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Hans Reichenbach: Philosopher-Engineer

by  
Roger Michael McAdam

submitted for the Degree of Master of Letters  
University of Durham  
1992

A B S T R A C T

This thesis relates Hans Reichenbach's philosophy of science both to his historical context and to his interest in the physical world.

The thesis begins with a review of his life, and notes the most significant influences on him. His early ambition to become an engineer stimulated in him an active interest in understanding physical things, and his enjoyment in disseminating what he knew entailed that he maintained a keen interest in contemporary ideas. By the age of twenty he had turned to philosophy to enhance his appreciation of science, and was influenced by Kant and the neo-Kantian interpretation through Ernst Cassirer.

His subsequent work is concerned with providing philosophical explication of the major innovations of twentieth century science, and particularly of the implications of Einstein's Theories of Relativity and of Quantum Mechanics. The thesis proceeds by summarising Kant's and Cassirer's writings on the philosophy of science before examining Einstein's theories. Subsequent chapters analyse Reichenbach's most significant publications in chronological order, namely The Theory of Relativity and A Priori Knowledge (1920), The Philosophy of Space and Time (1928), Experience and Prediction (1938), Philosophic Foundations of Quantum Mechanics (1944), and The Direction of Time (1956). The chapter on Quantum Mechanics is introduced with a summary of the scientific concepts introduced prior to Reichenbach's writing about them.

Although he demonstrates the shortcomings of Kant's philosophical justification, the objective Reichenbach set himself throughout his work was to identify the principles that regulate our empirical knowledge. Despite his close friendship with Rudolf Carnap and Moritz Schlick, he differentiated his Empiricism from Logical Positivism, and he refused to accept that Conventionalism could offer a satisfactory analysis of knowledge of the objective world. The final chapter summarises the impact of his writing and his major contribution to philosophy.

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Submitted for the Degree of Master of Letters

January 1992

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Hans Reichenbach: Philosopher-Engineer

CONTENTS

	Introduction	1
Chapter 1	Reichenbach's Life and Early Influences	3
Chapter 2	Immanuel Kant and the Neo-Kantian Inheritance	24
Chapter 3	Einstein and his Theories of Relativity	45
Chapter 4	Reichenbach, Relativity, and Kant	58
Chapter 5	The Philosophy of Space and Time	78
Chapter 6	Reichenbach on Probability, and Experience and Prediction	105
Chapter 7	Quantum Mechanics	127
Chapter 8	The Direction of Time	143
Chapter 9	Concluding Remarks	163
	Bibliographical references	166
	Index of Names	171

## Hans Reichenbach: Philosopher-Engineer

### INTRODUCTION

The objective of this thesis is to trace the development of Hans Reichenbach's philosophy of science from his early influences and through his major publications.

As a boy Reichenbach's ambitions centred on being an engineer, and his acquisitive search for knowledge was to reinforce his understanding of physical things necessary to a practical engineer. As a student his interests extended into understanding the structure of scientific knowledge, and he became absorbed in Kant's philosophy. With his understanding of mathematics and physics in the early years of the twentieth century, he recognised the potential challenge offered by Boltzmann's statistical methods to the established deterministic science based on Newtonian principles that had also served as Kant's basis of reference. His early philosophical work, therefore, centred on an attempt to reconcile Kant's writings with the challenge of twentieth century science. His later work reflects this reconciliation, although he can justly claim to have developed an epistemological method of Logical Empiricism that is influential in contemporary writings in the philosophy of science.

Reichenbach's philosophical development ran parallel to the development of logical positivism, itself a reaction to the scholastic traditions of European philosophy at the end of the nineteenth century, and he was a close friend of two members of the Vienna Circle, - Moritz Schlick and Rudolf Carnap. His interest in science, and physics and mathematics in particular, led him to give particular attention to the two contemporary innovations of major import, - relativity and quantum mechanics.

The first three chapters essentially provide the early context for Reichenbach's work, beginning in Chapter one with a summary of his life and early influences on him. The second chapter reviews the Kantian philosophical influence, and the third chapter examines the theories of Relativity which were the inspiration for his earliest publications.

The next five chapters are devoted to an analysis of his major writings in the philosophy of science. Chapter four concerns his 1920 publication The Theory of Relativity and A Priori Knowledge which is Reichenbach's attempt at direct reconciliation of Kant with Einstein's theories. Chapter five is devoted to his final publication concerned with the post-relativistic physics of space and time, - The Philosophy of Space and Time published in 1928. Chapter six relates to the work that gives the clearest exposition of his epistemology, namely Experience and Prediction

published in 1938, but the chapter is introduced with a review of Reichenbach's interest in the application of probabilistic considerations to empirical events. Chapter seven is introduced with a review of the development of quantum mechanics, before proceeding to Philosophic Foundations of Quantum Mechanics published in 1944. Finally, chapter eight is concerned with Reichenbach's posthumous publication The Direction of Time.

The concluding ninth chapter is an overall review of the philosophical impact of Hans Reichenbach.

## Chapter 1

### REICHENBACH'S LIFE AND EARLY INFLUENCES

#### Childhood and youth

Hans Reichenbach's childhood was spent in comfortable circumstances in Hamburg. He was born on 26 September 1891 as the third in a family of five children.

His father, Bruno, had a successful grain importing wholesale business in which he had immersed himself since the death of his own father when he was twentythree. Bruno was born into a Jewish family but converted in his twenties to the Reformed Protestant Church which he saw as a fulfillment of his Jewishness. His early pre-occupation with working life, which had been a necessity on his father's death, prevented him adopting a scientific career, and this was a source of regret.

Hans' mother, Selma, nee Menzel, was from a family whose Protestant heritage was traceable back to the Reformation and an abbot Bernhard von Senden who was one of the founders of the Evangelical Reformed Church. The von Senden family had spawned generations of doctors, clergymen, and pharmacists, and Selma's own mother Wendelina von Senden, grew up in the von Senden Pharmacy in Emden in East Friesland before her marriage to a Construction Engineer - Hermann Menzel. Selma was passionately interested in music and before marrying Bruno she had been a schoolmistress. She generated a keen cultural, but supportive, family environment for her five children.

The household was financially secure and there was a common eager awareness of contemporary cultural events during Hans' boyhood. The family members played musical instruments and attended concerts in Hamburg and they enjoyed avid discussion of contemporary works of literature by authors like Ibsen and Shaw. Hans' elder sister Maria was four years his senior; his brother Bernhard, with whom he remained close in his younger years, was three years older; sister Wendelina was five years younger; and brother Hermann was seven years younger than Hans. Comments on Hans as a boy derive either from Bernhard or Wendelina, or from letters or recollections from Hans himself.

Hans showed early aptitude in both his thirst for understanding and his practical abilities. His mother would turn to him to fix minor household repairs, and he adopted the role of tutor in scientific understanding to both his older brother and younger sister. Based on recollections it is difficult to establish the chronology of early development of Hans and his relationships

with his siblings, but the record is of a lively and precocious boy, alive to the world and to his own ego. He developed with complete confidence in himself and his abilities, and when very young exhibited sharp turns of temper when prevented from pursuing his own course of action. Hans recognised this weakness in himself and as a schoolboy succeeded in imposing his will to curb his tantrums. This quickness of temper was a feature he shared with his father, but in appearance and motivation he had inherited the characteristics of the Wenzel family. Certainly from the age of six he aspired to be an Engineer or Technician and he regarded his schooling as preparing him for that role.

His aptitude for constructive and coherent reasoning gave him an early appetite for board games, and as early as five years old he was able to beat his parents at checkers. When he was twelve he was introduced to chess at school, and quickly established himself as an outstanding talent, but by the time he was fifteen he had given it up because it distracted him from his serious pursuit of knowledge. Despite this apparent seriousness and dedication to his career, references indicate that he was a boy of great energy who relished physical recreation. This energy appeared to characterise him throughout his life, and although almost chubby in appearance, he is remembered whether as brother, colleague, or teacher, as an active, engaging, and open personality with a joy of living and keen sense of humour.

Despite the religious grounding of the family with a father who had converted from the Jewish faith and a mother of strong Protestant origins, Hans never appears to have had any affinity with religious sentiments, and his extensive recorded writings are marked by absence of reference to religious concepts. His early identification of himself as an engineer focussed his attention on explaining how the World of direct experience works, and this pre-occupation left no scope for metaphysical religious speculation. As a student in his early twenties he regarded the Catholic Establishment as a threat to the freedom of students to pursue objective knowledge, and in an article in 1912 in Das Monistische Jahrhundert No 16 he writes under the title "Studentenschaft und Katholizismus" -

The assertion that the dogmas contain the truth is totally unproven and vague in the eyes of a thinking person, who must therefore reject them as completely unscientific. For Science desires coherent knowledge; what is known through so-called supernatural means is not worthy of bearing its name.

(Reichenbach [1978], v.1, 105)

His disdain as an engineer for religious concepts, however, didn't extend to his feeling for political issues, and through his later years in Hochschule and throughout his student years he was actively involved in issues relating to individual freedom. His active participation whilst at school began with

the "Wandervogel" whose creed was a reaction against the constrained and over-specified system of education in Germany. At the age of eighteen in a review of his years at school, Reichenbach writes -

To be sure, I have learned much, very much in school, but I have also lost a lot. School does not end with the instruction period at 2 p.m., but because of the homework it takes up the better part of the afternoon. The worst of it is that homework is precisely prescribed . . . . I must criticise this pressure which is constantly being exerted on the mind. Wouldn't it be much better if, at home, the student could do the kind of work he really likes?

(Reichenbach [1978],v.1, 12)

The "Wandervogel" movement incorporated this reaction to the encroachment of the State Education System on the total life of young people, but it was not actively revolutionary, rather a means of withdrawal. Thus hiking groups were formed which went off into the countryside, and camps were organised. Of course older generations of Germans did not react to this as a threat to the established order, perceiving it as a wholesome German tradition of "die Gesundheit". The culture that developed in the early years of the 1900's involved a mystique of fellowship of young people, free from external constraints, and with a common enjoyment of natural things. As the movement became more established, however, diversification occurred and nationalistic sentiments developed, as did the belief that the movement should be more pro-active in changing the established order.

There is no record of what Hans Reichenbach expected of the "Wandervogel", nor of the extent of his involvement, only that he was involved, and this is entirely consistent with his beliefs and energy. The antagonism towards intellectual disciplines that developed within the movement would not, however, have met with his approval. His reaction against the system of education was that it inhibited his opportunities for extending and developing his own intellectual pursuits. Later, at University, he was to apply his energy to the "Freie Studentenschaft", whose aims were to develop opportunities for liberal intellectual development for students.

Hans Reichenbach left Highschool in 1909 at the age of eighteen. He had had a distinguished school record and was at the top of his class in all subjects. His passion was for mathematics and science -

The greatest joy I derived from lessons in mathematics and natural sciences . . . only since I have known of analytic geometry, differential and integral calculus, have I

understood why mathematics is of such tremendous importance for the technical sciences. In Chemistry and Physics classes I learned that true science does not consist of the knowledge of a certain amount of facts and numbers but of the inner appreciation for the great interconnectedness of nature.

(Reichenbach [1978],v.1, 11)

But he had derived great stimulation from his studies in German literature and foreign languages -

here did I learn to speak French and English fluently, and, above all, to grasp the spirit of these languages . . . . Goethe and Schiller became noble men to me . . . . I got an idea of the monumental intellectual struggles of humanity.

(Reichenbach [1978],v.1, 11)

#### Student years

In 1910 and 1911 Hans studied Engineering at the Technische Hochschule in Stuttgart, the natural development of his ambitions. But -

During this time I first realised that my interests were predominantly theoretical.

(Reichenbach [1978],v.1, 1)

Reichenbach had been freed from the narrow constraints of traditional German schooling about which he had complained, and in reading beyond what was required of an Engineer he stumbled on other influences, particularly Boltzmann and Kant. He decided to abandon the subject to which he had seemed pre-destined and went to the University of Munich in 1911 to study Mathematics, Physics, and Philosophy. Although it was to the Philosophy that he looked for "the inner appreciation for the great interconnectedness of nature", he found that traditional philosophy as taught in Universities was -

inexact and too little connected with the natural sciences

(Reichenbach [1978],v.1, 1)

and

I was not too interested in historical philosophers; I read some of them with great respect, such as Descartes and Spinoza; yet, my own philosophical work always related directly to physical problems without consideration for historical connections.

(Reichenbach [1978],v.1, 1)

He was disappointed in the approach of the teaching

philosophers, and had respect only for Ernst von Aster at Munich. Aster had a particular interest in English philosophy and in particular Locke and Hume. In his book on the history of English philosophy published later in 1931, Aster specifically credits these philosophers as "having promoted the standpoint of empiricism" and proceeds -

sobriety and clarity, a clarity which repudiates nothing so keenly as incomprehensibility and obscurity masquerading as profundity, a sobriety which wishes to see things only as they really are

This is a philosophy of direct appeal to a young engineer.

Aster, however, was influenced primarily by Kant, and averred that the "Knowable" had to be structured. He was therefore concerned for a valid philosophical foundation for science.

In addition to his studies at Munich the young and restless Reichenbach also spent some time at the University of Berlin. Evidence for this appears in a letter to his older brother Bernhard written in November 1911. In the letter he advocates to Bernhard what reading he should undertake as an introduction to the writings of the major philosophers. He also mentions that he is attending a seminar organised by the physicist Max Planck -

I better hurry and get to bed; otherwise I won't be able to pay enough attention in Planck's seminar.

(Reichenbach [1978],v.1, 15)

It is highly probable that whilst in Berlin at this time, he also encountered the teaching of Ernst Cassirer. Cassirer was certainly an influence on the young Reichenbach's early studies of philosophy, as he writes in his autobiographical memoirs in 1932 -

The philosophers Von Aster, in Munich, and Cassirer, then at Berlin, however were exceptions; they showed understanding of the problems of natural philosophy and were encouraging and stimulating.

(Reichenbach [1978],v.1, 1)

Cassirer was deeply rooted in the philosophy of Kant, and, actively interested in the science of the late nineteenth and early twentieth centuries, he worked to assimilate the new ideas into a Kantian framework.

At some stage between 1911 and 1915, Reichenbach's interest in mathematics took him to the University of Gottingen where he attended lectures given by the mathematician, David Hilbert. At this time the Mathematics department there was outstanding, and

had included leading practitioners like Minkowski and Klein. Hilbert had been responsible for developing a general system of Geometrical axioms from which the traditional Euclidean model could be regarded as a special case. Reichenbach was later to make use of the Hilbert formalism in his analysis of Space post-Einstein.

Reichenbach studied Kant with care, and Boltzmann, with his statistical approach to the Kinetic Theory of Gases. This early fascination with a probabilistic assessment as a basis for a philosophical appreciation of the natural sciences is a recurrent theme throughout his life, and his dissertation in 1915 -

"Der Begriff der Wahrscheinlichkeit für die  
Mathematische Darstellung der Wirklichkeit"

concerned the application of the laws of probability to scientific knowledge. Strongly influenced at this time by the work of Kant, he used a Kantian approach to set a context for what was contemporary Physics. He could find no teacher who was interested in these problems and therefore produced the dissertation without guidance and submitted it in the University of Erlangen, which awarded him his Doctorate. This dissertation comprised a mathematical section on probability theory followed by an epistemological analysis, and at Erlangen he had been able to find a Philosopher and a Mathematician who between them were able to accept it.

This dissertation is the only published work by Reichenbach on his Philosophical work prior to 1919, but he generated many published items in connection with his role in the "Freie Studentenschaft", and a view of the whole man requires an examination of his role in this organisation in the years between 1911 and 1919. Much can be obtained from his own publications, but also from reminiscences from student colleagues Carl and Hilde Landauer.

The Freie Studentenschaft originated around 1900 and was active in several Universities by the time Hans Reichenbach became involved in 1911. This was a minority student organisation which had developed counter to the prevailing campus organisation, - the Korporationen. The Korporationen reflected the values of the German Reich, and were conservative, socially exclusive fraternities, and anti-semitic. Whereas the Korporationen regarded the University primarily as an Institution of the Reich, the Freie Studentenschaft perceived it as a community of students and teachers, opposed to all restrictions of academic freedom with equal rights for all students. Asserting this in 1912, Reichenbach writes -

the true academic freedom is the freedom that  
makes one's will the supreme authority . . .

If I come to a conclusion that contradicts ancient traditions or even dogmas, I want the right to advocate my view . . . . . The student's most precious possession is his freedom . . . . "the student" is still a dream of the future. Yet we can come closer to the goal - if we fight for it.  
(Reichenbach [1978],v.1, 103)

Hans Reichenbach's earlier association with the Wandervogel should have directed him into the Akademische Freischar, which was the University branch of the Wandervogel movement. The fact that he did not become involved with this is probably due to the impossibility of reconciling the Wandervogel philosophy with a University environment. Certainly the Freischar movement lacked a positive direction, deriving as it did from a movement whose tendency was to belittle academic development.

The Freie Studentenschaft, as a democratic self-help organisation, spawned circles of friends organised in discussion groups. In Munich, Reichenbach was involved in an earnest group which organised its own lectures and actively debated and studied academic and social issues. The group included lawyers, economists, and historians, and in Hans it linked into the physical sciences, mathematics, and philosophy. As reported by Carl Landauer, the group was prevailingly rationalistic, - apart from Hans who had a "romantic streak". The group met practically every day through the years 1911 to 1913. Subjects of continuing debate included analysis of teaching methods, the role of the family as either shackle or liberator of individual development, and the effect of the Catholic Church as an impediment to Research. On all such topics Hans Reichenbach was committed to the radical view which puts individual freedom and development above all social and Establishment institutions. In his paper of 1912 "Studentenschaft und Katholizismus" he asserts -

From the beginning, this organisation [Freie Studentenschaft] has supported a certain form of student education, demanding that every student become familiar with every point of view, that he develop his own point of view in the battle of minds, independent of every alien authority.

(Reichenbach [1978],v.1, 106)

Further than this, he opposes the right of membership to Catholic students with their inability to pursue unfettered intellectual enquiry, and affirms that -

the movement urgently needs to limit the right to vote and to take a clear position with a firmly delineated programme; . . . . May the Free Students succeed in carrying out their cultural mission despite internal and external enemies.

(Reichenbach [1978],v.1, 107)

In 1913, together with Freie Studentenschaft colleagues Carl Landauer and Hermann Kranold he published what he described as an attempt to synthesise the Philosophy of the Movement, as "The Free Student Idea: its Unified Contents". The style and self-confidence of this document are distinctively Reichenbach's, and not only does this draw together a coherent statement of his social views, but it uses the philosophical methodology that he employed in later work on the Philosophy of Physics.

He begins with a statement of the "Moral Ideal" of the Freie Studentenschaft and looks at the origins of the movement, where the concept of such a specific ideal was not a conscious issue. He in effect, but without using the terminology, explains the Ideal of the Movement in terms of "The Context of Justification" as opposed to an explanation from "The Context of Discovery", - ideas he used later in analysis of theories in physics. As in his later work he self-confidently presents his analysis as a definitive statement -

That a cultural movement requires fifteen years .. to develop and clarify its philosophical foundations does not tell in any way against the value of that movement. On the contrary, that action resting upon certain definite values precedes a clear recognition of these values, ... Yet that does not mean that a clear formulation of one's own volitional decision is unnecessary.  
(Reichenbach [1978],v.1, 108)

The Ideal that he draws up is -

The supreme moral ideal is exemplified in the person who determines his own values freely and independently of others and who, as a member of society, demands this autonomy for all members and of all members.  
(Reichenbach [1978],v.1, 109)

He is thus not prescribing a specific creed or set of values that an individual ought to adopt, but rather that each must freely choose a set of values and consistently follow them in complete freedom. He thereby defines immoral behaviour as -

an inconsistency between goal and action. To force a person to commit an act that he himself does not consider right is to compel him to be immoral .  
(Reichenbach [1978],v.1, 110)

Thus the task for the Freie Studentenschaft is defined as -

to educate students to the acceptance of this ethical ideal. ... The educational work of the

Free Students ought to culminate in the successful raising of free, self-determining people within the student body.

(Reichenbach [1978],v.1, 110)

Following this is presented a radical programme to reform student life within the University, and including, - organisation of open lectures; lectures by prominent public figures other than academics; mutual provision to support poorer students; work by students in the community and, in particular, in the juvenile courts and in workers' education; the right of lecturers to declare their political convictions as well as allowing Social Democrats to become lecturers; mutual discussion of teaching methods and timetables between teachers and students; reform of the student disciplinary system; and, finally, the ideal of a general student committee to regulate the affairs of the University.

Reichenbach is seen in this article as an indefatigable politician. A further publication of his at this time "Why do we advocate Physical Culture?" affirms the value of physical exercise, with particular emphasis on hiking. In 1914 in his article "The Meaning of University Reform" he pleads that the University -

must be the spiritual home of the student body.

(Reichenbach [1978],v.1, 131)

and that University is the place -

in which science can find its ultimate fulfillment

For Reichenbach a University is a free Institution open to all ideas, whose role is unfettered pursuit of understanding. Students attending are free to make their own decisions on what studies they pursue, and the teaching staff are there in support of this.

#### Post-graduate

Following presentation of his Doctoral Dissertation in Erlangen in 1915, Reichenbach was called into military service in the Army and was deployed in the Signal Corps on the Russian Front. He viewed the war as a tragedy and wrote -

that scientific-minded people have the particular duty to fight the spirit which breeds such catastrophes for humanity.

(Reichenbach [1978],v.1, 2)

He learned the principles of radio technology, but became

seriously ill after 2 1/2 years and was transferred from active duty.

He returned to Berlin where he supported himself from 1917 to 1920 by working for a firm specialising in radio technology. His father died in 1918, leaving him entirely self-supporting, and he became Director of the Loudspeaker Laboratory. Despite this work he attended lectures at the University where he studied Physics under Planck and Kantian Philosophy under Cassirer. He was accepted into the "Kantgesellschaft" early in 1918.

The Revolution in Germany at the end of the War brought together students in Berlin with a variety of Socialist views. Hans Reichenbach was instrumental in coalescing this group into "The Socialist Student Party Berlin" - SSPB. He was elected Chairman and set out the Platform Statement in "Platform of the Socialist Students Party", with three main objectives, - to seek the cooperation of every citizen in bringing about socialism within the State; to convert the intellectual class to socialism; and to reform the University along socialist lines. The two developments on his ideas from his days in the Freie Studentenschaft were, - his adoption of the socialist ideal as a means of avoiding war brought about by conflicts in the capitalist system; and that education should be structured from school through to University to enable students to proceed on grounds of competence rather than wealth. The programme, however, was accepted by only a small minority of students and before the end of 1919 it had effectively petered out.

Thus in 1919 Reichenbach is anchored in Berlin, a young man of 28, secure in a responsible and technical job, and passionately concerned with issues of personal freedom and a socialist society. It is an interesting speculation whether he might not have developed from here as a political animal as a shaping influence towards the Social Democratic Party that emerged after the Second World War. It appears that the events which led him away from the political life were the lectures on Relativity by Einstein, which Reichenbach attended in 1919. Certainly, from then on there are no records of publications by him on political issues, and over the next four years the papers he published were either directly related to his philosophical explications of Relativity or were related to his earlier work on applying probability considerations to science.

#### Teacher and Philosopher in Stuttgart

In 1920 Reichenbach moved squarely back into Academia; he gave up his job in the Loudspeaker Factory and accepted a Post at the Technische Hochschule in Stuttgart as Docent. This entailed his being accepted as an unsalaried teacher, paid directly for the lecturing he actually did. Hans Reichenbach brought into play

his complete portfolio of technical knowledge, lecturing on techniques of physical measurement, wireless telegraphy, relativity, and philosophical topics. He remained for six years in Stuttgart, during which time he was appointed Associate Professor of Philosophy. In 1924 he made a few notes on his situation as an unsalaried teacher. Whether he has been caught in a moment of self-pity, or whether, at the age of thirty-three, he is beginning to yearn for the acknowledgement of the establishment, is unclear, but the forceful radical writing of his Freie Studentenschaft and SSPB days is not evident. Thus he writes -

A worker once told me: " If I had learned as much as you, I would not work for this salary." He did not know that one does not work for the salary but *in spite of* the salary.

(Reichenbach [1978],v.1, 25)

A significant event had occurred, however, which may have re-aligned his relationships with the social world; in 1921 he had married a teacher Elisabeth Lingener. It is difficult to be precise about the actual year of marriage; 1921 is the year reported by Wesley Salmon in his biographical sketch, but Reichenbach himself refers to this in his "Autobiographical Sketches for Academic Purposes" in 1932 when talking about his work in Berlin between 1917 and 1920 -

I directed the loud-speaker laboratory of this firm. I also got married. Soon thereafter, my father died and for the time being I could not give up my engineering position because I had to earn a salary in order to provide for my wife and myself.

(Reichenbach [1978],v.1, 2)

Reichenbach's autobiographical notes are not entirely consistent in dating events in other details, as they appear to be primarily a record of the development of his thinking, whereas Wesley Salmon demonstrates general consistency - (Salmon (ed) [1979], 3 - 10). The combination of circumstances given by Reichenbach in this extract at least indicates that whilst still in Berlin he was taking the responsibility for supporting Elisabeth, if not actually married to her. What is known about Elisabeth at this time is that she already had a child (not Reichenbach's), and that, according to Reichenbach's sister-in-law Ilse Reichenbach, - wife of Bernhard -, Hans had begged that the child live with them; but Elisabeth had refused,- a decision she later regretted.

Hans Reichenbach and Elisabeth had two children, - Hans Galama born in 1922 and Elizabeth Austin (Jutta) born in 1924. The marriage appears to have been beset with difficulties from its earliest years. Elisabeth had no interest in Hans' work, which of course was his life's obsession. He appears to have alienated

himself also from his young family through his long working absences, and, as reported by Hans' niece Nino Erne (daughter of Wendelina), - "they were more attached to their mother". There is no doubt that Hans Reichenbach retained a great attractiveness to children throughout his life, and he indulged himself in their company, enjoying their amusement and opening their eyes to the workings of the world. The conclusion must be that there was a degree of bitterness in the Reichenbach household. The rift between Hans and his son widened as Hans Galama grew into a gifted and brilliant young man, but who left school despite his father's stubborn opposition.

In Stuttgart, Reichenbach began publishing in earnest. He had come there from Berlin pursuing two major courses of investigation,- Relativity, and Probability as a means of understanding causal relationships in the Physical world. Before leaving Berlin he had completed his first thoroughgoing analysis of Relativity - Relativity and A Priori Knowledge -, which was published by Springer in 1920. This analysis followed his attending Einstein's lectures on Relativity in Berlin in 1919, which had a dramatic effect on him -

I recorded the result of this profound inner change in a small book entitled  
Relativitätstheorie und Erkenntnis Apriori  
(Reichenbach [1978],v.1, 2)

Effectively, Relativity Theory had challenged the basis of Kant's philosophy which Reichenbach until that time had been able to reconcile with his own coherent view of physical knowledge. He introduces his book with -

Einstein's theory of relativity has greatly affected the fundamental principles of epistemology . . . .Euclidean geometry is not applicable to physics.  
(Reichenbach [1965], 1)

This book marks Reichenbach's reaction against Kant's Philosophy in the light of Einstein's work. Kant, a Century and a half earlier, had taken the Physics of his time and sought to develop the principles of understanding implied by it. As Reichenbach wrote in a short article "Philosophy of the Natural Sciences", published in the Vossische Zeitung in 1928 -

Kant, in building his grand system, fitted the concept of scientific knowledge into his framework of a universal rationalist philosophy  
(Reichenbach [1978],v.1, 229)

The Physics and Metaphysics of Kant, however, was essentially Newtonian, which was based on the concept of an absolute Space, each point effectively marked by unique co-ordinates and

connected by a Euclidean metric. Einstein, in his theories of Relativity, had demonstrated that the Newtonian concepts of space could not be consistently applied, and Reichenbach saw his task as re-defining a Philosophy of Physics that could be compatible with the science of his own time. In the same article he continues -

Kant's construction of the philosophy of this classic epoch was an historic achievement, yet it is entirely too antiquated when reproduced with minor variations in the era of Einstein  
(Reichenbach [1978],v.1, 229)

Reichenbach, with his interest in, and knowledge of, contemporary Physics and Mathematics, took Kant's task upon himself. He saw himself as uniquely qualified to this task, for, as he saw it -

present-day academic philosophy ...has lost all relation to science, and .. the scientist has given up all hope of obtaining from any such philosophy answers to the epistemological questions that confront him in the course of his research.

(Reichenbach [1978],v.1, 229)

Relativity and A Priori Knowledge was the first of three major works by Reichenbach on the effects of Relativity Theory on the Philosophy of Space and Time. The others were Axiomatic for the Relativistic Space Time Theory - published in 1924 - , and The Philosophy of Space and Time - published in 1928. Although during this time he published a great number of articles on other topics, and particularly on the application of Probability to our understanding of causal relationships, these were his only major works. Reichenbach had committed himself to providing a Philosophy for Twentieth Century Physics, and to replacing the Kantian System based on Eighteenth Century Science. Commenting on this work during his period at Stuttgart, Reichenbach writes

here the theory of relativity receives a philosophically correct justification ....  
I was the first to systematically uncover and compile all necessary definitions of correlation of the space-time-theory.

(Reichenbach [1978],v.1, 2)

#### Reichenbach and Contemporaries in pre-Nazi Germany

In 1926 Reichenbach was appointed as Professor of Physics in Planck's Department at the University of Berlin. The authorities in Berlin were opposed to Reichenbach's appointment largely on

account of his radical and anti-authoritarian views there as a student, but also because of his disdain for metaphysical speculation in Philosophy. He had two strong proponents in the Faculty in Planck and Einstein, and the story as recounted by Wesley Salmon is that Einstein, when challenged by the Establishment about the heretical ideas of his would-be appointee, replied "And what would you have done if the young Schiller had applied here for a position?"

Reichenbach established himself in Berlin as the directing influence in the method of Logical Empiricism, and he founded the "Berlin Society for Empirical Philosophy"; this group included Walter Dubislav, Kurt Grelling, and Carl Hempel, as well as the two psychologists - Kurt Lewin and Wolfgang Kohler. The group also organised a series of lectures each year on contemporary philosophical issues, and these were open to the general public (Hempel [1991], 6).

His one major publication during his seven years at Berlin University was his third major work inspired by Einstein - The Philosophy of Space and Time. He also published "Ziele und Wege der Physikalischen Erkenntnis" in 1929 in Handbuch der Physik v.4 pp1-80, and Atom and Cosmos. The World of Modern Physics in 1930. In addition to numerous articles in journals, however, he identified himself as a distinctive figure in the philosophical world through his founding with Rudolf Carnap of the journal Erkenntnis.

Because he had been on friendly terms with several members of the Vienna Circle, and with a particular respect for Moritz Schlick and Rudolf Carnap, he approached them with the proposition of founding Erkenntnis. He had first met Carnap at a conference on Symbolic Logic which the two of them had organised at Erlangen in 1923. The conference had included addresses on pure logic, the decision problem, the relation between physical objects and sense-data, a theory of knowledge without metaphysics, a comparative theory of sciences, and the topology of time. Carnap reports in "Carnap's Intellectual Autobiography"

Among all those who worked in Germany in a similar direction in philosophy and in the foundations of science, Hans Reichenbach was the one whose philosophical outlook was closest to mine. ... Our points of view were often quite divergent, ... Nevertheless, there was a common basic attitude and the common aim of developing a sound and exact method in philosophy. ... The Erlangen Conference may be regarded as the small but significant initial step in the movement of scientific philosophy in Germany.

(Schilpp (ed) [1963],14)

Even as early as this conference in 1923 Reichenbach had

proposed that a new periodical be founded as a forum for this new kind of philosophy, but it was not until 1930 that he and Carnap as joint editors finally launched Erkenntnis. In his editorial introduction to the first issue of Erkenntnis, Reichenbach writes -

Philosophy must be based on empirical research in natural and mental science ..... it is a method of clarification, not a science.

Carnap and Reichenbach met frequently after the Erlangen Conference and each used the other as critic of new ideas. Reichenbach contributed to the dialogue by his work involved with Physics, and Carnap contributed mainly with work in Logic. As Carnap remembers -

I often asked him for explanations in recent developments, for example, in quantum-mechanics. His explanations were always excellent in bringing out the main points with great clarity.

(Schilpp (ed) [1963], 14,15)

The further consequence of the collaboration between Reichenbach and Carnap was a series of conferences and congresses of what they saw as a new movement in Logical Philosophy embracing not only the Berlin Empiricists and the Vienna Circle but also the Warsaw philosophical group. The first conference on the "Epistemology of the Exact Sciences" took place in Prague in September 1929.

It was Reichenbach who had provided Carnap with an introduction to the Vienna Circle when Reichenbach introduced him to Moritz Schlick in the Summer of 1924. Schlick had initially made contact with Reichenbach by correspondence following publication of Reichenbach's Relativity and A Priori Knowledge in 1920. In that book Reichenbach refers to Schlick's Raum und Zeit in der gegenwertigen Physik. Zur Einführung in das Verständnis der Relativitäts- und Gravitationstheorie, published by Springer in Berlin in 1917; and Reichenbach attempts to moderate Schlick's rejection of the Kantian concept of absolute a-priori principles. This led to a correspondence referred to by Schlick in 1921 with -

Even in those questions about which he takes issue with me in the book, there is really no profound difference of opinion, as an elucidation of our opinions by correspondence has subsequently disclosed.

(Schlick [1979],v.1, 333)

In fact, the correspondence with Schlick in 1921 and 1922 marked a decisive change in Reichenbach's approach to philosophy. Reichenbach had attempted to reconcile Kant's system of a-priori

with Relativity in accepting the Kantian premiss that knowledge is obtained by application of constitutive principles to experience, but without claiming a logical necessity for a particular set of constitutive principles. Schlick had been given the task by Kant Studien of reviewing both Reichenbach's work [Reichenbach;1920] and Cassirer's [Cassirer;1921], and had countered that in rejecting the a-priori necessity of Kant's principles, Kant's approach as a whole should be rejected. Schlick's recommendation is, therefore, that the proper object for epistemological analysis is empirical knowledge itself, albeit recognising that experience is shaped through application of constitutive principles, and that these are conventions as prescribed by Poincaré.

Reichenbach's acceptance of Schlick's criticisms is acknowledged fully in "The Discussion of Relativity Now" published in Logos 10 1922, where he writes

Formerly I believed, on the basis of his opposition to Kant, that Schlick overlooked the constitutive significance of the categories in the concept of object, and ...I objected to Schlick's views on these grounds. However, in the course of our correspondence, it turned out that this objection was based on a misunderstanding and therefore I should like to take it back. ... Schlick's empiricism .. must be regarded as a method based on the belief that reality is given in experience, a method which takes as its task the *analysis of the process of experience* in the widest sense, without adhering to any specific interpretation. I am quite ready to accept this method because my so-called "analytic method" represents exactly this objective approach.

(Reichenbach [1978],v.2, 37)

In addition to this involvement with his fellow professional philosophers, Reichenbach broadcast a series of radio lectures in 1930 which were published as Atom and Cosmos. The World of Modern Physics. In these lectures he demonstrated that the conceptual scheme that has been successful in traditional physics becomes inconsistent when it is applied to sub-atomic events at one end of the scale of dimensions, or when applied to astronomical events at the opposite end of the scale.

Throughout his period in Berlin, and throughout the rest of his life, Reichenbach would return to worry at the problem area with which he began his philosophical career, namely the application of probability considerations to an epistemology of scientific knowledge. This pre-occupation had again been triggered by his study of Kant and consequent concern with causal ordering. Reichenbach himself comments in autobiographical notes made in 1936 -

I frequently interrupted other work in order to work on the problem of probability.

(Reichenbach [1978],v.1, 6)

He had first been impressed with the application of probabilistic analysis of physical events by the work of Boltzmann in Thermodynamics. He had developed his ideas in his doctoral dissertation in 1915, although at that stage he had not been prepared to throw off his Kantian yoke. In two papers written in 1920, - "The Physical Presuppositions of the Calculus of Probability" published in Die Naturwissenschaften 8, no.3; 46-55, and "The Probability Calculus" published in Die Naturwissenschaften 8, no.8; 146-153, - he demonstrates the necessity of adding the principle of probability to that of causality as "a necessary constituent of our knowledge of nature"; - as a Kantian synthetic a-priori judgment. By the time he had moved to Stuttgart as Docent, however, he had begun to question the validity of Kant's claim for synthetic a-priori judgments and the concepts from Eighteenth Century science of strict physical determinism. In 1928 he writes in the Vossische Zeitung in a short article "Causality or Probability?"-

we must speak of an objective indeterminacy in nature; the course of the universe is comparable, not to a clockwork, but rather to a perpetual dice game in which each stage in the event corresponds to another throw of the dice.

(Reichenbach [1978],v.1, 239)

He published two major works on this subject, - The Theory of Probability. An Inquiry into the Logical and Mathematical Foundations of the Calculus of Probability published in Leyden in 1935, and Experience and Prediction published in Chicago in 1938.

### Istanbul

The assumption of power in Germany by the Nazis in 1933 resulted in the dismissal of Reichenbach from his position at the University of Berlin. It appeared that it was his Jewish origins that gave offence to the Nazis, rather than his radicalism. He moved to Istanbul where he took charge of the Philosophy Faculty at the University, taking advantage of the high regard Atatürk had for education to attract a nucleus of bright students. He remained in Turkey until 1938, when he emigrated to the United States.

Reichenbach had a five year contract at the University of Istanbul together with access to funds to develop the Philosophy Department. This effectively gave him the opportunity to develop

a university in line with the radical ideas he had espoused whilst in the "Freie Studentenschaft". He was assigned a Turkish Interpreter, but in addition to his already fluent English and French, he was able to acquire a sufficiently good grasp of Turkish to be able to lecture in it. Reichenbach converted the Philosophy Degree into a multi-disciplinary study, so that students were obliged to study two theoretical and one experimental science in addition to studies in literature, history, and other humanities. He also organised Collegiums for the Philosophy students to which Professors from the other Faculties were also invited, so that philosophical problems could be examined from several points of view. He was a popular teacher who made himself easily available to his students.

Whilst in Istanbul, Maria Moll, with a PhD in Philosophy from Germany, became a friend of Reichenbach and his family. She later met him again in California, and became his second wife in 1946.

Whilst in Istanbul Reichenbach continued to produce papers for philosophical journals, including Erkenntnis. Almost all were concerned with probability, causality, and induction; and in 1938 Experience and Prediction was published by the University of Chicago Press.

#### The University of California at Los Angeles

After Ataturk's death, an increasingly nationalistic mood developed in Turkey, and most of the German and Austrian Professors who had moved to Istanbul in 1933 sought positions elsewhere. Reichenbach contacted friends in the United States and was offered a position at the University of California at Los Angeles as Professor of Philosophy in 1938.

He travelled to the United States via Switzerland where he indulged in a holiday of hiking and mountaineering, but on arrival in Los Angeles he suffered a coronary thrombosis. After six weeks however he had recovered sufficiently to begin his lecturing at UCLA where he remained until he died in 1953.

During this last fifteen years of his life he produced six major works, - From Copernicus to Einstein published by the Philosophical Library New York in 1942, Philosophic Foundations of Quantum Mechanics published by University of California Press in 1944, Elements of Symbolic Logic published by MacMillan Co New York in 1947, The Rise of Scientific Philosophy published by University of California Press in 1951, Nomological Statements and Admissible Operations published by North-Holland Amsterdam in 1954, and The Direction of Time published posthumously by University of California Press in 1956.

Whilst in the United States he was able to resume his close friendship with Carnap who succeeded Reichenbach at UCLA, and he re-established his friendship with Einstein whom he often visited in Princeton. Einstein regarded Reichenbach's work on Space and Time as a philosophical framework in which Relativity could be understood, as he (Einstein) comments in 1949 on Reichenbach's "The Philosophical Significance of the Theory of Relativity" included in Schilpp (ed) [1949] Albert Einstein: Philosopher-Scientist -

I can hardly think of anything more stimulating as the basis for discussion in an epistemological seminar than this brief essay by Reichenbach  
(Salmon (ed) [1979], 24)

In 1940 Bertrand Russell was visiting Flint Professor at UCLA, and shared Reichenbach's office. The two became good friends and maintained a contact throughout Reichenbach's remaining years. Reichenbach had previously held Russell in high esteem because of his work on the foundation of mathematics and for the clarity of his writing, but he was also impressed by the moral honesty in his social and political views. In an article on Russell in Obelisk Almanack in 1929, Reichenbach writes -

This true writer is to be compared among the ranks of philosophers with his great compatriot Hume, to whom he bears marked similarity both in his style ...and methodology

and

.. the earnestness of his character, the sincerity of his conviction, the nobility of his sentiments. He belongs as much to the philosophers of action as to the philosophers of theory, ..

(Reichenbach [1978],v.1, 303)

### Memories of Reichenbach

Recollections by students and friends of Hans Reichenbach during his period in the United States present a physical picture of -

short, almost rotund, stubby hands and feet, round face, snub nose, thick glasses, false teeth, a hearing aid, and a thin high-pitched speaking voice.

(Reichenbach [1978],v.1, 58)

and yet he was an engaging presence with energy, personal dignity, and keenness of intellect and wit. He was a teacher of great clarity who encouraged his students to develop their own

ideas and encouraged discussion both in his classes and at his home. As a boy he had been eager to learn as he prepared for his profession as Engineer, and he had become a disseminator of that knowledge both to his older brother and younger sister; and it appears he retained that passion for dissemination throughout his life. As a precocious boy, learning with practical intent, he had a need to be sure of his knowledge; and again he retained this self-confidence and belief in the ideas that he had thoroughly worked through himself. As Wesley Salmon remarks -

Reichenbach had the conviction that he was right.

and

..studying with Reichenbach was studying  
Reichenbach.

(Reichenbach [1978],v.1, 73)

Carl Hempel had been a student of Reichenbach's in Berlin in 1926, and even at this early stage of his philosophical career, Reichenbach "tended to be quite sure of his ideas, and occasionally too readily dismissive of dissenting views, but this did not affect his refreshingly receptive and informed way with students" (Hempel [1991], 5). His readiness to take an interest in his students, in their aspirations and their problems, was in sharp contrast to the prevailing tendency of German Professors at that time, and Hempel contrasts this with the attitude of Max Planck,

I recall once running after Max Planck to ask whether I might put a brief question to him about a point he had made in his lecture. He did not even turn round. "Ask my assistant" he said, vanishing into his office.

(Hempel [1991], 5)

Speaking at Hans Reichenbach's funeral in 1953, Abraham Kaplan, - who had joined Reichenbach as Professor of Philosophy at UCLA in 1940 -, summarised the effect Reichenbach had had on colleagues and students -

Whoever knew him, in whatever capacity, learned from him. He was a man of ideas, to whom ideas were all important, and he made their importance felt by all around him. ... For what he knew, he wanted others to know; the truth he believed in he wanted others to believe.

(Reichenbach [1978],v.1, 67)

Commenting further on Reichenbach's application to his work, Kaplan wrote -

In an age of science, he wanted men to look to the logic of science for a guide to belief and action. .... For this wisdom, and for the hard work which its acquisition entails, he had unlimited passion

and energy. His zest for the life of ideas was a vital part of his personality.

He never lost his passion for practical things. He was always interested in mechanical things, and was a serious photographer. He tried to use photography in his attempts to get Bertrand Russell to abandon his two-dimensional phenomenalist description of the world by taking stereo-photographs and showing them to Russell through a viewer.

The energy he displayed in his academic and practical work also went into his recreational activities which included walking, rock-climbing, camping, and he was an accomplished ice-skater. As a philosopher he brought energy and thoroughness to his deep understanding of the physics and mathematics of the first half of the Twentieth Century. He was a Philosopher-Engineer.

## Chapter 2

### IMMANUEL KANT AND THE NEO-KANTIAN INHERITANCE

An appreciation of the development of Reichenbach's philosophical method must begin with Kant. Kant's contribution to philosophy in the late Eighteenth Century had had a profound development on subsequent writing, and particularly in Germany where one hundred and fifty years later in the early Twentieth Century it was regarded, in Reichenbach's words as "a cornerstone of philosophical thinking" (Reichenbach [1978],v.1,389). In an article entitled "Kant und die moderne Naturwissenschaft" in 1932 in the Frankfurter Zeitung 77, nos 626-627 dated August 23, and translated by Maria Reichenbach for quotation in her introduction to the English edition of The Theory of Relativity and A Priori Knowledge, Reichenbach writes

Kant's Critique of Pure Reason stands before the philosophy of our Century as a towering edifice. Whoever has something to say about philosophy, whoever has constructed his own philosophical system during the last one hundred and fifty years, has been a student of Kant's, and even if he has become Kant's opponent, he once learned his philosophising from him. Those who do not consciously continue Kant's system show their contact with the Kantian method at least by their critique of Kant's ideas and by founding their own theories upon such a critique.

(Reichenbach [1965], XIX)

Reichenbach was educated in Kant's philosophy initially through Aster in Munich. This was consequent to the conversion of the young trainee Engineer to look to the philosophical foundations of his scientific knowledge. Aster's approach to philosophy with his respect for empirical investigation would therefore be of direct appeal to Reichenbach. Kant's task, of establishing the bases on which scientific knowledge was possible, was therefore the most appropriate work for Reichenbach to study.

The task Kant had set himself was to establish metaphysics on a secure and scientific basis similar to what had been achieved for Physics in the Eighteenth Century. The principles of mechanics developed by Newton with the systematic application of mathematics had generated a confidence, not only among scientists, but in enquiring thinkers throughout Europe, that knowledge of the physical world could be established on a few

firm and unshakeable principles.

Kant had studied philosophy, theology, physics, and mathematics at the University of Königsberg, where he was later to be appointed as Professor of Logic and Metaphysics. Reichenbach, in his essay on "Kant and Natural Science" in 1933, writes of him

Kant himself grew up with strong scientific interests. Among his writings we find a large number of purely scientific investigations, in which he reveals himself as an exacting expert in the handling of empirical facts, making great efforts to discover systematic connections underlying them.

(Reichenbach [1978],v.1, 392)

Reichenbach continues in this essay with his endorsement of Kant's credentials with -

... it would not be possible to name many philosophers today with such a comprehensive knowledge of the science of their time or such an intense desire for participation in scientific thought.

(Reichenbach [1978],v.1, 392)

Kant, the scientist-philosopher, was concerned to establish what could constitute knowledge. He was concerned with the reasonable extent of metaphysics; to determine which arguments and which objects of study were within the scope of human reason. His major work in setting out his critique is Critique of Pure Reason first published in 1781, but subsequently revised in the second edition published in 1787. In his Preface to the second edition he describes his concern -

Metaphysics ... has not yet had the good fortune to enter upon the secure path of a science.

(Kant [1929], B xiv)

Kant's two basic principles of analysis are that the laws of logic are a valid system of analysis of ideas and statements, and that human knowledge, developed through the methods of science, as exemplified by Galileo and Newton, is a unified and coherent system. His argument is that scientific knowledge is made subject to the laws of reason, namely of logic. This knowledge is acquired through application of certain a-priori principles to experience; and therefore these a-priori principles must form a complete set of necessary and logically connected concepts that define the totality of all possible experience.

Kant, in his Introduction to the second edition of the Critique of Pure Reason, states that -

though all our knowledge begins with experience,  
it does not follow that it all arises out of  
experience.

(Kant [1929], B 1)

His premiss in the Critique of Pure Reason is that empirical knowledge is derived by applying concepts to experience of the World. Thus concepts such as space, time, object, and causal determination, are applied to presented experience to organise it into a "knowable" form. His method of enquiry is therefore to examine the conditions under which such knowledge can be obtained, rather than to study the nature of experience itself, which had been the approach of the Empiricists Locke and Hume, whom he admired. As he writes in his Preface to the second edition -

Hitherto it has been assumed that all our  
knowledge must conform to objects . . . We must  
therefore make trial whether we may not have  
more success in the tasks of metaphysics, if we  
suppose that objects must conform to our knowledge.

(Kant [1929], B xvi)

Kant likened this *voite face* to the revolution that Copernicus had introduced into Astronomy -

Failing of satisfactory progress in explaining  
the movements of the heavenly bodies on the  
supposition that they all revolved round the  
spectator, he tried whether he might not have  
better success if he made the spectator to revolve  
and the stars to remain at rest.

(Kant [1929], B xvii)

For Kant, therefore, there are -

a-priori concepts to which all objects of  
experience necessarily conform, and with which  
they must agree.

(Kant [1929], B xviii)

This statement specifies the focus of Kant's concern in the Critique of Pure Reason; of determining those a-priori concepts which human reason brings to experience to make it knowable. Empirical experience comes to us through our senses; but sensory experience requires ordering into a conceptualised schema for it to be understood. Thus the visual and tactile sensations of a table are mere sensations unless the concept of a table is applied. In applying the concept "table", an assertion is being made that a part of the empirical world - namely a table - is

being encountered, as opposed to a form of sensory illusion. It is application of the concept "table" that human reason imposes on sensation, and this conceptualisation is to be effected through an ordered scheme so that the totality of experience is consistent,- a consistency which Ninteenth Century science demonstrated to Kant. This consistency can only be achieved for Kant if applied concepts conform to a complete system of logical rules employed by human reason, - a-priori rules. Thus these a-priori rules are a necessary condition of knowledge and form a complete system of logic, and furthermore in being a necessary condition they furnish judgments which are irrefutable by empirical experience. Kant sees that his primary objective is to identify these a-priori judgments, which constitute a set of irrefutable statements of knowledge. Irrefutable, because they constitute the very rules by which empirical knowledge is obtained, and also immutable, because they derive directly from a proven system of logic.

During the period in which he made the revisions to The Critique of Pure Reason prior to the second edition, Kant published the Prologomena to Any Future Metaphysics in 1783. In this he clarifies the nature of the a-priori rules he is attempting to elucidate

Judgments, when considered merely as the conditions of the union of given representations in a consciousness, are rules. These rules ... are rules *a priori*, and so far as they cannot be deduced from higher rules, are fundamental principles. But in regard to the possibility of all experience, ... no conditions of judgment of experience are higher than those which bring the phenomena, according to the various forms of their intuition, under pure concepts of the understanding, and render the empirical judgment objectively valid. These concepts are therefore the *a priori* principles of possible experience. The principles of possible experience are at the same time universal laws of nature, which can be cognised *a priori*.

(Kant [1902], 64)

In the Critique of Pure Reason, Kant proceeds in his analysis of the basis of knowledge in reason, secure in the system of logic derived from Aristotle, for -

That logic has already....proceeded upon this sure path is evidenced by the fact that since Aristotle it has not required to retrace a single step,.....It is remarkable also that to the present day this logic has not been able to advance a single step, and is thus to all appearance a closed and completed body of doctrine.

(Kant [1929], B viii)

His plan of attack therefore is to draw up the complete logical structure of knowledge and he compiles an Aristotelian Table of Judgments and an associated Table of Categories - of concepts - to which empirical statements must conform. This is the basis of his four a-priori categories, - Quantity and Quality, which Kant describes as concepts applying to objects as things in themselves; and Relation and Modality, which apply to relations between objects or to their interaction with knowledge.

Kant describes this epistemological approach as the *transcendental method*; analysis of the rules that we necessarily apply to our unstructured experience in order to make it objective knowledge. These rules are those we apply when we form concepts of objects and relate them within the empirical world.

The term "transcendental" ... signifies such knowledge as concerns the a priori possibility of knowledge, or its a priori employment.

(Kant [1929], B 81)

He explains in more detail in describing a transcendental logic

This ... logic, which should contain solely the rules of the pure thought of an object, would exclude only those modes of knowledge which have empirical content. It would also treat of the origin of the modes in which we know objects, in so far as that origin cannot be attributed to the objects.

(Kant [1929], A 56)

Strawson, in The Bounds of Sense, although not entirely sympathetic with Kant's objective of providing a secure basis for scientific knowledge, makes a clear precis of where transcendental analysis is directed

its fundamental premiss is that experience contains a diversity of elements (intuitions) which ... must somehow be united in a single consciousness capable of judgement, ... [and] this unity requires ... a connectedness on the part of the multifarious elements of experience, ... as is required for experience to have the character of experience of a unified objective world and hence to be capable of being articulated in objective empirical judgements.

(Strawson [1966], 87)

Buchdahl, in Metaphysics and the Philosophy of Science, is unrelenting in elucidating the requirement for experience of a unified objective world, and he sees it "as a presupposition of scientific research", and, using quotes from Kant, proceeds -

reason is regarded, not as assuming ("dogmatically") the existence of a unity, but as something "which

[itself] requires us to seek for this unity".  
(Buchdahl [1969], 506)

Buchdahl is therefore enabled to proceed, in sympathy with Kant's intentions, to summarise the transcendental act of reason

the necessary unity is transcendental. And to say that it is transcendental is again to say that it is a condition upon which alone anything can be conceived (cognised) as empirically real, as an object; whilst at the same time ... it is a condition of ourselves being *consciously* cognisant of any such objects.

(Buchdahl [1969], 633)

Before proceeding with an analysis of the logical categories he has tabulated, Kant in the "Transcendental Aesthetic" examines -

that which so determines the manifold of appearance that it allows of being ordered in certain relations, I term the *form* of appearance. That in which alone the sensations can be posited and ordered in a certain form, cannot itself be sensation; and therefore, while the matter of all appearance is given us a-posteriori only, its form must lie ready for the sensations a-priori in the mind, ... this pure form of sensibility may also itself be called *pure intuition* .....there are two pure forms of sensible intuition, serving as principles of a-priori knowledge, namely, space and time.

(Kant [1929], A 20,22)

Conceptualised experience must be organised within a domain; a domain on which the a-priori principles that control concept formation form a complete set of logical operators. Kant regards this domain as comprising two manifolds, - one spatial and one temporal. The spatial manifold, - the space of our experience -, is where relationships between objects of experience are determined, and where these objects are also posited in relation to the self. The temporal manifold provides a link through time of objects to themselves and to each other, but also enables the self as recipient of experience to participate within these relationships. The spatial manifold provides the framework, but the temporal manifold introduces the self as active participant.

Space is regarded by Kant as the "manifold of outer intuition" in which we disentangle our perceptions to arrange them as objects for knowledge, and he writes -

It [Space] must therefore be regarded as the condition of the possibility of appearances, ... . It is an a-priori representation, which necessarily underlies outer appearances. .. Space is essentially one; .... it follows that an a-priori, and not an empirical, intuition underlies all concepts of space.

(Kant [1929], B 39, A 25)

Thus, space for Kant is not an empirical concept derived from experience, but is a form of order that we necessarily impose on our experience. In this sense the geometrical properties we impose on space are, in fact, impositions, and not derived empirically.

We assert, then, the *empirical reality* of space, as regards all possible outer experience; and yet at the same time we assert its *transcendental ideality* - in other words, that it is nothing at all, immediately we withdraw the above condition, namely, its limitation to possible experience

(Kant [1929], A 28)

Thus, Space, in which we establish our knowledge of the arrangement of objects is a unity, and organised by reason itself so that its geometry is also determined by a-priori and necessary rules. Kant's confirmation of the force of this argument is in the "apodeictic certainty" of conclusions derived from Euclidean geometry, which, for the science of his time, was the geometry of empirical space.

geometrical propositions, that, for instance, in a triangle two sides together are greater than the third, can never be derived from the general concepts of line and triangle, but only from intuition, and this indeed a-priori, with apodeictic certainty.

(Kant [1929], A 25)

Given Kant's historical context, and the influence of Newtonian mechanics on his view of scientific knowledge, it might be supposed that, in demanding a unified spatial context for the world of objects, he is recommending an *absolute space* of a kind which had been challenged by Leibniz. In the Critique of Pure Reason this is not explicitly explored, but in the Metaphysical Foundations of Natural Science, which was published in 1786 and intended as an axiomatic basis for natural science, he clarifies the issue.

Firstly, all motion or rest can be merely relative and neither can be absolute, i.e., matter can be thought of as moved or at rest only in relation to matter and never as regards mere space without matter. Therefore, absolute motion ... is simply impossible.

Secondly, for this very reason no concept of motion or rest in relative space and valid for every appearance is possible. But a space must be thought of in which this relative space can be thought of as moved; ... that is, an absolute space, to which all relative motions can be referred, must be thought of.

(Kant [1970], 126)

Kant's point is that our experience inevitably relates the world of objects within a relative framework; we spatially locate the objects given us in experience against our local spatial reference frameworks. In order to comprehend the relationship of these particular objects with the totality of the objective world we have to have an idea of an all-embracing spatial reference frame. But, just as our local spatial reference frame is just a frame and not an independently given empirical object, - in Kant's terms it is "transcendentally ideal" -, so too is the all-embracing framework that we relate this to.

Kathleen Okruhlik, in her article "Kant on Realism and Methodology" (Butts (ed) [1986], 307 - 329), regards Kant's concept of absolute space as a limiting ideal -

absolute space is a sort of limiting ideal within which we are free to make whatever enlargements are necessary in order to achieve a unified treatment of all empirical motions.

(Okruhlik [1986], 309)

Michael Friedman, in his essay "Metaphysical Foundations of Newtonian Science" (Butts (ed) [1986], 25 - 60) also construes Kant's absolute space as "the ideal end-point of this constructive procedure - the inertial frame towards which it [successive idealisations of the local relative spatial frame] converges" (Friedman [1986], 35).

Kant is thereby enabled to avoid the Leibnizian criticism of specifying an independently given absolute space, and he provides a setting for an objective world to which universal physical laws can apply. His setting is effectively that for which Einstein's Principle of Relativity can be applied.

Kant's analysis of Time is similar to his examination of Space, excepting that he sees Time as -

the formal a-priori condition of all appearances whatsoever. Space ..... serves as the a-priori condition only of outer appearances.

(Kant [1929], A 34)

In The Bounds of Sense Strawson observes

the idea of experience in general seems to be truly inseparable from that of a temporal succession of experience.

(Strawson [1966], 50)

Time, therefore, in addition to providing an ordering of empirical events, also provides that organisation of "inner sense" that gives the essential unity to self as perceiver. It also -

is therefore to be regarded.... as the mode of representation of myself as object.

(Kant [1929], B 54)

The time manifold is additionally seen by Kant as providing for the concept of persistence in objects as a basis for knowledge of them.

Kant returns to the objective structuring of the time manifold when he considers the application of causal ordering in the Second Analogy which is considered later.

In his three Analogies of Experience Kant returns to his Table of Categories to give detailed consideration to the category of Relation in its three manifestations, - subsistence (substance), causality, and community. He writes -

Experience is an empirical knowledge, that is, a knowledge which determines an object through perceptions. It is a synthesis of perceptions, ....., This synthetic unity constitutes the essential in any knowledge of *objects* of the senses

(Kant [1929], B 218)

and he continues, examining this synthetic unity in temporal succession -

the determination of the existence of objects in time can take place only through their relation in time in general, and therefore only through concepts that connect them a-priori. .... The three modes of time are *duration*, *succession*, and *co-existence*. There will, therefore, be three rules of all relations of appearances in time, and these rules will be prior to all experience, and indeed make it possible.

(Kant [1929], B 219)

He proceeds to examine these three a-priori relationships

fundamental to physical knowledge. For *duration* he posits the "Principle of Permanence of Substance" and concludes -

Permanence is thus a necessary condition under which alone appearances are determinable as things or objects in a possible experience.  
(Kant [1929], A 189)

In reaching this conclusion he refers to our absolute acceptance "that nothing arises out of nothing" and to the conservation of weight of substance through physical transformations -

even in fire the matter (substance) does not vanish, but only suffers an alteration of form.  
(Kant [1929], A 185)

Kant thus illustrates, not an empirical conclusion, but that the pre-supposition of human reason is that when something burns the constituent matter goes somewhere - presumably into the smoke. Without the permanence of substance as an a-priori principle it is impossible to construct a body of knowledge of material things.

In his "Second Analogy", Kant regards the principle of *succession* as application a-priori of the "Law of Causality". Kant's argument for the necessity of applying causal reasoning to successive experiences hinges on the necessity to make subjective experience an objective fact -

I render my subjective synthesis of apprehension objective only by reference to a rule in accordance with which the appearances in their succession, that is, as they happen, are determined by the preceding state. The experience of an event ... is itself possible only on this assumption.  
(Kant [1929], A 195)

It is the application of the a-priori causal principle that therefore imposes an order on the temporal manifold of empirical events, which gives it objective significance as opposed to the time order of inner sense, - of subjective experience. The absence of a concept of objective causal ordering would deprive us of the facility to reach beyond the subjective time order of sensory experience, and would deprive us of objective temporal succession.

Kant counters Hume's empirical scepticism of the strict necessity of causal connections in "The Discipline of Pure Reason" (Kant [1929], A 764-769, B 792-797). Hume had shown that on the basis of empirical investigation -

*that there is nothing in any object, considered in itself, which can afford us a reason for*

*drawing a conclusion beyond it; and, that even after the observation of the frequent or constant conjunction of objects, we have no reason to draw any inference concerning any object beyond those of which we have had experience*

(Hume [1978], 139)

Kant's rebuttal of this scepticism is that a necessary pre-condition for imposing order on experience to make it knowable, is that we understand that events are causally related in the objective world. He agrees with Hume, however, that -

*a-priori, independently of experience, I could not determine, in any specific manner, either the cause from the effect, or the effect from the cause.*

(Kant [1929], A 766, B 794)

Concluding his case against Hume, he writes -

The passing beyond the concept of a thing to possible experience (which takes place a-priori and constitutes the objective reality of the concept) he confounded with the synthesis of the objects of actual experience, which is always empirical .

(Kant [1929], A 766, B 794)

Thus he agrees with Hume that it is not possible to specify with absolute certainty what the causal connection actually is in particular circumstances, but a-priori we can say that some causal connection is at work and it is the task of empirical science, on the basis of observations, to generate causal hypotheses. Without the a-priori understanding that temporal events are causally ordered, we lose grasp of the unity of the empirical world, even though we have no a-priori conception of the individual causal connections.

Buchdahl expresses this point clearly in refuting Strawson's interpretation that Kant was claiming necessary causal relationships -

Kant is only arguing that, given some such succession [of events], the general concept of such a happening requires that we *think* each of its members when regarded as "perceptions" ... as determined by some conditioning factor - a factor which ... must always be conceived in an entirely indeterminate fashion

(Buchdahl [1969], 665)

Kant is quite clear that the a-priori nature of both permanence of substance and principle of causality is necessary for the consistency of the whole spatio-temporal manifold required for a coherent empirical knowledge, but that this does not imply that

individual empirical events posited within the manifold can be connected a-priori.

Having determined the a-priori principles for locating objects in the spatio-temporal manifold in terms of their permanence and causal connectedness through time, Kant is obliged in his "Third Analogy" to locate them spatially as co-existent.

Thus the co-existence of substances in space cannot be known in experience save on the assumption of their reciprocal interaction.  
(Kant [1929], B 258)

and he concludes -

It is therefore necessary that all substances ... should stand in thoroughgoing community of mutual interaction.  
(Kant [1929], B 260)

Without this interconnectedness of objects within the spatial domain, not only would space itself be resolved into discrete and unconnected regions, but the principle of causality through time would be severely curtailed with the consequent destruction of a unitary time manifold. This would thereby confound "the mode of representing myself as object".

In determining the a-priori principles of empirical knowledge, Kant has argued from the necessary unity of the space and time manifolds to the co-ordinating principles that give this logical necessity. His method of argument has been to examine the pre-conditions for coherent empirical knowledge, rather than, like Hume, to examine the nature of empirical knowledge itself. In this approach, however, he was still constrained by the results of the science of his time. He was effectively erecting a logical justification of the premisses of contemporary physics, - effectively a system of Newtonian mechanics working in a Euclidean metric space.

Kant's achievement is to demonstrate that empirical knowledge can only be obtained by applying concepts to direct experience; that the empirical world necessarily requires ordering for it to be knowable. He proceeds beyond this, however, in his search for a-priori synthetic knowledge, by extending the necessity for application of concepts to the logical necessity of specific concepts that arise in the system of physics with which he is familiar. Thus he specifies the necessity of space as a manifold for empirical experience, but then extends beyond this to specify the particular space geometry being used, namely Euclidean. He is fortified in this extension of his argument by the logical consistency of Euclid's system and its apparent

universal applicability to spatial geometry.

Kant's fundamental case, however, is that knowledge of the empirical world is made possible only through conceptualising experience into objects. To be a coherent system, which science indicates knowledge to be, then certain relationships must link the conceptualised objects. There must be an object space in which relationships can function, and these relationships must include concepts of permanence, causal connection in time, and co-existent connections. Permeating this schema is the temporal dimension which links directly to the "inner intuition" of the experiencing subject and provides the frame against which that subject itself participates as an object.

It is apposite to review Kant's method and achievement against his own justification and objectives. In Reichenbach's terms, we should look at the Context of Discovery in relation to the Context of Justification. Kant's purpose, given that knowledge must be formed from experience, is to identify those components of our knowledge that relate to the forming process itself, as opposed to the empirical data that is presented. His justification of his method, develops from his argument that, because our knowledge of the world is a self-consistent system, the principles that are applied to form experience into a knowable form must themselves be self-consistent. He therefore determines that the forming principles derive from our system of logic. Kant accepted that classical logic is an immutable system, and therefore, the forming principles themselves are immutable. He is reinforced in this conclusion in his analysis of prevailing physical laws, and in particular of Newtonian mechanics and the universal applicability of Euclidean geometry to spatial measurement. This leads him to extend his system of forming *a-priori* principles to include assertions about the *a-priori* geometry of space itself. He is thereby enabled to conclude that the truths of Euclidean geometry represent necessary and immutable truths of spatial geometry against which our empirical knowledge is formulated. In Kant's terms, these are *synthetic a-priori truths*.

His continuing justification in his argument has rested on his reference to logical principles as guides to elucidating the principles that we actually apply to experience, but his analysis throughout the Critique of Pure Reason concerns itself with the principles actually employed in prevailing scientific knowledge. Thus, the space he describes as a necessary condition of knowledge, is a space that can accommodate Newtonian mechanics, and the principle of co-existence of objects in space

in thoroughgoing community of mutual interaction  
(Kant [1929], B 260)

accommodates the Newtonian picture of bodies related by

gravitational forces. His "Method of Discovery" is a thoroughgoing analysis of the principles underlying scientific knowledge, but, in applying his "Method of Justification" to his conclusions, he elevates these principles into eternal truths. Subsequent changes in scientific theory were therefore likely to contradict his philosophy.

### Kant's Legacy to Reichenbach

The impact of Kant on Hans Reichenbach must have been profound. The young engineer in his late teens had been increasingly excited at school in Hamburg by the science and mathematics to which he had been introduced. The mathematics of "analytical geometry, differential and integral calculus" (Reichenbach [1978],v.1, 11), provided him with a concept of a Euclidean spatio-temporal domain which was infinite in extent but infinitely divisible; effectively Kant's manifold of outer intuition. The laws of physics and chemistry provided him with an "inner appreciation for the great interconnectedness of nature" (Reichenbach [1978],v.1, 11), and he was "particularly aware of organised, logical thinking which must lead to a true understanding of nature."(Reichenbach [1978],v.1, 11). Kant pre-dated him by one and a half centuries; but Kant's secure belief, that knowledge was, and must of necessity be, organised into a coherent and unified system, was shared by the excited young Reichenbach.

Reichenbach, however, was confronting the World one hundred and fifty years later than Kant, and in that time scientific knowledge and mathematics had progressed. Even as early as his schooldays in Hamburg Reichenbach had encountered the Kinetic Theory of Gases, and in subsequent years he came to see the work of Boltzmann with his method of statistical analysis of aggregates of molecules as offering a challenge to Kant's principles of causal ordering. Later he was to encounter the further challenge to causal principles presented by Quantum Theory, and, in 1919, Einstein's lectures on Relativity contradicted the Kantian concept of a Euclidean spatio-temporal manifold. Before considering how Reichenbach responded to this new data it will be illustrative to understand the emphasis given to Kant's work by neo-Kantian philosophers at the turn of this century, and then later to compare Reichenbach's revised view of epistemology with that of Ernst Cassirer and of Moritz Schlick.

### Ernst Cassirer (1874 - 1945)

The student Reichenbach gives credit to only two of his teachers of Philosophy, - Ernst von Aster and Ernst Cassirer. Ernst

Cassirer was born 17 years earlier than Hans Reichenbach. As with Reichenbach he was the second son of a wealthy Jewish Trader, but unlike Reichenbach he was not fired with a burning professional ambition from his early years. In his teens, however, he became acquainted with the extensive library of his maternal grandfather and study became his main pre-occupation. His reading was wide and he "acquired the capacity for concentrated and persistent work" (Schilpp (ed) [1949], 4). At age twenty, whilst a student in Berlin, he became acquainted with the writings of Hermann Cohen and his interpretations of Kant, so that two years later he moved to Marburg - centre of neo-Kantianism - to become Cohen's pupil. Cohen was generally regarded as the authoritative interpreter of Kant.

Cassirer quickly established himself as a scholarly authority on Kant in his own right, as Cohen is reported to have remarked, "I felt at once that this man had nothing to learn from me" (Schilpp (ed) [1949], 7). Cassirer's ability to accumulate knowledge must largely be attributed to his exceptional memory, which enabled him to quote from memory long passages from classical works. He combined this with an ability to organise this knowledge with mental cross-references and reasoned justification. Kant's systematic approach to analysing the foundations and extent of knowledge was therefore fruitful ground for Cassirer.

Cassirer approached the subject matter of philosophy as a scholar, - connecting ideas, setting them clearly in their historical and cultural contexts, and explicitly cross-referencing. The Marburg School of neo-Kantianism to which Cassirer went in 1896, whose principal teachers were Hermann Cohen and Paul Natorp, had developed Kant's philosophy to take account of developments in science and mathematics. In mathematics they were particularly interested in systems of geometry other than Euclid's. It had been demonstrated in the Nineteenth Century, and particularly by Felix Klein, that a system of geometry is the study of properties invariant under a certain group of transformations, characteristic of the geometry in question, and that there were many such systems that could be applied consistently to spatial domains. For example, spatial geometry can be specified consistently that does not provide for the Euclidean axiom of non-intersecting, parallel straight lines.

Both Cohen and Natorp took Kant's basis for the possibility of knowledge; - that empirical experience must be subject to principles of reason, which themselves must be a logically complete system. Their basic requirement was that our empirical knowledge must be coherent, that it should form a logically unified system. Their concern was not to re-state Kant, but to continue in his spirit with his Critical Philosophy. They were primarily interested in scientific knowledge, which for them largely constituted mathematical physics (Schilpp (ed) [1949]

761). It was inevitable that a study of knowledge at the end of the Nineteenth Century should give particular prominence to physics and the mathematical relationships which physics established. Two centuries earlier, Newton had demonstrated that mechanical phenomena could be represented through universal mathematical relationships, and this had been followed by the field theories of physicists like Hertz and Maxwell whose work indicated that in mathematical physics a simple system of fundamental relationships was capable of representing the totality of physical empirical experience. The neo-Kantians therefore saw scientific development as being an unending process of coming to terms with the "given" of experience. It is a process of objectifying experience and relating it through principles of reason. "The context of cognition must be grounded in a unitary origin of thought", which is "the logical ideal of the all-comprehensive context of experience" (Schilpp (ed) [1949], 763). For the neo-Kantian, therefore, knowledge is a coherent and ideal system which relates to the diversity of our experience. As an ideal system, science is continually seeking refinement; to incorporate new data, to resolve apparent anomalies, and to simplify structural relationships. The contextualising process is a positive act of reason on experience, and Natorp describes this as a "posit", - an expression which Reichenbach introduces into his work Experience and Prediction to describe the function of imposing a hypothesis on empirical data.

Thus we seek for systematic unity as a basic pre-condition of knowledge. The "posit", or effective hypothesis in dealing with experiential data, is thus essentially a starting point, and in that sense is almost arbitrary, excepting that it must bear the scrutiny of logical consistency as argued through by Kant. A scientific hypothesis is effectively a posit whose validity is subject to the probing of scientific method, which subjects it to the two pre-requisites of conforming with empirical data and being consistent with other accepted scientific truth. The posit is thereby accepted as it stands, or modified, or rejected. Thus, for example, the neo-Kantian would take Euclidean geometry as a posit for the geometry of empirical space. Natorp was prepared to accept a non-Euclidean geometry for space provided that it was logically self-consistent, and, unlike Kant, he could not see the *logical* necessity for adopting the Euclidean system as *the* geometry of space. For Natorp, space and time were necessary (and hence a-priori) concepts for experience, but their geometry was to be determined a-posteriori from experience. The concept of the "atom" is also seen as a posit introduced to provide coherence of scientific knowledge, it is not a concept of correspondence to "a thing in itself" lying behind empirical data.

All knowledge, therefore, is defined through concepts which are subject to principles of coherence. The objects of knowledge have a relationship with experiential data, but are structured by coherent principles. Kant had referred in his Critique of

Pure Reason to the "thing in itself" which stand behind experience as forever inaccessible, our knowledge of it being confined to the form we impose on our sensory experience of it. Cohen and Natorp rejected the concept of the "thing in itself" as meaningless; for them our knowledge is the synthesis of concepts we generate through empirical data, and further speculation is fruitless. Following Kant, however, they accepted that the synthesis of concepts in knowledge must of necessity conform to the three categories of Relation, - substance, causality, and co-existence. Like Kant, Natorp also saw that causal ordering, as a pre-requisite of knowledge, was manifest in the physical principles of Newtonian mechanics.

It is unclear when Reichenbach was first influenced by Cassirer's teaching, but it is probable that it was during the period 1911 to 1914 when Cassirer was "Privatdozent" at the University of Berlin, and Reichenbach was travelling to pick up learning from the leading expositors of his time. Cassirer's lectures and seminars were popular; he was vivid, eloquent, and painstaking, in ensuring that his students grasped the ideas he was presenting. The clearest exposition of Cassirer's teachings which would have influenced Reichenbach are therefore to be found in Cassirer's work Substance and Function, which was published in 1910, (and later in his life Cassirer commented that this work contained the essentials of his philosophy of science).

In Substance and Function, Cassirer reviews the history and development of mathematics and the physical sciences, and identifies how a-priori principles are applied through the concepts that are employed. His premiss throughout is that of the Transcendental Idealist, that human knowledge of the world, and physical science in particular, is the result of the unification brought by the application of consistent logical principles to empirical experience.

It is interesting that he draws an early distinction as he initiates his analysis of the historical development of concepts between the "method of discovery" and the "scientific exposition" (Cassirer [1923], 69), - analogous with Reichenbach's later distinction in concept analysis between the "context of discovery" and the "context of justification". Although Cassirer in Substance and Function doesn't use the term "posit", his "method of discovery" refers essentially to a posit or hypothesis introduced to cope with new experiential data or new empirical relationships. In the "scientific exposition" the posit is thoroughly tested for coherence, and integrated with established scientific principles, as is the case with Reichenbach's "context of justification".

In his analysis of the mathematical concepts employed in number and geometry, Cassirer develops the conclusion that these are not empirical properties or measures but that they belong to

axiomatic systems, and he states

It is only the pure system of conditions, which mathematics erects, that is absolutely valid, while the assertion, that there are existences corresponding to these conditions in all respects, possesses of relative and thus problematic meaning.

(Cassirer [1923], 111)

He thus criticises Kant's assumption of the a-priori synthetic status of Euclidean geometry

as all the systems [of geometry] are equally valid in logical structure, we need a principle that guides us in their application. This principle can be sought only in reality, since we are not here concerned with mere possibilities, but with concepts and the problem of the real itself; in short, it can be sought only in observation and scientific experiment . . . Observation...leads from the many forms of geometrical space to the one space of the physical object.

(Cassirer [1923], 106,107)

Cassirer is not hereby appealing to correspondence with an underlying physical reality, or to a "real" geometry of the "thing in itself", but asserting that although many self-consistent systems of geometry are available to the scientist, the choice of system for science can only be determined through empirical measurement. Thus mathematics provides a framework of logical systems which are available for the physical sciences.

Cassirer then examines how the concepts employed by science are actually used, and what they specifically designate. Science deals with the properties of the empirical world and we would therefore expect the concepts that science uses to be directly derived from experience. Logical Positivism would request that scientific concepts be directly given in experience without intermediate and unverifiable hypothesis. Cassirer demonstrates that this can not be the case where science is concerned with measurement which in itself involves the application of hypothetical systems. For example, in the science of mechanics, measurement itself employs "the concepts of the material point, of uniform and variable velocity as well as uniform acceleration" (Cassirer [1923], 119). These concepts are not given directly in experience but are idealisations that are manipulable within systems of mathematics, and which, in their application, make presuppositions about, for example, "the continuity and uniformity of space" (Cassirer [1923], 119). Cassirer proceeds to recognise scientific concepts as "ideal limits". It is necessary for us to work with idealised concepts in order to relate them mathematically and logically to the total context of our empirical knowledge.

the ideal concepts of natural science...only go beyond the given, in order to grasp more sharply the systematic structural relations of the given.

(Cassirer [1923], 128)

The aggregate of sensuous things must be related to a system of necessary conceptual laws, and brought to unity in this relation. ...it presupposes an independent and constructive activity, as is most clearly manifest in the creation of limiting structures. ...without it, the world of perception would not be merely a mosaic but a true chaos.

(Cassirer [1923], 128)

Cassirer thus sees the concepts of science as ideal limits which are not found directly in experience but which can be related to experience, and which serve to draw individual experiences into the systematic unity of knowledge. He provides examples -

We investigate the impact of bodies by regarding the masses...as perfectly elastic or inelastic; we establish the law of the propagation of pressure in fluids by grasping the concept of a condition of perfect fluidity; we investigate the relations between the pressure, temperature and volume of gas by proceeding from an "ideal" gas and comparing a hypothetically evolved model to the direct data of sensation.

(Cassirer [1923], 130)

Science for Cassirer thus looks beyond the fleeting phenomena of experience to grasp ideal forms lying behind, or within, which can be subjected to the rigour of logic or mathematics, and which can therefore be related in a lawlike manner. Cassirer the scholar introduces the ideas of Plato to elucidate his conception of a scientific concept as an ideal limit. Reichenbach was also concerned with the concept of limiting structures for scientific concepts, but as an engineer he was to look at this as scope for application of the idea of a statistical limit.

Thus for Cassirer, the *Object* for science is an ideal which is constructed by the human understanding, but relates to empirical data. Even measurement itself is not a pure empirical procedure, but involves complex hypotheses,- for example of uniform temporal and spatial behaviour.

The objects of physics...are recognised as instruments produced by thought for the purpose of comprehending the confusion of phenomena as an ordered and measurable whole.

(Cassirer [1923], 166)

Cassirer hereby emphasises his philosophy of Idealism, and provides no place for the Kantian concept of "thing in itself". For Cassirer the systematic unity of the understanding is the necessary requirement for knowledge, - that the system of knowledge be totally coherent.

A process is first known, when it is added to the totality of physical knowledge without contradiction.  
(Cassirer [1923], 140)

As scientists, therefore, we must be proactive in arriving at our knowledge and understanding of the empirical world.

The "true hypothesis" ...is not introduced after the phenomena are already known and ordered as magnitudes.....but it serves to make possible this very order,.....it points the way by which we advance from the sensuous manifold of sensations to the intellectual manifold of measure and number.  
(Cassirer [1923], 140,141)

The order of the "real" and factual cannot be discovered .....without a conceptual anticipation of a possible order.  
(Cassirer [1923], 250)

The systematic unity of the understanding which Cassirer requires demands that objects be located in a spatio-temporal frame and that they be connected in a law-like and causal manner. Beyond that there are no necessary (or a-priori) conditions, so that our concepts and the hypotheses for laws which we generate are essentially provisional.

we inscribe the data of experience in our constructive schema, and this gives us a picture of physical reality, but this picture always remains a *plan*, not a *copy*, and is always capable of change

(Cassirer [1923], 186)

Science is not a representational system of a reality underlying our experience, but is a consistent conceptual plan that enables us to make sense of our experience. We effectively advance in science by replacing laws that new experience or new understanding invalidates, with more universal interpretations that can remain consistent with our overall view of the world. From this conception we can arrive at a concept of scientific truth -

We call a proposition "true", not because it agrees with a fixed reality beyond all thought and all possibility of thought, but because it is verified in the process of thought and leads

to new and fruitful consequences. Its real justification is the effect, which it produces in the tendency towards progressive unification.  
(Cassirer [1923], 318)

Cassirer has moved significantly beyond the position established by Kant, and indeed proceeded further beyond Cohen and Natorp. He has, however, used Kant's transcendental method of philosophical criticism in analysing the conditions under which empirical knowledge is possible, and taken the Kantian premiss that knowledge is only possible if it conforms to a synthetic unity in the understanding. To this end he accepts that spatial and temporal concepts, - albeit of problematic geometry -, are necessary to empirical experience and knowledge, and that, for structural unity, it is a necessary condition of scientific knowledge that universal laws connect events in the spatio-temporal domain. Thus he maintains the thesis that although these a-priori principles must apply, for knowledge to be possible, there is no a-priori necessary content of such knowledge. Unlike Kant he is not prepared to accept the necessity for Euclidean geometry, nor the necessity for a particular system of mechanics.

Cassirer, as Reichenbach's teacher, must have promoted these ideas. Reichenbach credits Cassirer in his "Autobiographical Sketches for Academic Purposes", (Reichenbach [1978], v.1, 1), as being important to his understanding of philosophy, but, although he makes reference in three of his articles to Cassirer's subsequent work Einstein's Theory of Relativity, published in 1921, he never refers to Substance and Function.

It will be relevant, in examining Reichenbach's treatment of Relativity, to look at Cassirer's analysis, but we must begin with an appraisal of Einstein's Theory.

## Chapter 3

### EINSTEIN AND HIS THEORIES OF RELATIVITY

Albert Einstein published the Special Theory of Relativity in 1905, and the General Theory of Relativity appeared complete for the first time in 1916. The significance of these theories is not just that they provide new insights in physics, but because they examine the fundamental relationships of mechanics within their spatio-temporal settings. For two hundred and fifty years mechanics had operated within the framework specified by Newton; Einstein's Theories supplanted the Newtonian system.

To appreciate the Special Theory of Relativity it is necessary to examine the historical context. Newton's mechanics are based on three principles, - his Laws of Motion :-

- 1 Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.
- 2 The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.
- 3 To every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal and directed to contrary parts.

(Newton [1934], 13)

The first two of these present conceptual problems which had been identified by Leibniz. The problem is in defining the framework against which a body can be deemed to be at rest or moving with uniform velocity. Newton's mechanical system is effectively set against an absolute spatial and temporal framework, so that each body in its spatial setting can be deemed to have an intrinsic absolute velocity. It was Leibniz' contention - "The parts of space are determined and distinguished only by the things which are in them. ..But space, taken apart from things, has nothing in itself to distinguish it, and indeed it has nothing actual about it". (Leibniz [1973], 235; Correspondence with Clarke, para 67).

Also, in his Third Paper to Clarke, Leibniz, in Para 4, maintains "space to be something purely relative....time is an order of succession" (Leibniz [1973], 211). Thus Leibniz' claim is that space is erected as a frame to relate bodies, and time is the frame that orders events. In other words, spatial and

temporal measurements are valid only in relation to objects and events, and hence the Newtonian system which depends on absolute position and absolute motion is fundamentally flawed. Kant, following Leibniz, also denotes space and time as frames to relate bodies and events, but takes a different view of this from Leibniz, who had asserted the primacy of objects and events, by demonstrating that objective space and time were necessary conditions for knowledge of such objects and events. Thus Kant is able to accept the concept of the primacy of space and time, and thereby provides an accommodation for Newtonian mechanics, but without resolving the basis on which the absolute co-ordinates required by Newton's Laws are to be established.

Despite this possibly inherent weakness in its foundations, science had used Newton's system for two and a half centuries without serious problems.

A consequence of the concept of an absolute space with absolute determination of position and velocity is a simple relationship for determining the relative velocities of moving bodies. An example, which Einstein himself uses in his popular exposition Relativity, published in 1920, concerns a man walking along a train in the direction in which the train is moving. If the train moves with velocity  $v$ , and the man walks with velocity  $w$ , then the man's velocity in relation to the embankment beside the railway is  $v + w$ . If instead of the man walking along the train, we consider a ray of light flashed along the train in its direction of travel with velocity  $c$ , then the velocity of light in relation to the embankment should then be  $v + c$ .

This consequence, towards the end of the nineteenth Century, had appeared at odds with emerging theory and experiment. In 1865 the Scottish physicist, James Clerk Maxwell, had produced a generalised electromagnetic field theory which contained a constant velocity of electromagnetic transmission through empty space. Maxwell had postulated that "empty" space be filled with a medium -the Aether- as carrier of electromagnetic waves (of which light is a specific example), and this aether allowed a constant and absolute velocity of transmission of light. The resultant velocity of light for observers from Maxwell's Theory should therefore depend on their own velocity relative to the aether. Thus, in the example of Einstein's, the observer on the embankment, if at rest relative to the aether, will record a light velocity of  $c$ , whereas the observer on the train will record a velocity of  $c-v$ .

Following from Maxwell's theory and the accepted belief in absolute space co-ordinates, against which the aether is motionless, it should have been possible to detect differences in the velocity of light from the Earth depending on differing relative speeds between the Earth and the aether. Such differences should emerge if the velocity of light is measured in directions separated by ninety degrees. The Michelson-Morley

experiment was executed in 1887, and no detectable differences in the velocity of light were detected. Thus, not only did this not demonstrate the effect of the hypothetical aether, but the Michelson-Morley result was also at variance with the simple law of addition of relative velocities that was a direct consequence of the Newtonian system. This anomaly had been examined by Poincaré and Lorentz; the latter having further developed Maxwell's field theories to account for electromagnetic phenomena, and in 1895 he provided a solution to the apparent incompatibility of Maxwell's theory with results of the Michelson-Morley experiment. Lorentz' hypothesis was that moving objects are foreshortened in their direction of travel through the stationary aether by a factor -

$$\frac{1}{\sqrt{1 - V^2 / C^2}}$$

(Where C is the speed of light and V is the speed of the object)

From this it follows that measuring apparatus moving through the aether will be foreshortened, and it can be demonstrated that on this hypothesis the Michelson-Morley experiment would yield a velocity of light as measured which was independent of the direction of measurement. That is, despite the relative motion of Earth and aether, the velocity of light measured in this way appears to be constant. This solution provides a coherent mathematical structure, but lacks both a scientific justification and independent physical evidence to support it.

Einstein's Special Theory of Relativity was first published in 1905 in Annalen der Physik, ser. 4, vol 17, 891-921, "Zur Elektrodynamik bewegter Körper". Einstein's objective is to reconcile the foundations of mechanics, not only with the apparent discrepancies which Lorentz had tackled, but also with the flaws in the Newtonian concepts of "absolute space" and "absolute time". He was alive to Leibniz' objections, and particularly to those made by the physicist/philosopher Ernst Mach in The Science of Mechanics: A Critical and Historical Account of Its Development, whose first German edition was published in 1883. Mach had attempted to relate mechanical events, not to an absolute spatial framework, but, to reference masses. Einstein therefore takes care to define the concepts he employs in mechanical measurement.

He makes a clear statement of the systems to which relative measurements are to be applied. Newton's First Law of Motion concerned itself with bodies in a state of rest or uniform motion as measured against Absolute space and time co-ordinates; Einstein's starting point, in rejecting the concept of absolute co-ordinates, was to consider spatial reference frames moving relative to each other with uniform velocity. His objective was to provide relationships between the measurements obtained to describe a moving body against one reference frame with the measurements obtained against a second frame, which was moving

uniformly with respect to the first reference frame.

He defines how he proposes to make physical measurements of spatial extension and temporal duration. Spatial coordinates in each reference frame are to be constructed from unit measuring rods, and temporal duration is to be measured by standard mechanical clocks. Coincidence of spatial position can be clearly established from any reference frame, but Einstein clarifies what is to be understood in the concept of simultaneity of events occurring at spatially distinct points. It is the consequence of working with this definition which gives the Special Theory of Relativity its revolutionary impact. The Newtonian system of mechanics doesn't require such a definition because an all-pervasive absolute time is presumed. Leibniz' objection to this concept had not been worked through in relation to temporal measurement of events until Einstein tackled it. Einstein was quite clear that when we come to measure objects, we choose how we do it. Thus in measuring spatial extension we do this with the aid of a physical object, - for example a standard metre -, and in doing this presume that this will provide consistency. The value of using this measuring system, however, is only demonstrated in practice when it provides consistent results. Thus the choice is in effect initially arbitrary, but its relevance and usefulness will only be proven in use when it gives repeatable results and a means of scientifically coming to terms with experience. We can proceed beyond the spatial measure 'itself by choosing a frame of reference - co-ordinates - against which we can record measurements made with our standard. With temporal measurement we use a standard clock, but we require a rule about how measurements made with this relate to spatially different positions. Einstein therefore defines simultaneous times at different points when light signals initiated at these events arrive together at a point situated equidistantly from the spatial locations of the events. Thus Einstein ties in the temporal metric with the spatial metric in a particular reference frame, and, for example, two events would be deemed to be simultaneous if an observer spatially equidistant from each were to be informed simultaneously of both events by light signals. It must be noted that the concept of simultaneity of specific events does not transform from one reference frame to another inertial frame, but is a property shared only by frames at rest relative to each other.

Einstein, in addition to defining his spatio-temporal metric, also introduces a scientific law into his theory, to take account of the Michelson-Morley experimental result and reconcile it with Maxwell's electromagnetic theory. The scientific law which Einstein propounds is that the velocity of transmission of light in vacuo is independent of the velocity of the body emitting the light. This law had been accepted by Maxwell and Lorentz, but they had regarded the transmission of light as a disturbance of the aether, and had therefore concluded that a reference frame moving relative to the aether

would result in a changed measure of light velocity. Einstein's law reconciles the apparent anomaly with experiment by disregard of the concept of aether as a carrying medium for electromagnetic transmission, and asserts the fundamental nature of the electromagnetic, or light, signal itself. His law, therefore, asserts that the velocity of a light signal has a common value in all uniformly moving inertial reference frames. It is on this ground that he is able to provide a consistent definition of simultaneity in a particular reference frame. It is also presumed in the analysis that the speed of light is effectively a limiting speed, that it provides the fastest signal.

Einstein completes the groundwork for his theory with his declaration of the Principle of Relativity. The Principle which Einstein presents is that the same general scientific laws which are demonstrated to apply in relation to a spatio-temporal co-ordinate reference system, will also apply when related to any other reference system which is moving uniformly in relation to the first system. Thus there is an equivalence between uniformly moving reference systems in describing natural phenomena. This principle is particularly relevant to Maxwell's equations of electromagnetic transmission which were only valid when measured against one reference frame,- namely the aether. The principle also contains the presumption that there are rules of space and time co-ordinate transformation between uniformly moving reference frames (inertial systems).

Thus, Einstein sets out with a chosen system of spatial and temporal measuring to investigate the results that he will achieve in relating physical data to inertial reference frames. The conditions that such results must be subject to, are that the velocity of propagation of light is both constant and a limiting velocity, and that physical laws must be equivalent in all inertial frames. Einstein is effectively defining a new epistemological basis for mechanics, and thereby modifying the Newtonian system with its direct appeal to the existence of absolute spatial and temporal reference frames. The direct consequence of this approach is that the Lorentz transformations are derived for relating measurements in one reference frame with those in another frame moving uniformly in relation to it. Whereas Lorentz, however, had mathematically produced his transformations in order to ensure that Maxwell's Laws could be consistent, Einstein had derived them from epistemologically considering the measuring process itself.

Various consequences emerge from the Special Theory of Relativity. First of all, the velocity of light does represent an upper physical limit of velocity, and the concept of mechanical propagation at higher speeds invokes the mathematics of "imaginary" numbers as well as the epistemological problem of a reversal of temporal (and causal) ordering. Secondly, a moving object appears to a stationary observer to be foreshortened in the direction of travel, such foreshortening approaching to a

limiting value of zero length as the object accelerates towards the speed of light. Further to this, temporal duration on a moving body appears to increase when measured by a stationary observer, and, as the body accelerates towards the speed of light, temporal duration appears to extend towards an infinite value.

These results are a direct consequence of application of the Lorentz transformations which pre-dated the Special Theory of Relativity; but whereas Lorentz had introduced these as a means of making electromagnetic theory consistent and introduced an unsupported hypothesis of length foreshortening in the direction of motion, Einstein had begun by considering the epistemological basis of statements and measurements of spatial and temporal properties. Although, therefore, it is not possible experimentally to discriminate between the applicability of the work of Lorentz and Einstein, because they provide the same empirical predictions, Einstein provides coherence and simplicity whereas Lorentz introduces an additional hypothesis to provide conformance between a theory and its wider applicability.

It is also worth noting that the Lorentz transformations, and hence Einstein's Theory, only give measureably different results from Newtonian mechanics when the factor -

$$\frac{v^2}{c^2}$$

is significant. That is, when the velocity of the measured body is of the same order of magnitude as that of light. This condition only has measureable significance when studying the movements of fundamental small particles, or on the inter-galactic scale. Experimental work in both of these areas has borne out the effects that Special Relativity predicts. For everyday terrestrial physics, however, the Newtonian system provides an adequate model.

Einstein continues from his study of measured behaviour in inertial frames by considering the concepts of energy and mass. There are three separate uses of the idea of mass in physics which Einstein identifies, but which classical mechanics had regarded as equivalent. Firstly, there is mass as representing a quantity of matter; secondly there is inertial mass (its resistance to acceleration by an applied force); and thirdly there is gravitational mass which determines a body's behaviour in a gravitational field. Einstein considers the third of these fully in his General Theory of Relativity, but he distinguishes between the first two in the Special Theory. A consequence of the application of his theory to dynamic systems is that measured inertial mass increases as the relative velocity of the moving body increases. Inertial mass approaches an infinite value as the relative velocity approaches that of light. Einstein effectively relates energy of a body to its inertial mass, and demonstrates the equivalence by the relationship for a

body at relative rest by -

$$\text{Energy} = MC^2$$

A consequence of this result is that if a body absorbs a quantity of energy  $E$ , its inertial mass is increased by an amount -

$$E/C^2.$$

Einstein regarded this demonstration of the equivalence of the concepts of mass and energy as the most significant result of the Special Theory of Relativity .

The mathematician Hermann Minkowski, in 1908, added to the Special Theory of Relativity, by demonstrating that the equations of mechanics could be simplified by replacing the three directional spatial co-ordinates and the single dimension of time with a unified four-dimensional continuum, in which the temporal dimension takes on spatial dimensions by using the unit of measurement  $iCT$  where  $i$  is the "imaginary" square root of  $-1$ . This yields the concept of a space-time invariant measure of incremental length as -

$$\text{square root}(dX^2 + dY^2 + dZ^2 - CdT^2)$$

where  $X, Y, Z$  are conventional space co-ordinates. The Theory of Relativity thereby provides an observer with an integrated view of space-time, and conforms to the requirements of Kant, for whom the empirical world, if it is to be the subject of knowledge, must be presented in a coherent spatial and temporal setting. Events must have spatial and temporal position, and must be causally relateable.

Minkowski's simplification enabled Einstein to develop his theory further with publication in 1916, in Annalen der Physik, ser. 4, vol. 49, 769-822, as "Die Grundlage der allgemeinen Relativitätstheorie", of The General Theory of Relativity.

The General Theory extends relativistic mechanics to general systems of reference, whereas the Special Theory had been confined to inertial systems moving uniformly in relation to each other. Einstein extends his Principle of Relativity to cover not only inertial systems, but such that the laws of physics apply to systems of reference in any kind of motion.

All bodies of reference...are equivalent for the description of natural phenomena (formulation of the general laws of nature), whatever may be their state of motion.

(Einstein [1920], 61)

Equipped with this and Minkowski's method of analysis of the space-time continuum, Einstein examines a system of a generalised geometry of space-time. He considers, for example, geometry on the surface of a rotating disc. Using the results obtained in the Special Theory we can imagine an observer at the centre of a rotating disc with two unit measuring rods at the perimeter, - one in a radial position and the other tangential. According to the Special Theory the tangential rod will suffer a length contraction as measured by the stationary observer, whereas the radial rod will maintain its measured length. Thus the measured ratio of the total circumference to the radius of the disc will be less than  $2 \times \pi$ , which is the result that would have obtained on a non-rotating disc. Thus, for the observer at the centre of the rotating disc, Euclidean geometry does not apply to the surface of the disc. The geometry is akin to that on the surface of a convex surface, - the further the tangential measuring rod is moved from the centre of the disc towards the circumference, the faster it appears to move in relation to the observer at the centre, and consequently the smaller the value of measured " $\pi$ " that is obtained. Similarly the larger the circle drawn on a convex stationary surface, the smaller the measured value of " $\pi$ ". Thus Einstein demonstrates that the actual geometry of general space is determined by the dynamic configuration of that space. Euclid's geometry can therefore have no universal application, but can apply only as an approximation in small volumes. The geometry of space is not determined a-priori, but is an empirical property dependent on the local dynamics. Einstein therefore moves on from considering rigid inertial reference frames, as in the Special Theory of Relativity, and refers measurements to a four-dimensional "mollusc". He uses this term to indicate the generalised geometry with which he is working, using a non-Euclidean system of a type as first used by Gauss.

Einstein continues to examine spatial properties, and looks at the effect of mass on spatial geometry, having previously identified that inertial mass and energy are effectively identical. He considers an isolated body subject to an acceleration, and concludes that resultant force on the body could equally validly be interpreted as either gravitational or inertial. He thereby concludes that just as the inertial forces on a body determine the local geometry of space, so does the local gravitational field, and that the gravitational mass of a body is equivalent to its inertial mass. For Einstein, therefore, the gravitational field is a local property of space. He has thereby withdrawn gravity from the contemporary search to relate it to the electromagnetic field properties developed by Maxwell and Lorentz. Gravity is a geometrical property of space, which is determined by the local configuration of inertial masses.

Several consequences derive from this which are empirically verifiable, of which the most immediate is that light must be subject to the influences of mass through the local

gravitational geometry. Rays of light are in effect propagated curvilinearly in gravitational fields, and hence light, when in the neighbourhood of inertial masses, does not maintain a constant velocity "c". This has been demonstrated by measuring the deflection of stellar light by the influence of the mass of the Sun, when this can be observed as during an eclipse. On the face of it, Einstein's Law of the constancy of velocity of light in vacuo appears to be invalidated by this conclusion, but he maintains that this Law does represent a limiting and ideal condition of the behaviour of light which is not subject to gravitational influence. In his simplified summary of the theory in his book Relativity, Einstein draws the analogy of the Special Theory being a limiting case of the General Theory of Relativity, by referring to electrostatics as a limiting case of electrodynamic theory, and being none the less relevant thereby. He then quotes -

No fairer destiny could be allotted to any physical theory, than that it should of itself point the way to the introduction of a more comprehensive theory, in which it lives on as a limiting case.  
(Einstein [1920], 77)

Einstein is following through the principle of scientific development of knowledge which Cassirer had enunciated in Substance and Function.

A further validation of the General Theory is its explanation of the precession of the orbit of the planet Mercury round the Sun, - which cannot be explained in terms of classical mechanics.

Einstein's achievement in the General Theory is twofold. He primarily clarifies our concepts of gravity and the generalised geometry of space; but he also provides a mathematical method of examining spatial properties by providing and interpreting Minkowski's generalised co-ordinates under a system of transformations using tensor calculus. He thus provides a method of transforming the universal laws of physics to relate to any general reference frame.

#### Cassirer on Relativity

Before considering Reichenbach's writing on Relativity it is apposite to review Cassirer's Einstein's Theory of Relativity (ETR) which he published in 1921, and which he regarded as supplementary to his earlier work in Substance and Function. This actually is published later than Reichenbach's first publication on Relativity - Relativity and A Priori Knowledge (Reichenbach [1920]) - but the argument is a direct consequence of the 1910 publication Substance and Function and which therefore will have had bearing on Cassirer's influence as

teacher of the student Reichenbach.

Cassirer's thesis in Substance and Function is that our scientific knowledge is a construct of concepts that enable us to come to terms with empirical reality. Truth of such concepts is not guaranteed by reference to an underlying reality, but by demonstration of their relevance and consistency in the use we make of them. These concepts are modified as science develops, the fundamental requirement being that they conform to an overall unity, - that the synthesised system be self-consistent. Thus he maintains the link with Kant's transcendental method, but has jettisoned Kant's acceptance of unchanging a-priori laws.

In ETR Cassirer reaffirms these conclusions and looks at the transition represented by the replacement of classical mechanics with the principles of Relativity. Classical mechanics had attempted to create a unity of scientific knowledge as a mechanism set against an absolute spatio-temporal framework, and had stumbled on the contradiction represented by the constancy of the velocity of light when related to the classical manner of treating relative velocities. Cassirer sees this contradiction arising from a misplaced objective of science in looking for "mechanism" rather than "unity", and "concerning this unity the physicist does not need to ask *whether* it is, but merely *how* it is; i.e. what is the minimum of presuppositions that are necessary and sufficient to provide an exact exposition of the totality of experience and its systematic connection." (Cassirer [1923], 373). He summarises the epistemological value of the Theories of Relativity in a concise paragraph -

But the path by which alone this true universality of the concept of nature and of natural law, i.e. a definite and objectively valid description of phenomena independent of the choice of the system of reference, is to be reached, leads, as the theory shows, necessarily through the "relativisation" of the spatial and temporal magnitudes, that hold within the individual system; to take these as changeable, as transformable, means to press through to the true invariance of the genuine universal constants of nature and universal laws of nature. The postulate of the constancy of the velocity of light and the postulate of relativity show themselves thus as the two fixed points of the theory, as the fixed intellectual poles around which phenomena revolve; and in this it is seen that the previous logical constants of the theory of nature, i.e. the whole system of conceptual and numerical values, hitherto taken as absolutely determinate and fixed, must be set in flux in order to satisfy the new and more strict demand for unity made by physical thought. (Cassirer [1923], 375)

For Cassirer, therefore, Einstein's Theory presents itself as a perfect example of the development of knowledge as a unity in our understanding and he relates this back by quoting from Kant-

"But it is clear," says Kant, "that we have only to do with the manifold of our presentations.....; the unity, which makes the object necessary, can be nothing else than the formal unity of consciousness in the synthesis of the manifold of presentations. Thus we say: we know the object when in the manifold of intuition we have produced synthetic unity."

(Cassirer [1923], 380)

Einstein is seen by Cassirer as vindicating the Kantian method.

Cassirer proceeds to examine Einstein's two postulates of the Special Theory of Relativity and distinguishes between them. The constancy of the velocity of light is an empirical fact, whereas the principle of the relativity of equivalence of reference frames for formulating universal laws of nature is "a general *maxim* .. for the investigation of nature, which is to serve as a heuristic aid in the search for the general laws of nature." (Cassirer [1923], 377). He designates the first postulate as "material" and the second as "formal", and asserts that in placing the formal principle above the material, Einstein makes the essential step to the General Theory of Relativity where he subjects the velocity of light to the constraints of local spatial geometry. Thus the postulate of relativity provides science with an object which is independent of the observer and his system of reference, it-

assures and grounds the empirical reality of all that is established by it as a "fact" and in the name of objective validity.

(Cassirer [1923], 393)

Cassirer later goes on to consider Kant's conception of space and time and the apparent paradoxes that result from his acceptance of the Newtonian mechanical system with its reference to absolute spatial and temporal co-ordinates, given that for Kant space and time were manifolds or constructs that we necessarily impose on the empirical world and were not independent and absolute existences. Cassirer takes pains to remove the paradoxes by examining Kant's doctrines of space and time and begins by quoting from the thirtyfour year old Kant, influenced by Leibniz, -

I should never say a body rests without adding with regard to what it rests, and never say that it moves without at the same time naming the object with regard to which it changes its relation. If I wish to imagine also a mathematical space free from all creatures as a receptacle of bodies, this would still not help me. For by what should I distinguish

the parts of the same and the different places,  
which are occupied by nothing corporeal.

(Cassirer [1923], 410)

Cassirer regards Kant's apparent acceptance of absolute time and space, as in the "Analogies of Experience" within the Critique of Pure Reason, or in his support of Euler's attempted proof of the validity of the absolute Newtonian concepts, as "an episode in Kant's evolution", - (Cassirer [1923], 411). He then proceeds to draw out quotations from Kant illustrating that space and time are sources of empirical knowledge and have no absolute reality, but act as reference frames for science. Kant was fully aware that all measurement was relative, but that it was necessary for us in order to assimilate the measurement to posit it in a spatio-temporal setting. Thus Einsteinein's postulate of the equivalence of reference frames finds its equivalence in Kant in the synthetic unity of experience grounded in a spatial and temporal setting. Two references from Kant are illustrative, the first Cassirer paraphrases from the "Inaugural Dissertation"

The two, space and time, signify only a fixed law of the mind, a schema of connection by which what is sensuously perceived is set in certain relations of co-existence and sequence. Thus the two have, in spite of Their "transcendental ideality", "empirical reality", but this reality means always only their validity for all experience, which however must not be confused with their existence as isolated objective contents of this experience itself.

(Cassirer [1923], 412)

and the second is taken from Metaphysical Foundations of Natural Science -

Absolute space is thus necessary not as a concept of a real object, but as an Idea, which should serve as a rule for considering all motions in it as merely relative, and all motion and rest must be reduced to the absolute space, if the phenomena of the same are to be made into a definite concept of experience that unifies phenomena.

(Cassirer [1923], 416)

This second quotation from Kant identifies a conceptual difficulty inherent in a science which accepts spatial and temporal relativity. Einstein, with his postulate of equivalence, effectively says that a fact or a law is only objectively significant if, in postulating it relative to a chosen schema of reference, I am also able to interpret it relative to any other possible reference schema. Kant's quotation identifies this point in that, recognising that knowledge is gained against a specific spatial reference frame, we need the idea of an absolute space to make it general and

properly objective. Whereas Kant's conclusion, however, leaves us with a conceptual difficulty in somehow envisaging an absolute spatial framework to encompass all possible relative reference frames, Einstein's solution is clear and unambiguous in providing only transformation formulae between frames.

Cassirer compliments the Theory of Relativity on this point-

It is the merit of the theory of relativity not only to have proved this (the unity of empirical knowledge) in a new way but also to have established a principle, i.e. the principle of the co-variancy of the universal laws of nature with regard to all arbitrary substitutions, by which thought can master, out of itself, the relativity which it calls forth.

(Cassirer [1923], 421)

Cassirer has thereby depicted the Theory of Relativity as a fulfillment of neo-Kantianism. Having previously removed the logical necessity of Kant's a-priori principles, and replaced them with reviseable constitutive principles, Cassirer is able to reconcile Kant's synthesis of space and time with Einstein's theory. Reichenbach's Kantian mentor was thereby enabled to maintain his philosophical position after the Theory of Relativity. It is now apposite to examine Reichenbach's response.

## Chapter 4

### REICHENBACH, RELATIVITY, AND KANT

It is appropriate to begin a consideration of Reichenbach's work with his early writing on Relativity, because although his most enduring fascination was with the application of probability to knowledge and causal structure, his first major contributions to Philosophy concerned Relativity. Einstein's lectures in Berlin in 1919, which Reichenbach attended, provided a major shock to the Kantian philosophy which underpinned the young Reichenbach's appreciation of science. Given, however, that Cassirer had been Reichenbach's teacher of Kantianism, it should perhaps have been expected that Einstein could have been interpreted as fulfilling the legacy of Kant through Cassirer, given for example Cassirer's observation in 1910 in Substance and Function

it [the Geometry of physical Space] can be sought only in observation

(Cassirer [1923], 106)

Reichenbach wrote three books specifically on the subject of Relativity, - The Theory of Relativity and A Priori Knowledge (RAK) published in 1920, Axiomatisation of the Theory of Relativity (ATR) published in 1924, and The Philosophy of Space and Time (PST) published in 1928. The first and third of these are examined here. RAK represents Reichenbach's review of Kant's critical philosophy against the radical introduction of Relativity into Physics, and PST is a more detailed analysis of Relativity in terms of its implications for philosophical understanding of space and time.

#### The Theory of Relativity and A Priori Knowledge (RAK) [1920]

In his Introduction to RAK Reichenbach begins -

Einstein's theory of relativity has greatly affected the fundamental principles of epistemology.

(Reichenbach [1965], 1)

He is primarily concerned with the work of Kant and proceeds to illustrate two points at which Relativity contradicts this -

It [relativity] deprived time of its character as an irreversible process and asserted that events exist whose temporal succession may be assumed in the opposite direction. This interpretation

contradicts....the concept of time held by Kant.  
(Reichenbach [1965], 2)

and

This theory asserts...that the theorems of Euclidean geometry do not apply to our physical space. ...Kant's transcendental aesthetics starts from the self-evident validity of the Euclidean axioms.  
(Reichenbach [1965], 4)

The first of these criticisms arises from Einstein's conclusion in the Special Theory of Relativity that temporal order can only be defined in relation to a particular reference frame. Thus, although event "A" may precede event "B" in one reference frame, it may not necessarily precede it when measured against a second reference frame which moves relatively to the first reference frame. Kant's reasoning in the Critique of Pure Reason can be interpreted as relating to a Newtonian reference framework of absolute temporal coordinates, against which there is a unique temporal sequence of events. Cassirer was to reconcile this apparent contradiction by illustrating that Kant's concept of temporal ordering could be reconciled with the principle of relativity, and that, although in the Critique of Pure Reason Kant appears to use Newtonian concepts of time and space, he had elsewhere recognised that these manifolds were not absolute realities but sources of empirical knowledge for which measurement was relative.

The second criticism of Kant by Reichenbach, refers to Kant's unquestioning acceptance that Euclidean geometry necessarily applied to the empirical world. Non-Euclidean geometries, with which Reichenbach was thoroughly conversant, had not been developed when Kant was writing. Given Kant's acceptance of Euclidean geometry, however, it is illustrative to reflect on Kant's view of its empirical relevance. Space, for Kant, expresses the order we impose on objects, and its geometry is an imposed transcendental ideal form. Kant would not go further than this to claim a pre-determined empirical result of the outcome of making physical measurements with rulers or theodolites; he would leave open the possibility that in some environments rulers may behave as if they're bent or foreshortened, or that light rays may appear to be deflected. Kant sees geometry in its method of constructing relationships in the empirical world, but he would not claim that it gives empirical knowledge of objects. Buchdahl sees Kant's use of geometry as a procedure

All that is perhaps acceptable in Kant's argument is its procedural approach: we have to feed some geometry or other into our treatment of physical phenomena, before we can even begin to reason geometrically or physically about them. ... Geometrical systems are not derived from experience. They are presupposed in order to carry out empirical investigations. On the other hand, if these

investigations become too cumbersome or complex, it is perfectly possible to replace one geometry by another.

(Buchdahl [1969], 610)

The General Theory of Relativity demonstrates that it is simpler at the cosmic level to work with non-Euclidean geometry; in attempting to use Euclidean geometry we are obliged to introduce new suppositions into our laws of empirical behaviour. Reichenbach's claim that Euclid's axioms "do not apply" makes the case a bit too forcibly, but there is a valid criticism of the Kantian system to make, in that Kant's arguments occasionally lean too heavily on the accepted scientific reason of his age. Reichenbach generates a more thorough discussion of spatial geometry in The Philosophy of Space and Time.

Reichenbach thereupon outlines his approach to his analysis -

First, we shall establish the contradictions existing between the theory of relativity and critical philosophy and indicate the assumptions and empirical data that the theory of relativity adduces for its assertions. ... we shall investigate what assumptions are inherent in Kant's theory of knowledge. ... we shall decide in what sense Kant's theory has been refuted by experience. Finally, we shall modify the concept of a priori in such a way that it will no longer contradict the theory of relativity ..... The method of this investigation is called the method of logical analysis.

(Reichenbach [1965], 5)

The objective of the exercise is a reconciliation of Relativity with Kant through a modification of the concept of a-priori.

Reichenbach, during this analysis, introduces three definitions of a-priori that permeate Kant's work -

what the forms of ... the concept of knowledge require as self-evident.

(Reichenbach [1965], 6)

"necessarily true" or "true for all times"

(Reichenbach [1965], 48)

"constituting the concept of object."

(Reichenbach [1965], 48)

Reichenbach's analysis is concerned primarily with elucidating the implications of the third definition, and then assessing these against the second definition. The first definition is dismissed as inadequate in that, for example, Kant's premiss of

the self-evident applicability of Euclidean geometry to the metric of physical space has been rendered invalid by the Theory of Relativity and the measureable physical consequences of its interpretation.

At root of Reichenbach's discussion is his agreement with Kant on the source of empirical knowledge -

It was Kant's great discovery that the object of knowledge is not immediately given but constructed, and that it contains conceptual [a-priori] elements not contained in pure perception.

(Reichenbach [1965], 49)

It is the nature of these "conceptual elements" and their application which is Reichenbach's concern, given that Kant's analysis is now found to be at variance with a demonstrable theory of physics. As an engineer he resorts to the mathematical tools of his trade, and he offers gentle criticism of the "metaphorical" nature of Kant's construction of categories -

Kant's conceptual constructions belong to an era distinguished more by grammatical than by mathematical precision

(Reichenbach [1965], 50)

Reichenbach sets out the dichotomy between the truth of mathematical propositions and the truth of propositions relating to the physical world. Whereas mathematics completely defines its objects and rules of connection to generate necessary consequences as truths - "they merely represent new combinations of known concepts according to known rules" (Reichenbach [1965], 36) -, the physical object cannot be fully determined in a similar a-priori manner -

It is a thing of the real world, not an object of the logical world of mathematics.

(Reichenbach [1965], 36)

The relationships that are established between physical objects and expressed in mathematical terms are not logical truths in the manner of the truths of mathematics, but should be conceived as "co-ordinations". Reichenbach gives an illustration of this in considering the significance of the relationship denoted by Boyle's Law  $P.V=R.T$ . This expression effectively "co-ordinates" perceptions and measurements we can make through the mediation of our senses. For example, the concept expressed by "P", which denotes the measured pressure of gas, relates certain direct perceptions of the gas "such as the feeling of air on the skin" with indirect perceptions of the gas "such as the position of a pointer of a manometer", (Reichenbach [1965], 37).

To elucidate the nature of the co-ordination that applies to physical concepts, Reichenbach plunges back into images

extracted from mathematics and examines the co-ordination between elements of mathematically defined sets. It is possible in mathematics to establish correspondences between defined and denumerable sets, and Reichenbach illustrates by coordinating from the set of rational fractions to points or intervals on a straight line. Such coordinations are possible in mathematics and can be uniquely defined, but, Reichenbach makes clear, in mathematics the concepts we are coordinating are all clearly defined and ordered. He emphasises the difference, however, between such a coordination between mathematical sets and the coordination of scientific concepts to the empirical world, in that whereas in mathematics the elements of each set are completely defined, when encountering the "real" there is no definition of the elements of the empirical world other than in the conceptual co-ordination.

Thus we are faced with the strange fact that in the realm of cognition two sets are co-ordinated, one of which not only attains its order through this co-ordination, but whose elements are *defined by means of this co-ordination*.

(Reichenbach [1965], 40)

The problem that then arises is in deciding whether a particular co-ordination is correct, because such a system cannot be unique. For example, how can we decide which system of geometrical axioms to co-ordinate with the properties of physical space? Reichenbach is effectively embarking on an analysis of Poincaré's Conventionalism. Henri Poincaré, the French mathematician and philosopher, writing at the end of the Nineteenth Century, had accepted the Kantian concept that knowledge is formed from experience through application of rules; but had argued against Kant's a-priori necessity for specific rules, and had decreed that these were *conventions*.

Reichenbach does not refer to Cassirer's work in this analysis, but his argument follows that developed in Substance and Function towards Cassirer's conclusion that

We call a proposition "true".. [if it is consistent with] ..the tendency towards progressive unification [of knowledge].

(Cassirer [1923], 318)

Reichenbach's approval of a "correct" co-ordination is subject to "the fact that it is consistent" (Reichenbach [1965], 43). Application of co-ordination to objects must therefore be systematic, in the sense that it must not contain implicit contradictions. It must therefore be regulated by co-ordinating, or constitutive, *principles*. Whereas Kant, however, had looked to the system of Aristotelean logic to provide a self-consistent set of principles, Reichenbach is claiming that the principles are refined by experience in their application through specific co-ordinations to provide empirical measurement. Thus the system

of co-ordination that is employed must consistently produce predictions that are in agreement with scientific observation and measurement. Disagreement implies that correction is necessary to the co-ordination or the constitutive principles of co-ordination. A theory is true "which continuously leads to consistent co-ordinations" (Reichenbach [1965], 43). He approves of Schlick who defines "truth in terms of unique co-ordination". Reichenbach's statement of what is empirically required is thus-

*Uniqueness of a cognitive co-ordination means that a physical variable of state is represented by the same value resulting from different empirical data.*

(Reichenbach [1965], 45)

He is effectively making the same claim on knowledge that Cassirer had done; that conclusions should not be contradictory. For example, if General Relativity theory suggests a particular solar deflection of light, then all methods of determining this should arrive at this result if our system of coordination is unique.

He therefore recasts Kant's search for the principles by which to establish synthetic a-priori judgments, with the question-

*By means of which principles will a co-ordination of equations to physical reality become unique?*

(Reichenbach [1965], 47)

Reichenbach takes care to emphasise the distinction between the "real" and our experience of it, because it is only through experience that it can be known.

*All attempts to describe it remain analogies or they characterise the logical structure of the experience.*

(Reichenbach [1965], 50)

It is meaningless to look for principles ordering the "real", there are "only principles referring to the conceptual side of the co-ordination" (Reichenbach [1965], 52).

Kant had recognised this distinction between the form and content of knowledge and set out to look for the ordering principles in mathematics and Aristotelean logic. Reichenbach now challenges him in this approach, since there is no necessity that a logically consistent conceptual basis will co-ordinate uniquely with the "real". Reichenbach's method of logical analysis therefore is to investigate *knowledge* itself to detect the axiomatic conceptual principles, rather than to investigate only *reason* which is unsullied by the challenge of physical experience.

This departure from Kant's justification of method is a decisive break, and represents an assertion of an empirical approach, as

opposed to Kant's transcendental logic. Having accepted the Kantian premiss that empirical experience must be formed through a conceptual schema, Reichenbach is not prepared to accept the additional premiss that this schema should conform to specific rules of reason. Reichenbach's source of these rules is to be empirical knowledge itself. The principles of co-ordination that he seeks are to provide the contextual setting for empirical concepts, effectively determining spatial and temporal ordering and rules of connection. These are the rules applying to Kant's space of "outer intuition", excepting that whereas Kant attempted to justify these from appeals to reason and self-evidence, Reichenbach's logical analysis demands that the principles be sought only within scientific knowledge itself. Kant, himself, of course effectively employed the same method, and established an epistemological justification for Newtonian physics, but the exposure of the shortcomings of Newton's system by the Theory of Relativity also exposes Kant's justification of the a-priori principles that his analysis reveals.

Reichenbach thus clarifies that he is searching for the axiomatic structure of contemporary physics. The principles which he is attempting to elucidate are for example genidentity - "the same thing remaining identical with itself in time", and time and space, - with the requirement "that four numbers are necessary to define a single point" (Reichenbach [1965], 53).

He is thereby exploring the third definition he gives of a-priori, that is of those conceptual elements that are brought to empirical experience. Reichenbach proceeds to review this against the second definition of being "necessarily true" or "true for all time". Having shown the weaknesses of the presumption of Kant that the principles of human reason are absolutely necessary and thus inviolate, Reichenbach draws attention to the conclusion of his own analysis that what is required is a *unique* co-ordination with physical reality. The "real" is quite independent of reason, and therefore the presumption that a particular set of logically consistent principles should necessarily provide a unique co-ordination with reality implies effectively that any self-consistent set of principles would also provide a unique co-ordination. The implication is that Kant's theory contains the hypothesis "that any arbitrary, explicitly consistent system of co-ordinating principles can arrive at a unique co-ordination of equations to reality" (Reichenbach [1965], 60). Reichenbach therefore looks to the Theory of Relativity to identify if this can be the case.

The Theories of Relativity clearly refute the general applicability of Euclidean geometry to the properties of physical space. Thus, a particular self-consistent system of principles can not be applied to co-ordinate with the geometry of space, indicating that this implied hypothesis of Kant is invalid. Reichenbach therefore makes the claim -

Kant's proof is, therefore, false. ....  
.. *There exist systems of co-ordinating principles which make the uniqueness of the co-ordination impossible; that is, there exist implicitly inconsistent systems.*

(Reichenbach [1965], 67)

Reichenbach goes further than this, in that he acknowledges that the Special Theory of Relativity provides a system of principles of co-ordination for space and time that supercede the Newtonian system accepted as "self-evident" by Kant. This resolution itself, however, is demonstrated to be inadequate within the wider considerations of the General Theory of Relativity. This is a demonstration of the inductive process of empirical science, in which not only is a particular empirical hypothesis under question, but the basic system of co-ordination underlying empirical concepts is also subject to revision. This progressive modification of co-ordinating principles through the two theories of Relativity does indicate that inconsistency - as with the applicability of Euclidean geometry - does not thereby result in a total recasting of all of science that has been developed to date. Einstein himself demonstrated that the Euclidean system and Newtonian mechanics were in fact limiting cases within the wider framework of Special Relativity, which in turn is a limiting case of General Relativity in the absence of gravitational fields. Thus -

the old principle can be regarded as an approximation for certain simple cases.

(Reichenbach [1965], 69)

Reichenbach names this "inductive procedure the *method of successive approximations.*" and states that -

*It is logically admissible and technically possible to discover inductively new co-ordinating principles that represent a successive approximation of the principles used until now.*

(Reichenbach [1965], 69)

Reichenbach's intention in RAK is to reconcile his grounding in Kant's philosophy with the shock of Relativity. He therefore refers his method of successive approximations back to Kant -

It seems to me that this method of successive approximations represents the essential point in the refutation of Kant's doctrine of the a priori. ....Kant based his theory of the a priori upon the possibility of knowledge; but he was well aware of the fact that he could not *demonstrate this possibility*. He did not exclude the idea that *knowledge might be impossible*; ... It seems strange that Kant clung to his dogmatic theory of the a priori with such tenacity in spite of his

clear insight into the accidental character of the affinity of nature and reason.

(Reichenbach [1965], 70,71)

Thus the conclusion on why Kant erred, must relate to the methods he employed -

he who had discovered the essence of epistemology in his critical question confused two aims in his answers to this question. If he searched for the conditions of knowledge, he should have analysed *knowledge*; but what he analysed was *reason*. He should have searched for *axioms* instead of *categories*. ... Thus his method always leads him back to the criterion of self-evidence.

(Reichenbach [1965], 72)

Reichenbach, determined to salvage some of his Kantian heritage, therefore redefines his objective in terms which Kant would have recognised, with the question: "What co-ordinating principles make a unique co-ordination of equations to reality possible?" (Reichenbach [1965], 74). His method must be a logical analysis of empirical knowledge itself, and the a-priori principles he is looking for are those co-ordinating principles which constitute the world of experience. That they exist is unquestionable given that we have consistent scientific knowledge, but we "must abandon the question of how long their specific forms will remain valid." (Reichenbach [1965], 78). Analysis will reveal only a specific formulation of co-ordination, which, just as General Relativity replaces Special Relativity, may be replaced by a more general formulation. We must accept

*the most general formulation attainable at a certain moment*

(Reichenbach [1965], 79)

It is interesting to compare this conclusion of Reichenbach's with Poincaré's enunciation in Science and Hypothesis, first published in French in 1902 -

The principles are conventions and disguised definitions. Yet they are drawn from experimental laws; these laws have, so to speak, been exalted into principles to which our mind attributes an absolute value.

(Poincaré [1946], 125)

Poincaré had recognised the weakness in Kant's concept of unchanging a-priori principles, which Reichenbach also identifies in RAK, and he therefore nominates these as *conventions* which develop as scientific knowledge develops. Reichenbach was always reluctant to embrace Poincaré's Conventionalism because it was not clear to him how it was possible to determine whether a particular set of conventions in

use would necessarily lead to consistent empirical consequences. Jerzy Giedymin in Science and Convention explores the degree of divergence between Poincaré and Reichenbach (Giedymin [1982], 15 - 17).

At this juncture Reichenbach returns to the question of whether a *unique* co-ordination will always be possible. Science contemporary to Reichenbach's writing of RAK indicated that a unique co-ordination for empirical knowledge was possible, - although the subsequent development of Quantum Mechanics would make this assertion problematic, given that descriptions of sub-atomic events cannot always be consistently given in terms of either a particle or a wave representation. Reichenbach, however, could establish no grounds on which a unique co-ordination was necessary. For Reichenbach, the implication of a unique co-ordination was the existence of physical constants, but this existence was demonstrated through science and was not a *necessary* consequence of empirical measurement. He also draws attention to actual empirical measurement which can never be free of random error, but which error is allowed for in relating the concept to experiment: thus in validating Boyle's Law of  $P.V=R.T$  we allow for small discrepancies from a perfect straight-line relationship. Reichenbach anticipates that we may have to add probability assumptions to incorporate some physical phenomena in a law-like schema -

this assumption replaces the concept of uniqueness with regard to determining the definition. Certain assumptions of quantum theory may suggest such a generalisation of the concept of co-ordination.  
(Reichenbach [1965], 85)

He therefore concludes -

that the uniqueness of the co-ordination cannot be *ascertained*; it is a conceptual fiction that is only approximately realised.  
(Reichenbach [1965], 85)

It is necessary therefore to

relinquish uniqueness as an absolute requirement and call it a principle of co-ordination, just like all the others  
(Reichenbach [1965], 86)

Before further consideration of Relativity, Reichenbach draws his conclusions on the object of knowledge

The principles of co-ordination represent the rational components of empirical science at a given stage. ... A particular law represents

the application of those conceptual methods laid down in a principle of co-ordination; the principles of co-ordination alone define the knowledge of objects in terms of concepts. Every change of the principles of co-ordination produces a change of the concept of object or event, that is, the object of knowledge.... *our concepts of the very object of knowledge, that is, of reality and the possibility of its description, can only gradually become more precise.*

(Reichenbach [1965], 87)

He also makes clear that because the principles of co-ordination are selected in order to comprehend reality, and are not prescribed by reality, they are in a sense arbitrary. We can therefore expect within the framework of co-ordination to find equivalent systems,- or perhaps more accurately subsystems. He turns to the Theory of Relativity to amplify this, in that choice of a spatio-temporal reference frame can be arbitrary, although relateable to other reference frameworks by equations of transformation.

the theory of relativity teaches that the metric is subjective only insofar as it is dependent upon the arbitrariness of the choice of co-ordinates, and that independently of them it describes an objective property of the physical world.

(Reichenbach [1965], 90)

It is illuminating to refer back to Cassirer's work Substance and Function written ten years earlier. The conclusion that Kant's a-priori principles cannot be necessary and unchanging is shared. Both writers see an evolution of knowledge, derived from empirical experience, but whereas Cassirer looks for empirical truth in a "progressive unification" of knowledge, Reichenbach cannot justify this "unique co-ordination" as a necessity or even as a possible ideal limit. Reichenbach writes as if fired by Cassirer's critique, but as an engineer he is more merciless with the Kantian logic and submits it to the final question that Cassirer has not asked - "Is it necessary for empirical knowledge to be a self-consistent system?" Two years after RAK Reichenbach wrote a paper which was published in Logos 10, no.3, 316-378, and translated in 1959 as "The Discussion of Relativity Now". In this he gives a thorough consideration of Cassirer's corollary to Substance and Function - Einstein's Theory, published in 1921. His approval initially appears unreserved -

His [Cassirer's] work is the masterful presentation of a historian to whom systematic analysis gave breadth of vision, and whose superior competence lacks dogmatism. His every sentence evinces a command of critical analysis that is bent, not on a *preservation of Kant's doctrines*, but on a

*continuation of Kant's methods.* The transcendental method searches for the presuppositions of knowledge; if the system of knowledge has changed since Kant, then Kant's presuppositions of knowledge must be corrected. There is no doubt that the contradiction between Kant and Einstein can be resolved in this way.  
(Reichenbach [1978],v.2, 26)

He continues his eulogy with approval of Cassirer's re-interpretation of Kant's concept of space as simply an "order of co-existence and succession" and without pre-supposition of a particular geometry. Reichenbach proceeds to develop two other conclusions in the article. He expresses surprise that Kant didn't realise that Newton's concept of space was incompatible with his own, and observes that the theory of relativity is entirely consistent with the concept of "outer intuition" as an "order of co-existence and succession".

the theory of relativity is not only consistent with Kantian philosophy, but also in a sense serves to complete it. It was Kant's great contribution to have pointed out that space and time have no physical reality, that they are merely structural laws of knowledge.  
(Reichenbach [1978],v.2, 27)

His second conclusion which he shares with Cassirer is that the theory of relativity lends support to Kant's analysis of the *concept of an object.*

Kant holds that a physical object is not a directly given thing but is *defined* by physical laws during the process of acquiring knowledge. Thus, Cassirer speaks of magnitudes rather than objects, and he regards it as the primary characteristic of scientific development that concepts of objects are continuously eliminated in favour of concepts of magnitude.  
(Reichenbach [1978],v.2, 28)

He emphasises the relevance of the theory of relativity by quoting from Cassirer-

Laws are neither discovered nor confirmed by observations and measurements made in an individual system, not even by those made in any given number of such systems, but only by the mutual co-ordination of results obtainable in *all possible systems.*  
(Reichenbach [1978],v.2, 29)

Reichenbach, however, having agreed with Cassirer, proceeds to make his major criticism

the certainty of the transcendental method has been undermined, and there is no guarantee that the hitherto unaffected axioms will hold forever. If physics should proceed, under the influence of quantum theory, to conceive of space as a discrete manifold (a matter that is undecideable at the moment), Cassirer's concept of pure intuition would require a further extension. Under such conditions, a continuous, metric-free space would no longer be an adequate framework for empirical reality.

(Reichenbach [1978],v.2, 29)

Reichenbach, therefore, is able to proceed further than Cassirer and is prepared to be more critical of the transcendental method.

Cassirer resolved the contradiction between Kant's epistemology and the theory of relativity by extending the concept of pure intuition. I agree that, in this way Kant's philosophy is rendered consistent with present-day physics, that this consistency is achieved with the minimum number of changes in Kant's philosophy, ... . Nevertheless, I maintain that such an approach is tantamount to a denial of synthetic *a priori* principles, and that there is no other remedy but to renounce the apodictic character of epistemological statements.

(Reichenbach [1978],v.2, 30)

Returning to RAK, further clarification is required of Reichenbach's re-definition of the Kantian "concept of object".

as the concept of object changes [with developing science], there is no final judgment concerning the contribution of reason to knowledge, only a gradual clarification

(Reichenbach [1965], 91)

Reichenbach, however, wishes to distinguish his analysis from a purely positivist approach which would make no allowance for the principles of co-ordination that give structure to empirical experience. The theory of relativity provides the perfect vehicle for demonstrating this, because

what was formerly a property of *things* becomes now a property of things and their systems of reference.

(Reichenbach [1965], 97)

Reichenbach also claims that this also contradicts Kant's concept of substance, as a "metaphysical substratum" on which change could be observed. It is certainly at variance with Kant's allusions to the "thing-in-itself" lying behind

experience, but it is questionable whether the objective measurement of an object as provided by the theory of relativity with accompanying transformation formulas for different reference frames, is any different from Kant's construct of object in "outer intuition". Reichenbach does proceed, however, with the observation that the theory of relativity replaces "The physics of forces and things .. by the physics of states of fields." (Reichenbach [1965], 103).

Reichenbach's final conclusion in RAK is that the co-ordinating principles determine how knowledge is obtained without saying what is known. Furthermore, because knowledge has developed since Kant, the co-ordinating principles themselves have been modified by experience.

"A priori" means "before knowledge", but not  
"for all time" and not "independent of experience".  
(Reichenbach [1965], 105)

It is interesting to compare the respective approaches of Kant, Cassirer, and Reichenbach, to the critical question "How is knowledge possible?". All agree that empirical knowledge is a construct shaped from experience, but their subsequent methodology is different. Kant has analysed the faculties of Reason and Logic to derive his Categories of Pure Understanding and then reflected them into his contemporary understanding of the physical world. Cassirer has reviewed as a scholar the state of science up to the early twentieth Century, and traced an evolution of concepts towards a unified understanding. Reichenbach attempted also, like Cassirer, to look for co-ordinating principles in contemporary knowledge, but in fact he actually looked at *how* empirical knowledge is derived. His fascination with the Theory of Relativity is precisely because this is a study of the meaning of empirical measurement. His "method of logical analysis" is not an analysis of knowledge itself as he claims, but an analysis of the meaning of scientific statements.

Momentarily stepping outside the Kantian tradition, it is illuminating to contrast the arguments developed with those of a contemporary empiricist. Michael Friedman in Foundations of Space-Time Theories rejects the value of attempting to distinguish "constitutive principles" from statements of empirical law; scientific method is an empirical study and its value lies in its overall consistency.

The present conception of scientific method involves no general distinction between factual statements on the one side and conventions or arbitrary definitions on the other. Using Reichenbach's terminology, we can discern no interesting distinction between "principles of coordination" and "principles of connection". ... They are all subject to confirmation and disconfirmation ... by a process of theoretical unification that looks

for repeated boosts in confirmation. It is futile, then, to attempt to distinguish "constitutive" principles that provide a framework for empirical theorising ... from ordinary empirical laws.

(Friedman [1983], 338,339)

Friedman's primary criterion for choosing between alternative theoretical structures (for example Einstein v Lorentz) is based on the principle of *parsimony*, that we should reject theories that contain an excess of theoretical content, although, of course, acceptable theories must also conform with a general unity of scientific knowledge. Thus Friedman would claim that there is a specific empirical geometry that obtains in a given objective situation, as opposed to Adolf Grünbaum who would maintain that the appropriate geometry results from the co-ordinative definitions that apply (Grünbaum [1963], 12). Friedman's thesis is that the empirical situation effectively determines what principles or definitions we can adopt, and that, for example, the definition of simultaneity introduced by Einstein in the Special Theory of Relativity is not an arbitrary convention or co-ordinative definition, but is necessary to the provision of manageable relativistic geometry. Reichenbach's case is that a definition is necessary, but that the actual definition introduced by Einstein contains an arbitrary factor. There is a direct appeal about Friedman's approach, - a Reichenbach uncluttered by Kant -, which prompts the question of the relevance of the transcendental approach to the philosophy of science. In dissecting a specific theory, Friedman's approach is undoubtedly productive, in that all presuppositions are open to detailed questioning. The weakness of the direct empirical method, which allows no precedence to structuring principles, is that it can fail to relate to systematic scientific knowledge as a whole. It is not a problem of *losing sight of the wood for the trees*, but of not relating a *particular view of trees* with a *corresponding view of all the trees*. Empirical knowledge is structured by principles, and Reichenbach and Cassirer were correct to modify Kant's intransigent insistence on unchanging principles. The principles employed to generate a scientific understanding of the objective world are modified by science itself, - modified to clarify understanding. They are modified through the interaction of the objective world with our understanding of it. Perhaps there is a danger in use of the phrase *empirical knowledge*, in that there is an implication in the concept of *knowledge* in somehow coming-to-terms with *things in themselves*. Substitution of *understanding* for *knowledge* perhaps clarifies that what we understand is a construct from impressions of the world. In constructing our understanding we do employ regulative principles which are reviseable, but because these permeate all of our understanding it is necessary that we identify them as principles which are of different status from empirical laws.

Before looking beyond Reichenbach's work on Relativity in RAK, it is essential to examine the writings of Moritz Schlick and the correspondence he had with Reichenbach on Relativity. Schlick was asked by Kant-Studien in 1921 to review Cassirer's Zur Einstein'schen Relativitätstheorie, as well as Reichenbach's RAK and an exposition on Relativity for physicists by Max Born. Prior to this, Schlick had written an article in 1915 in Zeitschrift für Philosophie und philosophische Kritik, 159 entitled "Die philosophische Bedeutung des Relativitätsprinzips" ("The Philosophical Significance of Relativity"). In his article in 1915, Schlick had reviewed the Special Theory of Relativity, - the General Theory not having been published then -, against the background of the two philosophical methods in current vogue in Germany; neo-Kantianism and Positivism. He begins with a clear statement of what he sees as the proper task of philosophy

We have known since the days of Kant that the only fruitful method of all theoretical philosophy consists in critical inquiry into the ultimate principles of the special sciences.

(Schlick [1979],v.1, 153)

He proceeds with a clear elucidation of the principles of the Theory of Relativity, and demonstrates how they remove the shortcomings of Newtonian mechanics. In particular, they provide the means to make spatial and temporal measurements in a consistent manner without making a presumption of absolute spatial and temporal references. He compares Einstein's theory with that of Lorentz, who had provided a resolution of the apparent paradox of a constant velocity of light with his hypothesis of length contraction of bodies moving through the aether. Schlick acknowledges that both theories are in perfect accord in terms of measurable consequences, and argues why one should be preferred to the other. He adopts a Conventionalist approach, and, like Reichenbach's later analysis in RAK, he identifies scientific propositions as *coordinations*,

the totality of our scientific propositions, in word and formula, is in fact nothing else but a system of signs *coordinated* to the facts of reality;

(Schlick [1979],v.1, 167)

He proceeds with this discussion, emphasising the conventional nature of the system of coordinations that we adopt

It is therefore no contradiction ... that under certain conditions several theories may be true at once, in that they provide a different but in each case perfectly univocal designation of the facts.

One of them, indeed, will do this more skilfully and simply than all the others, and we may therefore work with it alone, and even agree to call it the only "correct" one, but a logically compelling reason for this may not at first be apparent.

(Schlick [1979],v.1, 168)

Schlick identifies that Einstein's theory is simpler than Lorentz' theory because it contains fewer arbitrary assumptions, illustrating from Lorentz' work -

one may assume that there is an ether in which a stationary system of coordinates can be imagined; but we do not need any of these hypotheses in order to remain in accord with experience - they are subjective appendages having no significance for the depiction of what is objective.

(Schlick [1979],v.1, 171,172)

The criterion he establishes for choice between competing and univocal theories, or systems of conventions, is -

We do this by selecting theories with a minimum of arbitrary assumptions, in other words, the *simplest*. We are then sure of diverging from reality at least no further than is necessitated by the bounds of our knowledge as such.

(Schlick [1979],v.1, 171)

He proceeds to criticise neo-Kantian accommodations of Relativity, and particularly examines Natorp's Die logischen Grundlagen der exakten Wissenschaften, published in Leipzig in 1910. He begins by demonstrating misconceptions in Natorp's interpretation of the Special Theory of Relativity, as, for example, in quoting from Natorp, that Einstein has "proved that for the moving system the velocity of light in fact necessarily remains constant, if it is so in the stationary system" (Schlick [1979],v.1, 173). As Schlick points out, "Einstein does not prove this, but introduces it as a justified assumption - a vastly different thing!" (Schlick [1979],v.1, 173). He is most vehement in his attack on Natorp, however, over Natorp's attempt to reconcile Kant's, and Newton's, concept of absolute space and time with "their empirical, physical determination, which latter can only be relative throughout." (Schlick [1979],v.1, 173). He is adamant that

under all circumstances .. Einstein's theory does not admit the concept of absolute time even as a presupposition.

(Schlick [1979],v.1, 174)

He identifies Kant's concepts entirely with Newtonian physics,

and condemns the neo-Kantian attempt to reconcile them to the Theory of Relativity.

Kant's *a priori* form of intuition - this cannot be sufficiently stressed - is Newtonian time. And as surely as the physics of the relativity theory is not Newtonian physics, so surely is it impossible for that theory to be fitted into the Kantian scheme, let alone be derived from it. ... Could a supporter of the Kantian doctrine of "the" time, in which we are obliged to order all appearances, have held to be correct, or even predicted, the propositions of relativity theory? Honestly, now!

(Schlick [1979],v.1, 175)

His attack on the neo-Kantians is an attack on scholasticism, which attempts to relate new knowledge to the system of previously established wisdom. For Schlick the proper object for philosophy is "reality as something firmly confronting science", and he completes his admonition with -

We do a better service to philosophy, I believe, if we are not afraid to subject our well-loved doctrines to the modifications called for by the progress of knowledge, than if we try under all circumstances to reconcile them with the new discoveries.

(Schlick [1979],v.1, 178)

Schlick is more sympathetic in his consideration of the relationship between relativity and positivism. He acknowledges that "Einstein could hardly have arrived at his theory, if he had not himself already been toying with these ideas [positivism]." (Schlick [1979],v.1, 178,179), but he criticises those positivists who claim that the Theory of Relativity is a direct consequence of Mach's work. His conclusion is that

our principle [relativity] finds a comfortable berth in the positivist theory of knowledge. But this does not exempt us from examining the details of this concord, and we shall find on doing so that the capability of positivism is actually overestimated if we think that it could so simply have given birth to the physical theory of relativity, and thus can have nothing more to learn from it.

(Schlick [1979],v.1, 179)

Schlick, the logical analyst, is opposed to all forms of scholasticism which seek to clarify through relation to the previously accepted. Schlick will accept appeal only to the physically verifiable and empirically real. When he took upon himself the task of reviewing Cassirer's and Reichenbach's contributions to the epistemology of relativity, it was therefore inevitable that he would criticise any attempts they

made to relate it to Kant's philosophy.

In his article in 1921 in Kant Studien 26, entitled "Kritizistische oder empiristische Deutung der neuen Physik?", Schlick interprets the essentials of Kant's method of logical idealism.

All exact science ... rests upon observations and measurements. But mere sensations and perceptions are not yet observations and measurements; they only become so by being ordered and interpreted. Thus the forming of concepts of physical objects unquestionably presupposes certain principles of ordering and interpretation. Now I see the essence of the critical viewpoint [Kant's method] in the claim that these constitutive principles are *synthetic a priori judgements*, in which the concept of the *a priori* has the property of apodeicticity ..... inseparably attached to it.

(Schlick [1979],v.1, 323)

His argument that follows from this is that Kantianism is not unique in maintaining the necessity of constitutive principles, and, for example, "An empiricist .. can very well acknowledge the presence of such principles" (Schlick [1979],v.1, 324). It is the concept of apodeictic a-priori principles that is the essence of Kantianism, and these have been demonstrated as unsound by the development of science since Kant. Thus, Schlick, commending Cassirer on his scholarship, criticises him for going beyond the proper subject of philosophy, - which is the unfettered analysis of science -, by attempting to re-habilitate Kant in a diluted form. His criticism of Reichenbach is gentler, and follows a correspondence between the two of them in which they each appreciated that their approach to philosophy had much in common. He is, however, critical of Reichenbach's attempt to redefine Kant's a-priori principles, and he would designate Reichenbach's coordinative definitions "as conventions, in Poincaré's sense" (Schlick [1979],v.1, 333).

Thomas Ryckman has contrasted the development of Schlick's epistemology with that of Cassirer in his article "*Conditio Sine Qua Non? Zuordnung* in the Early Epistemologies of Cassirer and Schlick" in Synthese 88: 57-95, 1991.

J. Alberto Coffa in The Semantic Tradition from Kant to Carnap. To the Vienna Station [1991] traces the correspondence between Schlick and Reichenbach in 1920, which marks a significant change in Reichenbach's approach to philosophy. As Coffa observes -

Reichenbach's main problem was that his account of the a priori had made it virtually indistinguishable from the empirical. .... he had two options: to follow the positivists or to drop that distinction and try Schlick's

suggestion that it be explicated on the basis of the notion of convention. Reichenbach chose the latter, and a decade later had become the most eloquent proponent of relativistic conventionalism.

(Coffa [1991], 203)

Reichenbach's subsequent writings certainly are marked by a relative absence of reference to Kant's philosophy, or to other philosophical traditions. He is concerned to investigate the subject in hand by methodical analysis of the empirical facts. Despite this apparent departure from his Kantian heritage, his thorough-going concern for detail is reminiscent of Kant's painstaking method of investigation; he departs from Kant only inasmuch as he makes no appeal to apodeicticity in a "Context of Justification".

## Chapter 5

### THE PHILOSOPHY OF SPACE AND TIME (PST) [1928]

In RAK, Reichenbach had attempted a reconciliation of Kant's critical analysis with the introduction of the Theory of Relativity, by replacing the Kantian concept of the a-priori with the concept of an evolving system of co-ordinative definitions. In PST, Reichenbach's purpose is different, in that he provides a systematic analysis of the spatial and temporal concepts applicable to post-relativistic physics. Thus he begins with Space, then considers Time, and finally examines their kinematic relationship.

His approach to the task, unlike Kant who followed a logical scheme, or Cassirer who scholarly followed the historical conceptual development, is of an engineer who rolls up his sleeves and examines all aspects of his subject with close attention.

#### Space

In examining space he is concerned with geometry and metrical properties, and after providing an exposition of potential systems of geometry and topology that may be applicable to empirical space, he asks how we are to decide which systems are relevant. Having established in RAK that the geometry of space is not a-priori valid, "it becomes now a task of physics to determine the geometry of physical space" (Reichenbach [1958], 6), but it is the task of philosophy, and PST in particular, to determine the criteria that physics can employ in coming to a decision.

He was interested in geometry. As a student he attended lectures by Hilbert who had developed a generalised geometry as a system of algebraic rules or logical operators. He thus delights in providing explanations of non-euclidean geometries and giving illustrations of physical worlds in which these could apply. As Cassirer does, Reichenbach accepts the idea that a system of geometry is a self-contained system which need bear no relationship to the actual measured properties of physical space, the sole criterion that it should fulfil is that it should be self-consistent. Felix Klein, at the turn of the Century, had demonstrated that several geometries could be co-ordinated to each other so that a relationship demonstrated in one system could be interpreted through this co-ordination to a corresponding relationship in another geometry. Hilbert consequently had illustrated this correspondence through his logical formalism of geometrical operators. Reichenbach, aware of the reader's familiarity with the applicability of the Euclidean geometrical system to the immediate physical environment, illustrates how it could be quite natural to accept

a geometry which contained the concept of the straight line whilst rejecting the idea of parallel straight lines. His example of someone on a spherical surface for whom straight lines would be the great circles, (that is circles on the surface of the sphere which are centred at the spherical centre), would appreciate that all such straight lines necessarily intersect each other at two points. The geometry on the sphere would be entirely consistent, but it would not be Euclidean, and it would give us no particular difficulties in working with it.

Reichenbach wishes to move into post-relativistic geometry, however, and he directs the reader to Riemann's system which approaches geometry from the metric rather than from axioms of relationship. He explains how using the metric we are able to make deductions about the curvature of surfaces as in the example just described of geometry on a spherical surface. For example, the relationship between circumference and diameter of a circle would not be a constant "pi" as on a plane Euclidean surface. The ratio on a spherical surface actually decreases to a limiting value of "2" as the circle gets bigger.

Having equipped the reader with adequate geometrical engineering tools, Reichenbach sets out a physical situation for consideration. He considers a plane glass surface which contains in it a large hemispherical hump. Below it is a second, albeit opaque, plane surface. He considers the response of people living exclusively on each of these surfaces. The people on the glass plane equipped with their measuring rods would conclude that they were living on a surface with a hump in it; they would arrive at this conclusion by noting the differences between their measurements and the expected values of plane Euclidean geometry. Reichenbach also notes that if, as the people on the glass plane move over their hump with their unit measuring rods, shadows are cast down onto the opaque plane below, then the projected shadow lengths on the opaque plane would vary with position under the "hump". Thus under the centre of the hump the projected shadow length of a unit rod would almost be equal to the rod itself, whereas under the steepest slope of the hump the projected shadow lengths would be much shorter.

Reichenbach moves to the inhabitants of the plane opaque surface. He now introduces a strange condition on physical behaviour on that surface, namely that all objects including the unit rods used on that surface foreshorten to the lengths of the projected shadows from the glass surface above. The inhabitants would then evidently form the same conclusions about their surface as had the inhabitants of the glass surface about theirs. They would conclude that they had a hump in the middle of their surface.

If on the other hand they believed they lived on a plane surface they would have to explain why their measurements were apparently distorted. This would require that some force was at

work which affected measurements over a certain area of the surface. In this case it should be possible to identify the force at work. If, for example, the distorting force was caused by heat, then it should be possible to detect other effects, and we could expect that different materials would be affected in different measure, - for example the effect on a copper ruler would be different from that on a wooden ruler. Reichenbach calls such a force a "differential" force, that is one whose differential effects can be related to other empirical factors. In the example illustrated, however, the nature of the distortion would not allow of an explanation by differential forces, and therefore the inhabitants of the opaque surface, clinging to the idea that the surface was plane, would necessarily need to invoke what Reichenbach calls a "universal" force, which is a force affecting all materials in the same way.

Reichenbach uses this illustration to help clarify two issues; firstly, to determine the factors that enable a decision to be made about the geometry of space, and secondly to introduce the idea of universal forces. Returning to the example, we find ourselves unable to provide an unambiguous answer to the question of the geometry of the opaque surface, and Reichenbach's assessment is-

Is it meaningful to assert geometrical differences with respect to real surfaces? This peculiar indeterminacy of the problem of physical geometry is an indication that something was omitted in the formulation of the problem.

(Reichenbach [1958], 13)

His retort to this, returning to the conclusions of RAK, is that we require a "coordinative definition". In this case we need a coordinative definition of a unit of length as well as of a rigid body. A coordinative definition is equivalent to Kant's a-priori rule, an act of judgment through which we can impose form on the empirical world. For Reichenbach, a coordinative definition is arbitrary, excepting for the requirement - as Cassirer would express it - of its being useful and providing consistent results in its application. Reichenbach demonstrates that we need a physical body as a standard for a measure of length to which we add the definition that by whatever means it is transported it represents the same unit of measure at any point of space. This definition does not arise from a measurable property of space, but in itself is a pre-requisite for comparing length at different points. It does rely for its usefulness, however, on an empirical property that if two bodies have the same length at one point then they will have the same length at every other point irrespective of the spatial route each has taken, provided that the effects of differential forces are allowed for. If this did not apply then the definition of unit of measure would have little practical usefulness; effectively it would provide us with a non-unique system of measure, as Reichenbach summarises -

the factual relations holding for a local comparison of rods, though they do not require the definition of congruence in terms of transported rods, make this definition admissible. Definitions that are not unique are inadmissible in a scientific system. ... *It is again a matter of fact that our world admits of a simple definition of congruence because of the factual relations holding for the behaviour of rigid rods; but this fact does not deprive the simple definition of its definitional character.*

(Reichenbach [1958], 17)

Returning momentarily to the opaque surface with our definition of length and congruence we would be obliged to conclude that we have a plane surface with a hemispherical hump in it.

*The geometrical form of a body is no absolute datum of experience, but depends on a preceding coordinative definition*

(Reichenbach [1958], 18)

We could have provided a different definition, and Reichenbach indicates perhaps bizarrely, that we could call a measuring rod half its length after putting it down twice and a third of its length after putting it down three times, and so on, but the geometrical conclusions would be quite different. This is not a good example, however, as we would be unable to provide any consistent geometry whatsoever with this definition.

To conclude the coordinative definitions of measure required to establish the geometry of a space, Reichenbach, with his engineer's thoroughness, insists that we consider what we mean by a rigid body as used in a standard ruler for instance. His definition is -

*Rigid bodies are solid bodies which are not affected by differential forces, or concerning which the influence of differential forces has been eliminated by corrections; universal forces are disregarded.*

(Reichenbach [1958], 22)

Effectively the rigid body used as a unit of measure is a "closed system", unaffected by the differential forces in its environment. These definitions, as Reichenbach points out, are of fundamental importance -

This definition of the rigid body is not explicitly given in the literature of physics, but it is that definition on which the whole system of physics is based. With a different definition physical laws would generally change; this follows from the fact that in the dimensions of the fundamental

physical magnitudes, such as force and energy, the concept of length occurs; thus the values of these magnitudes depend on the definition of congruence. It must not be argued, however, that conversely the "truth" of our definition of congruence can be inferred from the truth of physical laws. The truth of the physical laws can only be asserted under the assumption of a definition of congruence; *the laws are true relative to the definition of congruence* by means of rigid bodies.

(Reichenbach [1958], 23)

Reichenbach, as a careful teacher, returns to the status of the coordinative definitions to emphasise their logical status for science. In his persistence at looking at all aspects of the problem and countering possible misunderstanding, his approach is similar to Kant in the Critique of Pure Reason. Like Kant, he is examining the prerequisites for empirical knowledge, and he also acknowledges the primacy of the geometrical structure we impose. He has the benefit of the development of alternative geometries post-Kant which emphasise that our spatial knowledge is founded on coordinations we choose, but which also remove the apodeictic necessity for a specific geometry having a-priori status. It is probable that a Twentieth Century Kant would have approached this subject in a similar fashion.

The clarification that Reichenbach wishes to make is over the status of the verifiability of the coordinative definitions as opposed to measurement problems of "*objective indeterminacy*". An example of the latter, as a technical impossibility, is a measure of "the number of molecules in a cubic centimetre of air", where it is beyond our means to achieve this count although "we must say that there will always be an integer which denotes this quantity exactly." (Reichenbach [1958], 28). A coordinative definition on the other hand can not be verified; logically it is an impossibility. It is not possible to verify that a standard unit of length remains unchanged at different positions. The coordinative definitions are necessary for determining the empirical properties of space. Reichenbach, however, does acknowledge that -

once the coordinative definition is given, the technical impossibility of an exact measurement remains. Even our definition of the rigid body does not permit a strict determination of the structure of space; all our measurements will still contain some degree of inexactness which a progressive technique will gradually reduce but never overcome.

(Reichenbach [1958], 29,30)

This latter point is not to be pursued in PSI, as the subject of empirical verifiability is the subject of later works. The other subject which Reichenbach has introduced and requires further

elucidation, however, is the concept of "universal forces".

A "differential force" causes measurably different effects in different materials. For example, heat causes different expansions in different materials, and magnetic forces affect different materials to different degrees. Reichenbach devises a simple instrument which can be used to search for some differential forces (e.g. heat), but which can also be used to investigate local spatial geometry. He provides us with a circle of wire with a wire diameter spoke fixed to the circumference at one end but with the other end freely resting against the circumference. If this device is placed over a heat source, the higher temperature in the spoke will cause it to expand more than the circumferential ring and the free end of the spoke will extend outside the ring. If this device were moved over a surface of varying curvature, however, similar effects could be observed. For example on a plane surface the free end of the spoke would coincide with the circumference, but on a spherical surface the free end would move inside the circle, and the greater the degree of curvature in the surface relative to the size of the circular wire the further away from the circumference is the free end of the spoke. Thus we could envisage spatial geometry and a specific empirical force providing us with similar results, excepting that if we now repeat these measurements with a similar device made from a different material, - copper as opposed to steel, say -, the effects of moving over a heat source will register different measurements of displacement of the free end of the spoke due to the different coefficients of expansion of the different materials. In the case of moving over a curved space, however, the two devices of different materials would record exactly the same measures of displacement. Thus although the example with the heat source can be interpreted as a consequence of a differential force being present, - heat -, the example of the curved space could be interpreted as a spatial property, or as a consequence of the presence of a universal force.

The distinction between universal and differential forces merely classifies the phenomena as belonging in geometry or in physics.

(Reichenbach [1958], 27)

Reichenbach makes an interesting speculation at this point which also adds to appreciation of The General Theory of Relativity -

we could very well imagine that the coefficients of heat expansion of all materials might be equal - then no difference would exist between a field of heat and the geometry of space. It would be permissible to say that in the neighbourhood of a warm body the geometry is changed just as (according to Einstein) space is curved in the neighbourhood of a large mass.

(Reichenbach [1958], 26)

Having provided a clear exposition of the concept of a universal force and its relationship to the geometrical properties of space, Reichenbach makes a creative step, inspired by Einstein's example in the General Theory of Relativity. It is possible for us to use any consistent geometrical system as a basis for the geometry of space, and, as Klein and Hilbert have demonstrated, any measurements made against this geometry can be translated into measurements into another self-consistent geometry. If, for example, we apply a Euclidean geometry to a space surface which is spherical, our physical investigation of this space will demonstrate the presence of universal forces. It would have been simpler for us not to accept a Euclidean metric, but to adopt the spatial geometry which eliminated the presence of such universal forces. Thus Reichenbach adopts the principle of "descriptive simplicity" in recommending that we can prescribe an actual geometry to empirical space as that geometry which eliminates universal forces. He takes pains to point out that the geometry of space elucidated in this manner is a consequence of the coordinative definitions of congruence and of rigid body that we choose to adopt, and is a meaningless concept in their absence. As an alternative coordinative definition we could have prescribed the geometry and then derived the definitions of congruence and rigid body to provide a physical space free of universal forces. Reichenbach's prescription, however, is that we should choose our coordinative definition on the basis of its "simplicity", (although perhaps in this respect Cassirer's concepts of "usefulness" and "consistency" would be preferable), and then derive the empirical geometry that eliminates universal forces. He doesn't tackle the problem of whether it may always be possible to eliminate universal forces in a consistent and continuous empirical geometry.

He acknowledges that Helmholtz, and subsequently Poincaré, were responsible for drawing attention to the fact that empirical geometry was dependent on basic definitions that were applied, such as on the definition of a rigid body. He disagrees with the conclusion that they derive from this, that it is consequently meaningless to talk of the geometry of space when it is a consequence of arbitrary definitions. He is dismissive of the subjectivity of their Conventionalism.

Unfortunately, the philosophical discussion of conventionalism, misled by its ill-fitting name, did not always present the epistemological aspect of the problem with sufficient clarity. From conventionalism the consequence was derived that it is impossible to make an objective statement about the geometry of physical space, and that we are dealing with subjective arbitrariness only; the concept of geometry of real space was called meaningless. This is a misunderstanding. ....  
.. once the definitions have been formulated, it is determined through objective reality alone

which is the actual geometry.

(Reichenbach [1958], 36,37)

Having established that it is possible to establish, by measurement, the geometry of empirical space, Reichenbach, conscious of his potential critics, wishes to explore the concept of the visualisation of non-Euclidean geometries. His particular concern is that Kant has bequeathed the concept that only Euclidean geometry is visualisable, and that consequently there is an argument for rejecting other geometrical systems as being unreal geometries. This is perfectly natural when we consider that until 1905 and the Special Theory of Relativity, mechanics and concepts of order in the physical world were established on Newtonian modelling. Newton himself had derived his Theory of Gravitational Attraction through classical Euclidean geometry of conic sections. When a physicist viewed the physical world, he was embedded in Euclidean concepts, and Reichenbach has so far worked within these constraints. In his analysis of the problem of physical visualisation, however, Reichenbach begins to free us from this geometrical inheritance and effectively substitutes a concept of physical logic for physical geometry. Until Hilbert, geometry implied the notion of visualised spatial relationships, but Reichenbach, in setting up his coordinative definitions for spatial measurement via physical rods has freed himself potentially from this constraint of spatial visualising with a robust physical logic. By discussing the properties of space in terms of "geometry", however, he has been guilty of some lack of clarity. It is interesting that Einstein, in the General Theory of Relativity, avoids the discussion of the geometrical concepts of the equivalence of gravitational and dynamic properties, but moves directly into the consideration of the observer in a cage which is being accelerated, and offers us the two equivalent interpretations that observer would give for the forces he feels subjected to. The problem we have with Einstein's approach is in our overall geometrical visualisation of the spatial context of the equivalence of a gravitational field with a dynamically accelerating body. The advantage for Einstein is that he is not encumbered with the apparent visualising difficulty, and he is enabled to establish a physical logic for space.

Reichenbach's analysis of visualisability of spatial geometry is preceded by a re-assessment of his previous analysis through which he begins to strip the concept of "geometry of physical space" of our preconceptions of diagrammatic visualisation.

it is the significance of coordinative definitions to lend an objective meaning to physical measurements. ... *The objective character of the physical statement is thus shifted to a statement about relations.* ..The geometry of real space .. is a statement about a relation between the universe and rigid rods. The geometry chosen to characterise this relation is only a mode of speech; however, our

awareness of the relativity of geometry enables us to formulate the objective character of a statement about the geometry of the physical world as a statement about relations. In this sense we are permitted to speak of *physical geometry*.

(Reichenbach [1958], 37)

With his analysis of the visualisability of Euclidean geometry, Reichenbach's target critics are philosophers of the Kantian tradition, for whom geometry not only appears to represent a diagrammatic representation of physical spatial relationships, but for whom the geometry of Euclid represents the necessary logic of such relationships. Thus Reichenbach presents the geometrical image of a triangle with a straight line intersecting one side, and we are compelled to accept by the inescapable logic of the plane diagram that the extended line must necessarily intersect one of the other two sides. The Euclidean system of geometry is the logic of plane diagrams, and whenever we attempt to visualise relationships on a piece of paper we are compelled to accept the Euclidean logic. Diagrammatic representation is a "tool" that facilitates our solving spatial and logical problems, but in choosing a diagrammatic approach we limit ourselves to the logic of the Euclidean system.

*The normative function of visualisation is revealed as a correlate of the logical compulsion and achieves the same results by means of the elements furnished by the image-producing function as the logical inference does by means of the conceptual elements of thought.*

(Reichenbach [1958], 42)

more restrictive laws hold for visualisation than for logical thinking ..... visualisation admits a narrower selection of geometrical structures than does logic.

(Reichenbach [1958], 43)

Reichenbach's conclusion is that in visualising we involve ourselves in diagrammatic representation and are therefore inescapably locked into the logic of such a schema, - which of its essence is the logic of Euclidean geometry. Therefore-

*We cannot visualise non-Euclidean geometry by means of Euclidean elements of visualisation.*

(Reichenbach [1958], 43,44)

It can be argued, and Reichenbach gives this full consideration, that we can make diagrammatic representations of non-Euclidean geometries. We can use diagrams that enable us to represent the geometry of Lobatchewsky and derive non-Euclidean conclusions from them. Reichenbach rightly points out that these are not what we would consider as visualisations in that they represent

relationships between logical operators, they are mappings, rather than representing a visualisation of a physical space.

When we revert to exploring the geometry of physical space we resort to our coordinative definitions and set out with our physical measuring rods. We can visualise this process and could visualise moving over a non-Euclidean surface, just as we visualised the inhabitants of the glass plane moving over their hemispherical hump. That works well for considering a two-dimensional surface within three dimensions of conception, but our problem with this physical visualisation commences when we wish to visualise a non-Euclidean three-dimensional space and are unable to conceive this without a fourth dimension which lies beyond our limits of visualisation. Reichenbach, however, persists with his attempt to introduce us to visualising non-Euclidean geometries. He has demonstrated that it is conceivable for us to set out with our measuring rod on a non-Euclidean surface and, in observing discrepancies between our measurements and what we would expect on a Euclidean plane surface, we are able to deduce either a different geometry or the presence of universal forces affecting our measuring instruments. He then reminds us of the manner in which we make adjustments in our physical perceptions in order to blend them into our total spatial conception. We are familiar with views of converging railway lines which we learn - effectively having explored them physically with our measuring rods - to accommodate as Euclidean parallels; and another example that Reichenbach offers us is of the motorist with his convex rear-mirror who learns to adjust the distorted image into his conception of the physical geometry in his environment. his conclusion is -

*Any adjustment to congruence is a product of habit; the adjustment is made when, during the motion of the objects or of the observer, the change of the picture is experienced as a change in perspective, not as a change in shape of the objects.*

(Reichenbach [1958], 55)

He therefore concludes that visualising a non-Euclidean geometry requires of us a re-adjustment of our conceptual scheme, and that it is a matter of learning or familiarising ourselves to it.

Whoever has successfully adjusted himself to a different congruence is able to visualise non-Euclidean structures as easily as Euclidean structures and to make inferences concerning them.

(Reichenbach [1958], 55)

He then attempts to remove the classical concepts that we tend to invoke when considering "geometry"

Space as such is neither Euclidean nor non-Euclidean, but only a continuous three-dimensional manifold. ...

It is, in fact, the result of training the eyes to adjust to the behaviour of solid bodies seen in different angular perspectives that enables us to visualise Euclidean congruence. If we readjust the eyes we can similarly visualise non-Euclidean congruence.

(Reichenbach [1958], 56,57)

At this juncture the reader believes that Reichenbach has exhausted the subject of spatial configuration and our capacity to come to terms with it, but he has not yet exhausted his capacity to attempt to present twentieth Century mathematics to us in a physical way. In looking at alternative geometries he has been exploring metrical properties, but he hasn't examined the properties of spatial connectedness which is the subject of topology. He thereupon introduces the topology of spherical surfaces and the torus, and illustrates their distinctive properties in providing mappings onto a plane surface. He initially concentrates on the properties of the torus because it provides apparent logical anomalies, when considered in Euclidean terms, such as pairs of closed loops which both contain and are contained in each other. He thereupon takes us by the hand and leads us into each of a torus world and a spherical world, relating our perceptions as we go of course in Euclidean terms. He presents us with two apparent anomalies. In the torus world we find that that we can continue climbing out of completely enclosed spherical shells into successive concentric shells only to find that we have returned into our original shell. This runs contrary to our logical understanding, and Reichenbach identifies this not only as logically anomalous but also as causally anomalous.

a causal anomaly occurs, consisting in the spatial periodicity of all happenings. The interdependence of all events at corresponding points cannot be interpreted as ordinary causality, because it does not require time for transference and does not spread as a continuous effect that must pass consecutively through the intermediate points.

(Reichenbach [1958], 65)

Causal connectivity implies a relation between a space metric and a time metric, and involves the logical consideration that if B is between A and C then the effect of a causal change at A will affect B before it affects C. If B is between A and C, and C is between A and B then this simple causal connection is confused, and on the torus we also have the additional anomaly that B is spatially between A and A. Thus in reconciling the world of the torus with Euclidean preconceptions we are compelled to abandon our concept of causal structure, and we can only avoid this by adapting our concepts entirely to the geometry of the torus. Applying Euclidean considerations to the torus provides us with non-local causal connections.

When we enter the spherical world with our Euclidean visualisation we again confront the causal anomaly of proceeding in one direction with our measuring rods and, although moving further away from our starting point, eventually re-encountering it, - apparently having passed through a Euclidean infinity with a finite measure.

Thus, if we are to determine the topological structure of physical space we must pre-arm ourselves with a further coordinative definition, namely that causal ordering should apply.

*Topology is an empirical matter as soon as we introduce the requirement that no causal relations must be violated. ... Only in this way does the topology of space constitute a well-determined question. It must be called an empirical fact that there is one kind of topology that leads to normal causality; and it is of course an empirical fact which topology yields this result.*

(Reichenbach [1958], 80)

In his paper "Das Raumproblem in der neueren Quantenmechanik", written in 1926, (Reichenbach [1991]), Reichenbach analyses the dimensionality of space against the context of emerging Quantum Theory which employed the concepts of multi-dimensional parameter spaces. His conclusion is that although it is possible to provide transformations of spatial coordinates between descriptions employing different spatial dimensionalities, it is not possible to transform causal connections between these descriptions. For example, it is possible to transform spatial descriptions of two point-objects operating in a three-dimensional space to a description of one point-object operating in a six-dimensional space, but any causal relationship applying in the three-dimensional description is lost in the six-dimensional case. Reichenbach's principle which he accordingly enunciates, is

*The principle of action by contact can be satisfied only for a single choice of the dimensionality of the parameter space; that particular parameter space in which it is satisfied is called the coordinate space or "real space".*

(Reichenbach [1991], 40)

He then emphasises that

*Natural processes satisfy the requirements of the principle of action by contact only in a space of three dimensions.*

(Reichenbach [1991], 40)

Commenting on this conclusion of Reichenbach's, Andreas Kamlah

relates Reichenbach's method to that of Kant,

the principle of action by contact becomes to be more than a guide for coordinative definitions. It becomes more and more a general principle for the selection of simple and informative descriptions of the world from others. ... Thus it is no longer a device to connect physical language with empirical meaning but rather to constitute the objects of physical theory quite in the same sense as Kant. It leads according to Reichenbach to the knowledge of the structure of the real world.

(Kamlah [1991], 51)

Thus Reichenbach clearly makes the claim that,

the three-dimensionality of space must describe an essential property of nature that exists just as independently from the human mind as any other property. Even though the *concept* of space, as any other *concept*, arises in the subject, its *applicability* states something about the world of *objects*. The assertion that physical space is three-dimensional and approximately Euclidean is therefore to be regarded as a genuine physical assertion, similar to all other physical assertions.

(Reichenbach [1991], 32)

In his consideration of Space, Reichenbach has demonstrated that the geometrical and topological properties are empirically verifiable once we have made coordinative definitions of congruence, of rigidity, and of causal connectedness. He has also illustrated that whatever the outcome of our verification, it is possible to provide a visualisable realisation, even though this may require us to modify our deeply held Euclidean predilections. That visualisation is important is emphasised by Reichenbach, because

visual pictures...establish the relation between thinking and reality; they connect perceptions with concepts

(Reichenbach [1958], 92)

The difficulty we have with visualisation is that it is learned in terms of logical relationships of shape on a two-dimensional plane, and therefore inhibits consideration to the logic of the geometry of plane surfaces. His demonstration of this clearly identifies why Kant felt compelled to accept Euclidean spatial geometry as a-priori. The final conclusion that Reichenbach should draw from his analysis, to free us from our Euclidean inhibitions, is that it is not the "geometry" of space which is our concern, but the physical logic of the metric.

## Time

When he considers the concept of Time, Reichenbach provides a post-relativistic warning

Whereas the conception of space and time as a four-dimensional manifold has been very fruitful for mathematical physics, its effect in the field of epistemology has been only to confuse the issue. Calling time the fourth dimension gives it an air of mystery. One might think that time can now be conceived as a kind of space and try in vain to add visually a fourth dimension to the three dimensions of space. It is essential to guard against such a misunderstanding of mathematical concepts.

(Reichenbach [1958], 110)

As with his analysis of space, Reichenbach sets out to construct a metric,- a requirement for a coordinative definition. He identifies two methods of measuring time

one consists in counting *periodic processes*, and the other in *measuring spatial distances* corresponding to certain non-periodic processes.

(Reichenbach [1958], 115)

As with the measurement of space where there is no means (logically) of determining whether a unit measuring rod maintains the same length in two separate locations, so with time when we take a periodic process as a unit of measure there is no means of establishing whether successive periodic intervals are equal. We can take care to establish, as with two clocks, that if they synchronise at one time they also synchronise at another, but we have no means of establishing, without substituting another basic unit, that successive time units are equal.

The equality of successive time intervals is not a matter of *knowledge* but a matter of *definition*

(Reichenbach [1958], 116)

The only prerequisite conditions we must impose in whatever periodic process we choose for our unit of time measurement, is that it offers "descriptive simplicity" and that it leads to a "noncontradictory description of nature". A basic clock appears to satisfy these requirements although there are complications involved in ensuring as far as possible that it is free from external influences, - that it be a closed system. As with the spatial metric, we must also be aware of the potential effects of differential and universal forces.

Equivalent to study of the space manifold it is also necessary

to make a coordinative definition of coincidence. In the case of time this is a definition of simultaneity of spatially separated events. Reichenbach refers to Einstein's definition for the Special Theory of Relativity and examines the epistemological significance of it

the time comparison of distant events is possible only because a signal sent from one place to another is a causal chain. . .we can determine the time of the distant event only with the help of an inference.

(Reichenbach [1958], 125)

Thus in making a choice of definition of simultaneity we are defining a basic unit of causal propagation or of signal transfer. Implicit in this is the definition that it is independent of spatial direction, although we could have incorporated a definition that did not presume this if we had wished. The signal chosen, based on scientific experience, is of course that of light. This also provides a connection between the properties of the space and time manifolds, as in allowing for the causal connections in space we necessarily involve the spatial metric in temporal determination.

It would appear that with his basic definitions of a unit of time, of successive measures of that unit being equal, and of simultaneity, that Reichenbach has sufficient bases for a complete description of the time metric. Just as he went on to consider the topology of space, however, and introduce the coordinative definition that physical causal ordering is a pre-requisite for a choice of topology, so too with time he chooses to look at topology and the problem of ordering, - of "before" and "after". His conclusion again is that without the concept of causal order, the topology of time is incomplete. In defining causal connectedness for a determination of time order, we must exclude closed causal chains which effectively make simultaneous two different points in time order and furthermore lose the concept of individual identity through time.

Reichenbach concludes his analysis of the temporal manifold by investigating the concept of simultaneity based on a finite signal speed, - light. With an infinite signal velocity it is possible to provide a unique temporal sequence for all events throughout space, - effectively events happening at every physical location are allocated a time coincident with the time registered with the observer. With a finite velocity this proves to be impossible; but Reichenbach's assessment is that we are unable to provide a temporal ordering, for example, between a distant event and a local event that occurs within the period between departure of the signal to the distant location and its return. This formulation appears to exclude the possibility of an interpolative ordering and is therefore too extreme a conclusion. What can be inferred from the concept of a finite signal velocity, however, and which Reichenbach later

investigates, is that simultaneous distant events can have no direct causal connection.

### Dynamics

Once we begin to examine dynamical properties, we need to consider the inter-relationships between the spatial and temporal manifolds, and we will be required to apply coordinative definitions to these relationships. Thus Reichenbach begins by adding to his coordinative definitions of the spatial metric

the measuring rod is to be regarded as having the same length whether at rest or in motion  
(Reichenbach [1958], 154)

We also need to define, as in the Special Theory of Relativity, how to measure the length of a line section moving relative to the frame of measurement, and for this we must invoke the concept of temporal simultaneity

The length of a moving line-segment is the distance between simultaneous positions of its endpoints.  
(Reichenbach [1958], 155)

The consequence of this definition of course had been established by Einstein, and

*It follows from the nature of the extended concept of length that the length of a moving segment is generally different from its rest-length.*  
(Reichenbach [1958], 157)

The objection that may be raised against what appears to be a dual definition of length, namely "Which is the true length?" is unreasonable. The concept of length has been defined in a manner in which it can be applied, and it is for measurement to give us the consequences under different dynamic conditions. The definition of simultaneity is a fundamental determinant of the possibility of dynamic spatial measurement, and Reichenbach makes a further observation on measurement of distant events -

We actually never experience distant events, but only the effects that reach us. Consequently we can choose how to coordinate these events to our visual images.  
(Reichenbach [1958], 161)

The metric for space requires a coordinative definition of a unit (length), just as for time a unit (interval) is required, and in addition the concept of a "first signal" (light) is needed to provide simultaneity and temporal ordering of

spatially distinct events. In involving both temporal and spatial metrics for dynamic consideration, the first signal, which relates physical separation to temporal separation, is operating alongside independent spatial and temporal units of measure. There are two independent manifolds, time and space, and we have two independent units of measure plus a further independent unit which combines the metrical properties of both manifolds. We have a system which is over-specified. Reichenbach does not diagnose the situation in this way, but he does arrive at the conclusion that it is possible, by use of the first signal together with our standard clock, to provide a spatial metric, as he claims

This fact is of extraordinary significance because it proves that space measurements are reducible to time measurements. *Time is therefore logically prior to space.*

(Reichenbach [1958], 169)

From the foregoing analysis, this claim of logical priority for time appears to be misplaced. It is possible to define the temporal metric in terms of a unit spatial measure (rigid rod) and a signal. It is a clumsy way of measuring temporal duration at a spatial location because it effectively involves "marking-time" with a light signal, but it is feasible. The alternative of defining the spatial metric with light signals and a clock is more straightforward and therefore *practically superior* rather than *logically prior*. Reichenbach's intention is to proceed beyond this simplification and introduce a metric for both space and time based solely on light signals, effectively by defining his standard measure of time in terms of the interval defined by a light signal completing a return journey from fixed points. This requires maintenance of the definition of a rigid body, but provides a combined metric of time and space based only on use of light signals. He attempts this without acknowledging the requirement for the definition of a rigid body, but when he subsequently investigates inertial systems using light-geometry he acknowledges the need for the rigid body definition, which he introduces, as was shown above, via the definition of a standard clock.

The rigid rod is not used for the definition of spatial congruence within the system, but only for the determination of one - and indeed only one - distance as rigid, i.e. for the definition of the *temporal congruence of spatial distances*. For this reason natural clocks can be employed for the definition of rigidity. It suffices to specify the *time metric* at a space point. Then the rigidity of the entire system ... is determined by means of light signals.

(Reichenbach [1958], 174)

Reichenbach has proceeded to investigate the practicability of a "light geometry" for space, and is required to introduce the concept of "between" which he defines as

a point B lies between A and C, if the first-signal ABC arrives at C at the same time as the first-signal AC.

(Reichenbach [1958], 169)

From this he is enabled to define a straight line

The straight line through A and C is the set of those points which among themselves satisfy the relation *between* and which include the two points A and C.

He now completes his coordinative definition for the spatial metric without using physical measuring rods and rigid bodies

If the time interval  $ABA = ACA$  then the spatial distance AB is equal to the spatial distance AC.

Reichenbach thus claims to have defined two separate systems for determining the space-time metrics. He has on one hand what he classifies as the *matter-axioms* based on definitions of metric via rigid rods and standard clocks coupled with a definition of simultaneity involving light transmission which effectively over-specifies the independent variables. On the other hand he has the *light axioms* which remove the over-specification of variables and rely on light transmission for determining the spatial metric. Both systems are applicable to the empirical world, it is for science to demonstrate the consequences of their application. What Reichenbach's attempt to separate out light-axioms from matter-axioms clearly distinguishes, however, is that the physical results from applying one system may have a different form from the results of applying the other system. For example if we define unit length in terms of light transmission, there is no logical reason why the relationship between the length of a relatively moving line-segment with its stationary length should correspond to the relationship obtained when physical measuring rods are used. Reichenbach correctly identifies that Einstein's Special Theory of Relativity provides a physical, and therefore empirically verifiable, theory

*that material things adjust, not to the classical, but to the relativistic light-geometry.*

In other words both metrics apply, provided that the Lorentz transformations are applied to physical rods and clocks.

This assertion constitutes what is new in the theory of relativity from the point of view of physics. Whereas all of the light-axioms hold in classical optics, to which the theory of

relativity adds only the assertion that the velocity of light is the upper limit for the speed of signals, the matter-axioms signify a deviation from classical theory. They contain the assertion that the Lorentz transformation, which in the light-geometry differs from the Galilean transformation only *by definition*, is at once the transformation for measuring rods and clocks. This assertion contains, therefore, that part of the relativistic theory of space and time which is to be tested empirically.

(Reichenbach [1958], 176)

It is fruitful at this point to assess Reichenbach's achievement in identifying the basic axioms applied in providing a space-time metric, and particularly in illustrating how the Theory of Relativity is able to reconcile the consequences of a metric based on the matter-axioms with one on the light axioms. The axioms are defined such that the physical consequences of applying either basis are the same in inertial systems. He demonstrates how the definition of simultaneity is the "key" to a relativist conception of space-time, but perhaps more fundamentally he shows that the Theory of Relativity improves on classical mechanics by rejecting the axiom that measure of length or duration is unaffected by relative movement.

There are two exercises that are worth following through, firstly it is worth examining the kinds of physical world in which particular metrics are appropriate, - with particular reference to the world of classical mechanics as opposed to relativistic mechanics-, and then to re-consider Reichenbach's disturbing example of the geometry of the opaque plane.

In the world of Newtonian mechanics, all events have absolute coordinates of space and time position, and consequently absolute values of velocity and acceleration. We can provide a cartesian framework for this world with unit measures defined by our standard metre and our standard clock (spring mechanism rather than pendulum). Causal connection of events results from mechanical interaction, and gravitational effects are not transmitted but have immediate effect at all spatial points. We have no requirement for a definition of simultaneity, because every occurrence has a unique temporal reference available to all observers, and a metre-long rod remains a metre-long rod whether it is on the desk in front of me or fired from a cannon. I have no cause to attempt to check its length whilst moving, since a rigid body will always occupy the same amount of space on my reference frame, whatever its state of motion. We have no cause to be anxious about this system, other than to be uneasy at Leibniz questioning the validity of our frames of reference. If we now introduce light into the system, not only as an object for scientific study, but as a tool for simplifying distant measurement, we have no reason for anxiety. If, like Einstein, we give light a unique metric of its own, we would recognise

that measurement with light might conflict with measurement based on our standard metre. We would tend, in case of conflict between our standard metre and light, to explain the discrepancy in terms of the behaviour of light changing as the medium through which it is transmitted changes, - given that it is an established fact that the properties of light can be changed in this way. If, however, discrepancy only arises in considering bodies in absolute motion, the environmental medium remaining unchanged, then it becomes necessary to produce a theory of the effect on rigid bodies of absolute motion, - as Lorentz did. Reichenbach's objection to such a theory would be that it introduces the concept of a universal force which affects all bodies equally, irrespective of their differing material composition. This criticism of his seems to run counter to the tendency in physics for greater generalisation of law-like behaviour, and the necessary compulsion to understand differential effects in terms of the application of generalised causes (or forces) to differing material structures. What better generalised law within a system of absolute spatial and temporal references, than a law which attributes changed measured physical properties to absolute motion. There is no question that Reichenbach's principle of elimination of universal forces does identify a principle which is necessary in science, and accords well with Ockham's Razor, in that we shouldn't introduce notions of spurious forces into science. Against absolute spatial and temporal coordinates, however, length contraction as a consequence of absolute motion would be an objective fact and capable of detection. It would belong within the causal order of our absolute universe. It is only when we try to establish a geometrical structure for space and time based on relative rather than absolute spatial locations that physical length contraction would appear as an arbitrary hypothesis.

It could be argued that the Lorentzian phenomenon of length contraction as a new hypothesis is an indication of something wrong with our geometry of space and time, and that this was a telling empirical blow against the concept of absolute spatial and temporal coordinates. This is an indication perhaps, but the problem with absolute space and time is not one of inappropriate coordination, as say with choice of a metric; it is epistemologically wrong. Leibniz demonstrated that the logic of absolute position and time is not coherent, and the subsequent Kantian constructs of space and time manifolds are observer-based. The Theory of Relativity is a demonstration that the wrong epistemological basis for science will provide incoherent empirical consequences. The concept of relative, as opposed to absolute, spatial and temporal determination, is not a coordinative definition which we are free to choose, it is a logical prerequisite of coherent science. Having accepted relative position, we are then *free* to choose our empirical metric.

Constructing a physical metric from a reference system in a relativistic world is well described by Reichenbach in PST. We

begin by creating a Riemannian reference grid with our definitions of length and time measure and rules of congruence. The spatial grid constructed from rigid rods is easy to visualise against our cartesian inheritance. In relation to time, we envisage positing our standard clocks throughout the spatial dimensions, and then provide ourselves with a simplified cartesian diagram of one space dimension related to one time dimension. The only real problem we have, as Reichenbach correctly emphasises, is in maintaining a concept of synchronicity throughout our spatial frame. How do we log the time of distant events on our local clock? It is feasible, for example, to consider, when logging the motion of a moving object, that local time is recorded as the object passes specific points, and then these recordings are returned to base for compilation. For example, consider a railway line as a one dimensional space, with standard time recorders set at intervals along it. As a train passes a time recorder we get a time coordination together with the spatial coordination. At the end of each day we assemble all the readings and fill in our two-dimensional cartesian chart logging train movements. We check that our time-recorders are all functioning normally, by bringing them back to base at intervals to compare with the master-clock. We have had no requirement for synchronicity, only the axiom that time recorders (and measuring rods) are unaffected by transportation. We have two dimensions on our master cartesian chart, and for each recording we have two independent measures, - so there can be no anomalies of measurement. If we wish to speed up the process of coordinating our recordings, then we could use a direct signal from the recording points back to base where we keep our cartesian chart. We have thereby by-passed our local time-recorders with an independent system, so that we are now in a position to compare this record with the end-of-the-day record obtained by the time-recorders in the field. There is no logical reason why these two charts should be exactly alike. Discrepancies could be due to :-

1. Incorrect adjustment for transmission speed of signal
2. Signal does not propagate with uniform speed  
    e.g. decay of speed with distance
3. Rigid rulers change length when transported away from base.
4. Clocks change when transported, and behave differently in different locations.

Both points 1 and 2 can be readily checked against our standard metric, and provided that discrepancies conformed to rules, then appropriate adjustments to recorded signal times could be made, - effectively a process of synchronisation. Exactly the same experiment would have to be used to check on 3 and 4, however, so it is appropriate to ask whether we adjust the signal times or the spatial and temporal divisions on our master-chart. In practice we would make the simplest adjustment, - which would be affected by other uses we make of measuring instruments and

signals. The fact that we have to make adjustments at all, is because we've over-specified our metric and used three independent physical systems to provide a measure of two independent variables. That we can find a signal that does provide a correlative system of measurement with rigid bodies and standard clocks is an objective property of the physical world, and reinforces, not just the regularity of the physical properties of the world, but our acceptance of its causal order.

Reichenbach emphasised the relationship between causal ordering and the use of the light signal. If there is universal causal order then it follows that there is a finite upper limit to the rate of propagation of effects. Instantaneous transmission of any effects prevents a causal connection being made within our spatial framework. If there is a finite upper limit to rate of causal propagation, then in choosing a signal velocity for the spatio-temporal metric, it is important that the signal used is at this upper velocity limit, otherwise signals from distant objects will be overtaken by subsequent effects. Choice of the signal must therefore itself be based entirely on empirical considerations. The further consideration related to Reichenbach's concern for the relationship between the causal principle and the spatial metric, is to note that the prime reason for introducing a light signal into an already fully specified space-time manifold, is to relate causal connections between distant events by establishing synchronicity. The order of time and its metric is thus a function of the causal structure of the world.

With these considerations in mind, it will be fruitful to return to the inhabitants of Reichenbach's opaque plane with the unusual metrical properties he describes. Let us presume that they busy themselves initially, solely with their measuring rods. Until they encounter the area under the hemisphere in the glass surface, they will establish Euclidean geometric properties. We presume that they adopt a principle of straight lines by overlapping coincident rods. Let us now imagine two of these inhabitants setting out from a common point at right angles to each other and progressing along tangents to the circular *problem area*. They stop, each at their tangential point, and turn a right angle, ostensibly to complete the other two sides of a square meeting under the centre-point of the glass hemisphere. When they compare the lengths they have travelled they will discover that the measured lengths of sides in the *problem area* are approximately 1.57 times as long as the sides of the square in the *Euclidean area* of their world. They would thereupon establish a complete map of this interesting part of their world, and either introduce the concept of a varying universal force that affects the length of rigid bodies, -(and they could establish a continuous mathematical function for this dependent on coordinate position)-, or a visionary mathematician could conceive of a third spatial dimension and explain that this part of the surface actually had a different geometry, - i.e. spherical. Note that in the

subsequent use to which they put either of these concepts, the practical outcome would be the same. Reichenbach would aver that the conversion of the formula for length distortion into the geometrical concept of spherical geometry is to be preferred, because the mysterious factor affecting length is removed from consideration.

It is preferable to suspend judgment on which description is to be preferred until other factors have been considered. Let us presume that the inhabitants resort to surveying their world with theodolites, that is that they introduce a light metric. We shall presume that light is unaffected by the projected force from the transparent surface above. The basic light geometry, without reference to measured length, will be consistent with a Euclidean world. Given this apparent discrepancy with the geometry based on physical measurement, the inhabitants would establish an independent spatial metric based on the velocity of light and a standard clock. The conclusion from this would support the diagnosis that the geometry is Euclidean, but that physical objects suffer dimensional distortion in one part of their world. An alternative explanation which accepted the spherical geometry, would necessarily conclude that either light accelerates on the slope of the hemispherical hump, or that clocks slowed in the same area. We would thus introduce the hypothesis of universal forces into the physical geometry that had been selected to eliminate them. Reichenbach did not pursue his exploration to this point, so we have no judgment from him. The reaction to alternative interpretations is to select the most useable, which would be a vindication of Conventionalism.

Reichenbach, having examined the bases of the metrics employed by the Special Theory of Relativity, proceeds to examine and elaborate on the results of the Theory. He explores the Minkowski representation of the space-time manifold as a four-dimensional space, and he demonstrates that if the Lorentz transformation is applied to the metric based on rigid rods and clocks, then the results are entirely consistent with those obtained from "light-geometry". Reichenbach is essentially an engineer, drawing out and elucidating the conclusions achievable from Einstein, and he examines the apparent paradoxes associated with clock retardation and length contraction of relatively moving bodies. He compares length contraction as explained by each of Lorentz and Einstein, and although he designates the Lorentz version as a "*real difference*", he points out that Einstein's version is not "*an apparent difference*" but -

*results from a difference in the conditions of measurement*

(Reichenbach [1958], 197)

In his final section of PST, Reichenbach elucidates the

conclusions of the General Theory of Relativity. In his subsequent analysis he draws the conclusion that in a static gravitational field, (as opposed to the gravitation-free inertial fields he has considered in relation to the Special Theory), the geometrical consequences of his matter-geometry (i.e. unit rods and clocks) do not correlate with the geometrical consequences of his light-geometry. Furthermore, in a varying gravitational field, the definition of simultaneity is affected by the dependence of light velocity on varying gravitational properties, which in turn has consequences for measures of length and time. We thus have anomalies like

Two rods equally long when compared at one place  
are no longer equally long when they are apart

Reichenbach therefore draws the paradoxical conclusion

The coupling of geometry and gravitation that follows from the theory of relativity has therefore a peculiar consequence. Its greatest success consisted in its explanation of geometry, in which it revealed the behaviour of measuring instruments as an effect of a gravitational field. But this conception subjects geometry to the variability of gravitational phenomena, and geometry loses its definiteness in fields in which the adjustment of measuring instruments is not uniform.  
(Reichenbach [1958], 265)

In such circumstances the physicist must work within finite spatial and temporal regions, where, because finite spatial domains of any topological structure are mappable onto Euclidean space, it is possible to establish a topological order. Under these circumstances, spatial and temporal ordering is possible only through the demand (coordinative definition) that we make for causal ordering

*not time order alone, but the combined space-time order reveals itself as the ordering schema governing causal chains and thus as the expression of the causal structure of the universe. ... The system of causal ordering relations, independent of any metric, presents therefore the most general type of physical geometry ... If rigidity and uniformity were to disappear, the causal chain would still remain as a type of order.*

(Reichenbach [1958], 268)

Reichenbach's final conclusion in PST is a reaffirmation of his empiricism -

*The reality of space and time ... is somewhat obscured by the appearance of an element of arbitrariness in the choice of the description.*



But in showing that the arbitrariness pertains to coordinative definitions we could make a precise statement about the empirical component of all space-time descriptions. ... Mathematical space is a *conceptual structure*, and as such *ideal*. Physics has the task of coordinating one of these mathematical structures to reality. ... physics makes statements about reality, and it has been our aim to free the objective core of these assertions from the subjective additions introduced through the arbitrariness in the choice of the description.

(Reichenbach [1958], 287)

It is apposite to review Reichenbach's achievements in PST. His purpose, as indicated in his Introduction, is to provide a comprehensive analysis of the epistemology of space and time in the light of developments in science up to that time, and particularly consequent to Einstein's Theory of Relativity. He acknowledges that the last comprehensive analysis of space and time based on a full comprehension of contemporary physics was by Kant in the Critique of Pure Reason.

In RAK he had stated that his dissatisfaction with Kant's analysis lay in Kant's belief and statement of method that the approach to a study of scientific knowledge must be based on the principles of reason, and consequent to that Kant's presumption that the bases of knowledge - a-priori synthetic judgments - were effectively immutable. It is perhaps pertinent to assess Kant's work using Reichenbach's own categories of "context of discovery" and "context of justification". Certainly, Kant, in his justification of the Critique of Pure Reason, appeals to a schema of Aristotelian logic, that is rightly open to criticism by Reichenbach as a suitable system for analysis of scientific knowledge. Kant's context of discovery, through which he subjects concepts to exhaustive analysis, is, however, the approach of the scientist/engineer who worries over all possible ramifications. Reichenbach's approach in PST is very similar, excepting that he makes no appeal to an external system for justification of his method.

His dissatisfaction with Kant's concept of an immutable a-priori led him to reject the relevance of Kant's analysis to twentieth century science, and yet his work accepts the Kantian axiom that knowledge is derived by *imposing* form on empirical content. He is unsullied by the methods of classical empiricism or of logical positivism with the primacy they give to unstructured perceptions. For Reichenbach, there is an independent world presented to us, which we come to terms with through a scheme of concepts that shape the presentations in a form that is useable. Thus although he rejects Kant's concept of the a-priori, he replaces this with a system of coordinative definitions. These

are the presuppositions we impose on experience. In PST he seeks the coordinative definitions requisite for us to handle the spatial and temporal concepts of post-relativistic physics. In RAK he had dismissed Kant's transcendental method as being misguided, criticising that Kant should have looked to the substance of knowledge rather than to the logic, and yet in PST he seeks out the necessary coordinative definitions for space and time by appeal to their structural logic rather than by analysing knowledge of spatial and temporal properties.

He approaches the subject with the Kantian method, but he enlarges the method by pursuing the criticisms he made in RAK; - "How can we determine that a particular set of coordinative definitions is the most appropriate?" and "Is a unique coordination in fact always possible?". The answer that he provides to the first of these questions is in effect a direct criticism of Lorentz' attempts to reconcile Electromagnetic Theory with the Michelson-Morley result of the constancy of velocity of light, - we must provide explanations of empirical phenomena without recourse to *universal forces*.

Carnap, in his Introductory Remarks to the English Edition of PST, draws attention to this "fruitful idea" of Reichenbach's, and comments

If this principle is accepted, the arbitrariness in the choice of a measuring procedure is avoided and the question of the geometrical structure of physical space has a unique answer, to be determined by physical measurements.

Reichenbach regarded the coordinative definitions we apply as quite arbitrary, unlike Kant who claimed necessity for his specific a-priori concepts. In their application, however, we may find that physical phenomena are subject to universal forces, - as Lorentz did with his reconciliation of the Michelson-Morley experiment. Reichenbach's response to the presence of universal forces is that this is the outcome of an inappropriate system of coordinative definitions. In the Lorentz case this is the definition that a moving rod should give the same length measure against a reference frame at rest irrespective of its relative velocity. Reichenbach therefore generalises his coordinative definitions to remove the anomaly of universal forces. Despite this modification, however, Reichenbach's definitions are still essentially arbitrary and therefore not necessarily a unique set, - as he demonstrates for inertial reference systems where light-geometry axioms provide the same outcome as matter-geometry axioms. Given a particular set of definitions, a unique empirical description will result once universal forces are eliminated. Reichenbach's dispute with Kant is therefore, not that we need to impose form on experience through basic coordinations, but that there is no necessity for a particular set of coordinations provided that they yield a description of experience without recourse to universal forces.

When he studies the geometry of complex gravitational systems he discovers that his basic systems of measure are no longer appropriate, and that universal force fields are necessary to interpret local geometry. He acknowledges that his definitions of spatial and temporal measurement are no longer appropriate, and can offer only one of his coordinative definitions to guide the physicist, - namely causal connection. It would appear that with this admission, Kant is finally vindicated. Kant's thesis is that empirical knowledge demands causal connection; that without it we lose the unity of the space-time manifold, and therefore causal connection must be a feature of our empirical knowledge. Reichenbach, in fact, is not so dogmatic; he makes no claim that we must always find causal connection, although he offers no advice on how to proceed in its absence. Reichenbach is prepared to accept that the empirical world may display instances of lack of causal order.

Hilary Putnam observes that Reichenbach gives a unique position to the principle of causal connection in his apparently Conventionalist approach to Space and Time,

With respect to the metric, as opposed to the topology, of spacetime, Reichenbach's position was a sophisticated form of conventionalism. The world as it is in itself does not have a unique metric; it does, however, have a unique topology, and this is defined ... in terms of the causal relations (and ultimately in terms of the statistical relations) between the events of which the world consists.

(Putnam [1991], 69)

We should not move on from PST without referring to Reichenbach's analysis of visualising non-Euclidean space. His treatment has an engineer's thoroughness, and in particular his identification of the way in which we use diagrammatic representation as a means of resolving problems, lends insight to the compulsion we have to cling to Euclidean concepts. As he points out, diagrams in a two-dimensional plane are subject to the logic of the plane surface, - i.e. of Euclid -, which is a restricted system of logic, and hence visualisation tends to be locked into this restricted system. Visualisation of other geometrical spaces therefore requires us to accommodate different aids to problem solving.

## Chapter 6

### REICHENBACH ON PROBABILITY, AND EXPERIENCE AND PREDICTION

After completing The Philosophy of Space and Time in 1928, Reichenbach returned to his preoccupation with the application of probabilistic concepts to science. His one subsequent major publication on the philosophy of space and time is The Direction of Time, which was published posthumously and restates many of the arguments of PST, but extends the scope with a probabilistic consideration of entropy and quantum mechanics.

Experience and Prediction was published in 1938 whilst he was Professor at the University of Istanbul, with the intention, as described in his Preface, of -

It is the intention of this book to show the fundamental place which is occupied in the system of knowledge by this concept [probability] and to point out the consequences involved in a consideration of the probability character of knowledge.

(Reichenbach [1938], vi)

Whilst at school, Reichenbach had been impressed by the statistical methods employed by Boltzmann in arriving at the thermodynamic properties of gases. This was possibly the trigger that stimulated his interest in the application of probabilistic considerations to the study of empirical events. Before proceeding with an analysis of Reichenbach's work in this area it is helpful to look specifically at Boltzmann's work.

#### Boltzmann's Theory

Whilst Professor of Mathematical Physics at the University of Graz, Ludwig Boltzmann, in 1872, published what has since been called the Boltzmann Equation. Boltzmann's problem was to accommodate the atomic theory of matter with the thermodynamic behaviour of gases. At this time, emerging atomic theory was very much the property of chemistry, and it had not been comprehensively introduced to account for the physical properties of matter. It was Boltzmann's objective to remedy this.

Boltzmann began by considering a gas as a collection of a very large number of molecules moving freely within a container at high velocities, and he elected to treat this as a statistical aggregate. The molecules themselves were considered as moving freely subject to the constraints of (Newtonian) mechanics. If a

snapshot of the molecular assembly could be taken, then the positions and momenta of the molecules would conform to a statistical distribution; that is there would be a probability function for the number of molecules in any sub-space of the system, and this would also apply to the number of molecules whose momenta were within particular limits. Boltzmann's hypothesis was that the probability function would be Gaussian, and would correspond to that derived by James Clerk Maxwell, dependent only on the absolute temperature and energy of the gas as a whole. From this basis Boltzmann is able to calculate properties for the volume of gas as a whole, and able to agree with well-established results, including the Gas Law -

$$PV = NkT$$

where P is pressure , V is volume , T is Abs. Temperature, N is Avogadro's number , and k is now Boltzmann's constant

Boltzmann, however, had also wished to reconcile the Second Law of Thermodynamics with classical physics. The Second Law asserts that the Entropy of an isolated system increases as time progresses, that is that differences in kinetic energy between parts of the system diminish. Another way of expressing the Law is that in a dynamic situation recognisable order can degrade into random motion, whereas the reverse cannot apply. Thus the Second Law represents thermodynamic processes as irreversible.

This concept does not appear to be reconcilable with Newtonian mechanics, which doesn't specify a preferred temporal direction for dynamic systems. For example, if it were possible to film the molecules of a gas bouncing around in their container, and then the film was played backwards, either direction of playing would be consistent with Newtonian mechanical principles; so that if entropy happened to increase over a specific time interval then it would decrease in this interval in the reversed film.

By approaching the molecular aggregate statistically, however, the most probable states of the aggregate are those which are most likely to be measured, and these are those of higher entropy. This corresponds with the expectation that the most probable distribution of molecules in a given space is the most uniform, - that we would expect the space to be fairly evenly filled by the molecules. Thus, whatever the initial configuration of the molecules, subsequent states will most probably display uniform distribution of spatial position and momentum; - that is of higher entropy. Thus Boltzmann has modelled an irreversible process in accordance with the Second Law of Thermodynamics and in apparent conflict with the reversibility of Newtonian mechanics. This therefore provides an apparent paradox of visualising reversible mechanical events yielding irreversible consequences. We are, however, accustomed to the fact of the mixing process that the Second Law effectively represents; and Boltzmann gives an example of this

in an address to the Imperial Academy of Science in 1886, (Boltzmann [1974], 13-32). Imagine a collection of white and black billiard balls moving randomly in a finite space, with initially all the white balls in one half and all the black in the other. As time progresses we would expect to see increasing intermingling of the black and white balls, and wouldn't expect to see at any subsequent instant the configuration of colour that we had initially.

This paradox fascinated Reichenbach and provoked him to regard the application of the probability calculus towards establishing empirical laws, as having a justification in its own right. He returned to this issue throughout his philosophical career.

In some respects the analogies with thinking in terms of a collection of black and white billiard balls, or even of taking a film of moving molecules, are quite misleading to an understanding of the concepts of molecules in a volume of gas.

23

For example two grams of hydrogen gas contain  $6 \times 10^{23}$  molecules. This is a number that is inconceivable in everyday terms. In statistical terms, after moving from an initial given configuration (as with withdrawing a partition dividing two dissimilar gases, or gases of different temperatures), the variation from predicted values for the equilibrium of the resultant gas would be within an order of one part in  $10^{11}$  to the power 11, - miniscule and effectively undetectable.

If it were possible, however, to follow through a collection of particles moving in a closed space on Newtonian principles, and a large series of random snapshots were taken of the whole collection to measure position or momentum, then the statistical distributions of these measurements would conform to the Boltzmann statistical model. The smaller the number of particles, then, according to the probability calculus, the greater the proportional scatter of the distribution, but on the frequency scale applicable to molecules in gases the distribution would demonstrate virtually no measureable scatter.

The apparent paradox only begins to dissolve when the whole context of the situation is examined. Considering the reversibility of Newtonian mechanics, there is a temptation to ask why the initial boundary conditions should not recur; why shouldn't diffused gases return to their initial separated condition at some stage? There is of course a probability that this might occur, but it is so small that allowed time to see it happen could be longer than the present history of the Universe, and it would be necessary to capture the measurement of the situation at the precise time, - before continuing motion re-mixed the molecules. Odd distributions will occur instantaneously in any dynamic system of particles moving according to Newtonian principles; the problem for the observer of the real situation is in capturing the measurement at the precise instant. Random observation will only confirm that the

Second Law of Thermodynamics applies.

The paradox of reconciling the Second Law with reversible mechanics seems to arise from a confusion of conception of the actual situation as it can be observed or measured. We create an initial configuration that we impose on the experimental situation (initial boundary conditions), such as two different gases separated by a partition, and then release the system to the free play of dynamics, - as in withdrawing the partition. We must not then overlook the practicalities of the observing and measuring process itself, including the concept of an instantaneous measure of a dynamic aggregate. We may have within the system in its subsequent development what might be regarded as instantaneous states, which persist through only the smallest of time intervals, where what we would regard as an improbable distribution applies. The likelihood of such a state coinciding with an "observation" of the system is however also improbable, and observations taken randomly will only bear out the statistical predictions as applied in Boltzmann's analysis. It could perhaps be objected, when considering the situation of a molecular aggregate, that if even instantaneous states of order occur then these should make themselves apparent. For example in a bath of water at 80 Centigrade we could expect to observe occasional local pockets of boiling water. This could be countered by examining statistical likelihoods, but given the possibility of a localised molecular collection with individual energies equivalent to that required for boiling, we require some temporal persistence for it to be observed at the macroscopic level. The possibility of the state being achieved is indeed of very low probability, but extending this probability to allow for any degree of persistence in time to allow the effect to be noticeable takes us beyond the statistical possibility of its practicable achievement. The effects of molecular aggregates at the macroscopic level can only present themselves as persisting through temporal intervals, and therefore we can only observe the effects of the most probable arrangement,- that is as though the space is evenly filled with molecules moving with the average molecular energy content.

Boltzmann himself, in an article in Nature 51 in 1895, entitled "On Certain Questions of the Theory of Gases", believed that "The Second Law [of Thermodynamics] can never be proved mathematically by means of the equations of dynamics alone", (Boltzmann [1974], 204). Boltzmann concluded this article by examining the implications of this application of statistical mechanics to the totality of the Universe -

We assume that the whole universe is, and rests for ever, in thermal equilibrium. The probability that one (only one) part of the universe is in a certain state, is the smaller the further this state is from thermal equilibrium; but this probability is greater, the greater the universe

itself is. If we assume the universe great enough we can make the probability of one relatively small part being in any given state ...as great as we please. We can also make the probability great that, though the whole universe is in thermal equilibrium, our world is in its present state .

(Boltzmann [1974], 208,209)

In a lecture "On Statistical Mechanics" given to the Scientific Congress in St Louis in 1904, Boltzmann develops the idea that in a macroscopic universe, relatively microscopic regions within it will show apparent decreases of entropy.

If only, therefore we imagine the world as large enough, then according to the calculus of probability there will supervene now here now there regions of the dimensions of the system of the fixed stars that have quite an improbable distribution of states. Both during their formation and during their dissolution the temporal course will be uni-directional; if there are intelligent beings in such a location they must gain the same impression of time as we do, although the temporal course of the universe as a whole is not uni-directional.

(Boltzmann [1974], 74)

Thus Boltzmann has also indicated a correspondence between an increase of entropy with an objective determination of the direction of time. This idea is later developed by Reichenbach in his book The Direction of Time.

### Reichenbach and Statistical Analysis

Reichenbach's first publications on Probability were in 1920 with the appearance of "The Physical Presuppositions of the Calculus of Probability" in Zeitschrift für Physik 2 No2 (150-171), and "A Philosophical Critique of the Probability Calculus" in Die Naturwissenschaften 8 No8 (146-153). In the first of these papers he determines to provide an objective basis for probability

there actually exist objective states of affairs that can be exhaustively described by means of probability laws (Reichenbach [1978],v.2, 296)

He then proceeds to develop his theory of objective probability as a limiting frequency from a potentially infinite series of occurrences

We will therefore define as equiprobable those cases that, with repetition, converge more and

more closely toward an equal number of  
realisations

(Reichenbach [1978],v.2, 296)

In the second paper he considers the epistemological significance of giving objective significance to probability measures of empirical regularity. This work relates entirely to his Kantian grounding, and his method is

the investigation of the compatibility between this hypothesis and the principle of causality in order to present the possibility of the laws of probability. Only afterwards will we turn to a demonstration of their necessity for physical knowledge.

(Reichenbach [1978],v.2, 314)

Like Poincaré previously, Reichenbach takes as his example the rotation of a roulette wheel as an event that can be repeated and provide measureable results. Despite a study of many of the causal factors at work, and attempts to control them, the roulette wheel will not stop each time in exactly the same position. This is a feature of the physical world; it is not possible to reproduce exactly all potential causal determinants. We will obtain a continuous frequency distribution of discrepancies from the mean probable total angle turned by the wheel. This distribution represents the effects of the variations in initial conditions for which we have made no causal allowance. Thus, in representing factors for which no causal connection has been made with the outcome, the distribution offers no contradiction to the causal principle. This is not a denial that causal factors may be at work in determining the discrepancies, but it is an independent objective fact that discrepancies that do occur will conform to a continuous frequency distribution. Reichenbach thereby demonstrates that the principle of probability can co-exist with the principle of causality.

In looking at the necessity of the probability principle for empirical knowledge, Reichenbach distinguishes between judgments in mathematics and logic as "stipulative judgments" and judgments of physical events as "reality judgments". Using the concept elucidated in the same year in RAK, of "coordinations", he describes how we can only coordinate concepts to empirical objects, whereas in mathematics we necessarily must completely define and specify the concepts we are using. A "reality judgment" therefore relates to objects which are only ostensibly defined, but in incorporating them within a scientific system we are obliged to coordinate these ostensive concepts with mathematical structures. We are making idealised approximations. Thus, in relating the Earth's gravitational constant to Newton's universal constant, we idealise the Earth as a spherical mass. Even if we attempt to be more precise and allow for the flattening of the poles, we are still making approximate idealisations; it is physically impossible to make

full allowance for every wrinkle on the Earth, - and in fact quite logically impossible to have a perfect mathematical realisation of a physical object. Thus, any conclusion we form of a law-like nature about physical objects, includes the notion that this is an idealised approximation. Any measure we make of a physical constant is therefore an approximation. Thus, a demonstration of causal connection makes implicit allowance for the approximation of actual measurement and elimination of disturbing factors. In formulating empirical laws, we are therefore presupposing that objective indeterminacy conforms to the principle of probability.

Expanding the Kantian idea, we must now declare the law of distribution to be an a-priori principle of knowledge in just this sense. For it is likewise a necessary presupposition of knowledge, and we may say: If physical knowledge exists, then the principle of distribution is valid.

(Reichenbach [1978], v.2, 325)

Reichenbach's argument for accepting the principle of objective probability is cogent, and yet it is not immediately clear whether or not it is a significant contribution to the work of Kant and Cassirer, or whether it has anything like the significance of his own work on "coordinative definitions". Imagining the setting of Reichenbach in his late teens and early twenties, we have the impression of an ambitious young engineer, bursting with enthusiasm for physical explanation of the world, confident in his capability in mathematics to master any developments in physics, and with a deeply-held belief that understanding must come through epistemology, and particularly through the inspiration of Kant. He sees the shortcomings in Kant, due largely to the physics and mathematics of the Eighteenth Century, and of course he will have worked through some of these with the scholarly Cassirer. It is understandable that, with his own abilities and understanding of post-Kantian physics and mathematics, he should want to make his own mark on epistemology; a real scientist providing a proper revision of the physics of Kant, rather than revision coming from the scholars of the neo-Kantian tradition. At school he encountered Boltzmann's statistical treatment of molecular collections, and the application of probabilistic reasoning to other aspects of physics would have appealed to him. Did he, as a consequence, distort the significance of objective probability, or has he made a real reinforcement of Kant's basic a-priori principles? The imagery that suggests itself, is of the great man Kant sitting at his desk writing his Critique, with his enthusiastic young son tugging eagerly at his coat-tails, being helpful, and pointing to a small ink-blot on the paper.

We are most aware of the problem of objective indeterminacy when we come to make measurements, which is generally in the scientific realm. Reichenbach, in his analysis, specifies two sources, - the effects of causal influences not accounted for,

and the discrepancy of empirical reality from our mathematical model. It is objective indeterminacy that is under scrutiny, so we can ignore variability associated with measurement. We must accept, with Reichenbach, that it is not possible in any physical situation to make allowance for all possible causal factors, - it is a physical impossibility. It may be, of course, that the precision of measurement we require makes generous allowance for all possible causal disturbances to the measuring process. For example, if I read my speedometer on the motorway, and it displays 60 m.p.h., I'm perfectly satisfied that all the potential causes of discrepancy between "actual" and "recorded" are insufficient to condemn me as a law-breaker. If the speedometer is displaying 70 m.p.h. and a police-car is following me closely, then it is likely to occur to me that the calibration of my speedometer was effected in England and not Switzerland, and that it is at least a month since I checked my tyre pressure: a prudent 65 m.p.h. is recommended. In such instances where we recognise that we haven't taken account of all influences, we accept that there is a continuous distribution of discrepancy, but we fully understand that this is the effect of causal influences. The a-priori principle, or coordinative definition, we employ, is that of causal connection. We expect a probability distribution because of our acceptance that the physical world is causally connected. We are not invoking another principle of uniform indeterminacy.

Although, when analysing the epistemology of the probability distribution, Reichenbach considered the Roulette-wheel, and hence discrepancies due to unidentified causes, his argument for inclusion of the principle as a-priori is based on the relationship between the ideal mathematical models employed by science with their imperfect physical correspondences. He is effectively claiming that we make allowance for the fact that what's out there is a little bit more awkward than our representations on bits of paper in diagrams or mathematical models, but that we are secure in this because we understand that the discrepancy behaves in a uniform manner. Our security, however, surely comes from our acceptance of the principle that causal connection operates in the physical world, and provided that we have taken into account the major influences, then we expect small discrepancies between model and actual, - due to the causal factors that we have ignored. We also expect these discrepancies to conform to a continuous distribution due to the multiplicative effects of a very large number of factors of decreasing size. Thus having modelled the Earth as a sphere, and made due allowance for the flattening at the poles, I give some consideration to the uneven surface distribution of land and water and then choose to ignore this, and I certainly don't even consider the distribution of populations, or of plant-life, or that the rabbit population of Australia is decreasing. Because the physical world is causally ordered, we are enabled to make models that are useful. There is no independent a-priori principle of probability distribution that we apply, only a principle of causal connectedness. Reichenbach is correct to

illuminate how probabilistic considerations enter into all measurement of physical things, but he is misguided in raising this to a-priori status.

### Experience and Prediction

EP begins by setting out the task of epistemology, which is defined as "the rational reconstruction of the context of justification [of scientific knowledge]". Reichenbach uses the designation "context of justification", as distinct from the "context of discovery", as a means of distinguishing the systematic presentation of an idea as an integral component of science. The rational reconstruction must include an analysis of those "decisions" that directly affect the form in which scientific knowledge is presented. The "decisions" referred to in this context are the "coordinative definitions" of PST and RAK, and it is noteworthy that Reichenbach has changed his nomenclature. He does indicate that it is not always easy to discern where a "decision" actually has to be made, - as with Einstein's discovery of the relativity of simultaneity. He also wishes to examine fully what is entailed by such specific "decisions", to avoid the misconceptions of "extreme Conventionalism". His criticism of Conventionalism, as defined by Poincaré, is that, although it has served a useful function in elucidating the volitional aspects of knowledge, it has not sufficiently pursued the logical interconnections and consequences through to the objective aspects of knowledge.

Analysis begins with a review of the function of language in science. This begins with "meaning"-

Meaning is a function which symbols acquire by  
being put into a certain correspondence with facts.  
(Reichenbach [1938], 17)

Thus Reichenbach is maintaining consistency with his earlier ostensive definitions of empirical concepts. Although "meaning" can be defined in this way, he affirms that it is only propositions which can express meaning. Reichenbach gives three properties to propositions; - "meaning", "truth", and "weight". It is necessary to be clear how Reichenbach intends to use the properties of "truth" and "weight". A proposition can only be "true" or "false" in relation to the facts. Thus the statement "Julius Caesar was in Britain." is either true or false. With a historical statement of this kind, we may not be certain which value to give the proposition, but as a matter of fact there is no doubt that it is either true or false. On the other hand, given the imperfect state of our knowledge, we may wish to attach a "weight" to the proposition, and this weighting may change as new facts are obtained. On the other hand, the notion of weighting is redundant if we are dealing with immediate facts like "It is raining outside."

Truth-value , therefore, is an absolute predicate  
of propositions, and weight a relative predicate.  
(Reichenbach [1938], 27)

Introduction of the "truth" concept introduces us to a consideration of verifiability and the Positivist interpretation "a proposition has meaning if, and only if, it is verifiable as true or false". Reichenbach wishes to add a second definition in order to secure the essence of "meaning" rather than leaving the definition only dependent on truth-value; "two sentences have the same meaning if they obtain the same determination as true or false by every possible observation", (Reichenbach [1938], 31).

Reichenbach thus sets off on an analysis of the possibility of verification, which is crucial to his epistemology and provides a sharp distinction of his empiricism from logical positivism. True to his patient method he carefully examines each concept that occurs. He begins with the "possibility" of verification, and considers three standpoints, - technical, physical, and logical. The most restrictive category is that of technical possibility, in that for example it is not technically possible (now) to specify the detailed structure of a human chromosome, although it is physically possible. Likewise, logical possibility is the broadest category, in that for example it is logically possible to assess if life exists in a galaxy in a remote part of the universe, but it is physically impossible to check this. Thus we have to be clear about how a process of verifiability is to be applied. When these distinctions in types of possibility are applied to the definition of "same meaning", they also apply differently, as in the example Reichenbach gives-

It is physically impossible to find facts which confirm the statement, "A moves towards B", and do not confirm the statement, "B moves towards A", - this is the content of Einstein's principle of relativity. ... (but) it is logically possible to imagine a world in which the principle of relativity does not hold.

(Reichenbach [1938], 44,45)

Reichenbach therefore looks towards Positivism and Pragmatism for further guidance. He introduces the concept of *indirect verification*, that is of *indirect propositions* which can be converted into an equivalent series of *direct propositions*, - and direct statements are capable of verification by direct observation or measurement. Reichenbach rejects that it is possible in all cases that indirect propositions can be converted to a series of direct observational propositions. For example, the statement, "The temperature at the centre of the Sun is forty million degrees Centigrade", can not be directly verified due to our physical limitations, although it is possible to make this statement and it has a meaning for a

physicist in a verifiable sense. The Positivist contention would be that the statement is equivalent to a chain of reasoning based on direct observation, and including for example statements about the measurement of intensity of heat from the Sun at the surface of the Earth, and measures of mass and distance of the Sun. Reichenbach's rejection of this is that such an indirect proposition contains elements that are generalisations and inductive reasoning, and is always more than a finite set of simple observational propositions. An indirect proposition of this type contains probabilistic implications.

We are forced, therefore, to make a decision:  
either to renounce indirect sentences and consider  
them as meaningless or to renounce absolute  
verifiability as the criterion of meaning.

(Reichenbach [1938], 53)

Reichenbach therefore recasts his two definitions of meaning in terms of "weight", rather than "truth". He also restricts their applicability to "physical possibility" as opposed to "logical possibility", because -

those propositions which demanded logical possibility  
for obtaining meaning within the truth theory receive  
meaning within the probability theory as indirect  
propositions.

(Reichenbach [1938], 54)

His two definitions of meaning are therefore-

a proposition has meaning if it is possible to  
determine a weight, i.e., a degree of probability  
for the proposition.

two sentences have the same meaning if they obtain  
the same weight, or degree of probability, by every  
possible observation.

(Reichenbach [1938], 54)

This transfer from truth to weight has resolved a problem of positivism which offers a narrower definition of "meaning" than is accepted in current use. Reichenbach has allowed that a proposition has meaning if we can make a physical appraisal of its validity as opposed to an absolute judgment of it. The positivist reply could be that "We have no right to make statements if we are unsure of their truth, unless we include a probabilistic qualification within them, which is then verifiable". This is a valid objection to Reichenbach, although the consequence would be to rephrase all scientific conclusions based on inductive reasoning. Reichenbach's definition is preferred, because in practice its consequences are simpler.

Reichenbach is concerned to relate his redefinitions of "meaning" in a positive way to both Positivists and Pragmatists,

but first offers sharp criticism of Wittgenstein's radicalism. Wittgenstein had maintained that we have no knowledge of future events, and therefore, although they are verifiable in the sense that we can wait to test them, we cannot emphatically give such propositions a truth-value now. Reichenbach is critical of this "intellectual asceticism which has suppressed all understanding of the 'bridging' task of science - the task of constructing a bridge from the known to the unknown, from the past to the future", (Reichenbach [1938], 75). Reichenbach wants propositions that he can "use", and he approves of Carnap's "degree of confirmation". He also offers to Pragmatism a recasting, - "there is as much meaning in a proposition as can be utilised for action", (Reichenbach [1938], 80).

Reichenbach continues his analysis of "meaning" of a concept, and wishes to contrast his position with a critical analysis of positivism. He creates an imaginary world for his reader to illustrate more clearly the point he wishes to make, namely that

-  
there is a surplus meaning in the statement  
about the existence of external things.

(Reichenbach [1938], 104)

In other words, a statement about an empirical object always contains more meaning than does a finite collection of statements of subjective impressions.

Reichenbach gives us an image of a world -

in which the whole of mankind is imprisoned in a huge cube, the walls of which are made of sheets of white cloth, translucent as the screen of a cinema but not permeable by direct light rays. Outside this cube there live birds, the shadows of which are projected on the ceiling of the cube by the sun rays;

(Reichenbach [1938], 115,116)

The men inside the cube can't directly see the birds, only their shadows on the ceiling, and, because there is a system of mirrors outside the cube, they can also see shadows on one of the vertical walls. We are invited to enter this world and observe what the inhabitants make of it. The initial conclusion will be that they are inhabiting a cube-shaped world, on whose external walls black dots move. Reichenbach suggests that at some stage a "Copernicus" will emerge who will correlate the shapes moving on the ceiling with the movements on the vertical wall. Thus if a distinctive shape, - for example with a long "neck"-, moves across the ceiling, then a similar distinctive shape will move across the wall. Also, for example, if two shapes on the ceiling appear to fight, there will be a simultaneous fight between similar shapes on the wall. Copernicus will then suggest a novel theory that -

the strange correspondence .. cannot be a matter of chance .. but effects caused by one individual thing situated outside the cube within free space. He calls these things "birds" and says that these are animals flying outside the cube, .. ,having an existence of their own, and that the black spots are nothing but shadows.

(Reichenbach [1938], 118)

Reichenbach then sets out the criticism of this theory that would be made by the Positivists.

all that is said about your birds is inferred from the black dots and is therefore equivalent to statements about the dots.

Thus although the correspondence observed between the dots on the two surfaces is a discovery, no new content is added by postulating independent entities outside the cubical world which is unavailable to the inhabitants. As it is impossible to make an external verification, no new meaning is added by the hypothesis of external objects.

Reichenbach interprets this refutation by Positivists as due to their holding to absolute verifiability.

It is conclusive if we accept nothing but truth and falsehood as predicates of propositions; but it is no longer so if we introduce intermediate values - if we introduce the predicate of weight.

(Reichenbach [1938], 120)

Reichenbach maintains, however, that a physicist would be inclined to accept "Copernicus'" theory that it is highly improbable that correlations could occur between the shadow activity on the ceiling and that on the wall, unless they were each the consequences of activity of some objects, - the "birds". In other words the physicist would be looking for the common cause of these correlated effects. He therefore draws the conclusion that -

This means that the physicist insists on the surplus meaning of his interpretation not because it has logical meaning but because it has physical probability meaning.

(Reichenbach [1938], 121)

Reichenbach's contention is that if "weight" value considerations rather than "truth" value considerations are applied to the views of each of the Positivists and Copernicus, then the Copernican view has greater weight than the view which refuses to concede the possible background causal connection. Thus although in terms of absolute verifiability and

truth-value, the hypothesis of the birds is a meaningless addition to the Positivist analysis, in terms of physical probability and weight the hypothesis of the birds gives additional meaning to the facts.

Reichenbach concedes that the Positivist is quite entitled to modify his position to accept the correlated behaviour on wall and ceiling without adding to it the hypothesis of the birds. In other words he would be accepting a causal connection between the patterns on wall and ceiling. He would thus have the same predictive potential from his theory as Copernicus would have from his. Reichenbach, however, insists that Copernicus' view still registers a higher probability, - weight -, than does the Positivist's view in that he provides a well-understood causal mechanism for its realisation, - i.e. light projecting shadows from objects -; whereas the Positivist will offer no such hypothesis which involves activity in an inaccessible domain.

The probability conception of meaning, therefore, allows us to distinguish between theories which furnish, for all observable consequences of a certain domain, the same weight, even if nothing but facts of this domain are at our disposal for the probability inferences.

(Reichenbach [1938], 124)

Reichenbach's contention, therefore, is that a theory about the world, or a concept used in its description, draws its significance from the degree to which it is integrated with our understanding of the overall causal structure of physical reality. His position is akin to that of Cassirer, who interpreted the development of knowledge in terms of its "progressive unification".

Reichenbach does not rest his case against the inadequacy of Positivism, but wishes to pursue the chimera of "absolute verification". He therefore supposes that the rules of the cubical world are broken and it becomes possible to penetrate the ceiling and look out. In seeing the birds, one might suppose, the hypothesis of Copernicus would be upheld. Reichenbach, however, offers us a theory that might explain the birds as optical images produced by light coming from the shadows on the wall or ceiling, and from what you see this could not be dismissed as false, but only "improbable". Reichenbach therefore clearly makes the point that there is no such thing as a "direct observation" of the facts, only -

an increase in weight for the theory of the birds  
but not a verification.

(Reichenbach [1938], 125)

Reichenbach has demonstrated that the methods of Physics employ statements whose meaning is based on definitions of weight or higher physical probability. In particular -

Considering observations of the physically inaccessible domain, we do not obtain facts which verify statements concerning things situated there but only facts which confer higher weight to such statements. But then there is only a difference of degree with respect to statements based on facts observed within the accessible domain.

(Reichenbach [1938], 127)

His conclusion is -

This *overreaching* character of probability inferences is the basic method of the knowledge of nature.

(Reichenbach [1938], 127)

Reichenbach makes scant reference to Kant in EP, but his refutation of the Positivist concept of "meaning" is based entirely on the Kantian premiss that knowledge must be given form, and is not directly given in observations. He is not taking issue with Conventionalism in this specific analysis, but the implication is that a system of knowledge is preferable which provides higher "weight" to its theories, and in essence provides a more integrated structure of causal explanation.

Reichenbach continues with his examination of the distinction between "positivism" and "realism" by investigating the respective language structures that each employ, with his conclusion that they employ distinct languages, - and he credits Carnap with this observation, (Reichenbach [1938], 145). The language that a Positivist must adopt is not our normal language and would limit us in its practical usefulness, whereas -

probability meaning ... leads to an unrestricted language. This .. is a decisive argument for preferring probability meaning. .. [this] leads to the realistic language of actual science;

(Reichenbach [1938], 153)

He returns to the concept of "meaning" itself. Eight years before Wittgenstein published his Philosophical Investigations Reichenbach provides us with the concept of "meaning as function".

Propositions are tools with which we operate; all we can demand is to be able to manipulate these tools. ... Meaning is a function of propositions; it is that function which is expressed in their usefulness as instruments for our actions upon the world.

(Reichenbach [1938], 159,160)

Thus when we discuss the "meaning" of a proposition, this is not "something" that is a crystallised entity, -

"has meaning", is always to be understood in the sense of the adjectival term "is significant".

(Reichenbach [1938], 158)

Reichenbach's final refutation of the positivist concept of absolute verifiability is through an examination of statements of direct impressions. Even statements of sensation contain more than the sensation itself in that they make reference to other sensations, - they categorise. My present sensation of greenness is only expressible in relation to a wider concept of greenness; it is based on an appreciation of a potentially infinite class of green experiences; it is based on presumptions of reliability of memory; and it is based on hypotheses of consistency of judgment. A statement of impression may have great "weight", but it is not absolutely verifiable in the pure sense that positivism requires.

There is no Archimedean point of absolute certainty left to which to attach our knowledge of the world; all we have is an elastic net of probability connections floating in open space.

(Reichenbach [1938], 192)

From this point of his analysis, Reichenbach investigates how we actually set about constructing our knowledge of the world, differentiating between different classifications of facts as having different "weights". The basis of our physical knowledge comes from the "concreta" that surround us in our everyday existence. These are the objects present to us with immediate effect. It is not that we have sensory impressions of them that provides us with a secure foundation in them, but that they are reliable in an objective sense. It is from observation of these that we move on to other knowledge (inevitably of lower weight), of other less accessible concreta, and of "abstracta" and "illata". As examples of other concreta, Reichenbach illustrates with "foreign people" and "unseen machines", - things for which evidence is less direct for us than, for example, this desk and chair, but they are things of which we are fairly sure given the established trust we are enabled to build up in our sources of facts that are continually confirmed. As Reichenbach concedes, there is no clear demarcation between concreta and abstracta, and our readiness to accept abstracta is an extension of our knowledge of concrete things and is justified in its confirmed and repeated usefulness. The "illata" are a further group with no clear boundary separating them from concreta, and we need only return to the lessons of the cubical world to appreciate this. The "birds", when inaccessible to us, were what Reichenbach would define as "illata", - i.e. probability inferences -, but as he demonstrated, even when we are able to "see" them directly through a hole in the ceiling, their existence as concreta is still questionable. Objects which we infer - as for example atoms - are real objects, although their "weight" might not be as high as that of objects more immediately available to direct sensory appreciation. Thus

Reichenbach sides with Boltzmann against Mach's denial of atomic reality as "a reducible complex of concreta". We thus build up our "elastic net of probability connections" based on the most familiar objects surrounding us. Reichenbach gives us his anthropological assessment -

Our immediate world is the objective world of primitive man; ... This primitive knowledge furnishes the frame of description into which we automatically press things in seeing them.

(Reichenbach [1938], 222)

We begin with knowledge of our immediate environment, and through inferences from this open up the structure of the less accessible world, tracing through the causal connections. This is not possible on the basis of absolute certainty, but is achievable only if we employ the concept of inferring probabilistically. Thus "truth" of an objective state of affairs is only equivalent to attaching a high "weight" to it.

Reichenbach's next task is to elucidate the concept of probability that he has been using. In particular he wishes to demonstrate that the colloquial use of "probable", although seemingly distinct from the precisely defined mathematical use of a limiting frequency, has the same implicit meaning. He takes issue with Keynes and Popper, for whom the concept of probability is an order of ranking of "more" or "less" - essentially a topological consideration. He acknowledges, however, that it is possible to differentiate between the mathematical concept as a "property of events, whereas the logical concept of probability states a property of propositions", (Reichenbach [1938], 302). Reichenbach's dismissal of both the topological concept of probability and of the concept of "rational degree of expectation" is that they can't be verified except by proceeding with the idea of a potentially infinite series of trials, - and hence through the measuring procedure implied in the mathematical "limiting frequency" concept. What he must endeavour to illustrate is that the "single-case" occurrence can be incorporated within this.

Reichenbach, fulfilling his requirement of meaning as function, defines his task as -

the meaning of probability statements is to be determined in such a way that our behaviour in utilising them for action can be justified.

(Reichenbach [1938], 309)

In order to investigate the single-case instance of a probability prediction, Reichenbach introduces the concept of a "posit", - a term that had been used in a similar context by the neo-Kantian Natorp. Reichenbach likens a posit to a wager by a gambler; it is an appraisal of the likely outcome of a trial or

of a process of verification. Making posits is an integral part of an active life, it is the basis on which we make choices relevant to our wellbeing. When we make such an appraisal of the outcome of a single event, it is not done in isolation from other considerations but effectively calls on classes of similar and related instances. A posit is a subjective appraisal of an objective event, and, although this generally takes the form of an instinctive appraisal, underlying it is the statistical method that is applied to determination of objective probability. Thus a doctor's appraisal of the terminal state of a patient is based on objective recorded evidence of the outcome of people whose symptoms have been similarly categorised, together with assessment of the relevance of the specific symptoms to the illness category. Implied in such reference to established data and its use in projecting future states of affairs is the concept of the statistical limiting frequency.

Two concepts intertwine in Reichenbach's analysis of posits and weighted judgments. On one hand there is the subjective assessment of an objective state of affairs through an applied weighting, which even in a single-case assessment can be understood to be based on a statistical summary - instinctive or explicit - of previous experience or measurements. On the other hand there is the practical use to which this weighting is put, in the sense of a wager, where consideration is also given to value judgments of the consequences. Reichenbach gives the example of an assessment of  $1/4$  that a friend may arrive at the railway station, and our reaction that it is worth going to meet him on these odds as a balance of inconvenience to us of three in four wasted trips as opposed to his inconvenience of one in four unwelcomed arrivals. If the odds were  $1/100$ , however, we would not contemplate making one hundred trips to the station for only one welcoming arrival.

Reichenbach's analysis of the human predicament in being unable to be absolutely sure of the outcome of any future event is clear. It is also clear that potential outcomes are assessed on the basis of experience available to the person predicting the outcome, and that this experience is most useful if organised in a statistical manner. Such statistics relating to objective states of affairs, governed by underlying causal factors, will provide a probability based on the limiting frequency in a potentially infinite series of measurements. The subjective assessment of the individual outcome therefore utilises the concept of mathematical probability. For knowledge, where we are indifferent to the likely outcome, therefore, our posit is an assessment of objective probability, and its weight will be increased or reduced on the outcome of the single trial. As a basis for commitment, as a wager, the posit must be subjected to cost-benefit analysis. Reichenbach presents us as, actively involved in the world, continually making such posits and judgments, and even the development of knowledge itself requires that we commit ourselves to test the weight we give an outcome in order to increase the statistical level of certainty.

Reichenbach draws the analogy of a man wishing to fish in the sea -

There is no one to tell him to fish in this place. Shall he cast his net? Well, ... I should advise him to cast the net, to take the chance at least. It is preferable to try even in uncertainty than not to try and be certain of getting nothing.

(Reichenbach [1938], 363)

In discussing the issue of induction through the concept of posits, Reichenbach examines Hume's criticism. He defines induction to conform with his analysis of the probabilistic inference

*The aim of induction is to find series of events whose frequency of occurrence converges toward a limit.*

(Reichenbach [1938], 350)

Reichenbach summarises Hume's criticism of inductive inference in that we have no logical grounds for accepting it, nor does any a-posteriori demonstration add any evidence that is relevant to its logical necessity. Reichenbach, like Hume, has shown that we can have no secure objective knowledge, but he would maintain that we need to get on with our lives, and to this end knowledge is a utilisable basis for action. Knowledge of objective events is not a secure logical construct, but is needed "for the purpose of action", (Reichenbach [1938], 346). Hume had maintained that induction could only be justified if it could be shown to be absolutely true, whereas Reichenbach is able to accept it as a basis for our best "wagers".

the principle of induction ... signifies nothing but the mathematical interpretation of what we mean by predictability.

(Reichenbach [1938], 360)

Whilst looking at Hume's position, Reichenbach dismisses Kant's answer -

It was the intention of Kant's synthetic a priori to secure this working procedure against Hume's doubts; we know today that Kant's attempt at rescue failed.

(Reichenbach [1938], 346)

an objection against our theory of induction: that there appears something like "a necessary condition of knowledge" - a concept which is accompanied since Kant's theory of knowledge by rather an unpleasant flavour.

(Reichenbach [1938], 360)

Wesley Salmon summarises the significance of Reichenbach's accommodation of the inductive process,

One of the key steps in Reichenbach's solution to the problem of induction was his recognition that what is needed is the justification of a rule, not the proof of a factual proposition such as the uniformity of nature. He realised, in addition, that it is impossible to justify the rule in question by proving that it will always, or even sometimes, yield true conclusions, given true premisses. He argued, nevertheless, that his rule of induction should be adopted because one has everything to gain and nothing to lose by employing it. ... it seeks not to justify belief in a proposition but rather to justify a practice.

(Salmon [1991], 100)

Reichenbach, in EP, has demonstrated that there can be no logical necessity about objective knowledge, nor can there be any certain facts. He has, however, demonstrated that knowledge is necessary for us to cope with the world and that the inductive procedure through probabilistic inference is the best, and perhaps necessary, tool to acquire this. In using probabilistic inference, a regularity of empirical behaviour is presumed because there are no limiting frequencies for random outcomes. Contiguous causal connection is a necessary requirement of regulated behaviour; - which is Kant's conclusion. Reichenbach's disregard for Kant in 1938, compared with his careful appreciation in 1920, presumably stems from his rejection of the "synthetic a-priori". For Reichenbach no objective knowledge has absolute certainty, and yet if we strip away Kant's specific adherence to the certainty of belief in his time in the unique applicability of Euclid's axioms and Newtonian mechanics, we have an analysis of the necessary conditions for knowledge which also removes objective certainty from specific facts. Kant demonstrated the necessity of the causal presupposition, and Reichenbach's analysis effectively also presumes this as a general principle, even though he does claim that isolated instances of uncaused behaviour can be accommodated.

Given the position of both Kant and Reichenbach, that empirical knowledge is formed, then a specific fact can have no logical certainty; hence Reichenbach's appeal to probabilistic reasoning and the concept of weighting has great attraction. Our difficulty in accepting this is not that we are thereby obliged to doubt everything we know about the world, but that it is doubtful whether Reichenbach's interpretation of a measurement of weight of truth of a fact is really practicable. Although he dismisses Popper's "Propensity" explanation of probability and Popper's concept of ranking the likelihood of outcomes, on the grounds that these are only validated under a strict limiting frequency, the methods of science and the inductive process do

proceed on the basis of being more or less probable. Science does not establish relative weightings of theories and conclude that Theory A has a weighting factor of 8.2 as opposed to a weighting factor of 7.3 in Theory B, and therefore Theory A is to be preferred. Science, as Popper would analyse, rejects Theory B because, having taken account of all conceived extraneous influences, it fails in a trial of its predictive ability, whereas Theory A continues to correspond to observed facts. Reichenbach provides us with schemas through which weighting measures can be allocated, of concatenations, and of probability lattices, but, although these may provide procedures for an objective measure of weighting, they are not actually employed in physics.

As an empiricist, Reichenbach is determined that we shall establish objective "truths" about the physical world. His analysis in EP, and his Kantian inheritance, demonstrates that such truth can have no logical foundation, and, instead of therefore looking for principles of "best fit" of knowledge to the world, he requires to give objective validity through the concept of objective probability. Cassirer, on the other hand, had been content to define objective truth in terms of its consistency and its contribution to unification of knowledge. Cassirer acknowledged that empirical truth was of different status from logical truth, and in a sense was a system of posits of only probable validity, but it is questionable whether Cassirer would have attempted the task of ascribing a measure to this probability. In Cassirer's terms it is not possible to allocate a measure of certainty of knowledge.

Reichenbach, has compounded together two uncertainties about the physical world, both of which he identifies in EP but does not segregate them in his analysis. On one hand we have, from the vivid example of the cubical world, the uncertainty of the empirical reality of the birds, and our dilemma of never being able to establish this beyond all doubt; and on the other hand we have the uncertainty attending any measurement, - of accuracy and of elimination of extraneous influences. The measurement situation is analyseable through the methods of statistical analysis, from which we can say, as Reichenbach does, that "The probability that the velocity of light lies between 299792 km/sec and 299800 km/sec is  $\frac{2}{3}$ "; but we can't allocate a meaningful probability measure to the concept of light itself as a physical entity, just as we can't give a weighting to the existence of atoms. Concatenation of probability measures of physical constants provides the physicist with real information, but nothing can be achieved with respective weightings on the applicability of physical concepts. Reichenbach correctly illuminates us about the way imprecise measurement can be incorporated into knowledge, but he misleads us in extending this method to cover the generality of scientific concepts and hypotheses. We can employ the concept of relative weighting to concepts and hypotheses, as the example of the birds illustrates clearly, by comparing them in the terms of the physicist against

the causal connections that we understand in the physical world. This weighting, however, has no measure; it is a topological comparison only. Thus, although we can confer objective probability on measurement, and on predictions of measurement, their very objective nature is still subject to Cassirer's structure of causal unity.

In his analysis of probability implications in EP, Reichenbach compares probability logic with the operation of the logic of absolute truth and falsehood. Whereas the logic of absolute truth is a binary system, of "T" or "F", probability combinations give an infinitely divisible scale of outcome from 0 to 1. We can choose to work with probability logic as two-valued by arbitrarily deciding a number above which a probability measure is to be regarded as true, and for measures of equal or below to be regarded as false. Alternatively, we can introduce a three-valued logic where measures close to one are accepted as true, those close to zero accepted as false, and other intermediate measures to be regarded as indeterminate. He does not make positive use of these ideas in the development of the thesis of EP, but he returns to three-valued logic in Philosophic Foundations of Quantum Mechanics.

#### Summary of EP

In EP Reichenbach has demonstrated that knowledge is possible only on the application of probabilistic considerations to our empirical experience. It is interesting to contrast his analysis with that of Kant. Both accept that knowledge has to be formed from experience; it does not present itself ready-made. Kant affirmed that this "forming" of knowledge necessarily conformed to basic logical principles which were immutable, whereas Reichenbach rejects this and substitutes a pragmatic requirement for knowledge in that it must be useable or relevant to the task in hand. Reichenbach distinguishes his position from that of the conventionalist by emphasising how knowledge "grows" out of the objects of our immediate environment. By emphasising the application of the probabilistic nature of knowledge, however, he is only able to proceed against the presumption of a causally connected world. Thus although he clearly presents the human predicament of never being able to verify absolutely the causal structure of the world or even of the objective existence of familiar concepts, the basic presupposition of knowledge itself is causal order. Thus, Kant's analysis gives us causality as a logical pre-supposition of knowledge, - and Reichenbach's analysis effectively supports this; Reichenbach's analysis demonstrates that in using the causal presupposition, we employ probabilistic considerations.

## Chapter 7

### QUANTUM MECHANICS

The Philosophic Foundations of Quantum Mechanics was published in 1944. In his Preface, Reichenbach contrasts the Theory of Quanta with the Theory of Relativity, the two physical constructions which "have shaped the face of modern physics", (Reichenbach [1944], v). He observes that whereas the Theory of Relativity was largely the result of the inspiration of one man, Einstein, Quantum Theory has been developed through the work, and collaboration, of several individuals. Although Reichenbach briefly describes the development of Quantum Theory in four main stages, it is perhaps instructive to trace the chronological development of the theory.

At the end of the Nineteenth Century, physical explanations were essentially conceived in the concepts of mechanics introduced by Newton, although the experimental work of Faraday on electrical phenomena had been incorporated into the electromagnetic field theories of Maxwell and Lorentz which appeared to offer the prospect of a generalised description of natural phenomena. The electromagnetic theories indicated that the physical properties of space could be characterised by *field* equations which defined an electromagnetic field potential at each point, and which affected the behaviour of transmitted waves of electromagnetic energy. Maxwell's equations of electromagnetic wave propagation were first presented in 1862 before the possibility of physically demonstrating the existence of such waves, but these were substantiated in 1887 in a series of physical demonstrations by Hertz. Thus, radiation of energy in all forms was identified as a propagation of waves, and the Newtonian concept of light as corpuscular was generally disregarded.

It was consideration of an apparently small anomaly in physical theory, however, which led to a challenge to the concept of a continuous energy waveform and led to the development of quantum mechanics. The anomaly related to the exchange of energy in a container with properties of perfect energy absorption and emission, - a black body. In classical theory, based on continuous absorption and emission of energy of all frequencies, predictions indicated an infinite energy level with a preponderance of energy in higher frequencies of radiation. Max Planck was able to resolve this in 1900 when he proposed that energy exchange was a discontinuous process and occurred in discrete packets whose energy content was a multiple of the frequency times a constant, - Planck's constant. This hypothesis was given additional weight in explaining the specific heats of substances at low temperatures. Albert Einstein, in 1905, extended this corpuscular nature of energy to explain the photoelectric effect in which light of sufficiently high frequency displaces electrons in metals to generate electric

currents. He revived the Newtonian concept of corpuscles of light, - photons. Energy was thereby characterised as being both wavelike and continuous, as well as corpuscular and discrete.

A significant development occurred in 1911, when Ernest Rutherford demonstrated that when he bombarded a metal foil with alpha particles, most passed straight through, and only a small proportion were deflected, leading to his hypothesis of a small positively charged atomic nucleus surrounded by a swarm of planetary electrons. This provided the basis for Niels Bohr's theory of the hydrogen atom which he formulated in 1913. He accommodated Planck's concept of discrete packets of energy into his atomic model by postulating discrete potential orbits for the planetary electron, only those orbits being allowed whose angular momentum is a multiple of Planck's constant. The consequence of this theory, that absorbed energy by the hydrogen atom corresponded to the difference in energy levels between permissible electron orbits, was confirmed in the spectral frequencies of hydrogen. Extension of this mechanical model to more complex atoms proved to be more difficult.

Significant further development of the atomic model and quantum mechanics was arrested until 1923, when Louis de Broglie began publication of a series of papers in which he ascribed wave-like properties to particles. He substituted wave packets for particles, with momentum of Planck's constant divided by the associated wavelength. This work was then utilised by Erwin Schrödinger who, in 1926, produced his celebrated wave equation to represent the behaviour of fundamental particles. At this stage the visualisable mechanical model of the atom, that had been generated by Rutherford and Bohr, began to disappear, as it became clear that in representing electrons as waves they were not physically localised but spread out through their atomic orbits. Schrödinger proceeded to demonstrate that his formulation accommodated the independent work done by Werner Heisenberg in 1925 who had formulated the atomic model in matrix form in terms of transition probabilities between potential electron states. The basis of the mathematical formulation of quantum mechanics was completed with Schrödinger's equations, what followed becomes chiefly a matter of interpretation and application. What is surprising is that a theory which evolved largely through inspired hypotheses should have been so resilient and successful in its application to quantum physics.

It is apposite to describe the features of this formulation which differentiate it from formulations of classical mechanics. The fundamental departure is that this model has dual interpretations of fundamental particles, which can be represented either as discrete particles or as wave packets. There is also the concept that change in nature occurs in discrete quanta rather than as a continuous process. Additionally the representation of a particle via the Schrodinger formulation is a wavefunction which represents the state of the particle against a continuous time dimension. This

does not, however, give a direct magnitude of measurable properties of the particle, such as its energy, momentum, or position. These measurable properties can only be calculated by applying appropriate mathematical operators to the wavefunction, which then provide numerical measures of the relevant quantities, - these measures being referred to mathematically as eigenvalues. The dilemma, however, is that the eigenvalues associated with, say, the momentum operator, are not paired with the eigenvalues for the position operator; - in other words it is not possible to obtain simultaneous measures of position and momentum of a particle. This is a direct consequence of the mathematical formalism, and also relates to the practical situation where measurement of one characteristic disrupts the behaviour of the particle and precludes a measurement of other characteristics.

The use of a wave function to represent a particle and the consequent lack of precision in determining measurable values led developers of the theory like Max Born and Paul Dirac to regard the wavefunction, not specifically as a physical manifestation, but as a probability function. Thus the function is used to determine the probability that a particle is within a specific space-time range, or that its momentum should be within specified limits. This form of representation, though, does provide a problem of physical interpretation.

The most clear exposition of the peculiarities of the new quantum formulations came from the Copenhagen School, and particularly from Werner Heisenberg and Niels Bohr. In 1927 Heisenberg introduced his *Uncertainty Principle*, which he derived by considering the measuring process itself, and which declared that it is impossible to specify exactly the measures of complementary properties of a body, - for example position and momentum. In fact the product of the inaccuracy of measurement of position and momentum is inevitably greater than Planck's Constant divided by twice  $\pi$ . This applies to all bodies subject to measurement but only has significance in the world of fundamental particles for which Planck's Constant is a relevantly large quantity. In 1928 Bohr introduced his *Complementarity Principle* which stated that the wave and particle representations of quantum occurrences complement each other, that in some situations it is preferable to use one form as a description and in other situations the other would be preferable, but in no instance would it be possible to falsify either as an adequate representation. In other words it is impossible to make a telling physical intervention in the sub-atomic state that would discriminate between these representations; the degree of uncertainty in the measurement is too great for such discrimination. These two principles led to the Copenhagen Interpretation of quantum mechanics, which specified that it is meaningless to ascribe physical reality to the mathematical formalism of the state of a particle; description is only relevant when applied to an actual measurement in which only the property being measured has

relevance. This interpretation is essentially an application of logical positivism to the situation.

Although this interpretation was largely accepted by practical physicists, Einstein regarded the theory as incomplete in that predictions of the outcome of a situation could only be expressed in probabilistic terms even though initial conditions could be completely specified. He was unhappy that causal explanations of quantum processes could not be effected, and that non-local events appeared to affect each other without the possibility of causal interaction. He debated the issues with Bohr through the medium of "thought experiments", but was unable to give a convincing counterdiction of the Copenhagen Interpretation.

Reichenbach was actively attentive to the development of quantum theory in the 1920's, and in fact in April 1927 produced an up-to-date summary which was published in Die Umschau 31 no. 15, as "Ein neues Atommodell" (Reichenbach [1978], v.1, 219-225).

For discursive treatments of quantum mechanics see Polkinghorne [1984], Squires [1986], or Gibbins [1987], or for a more thorough study see Schiff [1968].

#### Philosophic Foundations of Quantum Mechanics

Reichenbach presents his exposition in three distinct sections; - the first concerns a general elucidation of the concepts involved in Quantum Theory, the second gives an outline of the mathematics of the theory, and the third section explores the implications of the theory for the epistemology of physical knowledge. This analysis will pay little attention to the mathematical section except to indicate how particular conclusions result from the mathematical modelling.

Reichenbach summarises the challenge posed by Quantum Mechanics to Philosophy as firstly a replacement of causal laws by probability laws, and secondly in terms of treatment of unobserved objects.

He begins by looking at the probabilistic nature of physical knowledge as explored previously in EP, but initially refers to Boltzmann's work on the thermodynamics of gases as the point of departure from our secure acceptance of strict physical determinism to an understanding that probabilistic interpretation of micro phenomena is compatible with causal regularity at the macro level of everyday objects. He makes the point that if elementary particles are subject, not to laws of strict causal determinism, but to laws of a probability

character, then, because of the very large numbers of such particles, their aggregate behaviour will conform to an apparently regulated pattern. He also identifies that regular behaviour at the macro level does not of necessity imply regular deterministic behavior at the micro level. Reichenbach does not enlarge on Boltzmann's work, who did not reject mechanical determinism at the micro level, but in fact presumed it in order to present a statistical model that he could work with. Even though the Second Law of Thermodynamics was derived from Boltzmann's statistical analysis, the analysis was founded on atoms subject to Newtonian Mechanics but considered as a statistical aggregate. Reichenbach, therefore, does not make clear what he implies by probabilistic behaviour as opposed to causal behaviour at the micro level when he refers to Boltzmann. He evidently is not referring to the fact that a convenient way of treating large aggregates which behave according to apparent deterministic mechanical principles is offered by treating them probabilistically, but that if causal determinism in a strict sense does not apply to individual particles, determinism at the aggregate level may still appear. He does not clarify that this situation only applies if the behaviour of the particles is not random and therefore constrained by some objective laws.

He proceeds to examine causal relationships as they are understood in the physical world accessible to direct observation and measurement. His basis of analysis in many respects is similar to that of Cassirer who would consider the accumulating system of knowledge of approximating more closely to an ideal, but in PFQM Reichenbach makes no reference to either Cassirer or Kant. He thus regards the causal laws of Physics as being understood to hold between idealised physical states, whereas statements about the physical world must be verifiable in observational terms of states of affairs that can only approximate to the ideal situations expressed in the laws. Just as in his previous analyses of the application of probability considerations to empirical behaviour, he illustrates that practical measurement and observation is understood to be only an approximation to an ideal situation as expressed by the laws of physics. He therefore summarises his position as -

The statement that nature is governed by strict causal laws means that we can predict the future with a determinate probability and that we can push this probability as close to certainty as we want by using a sufficiently elaborate analysis of the phenomena under consideration.

(Reichenbach [1944], 2,3)

On this basis he claims that if causality is merely a limit of probability implications, then it loses its a-priori character and becomes an empirical hypothesis.

Reichenbach proceeds to examine the consequences for the

principle of causal connection implied by Heisenberg's Principle of Indeterminacy. He clarifies that the classical causal laws of physics are temporally directed, and that even simultaneous occurrences are regarded as consequences of temporally prior causes. The Principle of Indeterminacy, however, relates to simultaneous measurement of independent parameters, and - in Reichenbach's terminology - it is quite separate from causal laws and is a *cross-section law*. The Principle of Indeterminacy states that the more precisely we measure, say, the position of a fundamental particle, the less precise we can be in our knowledge of its momentum, and vice versa. Thus, if we have incomplete knowledge of the particle, we are unable to make testable predictions of its future behaviour; and hence a statement of causal connection between states of the particle at different times is unverifiable, and therefore physically meaningless. It is with this argument that Reichenbach is at variance with his analysis of "meaning" in EP, where he argued that physical meaning should be related to "weighting" rather than to absolute criteria of verification. His analogy with the hypothesis of the birds outside the cubical world, was used to demonstrate that the concept of causal connection leads us to prefer the concept of real birds to a mysterious connection between shapes on ceiling and wall. Even though it was impossible to verify the reality of the birds, or to distinguish between the predictive values of the rival theories, we were happy to employ the concept of causal connection to strengthen belief in one theory. This is at odds with his conclusion on indeterminacy in PFQM -

According to the verifiability theory of meaning, which has been generally accepted for the interpretation of physics, the statement that there are causal laws therefore must be considered as physically meaningless.

(Reichenbach [1944], 4)

Reichenbach then makes a potential concession to the causal principle, that although it is necessarily impossible to measure the values necessary to describe the events in question, -

we can attempt to assign definite values to the unmeasured .. entities in such a way that the observed results appear as the causal consequences of the values introduced by our assumption.

(Reichenbach [1944], 4)

He classifies this use of causal connection as a *convention* or *definition*. It is not clear, however, how this use of causal connectedness differs in any way from the causal connections we make in other situations where we are unable to establish criteria for verification. For example the statistical measurements of Mendel led to a theory of inherited characteristics, based on an underlying causal principle, but without the possibility of verification in a direct sense and

certainly not on an individual outcome, but predictable only on a probabilistic basis. Reichenbach's intention, however, in conceding this possibility of a causal convention that can be assigned to an underlying determining function of behaviour of fundamental particles is to demonstrate that it is inappropriate in Quantum Theory.

In explaining the Principle of Indeterminacy, Reichenbach illuminatingly uses an example derived from his experience as a radio engineer, where he illustrates how it is impossible to adjust a receiver for both high fidelity and high selectivity. He is a practical man with a physical instinct for empirical behaviour.

Reichenbach proceeds to consider the relationship between the observer and quantum object, and the disturbance caused in the act of observation. He asserts that this is not a subject for metaphysical speculation about the effects of human beings as observers, but is entirely a physical effect between physical things. He moves through his analysis with the firm determination of the practical man who knows his subject, and who doesn't wish to be side-tracked by speculation from academics who lack physical "feel". He places before us Heisenberg's statement that

the uncertainty of predictions is a consequence  
of the disturbance by the means of observation.  
(Reichenbach [1944], 16)

Reichenbach points out that this is not sufficiently precise in elucidating the indeterminacy involved. In many physical measurements the act of measuring disturbs what is being measured, for example in measuring the temperature of a glass of water the introduction of the thermometer has an effect on the temperature; but in such instances we can use established physical theory to take account of the effect of the disturbance. With Quantum Theory, however, this is not possible. The physical theory that is used to take account of the disturbing influences of the measurement process, itself contains the principle of indeterminacy. It is therefore necessary to recast Heisenberg's statement in the form

We have no exact knowledge of physical states  
because the observation disturbs *in an unpredictable*  
way.

(Reichenbach [1944], 17)

It is necessary now for Reichenbach to discuss the way in which we describe objects, and, as in EP, he demonstrates that we can employ different conventions for this, although wherever possible we maintain descriptive simplicity that avoids extraneous hypotheses of empirical behaviour. He summarises the two principles that classical physics employs in dealing with unobserved entities -

1) *The laws of nature are the same whether or not the objects are observed.*

2) *The state of the objects is the same whether or not the objects are observed.*

(Reichenbach [1944], 19)

Thus we maintain that an object like a tree persists and maintains its physical characteristics when we turn away from looking at it. The tree is an object that is directly accessible to us and our experience of it is immediate. Observation of the quantum world, however, is not so readily accessible to observation. Experience of quantum objects is provided through the intermediation of scientific measuring systems. We don't see quantum objects in the same sense that we see a tree, but we may register traces of their effects on our instruments. There are occurrences which are registered relatively directly "by short causal chains" (Reichenbach [1944], 21), such as on a Geiger Counter or in a Wilson Cloud Chamber, which Reichenbach describes as *phenomena*, but the occurrences which happen between such phenomena are unobservable by us, and can be regarded as *interphenomena*. Thus the phenomena are verifiable occurrences, whereas interphenomena are the subject of Quantum Mechanics which includes the principle of indeterminacy, and they are therefore unverifiable.

Prior to the start of the Twentieth Century, matter was generally regarded as consisting ultimately of fundamental particles, whereas electromagnetic radiation consisted of waves. The development of Quantum Theory disturbed this conception as light was shown to have a corpuscular identity and material particles were shown to behave like waves. Thus explanation of some experiments was given satisfactorily by a wave interpretation, whereas others were only satisfactorily explained by particles. The most consistent explanation was provided by Born who interpreted the waves as probability packets to explain the statistical behaviour of particles, but this could not be applied in all instances. Bohr's *principle of complementarity* resolved the apparent contradictions by demonstrating that both concepts were equally valid in that contradictions only occur within the range of indeterminacy specified by Heisenberg's principle. Thus both interpretations can be used to explain all occurrences, since it is impossible to construct an experiment that discriminates between them.

Reichenbach construes this explanation as offering us two complete classes of description of *interphenomena*. Thus although we have one normal system of explanations for ordinary macroscopic occurrences, which also includes the observed phenomena of the quantum world, for interphenomena two equivalent systems of description are quite compatible. It is necessary, however, to demonstrate that both explanations satisfy the principle that the laws of nature are not changed by

observation. The principle of classical physics, that objects are unchanged by the process of observation, is not, however, applicable to interphenomena.

With this introduction it is appropriate to consider a classic paradox of quanta, and Reichenbach investigates in detail. A low-intensity source of electrons or photons (light) is projected towards a screen, and between the source and screen is interposed an opaque barrier. A narrow slit "A" is made in the barrier so that some electrons will pass through illuminating the screen with tiny flashes. Thus the phenomena, in Reichenbach's terminology, are the flashes on the screen and the pattern of distribution they make there, whilst explanations of what is occurring between source and screen must be in terms of the unobserved interphenomena. Using the corpuscular description of electrons we can describe what is occurring in terms of electrons being projected towards the barrier, some passing through the slit, and being deflected as they do to impinge on the screen in a probability distribution. This is a perfectly consistent explanation and satisfies the rules of the normal system of explanation of classical physics. If the wave description of electrons is applied to the system, then the spherical wave-fronts emitted from the source are interrupted at the barrier with only a small progression allowed at the slit. This continued progression subsequently spreads out as a wave-front from the slit and generates an interference pattern of intensity on the screen. This explanation is only at odds with the facts of the case in that it fails to account for the flashes on the screen. There is therefore a causal anomaly in the wave explanation of what is occurring.

It is now necessary to add to the configuration with a second slit "B" in the barrier parallel to slit "A". There now obtains a pattern of flashes on the screen which is different from that obtaining in the one-slit case, and it is different from the pattern that would be generated if the one-slit pattern from "A" were supplemented by the same pattern that would originate from "B". The pattern from two slits in fact is consistent with the interference fringes of wave fronts being diffracted through two slits. Thus for this configuration the wave explanation of electrons again provides an explanation, apart from the anomaly of the flashes of light on the screen. If the corpuscular explanation is attempted, however, we have problems of explaining the interference fringes, - of alternating dark and light bands on the screen. By the corpuscular explanation we would expect the two-slit pattern to be the direct sum of the patterns from one-slit when first "A" and then "B" is open with the other slit closed; but it isn't. The behaviour of an electron leaving the source and passing through a slit appears to be affected by the second slit being open. No causal mechanism can be detected that accounts for such an influence, and so although the corpuscular theory accounts for the flashes on the screen it doesn't provide a coherent causal explanation of the process through which they occur. Reichenbach considers a

third possibility of explanation using De Broglie's concept of pilot waves. In this explanation a wave field is emitted by the source and undergoes diffraction at the two slits to form a probability interference distribution on the screen. The intensity of the wave field determines the probability of finding a corpuscle at that point, and effectively serves to "pilot" the particles from source to screen. This theory appears to offer the attractive compromise of explaining both the dependence of the interference pattern on the screen on the configuration of slits, together with the phenomena of the discrete flashes on the screen. Reichenbach dismisses this as an inadequate "causal" explanation through its use of a determining wave field devoid of energy to do the job.

At this stage of his analysis Reichenbach has not demonstrated that some explanation, not previously considered, may describe the situation without causal anomalies; but later he demonstrates from the mathematics how the system of quantum mechanics incorporating Bohr's principle of complementarity must inevitably include causal anomaly under a normal description. Reichenbach therefore proclaims the *principle of anomaly* -

The class of descriptions of interphenomena  
contains no normal system.

(Reichenbach [1944], 33)

He embarks on a means of incorporating such descriptions into an acceptable system of physical explanation. He asserts that although a normal system of explanation of behaviour is not possible in all situations involving interphenomena, every phenomenal occurrence is explicable by one system. In other words in the two-slit experiment the interference fringes are explained on the wave description, whereas the flashes of light are explicable on the corpuscular description. He further makes the point that each system of description, that is wave or corpuscle, in itself is causally coherent. As an analogy he considers a geometrical system of orthogonal coordinates drawn as the lines of longitude and latitude on a sphere. These are functional for navigators at all points except at the Poles where longitude is indeterminate. At these points of singularity at the Poles, there is no physical difference, only a problem with the coordinates, and a navigator can continue by imposing a localised alternative set at these places. Thus we can have a functional set of coordinates to cover every extended area on the sphere, but no one system that covers all areas. Thus for Quantum Mechanics we can have a system of interphenomenal concepts which provide explanation over a range of situations, but which become anomalous when applied to every situation. Reichenbach accredits this fact to the principle of indeterminacy.

We are thus encouraged by Reichenbach to accept that, just as a navigator may use a different coordinate system when his normal system is inappropriate, a physicist may choose to employ either

the wave interpretation or the corpuscle interpretation to provide an explanatory answer to a specific question concerning interphenomena. The justification for this is solely on the grounds of eliminating causal anomaly, as Reichenbach admits. Thus, he concludes that

in the world of atomic dimensions the postulate of unchanged laws of nature cannot be carried through for the totality of interphenomena, and therefore does not determine one interpretation as the normal interpretation of all interphenomena, although it determines one normal interpretation for every interphenomenon.

(Reichenbach [1944], 39)

Reichenbach asserts that this is not a breakdown of our system of concepts, but happens to be an objective property of the world in the microcosm. He conceives that if such behaviour were manifest at the macro level we would adjust our interpretations of behaviour to take account of it.

He then considers the *restrictive interpretation* favoured by Bohr and Heisenberg. They claimed that only statements about measured entities, - phenomena -, were admissible, and statements involving interphenomena were meaningless. They thereby adopted a strictly positivist view of physical explanation. This returns us to the arguments against positivism that Reichenbach employed in *EP*, and although he acknowledges the advantage of the Bohr-Heisenberg approach in eliminating causal anomaly, he criticises it in that we lose the potential of manipulating concepts that connect statements about observed entities with unobserved entities. Thus, in *EP*, the explanation of the moving shapes on the walls of the cubical world as the effects of unobserved birds, was regarded by Reichenbach as preferable to a positivist interpretation because it furnishes us with a useable hypothesis that connects with our concepts of a causally integrated world.

The restrictive interpretations do not say the causal anomalies, but they do not *remove* them. The causal anomalies cannot be removed because they are inherent in the nature of the physical world. ... It is positive knowledge, deep insight into the nature of the atomic world, which constitutes the basis of this strange network of rules, formulated as rules limiting descriptions, but expressing implicitly rules holding for all physical occurrences.

(Reichenbach [1944], 44)

Michael Redhead is more forthright in his denunciation of a restrictive interpretation of quantum events

Setting dogmatic limitations on scientific theorizing, on the basis of obscure philosophical preconceptions,

is a dangerous prejudice from the standpoint of a conjectural-fallibilist approach to the nature of scientific activity.

(Redhead [1987], 51)

That Reichenbach should be more constructive in his criticism of the positivist view held by Bohr, probably reflects his closeness to that philosophical school and a degree of respect for a view that demanded an empirical demonstration of theory.

With this statement Reichenbach concludes the first part of his analysis before proceeding to a mathematical exposition of quantum mechanics. It is remarkable that he has not referred any of his epistemological investigation to contrast with Kantian concepts, nor, as opposed to EP, has he maintained a position explicitly against logical positivism or conventionalism. It is as if these were ghosts of his past which he has finally exorcised, and he is free to pursue a straightforward investigation of the philosophical implications of his subject. His position at this juncture, however, appears to be somewhat at odds with what we would expect from this vigorous empirical realist; his advocacy of the equivalence of wave and corpuscle descriptions of fundamental particles would appear to be more consistent with the position of a transcendental idealist, despite his protestation that this is a "deep insight into the nature of the atomic world."

As he explains in his Preface, Reichenbach's objective in presenting, in the second section of this book, an outline of the mathematics of quantum mechanics, is

to open a short cut toward the mathematical foundations of quantum mechanics for all those who do not have the time for thorough studies of the subject.

(Reichenbach [1944], vii)

He subsequently uses some of the mathematical concepts introduced here in his analysis in the third section of the book, but this detail is not relevant to an understanding of his epistemological argument. This is Reichenbach the teacher at work, improving our grasp of a diffuse subject.

Reichenbach begins his mathematical lecture with introductory units on handling complex functions, attempting to give the reader a grasp of the means to manipulate them. He proceeds from this to an exposition of the derivation of Schrödinger's Equation, and explains its origin. The equations for Quantum Mechanics were conceived as being generalisations of those of classical mechanics, but without there being a clear logical directive for establishing a rule of generalisation. Given wide scope, therefore, development proceeded heuristically and on the basis of bold assumptions. Without a clear logical theory behind the work, the single justification for the conclusion is that

the mathematics has provided exceptional predictive accuracy. De Broglie began the process by extending the concepts of the dualism inherent in the wave-corpusele theory of light to fundamental particles of matter. Schrödinger then used this to extend classical mechanics into wave mechanics, and Heisenberg concluded that lack of direct verifiability implied that the equations represented probabilities of transition only and were expressible in matrix form. Reichenbach again illustrates a point that theories should be assessed in their "context of justification" by their coherence and predictive value, rather than in their "context of discovery".

He then sketches through a derivation of Schrödinger's equation, and proceeds to show that solutions will provide discrete energy levels consistent with Bohr's atomic model. Furthermore, if we examine the properties of position and momentum of a particle, it can be shown that these are non-commutative properties and therefore provide separate and distinct sets of eigen-functions and eigen-values, with the consequence that it is not possible to establish a measuring situation that provides simultaneous values of these properties. Schrödinger's equation provides us with a wave representation of a fundamental entity, not in corpuscular form but represented as a wave with properties of amplitude measured against space and time coordinates. This can be interpreted into corpuscular terms through transformation to give a relation of time-dependence for commutative properties. Different transformations are required for properties which are non-commutative.

Reichenbach proceeds in the third section of PFQM to examine the implications for causality of the dualist interpretation of the equations of quantum mechanics. He requires a "causal law" to meet two conditions -

First, it is required that the cause determine the effect univocally; second, it is demanded that the effect spread continuously through space, following the principle of action by contact.

(Reichenbach [1944], 117)

As a wave theory alone quantum mechanics provides a system of causal ordering that applies to interphenomena, but breaks down only at the level of the discrete phenomenon which is located spatially and temporally. The corpuscular theory, on the other hand, can not provide a continuous spatial and temporal account, due to the non-commutative properties of the space and momentum vectors within the controlling function. It does, however, enable the construction of class models, for example of the hydrogen atom, against which discrete measurement can be obtained, but we are not enabled to pursue the development of this model through time as a physical structure against causal interaction.

Reichenbach therefore looks to the languages that we are using.

There are two, an observational language relating to the phenomena, and a quantum mechanical language which relates to the interphenomena. These languages are related inasmuch as the truth or falsehood of statements made in the quantum mechanical language can only be determined in terms of measurements in the observational language. Thus "meaning" in the quantum mechanical language relates to statements in the observational language, as for example a statement of a position of an electron is relateable to an observed flash on a screen or a blip on a Geiger Counter. If we pursue this, however, we must conclude that if we have a statement of position of an electron, then a statement about a simultaneous momentum of that electron is effectively meaningless, in that in measuring position we are physically unable to measure momentum. Reichenbach wishes to avoid the consequences of a language which generates physically meaningless statements, and he therefore extends his definition of truth-value to accommodate this, by introducing a third value, - neither true nor false, but indeterminate. He compares it to the case of two dice players, "A" predicts a six if he throws next and "B" predicts a five if he throws next. "A" throws four, and his prediction is therefore false; but "B"'s prediction can be neither true nor false, but indeterminate. Reichenbach does continue by asserting that in this "macro" situation it would have been possible perhaps to re-cast the situation for "B" then to test his hypothesis, whereas the quantum situation does not allow this.

Reichenbach continues, to demonstrate that this three-valued logic can be applied consistently to the quantum-mechanical language in a manner that provides a more complete description of events than does, for example, the Bohr-Heisenberg restrictive interpretation. It avoids the explicit announcement of causal anomaly in a description, but classifies groups of statements as indeterminate. It is questionable if his analysis using three-valued logic has either added to understanding of the quantum-mechanical domain or enabled us to operate with apparent causal anomalies. He introduced the concept of three-valued logic in EP to account for the concept of "weighted" rather than "absolute" truth; in this case he is not involved in probabilities or weightings, but purely with indeterminate measurement. The one virtue of using the "indeterminate" value is that the alternative in two-valued logic is a designation of meaningless. Thus we would expect Bohr to assert that the concept of a value for momentum of an electron as its position is established, is meaningless; whereas Reichenbach's designation of "indeterminate" does provide a clearer and more relevant statement.

Reichenbach makes a summary of the book's analysis. He reflects that indeterminacy is a fundamental physical law, involving disturbance of the object by measurement. The physical world therefore divides into phenomena which are accessible to observation and inferential reasoning, and interphenomena which are based on interpolation and which generate systems not free

from causal anomaly. He then advances into a Conventionalist position -

Instead of speaking of the structure of the physical world, we may consider the structure of the languages in which this world can be described; such analysis expresses the structure of the world indirectly, but in a more precise way.

Reichenbach's intention in this book was to replace causal laws with probability laws, and to explore the interpretation of unobserved objects. He has not demonstrated that in the quantum world, probabilistic connection supplants causal connection. He has illustrated physical causal anomalies, but he has only been able to adjust the logical structure of language to accommodate them, he has not provided probabilistic support for this. One of Reichenbach's enduring passions has been his recognition that actual knowledge is obtained imprecisely and sifted through a statistical filter to give it substantial form. He was fascinated by Boltzmann who effectively reversed the traditional process by deliberately using probabilistic imprecision on large aggregates, to produce measureable predictions at the aggregate level. The development of quantum mechanics with its modelling interpreted in probabilistic terms would appear to offer him an opportunity to establish a probabilistic conception of the physical world, but he appears unable to achieve this. We must also be critical of his conclusions regarding unobserved quantum objects where he appears to withdraw from his empirical realism into a conventionalist interpretation. In this book he was not setting out specifically to defend a philosophical position against others, rather to provide an elucidation of a physical theory, and the consequences in his philosophy are not clear even though he provides a clear exposition of the apparent anomalies inherent in quantum mechanics.

He has concerned himself exclusively with the expression of quantum theory in terms of functions related to the behaviour of individual particles. As an extension of classical mechanics, quantum mechanics examines the behaviour of individual particles in electromagnetic fields. The consequences give a basis for models of atoms and energy emissions that conform well with observed physical effects. He observes that the sole justification of quantum theory is its ability to provide conclusions which correspond with the facts; but just as Kant's philosophy was distorted by his acceptance that Newtonian mechanics appeared to provide a conclusive final theory, there is a danger that Reichenbach's epistemological conclusions arising out of quantum mechanics may be over-hastily drawn. A conclusion he could have perhaps emphasised, relating back to Boltzmann, is that despite apparent causal anomaly at the level of the individual quantum particle, the consequence of considering particles in aggregate provides no such anomalous

behaviour. Thus the absorption spectrum of hydrogen gas is predicted by the theory at the macroscopic level, and we can draw conclusions on the emitted light of stars to conclude that the presence of hydrogen gives us the measurements we obtain. We understand the causal connections in this phenomenon right down to the structure of the individual hydrogen atom. Causal anomaly only intervenes when we attempt to track an individual photon contributing to the total phenomenon. The causal anomalies in the two-slit experiment arise through the interaction of the observations with the quantum description of the electron. If we describe it as a corpuscle we have to explain how its behaviour in passing through one slit is apparently affected non-locally by the presence of a second slit; and if we describe it as a wave we have to explain specific localised flashes on the screen. The anomalies may disappear, however, with a different concept or a different quantum model.

His classification of non-measured or unmeasurable interphenomenal properties as indeterminate does provide a helpful reconciliation with the macro world. As he points out in EP, meaning is a basis for usefulness, and the Bohr-Heisenberg restriction on unobserved interphenomenal properties as meaningless concepts, deprives us of a language for relating quantum events. If we describe the momentum of impact of a particle with a spatial determination as *indeterminate*, we have a means of accommodating this understanding; whereas its designation as *meaningless* actually limits our understanding of what it is whose position we have measured. The concept of an indeterminate event is familiar to us. Take the example of a dice thrower; the potential outcome of a throw is indeterminate, and we are quite unable physically to take account of all possible causal influences on it, - even though there seems a feasibility for this. We know that in aggregate a six will appear with a frequency that gets closer to one-sixth as the number of throws increases, but each next throw is indeterminate. The indeterminacy of quantum mechanics arises from a physical inability to determine all parameters of a quantum event without upsetting them in the measuring process, and we therefore can't provide a positive prediction of an individual occurrence. We can, however, provide accurate predictions of the aggregate of such occurrences. The individual outcome is not meaningless, it is indeterminate. Perhaps it needed an empirical realist to provide this more pragmatic understanding.

## Chapter 8

### THE DIRECTION OF TIME

The Direction of Time was published posthumously in 1956. In this book are represented Reichenbach's later conclusions on the subjects of his writing that we have been considering, and particularly on the relationship between causal determination and the physical world. In his Introduction he declares his intention to examine the objective property of time as it manifests itself in physics, as opposed to our subjective temporal experience, and he makes a criticism of Kant's concept of time for its subjectivity. He attributes this to Kant's wish to free man's will from a deterministic world, and as a consequence Kant's philosophy asserts the dominance of man over time and causal order

Kant's philosophy of subjective time and subjective causality is a form of escapism.

(Reichenbach [1956], 15)

Of course it is possible to interpret Kant's philosophy of space and time as a subjective construct, and Kant's analysis is that we impose causally ordered form on experience; but Kant would also assert that this is a real property of the empirical world. Kant's case is that we can't come to terms with empirical knowledge unless we structure it in a necessary way, and in his publications prior to this Reichenbach has been unable to demonstrate that a spatio-temporal structure with causal connection is not a necessary pre-condition. Following his break with Kantian philosophy in 1921, and since moving from Istanbul, Reichenbach has been operating within a different philosophical tradition, dominated by the works of the American Pragmatists, and perhaps influenced also by Russell. Russell's method of analysis was not sympathetic to Kant, and he was particularly impatient with Kant's grasp of concepts like "infinity" and his presumption that an infinite series necessarily has an infinite sum. We can therefore understand Russell's dismissal of Kant's concept of time as purely subjective when we read in Russell's Our Knowledge of the External World -

"With a cynical smile he pointed the revolver at the breast of the dauntless youth. 'At the word *three* I shall fire,' he said. The words one and two had already been spoken with a cool and deliberate distinctness. The word *three* was forming on his lips. At this moment a blinding flash of lightning rent the air." Here we have simultaneity - not due, as Kant would have us believe, to the subjective mental apparatus of the dauntless youth, but given as objectively as the revolver and the lightning.

(Russell [1926], 122)

In 1929, in an article in Obelisk Almanach entitled "Bertrand Russell", Reichenbach writes -

the real philosophy of our day has developed along with the positive sciences and can only be discovered if we keep our eyes open for the special form of philosophical thinking that is an outgrowth of the construction of scientific concepts and the mental apparatus of the sciences. ....There are probably a good many philosophically minded professional scientists, but there are few philosophers. The following remarks are dedicated to one of these, the worthiest representative of such a philosophy of the positive sciences: Bertrand Russell.

(Reichenbach [1978], 298)

Given his admiration for Russell in 1929, it would be unsurprising if he wasn't influenced by him, when, eleven years later, he shared a room with him at UCLA.

Although Reichenbach may appear too readily dismissive of Kant, however, this observation does mark the fact that Reichenbach has been able to free himself from the traditions of his early philosophic education, and that he has established a direct unfettered approach to philosophy. This final major work of his is marked by a thoroughness and directness, and without an intention to support or attack other systems of philosophy. This is Reichenbach the philosopher-engineer at work.

Reichenbach begins his study of physical time by examining its qualitative, or topological, properties. He refers the reader to PST for a study of the quantitative properties of time. He sets down six statements as markers for topology

1. Time goes from the past to the future.
2. The present, which divides the past from the future, is now.
3. The past never comes back.
4. We cannot change the past, but we can change the future
5. We can have records of the past, but not of the future.
6. The past is determined; the future is undetermined.

(Reichenbach [1956], 20-23)

He proceeds to summarise that these indicate that time has not only order, but direction. He then turns to causal relationships as the basic determinants of temporal order, and defines these as -

An event A is *causally connected* with an event B if A is a cause of B, or B is a cause of A, or there exists an event C which is a cause of A and B.

(Reichenbach [1956], 29)

In dealing with time, however, he indicates that causal connection itself does not give a complete topology, as such connections apply to both reversible and irreversible physical processes. With a reversible process we can reverse the time coordinates and still have a satisfactory description consistent with the physical world; this would be analogous to reversing a film of an engine running along tracks. Such instances are common in classical physical laws, as for instance the trajectory of a ball being thrown through a frictionless environment. In an irreversible process, on the other hand, this does not apply, - as for example in the mixing of two gases or liquids, or the movement of heat from bodies of higher temperature to those of lower temperature. He does point out, however, that although only irreversible processes give a direction to time, reversible processes do define a temporal ordering and hence an asymmetrical relation. It is arguable whether the asymmetry of a reversible process, however, has any relevance unless a direction defined by an irreversible process has already been established, and Reichenbach later concedes this. A reversible process does, however, specify an ordering in terms of between, but without specifying a necessary direction, so that it is possible to connect such processes in a network in which, once a direction is given to one element, a unique direction is given for every element. We can now travel through this network, at each node selecting a line to travel through. Reichenbach calls such a route a *causal chain*, and observes that in following such a route we never return to the starting point; "there are *no closed causal chains*", (Reichenbach [1956], 36). Reichenbach observes that this is an *open net*, which property also holds if directions are reversed, thus

the openness of the net is an order property,  
not a direction property.

(Reichenbach [1956], 36)

This openness property is an empirical fact, as there is no logical reason why it may not be closed, and he illustrates the paradoxes of identity that would ensue from moving through a causal chain and returning to the original starting point. It generates the paradoxes of travelling backwards in time with the problems of self-identity (of self or object) that result; persistence of identity through time, he classes as *genidentity*. Genidentity is only possible in a world with an open causal network. The causal net thereby defines a time order for the world, but not a time direction. The structure of the net may not always provide determinate relationships of order between some events, - for example events A,B,C,D connected only by causal links AB,BD,AC,CD provides no relationship of order between events B and C which are therefore indeterminate in relative time order; they can be considered as simultaneous.

Reichenbach then considers irreversible processes. These are characterised, within a completely closed system, by an increase

in Entropy, - as characterised by the Second Law of Thermodynamics. The measure of entropy of a closed system is a measure of its degree of equalisation. Thus in a system exhibiting disparities in thermodynamical properties, there is an irreversible tendency towards higher entropy and equalisation. Even what we have been regarding as reversible processes are in fact idealisations, in that physically no closed system operates without generating friction, and hence an entropy increase in dissipated energy. Reichenbach then returns to Boltzmann, and his derivation, from probability considerations, of the Second Law. That entropy increases through statistical necessity rather than through a strict law leaves open the possibility of temporary entropy reductions, but, because when we consider thermodynamic systems the active units are large numbers of atoms, the overwhelming probability is towards an increase in entropy. In this connection Reichenbach makes the observation that has been implicit in much of his work, without being expressed so clearly

We have no proof that the motion of atoms is governed by strict laws. Perhaps we should explain all causal laws of macrophysics as the product of the law of large numbers, which transforms the limited probability of elementary occurrences into the high probability of processes in large assemblages.

(Reichenbach [1956], 56)

This is the vision that has propelled him since, as a schoolboy, he first encountered Boltzmann's work. This is the most clear exposition of it, although in his work "The Aims and Methods of Physical Knowledge" published in Handbuch der Physik v.4 in 1929, he wrote -

the law of entropy .. originally appeared as a purely causal law in thermodynamics, yet .. it revealed itself as a statistical law presenting the macroscopic form of many interacting elementary processes. We cannot exclude the possibility that this will turn out to be the fate of all causal laws; recent conditions in quantum theory have, indeed, made a reality of this conjecture ... No *a priori* pronouncement is possible, of course; we must await the judgment of physical experience.

(Reichenbach [1978],v.2, 207)

The formulation of quantum theory of course was not effected in terms of assemblages, and so although a probabilistic element was introduced into that theory, it was not aggregated into a form that generated the explanation of causal necessity at the aggregate level as Boltzmann had achieved for the Second Law.

Reichenbach takes us through the outline of Boltzmann's derivation, drawing attention to the basic presumption only of

an initial probability metric, that is of equiprobability of all arrangements of gas molecules. The problem that we face is that the presupposition itself, which requires the ergodic hypothesis that all microstates are equally probable, can only satisfactorily be demonstrated (as by Birkhoff and Von Neumann in 1931 and 1932 respectively) by the applicability of the laws of classical mechanics to the behaviour of the molecules. In other words the probability hypothesis itself depends on applicability of a strict causal law. We have the phenomenon of demonstrating the necessity of the irreversible process on the basis of application of reversible mechanical laws. Reichenbach points out, however, as a practical man, that isolated systems are unachievable, and therefore any apparently closed system is still subject to minute external perturbation, which in itself will generate equiprobability of all microstates. At the limit, however, the Universe is a comprehensively closed system, and therefore subject only to strict causal laws, undisturbed by impacts from outside. In other words the Universe as a whole is governed by deterministic laws, which Reichenbach must now investigate.

Reichenbach states that Determinism is not an observational fact, but an extrapolation from the great predictive powers of physical laws, which are themselves substantiated from observations. Although we are limited in the precision with which we observe and measure -

A set of ultimate causal connections is supposed to be hidden behind observable relationships. Determinism is thus based on an extension of observed regularities to unobserved ones; and it is assumed that the flaws of attainable predictions would vanish if we could only uncover the ultimate causal structures.  
(Reichenbach [1956], 82)

Thus, in a predictive situation, we attempt to take account of all major causal influences, and effectively supplement this with a probability hypothesis that potential influences not accounted for behave within a constrained distribution of divergence. We expect that we could achieve higher predictive accuracy by taking account of even more influences, with the ultimate physical, (although not technical), possibility of accounting for all of them. Determinism implies that this possibility of absolute predictability is potentially achievable.

John Earman in A Primer on Determinism attempts to analyse the concept of Determinism without involving the concept of causal determination, and introduces the concept in terms of a hypothetical *other worlds* definition -

if two worlds agree for all times on the values of the conditioning magnitudes and if they agree at any instant on the values of the other magnitudes, then

they agree at any other instant.

(Earman [1986], 14)

As a tool of analysis this definition generates fruitful discussion, but Reichenbach's more direct attack on the concept maintains a direct relevance to traditional preconceptions.

Reichenbach next examines how we would set about obtaining greater accuracy by reducing the influences not accounted for. He proposes three principles which are summarised below -

1. Extend the environment to account for potential external influences.
2. Make more precise measurements of the parameters within the system.
3. Use improved causal laws.

(Reichenbach [1956], 83,84)

He considers these factors, looking first at the potential for accounting for an extended environment. In pre-relativistic terms, ultimate predictability can only be achieved by extending the domain considered to the whole Universe, because anything less includes the possibility of some external factor unaccounted for. An infinite universe implies a potentially infinite number of parameters, which makes it impossible to specify the initial conditions. Following Einstein, we now appreciate that we only need to account for that part of the Universe that can interact causally within the time period required of the prediction. In practice this again becomes physically impractical, because gathering the information from such a sector of the Universe is itself limited by the speed of light, and the delay required to gather this also implies that the causally related sector itself must become bigger, - we are chasing our tail. If, however, the Universe is spatially finite, it is theoretically possible to locate a maximum environment from which a finite number of parameters would specify an initial state, although this "might be billions of years ago", (Reichenbach [1956], 86). From this it could be possible to predict any future state in a deterministic world. The practical feasibility of such a total measurement is highly improbable, and in any case it relies on the universe being finite, so an alternative must be examined.

Reichenbach therefore accepts that a guarantee of perfect knowledge of any closed system is unachievable, and he therefore looks at serial methods of obtaining information. Having identified a small spatial region which is to be the object of predictional analysis, Reichenbach encloses it within a larger region with a finite boundary surface. His purpose in doing this is ambiguous, and he doesn't explain how to use it effectively in the ensuing analysis. For the practical Reichenbach, this is unusual. This can serve two purposes; - the outer surface can be considered as a boundary of effective

causal influences on the smaller spatial domain being studied, or extraneous causal interference can be identified at this outer boundary. The subsequent analysis presumes the first of these, but Reichenbach does not make it clear practically how this could be effected.

He then considers a series of assessments of the small domain being studied, each serial assessment taking a more detailed account of the initial conditions and relevant causal factors affecting a particular predicted measurement. In a Deterministic World there is a presumed ultimate description which can act as a basis for certain predictions, so that the series of assessments can be seen as converging towards this ultimate description. In an Indeterministic World, on the other hand, we have no reason to presume that such an ultimate description exists. Reichenbach also considers, associated with each assessment, a series of estimates of the required measurement for succeeding times. If we assign a probability of prediction to each of these estimates, then the probability of prediction of the value for an earlier time will be higher than the probability for a later time. We also expect that for a given time of measurement the probability assigned to a prediction based on a more detailed assessment of causal factors will be higher than that for a prediction based on a less detailed assessment. Reichenbach therefore presents us with a potentially infinite matrix whose top row presents the series of assessments of initial conditions and causal factors, and whose succeeding rows give the assigned probability of prediction for each of these at succeeding time intervals: - thus column position, from left to right, indicates the detail of assessment of causal factors; and row position, from top to bottom, indicates the time sequence for the predicted value. The probability of prediction used in this matrix can be defined as the probability that the predicted value differs from the actual value subsequently realised by less than a pre-defined small error.

If we consider any row of probabilities, representing the probability of prediction for a time on the basis of succeeding more detailed assessments, then we have a series which converges towards a probability value of one in a Deterministic World provided that the time from assessment to measurement precludes extraneous influences. If we ignore the conclusions of quantum mechanics and yet don't presume determinism, Reichenbach proposes that our empirical evidence still suggests that the probability series measured along a row will still converge towards the probability value one. For a possibly Indeterministic World, therefore, in which we can't presume a convergence of initial assessments, our physical evidence indicates that we can still predict subsequent measurements with a probability converging to one. Each lower row, of course, representing a longer period of time between assessment and measurement, has lower probability values in each column compared with the row above, but in a Deterministic world these

values in each row would still converge to the value one; and this appears to apply in our physical world where determinism can not be presumed. If, on the other hand, we proceed down any column, representing increasing time interval between assessment and measurement, then the probability of prediction converges to a limit "p", which is the objective probability of that measurement occurring independently of specifying initial conditions. An example of this is a prediction that at least one inch of rainfall will occur in any week in County Durham.

If we therefore look at Reichenbach's matrix, we have values of probability measure in rows converging towards the value one, and values in columns converging towards "p". If the world is deterministic, we would expect that although left-hand columns converge towards "p", the lower rows would still converge towards one as they progress to the right, representing fuller information of initial conditions and the causal structure of the situation. The existence of such a probability matrix would not, however, represent a proof that a limiting initial description exists (i.e. that the world is Deterministic), since this could also be compatible with there being no limiting description. On the other hand, if we have a matrix demonstrating non-uniform convergence, with the higher rows converging towards the value one as we move to the right, whilst each column as we move down progresses to the limit "p"; this is not a proof that an ultimate description doesn't exist or that the world is not deterministic.

This does not mean that the schema represents evidence against the assumption of a limit; it merely does not support this assumption. It makes the assumption of a limiting description appear as an empty addition, which does not manifest itself in observable relationships.

(Reichenbach [1956], 93)

Reichenbach illustrates his thesis by returning to the Boltzmann model of a gas, and pointing out that even if classical mechanics is not presumed but that a probability distribution is, then we get converging predictions without the presumption of determinism.

Determinism is logically compatible with classical physics; but determinism is by no means proved by it, nor made probable by inductive evidence. Even for classical physics, determinism is a redundant addition to the system of hypotheses which formulate the basic laws of the physical world.

(Reichenbach [1956], 95)

Reichenbach had examined Determinism in an article he wrote for the Bavarian Academy of Sciences in 1925, "The Causal Structure of the World and the Difference between Past and Future". He had employed a similar argument, based on the empirical ability to

make increasingly improved assessments of a particular situation, to arrive at the conclusion -

the deterministic hypothesis is completely empty for physics; and while it cannot be directly refuted, there is also nothing to be said in its favour.

(Reichenbach [1978],v.2, 83)

Reichenbach's argument, in brief, is that because we can describe the physical world in a manner that allows us to make predictions as accurately as we require, this does not demonstrate that the world is deterministic. This can similarly be expressed by saying that indeterminism of detail can still be consistent with overall uniform, or predictable, behaviour.

It may be instructive to examine a physical situation where our ability to predict is constrained, such as the tossing of a coin. The presumption that Reichenbach makes in his matrix of probabilities is that more detailed information provides us with the ability to make better predictions, and that in the coin-tossing case we should therefore be enabled to have enough information to progress from a probability of one half in our predictive potential to a probability of one. In other words, even in an indeterministic world, if we have a macro situation with two positions of stable equilibrium - heads or tails - we can always collect enough information to establish which position will result. For a Realist like Reichenbach this is a dangerous pre-supposition, and is not borne out by his own analyses of probabilistic situations. Poincaré had indicated, in his analyses of three body dynamics in a gravitational field, that classical methods of analysis of the problem were inadequate to provide predictive models; and in the last decade simpler physical situations have been shown to be predictively intractable. An example, analagous to the tossing of a coin, is a frictionally damped pendulum swinging over two attractors, - magnets for instance. There are two positions of potential stable equilibrium as the pendulum comes to rest, one above each attractor. The initial conditions, with the pendulum released from rest, can be specified with great accuracy, and the mechanical equations of subsequent motion can again be specified closely; but the final predicted position of equilibrium can not always be determined by any degree of accuracy we choose to employ, - the probability remains one half. If we were to plot a two-dimensional chart representing the initial position of the pendulum bob that produces a final position above one of the attractors, we could find in some regions a complex pattern of fractal geometry. In other words adjacent initial positions, separated by a distance smaller than any distance we care to specify, will produce different final positions of equilibrium. In other words in these regions it is physically impossible to specify initial parameters accurately enough to increase the probability of the outcome above one half. Thus, although we understand the causal laws operating in this situation, we are unable to predict the final outcome. Common sense seems to

indicate that this cannot apply, that Laplace's Demon could determine a relationship between absolute initial position and final equilibrium; but the nature of fractal geometry precludes this, given that space is infinitely divisible, - that it is continuous and not discrete.

We therefore have the potential combination of accurately specified causal relationships providing indeterminacy of outcome. Whereas Reichenbach would replace the causal connection between succeeding events with a probabilistic connection, fractal analysis indicates that we should perhaps retain the concept of causal connection, but operating on an indeterminate situation.

Reichenbach continues by looking at mixing processes; processes which move from ordered to disordered states, states of higher entropy. He examines what he describes as "probability lattices". Given an aggregate, each row of a probability lattice represents an individual, and each column represents a succeeding temporal state, so that the probability of an individual having a specified value or position at a point in its history is located at the corresponding point. As a practical example, we can look at the mixing of two gases from parts "A" and "B" of a container after a partition has been removed. The probability function can be regarded as the probability of finding a specific molecule in part "A" for example. For a molecule of the gas originally in "A", the column one probability will be one, as will succeeding columns until the temporal interval has been reached at which the molecule could have first entered, at the speed of sound, into part "B". For columns to the right of this the values in the row corresponding to this molecule will progressively tend towards the value one half, as it becomes physically equiprobable that the molecule could be in either A or B. Thus a particular column as a whole represents the probable distribution of all molecules, whilst a particular row represents the probabilistic transition of one molecule. Reichenbach designates a row as a *time ensemble* and a column as a *space ensemble*. He also draws attention to the initial columns, where in the above example the probabilities are in transition from value one to one half, and describes this as the *aftereffect*. We have an example of the aggregate moving from its initial ordered position, through the period of aftereffect of increasing entropy, to the position of relative stability and maximum disorder.

Reichenbach now uses this model of a mixing process to consider the problem of the direction of time. He has shown earlier that we can order reversible processes in a causal net, and he now wishes to explore whether this net can be given a direction in relation to statistical processes. He is confronted with the paradox that the equilibrium position of maximum disorder is based on statistical probabilities. Thus the conclusion of maximum entropy is based on the probability premiss that all states for each individual in the aggregate are equally likely,

and therefore all possible combinations of the *space ensemble* are achievable. This must therefore include states of relative order, or relatively low entropy. He also offers the paradoxical example, as applied to the mixing of molecules in A and B, of a simultaneous reversal of all molecular velocities after mixing, so that we recover the initial state of the two gases separated in each of A and B. As the probability of a molecule's velocity is independent of the sign (direction) of that velocity, we could conclude from this example that "separation processes must be exactly as frequent as mixing processes", (Reichenbach [1956], 110). Reichenbach's direct examination of this paradox is only partial, and he contends that we don't have perfectly isolated systems, so that random extraneous influences will affect the mixing or separating process. He contends that a minor disturbance to a process of separation can have a major effect on it, since this can destroy the implicit order being established, whereas a minor disturbance to a mixing process would not impede the transition to greater disorder. This argument, although plausible to a practical man, doesn't really apply to an idealised situation where the reversibility premiss has been accepted that mixing processes are equally as likely as separating processes. Given that premiss, an extraneous random influence is as likely to push a mixing process into reverse as it is a separating process. A more satisfactory examination of the paradox must follow the instincts of the practical man rather than the compulsions of the logician. We are dealing with aggregates, and the impact of an aggregate on its environment or on an observer can not be an "instant slice of space ensemble", but of necessity is a time-weighted effect. Although we can have probabilistic states of relative order exemplified in a matrix lattice, these states of order are actually temporary transitions between states of relative disorder, so that the observed effect is masked by the enveloping disorder. Reichenbach does point out a physical case where indications of temporary transitions through ordered states are observable, - namely in Brownian Motion of small particles in suspension -, but he doesn't develop the case as outlined here.

Having noted this paradox, Reichenbach begins to consider further the implications for time direction. Given any particular *space ensemble* and level of entropy in equilibrium, it is more probable that the succeeding state of this aggregate will have a higher entropy. But it is also more probable that the preceding state will also have higher entropy. On this basis we must conclude that if state "B" has a higher entropy than state "A", this still does not tell us which of the two states is later in time.

Having appeared to lead his reader again into an impasse in the logic of mixing processes, Reichenbach looks at physical manifestations. For example, if two gases have been observed by one observer in containers A and B relatively segregated, and seen by another observer in a well-mixed state, we would

conclude that the gases had originally been partitioned and that the second observer was later in time than the first. In other words, we make the presumption that although we have now an apparently closed system, it has been subject to significant interaction with its environment.

Our environment is rich in processes which, either as a natural product or through the intervention of man, create as part of their results ordered subsystems, which from then on remain isolated and run through an evolution toward disorder

(Reichenbach [1956], 117)

Reichenbach thereafter creates another lattice representing such subsystems, which he sees as branch systems, branching off from a more general interaction into relatively closed systems. His lattice provides a row for each such branch system, with columns representing successive states of the entropy measure of each branch. Reichenbach's argument is that in looking at a single row we are unable to counter the reversibility objections outlined above, but in looking at an ensemble of branches together with the presumption that branches start from positions of relatively low entropy, we can detect a basic asymmetry in the ensemble as a whole. Effectively this argument provides a probabilistic basis for time direction, that if several rows exhibit left to right asymmetry then this is a more compelling reason to explain this as a time direction than an apparent instance of temporary asymmetry in one row. What we are in effect doing is looking at combinations of *aftereffects* to give general time direction. Reichenbach does not look in detail at the sequence through a period of *aftereffect*, where a system is initially liberated, - as in withdrawing the partition between A and B. If a series of observations were made during this initial period, we would conclude that it is a highly improbable set of occurrences in a closed system unless it is immediately consequent to a branching operation. Application of Boltzmann's distribution to the molecular arrangements would indicate that such a series is highly improbable in a state of equilibrium. By extending this to Reichenbach's ensemble of parallel branch systems, we merely strengthen the degree of improbability.

Reichenbach therefore defines -

The direction in which most thermodynamical processes in isolated systems occur is the direction of positive time.

(Reichenbach [1956], 127)

Reichenbach's further conclusion from this is that if we look at the Universe as a whole closed system, then we cannot always expect a continuous increase in entropy; the reversibility argument applies. Therefore

we cannot speak of a direction for time as a whole;

only certain sections of time have directions, and these directions are not the same.

(Reichenbach [1956], 127)

He continues, having given credit to Boltzmann for his observations that there is no causal law which demands continuing increases in the entropy of the Universe, by observing that a reversal in the total entropy of the Universe would be separated by states of high disorder "in which living organisms cannot exist", (Reichenbach [1956], 128). Thus no practical problems are posed by this potential phenomenon.

He then examines what is meant by an apparent reversal in the direction of time. Early in this book he had demonstrated that time is given an order by reversible processes, but not a direction. It is against this order that we can meaningfully speak of the direction potentially alternating. It is possible, however, by studying the causal interactions of that part of the Universe accessible to us, to conclude that we are moving through a period of entropy increase; that a relatively highly ordered Universe provides branch systems that display increasing entropy.

Time direction is expressed for us in the directions of the processes given by the branch systems with which our environment abundantly provides us.

(Reichenbach [1956], 131)

Reichenbach concludes this argument with a summary of time direction as a function of entropy.

A statistical definition of time direction presupposes a plurality of systems which in their initial phases are not isolated, but acquire their initial improbable states through interaction with other systems, and from then on remain isolated for some time. ... The direction of time is supplied by the direction of entropy, because the latter direction is made manifest in the statistical behaviour of a large number of separate systems, generated individually in the general drive to more and more probable states.

(Reichenbach [1956], 135)

In his many references to Boltzmann during these arguments he makes a statement in relation to Quantum mechanics, which perhaps illustrates a lack of confidence in the theory and which is evident in Reichenbach's lack of convincing analysis in his own treatment of that subject. He writes, without further substantiation -

the quantum physics of our day is in need of Boltzmann's ideas just as much as the physics based on Newton's mechanics, for the very reason that this modern physics, too, did not discover irreversibility in

its elementary processes.

(Reichenbach [1956], 134)

He returns to look at time direction in quantum mechanics later in the book.

Having based his analysis so far on considering the behaviour of systems of aggregates, Reichenbach turns his attention to macro events and the relationship with causality. He begins by looking at familiar "shuffling" processes, as with playing cards or scattering billiard balls. Our conclusions on finding order in such assemblages, would be that an act of intervention had taken place; that a straight line of billiard balls had been deliberately positioned thus, and had not come about by chance. If we find human footprints in the sand, we conclude that someone has recently walked here; that this explanation far outweighs in probabilistic terms any other, and is a consequence of the statistics of macro-systems. We see the footprints as a record of an interaction on the branch-system of the sand.

the footprints take over the function of a record. They allow us to infer that at some earlier time an interaction took place, that a person's steps caused the ordered state of the sand; because this state was not "shuffled away", it is a record of the interaction.

(Reichenbach [1956], 151)

We have thus introduced a causal explanation to explain an instance of improbable order. Reichenbach therefore looks at alternative ways of describing the phenomenon, and particularly on the premiss of time direction moving in the reverse way. The description in reverse is of prior footprints, followed by someone stepping into them, after which an immediate shuffling takes place to restore the equilibrium of the sand. We can only explain such instances on the basis of *purpose*, in which the future determines how the past should behave. Such a language can be consistent, but it is unnatural and appears to contradict the time direction of our psychological experience. Reichenbach warns the Conventionalist at this point that in selecting a convention for use you cannot divorce yourself from the empirical consequences.

It is an empirical fact that in all branch systems the entropy increases in the same direction. For this empirical reason, the convention of defining positive time through growing entropy is inseparable from accepting causality as the general method of explanation.

(Reichenbach [1956], 154)

With this concept of cause as the interaction that produces the branch system, which is thereafter committed to the probability of entropy increase, Reichenbach indicates that thereby "the past *produces* the future", (Reichenbach [1956], 155). We can

thus demarcate the present -

The present is intermediary between past and future; it contains the active agent that produces the future, and it contains the records of the past, which is completed and irretrievable.

(Reichenbach [1956], 155)

Having provided this clear elucidation of the relationship between causation and temporal order, Reichenbach provides a brief summary of causal structure and time.

an order of time can be defined (without reference to a direction) by means of causal chains, and that, furthermore, the causal net is ordered as a whole. It follows that if we assign the positive direction of time to one causal chain, such a direction is assigned to all causal chains. By this relationship, the direction of time is determined for any two events that are connected by a causal chain, even if the process is reversible.

(Reichenbach [1956], 156)

Reichenbach diverts temporarily to consider the relationships between the concept of *information* and entropy, although this is irrelevant to the development of his overall argument. This is Reichenbach the engineer at work, fascinated by the application of mathematics to modern information technology. Subsequent to this he re-examines the concept of order in a causal net, given that knowledge of causal laws is not absolute but based on probabilistic assessments. He demonstrates that an ordered net can be constructed from probabilistic rather than causal implications. He subsequently describes a "marking" process as an irreversible event that establishes causal ordering, and hence a means towards a causal net. A mark is effectively a tracer that separates the time sequence of a subsystem, as for instance a chalk-mark on an object. He defines that -

If a mark in an event  $A(i)$  shows in an event  $A(k)$ , then  $A(i)$  is causally relevant to  $A(k)$ .

(Reichenbach [1956], 200)

This development does not add to his previous argument, but serves to introduce the concept of genidentity that he employs in his subsequent analysis of time direction in the quantum world.

The final section in DI is concerned with the quantum world. Reichenbach's purpose is to extend his analysis of time-direction through inclusion of quantum phenomena. He clarifies initially that although Schrödinger's equation takes a

different form from that of classical mechanics, it still represents a reversible relationship, and therefore in itself does not add a fundamental insight into time direction. That the solutions of the equation to provide observable measurement are probability implications, however, does involve us with causal indeterminism. Thus the probability lattice that would be constructed round a quantum system would specify a limiting description of the initial conditions, but the probabilities associated with predictions based on increasing knowledge of this description would not converge to a limit of one, but to some probability dependent on the experimental arrangement under the principle of indeterminacy. He continues as in PFQM to analyse the Heisenberg Principle of Indeterminacy as an objective property of the world inherent in the quantum formulation, rather than as being dependent on observational disturbance. He again justifies the formulation of the theory on the strength of its predictive power, and further concludes that in its existing form it removes causal anomaly from the observable world and contains it within the world of interphenomena.

He proceeds to investigate the genidentity of quantum objects. He begins by contrasting two modes of speech, - speaking of things, or speaking of events. The two modes are translatable into each other, and this relationship is important because we define a "thing" in relation to events succeeding each other in time. Thus Reichenbach asserts that "A thing is a series of events succeeding one another in time", (Reichenbach [1956], 224). He continues by qualifying a definition of macroscopic material genidentity under three conditions, which we can summarise as below -

1. Genidentity requires continuity of change; for example a continuous transition between spatial locations.
2. Spatial exclusion; two objects cannot occupy the same space.
3. Distinguishability of identity during changed location.

He points out that although these conditions are necessary to the concept of genidentity, other factors may also be required when dealing with, for example, an assembly like a wall. He then illustrates what he describes as functional genidentity, where the last two conditions may be violated, as, say, in the identity we assign to waves, or to a transferable package of kinetic energy. When we get involved in concepts like a river or a flame we have problems in rescuing our concept of genidentity, and Reichenbach points out that introduction of the concept of *atoms* restored our ability to trace concepts of unchanging identity through such apparently ephemeral occurrences

atoms are those last units which in their immutable sameness draw lines of material genidentity through the physical world.

(Reichenbach [1956], 227)

Thus the example of the two gases mixing in a container appears to require that two substances occupy the same space, until the conceptualisation in terms of discrete atoms is realised. The problem arises in the microscopic domain when we attempt to put an observational meaning on the concept of identity of fundamental particles. We cannot test for continuity of motion in a domain where the principle of indeterminacy applies, or attempt to trace identity by marking. Our only resource is through statistical measure, whereby the principle of genidentity leads to certain observable characteristics. Reichenbach therefore looks at the application of Maxwell-Boltzmann statistics, where, given "n" particles and "m" states or compartments, we have "m" to the power "n" possible arrangements. This is substantiated at the molecular level through Boltzmann's analysis of gases and the consequent derivation of measurable properties like entropy. When these statistics are applied to quantum entities, they no longer provide verifiable results. In the quantum domain, it is necessary to categorise the space by quantum energy states. It is illustrative to look at a trivial statistical example to differentiate the different statistical properties of the quantum domain. Divide the space into three states to be occupied by two particles. Under Maxwell-Boltzmann statistics we have nine possible arrangements, under the premiss of material genidentity and hence the individuation of particles. In quantum mechanics, however, we arrive at a different total number of arrangements. For some processes we would have only six possible arrangements, and for other processes only three. These can be shown to develop from different statistical treatments of the particles.

For the case of six arrangements we have correspondence with Bose-Einstein statistics which disregard the identity of individual particles; where for example under the classical statistics we would differentiate between the arrangement of particle "A" in state 1 with "B" in state 2, from the arrangement of particle "B" in state 1 with "A" in state 2, Bose-Einstein statistics makes no such differentiation. Thus all particles are indistinguishable. As an analogy Reichenbach suggests tossing two coins simultaneously, whereupon we expect one in four outcomes to give two heads, the same frequency for two tails, and two in four outcomes to give a head and tail together. If Bose-Einstein statistics were to apply to this situation we would in fact get one in three occurrences for each of the outcomes, two heads or two tails or a head and a tail together. We know that the coins are distinguishable, so that we would interpret the effect of a Bose-Einstein outcome as due to a causal connection between the coins, - a mysterious action at a distance. Thus an assignment of physical identity to a Bose-Einstein outcome must lead to apparent causal anomaly.

Referring back to the previous example, there are processes which would be consistent with providing only three possible

arrangements of two particles between three states. This would conform to Fermi-Dirac statistics which would require a maximum of one particle in any state. These statistics do not generate a direct counterdiction of genidentity, but this concept leads to a causal anomaly of mutual exclusion of particles at a distance. Thus the quantum formulation precludes the concept of genidentity unless causal anomaly is to be accepted. Only a form of functional identity can be accepted in the quantum domain.

Reichenbach subsequently sets out to construct an entropy concept for quantum systems, characterising the system by states rather, as in his gas-molecular analysis, than by particles. He thereby builds a lattice of the time-dependent development of parallel states. The conclusions for the two different statistical systems introduced with quantum mechanics differ significantly from those employing classical statistics when state occupancy is dense, but are similar at relatively low densities. This is consistent with empirical observation, where the greatest discrepancy from the Boltzmann predictions occur in gases at low temperature with a limited number of occupation states and a correspondingly high density of occupancy.

Reichenbach's claim is that if we attempt to distinguish the identities of quantum particles, we are involved in causal anomaly of a non-local nature. He therefore sets out, as in FFQM, to establish a descriptive language for interphenomena that preserves genidentity whilst changing the causal anomaly to a more manageable nature than that incurring non-locality. His conceptual hypothesis for the interphenomena with genidentity is that they can persist in either an "active" state or a "frozen" state in which they are unable to interact. On this basis he is able to construct an interphenomenal model that does not include non-local causal connection. He is able to justify this form of Conventionalism when dealing in the interphenomenal world, and is careful to avoid accusation of suggesting a physical hypothesis.

this interpretation does not constitute a physical hypothesis ... [it] represents merely a mode of speech. The assumptions on which it is based ... are all true by definition. They represent conventions on which this interpretation is based; these conventions are admissible, because they are compatible with the observed statistics. The interpretation shows that when we wish to introduce material genidentity into gas statistics, the resulting causal anomalies are still subject to our choice.

(Reichenbach [1956], 262)

Bas Van Fraassen, writing in Quantum Mechanics: An Empiricist View, and commenting on Reichenbach's analysis of time as applied to quantum phenomena, is clear that the concept of identity of quantum particles can not be sustained -

identity through time-history or, in Reichenbach's terminology, "genidentity" - loses at least its empirical significance in quantum mechanics.

(Van Fraassen [1991], 430)

He then concludes

individuation ... is by characteristics not describable in quantum-mechanical terms, as well as being empirically superfluous

(Van Fraassen [1991], 432,433)

Whereas Reichenbach wishes to pursue anomalies and to identify alternative approaches to some overall accommodation, Van Fraassen, as honest empiricist, provides a clear exposure that can be reflected back to the physicists, and leaves the matter there.

In his analysis of the quantum world Reichenbach has strayed from his thesis on the direction of time as if to partly make amends for the brevity of his quantum analysis in PFQM. In the final section of the book, however, he picks up the interpretation of some quantum phenomena by Stueckelberg and Feynman, whose interpretation requires particles to move backwards in time. A particular sequence to which this description is given would be classically described in the following way, - a gamma ray spontaneously generates an electron and a positron, subsequent to which the positron quickly collides with a second electron for both to vanish leaving only a gamma ray. Such a series has been observed on photographs from a Wilson cloud chamber. The Feynman description would start with the second electron, which disappears to release a gamma ray and a positron, which then travels backwards in time before colliding with a gamma ray to disappear and release an electron, which then proceeds in positive time. Thus the causal anomalies of creation from nothing and vanishing into nothing are eliminated, but the anomaly of reverse time direction is introduced. Reichenbach's observation is that -

As always in quantum mechanics, an exhaustive description of interphenomena is associated with causal anomalies; we have merely the choice where to place them.

(Reichenbach [1956], 266)

Reichenbach also observes that in the Feynman example, it is not only time direction which is reversed, but time order itself is abandoned in terms of the relations of "betweenness" of events. Previous analysis has related macrocosmic time direction and causal intervention to statistical concepts, and in a sense these interphenomenal events pose no direct threat to this analysis, but they challenge the fundamental concepts of time order and genidentity. Reichenbach offers no answer to these

challenges, but recommends that -

A logical analysis of these problems is highly desirable.

His final conclusion is therefore -

Time appears to be a completely macrocosmic phenomenon, which cannot be traced into the microcosm; it is born anew at every moment from the atomic chaos as a statistical relationship. Strangely enough, this origin from disorder does not make macrocosmic time inferior. On the contrary, it will be seen that the birth from an atomic chaos endows the statistical cosmos with a time of exactly those properties which commonsense and everyday experience have always regarded as intrinsic characteristics of temporal flow.

(Reichenbach [1956], 269)

Reichenbach had intended to write a final chapter to this book on the relationship between the subjective experience of time with its objective properties. His death intervened.

The Direction of Time displays the pragmatic Reichenbach in his most conscientious analysis of causal order. Although some of his arguments invite criticism, the thoroughness with which he analyses the concept of determinism and the relationship between entropy in isolated systems following causal interaction, adds significantly to our understanding of temporal order in the objective world. The analysis is empirical, and makes no reference to other philosophical systems, and yet underlying is the presumption that temporal direction is a concept that is imposed on experience. The topological order that we impose on the time manifold is demonstrated to be inextricably connected to the causal ordering through which we relate events in the world.

## Chapter 9

### CONCLUDING REMARKS

We have been able to trace the development of Reichenbach's philosophical writings from his initial attempts to incorporate probabilistic concepts and the relativisation of space-time into a Kantian context, through to the practical empirical analysis he employs in The Direction of Time. Although he rejects the logical structure that Kant used as a context of justification for his transcendental method, Reichenbach has continued to employ the Kantian method of investigating how empirical knowledge is derived through imposing formal order on unstructured experience. Thus The Direction of Time is an analysis of the rules employed in determining empirical time order and direction, and the Philosophic Foundations of Quantum Mechanics investigates the relationship between the rules we apply to the interphenomenal world of quantum mechanics and the rules we apply to the world of objects of immediate experience. Despite his rejection of the Kantian schema, Reichenbach resorts to the rule of causal connectedness as the guiding principle through which we form objective knowledge. Although he dismisses Kant's a-priori necessity for empirical causal ordering, Reichenbach's ultimate criterion for choice between rival scientific theories and explanations is in the degree to which they exhibit causal connectedness. His justification is that of the pragmatic engineer; that if we are to come to terms with the empirical world then we need to operate on the basis of its being orderly, that it is subject to causal connection, and that inductive methods are our best strategy. Hilary Putnam, in reviewing Reichenbach's work, observes

If we picture Reichenbach's system as an arch, with the causal theory of time, the probability theory of causality, and the theory of the spacetime metric as one side, and the theory of the epistemological primacy of physical things and the inductive inferences to unobserved things and to illata as the other side, the keystone of the arch is his celebrated pragmatic vindication of induction.

(Putnam [1991], 71)

Reichenbach, as empirical philosopher, looks beyond Hume's ascetic scepticism on the grounds that we have a need to deal with the world, and although experience can never provide us with unrevisable empirical truth, inductive assessment does give us a workable basis. He rejects Kant's appeal to the logical necessity for specific a-priori principles that must apply to knowledge, but he accepts the premiss that empirical knowledge only arises through the structure we impose on experience, - and objective causal structure is a prime requirement. The practical Reichenbach has the benefit of

developments in mathematics and physics through the nineteenth and early twentieth century, which he can assess against Kant's system. He is thereby enabled to appreciate that the rules we employ to structure knowledge are reviseable. He would thus agree with David Hume that absolute and sure knowledge of the objective world is unattainable, but he is prepared to commit himself to obtaining improved formulations of knowledge that are useable, and thereby vindicates Kant's transcendental method without, however, appealing to a logical justification of a-priori principles. Gernot Boehme discusses the Kantian method in "Kant's Epistemology as a Theory of Alienated Knowledge",

The aim of a transcendental theory of knowledge is to comprehend the connection between the rules of cognition that one follows and the constitution of an object.

(Boehme [1986], 338)

Reichenbach used a transcendental methodology throughout his philosophical work, even though, influenced by Moritz Schlick, he wished to distinguish his work from neo-Kantian scholasticism.

Wesley Salmon, in his resume of Reichenbach's work in "The Philosophy of Hans Reichenbach" (Salmon (ed) [1979], 1 - 84), observes on Reichenbach's epistemology

Since, for him, empirical verification is probabilistic or inductive, the way became clear to adopt a thoroughgoing empiricism without becoming involved in any form of phenomenalism.

(Salmon (ed), [1979], 43,44)

This over-simplifies Reichenbach's approach, in that his analysis is always directed towards the constitutive rules employed in concepts related to empirical description.

The two contemporary developments in philosophical method, which reacted to Kant's system, were logical positivism and conventionalism. Reichenbach was sympathetic with both, but was unable to embrace either as viable philosophical systems. His most cogent rejection of logical positivism is enunciated in Experience and Prediction where he demonstrates that verification of statements about empirical events cannot be absolutely realised in terms of simple truth or falsehood. Any statement about objective events carries with it concepts which have probabilistic and predictive elements embedded in them, and an appeal to direct verification must presuppose either the primacy of unstructured sense-impressions or of a directly given objective realism; - both of which, Reichenbach demonstrates to be mistaken simplifications. Differentiating his position from Poincaré's conventionalism is not so straightforward. Reichenbach was uneasy about a philosophical system that gave equal weight to alternative descriptions of reality; that all

self-consistent sets of conventions or coordinative definitions are equally valid. Reichenbach offers two means of discriminating between scientific theories employing different conventions; in Philosophy of Space and Time he recommends the adoption of the theory that eliminates *universal forces*, thus preferring Einstein's Special Theory of Relativity to that of Lorentz; and his second criterion is that a normal scientific explanation should conform to spatio-temporal causal ordering. As a pragmatic transcendentalist, Reichenbach necessarily adopts a conventionalist point of view, but as a practical engineer his analysis aims to provide the most useful and conceptually simple description of the world. Although conventions are arbitrary, the language which employs them relates to an objective world which is not; -

There are some essential features of language which are not arbitrary but which are due to the correspondence of language with facts; the task of philosophy is to point out these features and to show which features of language reveal structural features of the physical world.

(Reichenbach [1938], 271)

Thus any system of conventions which ascribes more than three dimensions to space is quite wrong.

Reichenbach's most distinctive achievement is in rescuing the transcendental method from scholastic neo-Kantianism and updating it against the developments of twentieth century science. His education as an engineer prepared him as master of modern mathematics and physical science to take account of the impact of twentieth century science on philosophy. His analysis is always based on a thorough understanding of the relevant scientific subject-matter, and his objective is to provide complete explication of the concepts involved.

In reading Reichenbach's analysis of a scientific theory, we are being led by the engineer with his avid thirst to understand, and which as a boy he had expressed

true science does not consist of the knowledge of a certain amount of facts and numbers but of the inner appreciation for the great interconnectedness of nature.

(Reichenbach [1978], v.1, 11)

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## INDEX OF NAMES

<p>Avogadro 106</p> <p>Birkhoff, G.D. 147</p> <p>Boehme, G. 164</p> <p>Bohr, N. 128-130, 134-142</p> <p>Boltzmann, L. 1, 6, 8, 19, 37, 105-109, 121, 130, 131, 141, 146, 150, 154, 155, 159, 160</p> <p>Born, M. 73, 129, 134</p> <p>Boyle, R. 61, 67, 106</p> <p>Buchdahl, G. 28, 29, 34, 59, 60</p> <p>Carnap, R. 1, 16, 17, 21, 107, 116, 119</p> <p>Cassirer, E. 7, 12, 18, 37-44, 53-59, 62, 63, 68-80, 84, 111, 125, 126, 131</p> <p>Coffa, A. 76, 77</p> <p>Cohen, H. 38, 40, 44</p> <p>Copernicus 20, 26, 116</p> <p>de Broglie, L. 128, 136, 139</p> <p>Descartes, R. 6</p> <p>Dirac, P.A.M. 129, 160</p> <p>Dubislav, W. 16</p> <p>Earman, J. 147</p>	<p>Einstein, A. 1, 12, 14, 15, 16, 20, 21, 31, 37, 44, 45-57, 58, 59, 65, 68, 72, 73, 74, 75, 83, 85, 92, 93, 95, 97, 100, 102, 113, 114, 127, 130, 148, 165</p> <p>Euclid 35, 38, 52, 60, 86, 104, 124</p> <p>Euler 56</p> <p>Faraday, M. 127</p> <p>Feynman, R. 161</p> <p>Friedman, M. 31, 71, 72</p> <p>Galileo 25</p> <p>Gauss 52, 106</p> <p>Gibbins, P. 130</p> <p>Giedymin, J. 67</p> <p>Goethe, J.W. 5</p> <p>Grelling, K. 16</p> <p>Grünbaum, A. 72</p> <p>Heisenberg, W. 129, 132-134, 137, 140, 142, 158</p> <p>Helmholtz, H.v. 84</p> <p>Hempel, C. 16, 22</p> <p>Hertz, H. 39, 127</p> <p>Hilbert, D. 7, 8, 78, 84, 85</p> <p>Hume, D. 7, 26, 33, 34, 123, 163</p>
---	--

Kamlah, A. 89, 90  
 Kant, I. 1, 6, 7, 8, 14, 15, 18,  
 19, 24-44, 46, 54-77, 78, 80,  
 82, 85, 90, 97, 102, 103, 104,  
 111, 119, 123, 124, 126, 131,  
 141, 143, 159, 163, 164  
 Kaplan, A. 22  
 Keynes, J.M. 121  
 Klein, F. 8, 31, 78, 84  
 Kranold, H. 10  
 Landauer, C. 8, 9, 10  
 Landauer, H. 8  
 Laplace, P.S. 153  
 Leibniz, G.W. 30, 45, 46, 47,  
 48, 55, 96, 97  
 Lobatchewsky, N. 86  
 Locke, J. 7, 26  
 Lorentz, H.A. 47, 48, 49, 50,  
 52, 72, 73, 74, 95, 96, 97,  
 100, 103, 127, 165  
 Mach, E. 47, 75, 121  
 Maxwell, J.C. 39, 46, 47, 48,  
 49, 52, 106, 127, 159  
 Michelson-Morley 46, 47, 48,  
 103  
 Minkowski, H. 8, 51, 52, 53, 100  
 Natorp, P. 38, 39, 40, 44, 74, 121  
 Newton, I. 25, 39, 45, 46, 47, 69,  
 74, 85, 110, 127  
 Ockham, W. 97  
 Okruhlik, K. 31  
 Planck, M. 7, 12, 15, 16, 22, 127,  
 128, 129  
 Plato 42  
 Poincaré, H. 18, 47, 62, 66, 67, 84,  
 110, 113, 151, 164  
 Polkinghorne, J.C. 130  
 Popper, K.R. 121, 124, 125  
 Putnam, H. 104, 163  
 Redhead, M. 137  
 Reichenbach, M. 20  
 Riemann, B. 79, 98  
 Russell, B. 21, 22, 143  
 Rutherford, E. 128  
 Ryckman, T.A. 76  
 Salmon, W. 13, 16, 21, 22, 124, 164  
 Schiff, L.I. 130  
 Schiller, F. 6  
 Schlick, M. 1, 16, 17, 18, 37, 63,  
 73-77, 164  
 Schrödinger, E. 128, 138, 139, 157  
 Spinoza, B. 6  
 Squires, E. 130  
 Strawson, P.F. 28, 31, 32, 34  
 Stuckelberg, E. 161

Van Fraassen, B. 160, 161

Von Aster, E. 7, 24, 37

Von Neumann, J. 147

Wittgenstein, L. 119

