes till disappearing (due to the growing unobservability). At the very end of his essay, Riemann writes: "*But it seems that the empirical concepts on which are based the spatial definitions of the physical universe, the concept of* rigid body *and of a* light ray *no longer are valid in the infinitely small. Thus, it is permissible to think that physical relations in space in the infinitely small do not correspond to the axiom of [euclidean] geometry; and, in fact, this should be allowed if this would led to a simpler explanation of the phenomena*"(Riemann[1854] in Einstein [1920]: 217 it. tr.). Thus a problem emerges for the validity of geometrical postulates, that is the problem of space. Indeed if the geometrical postulates in some way hold in the microscopic domain (and we have reasons to affirm it) and if they cannot be derived directly from the notion of magnitude[196]nor from the direct

---

[192] They already look for characters which would be invariant. Klein's *Erlangen Programm* insisting on invariants and transformation was formulated later, in 1872, and recollected the previous reflections.

[193] Riemann analyzes the concept of *multi-dimensional magnitude* and proofs the Euclidean space to be a limiting case of three-widespread (dimensional) *manifold*, considered under a 'local', 'infinitesimal', analysis.

[194] Riemann's work shows the general space to be a *n*-dimensional manifold whose special cases are the Euclidean (parabolic, with 0 curvature), the spaces of Lobachevski and Bolyai (negative curvature, iperbolic spaces) and the elliptic space (positive curvature). Riemann's mathematical researches became the pillars of the inquiry into the problem of space, with the introduction of new concepts (*manifold*), the introduction of the differential analysis, the distinction between local and global analysis (so fundamental in GR), the considerations on *surfaces* and on *invariants*, and so forth.

[195] The lesson which mathematicians brought form the arising of non-euclidean geometries concerned the impossibility to *a priori* choose between the different geometries in representing the relations between physical bodies.

[196] The concept of magnitude (as intuitively something which is open to + and -) enters in the first place the theory of proportions, which enables Euclide to treat at once the proportions between numbers, segments,

experience, we must clarify the *internal foundation* of spatial relations: the issue is the discovering of the simplest facts from which the metrical relations arise. This is particularly interesting in the domain of the infinitely small[197]: the validity of geometrical postulates within the domains which go beyond the observable is intimately connected with the internal foundation of the metrical relations of space. Where does the foundations of the metric[198] must be placed? Riemann provides an exceptionally farsighted answer: *"the foundation of metric relations must be found… in cohesive forces between bodies"* (Riemann [1854], in Einstein [1920]: 220 it. tr.). In this sense he intuited a feature which will later constitute one of the pillars of the great revolution brought by the general theory of Relativity and which Einstein himself continued to study even after 1916.

Moreover, Einstein remarked that Riemann intuited the physical meaning of the generalization of Euclidean geometry, through the introduction of the generalized tensorial calculus and through extending Gaussian concepts to *n*-dimensional continue manifolds: in this sense he had a prophetic vision[199]. In his words, the fundamental superiority of the general theory of Relativity is due to its ability to explain the equation between inertial mass and gravitational mass, which induces the gravitational field to *determine* the metrical laws of the spacetime continuum[200]. If such laws are geometrically expressed, then the gravitational field makes the geometry to be non-euclidean. Riemann's intuition of space corresponds to the experience of the properties of some magnitudes. The reorganization of physical space resulting from the developments of geometry does not belong to an arbitrary or conventional choice. Nor, on the other hand, it is given *a priori*. It rather belongs to both an analytical method (through which he derives the positive curvature) and some underlying

---

surfaces, and so on. Indeed in considering such proportion through the individuation of the common feature of such classes of geometrical elements: axioms of equality, definition of sum and difference. In this sense Euclide provided an implicit definition of the concept of magnitude which was made explicit in XIXth century through the *class of homogeneous magnitudes*: a class of somewhat elements which satisfy a definition of equality and obey an operation of sum in order that the continuity postulate holds.

[197] It is amazing that the problematic nature of the microscopic domain emerges within mathematics already in 1854, when quantum mechanics was not yet been formulated, nor even the theory of Relativity.

[198] A crucial point of Riemann's essay is the distinction between two perspective on the relation between physical bodies (or physical elements) and their spatial positions. In the first place physical elements could be considered as independent from their own positions: it is the case of a space constituted as a discrete manifold in which the metrical relations are implicitly derivable (through measurement). In the second perspective physical bodies are dependent from their positions: space is a continue manifold. In such a *n*-dimensional continue manifold, metrical properties are not intrinsic: any point of the manifold is characterized by *n* numbers, yet there is not a definition of the *distance*.

[199] see Einstein (1922), italian version 1950: 71-72.

[200] This is a fundamental step ahead the special Relativity, where the spatiotemporal continuum was somehow 'agent, but not *acted* on' (also violating the action/reaction principle) as, on the other hand, the movement of matter is *deduced* and *driven* by the metric field.

regularities, concerning for instance the *isotropy, homogeneity* and *continuity* of space, which will turn out to be connected with the conservation of some peculiar physical quantities. Through such a work the theory of invariants become fundamental.

In *Space, Time and Matter*[201] Weyl moves from Relativity to build the space. The claim that the latter relates deeply to the material content which fills it finds a clear seat also eliminating the very idea that geometry could be independent on physics. We do not lose the intuitive value of Euclidean space, which becomes a particular case of an infinitesimal metrical space, and we gain the explanation of General Relativity. Defining the structure of the infinitesimal metrical space, the relations between elements of the space are also defined. The fundamental point is the new function, the tensor[202], which expresses relations between systems of coordinates, originated from translations, rotations, roto -translations of those very systems.

The contact point between Gauss/Riemann's view and Einstein's view is represented by the reflection on metrical properties of the *n*-dimensional manifold: in parabolic geometry the infinitesimal interval *ds* is physically important as it is measurable; the same geometry could be developed on a curve surface through considering its infinitely small portions; but for finite regions of the curve surface (as for the finite regions of spacetime) the metrical relations of the special Relativity do not hold. On the other hand *ds* remains for arbitrary coordinates such that $ds^2 = g_{\mu\nu}dx_\mu dx_\nu$, where the coefficients $g_{\mu\nu}$ define the metrical relations and the gravitational field (see Einstein 1922: 71 it.tr.). We mentioned Weyl's claim that the geometrical properties emerging from the study of space acquire a full validity in physics: following the route Riemann – Einstein it is evident that such a claim has a farsighted expression in Riemann's essay.

---

[201] In the preface to the first American printing (of *Space Time and Matter*)(1952) Weyl affirms his will of taking into account also some modifications of Relativity as occurred after the development of quantum mechanics.
[202] Tensors are elements of the metrical space, preserved through the passage from the pre-relativistic to the relativistic view. It is used in representing relations invariant under transformations. A precise definition could be found in Dorato(2005) (it.ed.:56-57 my translation): "*A tensor H of the kind (m, k) – which is designed as* $H^{a_1 a_2 ... a_m}_{b_1 b_2 ... b_k}$ *with the* m *symbols* a_i *standing for* m *cotangent vectors and the* k *symbols* b_i *standing for* k *tangent vectors – is defined as a linear application with m-variables from* m *elements of the cotangent space* V_p^* *and* k *elements of the tangent space* V_p *to a real number:* $H : V^* \times V^* \times V^*_{(....m-times)} \times V \times V \times V_{(...k-times)} \rightarrow \Re$. Dorato also provides the definition for the linked notions of cotangent vectors, cotangent space and so forth.

Once a physical meaning[203] is immediately provided in a mutual reciprocity with the geometrical description, the understanding of the latter becomes a fundamental requirement in order to understand the former. Thus the problem of space become the occasion to deepen the relationship between mathematical (geometrical descriptions) and physical knowledge (physical meaning), a feature which figured among Eddington's motivations (cfr. Chapter 1). In this respect we mentioned that Weyl's attitude toward the mathematical instruments recalls Eddington's attitude. They both affirm the mathematics to be a limiting boundary for our representations of the physical world. They both endorse an analysis of the instruments of such representations. And such attitude is recovered and emphasized, as we will see, in the recent structuralist approach to the group-theoretic language.

On the other hand we cannot forget Eddington's neokantian tinge: in his view the informations we obtain from the analysis of methodological tools concern the character of our knowledge as irreducibly subjective and thus the unique forms which physical objects can assume in order to be object of *our* knowledge. Though some few characters appear as *intrinsic* to the world, independently on our knowledge, they are by the way filtered through it. This does not make them unreal nor imaginative: they are real relative characters of a world which is always *perspectively* known by the human being. In this sense his "no-one in particular" point of view is not a strictly mind-independent, neutral, point of view; it rather is a sort of meta-subjective point of view, common to all the observers.

Weyl's analysis of the re-organization of space[204] is made as well through the analysis of concepts and formal instruments; on the other hand his view is not to be linked to a kantian perspective: the contribution of the objective dimension (i.e. pertaining to the object) to the cognitive dynamics is much more consistent than in the kantian realm[205]. In such a respect his reflection is more suitable to be run from the side of a *realist* approach to structuralism. Thus the analysis of the *raumproblem* provides an allowable justification for

---

[203] In such a respect a line could be drawn, linking the reflections of Gauss, Riemann, Mach, Helmoltz, Clifford, Poincarè, Lorentz and culminating in Einstein's General Relativity (see Jammer (1953) and Longo(1999)(2002)): it is the path which considers a mutual relation between the space structure and the field equations, a reciprocity between the metric and its material fulfilling.

[204] The analysis of such an issue is to him "*..a good example of the kind of analysis of the <u>modes of existence</u> which is the object of Husserl's phenomenological philosophy… The historical development of the problem of space teaches how difficult it is for us human beings entangled in external reality to reach a definite conclusion.*" (Weyl 1918: 4-5).

[205] In such sense Weyl rather is under the influence of Husserl. For further details on his philosophical belonging see Bell(2000), (2004), Longo(1999),Howard (2005), Ryckman(2005).

the structural realist[206] insistence on the particular descriptions involved in the current scientific theories as the starting point to frame the ontological research.

§4.2.2. Congruence and transformation

Thanks to the results of Riemann, Weyl inquiries into the transition from affine geometry[207], where the space is represented as a three-dimensional region of linear quantities, towards metric geometry (grounded on Riemann's turn).

The Euclidean space is the starting point due to its intuitive nature and characteristics. It basically is grounded on a *principle of congruence*: there is a biunivocal relation between two positions of a *rigid* body in space at two different times[208]. Such a principle manifests itself as the superimposability of the congruent elements (geometrical figures). Accordingly, the theorems of congruence rule the changes in positions of rigid bodies.

As mentioned, according to Weyl, space is first of all a form of existence of material reality (Weyl 1921:1) and every material thing can occupy different positions in it *without changing content*. In pre-relativistic physics, the latter expression has a definite meaning in the idea that ideal rigid bodies could be arbitrarily moved and that their behaviour with respect to orientation is independent from their material and their changes in positions. Moreover the principle of congruence manifests a fundamental underlying property of space, that is its homogeneity. According to the principle of congruence the objects of classical geometry are linked through the functional-concept of *translation*: a bijection which preserves distances among points, i.e. an isometry[209].

---

[206] In this section we are not yet concerned with the specific way (eliminative or moderate) the structural realism should be developed. We just note that the debate over the foundation of space and over its significance provides a the basis for a *realist* reading of the structural perspective developed, for instance, throughout Eddington's works.

[207] The affine geometry deals with those properties of figures (in plane, space or iperspace) which are invariant under *affinities*, i.e. under those homographies which map into itself a straight lines or a plane or a iperplane.

[208] As Einstein notes in *The Meaning of the Relativity* (1922), the changes in positions are the most simple changes we perceive in objects. Then, if the two positions of the body at different times are represented by two figures S and S', the congruence among the two figures implies that any point $x \in S$ has a correspondent *homologous* $x' \in S'$. Congruence is a peculiar case of similitude, when the report of similitude is 1: two congruent bodies have the same size.

[209] The isometries in the Euclidean space are translations, reflections and rotations. Any point of the Euclidean space is assigned with three numbers, its cartesian coordinates, and between any two points on a rigid body an interval is assigned: its fundamental form is expressed in the Pythagora's theorem. The length of

After Riemann's work the strictly euclidean structure is generalized, according to the new view on *n*-dimensional geometry, grounding on vectors which formally express *relations between points*[210]. In order to completely reach Riemann's space Weyl further needs the introduction of two functions: the bilinear form and the quadratic form. Taking his definitions:

"*a function Q(**xy**) of two arbitrary vectors **x** and **y** is called a bilinear[211] form if it is a linear form in **x** as well as in **y**.*" (Weyl1921: 26). Given a coordinate system with ξ_i as the components of

x and η_i as the components of **y**, then $Q(xy) = \sum_{i,k=1}^{n} a_{ik}\xi_i\eta_k$ holds, with a_{ik} as constant coefficients.

When Q(**xy**) = Q(**yx**), the bilinear form is symmetrical and the property $a_{ik} = a_{ki}$ holds for the coefficient. In that case "*every bilinear form Q(**xy**) give rise to a* **quadratic form** *which depends on only one variable vector **x***

$$Q(x) = Q(xx) = \sum_{i,k=1}^{n} a_{ik}\xi_i\xi_k \text{ "}.(ib.:26)$$

The two forms (quadratic and bilinear) allow Weyl to define a *metrical ground-form* and reformulate congruence of mathematical objects, as the congruence of the relative metrical ground-forms (i.e. as equality of metrical ground-forms[212]):

"*METRICAL AXIOM: If a unit vector **e**, differing from zero, be chosen, every two vectors **x** and **y** uniquely determine a number* $(x \cdot y) = Q(xy)$*; the latter, being dependent on the two vectors, is a symmetrical bilinear form. The quadratic form* $(x \cdot x) = Q(x)$ *which arises from it is positive definite[213].* Q(**e**)=1.

---

an interval is uniquely determined once an arbitrary unity of length is fixed. Thus *length* is the outcome of a measure by means of a unitary arbitrary sample.

[210]The generalization is made via the *Riemann's surfaces* which on their side are mathematical algorithms which explain *relations between elements*. A general approach to non-euclidean geometry through the study of *Riemann's surfaces* is presented in *Mathematischen Analyse der Raumproblem*.

[211] A function is characterized as *linear* if it is a correspondence which preserves the two fundamental operations of scalar product and sum of vectors. Considering two vectors $r, u \in \Re$ *and* the correspondence

$A: \vec{r} \to \vec{r'} \in \Re$, *A* is characterized as a *linear* correspondence if $A(a\vec{r}) = aA\vec{r}$ for any scalar *a* and $A(\vec{r} + \vec{u}) = A\vec{r} + A\vec{u}$.

[212] Thus he reformulates the congruence of mathematical objects, which manifests the homogeneity of space, as an invariance a form (the metrical groundform) expressing a *relation* among points(elements).

[213] A quadratic *form* $(x \cdot x) = Q(x)$ is *positive definite* if $Q(x) > 0$ for any vector x.

We shall call Q the **metrical groundform**. *We then have that an affine transformation which, in general, transforms the vector* **x** *into* **x'** *is a congruent one if it leaves the metrical groundform unchanged"*(*ib.*:28).

The metrical form is *invariant* under congruent transformations. It grounds the metric which in its turn determines the characteristics of space. Gauss already recognized that the metrical groundform is a fundamental factor in geometry of surfaces, since it determines lengths, angles, size of given regions (metrical relations). The coincidence of the coefficients of two metrical groundforms is at the very basis of the reformulation of *congruence*. Going further on this direction, Riemannian geometry pursues a theory of invariance with respect to arbitrary transformations of coordinates and builds metrical relations for *n*-dimensional magnitudes of an *infinitesimal* kind. The new general geometrical structure[214] is infinitesimal, i.e. it considers very close points[215]. Here is a passage from congruence, referring to the mobility and superposition of bodies within space, to the mathematical notion of transformation among systems of coordinates (Riemann, Klein and Lie): congruence (a geometrical concept grounded on the homogeneity of space) becomes *invariance under transformations* of space into itself. Through such a passage space does not ground any longer on congruent figures, rather on *metrical relationship*, between a point and its neighbourhood: the metrical conception is not built on the definition of single points, rather on the infinitesimal interval in the neighbourhood of a point and through *congruent*

---

[214] The passage from Euclidean to Riemannian geometry holds on the passage from conceiving the distance between two points as a quadratic form of respective coordinates to the case in which such two points are seen as infinitesimally close. Phythagoras theorem which gives the distance between two points in the Euclidean realm is a quadratic form of the relative coordinates of points. If we take it as valid also for two extremely close points, we enter the Riemannian realm. Thus Riemann's formulation is a generalization which gives Euclidean geometry as a limiting case. It provides *n*-dimensional manifolds whose elements are specified through *n* quantities, their "coordinates", which are continuous functions within the very manifold (cfr.Weyl 1918:84). From the mathematical point of view, a function $f(x)$ is *continuous* in a point x_0 of its defining interval if $\lim_{x \to x_0} f(x) = f(x_0)$. It basically means that any infinitesimal variation in x corresponds to a variation in the function.

The number of dimensions of a manifold depends on the number of variables needed in order to define its objects. Hence a two dimensional manifold is defined from 2 numbers, e.g. the ellipse (major axis and minor axis) or the conditions of balance of an ideal gas which are specified by two variables (pressure and temperature); the sensation of colour, from the physiological point of view is given by a three-dimensional manifold since it is the result of the retinical composition of three chemical processes (black-white, blue-yellow, red-green); the possible positions of a mechanical system with *n* degrees of freedom represent an *n*-dimensional manifold.

[215] Weyl initially emphasized the infinitesimal constitution of space; after the rising of quantum mechanics he was led to abandon a purely infinitesimal perspective (see Howard [2005])

transformations. "As natural phenomena take place in a metrical space this tensor calculus is the natural mathematical instrument for expressing the uniformity underlying them"(Weyl 1928: 43). The metrical space is then a space where a relation among elements is defined. The *distance* is defined through the reference to a metrical groundform which covers the infinitesimal neighbourhood of a point. Thus space is rebuilt as a lot of distances interlocked. We get back Eddington's definition (chapter 2).

Again, concerning Weyl's successive abandonment of the purely infinitesimal geometry, Howard notes that Weyl "*contemplated the rise of the new Quantum Mechanics... since the quantum theory fails to individuate systems on the basis of non-null spatial (or spatio-temporal) separation alone, because of entanglement, its notion of an "object" differs fundamentally from that of any space-time theory – both Weyl's and Einstein's included – that, in effect, treats each point of the space-time manifold as a separate and separable physical system"*(Howard 2005: 7). Weyl and Einstein treated each point of the space-time manifold as a separate and separable physical system. *Separability* is then the a fundamental characteristic of spacetime theories, which falls out of Quantum Mechanics. In this respect Howard notes that the difference introduced by the latter regards the impossibility of conceiving objects in such a separated way.

Going back to Eddington's perspective the divide is mitigated in conceptual terms. In practise physical objects(bodies) count as separable. But conceptually speaking Eddington pursues an ontological holism in which objects(elements) are always parts of a whole. In this respect the relevance of the emerging 'point-neighbourhood' perspective is interesting: as far as the conception of physical objects is under scrutiny, it seems that a change in the conceptualization is already working within the study of space and it is got from the (neo)kantian approaches to physical theories. It is even more evident considering the Eddington's treatment of the particles in General Relativity, as presented in *Relativity Theory of Electrons and Protons*: there Eddington chooses to present the analysis of particles according to a suggestion he takes from Dirac, in the relationship particle-environment. The change in the conceptualization of the object which is a turning point in Weyl and Einstein is in Eddington's view just a confirmation for his structural/holistic perspective.

Through the notion of congruent transformations the interest grows for the *invariant* features of different systems[216]. On the other hand, the development of such studies makes geometry to emerge as the doctrine of *space itself* rather than the study of different spatial configurations (one, two, three or more dimensions, parabolic, elliptic, iperbolic). Over such space different, say, 'classes' of transformations could be defined, inducing an interest in deepening their properties.

§4.3. New perspective: the notion of group

In the following section we will delineate the main features of the group-theoretic approach, which according to us is brought from space-time into the quantum domain, in terms of: i) the reciprocity between geometrical and physical descriptions; ii) the focusing on relations rather than in the specific elements, which enables an holistic approach. These two features are manifestly common to the structuralism of Eddington and to the perspective emerging from Weyl's studies on space.

On the other hand both the features enter the supported view of ontic structural realism, since it pursues a shifts in focus "*away from objects…to the structures in which they are (supposedly) embedded*"[217] through focusing on the relevant symmetries holding for the quantum mechanical systems and it emphasizes the ontological weight of the relations rather than the relata[218].

The first aspect, concerning the reciprocity between geometrical and physical descriptions is particularly linked in the first place to the possibility to recognise certain symmetries of physical systems, in the second place to a shift toward the individuation of the possible solutions of certain equations, according to the symmetry principles.

A relevant element in the conceptualization of the raumproblem through the farsighted work of Riemman was the urgency to maintain the significance of geometry in

---

[216] For instance in the Cartesian systems the measurable distance among to points $s^2 = \sum \Delta x_\nu^2$ (Δx is the difference between the coordinates; ν may vary from 1 to 3) is invariant under linear orthogonal transformations.

[217] (French [2006:1]; French and Ladyman [forthcoming: 1]).

[218] Though absurd, it is difficult to find a definition of structure within the structuralist literature. We will refer to the general notion rebuilt by Krause: "*in short, a structure results to be a* n-*tuplewhose elements are sets and relations on this sets*"(2005:114). The picture is always provided informally: "*the idea of a structure has to do with relations between the elements of some systems of elements*"(Chakravartty: 2004: 152).

its connection with physics. Due to the work of Gauss and Riemann a number of studies emerged on the mutual relationships between the different geometries of space, focusing on the emerging characteristics of invariance with respect to certain kind of transformations[219]. The focus shifts to the analysis of such transformations which left sets of objects invariant, in particular through Klein's *Erlangen Programm* (1872) which introduced the notion of *group of transformations.*

A certain set of transformations $\Gamma = \{S, T..\}$ is a *group* if, given any couple of element S,T , the following axioms hold:

(1) *(associative law)* (ST)U=S(TU)

(2) *(identity)* there exists a unity element **E** such that **E**T= T**E**=T

(3) *(inverse element)* each element $S \in \Gamma$ has an inverse element $S^{-1} \in \Gamma$ such that $SS^{-1} = S^{-1}S = E$.

Considering any two elements S,T the outcome of their successive combination ST is again an element of the set.

From the notion of *group of transformations* the notion of group could be obtained through abstraction. *A* group is a set of element for which a laws of multiplication is defined for any couple of elements. If the set G is a group, the following properties of multiplication hold for any $a, b, c \in G$:

1) (associative properties) $\forall a, b, c \in G$ it holds that $a(bc) = (ab)c$

2) there is a *neutral element* ***u***, such that $\forall a \in G$ $ua = au = a$

3) $\forall a \in G$ there is an *inverse element* a^{-1} such that $a^{-1}a = aa^{-1} = u$

Such three requirements are called *axioms of the group.* The total number of the element of the group is its *order.* The group is said *abstract* when the abstract scheme of composition of the group is considered, while the nature of the elements is ignored or unknown. In this sense they could be algebraically treated. The groups could be further distinguished according to their characteristics: for instance they could be abelian (commutative)[220], finite

---

[219] We saw the concept of transformation to be an extension of the concept of translation in terms of a biunivocal correlation between, say, two sets of elements which preserves the metrical structure (hence the metrical groundform) of the first into the second.

[220] A group G is *abelian* if given any two elements $a, b \in G$ the $ab = ba$ holds. Furthremore, it is *finite* or *infinite*: in the first case it contains a finite number of *n*-elements, in the second case it contains an infinite numbers of elements. The group is continuous if its elements depend on arbitrary parameters which vary

or infinite, continuous and so on. These characteristics emerges in the multiplication table, thus enabling their distinction into isomorphic classes according to the different schemes of composition indicated by the multiplication table. Hence the study of the properties of space through the study of transformations and invariance under transformations brought the research on an highly abstractly characterized domain. A first example of group of transformation is the Euclidean group E_3 which consists of all the translations, rotations (with respect to a defined point) and roto-traslations (the composition of the two). The rigid movements in the Euclidean space are invariant with respect to this group, which indeed defines the Euclidean geometry.

Though the research in such domain grew as a general study of relations, apparently divorced from intuition, the parallelism with the physical domain is still at work through the concrete representations[221] of the groups and the possibility to establish isomorphisms between different domains. For instance Weyl uses the notion of isomorphic representation in order to represent space in the field of linear algebra, due to the introduction of Cartesian coordinates. He also makes the example with electric circuits and currents' distribution, whose representations satisfy the laws of Euclidean space, enabling us to derive for specific problems (example of distributions of current in case of electromotor forces) the kind of allowed solutions and the methodologies for calculations(see Auyang). In this respect it emerges the power of symmetry analysis in leading the solutions for complicated systems of equations: this will be a fundamental element in the employment of group theory in Quantum Mechanics, mainly in Wigner's program.

Hence Geometry and physics emerge as two fields that cannot be superposed, nor reduced each other: they rather represent two crossing domains. The former finds its proper validity in physics, from which it is derived through abstraction and idealization.

---

according to continuity (i.e. according to continuous functions) in such a way that it possible to pass from an element of the group to any other element through that continuous variation.

[221] The representations of the group are the 'operations' which a group of transformations induces into a given space. They represent in some sense the way the group 'act' on the space.

§4.3.1. Conceptual perspective

The relevance of the notion of group in our history relies in the first place in the fact that it enters the characterization of space. Indeed Klein's work introduces a mean to deeply inquiry into the mutual relationships between different geometries[222]: he characterized geometrical structures according to the invariants of a transformations group. According to Weyl (1951: 476-7) the aim of Klein's program is to fix as *invariant with respect to the very group* the operations of a given transformations group[223] of a manifold. From the study of transformations group Weyl gets the definition of abstract group: " *If we study a group of transformations we ignore that it consists in transformations and we simply look at the way each couple(pair) of transformations S,T gives a composite ST, we obtain thus the abstract scheme of composition of the group.*" (Weyl 1951: 447). The nature of the element of the group is *unknown* or *irrelevant*.

In the previous chapter it has presented the way the definition of a group is conceptually interesting, for instance in Eddington's account: in the first place the relevant feature is the *rule of composition* for couple of elements, which Eddinton takes to resemble his idea of *interrelatedness*; in the second place he revolves the perspective of the elements of the group and consider them as gaining their characteristic as element of the group.

In introducing the notion of *group* Weyl considers a point-field (as a generic domain of elements) on which some transformations operate and takes it to underlie the transformations. The point-field could contain a finite number of elements individually separated or an infinite number, i.e. a continuum of elements. For instance space and time could be considered as continua of elements.

An important feature is that the work on invariances under transformation enable the individuation of some properties: in the first place the properties of certain objects (as the geometrical figures), in the second place the properties of space. In the third place we will be able to define some requirements for our descriptions: indeed, once we found certain

---

[222] On the other hand his work involves that the, for now, geometrical object (i.e. the object of geometrical research) is not anymore a single isolated figure, rather it is the operations which transform one into the other such figures (Ihmig 1999: 519).

[223] This is also the topological point of view, which studies those properties of geometrical figures, which persist even when the objects undergo such deep deformations that they lost all their metrical and projective properties (Courant and Robins: 353).

properties of space, we will find that our descriptions are bounded to respect those symmetries.

§4.3.2 From mathematics to physics

Apart from the conceptual 'suggestions', which is the primary concern in the early structuralist perspective, the group theory chief feature is its finding a fruitful domain of application in physics through becoming the most appropriate language to express certain physical properties, a feature which led the interest of OSR.

This is already evident through the studies on space so far mentioned. We saw the work of Riemann in enlarging the study on surfaces toward the concept of *n*-dimensional manifold. We also saw the development of Klein's program in studying properties of invariance and defining geometries according to the relevant groups. In his work the emphasis for the purely abstract analysis seems to leave aside Riemann's emphasis on the physical link. The emphasis on *abstract* groups is not surprising in Klein's perspective as he developed his program on the ground of a clear distinction between pure and applied geometry (Ihmig 1999). He does not manifest an interest toward the physical significance of geometry: in his view the, say, "divorce from intuition" is not a problem, it is maybe taken as a matter of fact, and the interest move to purely geometrical properties and operations. On the other hand Weyl (1949) comes back to the issue. The aforementioned claim that geometry attains its full validity in physics neither implies the reduction of the former to the latter, nor *vice versa* the reduction of physics to geometry.

The physical *validity* is obtained through

1)   the definition of geometries according to the transformations groups, which bears the identification of the fundamental group of special Relativity, namely the Lorentz-Poincarè group.

2)   the link between such transformations and the characteristics of space as homogenous and isotropic. In some sense such properties connect space with the possible interactions within it.

3)   The intimate link, enlighted by Emmy Noether's theorem(1918), between the properties of symmetries with respect to certain transformations and the conservation of some fundamental quantities. It defines the possibility to

individuate certain conserved quantities *via* the invariant symmetries of dynamical equations. Indeed from the invariance of the dynamical equations through temporal translations, rotations and spatial translations, the laws of conservation of energy, angular momentum and impulse follow (both in Newtonian and relativistic physics) [224]. Thus in a mechanical system, each symmetry corresponds to the conservation of a quantity. Those principles of conservations so far taken as un-demonstrable and self-evident are "plugged" into the symmetries of the physical systems. Those invariances reflect, on the other hand, the mentioned properties of space(time)(the homogeneity of space and isotropy).

As we move to General Relativity, the mutual relation between the field and the metric establishes the invariance of physical laws for moving bodies, through the fact that moving bodies drag the metric field, despite the non-homogeneity of the metric field. In this respect we get back the character of invariance under translations which characterized the Euclidean space due to its homogeneity. Indeed in the Euclidean space the congruence of bodies, namely their superimposition, manifested the homogeneity of space. In the space of General Relativity the reciprocity between metric and matter gains back the invariance not any longer in terms of superimposable bodies, rather in terms of the invariant interactions due to congruent transformations. The fundamental group of General Relativity is the group of all the automorphisms of spacetime into itself (Ω, the group of all differentiable transformations)[225].

The most interesting point is that such a connection between mechanical properties and the nature of space and time, finds a natural place within the structure of Quantum Mechanics. This means that physical systems present some properties of symmetry

---

[224]In particular: the invariance under temporal translations brings to the conservation of energy, the invariance under spatial translations brings the conservation of linear momentum and the invariance under rotations brings the conservation of angular momentum.

[225] Bailly and Longo (2007) distinguish symmetries in external and internal. Accordingly in the theory of Relativity the symmetries are *external*: they are *sets operating over space-time*(Bailly-Longo). They express plainly their role under the Lorentz-Poincarè group (= invariance over translations and rotations within a Minkowski space). In GR the relevant group is the group of diffeomorphisms of space-time. In quantum symmetries are considerable as *internal* symmetries "*operating on fibers of the corresponding fibrates: it is the gauge sets which generate the gauge invariances and present themselves as Lie groups (continuous group)*"(Bailly and Longo[2007]:7). In many situation we rather observe phenomena of symmetry breakings which are due to the arrow of time and dissipation, in the theory of Relativity; in quantum mechanics we have the goldstone and Higgs field symmetry breakings which are the (considered) sources of the masses of quantons.

(invariant under certain transformations) which reflect the conservation of some physical quantities of the very system.

§4.3.3 Symmetries and Quantum Mechanics

The shift from the group theoretic applications in spacetime physics to group theoretic applications in Quantum Mechanics is due to two internal symmetries of physical systems: the first concerns the peculiar property of spin of quantum particles; the second refers to the permutations invariance of quantum systems due to the indistinguishability of particles. Through such symmetries the group-theoretic language enters the classification of the energy levels of the atoms in a way that makes the structure of atomic states independent on the details of the dynamics: indeed they are linked to the properties of symmetry of the atoms with respect to rotations, spatial reflections and the exchange of electrons thanks to their indistinguishability. Moreover, the group theoretic approach makes it possible to find the solutions for certain equations in the cases of *n*-electron atoms and to find some constraints for the systems which explain the peculiar statistics of Quantum Mechanics.

Hence the emphasis on the importance of group-theory is not the attempt to reduce physics, especially the understanding of Quantum Mechanics, to such a mathematical instrument (as if the slogan would be "group-theory and nothing more!"). The target is different: analysing symmetries of physical systems provides a lot of important informations concerning some properties of those very systems[226].

Thanks to the established connection between group theory and physics, in the years'20-'30 in Göttingen Eugene Wigner, Werner Heisenberg and Hermann Weyl began to work on the translations of the outcomes of group theory to Quantum Mechanics. Hence in 1926 Eugene Wigner and Werner Heisenberg published a number of works on the *Zeitschrift für Physik* on permutation of electrons generalizing toward atoms with *n*

---

[226] Also Wigner noted, such an analysis of the symmetry properties of physical systems is made *before* solving equations, before doing calculations. Auyang also remarks that "*Since symmetries reveal the overall structures of physical systems, they provide a powerful tool to extract information about the system without knowing the details of its dynamics*" (Auyang 1995:35).

electrons. Such works made clear overall that the theoretical studies in physics must deal with group-theoretic properties. After a few years Weyl published his masterpiece on the argument: *Gruppentheorie und Quantenmechanik*. The aim of the work was a derivation of the relevant Quantum Mechanics' relations in connection with group-theoretic principles of symmetry[227]. He puts the emphasis on the importance of the standpoint afforded by the theory of group in the understanding of quantum mechanical laws: the desire is to show how concepts arising within group theory find physical application in physics[228].

The two programs of Wigner and Weyl deal with the two fundamental symmetries holding in Quantum Mechanics: permutation invariance and rotational symmetry:

1) the laws governing the possible electronic configurations grouped around the stationary nucleus of an atom or a ion are spherically symmetric[229] with respect to the nucleus(rotations 3D).

2) the configurations are invariant under permutations since the various electrons composing the atom are identical.

In particular quantum mechanic and the theory of representations of groups share the same mathematical field of operation which is the n-dimensional affine space. In order to understand it we must remark that in Quantum Mechanics each physical system is described through the Hilbert space[230]. The autovalues of the autofunctions on Hilbert

---

[227] The history of the introduction of the group-theoretic language into quantum mechanics is recently treated from the starting point of Mackey's distinction between two main research programs: Wigner's program (Wigner 1926, 1927 and 1959) and Weyl's program (1925, 1927,1928). They basically differ for the perspective through which the group theory is applied to quantum mechanics: Wigner directly refers to its application to quantum phenomena (especially to the nucleus), Weyl founds a more general introduction in the very *foundation* of quantum mechanics claiming the group-theoretic language to be the most appropriate language for dealing with the theory. On the other hand, they both follow from the works of Heisenberg and Dirac on quantum statistics of the systems of indistinguishable particles, which provide the fundamental statistics for the quantum domain (Bose-Einstein and Fermi-Dirac) differing from the classical one (Boltzmann).

[228] "*Transcendental methods, which are in group theory based on the calculus of* group characteristics, <u>have the advantage of</u> <u>offering a rapid view of the subject as a whole, but true understanding the relationships is to be obtained only by following an</u> <u>explicit elementary development.</u>" (GTundQM, p.ix).

[229]The rotational symmetry requires an idealization since the inter-electronic interactions must be ignored.

[230] The Hilbert is an *n*-dimensional "*space of vectors provided with a rule for the scalar product*" (Allori et al. 2005:240, my tr.). It is a subspace of the *functional space* (any point of the space is a function $f(x)$) whose points have a determinate and finite distance from the origin. The vectors **f** of the Hilbert space represent functions *f* linking the points of the space. The modulus of the vector, i.e. the positive number $|\mathbf{f}|$, is the *norm* of the function *f*. The unitary vector is called *versor*. The *normalized functions* are those function whose norm is 1,

space represent different possible values of a physical quantity. Hilbert space could be divided into subspaces which are *invariant and irreducible*[231] *with respect to a particular group* (French 195 –by Weyl 276). Weyl intuited a relevance of group-theoretic features in the understanding of fundamental properties of microscopic realm.

Concerning 1): through this fact Weyl endeavours the treatment of the kinematical structure of atoms in terms of the rotations group. In the first place he derives from it the components of the *moment of momentum*(or angular momentum)[232] and separates it into the orbital moment of momentum (which appears in classical mechanics) and the spin moment of momentum (spin or intrinsic angular momentum) which both satisfies some commutation rules. Then he recognizes that only their sum, i.e. the total angular momentum, satisfies a law of conservation. Then gradually he associates the treatment of all the quantum numbers. Moreover, through the introduction of the rotations group he establishes a fundamental analogy between the kinematical structure of a physical micro-system and an irreducible Abelian group of rotations of unitary ray in the Hilbert space: "*the kinematical structure of a physical system is expressed by an irreducible Abelian group of unitary ray rotations in system space. The real elements of the algebra of this group are the physical quantities of the system; the representation of the abstract group by rotations of system space associates with each such quantity a definite Hermitian form which "represent" it. If the group is* continuous *this procedure automatically leads to* Heisenberg's formulation" (Weyl 1931: 275-276). The group of rotations induces a group of transformations in Hilbert space such that it decomposes into invariant subspaces. In each subspace the rotations group has a definite representation, which Weyl indicates via an index $j = 0, 1/2, 1, 3/2 ...$The corresponding subspace has $2j + 1$ dimensions. The real elements of the Abelian group of rotations of unitary ray are taken to represent the physical quantities of the system.

In particular Weyl imposes the requirement of *continuity* and *irreducibility*[233] to the group. Through such requirements he obtains Heisenberg's formulation (through the

---

i.e.represented by the versor. On the space of Hilbert it is possible to represent the *linear operators* which operates on the states of quantum objects.

[231] Consider a correspondence U of a space R into itself. A linear subspace R' of R is said to be **invariant** *under* U if the vectors of R' are transformed into vectors of R' by U. A system of correspondence S (for which R is invariant,ndr.)… is called **irreducible** if R does not contains any other subspace than R itself and the space 0 consisting only of the vector 0 which is invariant under S.

[232] "*The moment of momentum plays the same role with respect to the virtual rotations of space as the energy with respect to the actual displacements in time*"(Weyl 1931: 187).

[233] See notes 35 and 52.

continuity) and the possible couples of canonical variables [234](through the irreducibility). Finally he couples the picture with the representation of Schroedinger's equation and achieves the sole possible irreducible representation which is physically *existent*, also showing how to derive from Heisenberg's commutation rules a particular operator of Schroedinger's equation[235]. The operator for the angular momentum is separated into 'partial' operators: each one acts on one subspace of Hilbert space. They can be tracked independently on the details of the dynamics of the physical system. On the other hand French remarks that "physically" something else happen: the dimension of the subspace is physically the degree of multiplicity of an energy level (French 1999:195). The physical counterpart of the group-theoretic characterization are first of all the energy levels[236]. A quantum state corresponds to each level. To each quantum state (energy level) corresponds a spectral term. This is fundamental for the complete description of quantum relations: all quantum numbers, but the principal, are *indices characterizing representations of group.* (Weyl 1931: xxi). Moreover, group theory *reveals the essential features which are not contingent on a special form of the dynamical laws nor on special assumptions concerning the forces involved. (ib.)*

Through two different approaches, the works of Dirac and Heisenberg emphasized the derivable consequence of the indistinguishability of particles. For instance Heisenberg linked quantum statistics with the *symmetry characteristics* of the *relevant states* of the particle systems, where the relevant states in such a case are the spins of the particles. Starting from the works of Heisenberg and Dirac, Wigner and Weyl developed their group-theoretic account of quantum mechanical systems, serving two slightly different purposes. Wigner "*was concerned with the solution, or side-stepping, of the dynamical problems by focusing on the underlying invariances of the situation*"(Bueno&French1999: 39). The issue is the following: the description of physical systems is provided by their Hamiltonian (which summarizes the relevant physical quantities of the systems and associates them with vectors on an Hilbert

---

[234] The *canonical variable* are positions and linear momentum.

[235] The precise derivation could be found in Weyl(1931) pp.272-280. In order to gain a general perspective see Bueno&French(1999) and French (2000). It also could be useful to consider Wigner's memory of 1939 on the inhomogeneous lorentz group.

[236] The energy levels are those discrete values which Energy could assume according to $E_n = -\dfrac{1}{2}\dfrac{Ze^2}{a_n}$

where Z is the atomic number, *e* is the electronic unity of charge of and a_n is the ray of the *n*th orbit. In its Hermitian form, the observable "Energy" is $H \rightarrow -\dfrac{h}{i}\dfrac{\partial \psi}{\partial t}$.

space), which has certain eigenvalues. When a *n*-electrons atoms with *n>3* is perturbed, the effects on the Hamiltonian (i.e. the splitting of the eigenvalues) is difficult to calculate with standard methods, but Wigner noted that it is suitable to be calculated through its group-theoretic representation. In order to do it Wigner[237] tracked the two key features of Heisenberg formulation:

1. states could be parted into *n!* groups (irreducible) such that an atom in a state in a group cannot pass into another state in another group. Thus atoms are univocally characterized, according to the symmetric or anti-symmetric characterization. The anti-symmetric side obeys Fermi-Dirac statistics, the symmetric one obeys Bose-Einstein statistics.

2. Moreover, one of such groups obeys Pauli's exclusion principle (thus Fermi-Dirac statistics), thus adding a further characterization: the irreducible groups of permutations are also linked only with certain properties associated with the spaziotemporal symmetries (irreducible representation of Poincarè group).

   The analysis in terms of the group-theoretic characterization of the system is due to an internal connection between the irreducible representations of the symmetric permutations group and the representations of the group of unitary transformations in Hilbert space. It is also due to the fact that

the states of quantum system are represented into the Hilbert space: the group-theoretic representations reduce the state-space of a system of indistinguishable particles into invariant sub-spaces and imply a separation of the states of the system into sets of dynamically non-combining states (French 2000: 194). Thus the indistinguishability enable the application of permutation group in order to calculate the splitting of the eigenvalues (not the eigenvalues per sè, but the way they split, i.e. the sole possible combinations of outcomes.. which reflect physical situations).

   A similar discourse is made by Weyl in considering a system of two identical particles. The physical quantities of their joint system, represented by an Hermitian form[238], are

---

[237] Wigner (1931) *Group Theory and its Application to the Quantum Mechanics of Atomic Spectra* New York Academic Press (english version 1959).

[238] In quantum mechanics each state of a system is represented by a particular vector **r** modulus 1. The physical quantities associated with the system are represented through hermitian forms in the space. Hence the hermitian forms Q represent all possible physical quantities of a given system in a system-space. The hermitian forms are introduced in the unitary geometry by means of replacing some previous quadratic form,

objective (i.e. they have a physical meaning) when they symmetrically depend on the two particles. Hence their correspondent system space[239] is reducible into two irreducible independent sub-spaces A and B, respectively the space of symmetric tensors and the antisymmetric. Our expectation is that nature uses just one of the two subspaces for our original system, as they are non-combining subspaces. But our formalism per sé does not say whether it is the case that A or B holds. The choice depends on further principles (as Pauli's one) which help to distinguish the *kind* of particle we are dealing with[240].

Weyl individuates some fundamental *reciprocity* (to say it with Bueno and French) within the mathematical apparatus which is extremely significant at the physical level, since it lets identify the useful representations in order to individuate the sole physical possibilities. Together with Wigner they established a fundamental correspondence between the representations of the group of all unitary transformations[241] (which lies on a linear manifold of all the tensors of order *f* which satisfy certain symmetry conditions) and the representations of the symmetric group of permutation of *f* things (which express the symmetry properties of a tensor in terms of linear relations between it and its *f!* permutations). (Weyl 1931: 281). Such a reciprocity is a relation to which quantum physics *very naturally* (Weyl - 291) is associated (or associates). Since this reciprocity holds then group theory is suitable for Quantum Mechanics.

Our long route from the conceptualization of the space, to its properties, to the rising of invariance, finally makes the theory of group 'landing' on the domain of Quantum Mechanics.

---

used in determining the absolute magnitude of a vector. All the questions concerning physical quantities in quantum mechanics are questions concerning its *possible* values and the *probability that it assumes a definite one of these values in a given case.*

[239] The particles are represented by vectors $r = (x_i)$ in a system-space $\Re$. The system-space corresponding to the physical space I^2 of two identical particles is $\Re^2 = \Re \times \Re$ whose vectors are the second order tensors $r = (x_{ik})$.

[240] $\rightarrow$ according to Weyl there is not an alibi for the electrons – there is not the possibility for the first to say I'm ike and for the second to say I'm mike. The differentiable case is not included = the two individuals has not an identity = leibnizian *coincidentia indiscernibilium* holds in quantum mechanics.
…it is even more odd, since weyl does speak of individuals.

[241] A unitary group is made of all the unitary matrixes of a given order *n*. It is a Lie Group, i.e. it is a topological space *S* to which a group-theoretic structure has been attributed. $\exists x \in S$ there is a transformation *t* of a certain manifold *S'* into itself. U(n) is the multiplicative group of all the unitary matrixes. SU(n) is the subgroup of U(n) with matrix 1.

In such a route we saw the notion of *invariance* acquiring the great importance as referring first of all to geometrical objects (figures), then to the space and finally to some characteristics of both certain physical equations and certain physical systems. In such a route we also continuously found a particular reciprocity between the two linked domains: geometry and physics. On the other hand in the final landing-place such a link needs a further support: though we saw that the group theoretic approach enters both the description of the energy levels and of the internal constitutions of quantum systems, the group theoretic characterization of the physical domain needs an interpretation which lets us understanding what meaning should be attached to it in terms of the underlying ontology of physical science. Moreover as a significant role in the link between the two fields (quantum theory and group theory) is played by an relation internal to the mathematical apparatus. But it also must be minded that it is balanced by the indistinguishability of particles on the physical side.

As well as the study of the different geometries was in the end the study of what the space is, it seems that the study of the properties of quantum should at least suggests something about how they should be considered. Hence in the second part of the work we will consider in a critical sight the 'lesson' which the ontic structural realist wants to gain from the group theoretic characterization of quantum systems.

Part II

§4.5. Group theory, Quantum Mechanics and the constitution of objects

Which lesson should be gained from the holding of symmetry principle? In which terms does the group theoretic characterization of the fundamental properties of particles tell us a story on the metaphysics of physical objects? The ontic structural realism wants to gain from it its own peculiar structural story on the relevant ontology of the theory, claiming that physical objects should be better "*reconceptualized in structural terms*"(French 2006b:180) as nodes of relations, devoid of individuality and intrinsic properties. Within this claim it couples both the group-theoretic characterization of quantum properties and the metaphysical underdetermination of Quantum Mechanics.

With respect to our starting point, that is Eddington's approach to scientific knowledge, the insistence on the group theoretic characterization constitute a step ahead since Eddington did not deepened so forth the details of such a characterization: he did not expressively treat the group-theoretic characterization of quantum particles. On the other hand he focuses on the quantum indistinguishability of particles, which is the first element enabling the connection[242], since it bound the possibility to apply the language of symmetries.

One of the feature which Eddington genuinely anticipates is the employment of the group perspective with respect to the objects of knowledge. Whilst our physical objects (particles) behave as elements of a group, it could make sense to say that their characteristics are defined through the relations in which they stand with respect to the whole. Indeed, among the others, the elements of a group are defined through the proper operations of the group and they are neither isolated nor independent with respect to it. Through the analysis of the group theoretic characterization of particles, the structural realism[243] allegedly is a step ahead with respect to Eddington's view precisely in providing a

---

[242]On the other hand it also ought to be noted that Eddington in considering the wave-tensor calculus on the one hand recalls the blanck sheet, on the other hand says he starts form "*the properties of symmetry and antisymmetry of the matrices of a certain system*"(1936: 40).

[243] The explored idea of OSR lies on the persuasion that it is impossible to describe the most fundamental features of matter (world) without some scheme of symmetry. The issue is always to pass from description to

sense in which the holistic-structural approach of the former could be substantiated in a realist sense. Through this perspective the *structural reconceptualization* could be evaluated, according to us, in its philosophical consequences in terms of fundamental ontology.

According to us a crucial point in the discussion on such ontological consequences is the association between the group theory as the suitable language for physics and the *constitution of physical objects*, which has been emphasized by Castellani (1993; 1994; 1998). In her view, the theory of group provided a useful mathematical language in order to manage the invariances of physical systems. It provides a *method* for the identification of those properties, which accordingly are considered as *relevant* due to a common association between the notion of invariant and the notion of objective. In this sense, according to Castellani, group theory provide a way to *distinguish* the objects within the theory. It ought to be noted that the possibility to *distinguish* objects is not to be meant a sort of principium individuationis: the distinction according to the group-theoretic characteristics enables a differentiation according to *kinds* (electrons, protons, neutrons, and so on). Hence Castellani individuates a first group of properties: "*The invariant properties which are ascribed to a 'particle-object' on the basis of group-theoretical considerations - as, for example, definite properties of mass and spin are ascribed to a (quantum) particle which is associated with an irreducible representation of the Poincaré group - are necessary for determining that given particle (an electron couldn't be an electron without given properties of mass and spin), but they are not sufficient for distinguishing it from other similar particles. In addition to these 'necessary' properties (sometimes called 'essential' properties), one does need further specifications in order to constitute a particle as an individual object*"(Castellani 1993:109). She uses the term *necessary properties* to indicate the usually defined *intrinsic properties*. We accept her nomenclatures, as it is more suitable to be associated with a structural perspective: the character of *necessity* does not enable the separability of the system from the rest which instead is involved from the *intrinsic* qualification. Moreover the necessary properties of definite mass and spin are as much necessarily associated with certain irreducible representations of the Poincarè group[244] (i.e. to a certain spatio-temporal symmetry).

On the other hand the spatiotemporal symmetries, represented via *certain* representations of the Poincarè group are associable to the properties of mass and spin. In associating the *necessary properties* with the spatiotemporal symmetries, they maintain their fundamental character, but they lose their intrinsicness in terms of independence and

---

reality: this is a general problem of realism, which is deeper in quantum mechanics as we deal with *operators* which cannot strictly speaking be taken as the real objects/properties of the world.

[244] The Poincarè group is the group of transformations in the minkowskian spacetime.

perfect separability from the rest. Furthermore "*in addition to spatio-temporal symmetries, there is the permutation symmetry which needs to be accommodated within this approach*" (Castellani 1993: 109). In considering Quantum Mechanics the latter is the most important symmetry. The two descriptions provide a possible characterization of particle-objects in terms of a *natural kinds* classification. On the other hand it fails to indicate the individual objects: i.e. *individuality* evidently relies on some further principle. Castellani defines it following Mackey's notion of *systems of imprimitivity*, which would "*determine 'particularizing' observable quantities such as position*"(French 2006: 177). Rather than supplementing the group-theoretic account with a somewhat principle of identity French and Ladyman look for a structuralist reading of the group theoretic description.

A first point to be noted concerns the fact that their target is still a *natural kinds* domain. In this respect the ontic structuralism realism (henceforth OSR) seems not to be meant as a sort of mathematical Platonism. The group theory would then provide the realist with a classification whose fundamental *kinds* are the fermions and the bosons followed by the description of the relevant properties associated with the Lorentz-Poincarè group, as well as in Castellani's account.

OSR takes the link between symmetry and indistinguishability as fundamental since it makes the permutations of particles to be "*treated as a symmetry of the systems*"(French 2000: 103), what should enable a *categorization of elementary particles as, ontologically, nothing more than sets of invariances.*(*ib.*)

The issue holds for the '*ontologically nothing more than*'. Compare the two following:
1) Categorization of elementary particle as sets of invariances.
2) Categorization of elementary particle as, *ontologically, nothing more than* sets of invariances.

Statement 1) involves the idea that a suitable *classification* of particle is to be done according to their description in terms of invariant properties / symmetries.

Statement 2) involves a, say, "ontologization" of the descriptions, which sounds difficult. Nor it is a prerogative of the structural account since it could perfectly be developed within a standard realist approach, for instance through the bundles theory:

- elementary particles(objects) are bundles of properties
- properties are sets of invariances (and so the bundles)
- elementary particles (objects) are sets of invariances.

The challenged feature concerns the possibility that a categorization of elementary particles, hence in some sense a taxonomy, could be 'ontologized': they should *ontologically* be *nothing more than sets of invariance*. What could a set of invariance mean *ontologically*? A reference to the *representative* role of the description must be added.

A fundamental element in this view concerns, according to us, the shift from a criterion of objectivity of the descriptions toward a criterion of objecthood. The issue is not so much the structuralist perspective, i.e. the focusing in the relations among relata, rather the ontologization of the descriptions – which is heavier or at least more evident in OSR, at least in French's paper (2000).

On the contrary the statement 1) induces a reflection on the kind of properties involved, which are properties of the systems (i.e. non intrinsic). Such a reflection *could* be further developed in structural terms (or not). <u>Once</u> we understand that the fundamental properties are properties of the systems and we decide to endorse the holistic view in his structuralist acception *due to the way we gain it* from General Relativity, according to Eddington, or from Quantum Mechanics, <u>then</u> the ontology of structures could be suggested not in terms of a transfer of the mathematical structure into the world, rather as a sort of ontological holism mathematically informed at the level of descriptions: s*tructuralism* then, since the relevant features of the descriptions are provided according to the mathematical structure of the group-theory and suggest on their turn a holistic view of physical systems in terms of complex (wholes) of relations and relata. In this sense Eddington's approach could be a leading perspective. Our purpose is to follow the route of 1), which considers the classifications, the descriptions. It is not motivated by the specific of the quantum underdetermination, rather from the approach with the consistent research on the significance of the involved language of theories, the significance of geometry in his link with physics, the development of the studies on space, the significance of certain group-theoretic descriptions.

Summarizing OSR involves two ideas on objects:

a) object are better reconcepualized in structural terms

b) they are to be taken as *ontologically, nothing more than sets of invariances.*

The two do not necessarily go together.

In interpreting invariances different route could be followed. French (2000) quotes Born which said that *invariants* are the *concepts* which science treat *as if* they were things. To this perspective a 'but they are not' should be added: *invariants* are the *concepts* which science treat *as if* they were things *but they are not* and (continuing) for which it provides names as if they were ordinary things, *which they are not*. In this respect the fact that we represent them group-theoretically does not force the *understanding* as sets of invariances. In other words, an interpretation is to be provided: the interpretation has to consider the features emerging from the descriptions, but it does not have to 'ontologize' them.

On the other hand the ontic structural realism maintains that there holds a differentiation in the (according to the structural realist) structure they want to accept as the physical one, the structure of the world. As mentioned it is indicated at the mathematical level in the symmetric and antisymmetric enabled representations. In order to set aside the above claim b) and to rather develop a) it could be remarked that the mentioned differentiation attains its full meaning once a further principle is involved which fixes and motivates the distinction in the taxonomy(Pauli's Principle). In *this* a sense the first *natural kinds* emerge: fermions and bosons. Moreover, a further specification of the natural kind structure is due to the link with the spacetime symmetries. The combination of such multiple and fundamental descriptions produces an interrelated structure. For sure it brings into the picture a mutual dependence into *n* - particles systems. On the other hand it does not force the avoidance of the relata.

Indeed the further issue concerns the fact that the process which bring us to a certain metaphysical characterization *begins* with a classic perspective of the phenomena. It breaks into the quantum domains. The entities are classified via the permutation group which enables the distinction in fermions and bosons. On the other hand, in front of the metaphysical underdetermination the theory fails in providing a guide to ontology. French concludes that *"thus the elements themselves, regarded as individuals, have only an heuristic role in allowing for the introduction of the structures which then carry the ontological weight"*(1999: 204). Despite the fact that particles evidently have an heuristic role in leading to their very group-

theoretic characterizations[245] they are further dismissed from the ontological picture, at least from bearing an ontological weight. The dismission of the ontological weight of particles in the picture still represent an open issue for OSR, which motivates our looking at rather moderate form of structuralism.

The way group-theory 'meshes' with Quantum Mechanics for sure induces a difference with the pure mathematical theory. Perissini claims that the pure group theory and its quantum mechanical counterpart are not strictly speaking identical since "*they are about different things: the groups/members that appear in quantum theory are taken to be specific group/members that are interpreted as the physical properties (spin) of physical objects (particles)…The physical interpretation, which is at the heart of the difference between pure theory and physical application, is far from being trivial as a look at the details of mathematical application will reveal*"(Perissini, quoted in Bueno and French[1999]: 61). In replying to such a view Bueno and French note that a plain idea for the 'interpretation' would involve a complete understanding of the physical object (object vocabulary) which is not the case in quantum domain:" *if the fundamental basis of what grasp we have of the fermionic nature of electrons lies with group theory, how can we separate the 'pure' mathematical vocabulary from the physical object vocabulary?*"(*ib*.1999: 61-62).

§4.6. The strange case of spin

A criticism on the possibility to derive a structuralist account as due to the conceptual difficulties of the quantum domain has been developed by Margaret Morrison (2007)in a paper on the discovery of spin. The case of spin is typical for us since it is considered one of the properties which elementary particles possess intrinsically. On the other hand it is the focusing property of the group-theoretic characterization. In her paper Morrison inquiries into its ontological status as a properties since: "*Although it is defined as an internal momentum much of our understanding of it is bound up with the mathematics of group theory*" (Morrison 2007: 529). According to the received view it has been discovered in 1921 with the Stern Gerlach experiment, which is also taken as providing a *measure* of it, while the theoretical

---

[245] "*the particular sub-space in which a system is located*(symmetrical or antisymmetrical, my note) *is an initial condition, as it were, determined by the kind of particle considered* (French 1999:198).

formulation arose only five years later in the works of Goudsmit and Uhlenbeck[246]. The story of this property is really peculiar from many points of view. The main feature seems to be that the acceptance of spin hypothesis "*had little to do at that time with a 'physical' understanding of its nature nor was it linked to independent experimental verification…Our current understanding of spin seems to depend primarily on its group theoretical description which suggests, perhaps, that we ought to think about it as a mathematical rather than a physical property*"(*ib.*: 552). Nevertheless we have now experiments which prove it to be measurable in some indirect sense: "*this seems to restore a physical component to our understanding of spin and so to that extent it is perhaps best viewed as a curious hybrid of the mathematical and the physical*"(*ib.*). In this respect it seems to fit with the structuralist perspective. On the contrary, in concluding her essay, she critically tries to show that the ontic structural realist approach does not gain any further understanding of the notion of spin. Our point of view is that Morrison's criticisms against OSR prove a misunderstanding of the position. Let us consider her arguments.

As the first, she presents the alleged advantage of the ontic position with respect to the epistemic one. She claims that since the entity or property which undergoes the structural reconceptualization is dissolved into structure, *consequently there is nothing left over that would serve as the basis for 'knowing' the entity itself. The entity is not* represented *by the structure, thereby leaving an epistemic gap between the thing and the representation: the structure is all there is*"(*ib.* 553). The thesis that the ontic structural view implies the elimination of the entities will be discussed in the conclusions of the present work and our attempt is not to defend it. On the other hand it must be remarked that the re-conceptualization is a reformulation of a classical concept which proved to be problematic. In the end it induces a shift toward structure, though it does not necessarily involve their complete elimination. By the way it is not meant to create a gap between an un-representable entity and the structure: "*Let us clear: we are not 'anti-ontology' in the sense of urging a move away from electrons, elementary particles etc…rather we urge the reconceptualization of electrons, elementary particles, electrons and so forth in structural instead of individualistic terms*"(French and Ladyman 2003a:37). For sure the ontological weight of relata diminishes, balanced with a growing ontological weight of relations. On the other hand the concept of entity is not substituted by the concept of structure, rather it is

---

[246] "*In 1925, George E. Uhlenbeck and Samuel Godsmit announced that the observed hydrogen spectra can be explained accurately if the electron has, besides its orbital angular momentum, an additional intrinsic angular momentum of half Planck's constant,* $\eta/2$ " (Auyang 1995: 253, footnote 176).

reformulated in its being somehow a part of a structure, in terms of a node, whose metaphysical nature should probably be clarified but for sure is not meant to leave an epistemic gap between the thing and the representation: rather it is meant to fill that gap, which the epistemic position left, by providing an ontology which effectively arises from the theoretical descriptions.

The second issue which Morrison presents is pretty common to the realm of critics of OSR and it is that *"a closer look reveal that there is no real answer as to what these "structures" actually are"*(Morrison 2007: 554). Part of the problem in such case arises from the structural literature. It is true that the position suffers a vagueness in showing *what* is a structure. Nevertheless the very question hides a misunderstanding. Let us endorse the most naïve and general structural realist point: we want to give a new framework of understanding reality, the very same reality which the standard realist 'experiences/speaks of'. About that the naïve structural realist says "I conceive your very world in a slightly different way from yours. You think of the fundamental elements as individual furnished with intrinsic properties. I think that whilst there is individuality, it is absolutely thin and that for sure there are not intrinsic properties, since every property is determine by the net of physical/causal relations in which elements are as nodes, terminal points of intersections so as to all the fundamental 'entities' of our world. There are not such individualistic/atomic things *holding independently on the rest*, but everything is characterized, defined and determined by a place which it occupies into a bunch of physical relations". In this sense, everything in the external world, is structure. We could better say that we are in a structural universe, a relational universe, and a universe in which everything is dependent, as regard to its features, on the relation with something else.

This could seem a trivial remark, but it contains a fundamental revolution on the very understanding knowledge and reality, a revolution brought in the first place by the general theory of Relativity. For sure, this view does not dispense the ontic structural realism from its own duty to provide effectively the concrete sense in which their structure has to be meant.

Going further in considering the metaphysical reconceptualization Morrison notes that " *the ontology of these theories is not the mathematical apparatus (group theory, differential geometry) as they originally indicate, but something else, namely the structures that these mathematical entities represent"*(*ib*.). In this respect she individuates the purpose of the ontic structuralism which does not aim to tell a story about mathematical entities, rather a story on physical world as

represented through a specific and bounded mathematical apparatus. The theme deals with one of the most thorny issues, i.e. the way the interpretation of the invariant features provided by the group theory should be meant in terms of ontology. Anyway the starting claim for the discussion is that group-theory, embedded within Quantum Mechanics, gives a description/definition and such a description *must* be considered as a fundamental point in understanding the kind of property or the kind of entity it is describing. The main criticism of Morrison against the structuralist view is that it does not help at all in trying to understand the physical nature of a property like spin. On the other hand the criticism seems to be due to a misled understanding of the framework which OSR aims to provide. In this respect the very question: " *how much does this help ..in understanding the physical nature of a property like spin?*" is ill-posited. Indeed OSR is not formulated to answer the question 'what is the physical nature of a property like spin?". It is meant to provide a new metaphysical picture within which that property with its peculiar character could be set. Spin is a peculiar property; the mathematical part of it seems to count more than the physical and it is physically measurable only indirectly. Such characters, mainly the group theoretic characters, suggest that it is not conceivable as the traditional 'intrinsic property'. It is for sure a physical property, in the sense that it concerns the physical structure, the physical world. The claim of OSR is that the physically interesting properties at the fundamental level are not the traditional kind associated with singular elements/particles alone in the universe. It seems to us that the structuralist view represents a suitable approach to many particles systems, enabling an holistic view which considers the involved properties as properties of the system. On the other hand, we mentioned, such a view induces a sort of global holism in which the character of intrinsicness should be strictly speaking assigned only to the properties of the whole structure (the universe) and could eventually be assigned to the sub-structures (physical system*s*) only with a weak degree.

  A further misunderstanding moves the objection that structural realism does not help us to determine reality of that structure. According to this criticism it seems that the structural realism would pose a new thing in the world (the structure) and should be forced to prove its reality. On the contrary the ontic structural realism does not *pose* the structure *in* the world as it would be something *ante rem* whose reality (its happening/appearing *in re*) has to be demonstrated. This view could be perhaps tracked within the *mathematical forms* of

structuralism. In this respect Psillos' criticism[247] also focuses on such distinction between *ante rem* and *in re* structures. On the other hand the structural realist perspective does not face the issue to *determine the reality of the structure* since it rather pursues a re-conception of the world: it says the world to be different from how we conceived it.

The final remarks on spin, far for avoiding the structural view, recall the need of a new understanding of the metaphysical relapse of our theories: *"All too easily we knowingly and mistakenly think of spin as a rotation of a particle about its own axis, a picture which is described by mathematical relations between observables represented by numbers. But, in Quantum Mechanics the mathematical relations are operators and are not the image of a point particle revolving around a centre and rotating around its own axis. Indeed, the electron in the hydrogen atom is not such a particle; it is called a particle when it is approximately a generalized eigenstate of the position operator because localization is the characteristic property of a particle."*(Morrison 2007: 554). Moreover she says *"the electron does…appear in a form that is different from both these descriptions* (particle/wave) *as an angular momentum and energy eigenstate in which it has neither a definite position nor momentum; but it does have a definite angular momentum(rotator). In this sense spin* is *a defining feature of electron and many other elementary particles as well"* OSR's sustainers could emphasize that spin is exactly the kind of property which the structural account require: it is a fundamental property, it is group theoretically described (hence it allegedly enables the reference to a holistic perspective) and it has the *defining* function which the structural properties would have, it could be taken as a *necessary property*.

§4.7. Conclusions

Throughout the first part of the present chapter we saw that the research on the foundations of geometry and on space, which led to the great formulation of Einstein's theory in 1916, enlightened the intimate connection between (geometrical) descriptions grounding space and the very properties of space(time) and matter. In this respect it emerged a mutual relationship of significance and interrelation between the domain of physical phenomena and the domain of geometrical descriptions. In the development of such studies, a change happens in those very descriptions, progressively focusing on space

---

[247] See Psillos (2001) and (2006).

as system of relations[248] which highly recalls Eddington's idea that space is a tangle of distances interlocked.

Furthermore, a fundamental field of research emerges focusing on the *invariant* features of certain operations on space. On the basis of such invariance the theory of groups of transformations was developed, finding a fundamental application at physical level due to the connection between certain properties of space reflected in the spacetime symmetries and the conservation of fundamental properties as energy, linear momentum and angular momentum.

We spent a lot on such argument in order to provide a content for the ontic structural realist approach to the descriptions involved in the physical theories, in particular to the group theoretic descriptions. Indeed to a great extent the structural reaconceptualization of objects is led by the purpose to *take seriously* the group-theoretic descriptions of physical systems in Quantum Mechanics. Throughout the study of conceptualization of space and of its link with time and matter in General Relativity we basically explored a route in which the descriptions are taken seriously (at least in the view of Riemann and Einstein) as *significant*.

The first part's discussion was an introduction to the second part where we considered the way the group-theoretic description is involved in Quantum Mechanics and the way the structuralist perspective aims to interpret such story.

The difficulty in driving ontological consequences from the group theory relies on basically three features:

1 – Group Theory is a very abstract formalism used for many different discipline/topics.

Concernig this point it ought to be noted that, as we saw, the employment of the group theory within Quantum Mechanics is restricted in very precise way, whose constraints are expressed in Weyl's work. Indeed he is just interested in the permutations group and in the rotations group. Moreover only some of their induced representations are physically significant: in fact there are some constraints in the physically admissible representations[249] (French and Redhead remark in this sense the presence of a surplus

---

[248] For instance we saw that the vectors, tensors, metrical ground-forms represent *relations* between (generally speaking)elements.
[249] In this respect we seems to find an example in which a way appears to bring the structures from the mathematical level to the physical level via some constraints(principle) which enable a sort of *reduction* of the

mathematical structure), which indeed are taken to represent the physical possibilities. Hence the theory is not involved as a whole. The admissible representations are gained via the coupling of group theory with other principles, for instance Pauli's principle for electrons which dictates their antisymmetric representation. This point provide a partial answer to the issues concerning "why group theory?" and "to what extent?": group theory appear as a useful language in order to understand describe the energy levels and it should be surely taken to the extent of the individuated representations physically significant in accordance with some further principles(for instance Pauli's principle). Moreover the remarkable features of the theory of group is that it provides a taxonomy through which the zoo of micro-particles could be classified. And accordingly it enables some fundamental discoveries. An example is provided by Wigner's work in treating the nucleus in analogy with the atomic-structure, under the principle of indistinguishable particles. The analogy between the atomic structure and the nuclear structure was drawn after Heisenberg assimilation of neutrons and protons as two states of the same particles, nucleons. Thus Wigner gives its group-theoretic representation, where the internal symmetry of the nucleus is taken as 'isotopic spin'[250]. Through the limits of such analogy, it leads to fundamental predictions: for instance the attempt to combine SU(2) (group of isospin) with U(1) (group of strangeness) led Gell-Mann and Ne'eman to independently propose SU(3) as the fundamental group for quark model; and also Kemmer predicted the pion triplet[251].

2 –The interpretations of Quantum Mechanics usually focus on issues as the measurement problem and the deterministic/indeterministic evolution of the formalism: OSR does not precisely address them, then it is hard to see how it should be placed in terms of such traditional issues.

For sure the structural literature did not develop a proper consistent reading of the traditional issues on Quantum Mechanics. On the other hand it is our persuasion that,

---

mathematical apparatus indicating the physically significant. There is a surplus structure which actually does not (yet) enter strictly speaking the domain of physics. This fact somehow constitute a reversion of Nweman's problem: there we had the partial importation of physical domain through the mathematical domain, with the loss of significance. Here we have the reverse process, which is a process of *acquiring significance*: the possibility to transport mathematics into physics by the reduction is an index of a , say, similarity of structure which is not empty, it rather significantly bounds the possibility since it manifests that the physical domain has a proper structuration which is not trivially representable.

[250] The constraints of the analogy are that nucleus has both isospin and spin and it has not axis symmetry

[251] The limits to which wigner's analogy should be corrected indicated the need of appropriate representations and symmetry group, four-dimensional unitary group(supermultiplet).

beside such specific issues, there are genuine features in the physical and mathematical research in between the end of XIXth century and the beginning of XXth which pursue a change in perspective in the way physical knowledge suggests the ontology of theories to be derived: such a change in perspective is basically a change in the way physical objects are predicated. In particular, the better way to understand the change in perspective is provided in General Relativity which modifies the way causality and determination should be meant. The classical mechanicistic view is there abandoned in favour of a structural perspective, which emerges from the studies on space. It involves a mutual determination between metric and matter. Such a perspective could be taken as suitably expressed in Eddington's structuralism. In such a respect the structuralism seems not to be meant to solve the traditional problems of Quantum Mechanics, rather to provide a suitable reading of some peculiar features appearing within it as it might be the entanglement of quantum systems.

3 - The main issue: why should the group theory be taken to allow for a structural (realist) interpretation, rather than allowing for a traditional object-oriented interpretation?

Concerning the group theoretic descriptions of physical systems, different stories could be derived, according to the different notions of objecthood which leads the metaphysical reflection.

Thus the traditional standpoint takes the invariance as a mean for objectivity, building on it the intrinsicness of properties. The criterion of objecthood at the basis of such an identification is the idea of physical objects as individual (whatever individual might be) elements provided with intrinsic properties. In such a view the simple fact that a theory emphasizing invariances would enter quantum domain would lead us to recognise the intrinsicness of the invariant properties of that domain.

On the contrary the structural point of view, in particular the position à la French and Ladyman, considers the group-theoretic invariant properties in terms of the underlying natural kinds structure: *Thus proceeding down the 'natural kind structure' a particle will be understood as a fermion, say, in terms of the relevant (antisymmetric) representation of the permutation group (and hence the relevant symmetry of the wave function) and as an electron in terms of properties of mass and spin associated with the relevant irreducible representation of the Poincarè group, and so on*(French 2005: 171-172). The invariants describe the *nodes* of the structure. The symmetry principles are taken to create a "web of relations".

With respect to the notion of objects, the structuralist *tendency*[252] (independently of the different degree of 'thinness' of the relata) proposes an approach which is linkable with Eddington structural-holism. In some respect Eddington's approach manifests the structural perspective to be relatively independent on the issues which motivate the ontic structural rejection of individuality. His perspective emphasizes a feature of interrelatedness which is already clearly manifests within the spacetime-gravitational universe, the main structure he refers to, due to the intrinsic interrelatedness of all its constituents and to the relevance which the geometrical tools have in its description. In this sense the fact that the structural approach emerges *also* as a viable way to understand the ontology of General Relativity due to the connection between metric and matter *and* to the metaphysical underdetermination (which is problematic for the traditional realism), could be taken to support the revolving way in considering objects. In this respect the group-theoretic characterization is taken to allow for the structural perspective as the conclusion of the previous route.

In the first place we might take the structural perspective to emerge from General Relativity and to mesh in a conceptual way with the notion of group through Eddington's work and Weyl's suggestions. Once the conceptual approach is given, it also emerges that the group theoretic description affords a new deep significance in the structural-holistic understanding of the world.

In accepting the structuralist perspective as a suitable way to understand the ontology of physical world, the difference could be placed in the way the relata play somewhat role within the structure. In this respect our view differs from the eliminative approach of Ladyman and French and we prefer to follow the line of a moderate approach, which will be considered in the conclusions of the work.

---

[252]In this case we speak of structural *tendency* rather than of ontic structural realism since we do not want to be bounded to the specific position of Ladyman and French (which instead constitute a limiting case due to the eliminativism with respect to the relata). It seems to us that it could be a common feature to different forms of structuralism.

CONCLUSIONI

Relazioni, Relata e Strutturalismo Moderato

Nel ricercare le origini della riflessione strutturalista in filosofia della scienza abbiamo visto, nei capitoli precedenti, come sia possibile considerare effettivamente Eddington un precursore delle recenti posizioni strutturaliste. Le sue considerazioni, saldate nel più ampio orizzonte del significato della Relatività come punto d'approdo di una fondamentale comprensione dello spazio(tempo) e della materia, rendono l'approccio strutturalista una valida possibilità di comprensione dell'universo fisico predicato dalle teorie fondamentali.

D'altra parte il Realismo Strutturale Ontico (RSO) ha un costo metafisico molto alto. RSO non implica unicamente una forma di olismo-strutturale in base al quale gli oggetti fisici divengono nodi in una rete di relazioni, bensì propone una tesi forte secondo cui essi 1) non sono individui, 2) non hanno proprietà intrinseche, e soprattutto 3) non hanno alcun peso ontologico. Viceversa in Eddington, come nelle forme moderate di strutturalismo, la struttura è una rete di relazioni *fra* nodi, i quali mantengono un proprio peso ontologico. In conclusione di questo lavoro e nell'accettare la validità dell'approccio strutturalista all'ontologia della scienza, si intende suggerire una forma moderata di realismo strutturale.

Realismo Strutturale Ontico: relazioni senza relata

La proposta di riconcettualizzare strutturalmente le entità della fisica fondamentale come nodi all'interno di una rete di relazioni nasce, per RSO , da una duplice necessità: la necessità di rendere conto della sottodeterminazione metafisica degli oggetti quantistici e la volontà di interpretare l'ontologia fisica sulla base di quanto suggerito dal *tipo* di descrizioni in essa coinvolte[253]. La sfida del realista è di fornire una ontologia per le teorie scientifiche che sia valida, soprattutto nel dar conto delle problematiche legate alla Meccanica

---

[253] Questo approccio contrasta, ad esempio, con l'approccio di N.Huggett per il quale l'utilizzo di un formalismo piuttosto che di un altro è indifferente rispetto alle conclusioni metafisiche che se ne possono derivare (vedi Moranti, 2007). In questo senso Huggett sembra manifestare un approccio strumentalista, mentre RSO adotta effettivamente un'attitudine realista.

Quantistica. La proposta strutturalista è quella di adottare una ontologia di strutture sulla base delle relazioni emergenti dalle descrizioni fisiche. Come più volte menzionato si prendono le mosse dalle descrizioni fisiche per derivare da esse un orizzonte ontologico di riferimento. Una tale prospettiva presenta l'immediata difficoltà dovuta al fatto che una teoria fisica o una sua interpretazione non è mai condotta sulla base di una tabula rasa, dal momento che la conoscenza pregressa porta con sé una immagine[254]. In questo senso ci è stato di ausilio lo studio dei profondi mutamenti avvenuti nel campo della matematica, permettendo l'elaborazione di nuovi strumenti di analisi, descrizione e comprensione della realtà modellati sulle fondamentali proprietà della realtà stessa. In questo senso, nel capitolo precedente si è seguito l'emergere di una prospettiva, che abbiamo denominato 'gruppale', nell'interpretazione delle descrizioni fisiche, grazie al crescente affermarsi del linguaggio dei gruppi come linguaggio significativo sia in Relatività che in Meccanica Quantistica.

Questo 'umore' unificante caratterizza anche le prime formulazioni strutturaliste, assumendo assume alcune intuizioni significative provenienti da un ampio lavoro di riflessione sui fondamenti della geometria e sulla costituzione dello spazio. Weyl approfondisce il collegamento tra le descrizioni matematiche e l'universo fisico. In questo senso il suo lavoro giustifica l'ambizione realista dell'odierno strutturalismo, mostrando il contenuto *fisico* dell'approccio gruppale. Dall'analisi della costituzione degli oggetti fisici e dello spazio, che si ritrova sia nei lavori di Eddinton, che in quelli di Weyl, emerge una immagine unificata dell'indagine scientifica. E' dunque in primo luogo il carattere gruppale della fisica contemporanea a rendere il dibattito sullo strutturalismo particolarmente significativo anche attualmente.

Grazie ai principi di simmetria è possibile individuare gli invarianti per trasformazioni gruppali, ossia quelle caratteristiche che non variano al variare di un sistema fisico. Nelle descrizioni quantistiche le proprietà quantistiche con tali invarianti. Sulla base di queste

---

[254] Rispetto a questo tema, ancora una volta la prospettiva eddingtoniana provvede un'utile intuizione nel mostrare come le categorie di pensiero che informano l'attività scientifica siano suscettibili di essere revisionate. In effetti nel suo caso la prospettiva olistica-strutturale emerge da una riflessione su 1) il riscontro di categorie atomistiche effettivamente operanti e la necessità di un loro superamento 2) gli elementi emergenti dalla nuova prospettiva relativistica e 3) il *conseguente* superamento/inserimento della prospettiva precedente (individualistica/atomista) in una prospettiva nuova (olistica).Se accettiamo l'idea di Eddington che le descrizioni siano esse stesse teoricamente informate dalle forme di pensiero, anche le descrizioni non sono neutre, ma metafisicamente informate. In breve, la conoscenza precedente implica l'esistenza di una immagine metafisica previa (a livello pratico il *blanck sheet* non è mai possibile, è infatti una scelta teorica precisa per Eddington). Tuttavia queste forme di pensiero, come abbiamo visto sono modificabili. Il punto non è tanto abbandonare la prospettiva metafisicamente informata, quanto metterla in dialogo con i risultati della ricerca scientifica.

descrizioni, RSO formula una struttura naturale di tipi naturali: French (2006b) parla dapprima di una '*natural kind'structure* (*ib*.:171) e poi parla delle distinzioni interne ad esse come *natural kinds* (*ib*.:183). In questa struttura naturale la prima distinzione fondamentale è fra il tipo 'fermione' e il tipo 'bosone', senza ulteriore specificazione ontologica. Sono le rappresentazioni gruppali a fornire da base per la tassonomia di differenziazione della struttura . Nel concludere il capitolo precedente, notavamo le difficoltà sollevate da un lato dall'idea che gli oggetti quantistici debbano essere considerati come *ontologicamente* nient'altro che insiemi di invarianze, dall'altro lato dall'idea che la caratterizzazione fornita in termini di struttura di tipi naturali sia effettivamente indipendente da particelle/campi, che pure di partenza hanno un ruolo euristico nell'orizzonte strutturale. La proposta interpretativa del RSO necessita in primo luogo di una ulteriore discussione ed argomentazione del passaggio dalle descrizioni matematiche al significato fisico. Tale passaggio ha avuto una limpida delucidazione, per la teoria della Relatività, nelle riflessioni di Riemann ed Einstein. Nel caso della Meccanica Quantistica esso richiede un ulteriore approfondimento e non può essere considerato immediato. In secondo luogo, va motivata ulteriormente l'idea che la descrizione 'gruppale' debba costituire una evidenza per la dissoluzione dei relata . La riconcettualizzazione strutturale del RSO insiste in primo luogo per una eliminazione degli individui dalla Meccanica Quantistica. In secondo luogo si assegna una crescente priorità alle relazioni. Infine si vuole concludere, dalla priorità delle relazioni sui relata, che il peso ontologico di questi ultimi sia inesistente all'interno della struttura. Tuttavia è nostra persuasione che la eventuale non-individualità delle particelle non generi automaticamente l'idea che esse non abbiano alcun peso ontologico nella struttura. Inoltre uno dei primi problemi aperti per il realismo strutturale ontico è costituito dal fatto che, fatto salvo il caso dello spin, manca nella letteratura strutturalista una trattazione dettagliata della *traduzione strutturale* di altre proprietà come la massa o la carica. L'attenuante potrebbe essere data dal fatto che la massa può essere associata alla rappresentazione irriducibile del gruppo di Poincarè[255]. Ma anche in questo caso, nel momento in cui i relata sono privati di ogni valore ontologico, non si ha una chiara trattazione di come dar conto della, per così dire, *diversificazione delle occorrenze*: il fatto cioè che una certa quantità di massa e una certa quantità di carica e una certa quantità di spin provvista, sì, delle caratteristiche simmetriche, si trovino sempre aggregate insieme in un certo modo, che ci fa parlare, a seconda dei casi, di elettroni o piuttosto di protoni, o

---

[255] Cfr. Castellani (1993)(1998) e French (2000)(2006).

piuttosto di pioni o piuttosto di…lo zoo di particelle. RSO attualmente manca di una precisa delucidazione di come queste associazioni possano essere comprese. D'altro canto nè la difficoltà nel definire l'individualità, nè la sua ambigua manifestazione in Meccanica Quantistica, nè le difficoltà nella definizione delle entità quantistiche sembrano avallare una completa eliminazione del peso ontologico dei relata.

In mancanza di una delucidazione ulteriore della caraterizzazione particolare della strutture, la pretesa che i nodi non abbiano peso ontologico deve essere quantomeno indebolita. Il come poi il rapporto tra relazioni e relata vada inteso è materia di discussione e non implica un automatico ritorno alla visione metafisica tradizionale. In conclusione del nostro lavoro vogliamo pertanto sostenere una forma più moderata di realismo strutturale alla quale è possibile associare l'approccio à la Eddington, che dia conto della rilevanza delle relazioni senza indurre una completa eliminazione dei relata[256].

Sulla preferibilità di una metafisica di relazioni

Nel corso del lavoro si è trattata la posizione ontica di realismo strutturale principalmente in merito alle tesi di James Ladyman e Steven French, che effettivamente hanno formulato per primi tale prospettiva nell'ambito del dibattito sul realismo. Entrambi fanno esplicitamente riferimento alle riflessioni di Eddington e Cassirer. Nondimeno non bisogna pensare che la loro prospettiva eliminativista sia l'unica possibile forma di strutturalismo rispetto all'ontologia[257]. Al contrario, proprio le difficoltà che lo strutturalismo di Ladyman e French incontra nell'alveo delle posizioni realiste hanno generato una molteplicità di approcci al problema. Gli stessi Ladyman e French (forthcoming) presentano la propria posizione nel contesto di una rosa di possibilità.

Nel contesto delle posizioni ontiche lo strutturalismo emerge, secondo quanto visto, non tanto come una tesi concernente *direttamente* il problema dell'individualità degli oggetti quantistici. E' ovvio che, nel caso di RSO la sottodeterminazione metafisica della

---

[256] Ciò che motiva in noi un certo scetticismo rispetto alla possibilità di privare i relata del loro peso ontologico non è tanto la questione dell'individualità, quanto la questione della loro esistenza nella rete, come emerge nella prospettiva di Eddington.

[257] Nel prosieguo continueremo ad adottare la dicitura *realismo strutturale ontico (RSO)* per indicare la posizione di Ladyman e French. Per le altre posizioni si utilizzeranno diciture differenti (ad es.'strutturalismo moderato'). In ogni caso si parlerà indistintamente di 'realismo strutturale' o 'strutturalismo' mantenendo implicitamente l'istanza realista.

Meccanica Quantistica è il motore principale della tesi che conduce alla negazione di individualità degli oggetti quantistici e alla loro eliminazione. Tuttavia un vantaggio dell'orizzonte teorico affrontato nei capitoli precedenti è stato proprio quello di mostrarci come il principale target dell'approccio all'ontologia della scienza non sia tanto la questione dell'individualità o meno degli oggetti quantistici, quanto la questione della metafisica suggerita in senso globale dalla teorie scientifiche fondamentali. Le riflessioni di Eddington e di Weyl ci hanno mostrato indipendentemente questo aspetto. Ci sembra di poter concludere che il discrimine tra il cosiddetto 'object-oriented realism' e le forme strutturaliste di realismo ontico riguardi precisamente quale sia la metafisica più adatta per dar conto della nostra conoscenza e della realtà, dove le opzioni sono una metafisica individualista *versus* una metafisica di relazioni.

Nel primo caso si ritiene che il modo migliore di esprimere la conoscenza fornita dalla fisica e la realtà fisica da essa suggerita, sia adottare una metafisica di oggetti intesi come individui dotati di proprietà intrinseche indipendenti da tutto il resto, le quali proprietà fondano le relazioni instanziate tra di essi. Viceversa nel secondo caso si ritiene che il modo migliore per esprimere la conoscenza fornita dalla fisica e la realtà fisica da essa suggerita, si fondi sull'adozione di una metafisica di relazioni, in primo luogo, poi raffinabile in una metafisica di strutture.

A ben guardare, il motivo fondamentale che induce a considerare problematica la nozione di individualità nel dominio quantistico è il modo in cui questi supposti individui si comportano quando sono in aggregazione con altri: "*they behave very differently in aggregates form 'classical' individuals*" (French, 2006a). Sembra che la nozione stessa di individualità riveli la sua capacità di cogliere o meno una realtà rispondente all'oggetto – dunque in certo senso dimostri la sua validità operativa – solo nel momento in cui quell'oggetto, finora considerato in 'isolamento' dal resto, comincia ad interagire *con* il resto. In quel dominio, nel dominio dell'interazione, la nozione standard di individualità non funziona più perché gli aggregati quantistici si comportano in modo molto particolare e soprattutto differente da quello che classicamente ci aspetteremmo essere il comportamento di un sistema di individui. Il percorso che conduce a tale conclusione comincia dalla nostra comprensione 'classica' di oggetto fisico (entità individuale dotata di proprietà intrinseche e indipendente dal tutto il resto) per valutare se possa essere anch'essa, per così dire, una nozione invariante, mettendola in gioco nel 'gioco' di comprensione della realtà: quello che si scopre

è che essa NON E' invariante. Se la facciamo 'girare' sulla ruota della nostra comprensione degli aggregati in senso classico, funziona; ma se la facciamo 'girare' sulla ruota della nostra comprensione degli aggregati in senso quantistico, salta. La conclusione immediata che se ne vorrebbe trarre è "gli oggetti quantistici non sono individui". La conclusione del RSO è "non sono individui ma nodi nella struttura". La nostra conclusione è leggermente diversa, dal momento che non si intende trarre da quanto visto una lezione sull'individualità. Ciò che ci interessa è piuttosto la struttura, ossia i relata come nodi all'interno di una struttura di relazioni. Ci interessa il fatto che una reale comprensione metafisica di quegli oggetti, o un vaglio della nostra comprensione metafisica di quegli oggetti, si ottiene solo nel momento in cui si consideri la loro dimensione relazionale/interazionale, il modo in cui essi lavorano in aggregato (nella loro se vogliamo 'socialità'). La questione è dunque legata alla 'trama', per usare le parole di R.Penrose, o al tessuto della realtà. Diventa imprescindibile in questo senso un superamento dell'approccio individualista-atomista, che secondo Eddington era in atto nella comprensione e nella dinamica della conoscenza scientifica, verso una prospettiva olistica. D'altra parte la prospettiva strutturale diviene una reale opzione interpretativa, nel senso che il famoso "nodi nella rete di relazioni" comincia ad acquisire un significato concreto.

Da quanto visto nei capitoli precedenti, ci sembra pertanto che nel farsi araldi di una metafisica di relazioni (o proprietà relazionali) le posizioni strutturaliste siano effettivamente in grado di garantire uno sfondo teorico che si ritiene sia fondamentale per sviluppare il problema ontologico. Pertanto in conclusione del nostro lavoro:

1) si sostiene una metafisica di relazioni come idonea per sviluppare il problema ontologico.

2) si sostiene il passaggio ad una metafisica di strutture che mantenga l'inscindibilità di relata e relazioni, come espressa da Eddington.

Attraverso la metafisica di relazioni è possibile sviluppare l'idea di relazioni non sopravvenienti su proprietà intrinseche soggiacenti. Un raffinamento della metafisica di relazioni si ha nella metafisica di strutture che, secondo formulazioni più o meno radicali, sviluppa il rapporto tra relazioni e relata (la nozione e il peso che gli si vuol dare). La posizione sviluppata da Eddington in questo senso ammette una sorta di codeterminazione

costante tra relazioni e relata, in una forma di strutturalismo meno forte rispetto a RSO, dal momento che ammette i relata nella struttura come indisgiungibili dalle relazioni.

Nel proporre una metafisica di relazioni, e poi di strutture, un nodo fondamentale è cosa si vuol fare delle proprietà intrinseche e se esse siano effettivamente riconducibili in una trattazione relazionale. Una possibile opzione interpretative è suggerita dalla posizione moderata di M.Esfeld.

Il Realismo Strutturale Moderato di Esfeld

Come già accennato, nel terzo capitolo e nell'introduzione del presente capitolo, il primo passo verso lo sviluppo di una metafisica strutturale è l'adozione di una prospettiva olistica che oppone alla metafisica individualista una certa metafisica di relazioni, poi ampliata in una metafisica di strutture.

Nella prima, un'entità fisica fondamentale è un individuo dotato di fondamentali proprietà intrinseche indipendenti da tutto il resto e fondanti le relazioni che essa può instaurare nei confronti di altre entità. Questo punto di vista coinvolge una serie di tematiche: il tema della individualità/non individualità degli enti fisici, il tema dell'esistenza o meno di proprietà intrinseche per tali enti, il tema della indipendenza da tutto il resto, il tema del rapporto tra proprietà intrinseche e relazioni (proprietà relazionali). Negare che il mondo fisico sia popolato di siffatto genere di enti implica negare almeno una delle seguenti affermazioni:

1. gli enti fisici sono individui.
2. gli enti fisici sono dotati di proprietà intrinseche.
3. individui e/o proprietà intrinseche sono indipendenti da tutto il resto.
4. le proprietà intrinseche fondano le relazioni tra individui.

Nel terzo capitolo si erano considerati unicamente i punti 1 e 2. Tuttavia si è ritenuto necessario raffinare la questione inserendo anche i temi 3 e 4. Ovviamente i quattro temi sono strettamente collegati: così ad esempio la negazione di 1 (non individui) o la sua accettazione con la negazione di 2 (individui senza proprietà intrinseche) e /o di 3 (indipendenti/non) apre il dibattito sulla nozione di individualità; l'accettazione di 1 e 2 e la

negazione di 3 (individui con proprietà intrinseche non indipendenti dal resto) richiede una revisione della nozione di intrinsecità (tradizionalmente legata alla nozione di indipendenza), e via dicendo. Le possibilità da esplorare sono diverse, ma come guida nella formulazione di una basilare metafisica di relazioni idonea per lo strutturalismo adotteremo la riflessione di M.Esfeld. La sua posizione, essendo come vedremo di tipo moderato, necessiterebbe di ulteriori aggiustamenti qualora si volesse sostenere una posizione radicale à la French e Ladyman. Tuttavia sembra essere un buon punto di partenza per discernere tra le possibili combinazioni dei 4 punti sopraelencati.

Esfeld sviluppa la sua metafisica di relazioni in modo progressivo avendo come target principale la negazione del punto 4. Egli sostiene che le proprietà fondamentali della Meccanica Quantistica siano proprietà relazionali (relazioni[258]) non sopravvenienti. La tesi ha le seguenti implicazioni:

1) possono esistere proprietà intrinseche (con intrinsecità intesa à la Langton e Lewis[259]). 1*) Corollario: proprietà intrinseche pur potendo esistere sono tuttavia inconoscibili fintanto che non si manifestano in una chiave relazionale.

2) le proprietà fondamentali della Meccanica Quantistica *sono* relazioni

3) le relazioni della Meccanica Quantistica non necessitano di una base di proprietà intrinseche su cui sopravvenire. In questo senso sono *fondamentali*.

La metafisica tradizionale è fatta di "*independent individual things that are embedded in space-time*"(Esfeld 2004: 1) dove l'individualità è definita in base a tre caratteristiche: (i) la localizzazione spaziotemporale; (ii) l'essere un *soggetto di predicazione di certe proprietà* e (iii) il sussistere di proprietà *qualitative* che permettono di distinguere ciascuna cosa da una qualsiasi altra[260]. Tutto ciò che manifesta (i), (ii) e (iii) sarebbe poi indipendente perchè le sue proprietà fondamentali sono intrinseche. Il problema fondamentale nella standard view

---

[258] L'approccio strutturalista propone una metafisica di relazioni. Possiamo seguire Esfeld nel concepire relazioni e proprietà relazionali come sinonimi, indicanti proprietà *n*-adiche (proprietà dal momento che anch'esse vengono predicate circa le cose).

[259] Esfeld definisce proprietà *intrinseche* (o monadiche) "*all and only those qualitative properties that a thing has irrespective of whether or not there are other contingent things; all other qualitative properties are extrinsic or relational*"(2003: 1). In questa definizione Esfeld riprende la nozione di intrinsecità à la Langton e Lewis(1998) aggiungendo un vincolo sul fatto che in quest'ottica le proprietà fondamentali, siano esse monadiche (intrinseche) o *n*-adiche (relazionali), sono non disgiuntive ("essere rosso o verde" non è considerata una possibile proprietà fondamentale in questa prospettiva).

[260] Esfeld parla di proprietà qualitative come di quelle proprietà la cui istanziazione non dipende da alcun particolare individuo (in questo senso la posizione spaziotemporale è qualitativa, non dipende da *chi* è posizionato lì).

è, secondo Esfeld, il fatto che fintanto che le proprietà degli elementi sono concepite come intrinseche, nel senso di indipendenti da tutto il resto esse non possono essere conosciute[261]. Questo crea un divario, nella standard view, tra l'epistemologia e la metafisica[262]. E' importante notare che nel presentare la tesi circa l'inconoscibilità delle proprietà intrinseche, non si vuole sostenere un riapparire della cosa in sé di kantiana memoria, quanto rimarcare il fatto che il modo in cui la conoscenza è ottenuta (attraverso l'interazione) pone un vincolo: la realtà fisica manifesta le sue proprietà (siano esse intrinseche o meno) solo grazie alle relazioni che intesse e non per l'intrinsecità delle sue caratteristiche. Il significato stesso delle affermazioni con cui descriviamo le proprietà fondamentali le indica come proprietà relazionali. Senza dubbio questa prospettiva richiama la tesi sviluppata da Eddington proprio in chiave kantiana . Tuttavia dal nostro punto di vista è possibile operare un rovesciamento: mentre Eddington enfatizzava la soggettività della conoscenza, la nostra intenzione è piuttosto rimarcare la dimensione relazionale intrinseca nell'interazione stessa. Questa interazione è sì all'origine della nostra possibilità di conoscere la realtà, ma è ancor più all'origine della realtà stessa nel suo sviluppo dinamico (campi e particelle, atomi, molecole, elementi sono dunque attori di una trama di processi fisici basati sulle interazioni).

D'altro canto la tesi di Esfeld non concerne solo la rilevanza delle relazioni, ma critica apertamente le posizioni[263] secondo cui tutte le relazioni (salvo le relazioni spaziotemporali) siano sopravvenienti sulle proprietà intrinseche[264]. Ciò che rafforza la convinzione circa la necessità di una metafisica di relazioni è la Meccanica Quantistica stessa, che fornisce un esempio paradigmatico di proprietà relazionali non sopravvenienti come fatto fisico, non solo metafisico[265], nell'entanglement quantistico. L'elemento fondamentale è la formulazione di una metafisica di relazioni, che si basa per il dominio quantistico sull'idea della non-separabilità. In questo senso Esfled considera l'entanglement quantistico in un'ottica fondamentalmente olistica. Le distribuzioni di probabilità degli stati entangled

---

[261] Esfeld fa sua la critica di F.Jackson a J.Lewis (cfr. Esfeld, 2003).

[262] Lo stesso tipo di divario è, secondo Margareth Morrison (2007), un rischio del RSO. Nel paragrafo §4.6 abbiamo criticato questo suo punto di vista.

[263] "*Everything there is in a world like ours supervenes on the distribution of basic intrinsic properties over all space-time points*"(Esfeld 2004: 1).

[264] Le relazioni spaziotemporali sono legate alla metrica, che è legata alla materia in regime di reciprocità.

[265] Non ci si vuole fermare alla plausibilità di una metafisica di relazioni in quanto intelligibile, né ad una dismissione delle proprietà intrinseche come non necessarie (in quanto inconoscibili finchè non 'diventano' relazionali), sulla base di un rasoio di Occam.

sono completamente determinate solo dallo stato globale dei sistemi[266] considerati insieme: "*If we take the quantum state description to tell us something about the properties of quantum systems, entanglement is to say that the quantum systems in question do not have state-dependent properties such as position, momentum (mass multiplied by velocity) or spin angular momentum in any direction each; state-dependent properties are all and only those properties of a physical system that can change during the existence of the system*" (Esfeld 2004: 6). In questo senso la Meccanica Quantistica non chiama in causa proprietà dei sistemi separatamente considerati, come base per la sopravvenienza delle correlazioni. Inoltre le correlazioni (che ci permettono di elaborare le distribuzioni di probabilità) sono indipendenti dalla distanza. In una interpretazione realista sembra che i sistemi quantistici siano descritti in quanto soggetti ad entanglement. Questo fatto non costituirebbe solo il riconoscimento di un limite intrinseco della nostra conoscenza, quanto piuttosto un aspetto dei sistemi fisici: "*Whatever entanglement may exactly be, it is a relation among quantum systems*"(*ib.*7). Difatti quanto detto vale indipendentemente dal come l'entanglement si risolve: perchè si possa parlare di dissoluzione dello stato entangled, bisogna che si dia lo stato entangled prima. Inoltre, questa situazione non è un caso eccezionale: la Meccanica Quantistica è intrisa di stati entangled[267].

L'aspetto cruciale dell'interpretazione dell'entanglement quantistico formulata da Esfeld, è dato dal fatto che esso interessa, quanto alle sue conseguenze descrittive, solo le proprietà che sono dipendenti dallo stato: posizione, velocità (momento) e direzione del momento angolare di spin. L'entanglement non tocca le proprietà cosiddette state-indipendent, che tradizionalmente sono considerate le proprietà monadiche, intrinseche. Queste ultime sarebbero le classiche proprietà invarianti del sistema[268] (massa, carica e

---

[266] Esfeld parla di *quantum systems* già a proposito di singole particelle. Per questo poi parla dello 'stato globale' dei sistemi 'considerati insieme'.

[267] Esfeld nota che anche se i sistemi entangled possono essere descritti separatamente come stati misti, ma è comunque una descrizione incompleta: non tiene conto della relazione fondamentale che li caratterizza. D'altro canto, persino le variabili nascoste non necessitano di essere basi intrinseche per le relazioni. Secondo Esfeld, Einstein rifiutava l'idea di correlazioni non sopravvenienti e questo rifiuto costituirebbe la base dell'argomento EPR (separabilità dei sistemi fisici e località dell'azione): "…*it appears to be essential for…the things introduced in physics that, at a specific time, these things claim an existence independent of one another, insofar as these things 'lie in different parts of space'*"(Esfeld 2004: 8). Nel sostenere la possibilità che le proprietà relazionali non dipendano univocamente da proprietà intrinseche soggiacenti si sostiene, a nostro avviso, l'idea che anche la separabilità non *implichi* strettamente l'esistenza di proprietà intrinseche *come base* delle relazioni (non che non ci siano proprietà intrinseche, quanto che non siano una base necessaria per tutte le relazioni). La negazione di questo, ossia l'idea che la separabilità sia assolutamente legata elle proprietà intrinseche, condurrebbe a considerare l'esistenza stessa delle cose come completamente riducibile alle loro proprietà intrinseche. In realtà secondo Esfeld il razionale soggiacente al principio di separabilità è proprio l'idea che le relazioni sopravvengano sulle proprietà intrinseche. D'altra parte quest'ultima tesi è materia di discussione.

[268] Un dubbio potrebbe sorgere a questo punto, nel richiamare alla memoria l'esempio di Eddington circa l'incremento della massa con la velocità. Ma la massa cui ci si riferisce qui è la massa a riposo.

quantità di spin), ma non sono da considerare come proprietà fondamentali in Meccanica Quantistica . Esse sono in un certo senso fuori dalla 'giurisdizione' quantistica in quanto sono irrilevanti rispetto alle correlazioni quantistiche ed in nessun caso ne costituirebbero la base.

La posizione di Esfeld potrebbe richiamare l'olismo relazionale di P.Teller (1998), secondo il quale gli oggetti, che almeno in alcune circostanze possono essere considerati individui, sono dotati di proprietà relazionali "inerenti" (nel senso di non sopravvenienti). Nella prospettiva di Teller, ciascun oggetto riconosciuto come individuo è *ipso facto* dotato di almeno una proprietà intrinseca (non relazionale)[269]. Rispetto alla Meccanica Quantistica Teller dice : " *In the special case of the subject matter of Quantum Mechanics we need a different means of description. Where there are what people are in habit of describing as collections of qualitatively identical particles, occupation numbers provide the most adequate descriptions*"(1998: 136). Dunque si mantiene una forma di individualità e l'esistenza di almeno una proprietà non-relazionale. E' da notare che non tutte le posizioni strutturaliste rifiutano la nozione di individualità. Simon Saunders (2006), per esempio, recupera una nozione, sia pure debole, di individualità per i fermioni, sulla base di una loro discernibilità 'debole' (*weak-discernibility*[270]). D'altro canto la posizione di Saunders non esula dall'universo strutturalista dal momento che, anche nel caso della weak discernibility, l'individualità non è definita indipendentemente dal resto, bensì sulla base di proprietà relazionali. L'esempio della weak discernibility di Saunders è utile per comprendere in che senso Esfeld rifiuti l'olismo relazionale di Teller, che mantiene almeno una proprietà intrinseca come base delle relazioni quantistiche. Al contrario Esfeld sostiene la tesi che "*as far as quantum theory is concerned, there is no need for the correlated quantum system to have intrinsic properties over and above the correlations in which they stand*"(2004: 11). Le correlazioni quantistiche sono interamente relazionali[271].

Il realismo strutturale di Esfeld non mira ad eliminare i relata. Elettroni, protoni, fotoni possono essere considerati come sistemi quantistici *singoli* dal momento che ce n'è sempre un numero finito, nonostante i sistemi quantistici dello stesso tipo siano indistinguibili. La sua tesi non riguarda l'individualità, quanto la caratterizzazione

---

[269] In questo senso Teller considera evidentemente l'individualità come una proprietà.

[270] Il termine "weak-discernibility" è introdotto da Quine nella formulazione di una versione debole del principio di Leibniz. Due oggetti (i fermioni in questo caso) sono 'debolmente discernibili nel caso in cui soddisfano una relazione irriflessiva a due posti.

[271] Addirittura Esfeld suggerisce l'idea che una interpretazione in chiave relazionale possa tentare di derivare le stesse proprietà state-independent, massa e carica, sulla base delle proprietà che sono relazionali in quanto toccate dalle correlazioni della Meccanica Quantistica.

interamente olistica dei sistemi quantistici (in quanto quantistici)[272]. Dunque Esfeld accetta come primitiva una pluralità di elementi, una pluralità numerica di elementi, privi di condizioni di indentità.

Lo stesso tipo di metafisica relazionale è poi applicata al caso delle teorie dello spaziotempo (Esfeld e Lam, 2006). In conclusione una forma moderata di strutturalismo à la Esfeld non è guidata dall'idea che non esistano in generale proprietà intrinseche, quanto piuttosto dall'idea:

- non esistono proprietà intrinseche su cui le relazioni quantistiche siano sopravvenienti: le relazioni non sopravvengono sulle proprietà intrinseche (qualora ce ne siano) dei sistemi. In questo senso potrebbe darsi che i sistemi posseggano proprietà intrinseche. Nondimeno noi non siamo mai a conoscenza delle qualità intrinseche *in quanto* intrinseche

- conosciamo solo relazioni. Conosciamo massa, carica e spin, siano esse proprietà intrinseche o meno, unicamente in una loro parvenza relazionale.

- le proprietà *quantistiche* ossia le proprietà che entrano in causa nelle relazioni quantistiche sono proprietà relazionali non sopravvenienti.

La metafisica di Esfeld si compone di (*a*) una pluralità di elementi privi di condizioni di identità, e (*b*) una serie di relazioni fondamentali; infine ammette la possibilità di qualificare alcune proprietà come intrinseche, ma non fondanti le relazioni fondamentali. In questo quadro non c'è una assoluta priorità di uno degli elementi, in particolare (*a*) o (*b*), sugli altri. Piuttosto si manifesta una mutua dipendenza, sia ontologica che concettuale, tra relazioni e relata (cfr. Esfeld e Lam, 2006: 5).

Le principali problematiche legate alla metafisica relazionale sono legate allo status dei relata. I critici delle forme ontiche di realismo strutturale enfatizzano che (1) le relazioni richiedono dei relata; (2) questi relata devono essere qualcosa in sé. La posizione di Esfeld accetta la (1), ma sostituisce (2) con una (2*): questi relata non hanno proprietà intrinseche *soggiacenti* le relazioni in cui si trovano. La (2*) a sua volta può voler dire:

---

[272] Dal momento che nega l'olismo relazionale di Teller, ma accetta la distinguibilità numerica, Esfeld sembrerebbe non considerare l'individualità una proprietà, o quantomeno una proprietà intrinseca o al limite una proprietà intrinseca fondante per le correlazioni quantistiche.

- possono esistere proprietà intrinseche delle cose ma non fondano le loro relazioni.

- non esistono proprietà, se non relazionali, delle cose.

Esfeld è un compatibilista in questo senso. Lo strutturalismo di Eddington invece sembra optare per il secondo punto di vista. In ogni caso entrambi accettano, nella loro metafisica, relazioni *e* relata. La metafisica di relazioni è dunque la una base di partenza. Ma non basta . O meglio essa è propedeutica ad altro. Non possiamo considerare le relazioni da sole, in quanto esse stesse portano con sè sempre *altro*:

i – una regola di composizione, o per usare una terminologia eddingtoniana un *pattern of interrelatedness*.

ii – delle componenti, dei relata . Consideriamo ancora una volta l'idea eddingtoniana che ogni elemento α esista nella struttura in quanto elemento *di* quella struttura, definito dalle relazioni della struttura stessa . Eddington enfatizzava questa prospettiva indicando l'elemento come 'αo' e dicendo che il 'o' (la relazione) è inscindibile ("*the dot is undetacheable*"). Questo non elimina tuttavia il fatto che l'elemento stesso è inscindibile dalla relazione. Abbiamo pertanto bisogno di una metafisica fatta di relazioni *e* relata. E questa metafisica è inevitabilmente una metafisica di strutture.

Ovviamente a questo punto si potrebbe riproporre il problema della individualità/non individualità dei relata. In questo senso è fondamentale l'insistenza di Esfeld sulla pluralità numerica[273] e l'inciso sul fatto che la metafisica relazionale ammette la possibilità, ad esempio, della *primitive thisness. Ma* non è forzata a farlo. E questo rappresenta senz'altro un elemento di forza perché crea uno spazio condiviso all'interno del quale si può poi dibattere la questione dell'individualità. Il fatto che le relazioni prevedano i relata non *induce* ad adottare, ad esempio, la *primitive thisness*. Ammettere i relata significa semplicemente ammettere che la predicazione stessa richiede un oggetto di cui predicare. Si può aggiungere, ne richiede l'esistenza (attuale o virtuale). In questo senso, si può trovare un ulteriore spunto nella riflessione di Eddington. Egli non considera la questione individui/non individui: lo statuto dei nodi al di là delle relazioni è solidamente fondato sulla nozione 'strutturale' di esistenza . La caratterizzazione dei nodi e il come debbano/possano intendersi le proprietà e relazioni in cui sono coinvolti è la questione che

---

[273] La posizione che è propone supporta una metafisica di relazioni dove non ci sia individualità se non in un senso molto debole.

ci ha spinto a prendere in considerazione una piega del dibattito più incentrata sulla questione delle proprietà quantistiche, che non dell'individualità delle particelle.

Nel nostro lavoro si è in primo luogo cercato di capire i profondi mutamenti concettuali seguiti alla Relatività e alla Meccanica Quantistica nella comprensione, tanto ontologica   quanto epistemologica, della realtà fisica. La riflessione sulle posizioni strutturaliste, originate da tali mutamenti, induce una riflessione sulle proprietà e relazioni tra oggetti fisici, che genera una rivoluzione olistica nella modalità di predicazione della realtà. Essa richiede un mutamento anche nella metafisica soggiacente le nostre descrizioni. Il modo in cui si debba saldare la nuova metafisica con ulteriori aspetti della riflessione ontologica (un principio di oggettualità, una nozione di individualità) costituisce materia per una ulteriore discussione. Su tale terreno si dipanano le possibili giustificazioni per le posizioni più eliminativiste, in materia di relata nella struttura . D'altro canto l'effettiva rilevanza della teoria dei gruppi come linguaggio significativo nelle teorie contemporanee e la capacità della visione strutturalista di fornire un chiaro approccio alla Relatività generale nel suo profondo legame con le proprietà fondamentali dello spaziotempo[274] e della materia, rendono l'approccio strutturalista un interessante quanto fondamentale campo di ricerca .

---

[274] Rispetto al processo di 'geometrizzazione della fisica', che sembra caratterizzare il passaggio dalla prospettiva classica alla prospettiva relativistica, Bailly e Longo (2005) mettono in evidenza come esso costituisca un fondamentale mutamento dalla causalità (*causal lawfulness*) dell'universo newtoniano, in cui le forze causano accelerazioni di corpi, ad una *organizzazione strutturale dello spazio e del tempo* ('*structural organization of space and time*'(Bailly and Longo, 2005: 13)). Nel nuovo caso, l'intelligibilità sarebbe riscontrabile in termini di 'normatività' imposta dale strutture geometriche. Da questo punto di vista l'organizzazione strutturale dello spaziotempo sembra essere la sorgente /fonte dell'intelligibilità in una maniera che evoca fortemente l'olismo strutturale di Eddington.

Bibliografia

Allori, V.,Dorato, M., Laudisa, F. and Zanghì, N. (2005), *La Natura delle Cose. Una introduzione ai fondamenti e alla filosofia della fisica*, Carocci, Roma.

Auyang,S. (1995), *How Is Quantum Field Theory Possible?* , Oxford University Press.

(1998), 'Nature and our descriptions of it: Predicate, function, symmetry', part of a talk presented at the Philosophy Department Concordia University, Montreal. April 3, 1998.

(1999), 'The ontology of quantum fields: entity and quality', talk presented at the Center for Interdisciplinary Research, Bielefeld, Germany. October 1999.

Bailly, F. and Longo, G. (2004), 'Space, Time and Cognition From The Standpoint of Mathematics and Natural Science', in *Mind and Causality* (Peruzzi ed.), Benjamins, Amsterdam: 149-199. Original French version (2003) 'Espace, temps et cognition', *Revue de Synthèse*, Paris, **124**: 61-118.

(2008), 'Causes and Symmetries in Natural Sciences. The continuum and the discrete in mathematical modelling', in *More Geometrico*, (Giorello et. al eds) Elsevier.

Bell,J. (2000), 'Hermann Weyl on intuition and the continuum'**,** *Philosophia Mathematica* **8**(3): 259-273.

(2004), 'Hermann Weyl's Later Philosophical Views: His Divergence from Husserl' in R. Feist (ed.) *Husserl and the sciences: selected persepctives*, University of Ottawa: 173 -188.

Bird, A. (2007), *Nature's Metaphysics: Laws and Properties*, Oxford Publications.

(2002), 'Laws and criteria', *Canadian journal philosophy* **32** (IV): 511-542.

(2004), 'The dispositional conception of laws', *Foundations of Science* **152**: 1–18.

(2005), 'Explanation and Metaphysics', *Synthese* **143**: 89-107.

(2005), 'Laws and Essences' *Ratio(new series)* **XVIII**: 437-461.

Brading, K. and Castellani, E.(2004), 'Symmetry and Symmetry Breaking', in *Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/symmetry-breaking/

Brading, K.and Landry, E.(2005), 'The Semantic View of Theories, Scientific Structuralism and Structural Realism, A Minimal Construal of Scientific Structuralism' in *2004] Philosophy of Science Assoc. 19th Biennial Meeting - PSA2004: Contributed Papers (Austin, TX; 2004): PSA 2004 Symposia*, Austin, Texas. available at *PhilSci Archive* http://philsci-archive.pitt.edu/archive/00002181/

Bradie, M. (1977), 'The Development of Russell's Structural Postulates', *Philosophy of Science* **44** (3): 441-463.

(1996), 'Ontic Realism and Scientific Explanation', *Philosophy of Science* **63**: 315-321.

Braithwaite, R.B. (1929), 'Professor Eddington's Gifford Lectures', *Mind* **38**: 409-435.

Brown, H. R.(1993), 'Correspondence, Invariance and Heuristics in the Emergence of Special Relativity', in S.French and H.Kamminga(eds.) *Correspondence, Invariance and Heuristics*, Kluver : 227-260.

Braitwaithe, R.B. (1940), 'Critical notice: The Philosophy of Physical Science', *Mind* **49** (196): 455-466.

Bueno, O. (1997), "Empirical Adequacy: a partial structures approach", *Studies in history and Philosophy of Science* **28**: 585 – 610.

(1999), "What is Structural Empiricism? Scientific Change in an Empiricist Setting", *Erkenntnis* **50**: 59-85.

(2005), 'Dirac and the dispensability of mathematics', *Studies in History and Philosophy of Modern Physics* **36**: 465-490.

(2001), 'Weyl and von Neumann: symmetry, group theory, and quantum mechanics', draft paper presented in *Symmetries in Physics, New Reflections* Oxford Workshop, January 2001. Available at *PhilSci Archive* http://philsci-archive.pitt.edu/archive/00000409/

Bueno O. and French S.(1999), "Infestation or Pest Control: The Introduction of Group-Theory into Quantum Mechanics", *Manuscrito* **22**: 37-86.

Bueno O., French S. & Ladyman J. (2002), 'On representing the Relationship between the Mathematical and the Empirical', *Philosophy of Science* **69**: 497-518.

Cao T.Y. (2003a), 'Structural Realism and The Interpretation of Quantum Field Theory', *Synthese* **136**: 3-30.

(2003b), 'Can we dissolve Physical Entities into Mathematical Structures?', *Synthese* **136**: 57-71.

(2003c), 'What is Ontological Synthesis? – a reply to Simon Saunders', *Synthese* **136**: 107-126.

Carlson, C.R. (2009), 'Finite Eventism' in Skrbina D. (ed.) *Mind that Abides*, Benjamins Pub Co: 231-250.

Cassirer, E. (1910), *Substance and Function* , tr. It. 1973 *Sostanza e Funzione e Sulla Teoria della Relatività*, La Nuova Italia.

(1944), 'Group Concept and Perception Theory', *Philosophy and Phenomenological Research* **5** : 1-35.

(1936), *Determinism and Indeterminism in Modern Physics*, Yale University Press.

(1952) *Storia della filosofia moderna* II – da Bacone a Kant tomo II, it. tr. A.Pasquanelli, Einaudi.

Castellani, E. (1993), 'Quantum Mechanics, Objects and Objectivity', in C. Garola and A. Rossi, *The Foundations of Quantum Mechanics - Historical Analysis and Open Questions*, Kluwer: 105-114.

(1994), 'Sulla nozione di oggetto nella fisica classica e quantistica', atti del Congresso *Logica e filosofia della scienza: problemi e prospettive*, Lucca 7-10 gennaio 1993.

(1998) *Interpreting Bodies: classical and quantum objects in modern physics* Elena Castellani editor, Princeton University Press.

(2003), 'Symmetry and Equivalence', in K.Brading and E.Castellani (eds.), *Symmetries in Physics: Philosophical Reflections*, Cambridge University Press: 425-436.

Cei, A. (2005), 'Structural Distinctions: Entities, Structures and Changes in science' *Philosophy of Science* **72**: 1385–1396.

Cei, A. and French, S. (2006), 'Looking for the Structure in All the Wrong Places', *Studies in History and Philosophy of Science A* **37**: 637-655

Chandrasekhar, S. (1983), *Eddington, the most distinguished astrophysics of his time*, Cambridge University Press.

Chakravartty A.(1998), 'Semirealism', *Studies in History and Philosophy of Science* **29**: 391-408.

(2003), 'The Structuralist Conception of Objects', *Philosohy of Science* **70**: 867-78.

(2003b), 'The Dispositional Essentialist View of Properties and Laws', *International Journal of Philosophycal Studies* **11** (4): 393-413.

(2004), 'Structuralism as a form of Scientific Realism', *International Studies in the Philosophy of Science* **18**:151-171.

(2005), 'Causal realism: events and processes' *Erkenntnis* **63**: 7–31.

Ciccotti, G. and Ferrari, G. (1983), 'Was Poincarè a herald of quantum theory?', *European Journal of Physics* **4**: 110-116

Clifton R. K. (1998), 'Scientific Explanation in Quantum Theory',

Available at *PhilSci Archive* http://philsci-archive.pitt.edu/archive/00000091/

Courant, R. and Robbins, H. E. (1971), *Che cos'è la Matematica*, Bollati Boringhieri.

da Costa N.C.A. & French S. (1990), 'The Model-Theoric Approach in the Philosophy of Science', *Philosophy of Science* **57**: 248-265.

(1993), 'Towards an Acceptable Theory of Acceptance: Partial Structures, Inconsistency and Correspondence', in S.French and H.Kamminga (eds) *Correspondence, Invariance and Heuristics* : 137-158.

(2003), *Science and Partial Truth*. Oxford University Press, Oxford.

De Muynck, W.M. (2007), 'The Copenhagn interpretation, and pragmatism', contribution to the conference on "Pragmatism and quantum mechanics", CREA, Ecole Polytecnique and CNRS, Paris.

Debs, T.A. and Redhead, M.L.G. (2007), *Objectivity, Invariance and Convention – Symmetry in Physical Science* , Harvard University Press.

Demopoulos W. & Friedman M. (1985), 'Bertrand Russell's The Analysis of Matter: its Historical Context and Contemporary interest', *Philosophy of Science.***52**(4): 621-639.

Dieks, D. and Versteegh M. (forthcoming), 'Identical Quantum Particles and Weak Discernibility'.

Dingle, H.(1954), *The sources of Eddington's philosophy* – the eighth Arthur Stanley Eddington memorial Lecture , Cambridge University Press

Dorato M. (1999), 'Cao on Substantivalism and the developments of 20th century field theories', *Epistemologia* **XXII** : 151-166.

(2005), 'Filosofia dello Spazio e del Tempo', in Allori, V., Dorato, M., Laudisa, F. and Zanghì, N. (2005), *La Natura delle Cose. Una introduzione ai fondamenti e alla filosofia della fisica*, Carocci, Roma: 15-137.

Eddington, A. (1920a), 'The Meaning of Matter and the Laws of Nature According to the Theory of Relativity', *Mind* **29**: 145-158.

(1920b), 'The Philosophical Aspect of the Theory of Relativity', *Mind* **29**: 415-422.

(1921), *Space, Time and Gravitation*, Cambridge University Press.

(1922), *The Theory of Relativity and Its Influence on Scientific Thought*, Clarendon Press, Oxford.

(1923), *Mathematical Theory of Relativity*, Cambridge University Press.

(1926), *Internal constitution of stars*, Cambridge University Press.

(1928), *The Nature of the Physical World*, Cambridge University Press.

(1934) *New Pathways in Science*, Cambridge, University Press.

(1936), *Relativity Theory of Protons and Electrons*, Cambridge University Press.

(1939), *The Philosophy of Physical Science*, Cambridge University Press.

(1941), 'Discussion: Group Structure in Physical Science', *Mind* **50**: 268-279.

(1946), *Fundamental Theory*, Cambridge University Press.

Einstein, A. (1921), *Relatività: esposizione divulgativa – con scritti classici su spazio e tempo –* Boringhieri.

(1922) *The meaning of Relativity*, it. transl. by Luigi Radicati di Brozolo (1950) *Il Significato della Relatività*, Einaudi Editore.

Eisenbud L and Wigner E.P. (1958), *Nuclear Structure*, Princeton University Press, it.trans. by P.Casalini *La Struttura del Nucleo*, Boringhieri.

Esfeld M. (2003), ' Do relations require underlying intrinsic properties? A physical argument for a metaphysics of relations', in *Metaphysica. International Journal for Ontology &Metaphysics* **4**: 5-25.

(2004), 'Quantum entanglement and a metaphysics of relations', *Studies in the History and Philosophy of Modern Physics* **35B** (Dec. 2004) : 601-617.

Esfeld M. and Lam V. (2006), 'Moderate Structural Realism about Space-Time', forthcoming in *Synthese.*

Evans, D.S. (1998), *The Eddington Enigma* , Princeton.

Feigl, H. (1975), 'Russell and Schlick: A Remarkable Agreement on a Monistic Solution of the Mind-Body Problem', *Erkenntnis* **9**: 11-34.

Friedman, M. (2002), 'Kant, Kuhn, and the Rationality of Science', *Philosophy of Science* **69**: 171-190.

French, S. (1989), 'Individuality, Supervenience and Bell's Theorem', *Philosophical Studies* **55:**1-22

(1998), 'On the Withering Away of Physical Objects', in E. Castellani (ed.), *Interpreting Bodies: Classical and Quantum Objects in Modern Physics*, Princeton University Press: 93-113.

(1999), 'Models and Mathematics in Physics: The Role of Group Theory', in J. Butterfield and C. Pagonis (eds), *From Physics to Philosophy*, Cambridge University Press: 187-207.

(2000), 'The Reasonable Effectiveness of Mathematics: Partial Structures and the Application of Group Theory to Physics', *Synthese* **125**: 103-120.

(2000a), 'Putting a New Spin on Particle Identity', in Hilborn, R. and Tino, G. (eds.), *Proceedings of the Spin-Statistics 2000 Conference*, American Institute of Physics.

(2001), 'Symmetry, Structure and the Constitution of Objects', *Conference on Symmetries in Physics: New Reflections*, University of Oxford, January 2001; available at the *PhilSci Archive* at http://philsci-archive.pitt.edu/archive/00000327/.

(2003), 'Scribbling on the Blank Sheet: Eddington's Structuralist Conception of Objects', *Studies in History and Philosophy of Modern Physics* **34**: 227-259.

(2006a), 'Identity and Individuality in Quantum Theory', in *Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qt-idind/

(2006b), 'Structure as a Weapon for the Realist', *Proceedings of the Aristotelian Society* **106** (2)(March 2006): 167-185.

French S. and Kamminga H. (eds.)(1993) *Correspondence, Invariance and Heuristics: Essays in Honour of Heinz Post*, Boston Studies in the Philosophy of Science, gen. ed. R. S. Cohen, Dordrecht: Kluwer Academic.

French S. and Krause, D. (2006) *Identity in Physics: A Historical, Philosophical and Formal Analysis*. Oxford: Oxford University Press.

French S. and Ladyman J. (2003a), 'Remodelling Structural Realism: Quantum Physics and the Metaphysics of Structure', *Synthese* **136**: 31-56.

(2003b), 'The Dissolution of Objects: between Platonism and Phenomenalism', *ibidem*: 73-78.

(forthcoming), 'In Defence of Ontic Structural Realism' to Appear in Alissa and Peter Bokulich (eds) *Boston Studies in the Philosophy of Science: Scientific Structuralism*, forthcoming with Boston University Press.

French, S. and Redhead, M. (1988), 'Quantum physics and the identity of indiscernibles', British *Journal for the Philosophy of Science* **39**: 233-246.

(2003), 'Understanding Permutation Symmetry', In K. Brading, K. and E. Castellani, eds, *Symmetries in Physics: New Reflections*, Cambridge University Press: 212-238.

French S. and Rickles D. (2006), 'Quantum Gravity meets Structuralism: Interweaving Relations in the Foundations of Physics' in French S., Rickles D. and Saatsi J.T. (eds.) *The Structural Foundations of Quantum Gravity*, Oxford University Press.

French S. and Saatsi J.T. (2006), 'Realism about Structure: The Semantic View and Non-linguistic Representation' in *Philosophy of Science* **73** (5): 548-559.

Gawronsky, D. (1958), 'Cassirer's contribution to the epistemology of physics' in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer*. Open Court Publishing Company: 215-238.

Giere, R (1988), *Explaining Science: A Cognitive Approach*. Chicago: University of Chicago Press.

(2004), "How Models Are Used to Represent Reality", *Philosophy of Science* **71** (Supp.) S742-752.

Gower, B. (2000), 'Cassirer, Schlick and ' Structural Realism: The Philosophy of The Exact Sciences in The Background to Early Logical Empiricism', *British Journal for the History of Philosophy* **8**(1): 71-106.

Hacking, I (1983), *Representing and Intervening*. Cambridge: Cambridge University Press.

Hamburgh, C.H. (1958), 'Cassirer's Conception of Philosophy', in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer*. Open Court Publishing Company: 73-120.

Harman, P.M. (1982), *Energy, Force, and Matter –Tthe Conceptual Development of Nineteeth-Century Physics*, Cambridge History of Science Series.

Hartman, R.S. (1958), ' Cassirer's Philosophy of Symbolic Forms' in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer*. Open Court Publishing Company: 289-334.

Howard, D.(2005), ' "No crude surfeit": A Critical Appreciation of *The Reign of Relativity*' Pacific APA

Huggett, N. (1999a), 'On the Significance of Permutation Symmetry', *British Journal for the Philosophy of Science* **50**: 325-347.

(1999b), 'Atomic Metaphysics', in *The Journal of Philosophy* **96**(1): 5-24.

Husserl, E. E. (1954), *The Crisis of European Sciences and Transcendental Phenomenology*, trans. D. Carr (1970), Northwestern University Press.

Ihmig, K-N. (1999), 'Ernst Cassirer and the Structural Conception of Objects in Modern Science: The Importance of the "Erlanger Programm"', *Science in Context* **12**: 513-529.

Israel, G. (2003), *La visione matematica della realtà- introduzione ai temi e alla storia della modellistica matematica* Bari, Laterza.

Itzkoff, S.W. (1997), *Ernst Cassirer: Scientific Knowledge and the Concept of Man*, University of Notre Dame Press (1971).

Jammer, M. (1953), *Concepts of Space. The History of Theories of Space in Physics*. Cambridge Harvard University Press. It.tr.: *Storia del concetto di spazio*, 1979, Milano Feltrinelli.

Kauffmann, F. (1958), 'Cassirer's neokantianism, and phenomenology', in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer*. Open Court Publishing Company: 799-854.

(1958), 'Cassirer's Theory of Scientific Knowledge', in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer*. Open Court Publishing Company: 283-7.

Ketland, J.(2004) 'Empirical Adequacy and Ramseyfication', *British Journal for the philosophy of science* **55**: 287-300.

Kilmister, C. W. (1994), *Eddington's Search for a Fundamental Theory*, Cambridge University Press.

Krause D. (2000), ' Remarks on Quantum Ontology', *Synthese* **125**: 155-167.

(2005), 'Structures and Structural Realism', *Logic Journal of the IGPL* **13(1)**: 113-126.

Kuhn, H. (1958), 'Ernst Cassirer's philosophy of Culture', in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer.* Open Court Publishing Company: 545-574.

Ladyman J. (1998), 'What is Structural Realism', *Studies in History and Philosophy of Science* **29** (3): 409-424.

(2004), 'Modality and constructive empiricism: A reply to van Fraassen', *The British Journal for the Philosophy of Science* **55**: 755-765.

(2005), 'Mathematical structuralism and the identity of indiscernibles', *Analysis* **65**: 218-221.

(2007a), 'On the Identity and Diversity of Individuals', *The Proceedings of the Aristotelian Society.*

(2207b), 'Structural Realism' issue in the *Stanford Encyclopedia of philosophy*: http://plato.stanford.edu/entries/structural-realism/

Ladyman,J. and Leitgeb, H.(2008), 'Criteria of Identity and Structural Ontology', to appear in *Philosophia Mathematica*.

Langton, R. and Lewis, D. (1998), 'Defining `intrinsic'', *Papers in Metaphysics and Epistemology*: 116-132. Cambridge: Cambridge University Press.

Longo, G. (2001)'The Constructed Objectivity of Mathematics and the Cognitive Subject', *Epistemolgy of Physics and of Mathematics*, M. Mugur-Schachter editor, Kluwer.

(2005), 'Mathematical Concepts and Physical Objects', in *Rediscovering phenomenology* (L.Boi, P. Kerszberg, F. Patras ed.), Kluwer.

(1999),'The mathematical continuum: from Intuition to Logic', in *Naturalizing Phenomenology* (section on mathematics and formal methods) invited paper (Petitot et al eds.), Stanford University Press.

(2002), 'Lo spazio, I fondamenti della Matematica la resistibile ascesa della metafora: il cervello è un calcolatore digitale' in *L'uomo e le macchine* a cura di M.Bresciani Califano e Leo S. Olschki, Firenze.

Lovejoy, A.O. (1930), *The Revolt Against Dualism.* New York: W.W.Norton and Open Court Publishing Co.

Lyre, H. (2004), "Holism and structuralism in U(1) gauge theory" in *Studies in History and Philosophy of Modern Physics* **35**: 643–670.

Maxwell, G. (1962), 'The ontological status of theoretical entities', in H. Feigl and G. Maxwell, eds., *Minnesota Studies in the Philosophy of Science* **3**: 3-14.

Maxwell, G. (1970a), 'Structural realism and the meaning of theoretical terms', in S. Winokur and M. Radner, eds., *Analyses of Theoreis and Methods of Physics and Psychology: Minnesota Studies in the Philosophy of Science* **4**: 181-192.

Meelia, J. and Saatsi, J. (2006), 'Ramseyfication and Theoretical Content', *The British Journal for the Philosophy of Science* **57**: 561–585.

Morganti, M. (2004), 'On the preferability of epistemic structural realism', in *Synthese* **142**: 81-107.

(2007), 'Individual Particles, Properties and Quantum Statistics', paper presented at the first EPSA conference, Madrid 2007, forthcoming in the proceedings.

Morrison M. (2007), 'Spin: All is not what it seems", in *Studies in History and Philosophy of Modern Physics* **38**: 529-557.

McLendon H.J.(1955), 'Uses of similarity of structure in contemporary philosophy', in *Mind* **64**: 79-95.

Naumann, B. (1999), 'The Genesis of Symbolic Forms: Basis Phenomena in Ernst Cassirer's Works' *Science in Context* **12**(4): 575-584.

Newman, M. H. (1928), 'Mr.Russell's "causal theory of perception', in *Mind* **37**: 137- 148.

Norton, J. (1994), 'Science and Certainty', in *Synthese* **99**: 3-22.

Orilia, F.(2006), 'Quantum-mechanical statistics and the inclusivistic approach to the nature of particulars', in *Synthese* **148**(1): 57-77.

Persico, E.(1940), *Fondamenti della Meccanica Atomica*, trattato generale di fisica a cura del CNR, Zanichelli.

Poincarè H. (1898), 'On the foundations of geometry', *The Monist* **9**: 1-43.

(1902), *La science et l'hypothèse*, engl.tr. *Science and Hypothesis* (1952) Dover Publications, Inc.

(1905), *Le valeur de la science*, Flammarion, Paris.

Pooley, O. (2006), 'Points, particles and structural realism', in D. Rickles, S. French and J. Saatsi, eds. *Structural Foundations of Quantum Gravity*, Oxford: Oxford University Press.

Post H.R. (1993), 'Correspondence, Invariance and Heuristics: in praise of conservative induction' in S.French and H.Kamminga (eds) *Correspondence, Invariance and Heuristics,* 1-43.

Price, H.H.(1932), *Perception*, Oxford.

Psillos S.(1995), 'Is Structural Realism the best of both worlds?', *Dialectica* **49**(1): 15-46.

(1999), *Scientific Realsim. How Science tracks truth'*, Routledge, London.

(2000), 'The Present State of the Scientific Realism Debate', in *British Journal for the Philosophy of Science* **51** (Supp): 705-728.

(2001), 'Is Structural Realism Possible?', *Philosophy of Science* **68** (Proocedings): S13-S24.

(2006), 'The Structure, the Whole Structure and nothing but the Structure', *Philosophy of Science* **73**: 560-570.

Ria, D. (2005), *L'unità fisico-matematica nel pensiero epistemologico di Herman Weyl*, Congedo Editore.

Riemann, B. (1854), 'On the hypothesis which lie at the basis of geometry', in Einstein, A. (1999), *Relatività: esposizione divulgativa – con scritti classici su spazio e tempo* – trad. italiana di R. Pettoello - Boringhieri.

Ritchie, A.D.(1948), *Reflections on the philosophy of Sir Arthur Eddington*, the first Arthur Stanley Eddington Memorial lecture, Cambridge University Press.

Russell B. (1897), *An Essay on the Foundations of Geometry*, Cambridge University Press.

(1901), 'On the Notion of Order', in *Mind* **10**(37):30-51.

(1919), *The Introduction to Mathematical Philosophy*, Allen and Unwin, London.

(1921), *The Analysis of Mind*, Routledge, London.

(1922), 'Physics and Perception' in *Mind* **31**(24): 478-485.

(1925), *The ABC of Relativity*, Routledge, London.

(1927), *The Analysis of Matter*, Allen and Unwin, London.

(1940), *An Inquiry into Meaning and Truth*, Norton and Company

(1951), *Human Knowledge*, Allen and Unwin, London.

Ryckman, T. (2005), *The Reign of Relativity: Philosophy in Physics 1915-1925*, Oxford University Press.

Saatsi J.(2005), 'Reconsidering the Fresnel-Maxwell theory shift: how the realist can have her cake and EAT it too', *Studies in History and Philosophy of Science* **36**: 509-538.

Saunders S.(2003a), 'Critical Notice: Tian Yu Cao's "The Conceptual Developments of 20th Century Field Theories', *Synthese* **136**: 79-105.

(1993), 'To What Physics Corresponds', in S.French and H.Kamminga (eds.) *Correspondence, Invariance and Heuristics,* 295-325, Kluwer.

(2003d), 'Structural realism again', *Synthese* **136** : 127-133.

(2006), 'Are quantum particles objects?', *Analysis* **66** : 52-63.

Schillp, P.A. (1958), *The Philosophy of Ernst Cassirer,* The Library of Living Philosophers VI, LaSalle, Illinois: Open Court Publishing Company.

Sharma, C.S. (1982), 'The role of mathematics in physics', *The British Journal for the Philosophy of Science* **33**(n.3): 275-286.

Smart, H.R. (1958), 'Cassirer's Theory of Mathematical Concepts', in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer.* Open Court Publishing Company : 239-268.

Stein H. (1970), 'On the Notion of Field in Newton, Maxwell and Beyond', in *Historical and Philosophical Perspectives of Science: Minnesota Studies in the Philosophy of Science Volume V,* R. Stuewer (ed.), Minneapolis - University of Minnesota Press: 264-286.

Suarez M.(1999), 'Theory, Models and Representations', appeared in Magnani, Nersessian and Thagard (eds.) *Model-Based Reasoning in Scientific Discovery*: 75-83, Kluwer.

Swabey, W.C. (1958), 'Cassirer and Metaphysics' in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer.* Open Court Publishing Company, :121-148.

Teller, P. (1998), 'Quantum Mechanics and Haecceities', in E. Castellani (ed.), *Interpreting Bodies: Classical and Quantum Objects in Modern Physics,* Princeton University Press: 115-

Tenn, J.S. (1982), 'Arther Stanley Eddington', *Mercury* **XI**(6).

Toraldo di Francia, G. (1962), *L'indagine del mondo fisico*, Einaudi, Torino.

Van Fraassen, B.C. (1976), 'To save the phenomena', *Journal of Philosophy* **73/18**: 623-632.

(2006), 'Structure: Its shadow and substance', *The British Journal for the Philosophy of Science* **57**, : 275-307.

(2004), 'Representation: the Problem for Structuralism', in *Philosophy of Science Assoc. 19th Biennial Meeting - PSA2004: Contributed Papers PSA 2004 Symposia*, Austin TX.

Available at *PhilSci Archive*: http://philsci-archive.pitt.edu/archive/00002498/

(2007), 'Structuralism and science: some common problems', *Proceedings of the Aristotelian Society*.

Votsis, I. (2003), 'Is Structure Not Enough?', *Philosophy of Science* **70**: 879-890.

Weinberg, S. (1996), 'What is Quantum Field Theory, and What Did We Think It Is?', proceedings of the conference *"Historical and Philosophical Reflections on the Foundations of Quantum Field Theory"* at Boston University. arXiv:hep-th/9702027v1

Werkmeister, W.H. (1958), ' Cassirer's Advance beyond neo-kantianism', in Schilpp, Paul A.(ed.) *The Philosophy of Ernst Cassirer*. Open Court Publishing Company, : 757-798.

Weyl, H. (1918), *Raum, Zeit und Materie*, Berlin: Springer Verlag, translated in English as *Space-Time-Matter* (1950) tr. Henry L. Brose. New York: Dover

(1928), *Gruppentheorie und Quantenmechanik* translated in English as *The Theory of Group and Quantum Mechanics* (1950) tr. H.P.Robertson. New York: Dover.

(1949), *Filosofia della matematica e delle scienze naturali*, Boringhieri.

(1951), 'A half-century mathematics', *The American Mathematical Monthly* **58**: 523-53.

Weatherson, B. (2003), 'Intrinsic vs. Extrinsic Properties', *Stanford Encyclopaedia of Philosophy*

Sir Whittaker, E. (1947), *From Euclid to Eddington: a study of conceptions of the external world*, Cambridge University Press.

(1951), *Eddington's principle in the philosophy of science*, the fifth Arthur Stanley Eddington Memorial lecture, Cambridge University Press, Cambridge.

Whitehead, A.N. (1919), *An Enquiry Concerning The Principles of Human Knowledge*, Cambridge University Press.

(1920), *Concept of Nature*, Cambridge University Press.

Winsberg, E. (2006), 'Models of success versus the Success of Models: reliability without truth', *Synthese* **42**: 1-19.

Worrall J.(1994), 'How to remain (reasonably) optimistic: Scientific realism and luminiferous ether', *PSA 1994*: 334-342.

(1996), 'Structural Realism: the Best of Both Worlds?' in D.Papineau (ed.), *The Philosophy of Science*, Oxford University Press: 139-165 (originally published in *Dialectica* (1989) **43**: 99-124).

Worrall J. And Zahar E. (2001), 'Ramseyfication and structural realism', in Zahar E. *"Poincarè's Philosophy: From Conventionalism to Phenomenology"* Open Court, Chicago and LaSalle: 236 -251.

Yablo, S. (1999), 'Intrinsicness', in *Philosophical Topics* **26**: 479-505.

Yolton, J. W. (1960), *The Philosophy of Science of A.S. Eddington* , Nartinus Nijhoff, The Hague.

Zahar, E (2001), *Poincarè's Philosophy: from conventionalism to Phenomenology*, Open Court Illinois.