THE CONCEPT OF TIME IN EMPIRICIST PHILOSOPHY

AUGUSTINE FAGAN

THE CONCEPT OF TIME IN EMPIRICIST PHILOSOPHY

Augustine Fagan, B.A. (Hons.) Memorial

Submitted in partial fulfilment of the requirements for the degree of Master of Arts

Memorial University of Newfoundland

April, 1970

"This thesis has been examined and approved by:

Joseph J. Russell, M.A.
Professor, Department of Philosophy
Queen's University
Kingston, Ontario

Francis L. Jackson, M.A.
Associate Professor
Department of Philosophy
Memorial University of Newfoundland
St. John's, Newfoundland

Table of Contents

ABSTRACT

The topic of the thesis is the attempt made by empiricist philosophers, notably Carnap and Reichenbach, to "reduce" time, or temporal order, to some physically observable feature of the universe such as causal chains or entropy increases in closed systems. This was not merely an attempt to find some physical counterpart to our subjective sense of time order but an attempt to eliminate completely any dependence, in the scientific context, on this subjective sense. The thesis examines the validity of this reduction and attempts to show why, both in the light of scientific evidence and in view of some more general philosophical or epistemological considerations, the empiricist attempt has failed.

Reductionism, as explained in the first chapter, is basically the thesis that certain types of concepts, the higher-level concepts of scientific theory, subjective or allegedly a priori concepts, are all defineable in a language which is descriptive of observable physical features of the world. The causal theory of time, as explained and examined in the second and third chapter, is reductionist in as much as in this theory, the temporal order is explained and defined in terms of an independently ascertainable relation among physical events, the causal relation. I try to show that the definition is circular and suffers from certain other weaknesses due to the notion of causality assumed in the theory. The thermodynamical definition of time order in terms of entropy

increases in observable closed systems is shown, in chapter four, to be paradoxical and based on some very questionable cosmological assumptions. In the fifth and concluding chapter I suggest an alternative to the reductionist conceptualization of science in which the relation of dependence or presupposition among scientific concepts and theories is no longer unidirectional and in which the relation between theoretical and observational language is much more complex and flexible.

Chapter One

INTRODUCTORY

1.1. Introduction

The passage of time is something familiar to all of us. Time, as a phenomenon worthy of philosophical concern, has always been a source of puzzlement, perplexity and paradox. Since the days of Aristotle there has been no shortage of answers to the question later asked by Augustine, "What, then, is time?". For Aristotle time was not a substantial entity capable of existing separately from other things and he defined it as the "number of movement in respect of 'before' and 'after'". Time, for Aristotle, was an attribute of motion and motion was an attribute of substance.

For Augustine time was something essentially subjective or psychological. There is only a "present of things past, memory; present of things present, sight; present of things future, expectation". For Kant, time was also, in a sense, subjective, for it was the form of inner sense, the mold or structure into which our experience of phenomena must fit and, other than being a form of experience, time had no objective existence.

The present thesis will concern itself with a more modern philosophical attempt to provide an answer to the problem of time. This answer I refer to as "reductionism" or the "reductionist thesis". It is the attempt made by empiricist philosophers, notably Carnap and

Reichenbach, to "reduce" time or temporal order to some observable feature of the universe, such as causal chains or entropy increase in closed systems, as these features are expressed in the lawlike statements of empirical science. Such a "reduction" or "definition" aims at eliminating the "mystery" from the notion of time, and at eliminating, in the scientific context, any dependence on temporal knowledge which may be termed, in some sense, "subjective" or "a priori".

The present chapter contains, other than an explication of terminology, a brief statement of the reductionist thesis. The following chapter presents Carnap's early Kantian-style approach to the problem of time as found in "Der Raum". The causal theory is introduced and also Carnap's axiom system for space-time topology based on causal chains. Chapter Three contains a critique of the causal theory, both from the point of view of internal difficulties and from the point of view of the notion of causality assumed in the theory. Chapter Four concerns itself with the thermodynamical approach to time order, the classical entropy law, Boltzmann's statistical analysis, Eddington and "time's arrow", and the Reichenbach "branch hypothesis". The Eddington and Reichenbach proposals are criticized and rejected. The final chapter offers a general criticism of the reductionist attempt where I try to show that it is based on an unacceptable conceptualization of science and on a misunderstanding of the nature of scientific-theoretic terms in relation to the concepts of experience.

1.2. Explication of Concepts

A series of events is temporally ordered when it is established for any two events of the series that one is earlier than the other, or, when this is not the case, under what conditions they are to be considered simultaneous. The ordering relation is the relation earlier than, with it's converse, later than.

The points on a straight line can be ordered by the asymmetric transitive relation "to the left of", with its' converse, "to the right of". However, the specification of the order "to the left of" involves reference to an external viewer and his particular perspective. The ordering relation "to the left of" is therefore a conventional or extrinsic ordering relation. An order is intrinsic when it does not involve reference to an external viewer. The relation of "betweenness" for points on a straight line is intrinsic, in our sense, since it does not involve reference to entities outside the domain. Given the intrinsic "betweenness" relation a serial order can be introduced into the system by the establishment of the asymmetric relation "to the left of" between two arbitrarily chosen reference points. A serial order can thus be defined for the whole line but this serial order is extrinsic. The serial order of the system of real numbers with respect to the relation "smaller than" is intrinsic, for any two numbers, their ordering with respect to magnitude does not involve reference to the particular perspective of some observer or to any entities outside the domain. Similarly, once betweenness has been defined, one can choose any two reference states in time and extrinsically order this time serial by making one of these events "earlier than" the other through the assignment of suitable real numbers. But this time-order is merely extrinsic. Time order would be intrinsic if there were some property, possessed by each of the total states of the world, which would define a dyadic relation between every pair of states such that the class of states forms an order with respect to this relation. If such a property existed the world would be temporally anisotropic. This property would allow us to determine an intrinsic difference in direction between the relation and its converse. When we speak of the "direction of time" we refer to this static directional difference between the relation and its converse, between "earlier" and "later". It does not mean that time "flows" in any privileged direction. When we speak of anisothropy of time we do not make any assertion about "the" direction of time.

1.3. A definition of Time

We all feel intuitively that there is a deep and far-reaching difference between past and future, earlier and later, which is more basic than the difference between left and right. The asymmetric temporal order with respect to the relation "earlier than" is so much part of our immediate awareness of the world that it hardly seems to be in need of justification. However, all attempts to account for the asymmetry of time in terms of the deeper physical features of the universe have met with insurmountable difficulties. Is there anything in nature which would enable us to "define" temporal order, anything to which temporal order could be "reduced"? or must we rely solely, not only in our practical, but also in our scientific endeavours, on our subjective sense of time order? To the former question many philosophers have given an affirmative answer. Eddington, for instance, found in the second law of the thermodynamics "the only law of nature which recognizes a distinction between past and future more profound than the difference of plus and minus"[1]. The property of the total states of the world which, for Eddington, defined an intrinsically asymmetric temporal order was entropy, the measure of organization.

> "Without a mystic appeal to consciousness it is possible to find a direction of time on the four dimensional map by a study of organization"[2]

Reichenbach, in his earlier writings, found the physical criterion for temporal order in an independently defined asymmetric causal relation. The temporal order was, in his system, "reduced" to the causal order. The causal theory of time received an elaborate logical refinement in the construction, by Reichenbach[3] and Carnap,[4] of a relativistic topology of space and time. Carnap has shown, in three ways, that the topology of space is reducible to that of time and that the latter is reducible to the topology of causal chains. Carnap's axiomatization does not, as

---

[1]Eddington, A.S. The Nature of the Physical World, Cambridge: Univ. Press, 1929, p. 69.

[2]Eddington, A.S. op. cit., p. 69.

[3]Reichenbach, H. Axiomatik der relativistischen Raum-Zeit Lehre, Braunschweig: F. Vieweg & Sons, 1924.

[4]Carnap, R. Abriss der Logistik, Vienna: T. Springer; 1929.

such, commit him to the causal theory of time since the "causal relation" is primitive in only one of his three versions. The third version, however, exhibits the space-time order as the expression of a causal order whose nature can be understood independently and in so doing he has established the deductive fertility and the explanatory capabilities of the theory.

It is my purpose to examine, in this thesis, the epistemological viability of this thesis of the reducibility of the temporal order to some independently knowable features of the universe as these are formulated in known natural laws.

1.4 Time-order and Law: a nomological approach

Two things are to be noticed, first of all, about this thesis of reducibility. Leaving for the moment, the notions of "definition" and "reduction" unclear, it is to be noted that the physical feature of the universe to which temporal order is to be "reduced" or in terms of which it is to be "defined" must be knowable in such a way that this knowledge must, in no way, make use of or presuppose a prior knowledge of the temporal order. And, secondly, this feature or property of the universe to which temporal order is reduced is known through the laws and equations of physical science. This second aspect we shall refer to as the "nomological" aspect of the reductionist thesis. This does not mean merely that the "time" in which these philosophers are interested is primarily or only "time" as understood in the context of a scientific theory even though this may be, for the most part, true.

We refer to the reductionist's explanation of time as nomological because of the use of the concept of natural law which it involves. A nomological explanation of temporal order would seek to demonstrate that the laws and equations of physical science provide us with an intrinsic criterion for the ordering of events with respect to the relation "earlier than". This criterion would do three things:

(1) it would provide time with a "direction", in the sense already explained;

(2) it would provide us with a physical explanation of the ultimate difference between past and future;

(3) it would enable us to determine, for any two events, and without recourse to our subjective impressions, which one was "earlier than" the other.

I aim to show that the empiricist's attempt at reduction has failed, not only because of their own understanding or explication of the concept of natural law, but because of the laws and equations of science itself. In other words, as far as the known laws of nature are concerned, temporal order is isotropic; there is no intrinsic, i.e. observer—independent difference between past and future. This means, in particular, that all known physical laws would remain valid in a universe in which our temporal order were reversed, in a universe whose past and future are interchanged with ours. If time—order is isotropic, the natural laws with time variable t^F in frame of reference F would remain valid in a frame of reference F^1 with a new time reference t^{F1} whereby for every event E it would be the case that

$t^{F1} = t^{F}$. In a universe in which the classical second law of thermodynamics, the law of entropy increase in a closed system, were to hold absolutely, time would not be isotropic since the principle of entropy increase would not be covariant under time reversal. In such a universe there would be an intrinsically definable difference between earlier and later, past and future, and temporal order could be "defined" in terms of entropy. Thus there would be a physical counterpart to our subjective sense of time order which would eliminate the need for recourse to this subjective sense in the scientific context. That, in our universe, as we know it through the laws and equations of physical science, there is no such physical counterpart to our subjectively known temporal order, whose nature could be understood independently of prior knowledge of temporal order, is what I hope to show in what follows. Positively, I hope to give an account of the epistemological status of our knowledge of temporal order and its implications for an empirical philosophy.

Chapter Two

CARNAP ON KNOWLEDGE OF TIME ORDER

2.1. Time-order a topological concept

Time order is a topological concept, independent of considerations of metric. The topological properties of time are those which remain invariant in any transformation from one frame of reference to another. In "Der Raum" Carnap attempted to demonstrate the special significance of the topological properties of space and it is to be assumed that analogous considerations would apply to the topological properties of time.

2.2. Carnap's theory of space

Carnap first distinguishes between formal, visual (intuitive) and physical space.

Formal space is a pure "theory of relations" or "order theory". This formal theory is not concerned with what are normally called spatial constructions, e.g. triangles, circles, but with the meaningless termini of relations, which termini may represent practically any set of objects in so far as these objects exhibit relations that satisfy certain formal conditions. The basic concepts need have no determinate meaning (Begriffsbestimmung) since only the relations are important, only the logical form. The axioms establish certain relations among the basic concepts and the necessary theorems can be deduced logically from the axioms without taking into account any possible meanings for the basic concepts. This relational theory establishes a formal structure which becomes the structure of space as we know it if, in place of the indeterminate, uninterpreted concepts we insert the usual spatial concepts of point, straight line, etc. This theory of formal space is an extension of the theory of relations. It's basic propositions are deduced from the basic laws of deductive logic and are completely independent of experience. They are, in the well known terminology, a priori but analytic.

Physical space, on the other hand, is part of empirical knowledge. It is, in Kantian terms, both synthetic and a posteriori. We perceive, in our experience of nature, certain relations, e.g. betweenness, nearness, which we call spatial. These are physico—spatial relations and the theory of physical space, which is part of empirical science, must determine which of, and to what extent, these relations hold among the objects of experience.

Apart from formal and physical space there is also visual (intuitive) space(Anschauungsraum). "By visual space we understand that body of relations between what are usually called spatial constructions, i.e. lines, planes, etc. whose peculiarity we perceive through sensible perception or merely by representation (blosen Vorstellung). Here we are not concerned with the spatial facts of experience but with the 'essence' of these constructions themselves".[1] The question here is not

---

[1] Carnap, R. Der Raum. Berlin: Reuter and Reichard; 1922. p. 6.

the psychological one of the origin of our spatio--visual constructions but the logical one concerning the foundation of our knowledge of such constructions. In particular this question, in the context of visual space, is restricted to the axioms or basic principles since all other propositions can be formally deduced from these. "Experience does not provide the justification for them; the axioms are..... independent of the 'quantity of experience', i.e. knowledge of them does not, as in the case of a posteriori propositions, become ever more reliable through multiply repeated experience. For, as Husserl has shown, we are dealing here, not with facts, in the sense of empirically ascertained realities, but rather with the essence (eidos) of certain presentations whose special nature can be grasped in a single immediate experience".[2]

2.3. Topological properties of space

We have called physical space a part of empirical science. The question, however, whether three or more given physical points lie in a straight line, cannot be answered from facts of observation alone, without some previously freely chosen rule or convention. We may choose to regard a light ray as straight. Or we may choose a definite rigid body and choose two points on it and lay down the measure for the distance between the two points. In relation to this metrical convention the question regarding the three points can be answered.

One of the more general sections of the theory of visual space

---

[2] Carnap, R. Der Raum. Berlin: Reuter and Reichard; 1922. p. 22.

is the theory of topological visual space. The theory of topological visual space is a system constructed without the concepts of straightness and congruence. Corresponding to this we have the topological physical space, likewise constructed without the help of the conventionally determined metric. Only topological space can give us a unique representation of the objects of experience. The projective and metrical space depend on a freely chosen conventional element and the type of spatial order in these systems will therefore not be unique.

Here Carnap makes another distinction, analogous to the matter-form distinction, but within the realm of form itself; the distinction between necessary and elective form. That part of the matter of experience which appears only in the necessary form is called the "fact-content" (Tatbestand) of experience. We can test a proposition to see if it is a "fact-content" proposition and, if so, what element is "fact-content", and which elective, by asking if the proposition remains valid for all possible forms of spatial reference. This would be the case if the content of the proposition were to remain invariant under all possible transformations, and, as we have seen, this is the case for topological propositions and only for those. An example of a "fact-content" proposition would be

> "This porcelain body is surrounded on all sides by this glass body".

In the fact-content of experience we are given the three-dimensional topological space, not, however, the metrical space. The topological properties remain invariant under all possible metrical choices.

Topological space gives that which is common to all space systems and can be regarded as the "form" of space known through "essential intuition".[3] (Wesenserschauung). The spatial determinations contained in the fact-content of experience are necessary conditions of experience in the Kantian sense. Such spatial determinations are, as we have seen, the topological ones. Apart from the axioms of visual (intuitive) space these topological proportions are the only synthetic a priori propositions of geometry. The topological properties of visual space are necessary and universally valid, are known a priori and are constitutive of experience.[4]

Summary: In an attempt to achieve some degree of clarity in the long standing dispute over the status of geometrical knowledge Carnap distinguishes between three different objects, formal, visual, and physical space. Formal space is an analytic order theory derived from the logical theory of relations. It is a priori in the way logic is. Physical space is the object of empirical science but only its topological properties are independent of conventional choices of metric. These properties form the fact-content of experience, remaining invariant in all spatial forms of reference. The axioms of visual (intuitive) space are a priori but among the derived propositions only the topological ones share this status.

2.4. Topological properties of time

The unit of time or the congruence of time intervals are

---

[3] Ibid. p. 62.

[4] Ibid. p. 66.

metrical concepts. The time metric depends on the establishment of co-ordinative definitions for unit of time, uniformity, etc. When these have been established time measurement is possible. Time order, the ordering of two events with respect to the relation "earlier than", is a topological concept. The time order of two events is independent of whatever co-ordinative definitions are used for the time metric. An event A, earlier than event B in frame of reference F will be earlier than B in all other possible frames of reference. Time order is invariant under all transformations. Remembering what was said about invariant spatial properties we could say that time order was part of the fact-content of experience. It is the "form" common to all temporal frames of reference. Time order would thus be a priori and constitutive of experience. The a priori character of our knowledge of time order is not explicitly stated by Carnap in "Der Raum" since he is dealing here exclusively with spatial problems. His general position, however, with regard to the special status of the topological properties of space, stated in terms of Husserl's "Wesenserschauung", lend plausibility to the above account of the epistemological status of the topological property of time-order. These epistemological considerations are also in agreement with the methods used in physics to the extent that in physics a space-time co-ordinate system, and thus a temporal order, belongs to the basic concepts.

2.5. Empiricist account of temporal order

In a later work on the foundations of logic and mathematics[5]

---

[5] Carnap, R. Foundations of Logic and Mathematics. International Encyclopedia of Unified Science, Vol. I, no. 3. Chicago: Univ. of Chicago Press, 1939, p. 49.

Carnap denies the existence of synthetic a priori knowledge in general. In the atmosphere of the Vienna Circle his position "became more consistently one of empiricism".[6] He does not, however, give his reasons for no longer regarding the topological properties of space (or time) as having a special epistemological status. The general empiricist attitude to the intuitive experience of time-order is reflected in the following statement of Reichenbach:

> "All our so-called a priori judgements are determined by primitive experiences, the physics of everyday life, to a much higher degree than we think..... we shall therefore use the distinction "time as experience" and "physical time" only as a temporary aid which leads to a deeper scientific insight into the concept of time; we shall correct the intuitive experience of time accordingly."[7]

Time-order, according to this view, is no longer constitutive of experience. It must be possible then, to find some property of the physical world, the nature of which can be known without presupposing a prior knowledge of time order, in such a way that this property could then provide a criterion for determining time order. Such a criterion was found in the causal relation. This "causal theory of time" had already occupied an important place in the philosophy of Leibniz and Kant. In this century it was developed and refined in the work of K. Lewin,[8]

---

[6]Schilpp, P.A. ed. The Philosophy of Rudolph Carnap, Open Court, 1963. p. 957.

[7]Reichenbach, H. Philosophy of Space and Time, Dover Publications, Inc.; 1958. p. 113.

[8]Lewin, K. Die Zeitliche Geneseordnung. Zeitschrift fur Physik, Vol. XIII, 1923.

H. Reichenbach,[9] R. Carnap[10] and H. Mehlberg,[11]. The causal theory received great impetus from Einstein's development of relativity theory, especially from his criticism of simultaneity. The Lorentz transformations, which express Einsteins special theory of relativity, permit the reversal of time order of certain events, namely, of those which cannot be connected by causal chains. Time order, it was therefore, argued, could not be more than causal order. Time-order no longer retained its a priori status but was, in the words of Reichenbach, "reducible to causal order".[12] The deductive fertility of this theory was greatly enhanced by the development, by Reichenbach and Carnap, of a relativistic topology of space and time, as was already mentioned. In this system the relation of cause—effect (the causal—or signal—relation) was assumed as a primitive term and it was shown that temporal order, and even spatial order, could be reduced to this primitive relation. Carnap offers three versions of an axiom—system for space-time topology. In

---

[9]Reichenbach, H. Axiomatik der relativistischen Raum-Zeit-Lehre. Braunschweig: F. Vieweg and Sons; 1924.

[10]Carnap, R. Abriss der Logistik, Vienna: T. Springer; 1929.

[11]Mehlberg, H. Essai sur la theorie causale du Temps. Studia Philosophica, Vol. I, 1935 and Vol. II, 1937.

[12]Reichenbach, H. The Direction of Time, Berkeley: University of California Press; 1956.

only one of them is the causal relation assumed as primitive, represented by the single primitive sign of the system, S, standing for "signal—relation". Every topological property of space, as well as time, can be expressed as a property of the signal relation. The axiom system is based on the conception of space and time found in Einstein's theory of relativity. The assumed causal relation is asymmetric, transitive and dense. Since, in the causal theory, the time relation is defined in terms of a causal relation which can be determined independently, it must be demonstrated that an understanding of the asymmetric causal relation must be possible without the necessity of a prior understanding of time order. In the next chapter I will critically examine the causal theory and attempt to show that the causal relation alone is not sufficient to define an asymmetric time order. The causal theory put forward in Carnap's axiomatization is beset by a circularity in that knowledge of the asymmetric causal relation presupposes prior knowledge of the temporal order which it seeks to define.

Chapter Three

CRITIQUE OF THE CAUSAL THEORY

3.1. Temporal symmetry of causal laws

Despite the philosophic demand for clarity and scientific exactness made by the proponents of the causal theory, there still remains a great deal of uncertainty as to the exact sense of the question which the causal theory is supposed to answer. According to Reichenbach's early attempt[1] the problem is one of providing a "co-ordinative definition" for time-order. Co-ordinative definitions, according to the usual interpretation[2], are rules of correspondence between theoretical and observational terms. They are sometimes called "operational rules" or "operational definitions"[3]. There is a sense in which our subjective impression of temporal succession is itself such a rule. Another rule referrer to the use of a clock. Understood in this way the rule provided by the causal theory would, in certain important cases, take the place of those customary rules based on

---

[1] Reichenbach, H. The Philosophy of Space and Time, op. cit. p. 123.

[2] Hempel, C. Aspects of Scientific Explanation, New York; The Free Press, 1965. p. 184.

[3] Bridgman, P.W. The Logic of Modern Physics, New York; Macmillan, 1927. p. 5.

subjective impression on the use of clock. This seems to be the sense of Reichenbach's thesis:

> "With respect to two events that are sufficiently separated in time, the observer has an immediate experience of time order, and he uses this experience on the basis for the ordering of the events. However, ... we shall not refer to the subjective expression of time order. .... we must therefore establish a different criterion. Such a criterion is found in the causal relation. If E_2 is the effect of E_1, then E_2 is called later than E_1. This is the topological co-ordinative definition of time order."[3a]

The important aspect of such a rule is that it is not meant to hold without exceptions. It is not an explicit definition and may be regarded as only a criterion. In this sense also Reichenbach, in his posthumously published book "The Direction of Time", speaks of the "explication" of the concept of time, and explication "which can never be proved to be strictly correct". "We can merely require that an explication be adequate, that is, that the explicans correspond, at least qualitatively, to the usage of the term in conversational language, and that if the explicans is put into the place of the explicandum, most sentences of conversational language do not change their truth value."[4] The purpose of such explication is of course precision and the elimination of vagueness. It is very difficult then to understand how Reichenbach, immediately,afterwards, can formulate the much stronger thesis that time order is no more than causal order, that "if time order were more than

---

[3a]Reichenbach, H. The Philosophy of Space and Time, op. cit. p. 136.

[4]Reichenbach, H. The Direction of Time, op. cit. p. 24.

causal order the Lorentz transformations and Einstein's relativity could not be accepted."[5] In fact those who reject this version of the causal theory of time, who think that time order has a meaning independent of causal order, are forced to deny physical significance to the theory of relativity. The honesty of such a statement becomes even more questionable in view of the fact that in this book Reichenbach has given up his earlier attempt to define time order in terms of the causal relation alone and provides a schematization based on reversible processes, which is in fact a new criterion and a much more restricted one than that of the causal relation. My interpretation of the problem as given in Ch. I. is, in agreement with Mehlberg's,[6] a nomological one. This is the problem of accounting for the asymmetry of temporal order on the basis of natural laws, i.e. whether natural laws provide the basis or justification for an intrinsic (observer independent) distinction between past and future, earlier and later, or whether they can be distinguished only in relation to an individual frame of reference or an individual observer. This interpretation preserves the two initial aims common to all such approaches to the problem of time. I consider these two fundamental aims to be (1) that the solution to the philosophical problem of time is to be found in the laws and equations of mathematical physics.

---

[5] Ibid., p. 25.

[6] Mehlberg, H. Physical Laws and Time's Arrow, in Feigl, Maxwell Current Issues In Philosophy Of Science, New York, 1961, p. 109.

(2) that the attempt must be made to dispense entirely with the need for recourse to the deliverances of our psychological or subjective sense of temporal order. "The problem of time cannot be solved by an appeal to intuitive knowledge."[7]

Of course the problem which immediately presents itself for the causal theory, in whatever way it may be formulated, is that of providing a criterion for determining an asymmetric causal relation which does not make tacit or illicit use of our knowledge of temporal order. Do the laws of nature provide us with a causal relation which is intrinsically asymmetric or "directed"? The laws of physics state functional relationships between certain physical quantities, and they assert that if certain physical quantities have a certain value, another quantity has a determined value. Such laws do not provide us with an asymmetric causal order because of the convertibility of functions. The law of Boyle and Mariotte for perfect gases provides such an example. The statement of the law is

$$p. v = R. T. M/m.$$

where pressure (p) volume (v) molecular weight(m) mass (M) and temperature (T) are in a functional relationship which holds for all changes in the values of the quantities, but which does not tell us which change is the cause of another, in the sense that it comes first. This relation is one of causal connection and is systemetrical. We know, of course, which

---

[7]Reichenbach, H. <u>The Direction of Time</u>, op. cit. p. 16.

change comes first when we experiment with gas but this knowledge depends on our subjective experience of temporal succession and cannot be derived from the law alone. Other laws which establish causal relations are the laws of classical mechanics, including relativity theory. These laws describe physical processes and these mechanical processes are, as is known, reversible, that is, the laws remain co-variant under time reversal. They thus fail to provide us with a physical basis for temporal asymmetry since, on the basis of these laws alone there is no intrinsic difference between the process and its reverse. The differential equations expressing the laws of mechanics are of the second order involving time as an independent variable. If f(t) is a solution of such an equation then f(-t) is likewise a solution. If p is the position vector of a particle and v its velocity, the property of time symmetry or covariance under time reversal means that if the equations of motion lead in a time interval t from a state p_1v_1 to a state p_2v_2 then in the same interval they also lead from $p_2 - v_2$ to $p_1 - v_1$. In a world containing only reversible processes such as the worlds of Newtonion mechanics and of the Lorentz--transformations of special relativity a serial time could not be derived from the laws of nature alone but could be only introduced extrinsically, that is, as dependent on our subjective impression of temporal direction. In such a world temporal order would be more than causal order and could not be reduced to the latter because of the indispensibility of our intuitively based knowledge of time-order. Whether the situation is essentially different from the point of view of laws describing other than mechanical processes is what we must determine later. The conclusion we have reached so far is that we cannot provide a criterion for establishing an asymmetry in the causal laws describing mechanical processes which is independent of previous intuitive temporal knowledge. Reichenbach's early attempt to establish the mark-principle as such a criterion has been sufficiently criticized by Grunbaum, Mehlberg and others and, in any case, Reichenbach himself abandoned it in his later work. A philosophically much more serious difficulty encountered by the causal theory is connected with the problem of a satisfactory explication of the concept of possibility. Two events are simultaneous, according to Einstein's definition of special relativity, if there is no possibility of a causal connection between them. If S is the primitive causal (signal) relation,two events a and b are simultaneous if neither a S b nor b S a could be the case. The physical basis for this in relativity theory is, of course, the limiting character of the velocity of light. Similarly, to say that event a is "before" event b it is not necessary the a S b be the case, only that a S b should be possible. In the Einstein Minkowsky scheme a is before b if a is situated somewhere in the "prior cone" of b. (fig. a).

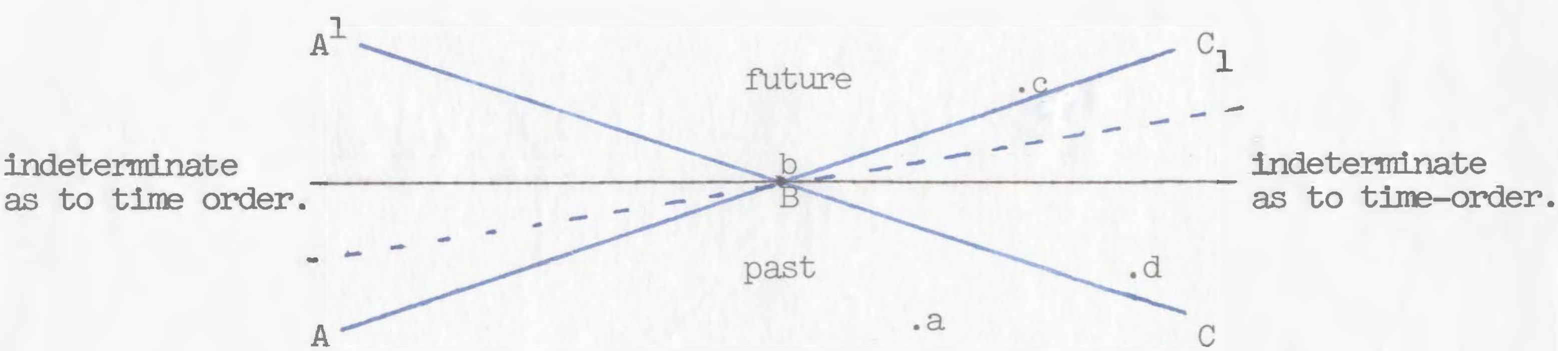

fig. (a)

In fig. (a) point-events b and d can be regarded as simultaneous.

All point events in the cone C^1 BC could be called simultaneous with b in cone A'BA because of the impossibility of establishing a causal connection between them and b. Similarly a, and all point events in the cone ABC, the "prior cone", are "before" .c. Some of these points events may actually be causally connected with C but this is not necessary in order for them to qualify as being before .C. The events in cone A^1 BC^1 are after b because of the causal connectibility of b and any event C in the cone A^1 BC^1. If temporal order is to be reduced to causal connectibility then, to avoid circularity, physical possibility must be definable or understood in such a way as not to presuppose the ordinal concept of time. This ordinal concept of time enters into the laws which tell us which physical processes are possible. It is no way out of this difficulty to arbitrarily stipulate, as Mehlberg[8] does, that any two events which can be possibly connected are to be regarded as actually connected. Given a class of simultaneous events and an event outside this class Mehlberg simply postulates that between this event and some event of the class there must be an actual causal connection. Such a hypothesis avoids the difficulty but does nothing to solve it. In any case it is an insufficiently grounded ad hoc assumption. Neither Reichenbach nor Carnap take account of this problem in their axiomatizations.

3.2. The Notion of Causality assumed in the theory

The first thing to be noticed about the notion of causality

---

[8]Mehlberg, H. La theorie causale du temps, op. cit. I, pp. 165-166, 240-241. II pp. 145-146, 169-172.

assumed in the causal theory is that it is an epistemological rather than an ontological category. By epistemological, in this sense, I mean concerned with our experience and knowledge of things rather than with some objective characteristic of the things themselves. If causality were the latter it would have ontological status.

This conception of causality is found in the philosophy of Locke, Berkeley, Hume and Kant. Locke, for instance, speaks of causality in the following way:

> "In the notice that our senses take of the constant vicissitudes of things we cannot but observe that several particulars, both qualities and substances, begin to exist, and that they receive this their existence from the due application and operation of some other being. From this observation we get our ideas of cause and effect. That which produces any simple or complex idea we denote by the general name, cause, and that which is produced, effect. Thus, finding that in that substance which we call wax, fluidity, which is a simple idea that was not in it before, is constantly produced by the application of a certain degree of heat we call the simple idea of heat, in relation to fluidity in wax, the cause of it, and fluidity the effect,.... For to have the idea of cause and effect it suffices to consider any simple idea or substance, as beginning to exist, by the operation of some other, without knowing the manner of that operation."[9]

Berkeley, likewise, emphasized the subjective nature of causality:

> "....we actually perceive, by the aid of our senses nothing except the effects or sensible qualities and corporeal things entirely passive .... real efficient causes of the motion and existence of bodies or of corporeal things in no way belongs to mechanics or experiment."[10]

---

[9]Locke, An Essay concerning Human Understanding, Book 2, Ch. XXVI.

[10]Berkeley, De Motu, section 40-41.

In the same manner Kant was later to argue that for human experience to be of the kind that it in fact is there must be, in addition to the empirical data provided by the senses, certain formal or structural elements which organize the manifold of sense into the patterns which comprise our actual experience. We experience the material world as consisting of material objects possessing qualities and involved in causal processes. The concept of substance or of thinghood and cause are not and could not be part of what is empirically received, but are the mind's contribution to experience; they are the formal as opposed to the material features of experience. Thus, according to Kant, the causal law does not apply to things but to experience alone. The relation between cause and effect is neither something observable nor something extracted from experience nor a product of subjective habit and association but rather a relation, into which the given of experience must enter, in order to make objective experience possible. Causality is thus the order of the given of perception according to a uniting principle (Einheitsprinzip) of thought, an application of the thought relation, reason and consequence, (Grund und Folge) to the material of perception. But although Locke had regarded causation as a connection, the distinctive mark of which was production, Hume and others following him have held that causality is only a relation; one relating experiences rather than things in the world. Hume rejects the concept of production as part of the notion of causality since it would not be empirically verifiable that a cause produces it's effect, but only that the event called cause is invariably associated with or followed by the event called effect. Causation is, then, according to this view, a component of experience rather than an objective form of interdependence obtaining among happenings in nature. The statement of a causal relation, therefore, between a class of events C and another class of events E does not involve any assertion about a unique bond or necessary connection between C and E. The causal law, "if C then always E" states no more than that there is, in Hume's words, a "constant union betwix the cause and effect".[11] The statement, "if C then always E" is a universal conditional statement expressing the constant conjunction of two kinds of terms. This constant conjunction is not an ontological connection but an external association, an invariable coincidence. The statement contains three notions associated with causality; the conditionalness peculiar to lawfulness, the existential priority of the cause over the effect, and the lack of exception, but it makes no assertion about any active or productive nature that causal agents are supposed to possess and nothing about the process out of which E emerges. The causal relation then becomes a statement of an exceptionless repetition. According to Ayer "every general proposition of the form 'C causes E' is equivalent to a proposition of the form 'whenever C then E' where the symbol 'wherever'

---

[11]Hume, Treatise, Book I, part III, section XV.

must be taken to refer, not to a finite number of actual instances of C, but to the infinite number of possible instances."[12] Likewise, for Reichenbach, causality is defined as a relation, belonging to the same category as statements like "B lies between A and C" and not as a connection.

> "To say that an electric current causes a deflection of the magnetic needle means that whenever there is an electric current there is always a deflection of the magnetic needle. The addition in terms of 'always' distinguishes the causal law from a chance coincidence. It once happened that while the screen of a motion picture theatre showed the blasting of lumber, a slight earthquake shook the theatre. The spectators had a momentary feeling that the explosion on the screen caused the shaking of the theatre. When we refuse to accept this interpretation, we refer to the fact that the observed coincidence was not repeatable.
>
> Since repetition is all that distinguishes a causal law from a mere coincidence, the meaning of causal relation consists in the statement of an exceptionless repetition - it is unnecessary to assume that it means more. The idea that a cause is connected with its effect by a sort of hidden string, that the effect is forced to follow the cause, is anthropomorphic in its origin and is dispensable; if - then - always is all that is meant by a causal relation. If the theatre would always shake when an explosion is visible on the screen, then there would be a causal relationship."[13]

But the notion of exceptionless repetition is really no more than the notion of lawfulness. But laws, in the impirical tradition, are not defined in ontological terms of the immanent

---

[12] Ayer, Language, Truth and Logic, London; Victor Gollanez, Ltd., 1936. p. 55.

[13] Reichenbach, H. The Rise of Scientific Philosophy, Berkeley: University of California Press; 1951. p. 157-58.

patterns of being and becoming but in the epistemological terms of conceptual constructions. Thus Braithwaite defines laws in the following way: "What we call the laws of nature are conceptual devices by which we organize our empirical knowledge and predict the future".[14] This is, of course, in line with the Kantian tradition. Carnap sees in the laws of nature just "assertions with a general content" and Mach says that a law of nature is nothing but "a rule for displaying all single predictions."[15] A law then is a statement within some scientific theory. The identification of law with rule of procedure made by Mach leads readily to another identification, namely, that of causality with lawfulness. Thus Mach writes, again:

> "The business of physical science is the reconstruction of facts in thought, or the abstract quantitative expression of facts. The rules which we form for these reconstructions are the laws of nature. In the conviction that such rules are possible lies the law of causality."[16]

The principle of causality is therefore no more than the assumptions of the lawfulness of all natural phenomena. Russell gave the following definition:

> "By a causal law I mean any general statement in virtue of which it is possible to infer the existence of one thing or event from the existence of another or of a number of others."[17]

---

[14] Braithwaite, R.B. Scientific Explanation, Cambridge: Cambridge University Press, 1953, p. 339.

[15] Mach, E. The Science of Mechanics, 1883. Reprinted in La Salle: Open Court Publishing Co.; 1902. p. 439.

[16] Ibid. p. 605.

[17] Russell, B. Our Knowledge of the External World, London: Allen and Unwin, 1926, p. 216.

The causal connection then, which plays such a central role in the causal theory of time, is to be found in a lawlike statement of scientific theory, which statement expresses a relation between two terms, a relation of constant conjunction.

We have seen how the concept of causal connection assumed in the causal theory contains the three notions of conditionality, temporal priority of cause over effect, and regularity or constant conjunction. In order to reduce temporal to causal order we must first drop the notions of temporal priority from the concept of causality. Thus we are left with the notion of regularity. By the statement "If C then always E" only a constant relation between two terms is meant, two terms that are "conjoined but not connected" (Hume) and of which, in this case, one cannot say which of them is temporally prior to the other. C and E are just regularly conjoined. Obviously there is nothing in this relation of constant conjunction which would make it intrinsically asymmetrical. This seems to me to be the main reason why the causal theory has failed to provide an independent criterion for temporal order. A concept of causality which would include, in addition to the notion of regularity, the notions of productivity or activity of the causal agent and the notion of the process out of which E emerges would be in a better position to provide us, it seems, with some physical criterion for a direction in the causal and thus in the temporal process. The causal law concept assumed in the causal theory cannot say that a given entity (or a change in it) is <u>produced</u> by another entity (or change) since, according to this theory, we cannot give an account of this production. As long as causality is identified with regularity then it cannot provide us with an independent criterion for temporal order and the empiricist exclusion of those other notions from the concept of causation has made the task of reduction an impossible one.

This account of causality which I have given is not meant to imply that the empiricist conception of causality is not an adequate one or that an adequate account of causality must also include the notions of productive agent or productive process. It was merely intended to show that the exclusion of these latter notions from the account of causality and its reduction to regularity makes impossible the empiricist attempt at reducing temporal order to an independently defined asymmetric causal relation.

Reichenbach had begun with the Kantian statement: E1 shall be called <u>earlier than</u> E2 when E1 is a cause of E2. But here he separated himself from Kant. Kant had presupposed the experienced time order in order to be able to define when E1 should be called a cause of E2. Reichenbach made the attempt to go forward without the Kantian assumption. E1 should be called a cause of E2 if a variation of E1 is always accompanied by a variation of E2, but not vice versa. He wished thereby to establish the asymmetry and, at the same time, the irreversibility of the causal relation. This was very sharply criticized by H. Bergmann who showed that Reichenbach's variation-method did not even produce the desired asymmetry. Reichenbach, in a later work, states his position as follows:

> "When we look at some simple cases of the causal relation we find that there are natural processes which show very clearly the difference between cause and effect. Mixing processes and such processes as go from an ordered to an unordered state are of this type. The physicists call them irreversible processes.... we can mix coffee and cream but we can't unmix them. It is a basic property of the world in which we live that the causal relation produces serially <u>ordered</u> physical events."[18]

But if one were to ask "when is E1 the cause of E2?" then one would ask in vain. Also, temporal order is now defined by means of increase of entropy in irreversible processes. If this is at all consistent with his previous definition by means of causal signals then the transmission of the signal from P_1 to P_2 must be assumed to be an irreversible process. But, in this case, it is the irreversible processes that are the foundation of the temporal order and it is not possible, in the context of Relativity Theory, to define a temporal order. For irreversible processes are as little evident in Relativity Theory as they are in mechanics. Thus a relativistic topology of space and time based on the causal relation is not possible. Apart from the difficulties peculiar to the variation-method the main cause of this failure seems to be the restricted notion of causality which is operative in the causal theory. The next chaper will be concerned with the attempted definition of time in terms of irreversible processes.

---

[18] Reichenbach, <u>The Direction of Time</u>, <u>op</u>. <u>cit</u>. p. 24.

Chapter Four

TIME ORDER IN THERMODYNAMICS

4.1. The Second Law

The impossibility of constructing an engine which, with no other outstanding changes, will convert a given amount of heat completely into mechanical work is a fundamental law of Thermodynamics. The first law is the statement of the principle of the conservation of energy, and it states that in all changes there exists a certain quantity, called energy, which retains a constant value. The second law states that there is another quantity, called entropy, which in some changes remains constant, but in other changes increases, whereas it is impossible that this quantity should ever decrease. Entropy can be created at will and there is an increase of intropy in every natural process, if all systems taking part in the process are considered. This law of thermodynamics was formulated by Clausius (1850) and Thomson (1851) and in terms of thermodynamical parameters such as volume, specific heat, absolute temperature, it makes possible the mathematical expression of a direction controlling the course of physical occurrences. As formulated by Clausius the second law required that "the entropy of the world keeps increasing." Later on the principle was reformulated so as to imply that the constancy of the increase of entropy applied to observable "closed" systems, that is, systems exchanging a negligible amount of energy with their surroundings, rather than to a single unobservable entity called "the world." The simple example of the mixing of substances at different temperatures, or the flow of heat from a higher to a lower temperature, is illustrative of all such natural processes. When all of the entropy changes in the process are summed up, the increases in entropy are always greater than the decreases. In the special case of a quasistatic process the increases and decreases are equal. In other words, no process is possible in which the entropy decreases. This fundamental law of nature, as formulated by Clausius, we refer to as the phenomenological second law of thermodynamics or as the classical entropy principle. What is the significance of the increase of entropy that accompanies every natural process? The answer, or one form of the answer, is that it represents the extent to which the Universe "runs down" in that process. Consider the example of the mixing of the hot and cold water. We <u>might</u> have used the hot and cold water as the high and low temperature reservoirs of a heat engine, and in the course of removing heat from the hot water and giving heat to the cold water we could have obtained some mechanical work. But once the hot and cold water have been mixed and have come to a uniform temperature, this opportunity of converting heat to mechanical work is lost, and, moreover, it is lost irretrievably. The lukewarm water will <u>never</u>, according to the phenomenological law, unmix itself and separate into a hotter and colder portion. Of course, there is no decrease in energy when the hot and cold water are mixed, but there has been a decrease in the availibility, or an increase in the unavailibility of the energy, in the sense that a certain amount of energy is no longer available for conversion into mechanical work. Hence, when entropy increases, energy becomes more unavailable, and we say that the Universe has "run down" to that extent.

The tendency of all natural processes such as heat flow, mixing, diffusion, etc., is, according to this interpretation, to bring about a uniformity of temperature, pressure, composition, etc., at all points. One may visualize a distant future in which, as a consequence of these processes, the entire Universe has attained a state of uniformity throughout. When and if such a state is reached, although there would have been no change in the energy of the universe, all physical, chemical and biological processes would have to cease. This goal toward which we appear headed has been described as the "heat death" of the universe. Thus, according to the second law of thermodynamics, the universe is constantly moving in the direction of ever increasing entropy. It is impossible that it should ever move in the direction of decreasing entropy, that is, in the direction of ever increasing order. Entropy is the increase of the random element in the universe and the universality and absoluteness of this increase of entropy offers an apparently dependable and, it seemed, exclusive indication of a physical counterpart to our subjective sense of the passage of time in the direction from earlier to later states. If the universe as a whole possesses at every moment a specific entropy, this value is subject to the general law of entropy increase; this means that, according to the classical principle, the universe progresses toward more and more equalized states. The direction of the increase is the direction of positive time.

The second law of thermodynamics states that the entropy increases in a closed system as long as any processes are going on within it, i.e. as long as a state of equilibrium has not been reached. This law applies to a system only as long as the system is closed. Assume we have a container with a partition in the middle. On one side of the partition is gas and the other side has been evacuated. We then remove the partition. The system is now a closed system. Immediately the gas flows into the vacuum from one side of the container to the other and entropy increases. We could restore order, i.e. cause a decrease of entropy, only by interfering with the system. But then it is no longer a closed system.

Obviously the laws describing such processes are, according to the classical principle, not covariant under time reversal. The process is an irreversible process and since it is irreversible it is unidirectional. That is, it provides us with an intrinsic, observer - independent difference between the process and its reverse, between one direction and its opposite. The existence of such a property would render the world temporally anisotropic since, as was stated in Ch. I, it would allow us to determine an intrinsic difference in direction, i.e., a static directional difference, between the temporal ordering relation "earlier than" and its converse. We could then account for temporal asymmetry in terms of this deep and all-pervasive physical fixture of the universe. This is, basically, what Eddington attempted to do. However, before we evaluate Eddington's attempt to explain time, we must discuss the important change brought about in the theory of thermodynamics by Boltzmann. To state it briefly, Boltzmann put an end to the absoluteness of the second law of thermodynamics. He found that the principle of the increase of entropy was not in fact a strict but a statistical law. According to Boltzmann we can no longer say "entropy will always increase" but only "it is highly probable that entropy will increase." Decrease of entropy, moving in the direction of greater order, is no longer an impossibility but an improbability, although a very strong one.

4.2. The Boltzmann statistical interpretation

During the latter half of the nineteenth century, it was realized by Maxwell, Boltzmann, and others that the extreme simplicity of the experimental behaviour of gases implied an extreme simplicity in the structure of gases on a molecular scale. Only by making a very simple picture of an ideal gas can one expect to derive such very simple laws. This picture and the derivations of the experimental laws from it constitute the subject matter of the kinetic theory of gases.

In order to derive results that are consistent with the fact that the specific thermal energy of a gas depends on temperature alone, it is necessary to assume that the molecules of a gas are essentially free particles, that is, that most of the time they are acted on by no forces. They do, however, make collisions with each other and with the walls of the containers, and during these collisions very large forces act to change the directions of the molecular motion. Between collisions the molecules move in straight lines in random directions at very high speeds. The pressure of the gas on the walls of the container arises from the collisions of the molecules with the walls. In the earlier development of the kinetic theory probabilistic law has already been applied by Maxwell to the arrangements of molecules. The actual velocites of molecules might be calculated by starting with the supposition that all had the same speed but a random distribution of directions. A short interval later some collisions would take place, the results of which could be calculated by the ordinary methods of mechanics. After another short interval more collisions would take place, and again the results could be calculated. Such calculations would be long and tedious, but Maxwell was able to work them out using statistical means. He found that after enough time had elapsed the distributions of speeds in the gas becomes constant. For every molecule that was slowed down by a collision another was being accelerated. According to his scheme there are practically no molecules with zero speed, a maximum number with a certain probable speed, and fewer than this with higher speeds. This statistical theory does not apply, of course, when the number of molecules involved becomes small. This sort of distribution is frequently encountered and is called a Maxwellian distribution. Using the results of the kinetic theory of gases, according to which the heat content of a gas consists in the irregular mechanical motion of its molecules, Boltzmann showed that the collisions of molecules are governed by statistical laws which lead to an average equalization of differences in speed. When a fast molecule hits a slow one, it may occasionally happen that the slow one imparts some of its speed to the fast one, which then travels even faster. Such occurrences are, however, an exception. In the vast majority of cases it will lead to an equalization of the speeds of both molecules. Going from higher to lower temperatures is then understood as the statistical equalization of differences in molecular speed. That entropy increases during physical process means, then, that ordered arrangements of molecules are changed into unordered ones. The law of the increase of entropy is guaranteed by the law of large numbers. The probability W of a state is therefore related to the state's entropy by the relation

$$S = k. \log W$$

The law however is no longer of the type of the strict laws of physics, such as the laws of mechanics. In other words, there are possible exceptions. But the increase of entropy in every closed system is guaranteed because the probability of an unordered state greatly exceeds the probability of an ordered state. The direction which entropy gives to physical processes is thus a statistical trend rather than an absolute direction. Becoming is a transition from ordered states to more and more unordered states, from improbable to highly probable configurations of molecules. Boltzmann's H—theorem, that the entropy source strength σ— is equal to or greater than Zero, expresses the fact that the entropy in a closed system can only increase in the course of time and, in fact, must approach a limit as the time t tends to infinity. The direction of physical processes, and thus the direction of time, is thus explained as a statistical trend and the law expressing this is a probabilistic rather than a strict or nomological implication. If the probability is extremely high one might easily mistake a probability law for a strict law. This, then, was Boltzmann's contribution to thermodynamics, to show that the strict phenomenological second law of entropy increase, formulated by Clausius was, in fact, a probabilistic or statistical law. It was on the basis of these results that Eddington formulated and developed his theory of the direction of time, of "time's arrow".

4.3. Eddington and Time's Arrow

Any change occurring to a body which can be treated as a single unit can be undone. The laws of nature admit of the undoing as easily as the doing. Such laws controlling the behaviour of single individuals Eddington calls primary laws. A sequence of states running from past to future is the doing of an event and the same sequence running from future to past is the undoing of the event. The earth, in its orbit around the sun is controlled by certain laws of motion and gravitation. But there is nothing in these laws of planetary motion which would prevent the earth from moving in the opposite direction. The laws of motion and gravitation are indifferent as to the direction, they do not distinguish between the doing and the undoing. So the primary laws of nature are indifferent as to the direction of time from past to future. There is no more distinction between past and future than between left and right. Such laws describe processes which are reversible and provide us with no intrinsic basis for our distinction between earlier and later, i.e. they are covariant under time reversal. The nomological approach to the reduction of temporal order would necessarily fail if all natural laws turned out to possess this covariance.

> "There is only one law of nature—the second law of thermodynamics—which recognizes a distinction between past and future more profound than the difference of plus and minus. It stands aloof from all the rest. But this law has no application to the behaviour of a single individual, and, as we shall see later, its subject matter is the random element in a crowd."[1]

Thermodynamics is the study of organization and, for Eddington, it is in connection with organization that a direction of time and a distinction between doing and undoing appears for the first time. There is a distinction because, if the event is a thermodynamical rather than a mechanical one, that which is done can never be undone. "Whenever anything happens which cannot be undone, it is always reducible to the introduction of a random element analogous to that introduced by shuffling".[2] Of course, since the law is a statistical one, it is not

---

[1]Eddington, A.S. Nature of the Physical World, Cambridge: University Press, 1929, p. 66.

[2]Ibid., p. 68.

impossible that the original order should, by some chance, return, but it is very highly improbable and "This kind of contingency can be disregarded".[3] Space does not have this one-way property. Nature is indifferent to the interchanging of left and right and a "looking-glassed" space continues to make sense whereas a "looking glassed" time becomes a "nonsensical farce." Eddington uses the phrase "time's arrow" to express this irreversible directional property of time. Of time's arrow he says,

> "we must note that
>
> (1) it is vividly recognized by consciousness.
>
> (2) it is equally insisted on by our reasoning faculty, which tells us that a reversal of the arrow would render the external world nonsensical.
>
> (3) it makes no appearance in physical science except in the study of organization of a number of individuals. Here the arrow indicates the direction of progressive increase of the random element."[4]

Without any appeal to consciousness it is possible to establish scientifically an intrinsic direction of time by a study of organization, i.e. by a study of the increase of the random element in the universe. And the introduction of randomness is the only thing which cannot be undone.

The certainty of the second law is the certainty of large numbers. When the gas of the previous example has moved from one

---

[3] Ibid., p. 64.

[4] Ibid., p. 69.

compartment into the other, disorganization has increased. There is a possibility, strictly speaking, that the molecules of gas may return to the one half of the container where they were held previously but this is a chance which can be ignored. The chance is absurd as a practical contingency, but it is precise as a measure. The measure of this random element is entropy and the law which says that entropy must always increase holds "the supreme position among the laws of nature".[5] The laws which forbid the impossible are the primary laws, those which forbid the too improbable are secondary. The second law of thermodynamics is a secondary law. Time loses its arrow only when complete thermodynamical equilibrium has been reached. Time still exists but it has no direction since nothing else can give time a direction when entropy fails to distinguish one. "So far as physics is concerned time's arrow is a property of entropy alone."[5a]

But even a statistically defined entropy has failed to provide time with an arrow and very serious objections can be made against Eddington's analysis. The transition from causal to probabilistic laws has had no effect on the problem of time. The probabilistic laws for a probabilistically redefined entropy will also be shown to be covariant under time reversal in spite of the fact that the predictive value of the original phenomonological principle can be retained completely. We must return to the work of Boltzmann and the

---

[5] Ibid., p. 74.

[5a] Ibid., p. 76.

problem of reversibility.

4.4. The Reversibility Objection

The difficulty to be discussed now concerns the question whether it is true that changes toward states of higher entropy, or of higher probability, are more probable than changes in the opposite direction. In his "Gastheorie" Boltzmann was especially concerned with the question, why it is possible to describe the behaviour of almost all physical systems by considering only equilibrium situations. He had introduced his famous H-theorem in order to show that any non-equilibrium situation would develop in such a way that it would approach an equilibrium situation. The answer to the question was, in this case, that the equilibrium situation is the most probable situation, that is, the most probable situation compatible with a few restricting conditions. Previous work in the kinetic gas theory had already brought a certain amount of agreement in the evaluation of probability methods in the explanation of aerodynamic processes on the basis of two fundamental groups of hypotheses. These hypotheses were

(1) Mechanical-structural hypotheses: Every gas quantity is a mechanical system consisting of an enormous number of similarly structured molecules.

(2) So-called probability hypothesis: lawlike behaviour can be attributed to the inestimably complicated movements of molecules in the form of statements about the relative frequency of different configurations and movements of the molecules.

Boltzmann arrived at the conclusion that these hypotheses, as used by Maxwell and Clausius, were sufficient to deliver a comprehensive explanation of the irreversibility of processes, i.e. a kinetic explanation of the increase of entropy with increase of time. T. Loschmidt (1867) and later other authors, among them especially E. Zermelo (1896), brought objections against the Boltzmann result which could be summarized in the following statement: It follows from the most basic assumptions of the kinetic theory of gases that an equally large increase or decrease of entropy are further justified. Loschmidt's "reversibility paradox" showed that for each system which shows a steady increase of entropy we can construct a system for which entropy is steadily decreasing. Another difficulty was pointed out by Zermelo who used a theorem of Poincare's. Poincare had shown that if a system enclosed in a finite volume passes through the sequence from t, to t_n, say, this sequence will be repeated as accurately as we wish it to be repeated after a finite time interval. This paradox is called the recurrence paradox. The reversibility and recurrence paradoxes invalidate the H-theorem in its unrestricted form, that is, the statement that entropy must always increase. It stands to reason that the second principle of thermodynamics, committed as it is to the irreversibility of processes, could not make a consistent adjustment to statistical mechanics derivable from Newton's reversible laws of motion except by severely restricting or abandoning the claim that irreversible processes occur in nature. The difficulty arises not only from the nature of mechanical processes but also from the nature of probability methods as such. The elementary processes of statistical thermodynamics, the motion and collisions of molecules, are described and predicted by the laws of Newtonian mechanics and are therefore reversible. Assume we have an insulated container with two compartments separated by a removable partition. One compartment is filled with gas and the other is empty. If we now remove the partition the molecules of gas flow into the empty compartment, all moving in an orderly fashion in the same direction, say +d. The molecules then collide with walls of the second compartment and are reflected in a disorderly fashion. Entropy, the measure of disorganization, has increased. But, in Boltzmann's gas theory, the probability that a molecule will have a certain velocity is independent of the sign of that velocity. If the velocity of the molecules moving in direction +d is +v, then, according to this, the reverse velocity, — v in direction -d, is equally probable. But the movement of the molecules in direction -d would mean a return of the molecules to the original compartment. But this is a highly ordered arrangement and entropy has decreased. This is not a description of a very likely occurrence but it means that, according to the basic assumptions of the mechanics of reversible processes, such a state may occur as a natural result of many collisions and that, in fact, the occurrence of such a state has a definite probability. In the long run, it can be shown that such processes occur with the same probability as their reverse, i.e. over a sufficiently long period of time processes in which entropy decreases occur as often as processes in which entropy increases. This is also a necessary result of the nature of objective probability as such. Every state which has a non-zero probability must occur with that non-zero frequency. Given a closed system which begins to develop from an ordered state, like the gas in the previous example, the initial state has a low entropy. The entropy will then increase until it reaches a state of equilibrium. The entropy may then retain a high value for a long period of time but there will be fluctuations. But will the system ever return to a state of order similar to its initial state? According to probability theory, since the initial ordered state had a definite positive probability value this ordered state must eventually recur. In fact, each point on the initial curve representing the initial entropy increase represents a state of the system with an ever increasing positive probability value. States represented by points close to the peak of the initial curve will occur more often, i.e. minor fluctuations will occur more often than major ones, but since the highly ordered state represented by the bottom of the curve has a positive value, it too must eventually occur, i.e. there will eventually be major fluctuations. The curve for such a closed system could be represented by the following graph:

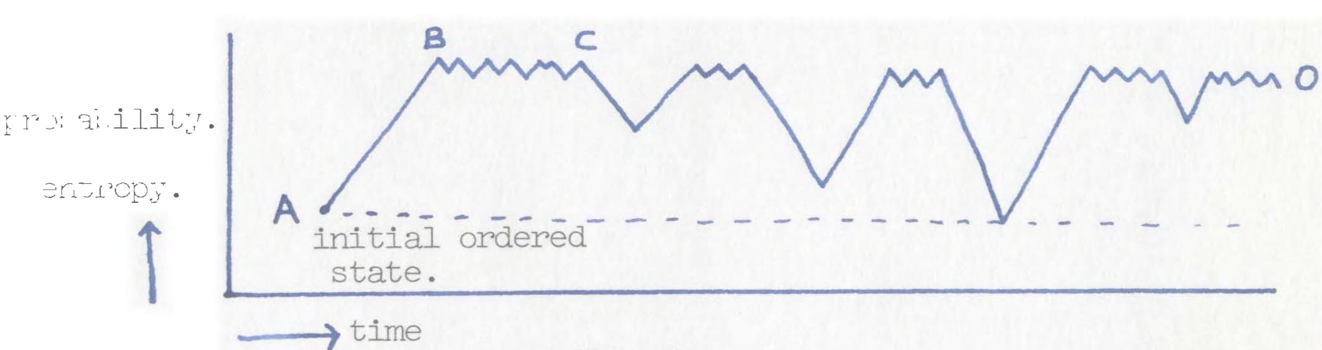

fig. 2.

The curve will stay at high values most of the time and, looking at the curve, we see that every increase of entropy, excluding the initial one, is preceded by a corresponding decrease and for a curve of infinite length there are as many increases as decreases. Therefore transitions to lower entropy are as frequent as transitions to higher entropy. This is the reversibility objection. Its relevance to the problem of finding a physical criterion for time-order is obvious.

Assuming the universe to be spatially finite, the curve in fig. 2. could also be the curve for entropy increase in the universe. Any point on the curve would represent an "instantaneous state" of the universe, a temporal cross-section through the four-dimensional space-time world. This means that the curve would also have to extend to the left of A, rising to a point of high entropy, and continuing to the left in much the same fashion as the curve ABC...O does to the right. Now increases and decreases occur equally often on the curve and therefore the curve does not possess a unique direction. Given any point P on the curve and if Q represents a state separated from P by a sufficiently long time period, i.e. if Q is temporally later than P, then it is more probable that the entropy of Q is higher than the entropy of P than vice versa since the curve stays in upper levels much longer than in lower levels. But if Q precedes P in time the same result follows since it does not make any difference when we move to the left or to the right on the curve. So, given two states P and W, such that the entropy of Q is higher than the entropy of P, we cannot decide, on this basis alone, which of the two states is the earlier one and which the later one. Thus the entropy curve does not provide us with a criterion for distinguishing between earlier and later, since the statistical entropy direction of the universe is not unique. The probabilistic laws concerning the variations of a probabilistically defined entropy are thus found to be covariant under time reversal. So entropy increase in closed systems has lost its ability to indicate "time's arrow" in Eddington's sense. In spite of the failure of Eddington's attempt many authors have made different attempts to derive from the second law of thermodynamics a criterion for the anisotropy of time, while at the same time accepting the consequences of the analysis given above. Reichenbach's posthumously published book "The Direction of Time" is one such attempt, which we shall now consider.

4.5. The Reichenbach Solution

The reason why the entropy curve just considered, and with it the reversibility objection, fail to provide us with a criterion for anisotropy is because it is the curve of a "time ensemble", i.e., it pertains to the "history of one system", in this case the system being the universe. Reichenbach abandons the time ensemble and turns to the study of a "space ensemble" which not only provides better results but is closer to "the actual procedure which is used when inferences concerning time direction are made". Whereas the time-ensemble is a single system, a space ensemble is a collection of isolated subsystems which have branched off from the main system and continue for a limited or unlimited time in relative isolation from the main system. Such subsystems are a natural product or occur through the intervention of man and, from a highly ordered beginning, remain isolated and run through an evolution toward disorder.

> "Nature abounds in branch systems of this kind, i.e. systems that branch off from the comprehensive system and remain isolated from then on for some length of time. Their evolution begins with an ordered state, that is, a state of relatively low entropy, and progresses toward disorder, that is, toward relatively high entropy. We use the word "relatively" here to indicate that this entropy is referred to the sub-system, not to the universe or the main system. These are the observational facts to which the statistical definition of time direction must be referred. When we infer from the inequality, $S_B > S_A$, that, in all probability, A was earlier than B, this probability is of a difference kind from the one discussed in connection with the reversibility objection; it refers, not to the sequence of states of the isolated system to which the states A and B belong, but to the series of similar systems, conceived of as an ensemble of branch systems. That is, it refers, not to a time ensemble, but to a space ensemble."[6]

We thus find systems with highly ordered initial states (e.g. an ice cube floating in a glass of hot water) which progress towards disordered states (e.g. a glass of tepid water). Now, consider a whole ensemble of such systems, the world lines of which are symbolized by a probability lattice, whose Y denotes an event in the history of the system.

Y1a	Y1b	Y1c	Y1d	..... Y1i
Y2a	Y2b	Y2c	Y2d	..... Y2i
....				
Yka	Ykb	Ykc	Ykd	..... Yki
....				

---

[6] Reichenbach, H., The Direction of Time, op.cit. p. 118.

The first element Yka of a row is in a highly ordered state. In the succeeding states the order gradually disappears until a state of disorder is reached. Each row represents a system. The development in any one system can give us no indication of a unique direction since, if the time element t is sufficiently large, there will be an equal number of increases and decreases and therefore no unique direction. The probability of a system, of a horizontal row, is called by Reichenbach a "one-system probability", in conjunction with which he develops what he calls a vertical probability or a many-system-probability. In the latter type of probability we are dealing with the statistics of an ensemble of branch systems rather than with the evolution of a single system. Now consider a vertical or sectional state A_k of the whole ensemble, which is followed by a state B_k. Reichenbach sets out to prove that in the overwhelming majority of cases the entropy of A_k is less than that of B_k if and only if A_k is earlier than B_k. We can say this because we are considering an ensemble of branch systems which, in a state of relatively high order, have broken off from the main system. Reichenbach can now give the definition; the direction in which most thermodynamical processes in isolated systems occur is the direction of positive time. The various branch systems have entropy curves which break off from the main entropy curve of the universe and return to it. The direction from earlier to later is given by the fact that the total entropy curve of the universe is on the upgrade. After aeons of time it might be on the downgrade, and if there were living creatures then their direction from earlier to later would be opposite to ours. It follows that a time direction can be defined only for sections of the total entropy curve. "Only certain sections of time have directions, and these directions are not the same".[7] It is only through its reiteration in branch systems that the entropy growth of the universe dictates to us a direction of time. The universal increase of entropy is reflected in the behaviour of branch systems and only their reflection of the general trend in many individual manifestations is visible to us and appears to us as the direction of time.

The statistical definition of time direction is based on five assumptions which Reichenbach regards as empirical hypotheses which are convincingly verified. These assumptions are

Ass. 1. The entropy of the universe is at present low and is situated on a slope of the entropy curve.

Ass. 2. There are many branch systems, which are isolated from the main system for a certain period, but which are connected with the main system at their two ends.

Ass. 3. The lattice of branch systems is a lattice of mixture.

Ass. 4. In the vast majority of branch systems, one end is a low point, the other a high point.

Ass. 5. In the vast majority of branch systems, the directions toward higher entropy are parallel to one another and

---

[7] Ibid., p. 127.

to that of the main system.

"In order to derive the direction properties of time, we have to add the factual assumptions 1 - 5." On the basis of these empirical assumptions and by means of a rigorous mathematical treatment Reichenbach therefore claims to have given a physical definition of time order in terms of entropy which avoids the reversibility objection that the Eddington attempt could not overcome.

4.6. Criticism of the Reichenbach Solution

In view of the fact that the reductionist thesis attempts to give an empirical definition of temporal order in terms of observable features of the world as these are expressed in scientific laws it is paradoxical that this apparently rigid empirical reduction should depend on certain assumptions about the cosmos which, in the present state of cosmology, could hardly be unreservedly accepted as reliable. In particular one would have reservations about his assumption that the entropy is defined for the entire universe, such that the universe as a whole can be assumed to exhibit the same sort of statistical entropy curve as defined for a permanently closed finite system. Similar considerations apply to the assumption that the direction of entropy increase for the entire universe parallels that of the entropy increase in the majority of systems of a space ensemble. In a singularly non-empirical manner Reichenbach also concludes that, cosmically, the statistical anisotropy of time fluctuates, i.e. that the alternations of epochs of entropy increase and decrease in the universe go hand in hand with the alternations of the direction of entropy increase of the ensembles of branch systems associated with there respective epochs. If the thermodynamical definition of time order depends on such far-reaching assumption about the cosmos at large then this is a very high price to pay for a co-ordinative definition.

Another objection to the Reichenbach definition is that it is not based on some pervasive feature of the physical universe but rather on certain isolated and limited systems, and it may be very arbitrary what we are willing to call, at any time, a branch system.

The definition in terms of branch-systems also represents a come-down from Reichenbach's original plan to find the solution to the problem of time "in the laws and equations of mathematical physics." For the statistical definition of time order depends not only on the statistical laws of entropy increase but also on certain complicated de facto nomologically contingent boundary conditions, namely, the de facto properties of branch systems.

The branch-hypotheses, on which Reichenbach's definition is based, I would consider to be gratuitous and I would say that his attempt to establish temporal anisotropy on the basis of conventional thermodynamics in conjunction with other independent and gratuitous assumptions has failed. This elaborate construction of rigid probabilistic laws and non-rigid cosmological assumptions can not present us, in any convincing way, with the scientific counterpart of the temporal order we know from experience and it has certainly not proven the dispensibility of the temporal knowledge in the scientific context.

Chapter Five

TIME, LAW AND EXPERIENCE

5.1. Time as experience and scientific time

It was the reductionist's conviction that the solution to the problem of time lay in the laws and equations of mathematical physics. The time of experience, or intuitive time, was to be reduced to some physical order such that, in the scientific context, there would be no reliance on this time of experience. Thus time of experience or subjective time was to be given its' real meaning and content by physical time, or time of scientific theory which was, in turn, reducible to some other physical order.

> "It has often been claimed that only the physical properties of time can be revealed in such an investigation and that, unaffected by physical time, the psychological experience of time retains its' a priori character and obeys its' own laws. This view which has been expressed by various philosophical writers in connection with the theory of relativity, must be rejected most emphatically...... We shall therefore use the distinction between time as experience and physical time only as a temporary aid which leads us to a deeper scientific insight into the concept of time; we shall correct the intuitive experience time accordingly......This analysis will clarify the meaning and content of everyday experiences; finally we shall learn in this way, better than through a phenomenological analysis, what we actually mean by the experience of time."[1]

The thesis which I wish to maintain in this chapter may be divided

---

[1]Reichenbach, H., The Philosophy of Space and Time, op.cit. p. 113.

into two parts:

(1) The relation between subjective time or time of experience and physical or scientific-theoretic time is not such that the former must be reducible to or explained in terms of the latter, and the reductionist attempt is based on a misunderstanding of the nature and status of scientific-theoretic concepts in relation to the concepts of experience.

(2) The time of scientific theory of physical time can be rendered asymmetrical or unidirectional only by presupposing certain basic assumptions about the time of experience.

Physical theory need not confine itself to the use of directly observable or experienced entities but uses also "theoretical constructs", or what Quine calls "cultural posits".[2] The totality of scientific knowledge is, according to this view, a man-made fabric which impinges on experience only along the edges. Speculative constructs may be introduced freely into scientific theory provided it can be shown what connection these constructs have with observation. Such constructs are not, however, necessarily defined in terms of observations and the chains connecting them may be long and involved.

> "Objects at the atomic level are posited to make the laws of macroscopic objects, and ultimately the laws of experience, simpler and more manageable; and we need not expect or demand full definition of atomic and subatomic entities in terms of macroscopic ones, any more than definitions of macroscopic things in terms of sense data."[3]

---

[2]Quine, W. From a logical point of view, New York: Harper and Row, 1963, p. 44-5.

[3]Quine, W. op. cit., p. 44-5.

The theoretical constructs become valid when the scientific theory of which they are a part becomes an efficacious device for the prediction of future experience or for working a manageable structure into the flux of experience.

One meets very often terms which, as a result of the nature of scientific theorizing, seem to have, as it were, a double meaning. We have, on the one hand, the "force" of our everyday experience, muscular exertion, pushes and pulls; on the other hand the "force" of scientific theory, force as it occurs in such contexts as "field of force" or "f = ma". One is not defineable in terms of the other nor is one reducible to the other. To call one subjective and the other objective is not to refer to their degree of objectivity but to the fact that one refers to the plane of experience, the other to the plane of theoretic construction. Similarly we have, on the one hand, the time of experience and, on the other hand, the time of scientific theory. The first is the time of temporal awareness, of immediate experience. The second is a theoretical construct which occurs in many scientific laws and equations and which is in no way bound to reflect or reproduce any or all of the properties of the time of experience. For instance, whereas the time of experience is unidirectional, moving from past to future, it is quite acceptable in scientific theory to speak of a time variable which moves in the opposite direction, from future to past. This does not mean that we would have to correct or change our concept of time of experience. Scientific time is not the "true" or "real" time any more than scientific force is the "true" force. It's just that one is a concept from our immediate experience and the other is a theoretical concept or construct related to our experience in quite a different way.

Physical or scientific time does not have a privileged status from which we could "correct" time as experienced or show what time as experience "actually means". To attempt this is to misunderstand the nature of both concepts. Reductionism is based on a hierarchial conceptualization of science in which the notion of "presupposes" is asymmetrical. If A presupposes B then it cannot be the case that B presupposes A. In this hierarchial conceptualization scientific theories are ordered verically or in pyramid-fashion where each level in the hierarchy presupposes, in some sense, the level or levels below it, but not vice versa.

> "In order to analyze the contents of cognitions, epistemology must investigate the objects (concepts) of (empirical) science in its various subdivisions (natural and cultural sciences). It must ascertain to which other objects the cognition of any given object may be "reduced". Hence, an "analysis" of objects is undertaken when the "higher" objects are reduced to "lower" ones. Those objects which can no longer be reduced are called "(epistemologically) fundamental" objects".[4]

"If the investigations whose results are here sketched are actually carried out (this is the task of construction theory), one

---

[4]Carnap, R. Logical Structure of the World, Pseudo Problems in Philosophy, Berkeley: University of California Press, 1967, p. 305-6.

is led to the following stratified epistemological system of the four most important object-types (to be read from bottom to top):

4. Cultural objects.

3. Heteropsychological objects.

2. Physical objects.

1. Autopsychological objects.

The objects within each of these levels can in turn also be organized according to their epistemological reducibility. The final result is a system of scientific objects or concepts which, from a few "basic concepts", leads in a step-by-step construction to all the remaining concepts. In this system each concept which can become the object of a scientific statement has a definite place. The organization of concepts in this system has a two-fold significance. To begin with, each concept is epistemologically secondary relative to the concepts which stand below it. Furthermore, each concept can be defined, that is, a definite description of it can be given by referring only to the concepts which stand below it."[5]

Whether the "fundamental objects" (concepts) be sense data, physical objects, simple experiences or even elementary logical or mathematical deductions, the basic view of science remains the same; it is hierarchical, it has "foundations", and "presupposing" or reducing" is unidirectional. I would suggest an alternative conceptualization in which there are no absolutely "fundamental objects (concepts)", no

---

[5] Ibid., p. 321-22.

absolute "foundations" and in which the decision as to what is to be presupposed or accepted will depend on the particular problem under consideration and the particular type of experimental design that can be devised to cope with it. The conceptual model suggested on pages 56 and 57 could be represented by a sphere, the center of which is occupied by pure or highest-level theoretic terms, such terms as play a central role in scientific theories and are farthest removed from experience, (e.g. force, energy, matter). Moving out from the center are many levels of theory until, at the rough edge of the sphere we have the level of experience or observation. In the hierarchical or reductionist conceptualization all concepts in the sphere must be cashed out in terms of the observational periphery, and each concept occupies a definite level. In the alternative conceptualization which I have suggested not only are the theoretic concepts not necessarily defined in terms of observations but no concept has a well defined or unique level. The sphere is not a static but a dynamic model and the relative positions of concepts or theories represented by it will depend on the nature or design of some particular scientific endeavour. What, in one experimental design, may be regarded as incontrovertable data may, in another related or unrelated endeavour be regarded as a highly theoretic construction. The symmetry of the presuppositional relation also makes it possible for concepts or theories to presuppose one another in a circular but experimentally meaningful way for their mutual advancement.

In the remainder of this chapter I will try to show that the problem of irreversibility connected with the second law of thermodynamics can be best resolved by making certain assumptions about the nature of time.

5.2. Subjective time and it's physical counterpart

We recall that the original problem was to find a co-ordinative definition of temporal order and we interpreted this as the search for some physical feature of the total states of world, expressed in known natural laws, which would define a dyadic relation between every pair of states such that the class of states forms a serial order with respect to this relation. We can order the events of our experience temporally but in doing so we rely on our own subjective sense of time order. A co-ordinative definition, as understood by Reichenbach, would enable us to determine, for any two events, without dependence on our subjective impressions, which one was earlier than the other. In other words, the co-ordinative definition of time order could not depend on any assumptions about the nature of time or on any prior knowledge of temporal order derived from our own (subjective) experience. Such a definition would eliminate the need for any recourse to the time of our experience in the scientific context. Time order is, in this very strong sense, reduced to this other order, e.g. the order of events in a causal chain, or the order of states of a system increasing in entropy. The causal or the entropic order would then be a physical counterpart to the temporal order. But there is also another sense in which we can speak of a physical counterpart to time order. Accepting the time order of our experience as valid we could look for some feature of the physical world which would reflect or give content to our experience of time order. Time order would not thereby be reduced to this physical feature but would remain an independent aspect of our experience. But the indication of structural similarities between both orders would enable us, in a real sense, to speak of a physical counterpart to the temporal order of an experience. I shall attempt to show in this chapter that, by accepting as valid certain basic assumptions about the time of our experience, we can indeed find in the statistical second law of thermodynamics, that physical feature of the world which gives clear expression to the temporal structure we know in our experience.

5.3. The elimination of subjective time in science

The elimination of the recourse to experienced time was, as we saw, one of the main aims of the reductionist thesis. This was not successfully accomplished in the causal theory because the specification of an asymmetric causal relation by means of the mark-method was open to the charge that either it made tacit use of prior temporal knowledge or that it had to assume an irreversible marking process. The attempt by Eddington to derive the temporal order from the statistical second law of thermodynamics failed because, as was shown, the H-theorem was time-symmetrical. According to the H-theorem we can define an entropy and know that a closed system, whose entropy value at a certain point in time is not its highest possible one, will, with very high probability have a greater entropy value at another point in time. But the H-theorem cannot define a direction in time and this is obvious from its derivation. For the proof of the H-theorem presupposes, apart from the concept of thermodynamic probability, only the law of mechanics which, as we have seen, are completely symmetrical, i.e. they do not change in a reversal of time direction. The mathematical basis for the H-theorem is, according to Boltzmann, the extraordinary growth of statistical probability as entropy approaches maximum value. A given state possessing a non-maxium entropy value has therefore, let us say, a greater choice of states with greater entropy value than of states with smaller entropy value. One can conclude, therefore, that, with great probability, the entropy value of the system at a later time will be greater. But with the same probability one can conclude that the entropy value of the system at an earlier point in time was greater. This contradicts the second law of thermodynamics since this law states that, also for the past, every entropy value of a closed system was preceded by a smaller or at least equal entropy value./So the second law does not follow directly from the H-theorem and from the H-theorem alone one could not derive an asymmetric time order. The H-theorem is compatible with the second law if the H-theorem could be used only to calculate the future but never the past entropy values of a system. This is, in a sense, what Reichenbach has achieved with his branch-system hypothesis. In most branch systems in a space-ensemble, each of which is initially in a state of low entropy, the entropy will be higher <u>after</u> a given time t, but not <u>before</u>, since the branch systems did not exist as distinct systems prior to the occurrence of their initial branching off states. Therefore these systems do not also exhibit the same higher entropy states at earlier times as they would have had they always existed as closed systems. Thus the space ensembles of branch systems do not reproduce the entropic time symmetry of a single closed system. Thus the H-theorem plus branch hypothesis should deliver the required asymmetry. But, as we have seen, there is very little real reason for accepting the very general cosmological assumptions on which the branch-hypothesis is based. Another problem with the branch-hypothesis is that it requires reference to observed systems which branch off from the main system at earlier times and if this observational criterion is meant to involve man's subjective time sense, it is not very clear how Reichenbach could justify having recourse to it. All those attempts therefore to dispense with recourse to the time of experience have met with insurmountable difficulties. There is, however, in the Reichenbachian-branch-hypothesis a very important kernel of truth, the implications of which we will attempt to show in the section that follows.

5.4. The past and future of experience

In Reichenbach's account the H-theorem is used only to calculate the future but never the past entropy values of a system. The reason for this is that the branch system did not exist prior to their branching-off state and therefore we can know the path of its origin and, with sufficient precision, the curve of its entropy values from its initial branching-off state to the present. Probability methods are not used to determine its initial state or its history to the present since these are, in fact, known. What is not known is its future entropy curve and, in this case, probability methods are necessary and appropriate. A probabalistically defined entropy thus becomes unidirectional by means of being applied only to future unknown states of a system and not to past states which are already known.

In all experiments in which the H-theorem is used to calculate the entropy value of a state, it is used only to calculate the entropy value of future states. Probability methods are not used to calculate values concerning the part of the system in question, since this is already known. In fact, every experiment concerning which the second law of thermodynamics offers a prediction, begins with a state to which the object of the experiment as a closed system would never have come on its own, e.g. experiments with heat engines with temperature difference, diffusion with a spatial separation of substances as in the gas example used previously. The initial state is usually produced artifically, directly or indirectly, and is thus known along with the entropic curve to the beginning of the system. The future entropy change is unknown and, for their prediction, the probability arguments of the H-theorem are appropriate.

But the second law of thermodynamics goes much further when it states that, for that part of the past which is known neither through the memory of the individual physicist nor through the documents of tradition, the entropy value of earlier states was lower than that of later states. The second law could then be derived only by making the following assumption about the universe: - that part of the world known to us was at one time in a very improbable state.

> "In as much as we can regard this part of the world as a closed system the increase of entropy for later time follows directly."[6]

Although the content of this assumption may be acceptable its' foundation is a problem. This statement by Boltzmann is problematic because it characterizes this state of the universe as extremely improbable and we are then led to the question--how is it that such an improbable state could be realized since the whole statistical foundation of thermodynamics rests on the assumption that with practical certainty only the most probable will always happen? If this question is not appropriate then it could only be because we need a characterization of the past which does not include the concept of thermodynamical probability as a basic concept. In other words, also for that part of the history of the world beyond the reach of experiment the application of probability methods is inappropriate.

We have come to the conclusion that the probabalistic arguments of the H-theorem are appropriately applied to the calculation of the entropy value of future states of a system and not of past states. For the derivation of the second law of thermodynamics and its temporal asymmetry we are therefore led to make the following assumption: At every moment the past is a completed fact to be regarded as basically something finished and known; the future however has not yet happened

---

[6]Boltzmann, L. Vorlesungen uber Gastheorie, Bd. II, Leipzig, 1895. p. 280.

and is undetermined and can therefore be predicted by probabilistic methods with the degree of certainty appropriate to such methods. From this follows, in conjunction with the H-theorem, the increase of entropy for the future. However, every past moment was a present. From this follows the increase of entropy for all those times which were then future, i.e. for all that time which at present is past.

This assumption concerning the difference between past and future (or some similar assumption) allows us to restrict the applicability of the H-theorem to future states of a system and this restriction allows us to find in the entropy curve of such a system the desired temporal asymmetry. We can thus see, in the entropic order, a physical counterpart to the temporal order of our experience.

This does not mean that the above assumption is ultimate in any sense. The suggested conceptual model would also allow the same assumption to be a derived statement in another framework, for instance, a framework in which man's own body participates in the entropic lawfulness of branch systems in the sense that man's memory, just as much as all purely physical recording devices, accumulates "traces" or records, the direction of which is dictated by the statistics of branch-systems.

BIBLIOGRAPHY

Black, M.: "The Direction of Time," Analysis, Vol. XIX, 1959.

Carnap, R.: Abriss der Logistik. Vienna: J. Springer; 1929.

________.: "Adolph Grunbaum on The Philosophy of Space and Time." The Philosophy of Rudolph Carnap. Edited by P.A. Schilpp. LaSalle: Open Court Publishing Company; 1963.

________.: Der Raum. Berlin; Reuter und Reichard; 1922.

________.: Introduction to Symbolic Logic and It's Applications. New York: Dover Publications, Inc.; 1958.

________.: "Über die Abhängigkeiten der Eigenschaften des Raumes von denen der Zeit," Kantstudien, Vol. XXX, 1925.

________.: The Logical Structure of the World and Pseudoproblems in Philosophy. Berkeley: University of California Press; 1967.

Eddington, A.S.: The Nature of the Physical World. New York; The Macmillan Company; 1928.

Ehrenfest, P. and T.: "Begriffliche Grundlagen der statistischen Auffassung in der Mechanik," Encyklopadie der mathematischen Wissenschaften. IV, 2, II.

Grunbaum, A.: Philosophical Problems of Space and Time. New York: Alfred A. Knopf; 1963.

Lewin, K.: "Die zeitliche Geneseordnung", Zeitschrift fur Physik, Vol. XIII, 1933.

Mach, E.: The Science of Mechanics. 1883. Reprinted in LaSalle: Open Court Publishing Company; 1902.

Margenau, H.: "Can Time Flow Backwards?", Philosophy of Science, Vol. XXI, 1954.

Mehlberg, H.: "Essai sur la théorie causale du temps," Studia Philosophica, Vol. I, 1935, and Vol. II, 1937.

________.: "Physical Laws and Time's Arrow", Current Issues in the Philosophy of Science. Edited by H. Feigl and G. Maxwell. New York: Holt, Rinehart and Winston; 1961.

Quine, W.V.O.: From a Logical Point of View. Second Edition. Cambridge: Harvard University Press; 1961.

Reichenbach,H.: Axiomatik der relativistischen Raum-Zeit-Lehre. Braunschweig: F. Vieweg & Sons; 1924.

________.: Philosophie der Raum-Zeit-Lehre. Berlin: Walter de Gruyter & Company; 1928.

________.: The Philosophy of Space and Time. Dover Publications, Inc.; 1958.

________.: The Direction of Time. Berkeley: University of California Press; 1956.

Russell, B.: Our Knowledge of the External World. London: George Allen and Unwin; 1926.

Scholz, H.: "Eine Topologie der Zeit im Kantischen Sinne," Dialectica, Vol. Ix; 1955.

Smart, J.J.C.: "Critical Study of H. Reichenbach's 'The Direction of Time'". Philosophical Quarterly, Vol. XIII, 1958.