CONCEPTUAL FOUNDATIONS OF SCIENTIFIC EXPERIMENTS: A PHILOSOPHICAL EXAMINATION OF THE MEASUREMENT OF THE THERMOELECTRIC POWER OF SOME METALLIC GLASSES

by

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Conceptual Foundations of Scientific Experiments

ERRATA

1, Page 76, line 2, for 'R' read 'ρ'.
2, Page 81, line 3, for 'P' read 'R'.

N.B. These corrections are to apply to each occurrence of 'R' and of 'P' in the subsequent pages.

ABSTRACT

In order to evaluate the adequacy of two alternative groups of philosophical theses concerning **the factual truth of scientific theories** and **the theoretical basis of scientific experiments,** a detailed piece of concrete scientific research is presented and analysed, namely, a set of experiments designed to measure the thermoelectric power of some metallic glasses. The examination of this scientific investigation shows that the positivistic account of the factual truth of scientific theories and of the theoretical basis of scientific experiments is inadequate, i.e. the theses defended by the positivist philosophers of science are not in accordance with actual scientific research. Rather, it is the conceptualist alternative position that is shown to be in better agreement with the actual work of scientists.

This dissertation presents also a radical critique of the traditional treatment given by philosophers to scientific investigation. The criticism focuses on the deep gulf between that which philosophers state about science and that which scientists do in actual research. In order to bridge this gulf, a new philosophical approach to science is proposed — the **FACTUAL PHILOSOPHY.** The main characteristic of this new approach is the requirement that the tests and developments of any philosophical thesis concerning the sciences be submitted to a close examination of an actual piece of concrete research.

RESUME

Afin d'évaluer l'adéquation de la solution proposée par deux théories concurrentes au problème de **la vérité factuelle de théories scientifiques** et à celui **du fondement théorique des experiences scientifiques,** un analyse detaillée d'une recherche concrete est présentée. Cette recherche a été concue afin de mesurer le pouvoir thermoélectrique de quelques verres métalliques. A la suite de l'examen de cette investigation scientifique la théorie positiviste s'avère inadéquate, i.e. que les thèses défendues par les philosophes positivistes de la science vont à l'encontre de la pratique de l'investigation scientifique. Ainsi, c'est l'alternative conceptualiste qui ressort comme etant la plus appropriée aux travaux de l'homme de science moderne.

Cette dissertation présente une critique radical de l'approche traditionnelle à la recherche scientifique suivie par les philosophes. Cette critique prend comme point de départ l'écart séparant ce que les philosophes disent de la science, de ce que les scientifiques font effectivement dans leurs recherches. Une nouvelle approche à la recherche est proposée dans le but de supprimer cet écart — la **PHILOSOPHIE FACTUELLE.** La principale caracteristique de cette nouvelle approche est la condition requise suivante: que les essais et développements de toute thèse philosophique portant sur les sciences soient soumis a un examen attentif d'une recherche scientifique réelle.

ACKNOWLEDGEMENTS

I dedicate this work to all my friends — whether they be philosophers, scientists, or just friends — who have helped me to understand the need for a new and "more concrete" philosophical approach to science. Through long and fruitful discussions with them I came to realize just how far from actual scientific research is the logical approach elaborated by all sorts of philosophical positivisms.

I want also to dedicate my work to Giordano Bruno who gave his own life in defense of the freedom to be intellectually creative. Let me offer to Giordano Bruno the right to present here a first word against logical positivism:

> Elpino. Come è possibile che l'universo sia infinito?
>
> Filoteo. Come è possibile che l'universo sia finito?
>
> Elpino. Volete voi che possa dimostrar questa infinitudine?
>
> Filoteo. Volete voi che si possa dimostrar questa finitudine?
>
> Elpino. Che dilatazione è questa?
>
> Filoteo. Che margine è questa?...
>
> Burchio. Questo ancor che sia vero, io non lo voglio credere; perché questo infinito non è possibile che possa esser capito dal mio capo, né digerito dal mio stomaco; beché, per dirla, pure vorrei che fusse cossí come dice Filoteo, perché se, per mala sorte, avenesse che io cascasse da questo mondo, sempre trovarei di paese...

Filoteo. Non è senso che vegga l'infinito, non è senso da cui si richieda questa conchiusione; perché l'infinito non può essere oggetto del senso; e però chi demanda di conoscere questo per via di senso, è simile a colui che volesse veder con gli occhi la sustanza e l'essenza; e chi negasse per questo la cosa, perché non è sensibile o visibile, verebe a negar la propria sustanza ed essere. Peró deve esser modo circa il dimandar testimonio del senso; a cui non doniamo luogo in altro che in cose sensibili, anco non senza suspizione, se non entra in giudizio gionto alla raggione. A l'intelletto conviene giudicare e render raggione de le cose absenti e divise per distanza di tempo ed intervallo luoghi. Ed in questo assai ne basta sufficiente testimonio abbiamo dal senso per quel, che non è potente a contradirne e che oltre fa evidente e confessa la sua imbecillita ed insufficienza per l'apparenza de la finitudine che caggiona per il suo orizonte, in formar della quale ancora se vede quanto sia incostante. Or, come abbiamo per esperienza, che ne inganna nella superficie di questo globo in cui ne ritroviamo, molto maggiormente doviamo averlo suspetto quanto a quel termine che nella stellifera concavita ne fa comprendere.

Elpino. A che dunque ne serveno gli sensi? Dite.

Filoteo. Ad eccitar la raggione solamente, ad accusare, ad indicare e testificare in parte, non a testificare in tutto, né meno a giudicare, né a condannare. Perché giamai, quantunque perfetti, son senza qualche pertubazione. Onde la verità, come da un debile principio, è da gli sensi in picciola parte, ma non è nelli sensi.

(BRUNO, 1584; pp.367-370)

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Finally, I wish to thank my wife, Ana Maria, for all the encouragement, support and love she has dedicated to me and to my work.

*I wish to thank Simona Massobrio for preparing the following free translation of this passage of Bruno's **De l'infinito, universo e mondi:**

> Elpino. How is it possible for the universe to be infinite?
>
> Filoteo. How is it possible for the universe to be finite?
>
> Elpino. Would you like to be able to prove this infinitude?
>
> Filoteo. Would you like to be able to prove this finitude?
>
> Elpino. What dilatation is this?
>
> Filoteo. What boundary is this?...
>
> Burchio. That this may be true, I do not want to believe because it is not possible that this infinite may be undesrtood by my head nor digested by my stomach; even though, so to say, I wish it were like Filoteo says, for if I, by any chance, were to fall from earth, still I would find a town...
>
> Filoteo. There is no sense which can perceive infinity, there is no sense from

which this conclusion can be requested; because the infinite can not be object of the senses; and he, who asks to know this through the senses, is like the man who would want to see substance and essence with his eyes; and he, who would want to negate the thing because of this, because it is not sensible or visible, would also want to negate his own substance and being. But a way must be found in which we are able to ask a testimony from the senses; to the senses we do not give place in anything else than in sensible things, however, not without suspition, if reason does not come into judgement. For the intellect it is convenient to judge and to render reason of absent things and things divided by distance of time and interval of places. And of this we have enough testimony from the senses because they make it evident and confess their stupidity and insufficiency through the appearence of finitude which they cause for their horizon, in forming which they again show how inconsistent they are. Or like we have it from experience, they deceive us concerning the surface of this globe in which we are, much more we should suspect them regarding what they make us understand about the limit of the heavenly spheres.

Elpino. What is the use then of the senses? Tell me.

Filoteo. To stimulate reason only, to accuse, to indicate and partly to testify, not to testify in everything nor less to judge, nor to condemn. Because as perfect as they can be, they are never without pertubation. Whence the truth, like from a weak principle, comes from the senses in a small proportion, but it is not in the senses.

(BRUNO, 1584; pp.367-370)

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INTRODUCTION

In this dissertation, I shall develop and defend a new philosophical approach to the study of science. In the course of the development and defense of this approach, issues both of a philosophical and a scientific kind arise. By examining an actual scientific research programme in detail, I shall argue against the traditional approach to science to which most modern philosophers of science subscribe.

Only in our century has philosophy of science (henceforth PS) attained the status of an independent field of inquiry. This fact is testified to on one hand by the springing up of new departments of history and philosophy of science (or smaller centers of epistemology where larger departments are not feasible), and on the other hand by the emergence of international publications devoted to philosophical study of science, e.g. **PHILOSOPHY OF SCIENCE**, published in the United States, **THE BRITISH JOURNAL FOR THE PHILOSOPHY OF SCIENCE**, and the international **SYNTHESE**. As a natural consequence, we have a remarkable increase in the number of new books devoted to this philosophical inquiry of science[1]. All these events can only bring satisfaction to anyone interested in meta-investigations of science.

Nevertheless, I cannot avoid expressing my disappointment. The independence of PS should provide a deeper and more accurate understanding of scientific research, since now the task can be developed by full-time researchers. But as we have learned from science, **QUANTITY OF WORK PRODUCED IS NOT THE SAME OF QUALITY OF WORK PRODUCED.** The independence of PS has meant the independence of the philosophers of science from the study of science itself. The results of this attitude could not be more regrettable: the product of this PS is estranged from science. It is neglected by most scientists[2].

A first attempt to understand the present situation of PS could consist of the claim that PS is a very young discipline. As with children or adolescents in their[3] first attempts to understand their experience of real events, PS does not have a clear conception of which are the objects of its reflection, which are the parameters relevant for its inquiry, and which method or methods should be used in its enterprise. I believe that this picture contains a half-truth. Beyond any doubt the present situation of PS resembles the pre-scientific theories which most of the present scientific theories had to go through one day. In this sense, I will be not surprised if in fifty years from today, the developments of PS so far undertaken during our century become seen as a pre-scientific state of PS. However, as I stated before, this picture of the present situation is only partially valid. Our tradition in the PS exhibits not only characteristics of scientific immaturity but it also has expressed a tendency to maintain such immaturity during its growth. We are faced with a special child, a child who has already received a **bad education.** In this sense, my defense of a new approach to scientific research is indeed an attempt to develop PS, but at the same time, it is a criticism of the traditional approach.

The particular contribution to this conception of PS which I will present here consists of a close examination of some experiments in contemporary physics — measurement of some electronic properties of metallic glasses. Through the analysis of this piece of concrete research, I will discuss some philosophical problems concerning the interesting and intricate interplay between theory and experiment which is beyond any doubt one of the most decisive problem to be faced for a better understanding of factual science.

To close these introductory remarks, I would like to suggest a name for the new approach to scientific research. This name, in my opinion, satisfies Bunge's request for a title which would reflect the character of the new epistemology of science which he works out. Bunge writes:

> Needless to say, whatever form the new realist epistemology take, it would fail to meet the standards of scientific research and consequently it would fail to help this enterprise if it were conceived as one more **ism,** i.e. as a set of tenets beyond criticism and above science. Wanted: a name for this nascent epistemology, one not ending in **ism,**

> for whatever ends in ism is apt to put an end to the quest for truth.
>
> (BUNGE, 1965; p.221)

I suggest that the new approach should be dubbed **FACTUAL PHILOSOPHY.** Though the name does not express all the features of the new approach, the choice may be justified, so far as it goes, in the following manner.

First, and obviously, the approach is PHILOSOPHICAL: it raises and tries to solve problems of a distinctively philosophical kind about scientific research. Second, the approach is FACTUAL, both in a direct and in an indirect sense. Indirectly, it is FACTUAL because it takes within its purview the factual assumptions — e.g. the assumption that electrons, protons, photons exist and interact among each other — actually made by the practicising scientist — whether or not they are correct to make them. Directly, it is factual because it considers scientific research as a CONCRETE PROCESS, and the philosophical claims made are directly accountable to the features of this process.

Before continuing, let me sketch how I propose to proceed. In CHAPTER I, I clarify, in a general fashion, how philosophical theses about science can be tested for correctness. In CHAPTER II, I discuss two problems which I am specifically concerned in the essay to resolve — first, the problem of whether or not scientific theories are factually true; second, the problem of whether or not scientific experiments have a theoretical basis

— and I examine two well-known philosophical treatments of these problems: empiricism and the conceptualist alternative. In CHAPTER III, a concrete piece of scientific research is described in detail. Finally, in CHAPTER IV, the results of the detailed description are used to demonstrate the adequacy of the conceptualist position. Throughout, I scrupulously avoid a priori argumentation about the issues. The conclusion reached are firmly based on actual scientific research.

Let us address ourselves to the task at hand.

Notes

[1]The emergence of the philosophy of science should be seen as part of a broader cultural movement. In addition to PS as an independent area of inquiry, we also meet with the sociology and history of science and technology. Can we not anticipate the eventual development of a new area devoted to the psychology of scientific research?

[2]The scientists's dissatisfaction with the philosophy of science is not only a function of their doubts about correctness on point of detail. It is also a general resistance to the very nature of the philosophical inquiry. A test for the approach I shall develop is whether it helps to overcome such resistance. Obviously, a philosophical treatment which in fact comes to grips with actual scientific practice is more likely to speak to the scientists than one which does not.

[3]I am going to follow L. Flower (FLOWER, 1981; p.4) in using the plural pronoun 'they' instead of 'he'.

Many people, and I am one of them, feel the "he" is no longer an adequate word for referring to both sexes, as in the sentence, "When a person goes to college, (he?),(she?)...". Yet English does not have what is called a common gender singular pronoun. There has been attempt to make up new pronouns, such as "co" and "s/he", but in general, language resist such tinkering. In face of this dilemma I have chosen to use the plural "they" instead of "he" for words that refer to people of both sexes... This choice will seem uncomfortable to some reader, as it sometimes does to me, because it violates a traditional rule of grammar that demands a singular referent...I apologize to those who find it jarring and remind my readers that this is a choice not all writers would make.

CHAPTER I

ON TESTING PHILOSOPHICAL THESES

> As a matter of fact, I am convinced that even much more is to be asserted: the concepts which arise in our thought and in our linguistic expressions are all — when viewed logically — the free creations of thought which can not inductively be gained from sense-experiences.
>
> (EINSTEIN, 1944; p.287)

A close study of the philosophical discussions on the interplay between experiment and theory in contemporary science brings several deep-seated conflicts to light. Among these is the dispute between empiricists and operationalists, on the one hand, and conceptualists and theoreticists, on the other, as to what is the basis of scientifc research: empirical data or theoretical hypotheses? The empiricists and operationalists maintain that scientific theories are constructed from empirical information; the experimental data are the beginning and end of any scientific enterprise. According to the proponents of this view, scientific laws can be identified with <u>empirical generalizations</u>, and scientific concepts defined in terms of <u>empirical observations or empirical operations</u>. Conceptualists and theoreticists, who take the opposite stand, maintain that no experiment, no empirical operation, is independent of some scientific hypothesis or other.

Scientific laws, they hold, are high-level hypotheses which are postulated within a theoretical context and must not be mistaken for experimental generalizations. By the same token, scientific concepts — e.g. the concepts photon and electron — are introduced in the broader context of a system of hypotheses, and must not be reduced to or identified with empirical operations or observations.

Another deep conflict revolves around the question of the nature of the factual truth in science: Is there any truth in science? Again the conceptualists and the empiricists are opposed, the former holding that scientific theories are indeed intended to represent and explain the nature of real objects and processes in the real world. Science, in short, assumes the existence of objects and processes, and proceeds on this assumption. Accordingly, degrees of partial factual truth can — it is held be assigned to scientific theories, and the adequacy of any particular theory can be measured, *inter alia*, in terms of its degree of factual truth. By contrast, empiricists maintain that though scientific theories are useful devices for organising the empirical data, e.g. for purposes of manipulation and prediction, these theories are not intended to explain and represent reality. It follows that, for these philosophers of science, the notion of factual truth is replaced by the notion of utility: "an axiomatic system is never true or false, but only more or less useful" (Von MISES, 1951; p.145).

Though these problems are only some among many, they are at the very core of any philosophical treatment of scientific research, and disputes concerning their resolution may aptly be described as fundamental.

According to one influential philosopher,

> A system of philosophy is not refuted, but becomes ignored...a clash of systems in the philosophical drama ends not in victory and defeat, but in a changing of the scene...the historical development of philosophy is more truly conceived as the periodic formulation of new questions, than as a series of attempted answer to an enduring body of problems...a system dies when the question it seeks to answer is no longer asked."
>
> (SELLARS, 1948; p.424)

If this were so, disputes among philosophers would not have any importance in the sense that by resolving them — seeing who is right and who is wrong — substantive advances are made in our understanding. In Sellars's view, there are no radical disputes between philosophers who theorize about science since the choice of one position over another is not based on a decision on truth-value. Accordingly, no significance at all is attached to the project of developing means whereby conflicting theses in philosophy can be tested.

One of the main aims of the new **FACTUAL PHILOSOPHY** is to challenge this conception. I am convinced that the purpose of PS is to elaborate true explanations about scientific research. If so, it does make sense to ask whether the hypotheses presented in the PS are true, and the question of how philosophical theses are to be tested is quite crucial.

Of course, it is one thing to assert that philosophical theories can be put to the test; another thing is to prove this. I shall now show how philosophical theories concerning science can in fact be tested.

Let us call any philosophical theory concerning science a **meta-theory** (henceforth M). A particular M can be tested by examining pieces of concrete scientific research. For instance, the claim that all scientific laws are empirical generalizations can be tested by examining concrete cases in which laws are postulated or deduced in actual scientific research. The relation between concrete research and the Ms is like the relation between experiments and scientific theories. Just as scientists suggest the performance of experiments as a way of avoiding metaphysical speculation, I propose that concrete research be examined as a way of ensuring that the philosophical treatment of issues in science will not fly off into pure speculation. To answer questions about the factual truth of a scientific theory of motion, we perform empirical tests: we observe real bodies in motion. To answer questions about the adequacy of a particular M concerning the factual truth of scientific theories, is it not then appropriate to examine how real tests are performed by the practicing scientists?[1]

In the remainder of the chapter, I will make precise, with the help of some formal tools, the nature of the similarity between, on the one hand, the relation borne by experiments to scientific theories, and, on the other hand, the relation borne by examination of concrete research to Ms. We will then be prepared to apply the results.

Let us suppose a set, T, of competing scientific theories, T',T",..........,Tn. We want to order the members of this set in terms of the degree of factual truth which each possesses. To accomplish this, we choose a property, p, of an actual object belonging to the common reference class of the Ts[2], and we then determine the value of p at a particular moment of time and a particular state of the object. For each Tn, $Tn \in T$, we get a value p. Should we represent the values of p on a graph, we would come up with a distinct curve for each Tn.

We now define the following relation $<^p$ on T:

$T_i <^p T_j =_{df}$ "the value of p predicted by T_i has a smaller degree of factual truth than the value of p predicted by T_j".

The relation $<^p$ orders T in terms of factual truth in predicting the value p. However, the definition of $<^p$ is incomplete since the sentence

$$'T_i <^p T_j'$$

is asserted relative to a particular set of experiments chosen in order to compare the factual truth of the Ts. Relative to one set of experiments, e1, we may find that

$$T_i <^p T_j$$

Relative to another set, e2,

$$T_j <^p T_i$$

This problem can be avoid by defining $<^p$ as follows:

$T_i <^p_e T_j =_{df}$ "relative to scientific experiment, e, the value of p predicted by T_i has a smaller degree of factual truth than the value of p predicted by T_j".

Let us now suppose that we have a set of meta-theories, M, and that we wish to order the set. We first obtain an order for the Ms in terms of their explanatory power. The explanatory power of any particular Mn is its ability to explain a particular meta-theoretical concept, c, which is taken as meta-analytically relevant to scientific research. If we have two competing Ms members of M, we can define:

$M_i <^c M_j =_{df}$ " M_j has a higher degree of explanatory power with respect to the meta-theoretical concept c than M_i ".

I will try to show below that the instrumental presuppositions informing the design of a scientific experiment are relevant to the philosophical study of the interplay between theory and experiment. Thus, we shall find a meta-theory which accounts for, another which overlooks, the relevance of these presuppositions.

Let us now turn to a more complicated case. Suppose we have two Ms which both explain the meta-theoretical concept c. How are we to order them? We define the relative degree of adequacy of accounts of c in the following way:

$$M_i <^c M_j =_{df} \text{"}M_j \text{ has a higher degree of truth or adequacy with respect to explaining } c \text{ than } M_i\text{"}.$$

Here, as before, it is important to make the same remark made when we discussed the factual truth of scientific theories. Depending on the particular piece of scientific research chosen, we could get either

$$'M_i <^c M_j'$$

or

$$'M_j <^c M_i'$$

So, again, we define as we did in the case of factual truth:

$$M_i <^c_e M_j =_{df} \text{"relative to the examination, } e, \text{ of concrete scientific research, the degree of truth or adequacy of } M_j \text{ is greater than that of } M_i\text{"}.$$

By comparing the preceding definition with the definition of factual truth above, we can gain a clearer grasp of the analogy between scientific experiments and the examination of concrete research. In both cases, we have a criterion for testing or comparing hypotheses, and our understanding of what is for an hypothesis to be true is relativised: we can speak of no more than the partial degree of truth or adequacy of an hypothesis relative to a particular test.

Another feature of the analogy, which will be discussed in detail in the last chapter, also deserves be put on record here. The relevance of scientific experiments to the testing of hypotheses or systems of hypotheses — I speak here specifically of empirical tests; non-empirical tests will be dealt with in the coming chapter — is beyond question one of the most important aspects of the interplay between experiment and theory and must not be undermentioned. However, another feature is of equal importance, viz. the power of scientific experiments to lead to new concepts and to new relations between old and/or new concepts. The analogy extends, though in a more subtle way, to this feature of scientific Ms as well. Not only is the examination of concrete research relevant to the **testing** of meta-theoretical hypotheses, but it is also relevant to the **invention** of new meta-theoretical concepts. In the new **FACTUAL PHILOSOPHY,** in other words, the elaboration of any M takes place within the context of a detailed analysis of pieces of scientific investigation. This is what leads us to expect that philosophical debate will indeed provide fruitful commentaries about actual scientific research. In fine, the philosophical treatment of issues in science will cease to be viewed as external to the scientific issues. In the new **FACTUAL SCIENCE,** the barrier between the philosopher and the scientist will break down. Neither will the scientists reject the results of their philosophical counterparts as irrelevant, nor the philosophers to see the scientific researchers as too naive fully to understand what they are doing.

To conclude, let me show, very roughly, how the preceding results can be brought to bear, upon testing philosophical Ms.

Consider, first, the conflict between two meta-theoretical approaches to the concept of factual reference, i.e. the concept of what scientific theories are about. Factual reference is made in claims such as these: 'biological theories are about living organism'; 'quantum mechanics deals with systems which include both physical objects and observers'. Here is a pair of conflicting definitions of factual reference[3], the first a realist definition, the second, an empiricist or operationalist definition:

> DEFINITION 1 - Scientific theories refer to real entities which the theories purport to represent and to explain. (e.g. suppose T=Bohr Theory of the Atom; then, R(T)='the set of atoms', where R(T) designates the reference class of T.)
>
> DEFINITION 2 - Scientific theories are about empirical operations or empirical observations, which the theories purport to explain.(e.g. suppose T=Classical Mechanics; then, R(T)='the set of measurements of mass', 'the set of measurements of speeds', and so on.)

The following question arises: which definition more accurately accords with actual scientific practice? If we follow the guidelines laid down above, we shall take some piece of concrete scientific research and evaluate the definitions with reference to it. Here we can clearly see the importance of the choice made. Should we select for examination a phenomenological theory, e.g. the behaviourist position in psychology, we will find more evidence for the second definition: the propositions of this theory are indeed about empirical operations or observations. Thus, if we consider for instance the behavioral definition of <u>learning</u>:

> L= "the modification of behaviour
> in response to stimulation"(BUNGE, 1980b;
> p.141),

we observe that R(L)='the set of animal behaviour', 'the set of animal stimuli', and 'the set of animal responses'. Thus, we have in fact a concept of learning which refers to notions which can be empirically observed.

However, should we select a non-phenomenological theory for examination, e.g. the neuro-physiological position in psychology, the first definition will be confirmed: the propositions here refer to real objects which are postulated within a theoretical context, and cannot be directly observed. Thus, if we consider for instance the psychobiological definition of <u>learning</u>:

L= "the formation or reinforcement of synaptic connections" (BUNGE, 1980b; p.212),

we observe that R(L)='the set of brain processes'. This concept of learning does refer to any object which can be directly observed, but it is postulated in terms of theoretical hypotheses which may receive indirect empirical evidence within the context of neuro-physiological research.

A second case is less abstract, and concerns the question of whether or not any scientific concept arises due to inductive reasoning based on experience. A positive answer here is associated with Francis Bacon:

> The evidence of the sense, helped and guarded by a certain process of correction, I retain. But the mental operations which follows the act of the sense I for the most part reject, and instead of it, I open and lay out a new and certain path for the mind to proceed in starting directly from the simple sensous perception.
>
> (BACON, 1620; p.268)

To evaluate this inductivist stand, let us consider Rutherford's invention, in 1910, of the idea of the atomic nucleus. This case holds a special interest because the new concept was invented in the laboratory context, and therefore may appear to offer irresistible support for the Baconian line of reasoning.

Let us analyse Rutherford's path to the atomic nucleus.

By the beginning of this century the physicists had already postulated the existence of the atoms in order to explain and to represent the structure of matter. With this hypothesis in mind they were able to obtain some knowledge concerning the structure of the atoms. The first model of the atom which accounted for all facts known at that time was proposed by J.J. Thomson:

<u>THOMSON</u> <u>MODEL</u> <u>OF</u> <u>THE</u> <u>ATOM</u>: The atom is a homogeneous sphere with thinly distributed mass and positive electricity. Inside this sphere there are negatively charged electrons which are arranged like seeds in a pumpkin.

This model presents an atomistic view of matter. It accounted for the existence of the sub-atomic particles, the electrons, and it explained the neutral character of the atoms.

Rutherford decided then to perfom new experiments which would produce new information and which would help in building new models of atomic structure. For this, Rutherford prepared an experiment in which a particle entered inside the atom and interact with it. The observation of the behaviour of this particle <u>before</u> <u>and</u> <u>after</u> this interaction did provide information about the atomic structure. The particles needed for those experiments had to satisfy two requirements: they had to carry a charge, so as to be able to interact with the positive part of the atom and they had to be energetic enough to penetrate sufficiently close to the center of the scattering atom.

Rutherford had at hand a particle with which he was familiar from his experiments with radioactive emission and which met these requirements: the alpha particles. The idea was to perform scattering experiments, i.e. to pass the alpha particles through thin metals foils, detecting the emerging particles by some method available. Rutherford had this method: he could detect alpha particles by observing scintillations produced on a fluorescent screen. A diagram of the experimental set prepared by Rutherford is shown in FIGURE 1.

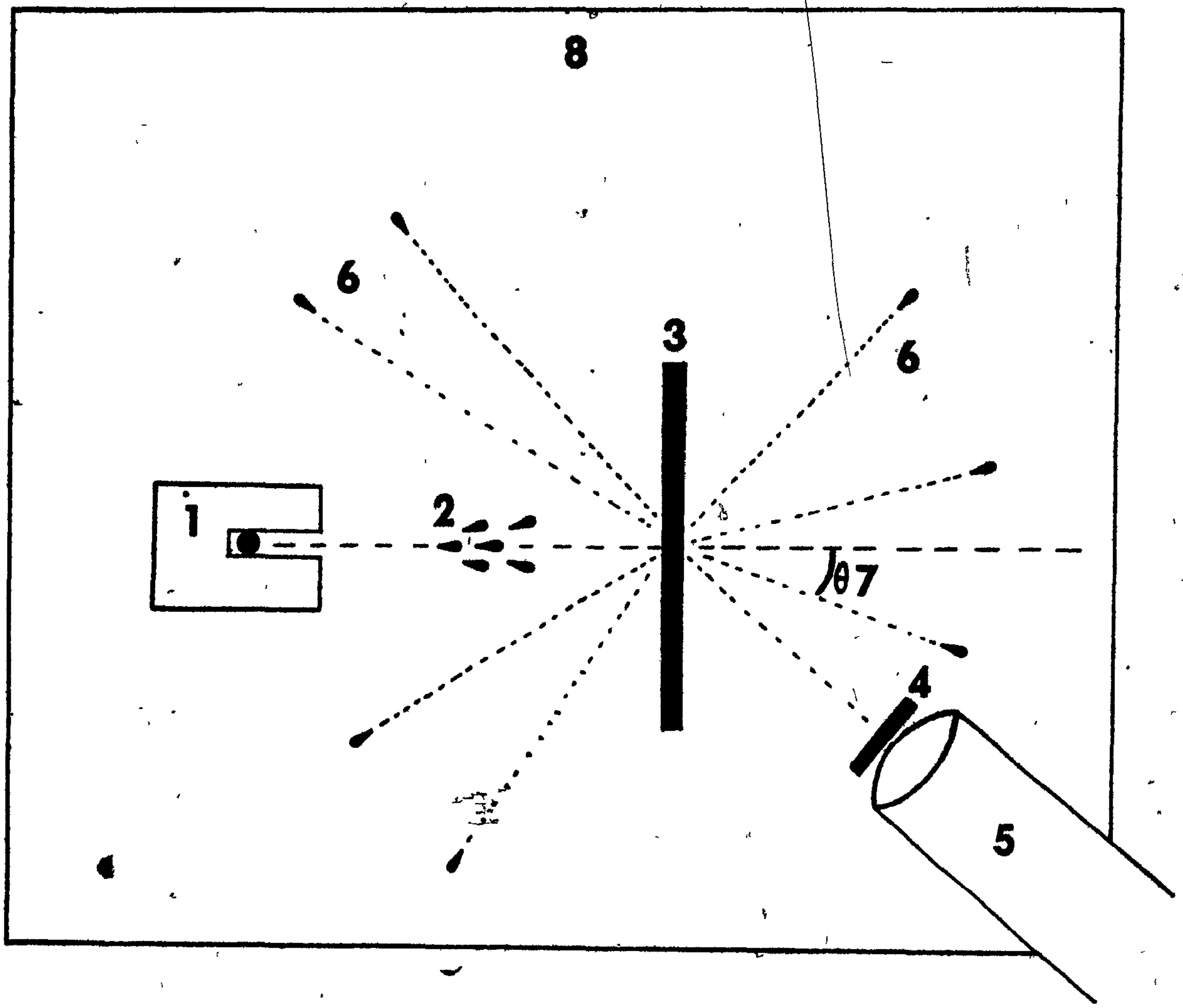
In terms of the Thomson Model and the knowledge which Rutherford had concerning the alpha-particles it was possible to derive the following prediction:

THEOREM The chance that any alpha particle can be scattered through a large angle in almost zero.

The proof of this theorem which can be presented in exact terms is based on the Thomson Model, the characteristics of the alpha particles and the assumption that the scattering was due to the accumulated effect of a number of small scatterings.

FIGURE 1 - Diagram of Rutherford scattering experiments.

1. Source of alpha particles, e.g. radium
2. Beam of alpha particles
3. Gold foil
4. Screen of fluorescent material
5. Microscope
6. Scattered alpha particles
7. Scattered angle
8. Vacuum


8
6
3
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1
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θ7
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5

Now we face the most interesting situation of any scientific research: Rutherford and his co-workers found that some of the scattered alpha particles were not only deflected by large angles but they were coming backwards[4].

The next step was Rutherford's invention of the idea of an atomic nucleus. He postulated that the massive, positively charged portions of the atoms must be extremely small. This concentration of positive mass forms the atomic mucleus. With this hypothesis Rutherford was able to elaborate an exact theory about the scattering processes and therefore to derive a theoretical formula to predict the scattered angle in terms of the relevant variables of the scattering processes. To test the validity of this theory, Geiger and Marsden subjected the formula to extensive checks over a wide range of its variables, and the experimental results proved to be in remarkable agreement with the theoretically calculated values. As we will discuss in the following chapters, Rutherford's hypothesis had deeper consequences, opening a door to quantum physics.

The analysis of Rutherford's invention of the idea of an atomic nucleus is clearly in disagreement with the inductivist thesis. There is no observation in the scattering experiment discussed above which directly suggests the existence of the atomic nucleus. In reality, it was only with the previous atomistic hypothesis — which is also a postulate of contemporary physics and not an empirical induction — that Rutherford could interpret the experiments and propose the atomic nucleus. Had Rutherford followed Bacon's maxim — 'the mental operation which follows the act of sense I for the most part reject' — he would never have invented the atomic nucleus.

It is now time to pass to the description of some philosophical theses which can be tested by examining scientific experiments in detail.

Notes

[1]An excellent case for examining concrete scientific research in testing philosophical theses about science is presented in R. Angel's The commensurability of scientific theories with particular reference to Newtonian and relativistic mechanics (ANGEL, 1978). In this illuminating analysis of the concept of commensurability, the author not only aims to refute the popular views of Kuhn and Feyerabend but he also tries 'to show that many theses in the philosophy of science can only be adequately supported or refuted by means of a detailed analysis of actual theories as distinct from both the analysis of abstract theory schemata on the one hand and, the casual reference to isolated parts of theories or anecdotes from the history of science on the other. The former method was characteristic of the Vienna Circle, and the latter of Kuhn and Feyerabend' (ANGEL, 1978; p.87).

[2]The concept of reference class of scientific theories is presented in the following chapter. For a detailed analysis, see BUNGE, 1974a.

[3]The definitions apply not to the referents of abstract theories such as logic and mathematics, but to the referents of factual theories such as physics and biology. Thus the name <u>factual reference</u>.

[4]As Rutherford himself described this surprising novelty:

> It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you...
>
> (RUTHERFORD, 1936; p.564)

CHAPTER II

TWO PHILOSOPHICAL PROBLEMS

THE TRUTH OF SCIENTIFIC THEORIES

AND

THE THEORETICAL BASIS OF SCIENTIFIC EXPERIMENTS

I now present two philosophical problems and some solutions which have been so far advanced. The analysis of the experiments in solid state physics to be exhibited in the next chapter will provide the elements for thé tests of the theses presented here. With this strategy in mind, I will try to develop this chapter as concisely as possible in order to pass directly to the discussion of these philosophical problems in the light of the analysis of concrete research.

Let us first approach a problem which has not received enough attention by most philosophers of science. The problems consists of the theoretical assumptions made by scientists in the design of experiments. The very fact that this problem has been neglected reflects a first position concerning the theoretical basis of scientific experiments:

THESIS 1 - Sciéntific experiments are theory-free. They consist of the pure collection of empirical data which is accompished without the help or interference of any theoretical concepts.

This empiricist interpretation of scientific experiments can be developed as a defense of the objectivity of factual sciences. It is true that positivists themselves have never insisted on the objectivity of science. However, since I will present here a defense of objectivity based in the alternative view, it is interesting to develop and to refute a "positivist" defense of the scientific objectivity. For that, we have to assume that:

THESIS 2 - An experiment is objective if and only if it is theory-free.

THESIS 1 and THESIS 2 give us:

THEOREM 1 - Scientific experiments are objective.

To get the objectivity of science from THEOREM 1 all we have to do is this next empiricist move:

THESIS 3 - Factual science is based on experiments alone.

Let us now concentrate our attention on THESIS 2. In one sense, we can realize that this thesis aims to refute the idealist philosophical tradition which postulates the complete impossibility of any objective experience or any objective knowledge since all data obtained from experience is determined by <u>human</u> <u>factors</u> [1]. Since THESIS 2 postulates the possibility of experiments completely free from theory — and therefore from subjective elements — it can be assumed that this thesis represents a refutation of the idealist philosophy. With this refutation as an implicit aim, we could take the empiricist theses as an interesting strategy. Nevertheless, as I have defended in the last chapter, we should not avoid the crucial questions: <u>Are these theses true? Is there any such thing as theory-free experiment in scientific research?</u>

I will postpone to the following chapters the discussion of these questions. Let us start with the following thesis:

THESIS 4 - All scientific experiments are theory-dependent.

It is clear that THESIS 4 is exactly the negation of THESIS 1:

THESIS 4' - There is no scientific experiment which is theory-free.

In order to substantiate THESIS 4 I will exhibit now four modes in which scientific experiments depend on theories.

<u>A - The conception of the experiment</u>

A scientific experiment is not the result of a spontaneous and casual experience; the experiment is conceived with a cognitive aim: it should help us to solve or to develop a theoretical problem. In this sense, the very conception of any scientific experiment aims to test a theoretical hypothesis — e.g. the patterns of diffraction of beams of electrons through crystals as evidences for the hypothesis of the wave properties of particles — or to suggest new insights in the elaboration of a new theoretical model — e.g. the scattering experiments discussed in CHAPTER II. The main consequence of this model of theoretical dependence is the fact that any scientific experiment can only be conceived in the context of some theoretical problems. Whether the theory or theories within which a particular experiment is conceived are more or less elaborated — e.g. Galileo's experiments to develop and to test the new mechanics, or the sophisticated experiments in solid state physics which we will approach in the next chapter — is a secondary matter for our present discussion. The point to be made is the necessity of a theoretical context for the very conception of any scientific experiment.

There exists an interesting objection which may be present to the theoretical basis of the conception of the scientific experiments: what about the facts which are discovered by chance? Aren't they counter-examples of the theoretic-basis of the experiments's conception? In order to answer negatively this objection, we have to realize that these surprising discoveries become intelligible only if the experimental scientists are able to embed them in a theoretical context; by doing this, the chance discovery becomes a scientific experiment with its theory-dependence. Furthermore, it is important to stress that even in those cases when we do observe an important contribution of chance to the discovery of new facts, the instrumental apparatus involved in the discovery of new facts is also theory-dependent. If we look at a classical textbook instance of casual discovery, the discovery of X-rays by W. Rontgen in 1895, we can see that: 1. the instruments involved in the discovery the Crookes tube and the crystals of barium platino-cyanide were well-known by Rontgen, and that, 2. Rontgen's hypothesis of the existence of X-rays to explain the bright fluorescence of the crystal placed nearby the Crookes tube in operation, was a theoretical assumption which could only make sense in terms of the theoretical context of Rontgen's time.

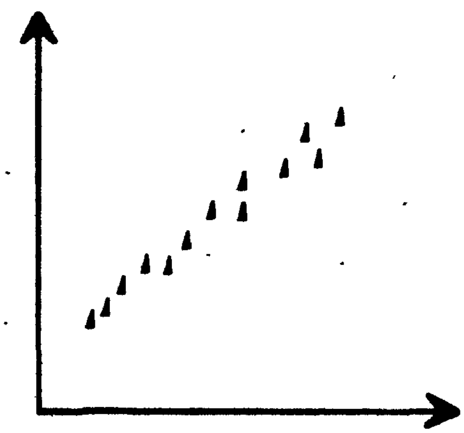
B - The design and plan of scientific experiments

The instruments used in contemporary scientific experiments are themselves theory-dependent. In general, the functioning of the instrument is not questioned when it is apply in a particular experiment. This means that the theories used in the construction of the instruments are not directly tested when the instrument is used in a particular experiment. In reality, since we have experiments which involve many instruments based in many distinct theories, in most cases the design involves other theories than the one under examination. Those other theories which are used in the construction of the experiments and which are not necessarily under examination have been called auxiliary theories (BUNGE, 1967b), the validity of which is provided by many other independent tests including experiments from other branches of physics. However, it is not only the construction of the instruments which depends on many auxiliary theories; their very functioning is also understood in the light of these theories. In this sense, we can state that the whole plan of a scientific experiment depends not only on the theory under examination but also on a number of other auxiliary theories used in order to design the experimental apparatus.

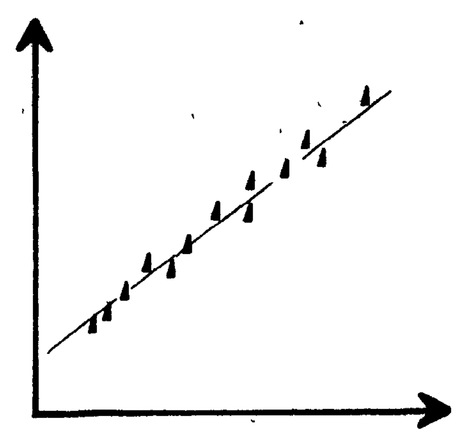
C - The reading of the data: the interpretation of the empirical information

Whenever we meet experimental scientists in a lab who say that they have finally finished their experiments because the data have already been produced, we can infer the contrary: their work is just beginning. In order to read a piece of empirical information, i.e. to look at it as relevant information concerning actual objects, the scientists must use "theoretical glasses". The end product of the experiments has to be interpreted, and this interpretation of the data depends on many theoretical concepts. A typical outcome of contemporary experiments is presented in FIGURE 2.a. The first step of the scientist is to obtain a curve — FIGURE 2.b — whenever possible. For the sake of simplicity, let us suppose that the scientists could draw the line shown in FIGURE 2.b. As I will discuss later on, this very act of drawing a curve is itself theory-dependent: the empirical data consist only of a set of discrete points; the curve is then a theoretical interpretation of the points. The continuity of the processes under observation must be assumed. Furthermore, knowledge about the instruments and their functioning is the only way to understand what the points of the graphic are about.

FIGURE 2 - Experimental Outcome:
a. a typical outcome of scientific experiments
b. a curve produced from the data obtained experimentally



(a)



(b)

Suppose the points are obtained from the reading of a voltmeter. Consider now that this instrument show the following output:

<u>1.009314</u>

What do these numbers mean? They are the measure of the value of the electrical potential between two points of the sample under examination. Thus we can re-read it:

<u>1.009314 Volts</u>

This first step presupposes quite a lot of information concerning the apparatus used. The work of interpretation does not stop here. As in another case we will analyse in detail a lot of theoretical calculations may be required before the reading of the electrical potential becomes the information needed — i.e. the value of the sample's temperature calculated from the voltmeter's reading. All these further steps of the data interpretation are extremely dependent on auxiliary theories. The following chapters will attempt to illuminate these remarks by concrete examples.

D - The analysis of the results

In most experiments the interpretation of the empirical data is just the first stage of a lot of difficult theoretical work. Once the data are interpreted, the scientist starts to analyse the results in terms of the theoretical predictions or expectations. This analysis does not consist only of a direct comparasion between the theoretical predictions and the empirical data. If the results are positive — i.e. if the values produced from the experiments are in agreement with the theoretical prediction within the limits of the experimental error[2] — then it may be the case that the results are taken as evidence for the hypotheses or theory under examination. If we do not have an agreement[3] then the scientists must review their interpretation of the empirical data. In reality, even a positive result is not immediately accepted. In most cases the analysis of the results leads to the discussion of all the assumptions and the theoretical basis described in A, B and C. Being the results positive or negative, the scientists can — in most actual scientific experiments they indeed do — question the experimental results. This is not surprising since I have just described at least three modes of the theoretical basis of scientific experiments.

These four modes of the theoretical dependence of the scientific experiments aim to substantiate THESIS 4. Before we pass to the next philosophical problem — the factual truth of scientific theories — let me comment briefly on the question of the objectivity of factual science. As we have observed when discussing the empiricist interpretation of experimentation, the theory-dependence of the experiments was associated with an idealist philosophy. If I have presented an alternative conceptualist view which defends the theoretical basis, it could be concluded that this view indeed refutes scientific objectivity, i.e. it could be argued that since the results obtained by the performance of experiments are **produced** by the experimental scientists, factual science does not refer to an objective reality, but **to the reality produced by the scientists.** This is indeed the strategy of most contemporary idealist attacks on science. In order to answer this objection and at the same time to maintain the objectivity of factual science, we have to analyse some other philosophical theses defended by the conceptualist alternative. First the thesis which rejects the idea that factual science refers to a constructed reality:

THESIS 5 - The factual referents of scientific theories are the objects which are assumed to exist in the real world independently of the human experience of them — e.g. protons, stars, societies.

This thesis is based in the ontological assumption that:

THESIS 6 - The real world is a system of actual entities which exist independently of the human experience of them.

With these two theses we can realize that the fact that every scientific experiment is theory-based does not imply that factual science refers to a constructed or ideal reality. THESIS 5 and THESIS 6 allow us to distinguish clearly the factual referents of scientific theories from the features of the assumed real entities which are objectivily studied through the performance of experiments. What is true is that these features studied through experimentation are not absolute signs or observations of reality. As empirical results they are produced with the help of theories and, of course, through the performance of actual interactions the experiments. While the positivist could base the objectivity of science on the possibility of theory-free empirical results, the conceptualist overtly states the theoretical basis of any experiment and then bases the objectivity of science on the process of constant questioning of experimental results. Here we have one of the clearest disagreements between the two views I am presenting: on the one hand the "positivist" who postulates the purity of empirical results and from this postulate derives the objectivity of factual science; on the other hand, we have the conceptualist who postulates the theoretical basis of scientific experiments and from this postulate — together with the requirement of constant questioning of the empirical results derives the objectivity of factual science. An important consequence of this conflict is that in the former case we face an attempt for an absolute criterion, whereas in the latter we have a incomplete and probably temporary decision concerning the certainty of the empirical results. To go deeper at this point we have to start the discussion of our next philosophical problem.

**** **** **** ****

The search for truth is considered by most of us the main goal of any scientific enterprise. No matter how paradoxical it may seem, empiricists refute the notion of truth in factual science because of its "metaphysical character". It is assumed that to ask about the truth ~~of a scientific~~ theory is to inquiry about the adequacy of this theory to explain and represent the real world. Since empiricist philosophers do not accept the even "more metaphysical" notion of the real world, they reject the notion of factual truth. For them, the truth of scientific theories is replaced by two other concepts:

1. In terms of a particular scientific proposition, it is assumed that its validity is given if it is verified by empirical tests. Then, the empiricist thesis,

THESIS 7 - A scientific proposition is valid only if it is verified by empirical evidence.

This thesis is based on THESIS 1, the postulate of the pure theory-free empirical data, and another empiricist thesis, namely,

THESIS 8 - All scientific propositions refer to empirical oberservations or operations.

Once THESIS 7 is assumed, the empiricist philosophers believe that they can provide a criterion for the validity of the scientific propositions. Furthermore, they conclude that science has finally been freed from any metaphysical contamination: scientific propositions, the meaningful propositions in opposition to metaphysical and meaningless ones, are verified by empirical tests. This demarcation criterion presupposes the empiricist view about the meaning of scientific propositions which I will not discuss here[4,5].

In terms of the validity of a single scientific proposition we can conclude that the empiricist position defends the direct test of this proposition through the comparasion with or verification of empirical data.

2. In terms of the truth of a complete scientific theory the empiricist philosophers replace the notion of truth or adequacy by the notion of simplicity and the power of explaining empirical results. When they must choose between two conflicting scientific theories, the empiricist philosophers will not look for the truer or more adequate theory: these are metaphysical notions because they are based on the assumption of an independent real world.

The best choice for the empiricist philosophers will be the one which can explain or describe more empirical observations assuming fewer basis concepts. From this perspective, the empiricist will finally replace the test of truthfulness by the test of usefulness. Let us repeat the thesis of Von Mises quoted before:

THESIS 9 - "An axiomatic system is never true or false, but only more or less useful".

Let us now move to the alternative, i.e. the conceptualist view which not only defends the notion of factual truth, but develops and presents it in exact terms. Since the aim of this chapter is only to present a brief and informal characterization of some philosophical theses, I will not present here a detailed theory of the factual truth of scientific theories[6].

Let us start by adding an epistemic thesis to the semantical — THESIS 5 — and to the ontological— THESIS 6 concerning the independence of the real world:

THESIS 10 - The real world can be partially represented and explained by means of scientific theories.

In other words, the conceptualist position assumes that a scientific theory is a hypothetical system which aims to represent and to explain a certain domain of actual events. Therefore, the search for true or adequate theories makes perfect sense from this philosophical position:

THESIS 11 - The truth or adequacy of a factual theory is evaluated by the comparasion between on the one hand the theoretical predictions derived from the theory with the help of auxiliary assumptions, and on the other hand the the empirical results which are also produced with the help of many auxiliary theories.

This evaluation is not the final word concerning the truth of the theories under examination — i.e. it does not say whether the theory is completely true or completely false. Rather, it offers a manner through which we can evaluate the degree of the factual truth of a scientific theory. I will now discuss some observations about factual truth.

A. The factual truth values are attributed to scientific propositions when two predicates — i.e. a theoretical prediction and a empirical result — are compared. In this sense, the concept of factual truth is not taken as an intrinsic property of propositions — as Platonist philosophers would state — but it is taken as a value attributed to predicates always in relation to another predicate.

B. The evaluation of the degree of factual truth of a scientific theory can not be made by verification of the correspondence between the theoretical model and the actual object which the model is supposed to represent. As I have explained before, the referents of a scientific theory should not be confused with its empirical evidence. In the example discussed in CHAPTER II, the referents of Rutherford Model are atoms — the electrons, the nuclei and the alpha particles. The scattering experiments can be considered as evidences for this model since the formula derived by Rutherford is in agreement with the empirical results produced. We cannot infer that we have a direct test for the correspondence between Rutherford Model and the real objects assumed by it — the atoms. In general, an empirical test provides evidence for some consequence of the theory concerning only some of the features of its referents.

C. The notion of the factual truth of a scientific theory is very far away from the notion of an absolute and final truth which is presented in classical metaphysics — e.g. Descartes — or in most theologies. If we look at the Judeo-Christian theology for instance, we find that God created the world and revealed the truth concerning this world in the holy Bible. Therefore, all that the wise man must to do to discover the truths about the world is search for them in the holy Bible where they reside. The ultimate truths exist and it is just a question of a correct way of finding them. To return to case of scientific research, these final truths are not supposed to exist. Since the factual truth's evaluation depends on empirical tests, and these tests are themselves theory-dependent, we can never reach a definite decision about the adequacy of the theoretical model. This is not surprising: the theoretical model is not supposed to be a mirror image of its referents since the model contains a number of simplifications and is no more than a hypothetical construction. Indeed, in concrete factual research — unlike mathematics and logic — truth and falsity are not completely contradictory. Sometimes, the same theoretical prediction may be evaluated with a high degree of factual truth from one set of empirical tests, and with a low degree of factual truth from another set of empirical tests. The empirical tests, although an important way of evaluating the degree of factual truth of scientific theories (these tests are in fact the main methodological distinction between factual and formal science), are neither an absolute criterion nor the only way of testing hypotheses. Scientists have in their hands many other ways of testing their theories. In order to elucidate, let me discuss some of these other ways, i.e. conceptual tests of factual theories.

The search for a higher degree of factual truth is not always the main goal of a research programme. In many cases, the search for a deeper approach to a scientific problem becomes more important than the search for higher factual truth. The most common instances of this situation consist in the introduction of a new theory in a particular field of research. If the new theory is supposed to replace or to offer an alternative to an old theory, it may be the case that in the first years of its developments, the new theory has a much lower degree of factual truth than the old theory; one of the main reason for this lack of empirical evidence is that the scientists may have difficulties discovering the right way to set up the empirical tests for the new theory because those tests are themselves theory-dependent. However, if the new theory promises deeper insight than the old theory, it may be the case that most research programmes will favour the new proposal.

Another important factor which may favour a new theory is the possibility of developing scientific explanations for a new domain of reality in opposition to accepting dogmatic explanations. This situation is illustrate by the relatively quick acceptance of Charles Darwin's theory of evolution by the scientific community. The evidences for Darwin's hypotheses were few and some were of doubtful character. Nevertheless, scientists were excited by its potential. Even though very complicated, Darwin's theory still received the necessary acceptance by the scientists of his time and became a new field of research. To sum up, Darwin's theory, though complicated and lacking empirical evidence, was nevertheless a scientific attempt to explain the origin and the evolution of life, and as such, opened up possibilities not found in the alternative, non-scientific approaches to the same problem — e.g. the creationist theory[7].

Even if we restrict our attention to an isolated scientific theory, we find many tests which are not empirical, e.g. the theory must not be self-contradictory, i.e. the theory must not imply a theorem and its negation; the theory must be semantically closed, i.e. it cannot imply theorems concerning objects which do not appear in the axioms and the primitive notions of the theory. These formal tests which are also presented in abstract theories are not always easy to perform because of the informal character of most factual theories.

A last test to which we can subject a factual theory is the test for the consistency with other theories within or between various branches of factual sciences. In the next chapter we have an instance of this kind of test: when we consider the atomic model proposed by Rutherford, and, at the same time, the principles of classical electrodynamics, we see that a contradiction is derived from the axioms of the model and we have to conclude that the model is too simple — see page67.

The reason for pointing out all these conceptual tests of factual theories is to show that the empirical test is not only 'partial' in the sense that it provides only a partial degree of factual truth (not absolute truth), but it is also 'partial' in the sense that it is but one of the many tests.

So far I have presented conflicting positions concerning two philosophical problems — the theoretical basis of scientific experiments and the factual truth of scientific theories — without any attempt to present a decisive argument for either of these theses. In order to offer such argument I pass now to the presentation of a set of concrete scientific experiments.

Notes

[1]As Kant said when discussing the foundations of SPACE in his Transcendental Aesthetic,

> It is therefore from the human point of view only that we can speak of space, extended objects, etc...
>
> (KANT, 1781; p.46)

[2]Suppose that the experimental result is X, the experimental error is Z (the estimated error of the measurement), and that the theoretical prediction is Y. We say that we have an agreement if

$$|X-Y| \leq Z.$$

[3]If

$$|X-Y| > Z.$$

[4]For a successful criticism of this notion of meaning and the proposal of a conceptualist alternative see BUNGE, 1974b.

[5]The following interesting remarks concerning the empiricist view on the meaning of scientific propositions illustrates how deeply this view is embedded in Kant's philosophy:

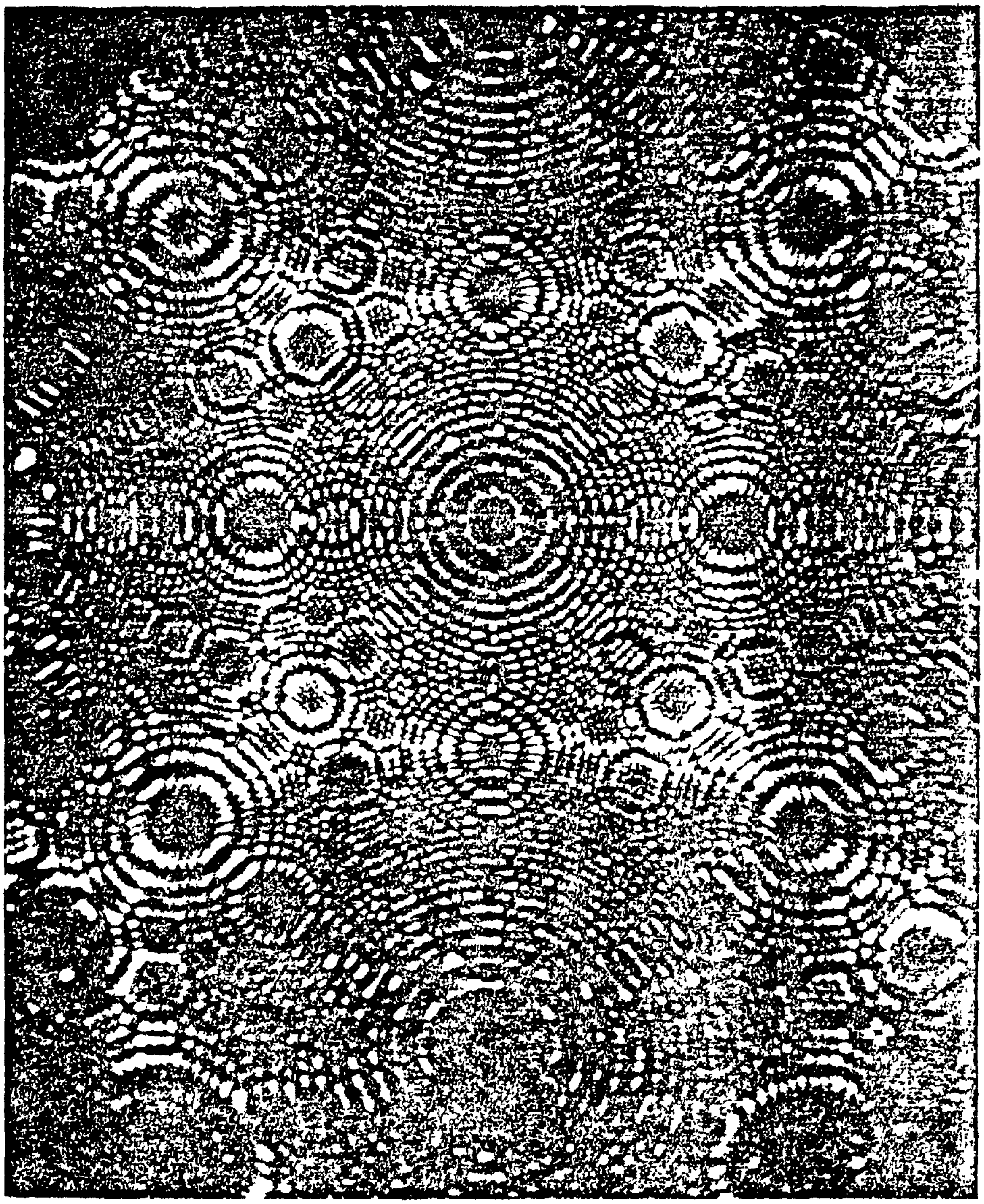
> We are only concerned here with experience, for otherwise things that can never be objects of an experience, if they were to be known according to their nature, would drive us to concepts the meaning of which could never be given <u>in concreto</u>...
>
> Hence the pure concepts of the understanding also have no meaning whatever if they try to leave objects of experience and to be referred to things in themselves (noumena). They serve as it were only to spell out appearances, so that they can be read as experience...
>
> (KANT, 1783; p.54 and p.73)

Kant did not only restrict the scope of the human knowledge to the objects of experience (appearances), but he also proposed a criterion for the meaning of the valid propositions, which is even more clear in his conclusion to a paragraph found in this same text quoted above, p.76:

> As soon as we depart from these (objects of possible experiences which are mere beings of the senses) not the slightest meaning is left to those concepts (concepts of the understanding and our pure intuition).

[7]This remark can be taken as a refutation of the positivist myth of the simplicity of scientific theories (see BUNGE, 1963). Though the theory of evolution was welcomed, the last thing Darwin could claim in his time was the simplicity of his theory.

FIGURE 3 - "Field ion microscope image of atoms on tip of a fine iridium needle".
(Reproduced from KITTEL, 1976; p.36)



CHAPTER III

THE MEASUREMENTS OF THE THERMOELECTRIC POWER OF METALLIC GLASSES

III.A - INTRODUCTION

In this chapter I will abstract from the methological and philosophical dimensions of this dissertation. I enter now into a different area of intellectual adventures: the land of theoretical and experimental factual science. In the following pages, I will not reflect on the way **we know or we can know** real processes through scientific research. The aim of this chapter is quite different: it is to present scientific knowledge concerning the structure and properties of physical objects — one of the oldest and most fascinating subjects of physics from the time of the pre-Socratic natural philosophers up to the time of experimental and theoretical high-energy physics. This presentation will provide elements for the examination of concrete research which I have defended as the best method for testing philosophical theses concerning science.

If the set of experiments I have chosen to analyse appears too technical and too specific — a text for a scientific publication rather than a philosophical debate — my choice needs some words of justification. Philosophers have claimed that the scientific method is induction, that the scientific method is deduction, that science is this and that. They have stated that what scientists do is this and that. But go and look for yourself. Go analyse the actual scientific theories or the actual work of scientists. Go to labs, read scientific publications. Go and look. Look and tell: what do you 'see'? I 'see' something very different. Maybe what philosophers have claimed to be science does not refer to the actual work of scientists, but to the work which philosophers think that scientists should do. These philosophers refer to an abstract theory which they take as the best description of scientific theory for a philosophical debate — e.g. the Vienna Circle. Other philosophers refer to isolated parts of scientific research, especially historical cases. Such thinkers offer us a series of philosophical theses based on oversimplified historical cases of scientific research. In both cases, philosophy of science becomes a reflection on an ideal science and not actual scientific research. This dissertation does not accept such a definition of the philosophy of science. Instead, I consider the PS to be a serious reflection on actual research, an intellectual endeavor which aims to understand and to explain concrete research. Thus I ask the reader to be patient and to accept the specificity of this chapter.

My choice is an ordinary piece of scientific research rather than a famous and dramatic case of the kind used by most philosophers of science. There is no mention here of Galileo's classical experiments or Newton's theoretical innovations. Rather, my analysis concerns investigations on metallic glasses, an area of research which is typical of the kind of experimental work being done nowadays. And I submit that it is only the analysis of this kind of research which can offer us valid conditions for testing any philosophical thesis. It is only by bringing philosophy to bear really happens in scientific laboratories and on what is written in scientific publications that we will be able to bridge the profund chasm which has deepned between scientists and philosophers for so many years.

It is important to stress that most of the scientific publications concerning actual experiments do not explicitly mention all the theoretical assumptions involved in the research in question. This fact implies a double task for the philosophers of science interested in the foundations of scientific experiments. To read scientific publications is not enough: the philosophers of science must explore the theoretical background of the experiments. This task is facilitated by working on it with the experimental scientists responsible for the experiments to be analysed. This cooperation is particularly relevant to the analysis of the theoretical background used in the plan, design, and interpretation of the experiments under examination. All of this may appear very complicated. No doubt it is; but if we want to understand the way scientific knowledge is produced, we must at least try to understand some specific piece of scientific research.

To conclude: let us abnegate the usual abstract and idealized approach to science. In order to develop the new **FACTUAL PHILOSOPHY**, let us be more concrete and try to analyse some actual experiments made by actual scientists. In other words, let us approach philosophy more scientifically, in the same way we expect scientists to approach their domain more philosophically. This movement will bring us back to the days which preceded the industrial revolution, when high-specialization had not become a cruel reality, and philosophy and science could be developed hand in hand.

III.B - THEORETICAL BACKGROUND

The main problem which will concern us now is the transport of electricity and heat through matter. In this section, I will discuss the theoretical background to this problem. In the next sections I pass to the description and scientific analysis of a set of experiments with a particular kind of material, the metallic glasses.

Let us start with the most basic assumption of any contemporary theory concerning the structure and properties of matter. This assumption is the well known atomistic hypothesis, which needs little explanation. It postulates that all material objects are formed by or constituted of basic elements, the atoms. The atomistic hypothesis is very old. We find its first formulation in the pre-Socratic natural philosophers Leucippus and Democritus. One of the basic differences between the contemporary concept and its first formulations of this hypothesis is the question of the unity of the atom. The Greek hypothesis states that the atoms are indivisible. Contemporary scientists postulates the divisibility of the atoms, and suppose that the atoms themselves are constituted of sub-atomic elements: protons, electrons, neutrons, and so on.

The next basic assumption of contemporary theories on the nature of matter is not as well known as the atomistic hypothesis. A real novelty of modern theoretical physics having nothing to do with ancient theories about matter, this assumption postulates the existence of a new entity in the physical word, the fields. Now, processes which take place in the physical world are no longer explained solely by the notions of atomic and sub-atomic elements. The physical world is supposed to be inhabited not only by atoms and their components but also by fields[1].

The notion of a field is not very easily grasped. It took a lot of work before the scientists themselves could accept the existence of fields as an entity in itself. In the beginning, the most scientists could accept was the existence of fields as a kind of vibration of the ether[2]. Let us reflect a little about the notion of fields.

Without fields, the physical world is represented as an immense void where the atoms and the sub-atomic elements move and interact. The void space is homogeneous, isomorphic, and, of course, empty. The atoms are the only entities extant in this world. Even some philosophers who postulated the existence of spiritual entities did not locate them in the same world as physical objects, Descartes for one. Therefore, the physical world was taken as the world of atoms. At that time, a theory concerning matter was conceived as a theory concerning atoms. Up to this point, it is not difficult to imagine, that is to form an image of the way physicists represent the material world. All we have to do is to imagine a world of small ping-pong balls and to conceive their motion and spatial configuration in terms of an analogy with the way we conceive the physical bodies of our common experience.

With the introduction of fields, the picture becomes more complicated. The first image of fields we get is in terms of waves. Mechanical waves are not difficult to picture: we can imagine the sound waves propagating in the air. We can 'see' the sea-waves propagating in the water. Fields, in their propagations's processes are not distinct from these mechanical waves.

Nevertheless, the essential difference is that the fields do not require any material enviroment, other than themselves, in order to propagate in time and space. For instance, we think of electromagnetic waves which can be radiated , become free, and propagate in the void. In this sense, we think of fields as existing entities in themselves, distinct from bodies — therefore distinct from atoms — but still physical and material objects[3].

With the inclusion of fields, the physical or material world is represented by physicists as an immense empty space, inhabited by atoms, sub-atomic elements, and fields. Any possible physical process is then described as the interaction of these material entities. This is the picture we are going to use in our search to understand the transport of heat and electricity through matter by means of theoretical representations refering to a material world inhabited by atoms, sub-atomic elements, and fields.

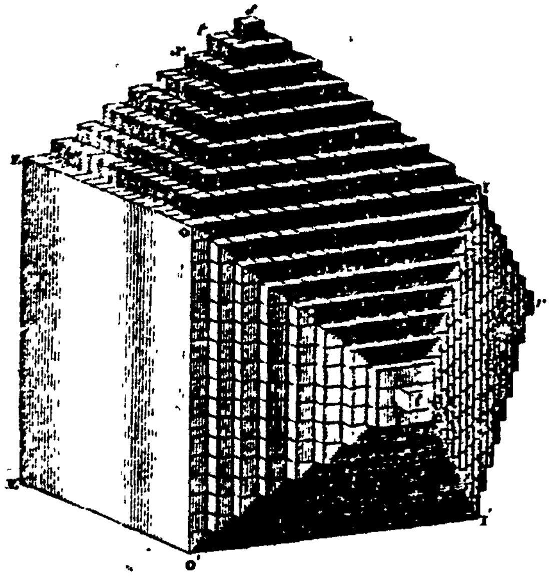
Scientists usually begin with a simple picture which slowly grows more complicated. Suppose we have a piece of metal and we want to understand the electronic and heat transport through this piece of metal. Let us assume further that this piece of metal is in the solid state and that it is crystalline. This last assumption leads us to visualize the spatial configuration of the piece of metal as a periodic structure of atoms, i.e. **a crystal** (FIGURE 3 and FIGURES 4a-d). Now we want to make a further and crucial assumption: let us assume that the main agent

FIGURE 4 - Crystalline Periodicity

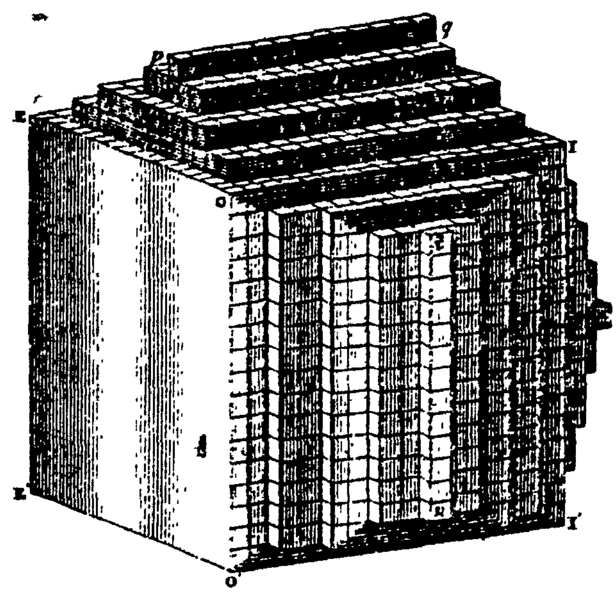
a. and b. "Relation of the external form of crystal to the form of the elementary building blocks. The building blocks are identical in a. and b., but different crystal faces are developed".

c. and d. "Models of the sodium chloride crystal."

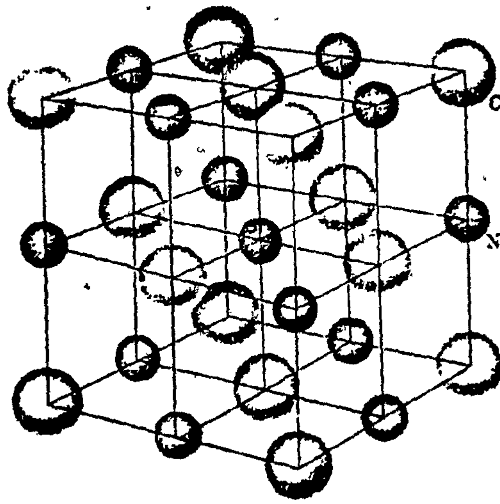
(Reproduced from KITTEL, 1976; p.2 and p.20)



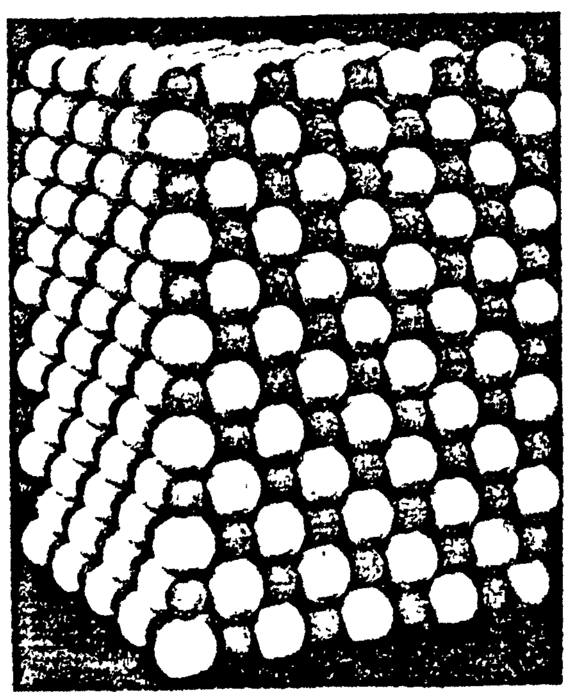
(a)



(b)



c



d

responsible for all these conduction processes are electrons[4]. Then our problem becomes: how do electrons move through a crystal? Before we start to answer this question, let us summarize what we have already theorized about matter.

In order to destroy the myth that axiomatics is a a monster of seven heads or to show that the monster is not so indomitable, let us remember that the axiomatic way of presenting scientific theories is a method invented by Euclid in his great book on geometry, The Elements, and this method has been used not only in the study of mathematical and logical systems but even in the study of the foundations of factual sciences, as in recent attempts for an axiomatization of classical mechanics, relativity, and quantum mechanics (see BUNGE, 1967c). It serves our purposes well by exhibiting clearly the assumption and the logical structure of scientific theories, and by representing a particular way of thinking which allows us to order our ideas and to reflect upon them. Furthermore, even though we present here an intuitive characterization of the background needed for the understanding of the experiments with metallic glasses, the axiomatic method will help us to keep in mind the essential points of the theories presented. As Bunge says,

> Axiomatics can help the maturation of physical science rather than mere growth in bulk. Indeed, axiomatics enhances cogency and clarity — hence exposure to analysis and criticism — which, together with depth or boldness, constitute maturity as distinct

from mere size...

> Finally, axiomatics can help us meet the information explosion, or rather deluge. For, if we cannot keep up with details, we can at least keep up with development of fundamental research in a given field: foundation problems are always "in" and final solutions to them are seldom to be expected.
>
> (BUNGE, 1973b; p178)

Let us then present our assumptions in an axiomatic fashion:

AXIOM 1 - The physical or material world is composed of atoms, sub-atomic elements, and fields.

AXIOM 2 - Atoms are composed of sub-atomic elements (For our purposes we need just three sub-atomic elements: electrons, protons, and neutrons).

AXIOM 3 - The transport of heat and electricity through matter is a result of the motion of electrons[5].

DEFINITION 1 - A crystal is a system of atoms in the solid state which has a periodic spatial configuration.

We are now ready to formulate two questions:

1 - How can electrons of the crystal's atoms (a) become free and (b) travel through the crystal's structure?

2 - How does the periodic structure of the crystal's atoms affect the motion of the electrons through this structure?

The answer to these questions is given within the domain of solid state physics. The difficulty we face now is that any theory in solid state presupposes quantum-mechanics (QM), classical electromagnetism (CE), and statistical mechanics (SM). If we were to present these 3 branches of physics here, our presentation would indeed become fantastically long. Thus, for my purposes, QM, CE, and SM are taken as basic theories, i.e. they are assumed to be valid in the models I will discuss. Whenever I find it necessary, I will offer an intuitive explanation of the concepts used for the reader unacquainted with these branches of contemporary physics.

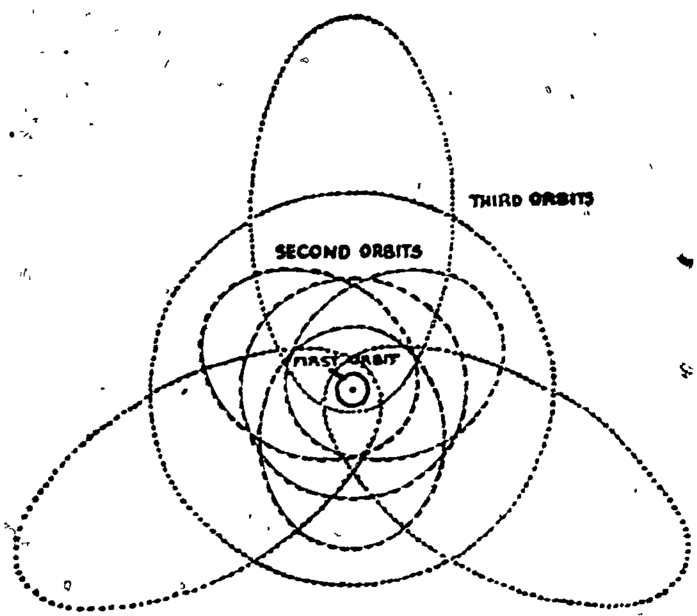
Let us start with question 1.a. How can the electrons of a metal be free in order to move and to transport heat and electricity? To answer this question we start with a classical atomic model, Rutherford's. The reader should have no difficulty visualising this model, since it is exactly this picture which most people use to think about atoms, a picture which has become the common symbol of the atomic era. This model relies upon the analogy between the atomic system and the solar system. The sun of the atomic system is represented by a nucleus — a massive center composed of protons and neutrons. Each proton has an electric charge of +1. Both protons and neutrons — the sub-atomic elements which compose the atomic nuclei — have one unit of mass, 1 a.m.u.. Around this atomic center we have the electrons which move in defined orbits around the nucleus (FIGURE 5). These electrons have an electric charge, -1, and consequently, we have the attraction between nucleus and electrons, in the same way we have the attraction between the sun and the planets. The mass of the electrons is much smaller than the mass of protons and neutrons (order of 1/1800) . All these assumptions can be expressed by the following axioms:

AXIOM 4 - The atomic nucleus is very tiny and is located at the center of the atom.

AXIOM 5 - The electrons are some distance away from the nucleus and circle in orbits.

Now, on the basis of Classical Mechanics (CM) and Electrostatic

FIGURE 5 - Atomic system
(Reproduced from GAMOW, 1964; p.55)


THIRD ORBITS
SECOND ORBITS
FIRST ORBIT

Theory of Coulomb (CT) we can derive the following theorem:

THEOREM 1 - It is not the case that the electrons fall into the nucleus under the attraction of the positive charge.

The proof of this theorem is obtained by AXIOM 4 and AXIOM 5, the classical treatment of body in a circular orbit under the attraction of a central force (CM), and Coulomb theory of the electrostatical potential (CT).

AXIOM 4 and AXIOM 5 summarize the assumptions of the Rutherford Atomic Model. THEOREM 1 could be interpreted as an attempt to extend the analogy atomic-solar system — all we have to do is to replace the gravitational force sun-planets by the electrostatical force nuclei-electrons. This theorem would also represent an attempt to derive the stability of matter — a consequence which must follow from any atomic model. However on the basis of CM, CT and Classical Electrodynamics (CD) — a theory which we have assumed as valid — we can derive further theorems:

THEOREM 2 - The electron radiates electromagnetic waves and therefore it loses energy.

This thorem is proved by AXIOM 2 and the principle of CD which states that:

AXIOM 6 - Any charged particle in accelerated movement will radiate electromagnetic waves and therefore lose energy.

With THEOREM 2, the hypotheses of CM and CT used in THEOREM 1, we derive that:

THEOREM 3 - The electron will spiral towards the nucleus.

The derivation of THEOREM 3 suggests to us that the Rutherford Model is too simple. The model was an important step in the evolution of contemporary theories because it postulated the existence of the atomic nucleus, a massive center separeted from the small electrons. However, as we have seen, from this model we cannot derive the stability of matter. The electrons would spiral and the atoms would collapse very fast[6]. To solve this problem without going to complicated quantum mechanical models, all we need is the first quantum model of the atom, **Bohr Theory of the Atom** (BT); from this model we can return to the transport of electrons. Now we look at the BT's axioms:

AXIOM 7 - An atom can exist in only one of a discrete number of fixed energy states, that is, stationary states.

AXIOM 8 - The atom radiates or absorbs energy only if it changes from one state to another.

AXIOM 9 - If the atom changes from a state of energy Em to a state of energy En then a quantity of energy En-Em is absorbed or radiated. If radiated the frequency of radiation emitted — a quantum of energy — is

$$f = \frac{En - Em}{h}$$

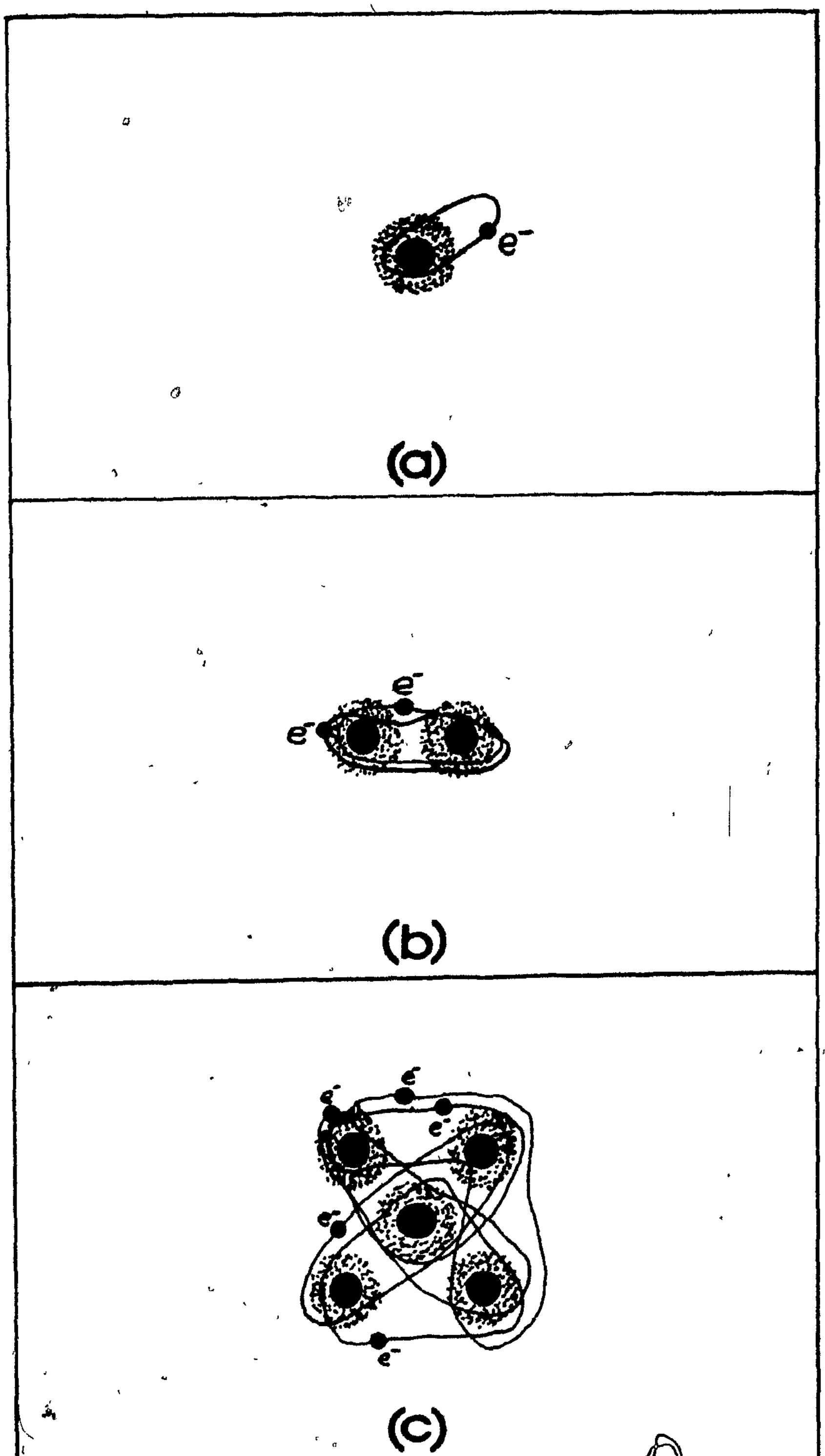
AXIOM 10 - An orbit is permissible only if the orbital angular momentum of the electron is an integral number of units of $h/2\pi$.

The BT's axioms summarize the first attempt to apply the quantum hypothesis to explain the structure of the atom: Bohr postulated with these axioms distrete states for the energy of the atom and therefore discrete values for the electrons' orbits.

Moreover, the energy radiated was seen as quantum of energy with defined frequencies. This assumption differs essentially from the classical treatment of electrodynamics. Within this model the electron will not constantly radiate energy and spiral towards the nucleus because now the electron can only occupy a discrete number of states. Therefore we have the stability of matter given by a planetary model of the atom even though it is a model less similar to the solar system.

Now we return to the problem we want to explain. Let us take a particular metal X in order to introduce a model for the free-electrons of the metals. Let us assume that metal X is a monovalent element, i.e. its atoms have only one electron outside their close shells. This electron is called the valence electron. Using BT, each atom which forms metal X can be visualized as shown in the diagram in FIGURE 6.a. In this diagram, the shadowed area represents all the electrons which occupy a number of discrete states of energy, electrons extremely attracted by the positive nuclei. These electrons are more closely connected with the nuclei than the electrons which occupy the next possible orbit — the valence electrons. Now, let us suppose we have two atoms of metal X and that they are very close. Each of them has its valence electron. If the atoms are close enough, each of them will attract the valence electron of the other. In this way we will get a new state of the two atoms: it becomes possible for both the electrons to circle about both ions

FIGURE 6 - Gas of free electrons
a. a single atom of metal X
b. a molecule of metal X
c. metal X
(Reproduced from ZIMAN, 1962; p.7)


e⁻
(a)
e⁻
e⁻
(b)
e⁻
e⁻
e⁻
e⁻
e⁻
(c)

together, just as if we had a doubly-charged nucleus with two electrons around it (FIGURE 6.b).

If we consider now a whole crystal where we have many of these atoms together, we expect a similar process between each pair of atoms. In this situation each valence electron starts to move on a very complex course, visiting each neigbour in turn (FIGURE 6.c). As Ziman says:

> Instead of having a cosy arrangement in which each ion has its 'own' electron bound tightly to it, we have a sort of communist society in which all the ions possess all the electrons in common, and the electrons can move freely from one ion to another...
>
> (ZIMAN, 1962; p.7)

This model suggests to us the notion of a sea of free electrons moving through a positive background, or, putting in a more relevant way, the model suggests a **gas of free electrons** existing inside the crystal.

The name 'gas of free electrons' contains more than a suggestive analogy or metaphor: it indeed indicates that many of the properties of the electrons's motion through solid matter can be studied in terms of the properties of the gases. If we think for instance of the high conductivity of metals, we can see that the model has already advanced our knowledge about these materials. The high electronic conductivity of metals can now be explained in tems of the weak connection of the valence electrons. However, if we leave the model at this point, the electronic conductivity of the metals would not only be extremely high, but even infinite, which is a very unrealistic result since different materials have different values for the electronic conductivity and of course, values different from infinity. Following the model of the gas, given a difference of electrical potential between the two extremes of a piece of of a metal, we would expect an infinite conduction. This consequence suggests to us that we have to improve this model. But before we do this, let me give another axiom.

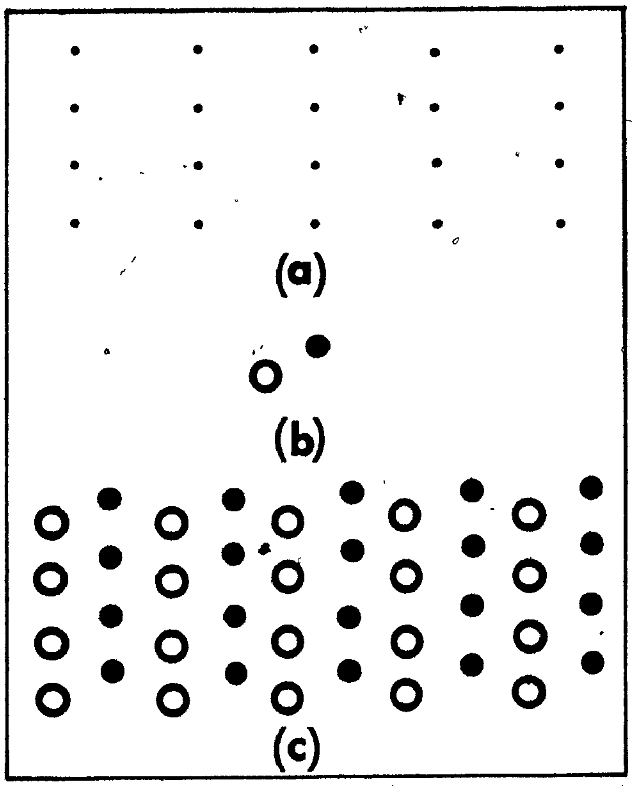
AXIOM 11 - The valence electrons of a metal move through the whole metal and therefore they constitute a gas of free electrons.

With this axiom we have solved half of our problem. We know now how the electrons can be free in metals. The question we face now is, how does the gas of free electrons interact with the atoms of the crystal through which the electrons move? This problem leads us to question the structure of the crystal since we have now to consider the action of the positive electrical potential of the atoms of the crystal in the gas of electrons. For this consideration we present some details of the crystal periodic structure stated in <u>DEFINITION 1</u>. The study of the periodic

FIGURE 7 - Crystal structure

"The crystal structure is formed by the addition of the basis (b) to every lattice point of the lattice (a). By looking at (c), you can recognize the basis and then you can abstract the space lattice. It does not matter where the basis is put in relation to a lattice point."

(Reproduced from KITTEL, 1976; p.7)


(a)
(b)
(c)

structure of the atoms of a crystal constitutes one of the most interesting applications of geometry in physics. The structure is represented in terms of a lattice. At each point of the lattice a basis of atoms is associate (FIGURE 7). We have then the famous "equation"(which appears in many solid state textbooks (e.g. KITTEL, 1976; p.4):

<u>CRYSTAL STRUCTURE = LATTICE + BASIS</u>

This geometrical model of the structure of the crystals helps us in the calculation of almost all the properties of the electronic transport, especially the calculation of the attractive potential acting between the electrons of the gas of free electrons and the atoms of the lattice. That is, with the knowledge of the geometrical structure of the crystal we can calculate the interaction between gas of free electrons and crystal lattice.

Once we have exhibited a model for the free electrons of the crystal and their interaction with the crystal lattice, we can go a step further and discuss the physical properties of the electronic transport relevant to the experiments we want to discuss. I first present the electronic conductivity (C), or the electronic resistivity (R) which is defined as the inverse of C. The electronic conductivity is assumed as an intrinsic property of any metal. This property correlate the rate of the motion of the free electrons to the external electrical field acting upon the metal. This process of interaction is represented by the following law (Ohm's law):

LAW 1 **The electronic conductivity of a metal is directly proportional to the electrical current passing through the metal when an external electrical field acts upon this metal, and inversely proportional to the external electrical field which generates this current. Formally we have:**

$$C = \frac{J}{E}$$

where 'C' designates the electronic conductivity, 'J' the density of electrical current, and 'E' the external electrical field.

We can understand the electronic conductivity as the relation between the external electrical field upon a metal and the current generated by this field. It is easy to realize that this law refers to an intrinsic property of each metal, since it depends of the way the electrons can move through the crystal lattice, which is a characteristic of each material. The electronic resistivity can then be defined as the inverse of the electronic conductivity (The concept of electronic resistivity can equally be taken as a primitive concept, and then, the concept of electronic conductivity is defined.):

DEFINITION 2

$$R = \frac{1}{C}$$

where 'R' designates the electronic resistivity. In terms of the electronic resistivity we can provide an intuitive picture of the processes represented by this law. If the electrons of the gas were completly free, the conductivity would be infinite and the resisitivity would be zero. But, as explained early, the atoms of the crystal lattice will act as obstacles to the electrons's motion. We can say that the ions[7] will scatter the conduction electrons. Furthermore, it may be the case that we find other scattering processes which interfer with the conduction of the electrons, e.g. an impurity in the metal or the electron-electron interaction. For each particular metal the scattering processes vary and this property is represented by the notion of electronic conductivity and resisitivity.

Similarly we can postulate a law for thermal conductivity which relates the heat which flows in a material to the difference of temperature which generated the heat flux.

Now, in view of AXIOM 3, we can realize that the existence of a difference of temperature and of a electronic current are not independent processes. Since we have assumed that the carriers of heat are mainly the electrons, if we have a thermal gradient between the ends of a piece of metal, an electrical current will be generated and a voltage will be developed between the ends of the metal. This difference of electrical potential between the ends of the metal with two points at different temperature is related to the difference of temperature, the electronic conductivity (or resistivity), and the thermal conductivity. The relation between the difference of temperature and the electrical potential generated is represented as another intrinsic property of any metallic material, **the thermoelectric power.**

LAW 2 **The thermoelectric power of a metal is inversally proportional to the difference of temperature imposed upon the material and directly proportional to the electrical potential generated at the points under different temperature.** Formally,

$$S = \frac{\Delta V}{T}$$

where 'S' designates the thermoelectric power, 'V' the generated voltage, and T the temperature difference.

From these laws and definitions concerning the relevant properties, I now pass to the discussion of the relation of this theoretical background to the set of experiments to be analysed.

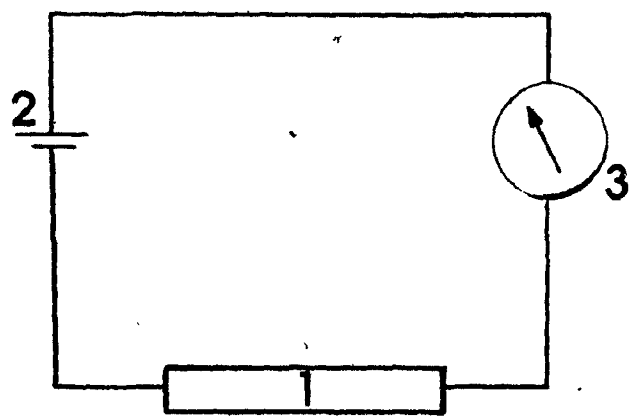
III.C HOW CAN THESE PROPERTIES BE MEASURED?

So far I have presented the theoretical background which allows to discussed the relevant properties of the metallic materials. Even before we start to talk about any concrete experiment to test a particular theory concerning these properties — e.g. a model for the temperature dependence of the thermoelectric power, S x T — we have to ask the crucial question which is the main distiction between factual and formal sciences. Is is the case that these properties can be directly observed?

Let us consider first R. Suppose that we have a piece of iron A (FIGURE 8) and that we apply an electrical potential V' between the ends 1 and 2 of A. NOw, we connect 1 and 2 to a device which enables us to read the electronic current flowing between the points, current J'. With this strategy we obtain a value for R, $R' = V'/J'$.

Suppose now that we take the same piece of iron and

FIGURE 8 - Measurement of the electronic resistivity and resistance
1. piece of metal
2. source of electrical fields
3. apparatus to read the electrical current generated


2
3
1

that we cut it in two equal pieces. If we repeat the same experiment with one of these pieces, we obtain a new value for R of the order R'/2 . Something is going wrong. As I have stated before, R is postulated as an intrinsic property which should not depend on the geometrical features of a particular piece of metal chosen in the research in question — at least this is true when we are not talking about experiments which allow interaction at the atomic distances. If R is represented in this model as a property associated with the interaction between the gas of free electrons and the lattice of the crystal, the length of the sample should not alter the value of R. Thus, if we do not consider atomic distances, the crystal lattice will have the same characteristics for a sample of 1 metre as for a sample of 2 metre. Although this result might make us think our model is wrong, we should not reach such a conclusion too quickly. The first thing we have to ckeck in a situation like that is whether or not what we are measuring in such experiments is indeed R: in other words, we realize that what we are measuring is a property which indeed is related to R but which is peculiar the geometrical features of the sample[8]. This dependence is reasonable for if we consider a sample of 1 metre we have a certain number of obstacles, namely, the ions of the lattice; and if we consider a sample of 2 metres under the same electrical potential, we have double the number of obstacles. These theoretical considerations based in our models then allows us to present another postulate introducing a new property, namely, the ohmic resistance:

LAW 3

$$P = R \cdot \frac{L}{A}$$

where 'P' designates the resistance, 'L' the length of the sample under examination, and 'A' the cross-sectional area of the same sample.

We conclude then that in actuality, R cannot be directly observed but it can be measured in terms of P which is a measurable property. The same consideration is valid for the electronic and thermal conductivity, which I omit without any loss.

In concrete experiments there exists a common strategy to avoid this problem and to directly measure R without knowing L and A which are not always easy to measure. The idea is to analyse all the relevant values of P always in relation to a fixed value P'. Then, if we have a series of measured values for P in terms of the temperature,

$$P''(T'')\ldots\ldots\ldots\ldots\ldots Pn(Tn),$$

and we consider,

$$\frac{P''(T'')}{P'(T')}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\frac{Pn(Tn)}{P'(T')}$$

for some $P'(T')$, we obtain,

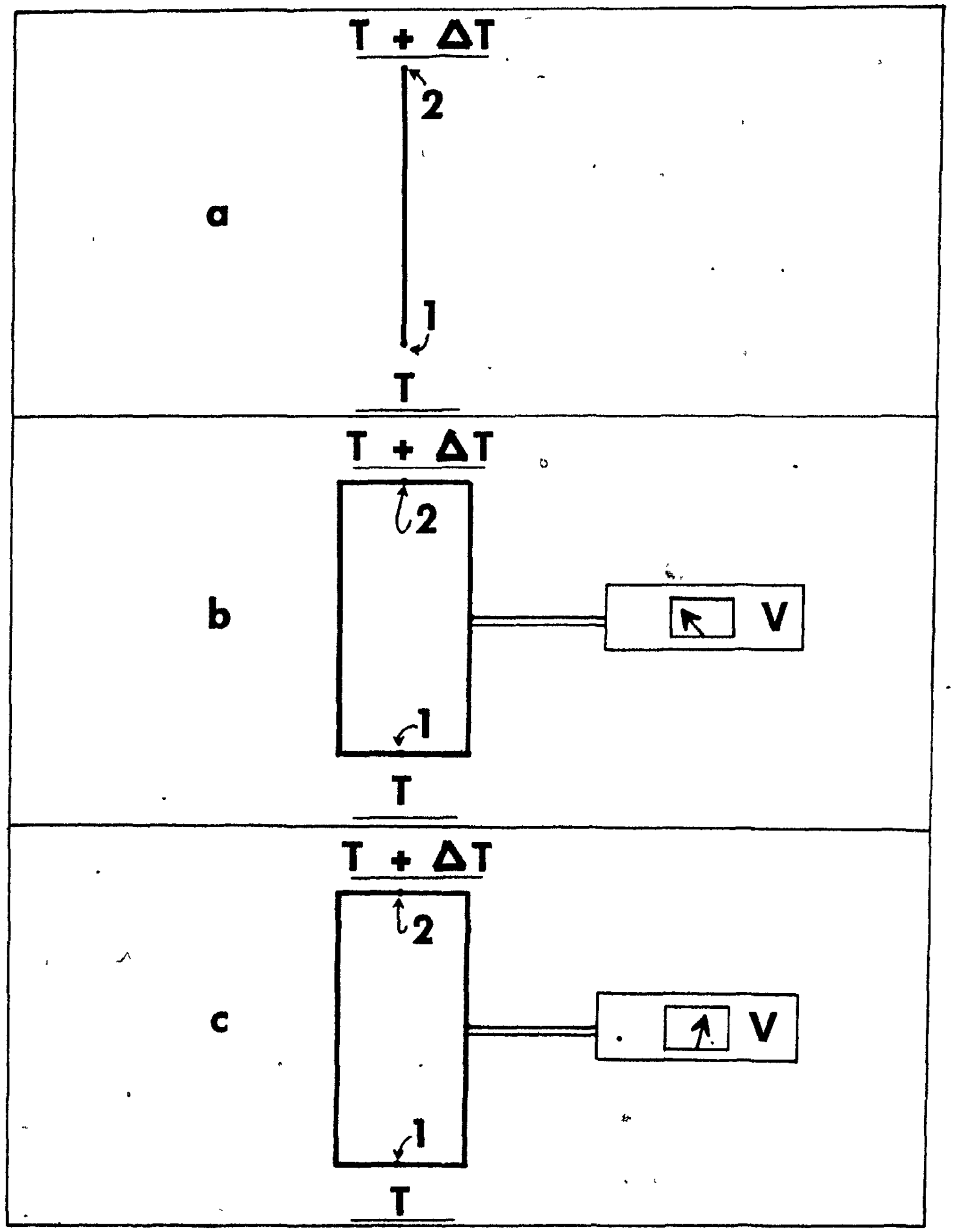
$$\frac{R''(T'')}{R'(T')}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\frac{Rn(Tn)}{R'(T')}$$

which gives us the dependence RxT, the aimed relation.

If we consider now the thermoelectric power (S), we face a further problem. In order to determine S already having measured ΔT, we have to measure V. To avoid the problem described above, we have to consider V/V', for a fixed V'. But in order to measure V we have to close the system (FIGURE 9.a) between points 1 and 2. If we do this with the same material we will get a value zero for V because of the symetry of the system (FIGURE 9.b). Then we have to make a thermo-pair or thermo-couple, i.e. we have to use a different material to close the system (FIGURE 9.c). By doing this, the value for S which we obtain is the for the S of the thermo-couple, i.e. a relative value. In order to calculate the absolute S of the sample under examination we have to know in advance the S of the material used to form the thermo-couple. It seems that we will encounter

FIGURE 9 - Measurement of the thermoelectric power

In order to measure the thermoelectric power of any material we must close the system at points 1 and 2 as shown in (a). If we do that as in (b), using the same material, the voltmeter will indicate zero. Only in (c) where we have formed a thermo-couple, do we have a value V different from zero.


T + ΔT
2
a
1
T
T + ΔT
2
b
V
1
T
T + ΔT
2
c
V
1
T

the same problem again and again. However, this problem is solved by a direct method of knowing the S of some particular material discussed on section III.E.

These two considerations suggest that even before the scientists start to look for an experimental method to study the behaviour of a physical property, they have to investigate whether the property in question can indeed be directly measured, or whether it is necessary to locate some other related property which can be observed empirically. Both the considerations concerning the electronic resistance and the used of Pb as a standard material to form thermo-couples — section III.e — are extremely theory-based. A more detailed discussion of this point will be presented in the section III.E.

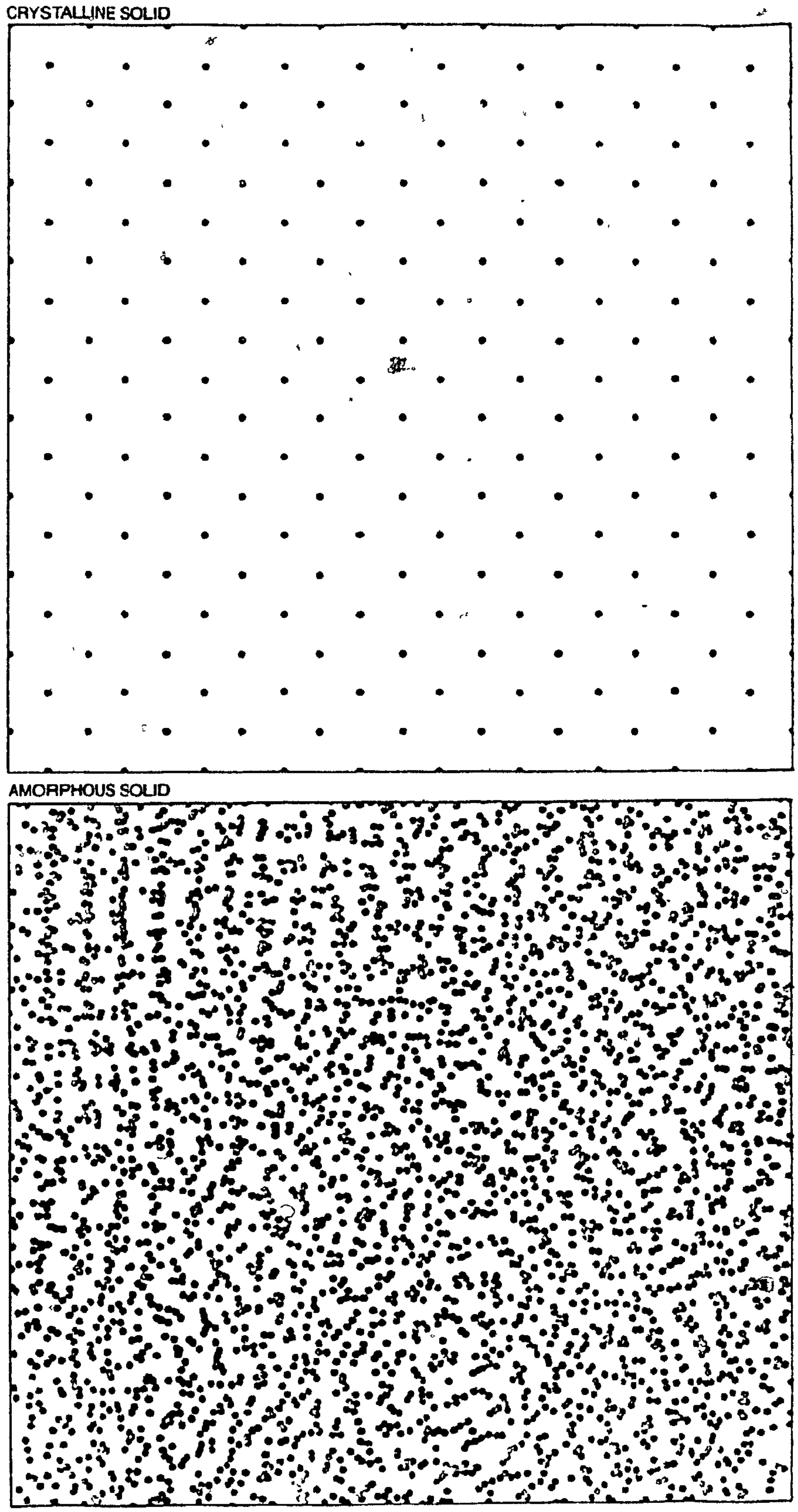
IV.D THE METALLIC GLASSES

The previous theoretical considerations all refer to crystalline solids, but some natural materials, such as common window glass, are amorphous rather than crystalline solids (FIGURE 10.a). The experimental technique called diffraction of X-rays shows that the common glasses, instead of having the crystalline structure we expect to have, possess almost the same

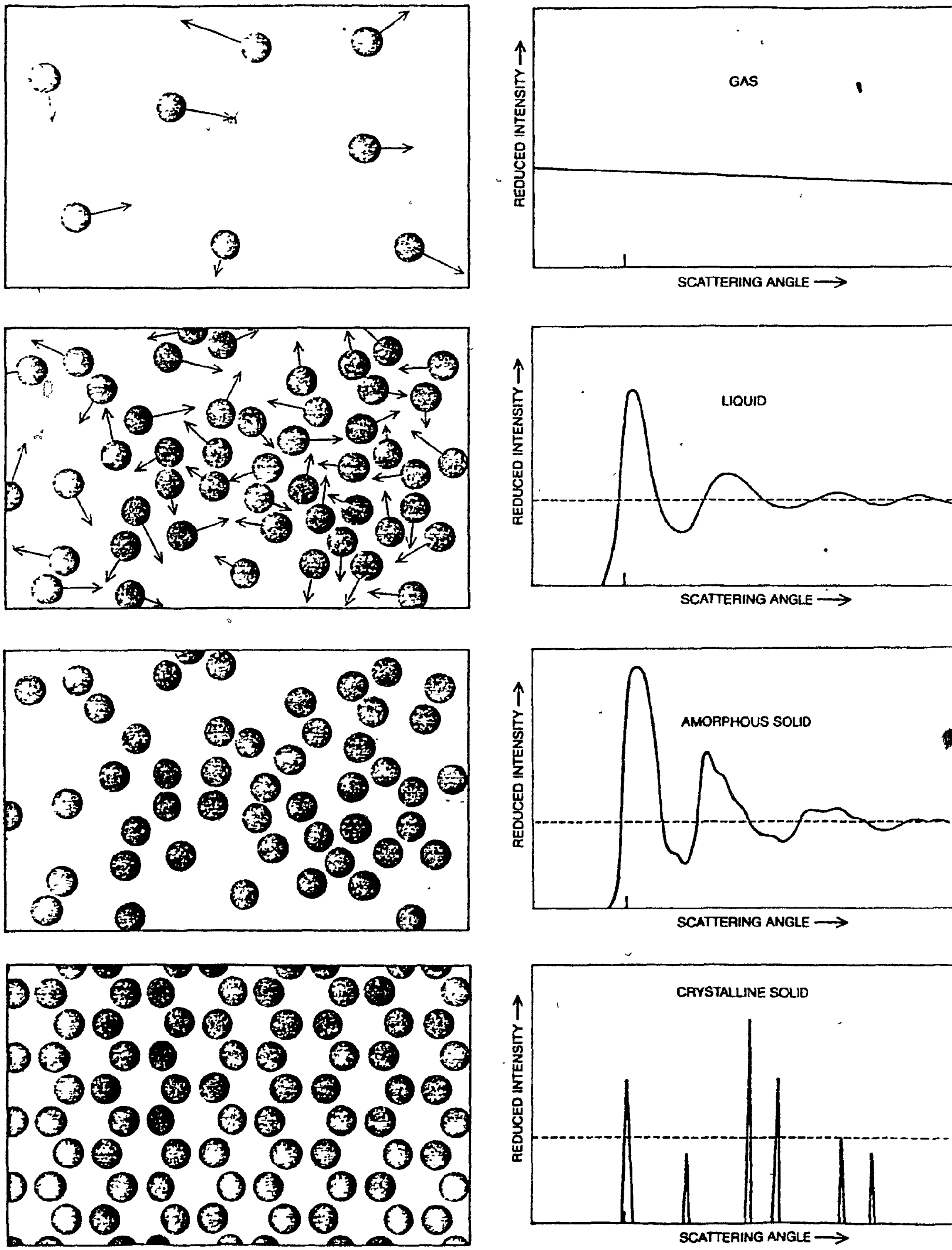
FIGURE 10 - Crytalline and amorphous solids

a."Crystalline and amorphous solids are similar in density, or average number of atoms per unit of volume, but differ in the arrangement of the atoms. The structure of the solids are represented by profections of the atoms onto a plane, as if the solids were illuminated by parallel rays of light and only the shadows were visible. In the crystal the structure is periodic over large distances... In the amorphous solid there is no periodic structure, although the positions of the atoms are not entirely random. Order in the arrangement of the atoms extends over short range only..."

b. "Distribution of atoms in a substance can be inferred from patterns created when X rays are scattered by atoms. The graphs record the reduced intensity of the scattered radiation as a function of scattering angle... For a rarefied gas the reduced intensity is essentially uniform over a broad range of scattering angles, indicating that the distribution of atoms is random. Liquids and amorphous yield reduced-intensity curves that are strongly modulated. A curve of this form suggests that positions of nearby atoms are correlated, but there is no long-range order. The reduced-intensity curve of a crystal is a series of sharp spikes, reflecting the regular arrangement of the atoms over large distances". (Reproduced from CHAUDHARI, 1980; p.100 and p.108)



a


REDUCED INTENSITY →
GAS
SCATTERING ANGLE →
REDUCED INTENSITY →
LIQUID
SCATTERING ANGLE →
REDUCED INTENSITY →
AMORPHOUS SOLID
SCATTERING ANGLE →
REDUCED INTENSITY →
CRYSTALLINE SOLID
SCATTERING ANGLE →

b

structure as that of liquids (FIGURE 10.b). That is to say that common glasses pass from the liquid to the solid state without crystallizing, so that when they attain the solid state, their structure is that of a frozen liquid. This happens because the temperature at which common glasses solidify (Ts) is higher than the temperature at which they crystallize (Tc), causing them to solidify before they crystallize. A deeper explanation of these processes is available from thermodynamics (TD) in terms of the minimum energy needed to attain a stable state. But we do not need to go into thermodynamics in order to conclude that the kind of bonds which unite the atoms of the common glasses in the solid state are not the same as the kind of bonds which unite the atoms of the metals; and therefore, we can predict that these glasses will not have the same electronic properties as the metals. For example. the electronic conductivity of the common glasses is much lower than the electron conductivity of the metals, a fact which explains why the common glasses are called insulators. Let us now ask an interesting theoretical question. Is it possible to find a metal that behaves as a glass, i.e. that passes from the liquid into the solid state without being crystallized? Such a material would be a metallic glass, i.e. it would have the structure of a glass but the properties of a metal. It would seem impossible to find such a material since the difference between the Ts and the Tc for the metallic elements is so small that whenever a metal attains the solid state it has already crystallized (FIGURE 11). And, in thermodynamic terms, the crystalline structures is the most stable state for a solid metal with a minimum of energy. Thus the chances of finding a metallic glass occuring naturally are almost zero. We must now ask whether such materials can be created artificially in the laboratory. And contemporary physics provides the answer.

Metallic glasses are usually created by cooling the liquid metal so fast that it attains the solid state before it can crystallize (see APPENDIX A). An explanation for the stability or metastability of these new materials is still a theoretical problem and recently many models have been developed. It is important to realize that even in nature we expect non-perfect crystals[9].

The details of the most common technique to produce the metallic glasses are presented in the APPENDIX A. Let us keep in mind that:

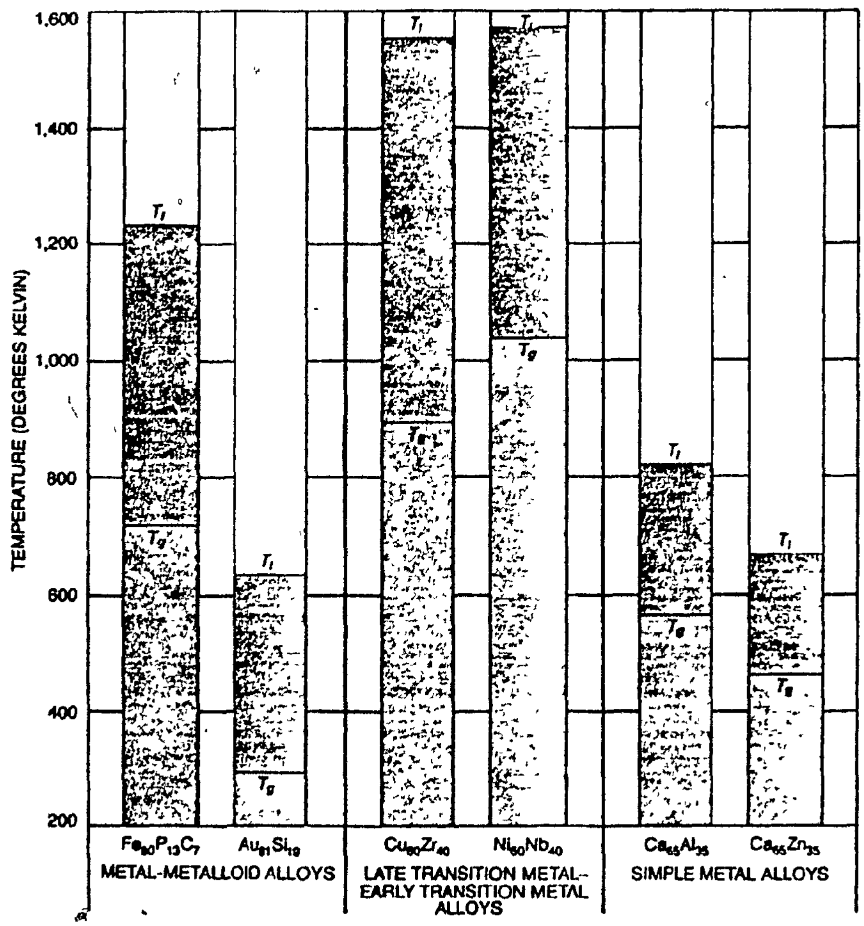
DEFINITION 3 - The metallic glasses are metallic materials obtained artificially which have the same structure as common glasses — frozen liquids — but which maintain metallic properties (e.g. electronic conductivity).

Many research programmes have been directed to the study of these new materials. The experiments I will now present

FIGURE 11 - Transition temperature

"Transition temperature for the formation of crystalline metals and metallic glasses have a major influence on the ease with which an alloy can be solidified in the glassy state. The liquidus temperature (Tl) is the temperature at which the crystalline phase can first appear when the liquid is cooled. As the temperature is further reduced the material must pass through a region where crystallization is possible before the configuration of the atoms is frozen in at the glass temperature (Tg). The ratio of the glass temperature to the liquidus temperature (Tg/Tl) is called the reduced glass temperature (Trg), and it defines the relative extent of the region where crystallization can interrupt the formation of a glass. In order to cross this region without crystallizing, the metal must be cooled quickly from above the liquidus temperature to below the glass temperature..."

(Reproduced from CHAUDHARI, 1980; p.102)



TEMPERATURE (DEGREES KELVIN)
1,600
1,400
1,200
1,000
800
600
400
200
T_l
T_g
$Fe_{80}P_{13}C_7$
$Au_{81}Si_{19}$
$Cu_{60}Zr_{40}$
$Ni_{60}Nb_{40}$
$Ca_{65}Al_{35}$
$Ca_{65}Zn_{35}$
METAL-METALLOID ALLOYS
LATE TRANSITION METAL–EARLY TRANSITION METAL ALLOYS
SIMPLE METAL ALLOYS

concern the study of the electronic transport through these metallic glasses.

IV.E EXPERIMENTAL INSTRUMENTS

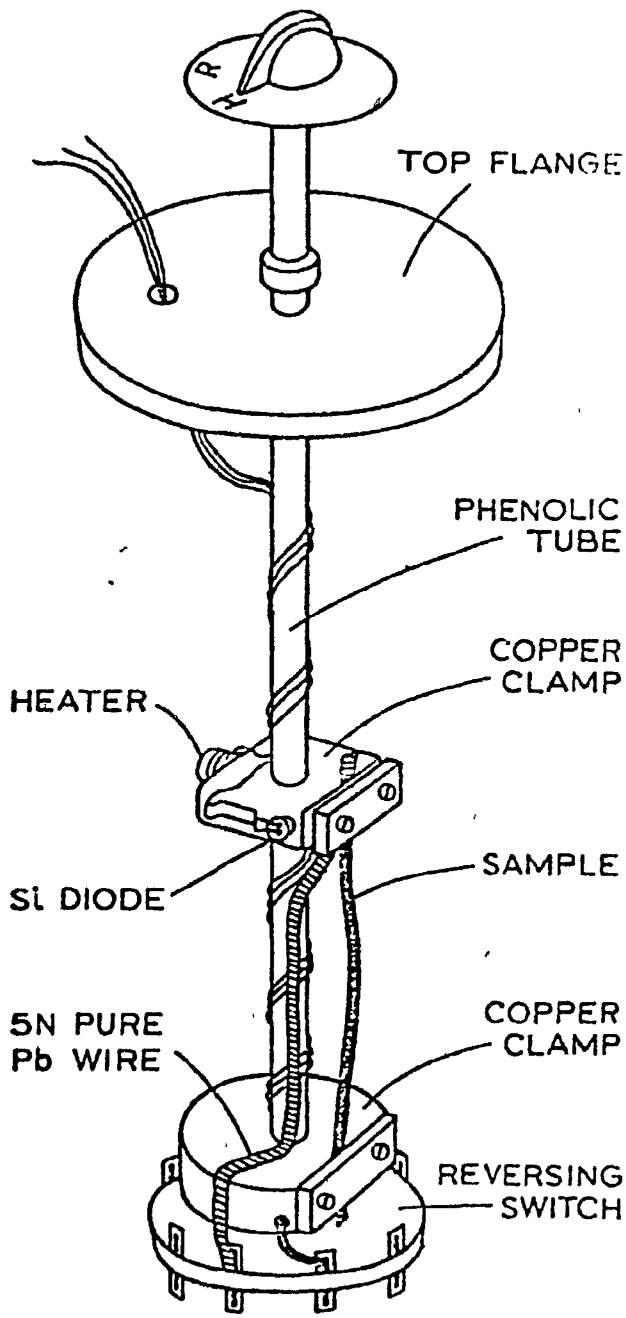
As I have stated in CHAPTER II one of the main problems whih I will analyse in the philosophical approach to these experiments in solid state physics is the theoretical basis of experimentatin. From these perspective, I present a topic nearly always neglected by most philosophical approaches to scientific research: the theoretical basis of the experimental instruments, i.e. the theories applied in the design of the instruments used in the scientific experiments. It is important to remark that the experimental physicist themselves do not usually discuss the theoretical basis of the instruments they used. In most cases the instruments are obtained directly from the companies and their main characteristics are specified in manuals and tables which come with them. This attitude may be justified in pragmatic terms: it is easier for the experimental scientists to accept that the instrument is well-constructed and that the manual and tables are truthworthy. However, this is not always the case. In many scientific experiments, the interpretation of negative results requires that the scientists doubt the very experimental instruments which they have used to produce such results. The experiments which I will analyse in this dissertation are examples of this situation[10].

Another important case in which the experimental scientists cannot avoid the study of the theories involved in the construction of their instruments occurs when they attempt to improve the quality or to extend the application of these instruments. The author of this dissertation had himself been engaged in technical physics research directed to the production of silicon detector for high-energy radiation. The attempt to use new methods for the doping of the crystals required not only the study of the quantum theory which accounts for the conductivity but also the theories which underlie the doping techniques.

If for the scientists themselves the analysis of the theoretical basis of the construction of the instruments is relevant in some cases and pragmatically neglected in others, the philosophers interested in the foundations of the scientific experiments must not underemphasize this fundamental aspect of any scientific experiment. Let us then expound the theory involved in the construction of each of the instruments used in the measurements of S.

FIGURE 12 presents a schematic diagrm of the cryostat

FIGURE 12 - Schematic diagram of the cryostat
(Reproduced from BAIBICH, 1979a; p.85)


TOP FLANGE
PHENOLIC TUBE
COPPER CLAMP
HEATER
Si DIODE
SAMPLE
5N PURE Pb WIRE
COPPER CLAMP
REVERSING SWITCH

where the sample of metallic glass is placed. FIGURE 13 presents a more complete diagram of the whole experimental apparatus used. Let us consider the theory or theories involved in each of these instruments.

A - THE THERMOMETER

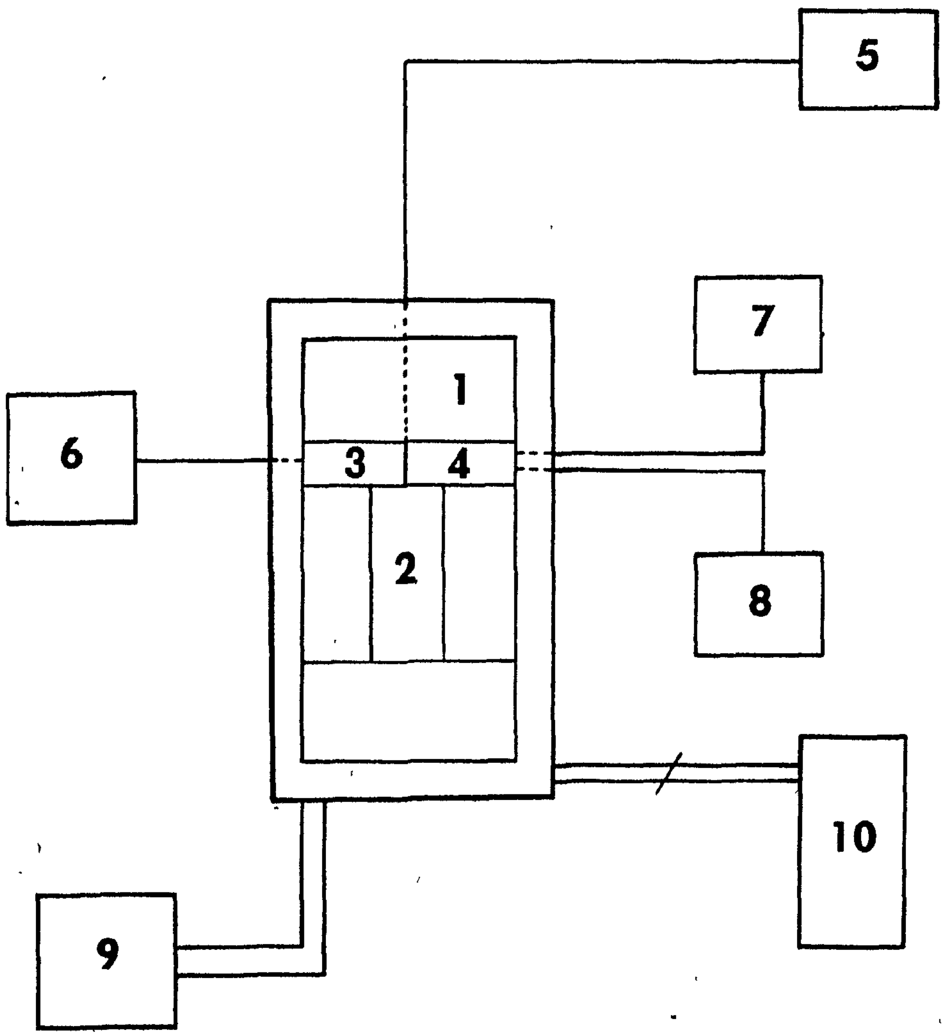
The thermometer used was a silicon diode. The theoretical basis of its function is given by the quantum treatment of the conductivity of semiconductor crystals. If a known electrical current passes through the diode in its conduction direction, the measurement of the voltage generated allows the calculation of the resistivity of the diode. The resistivity of the diode is a known function of its temperature. Therefore, given the resistivity of the diode, we can determine its temperature. In the actual experiments which we examine here, the measurement of the voltage were used to determine the temperature according to the table of conversion which was available with the Si-diode.

B - THE HEATER

The heater used to elevate the temperature of one of

FIGURE 13 - Schematic diagram of the experimental apparatus.

1. Cryostat
2. Thermo-couple Pb-wire and sample
3. Heater
4. Thermometer
5. Voltmeter I
6. Current source I
7. Voltmeter II
8. Current source II
9. Lquid Helium
10. Vacuum pomp



5
1
6
3
4
7
2
8
10
9

the ends of the sample was a 110V heater made of 38BS CuNi wire. The principle of function of the heater is very simple: when an electrical current passes through the CuNi wire energy is liberated (Joule Effect). While this principle has been known and explained since the last century by the first classical theories in electricity, other hypotheses made in the experiments in question presuppose further developments of classical and quantum electrodynamics. For example, it was assumed that the wire was non-inductively wrapped around the block, i.e. that the way the wire was wrapped prevented the existence of any electromagnetic field generated around it when the current was passing. This assumption was very important since the existence of electromagnetic fields could interfere with other instruments, mainly the thermometer.

C - THE REFRIGERANT SYSTEM

In order to be able to make the measurements over a wide range of temperatures, the thermoelectric power apparatus was placed inside a double Dewar assembly which allowed either liquid nitrogen or liquid helium to be used as refrigerant. The knowledge we have nowdays that allows the industrial production of such gases is based on classical thermodynamics.

D - THE CURRENT SOURCE

The current need for the temperature measurement could in principle be obtained by a simple battery. However, in order to gain precision, the source of current used — as well as the voltmeter needed for the measurement of the voltage generated between the ends of the Si-diode and the ends of the thermo-couple Pb-sample — were modern devices all based on quantum theories concerning electronic conduction processes.

E - THE Pb WIRE

As I have explained in the last section, the measurements of S of any sample cannot be obtained directly since it is required to form a thermo-couple with the sample and another material. Then the relative S can be measured. In order to calculate the absolute S of the sample, it is necessary to know the S of the other material of the thermo-couple. In the experiments in question the thick wire used was made of 5N pure Pb which was clamped to the block together with the sample. The absolute S of Pb as a function of the temperature is available as a table in R.B. Roberts's article <u>The absolute scale of thermoelectricity</u> (ROBERTS, 1977). Roberts's article deserves a particular and detailed examination because it is a rich example of the complicated interplay between experiment and theory. But all I want to do here is to remark on the theoretical knowledge presupposed in the production of such a table.

Pb at low temperatures is known to be a semiconductor with S=0, consistent with QM. Therefore, as Roberts states, from 0 to 7,2 K, the S of Pb is zero. The next step is the determination of the S at high temperatures. The method used by Roberts is as follows: if the S cannot be directly measured, we should look for another property which can be measured and which is theoretically related to S, i.e. a property such that given its value we can calculate S. The property which Roberts measured is the <u>Thomson heat</u>, a property of metals which is related with S within the context of thermodynamics by the following law:

LAW 4

$$S(T)= \int_{0}^{T} \frac{U(T)}{T}\, dT$$

where 'U' designates the Thomson heat. With the measurement of U and this formula derived from TD the S of Pb can in principle be determined. Roberts's article shows how difficult is the measurement of U, but in the light of further hypotheses and many independent experiments, in which these hypotheses were checked, Roberts could elaborate the table SxT for Pb from 0 to 350 k.

F - VACUUM PUMP

In order to avoid the presence of impurities and parallel processes which could interfere with the measurements, the system was prepared by a mechanical vacuum pump. The principles for the construction and use of such pumps are studied in a particular discipline called technology of vacuum. This discipline bases its models on the kinetic theory of gases but it also involves many other branches of physics.

These are the main theoretical foundations of the instruments used in the experiments we will analyse.

IV.F THE EXPERIMENTS

Using the instruments described in the last section, a series of experiments were made in order to gain a better understanding of the electronic transport through the metallic glasses, and consequently, a better understanding of the properties of these new materials. The experiments which the author of this dissertation had himself observed in the laboratory of solid state at McGill University (BAIBICH 1979, 1979a), measured the thermoelectric power of five metallic glasses, namely:

<u>BRAND NAME</u>	<u>COMPOSITION</u>
Metglas 2826	$Fe_{40}\ Ni_{40}\ P_{14}\ B_{6}$
Metglas 2826A	$Fe_{32}\ Ni_{36}\ P_{14}\ B_{6}$
Metglas 2605	$Fe_{80}\ B_{20}$
Metglas 2605A	$Fe_{78}\ Mo_{2}\ B_{20}$
Metglas 2204	$Ti_{50}\ Zr_{10}\ Be_{40}$

(BAIBICH, 1979a; p.8)

All the samples used were obtained from Allied Chemical Company as thin ribbons and were produced by rapid quenching from melt — see APPENDIX A. It is clear that we do not find a single sample made of a pure metallic element — e.g. a sample of composition Fe_{100} , that is 100% Fe. The method used to produced these samples never allowed the production of a pure metallic glass. This fact is explained in terms of the Ts-Tc difference for pure and compound materials. In the case of compound materials greater amount of energy is required for the crystallization because the geometrical sctructure to be formed is more complex. Therefore,the pure material crystallizes before the compound, and the method used is not fast enough to allow the production of pure metallic glasses.

The samples were cut to size and installed in the cryostat (FIGURE 12). To avoid crystallization, no heat treatment were given. This last point is very important,because if heated those metallic glasses which are in a metastable state will crystallize to attain a more stable state, and will become ordinary metals instead of metallic glasses.

The technique for measuring S as a function of T was to vary the current flowing through the heater, while controlling the temperature on the top clamp. This control was made by passing a known a electrical current through the Si-diode (the thermometer) and the resultant voltage was read. This information was used to determine the present temperature and also the difference of temperature. At the the same time, a nanovoltmeter was used to measure the voltage generated through the thermo-couple sample-Pb. A typical experimental output is shown in FIGURE 14. From this information and the theoretical considerations described in the last sections a curve for the SxT was obtained for each sample. FIGURE 15 shows the curve obtained for metallic glass 2204. Finally, from this curve, graphic SxT is derived. FIGURE 16 shows the final result for the same

FIGURE 14 - Typical experimental output as obtained from the X-Y Plotter.
"The horizontal axis correspondes to the reading of the Si diode used as a thermometer. The vertical axis is obtained from the output of the nanovoltmeter used to measure the voltage generated by the pair sample-lead".
(Reproduced from BAIBICH, 1979a; p.9)

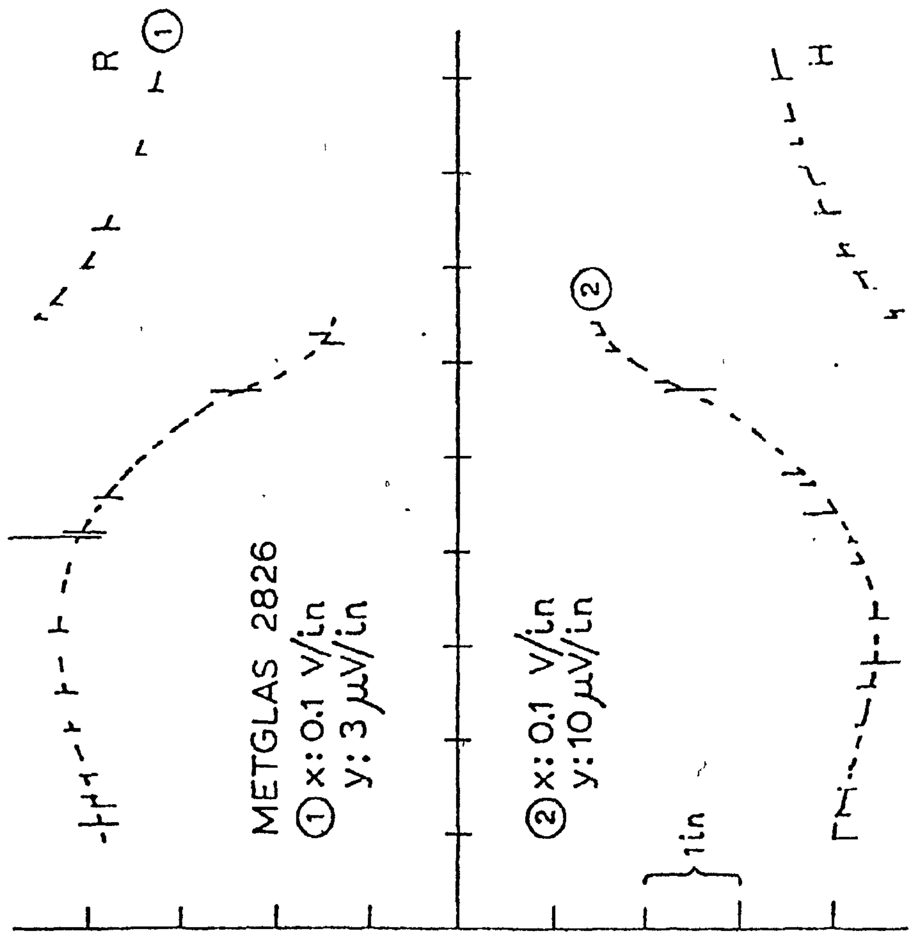
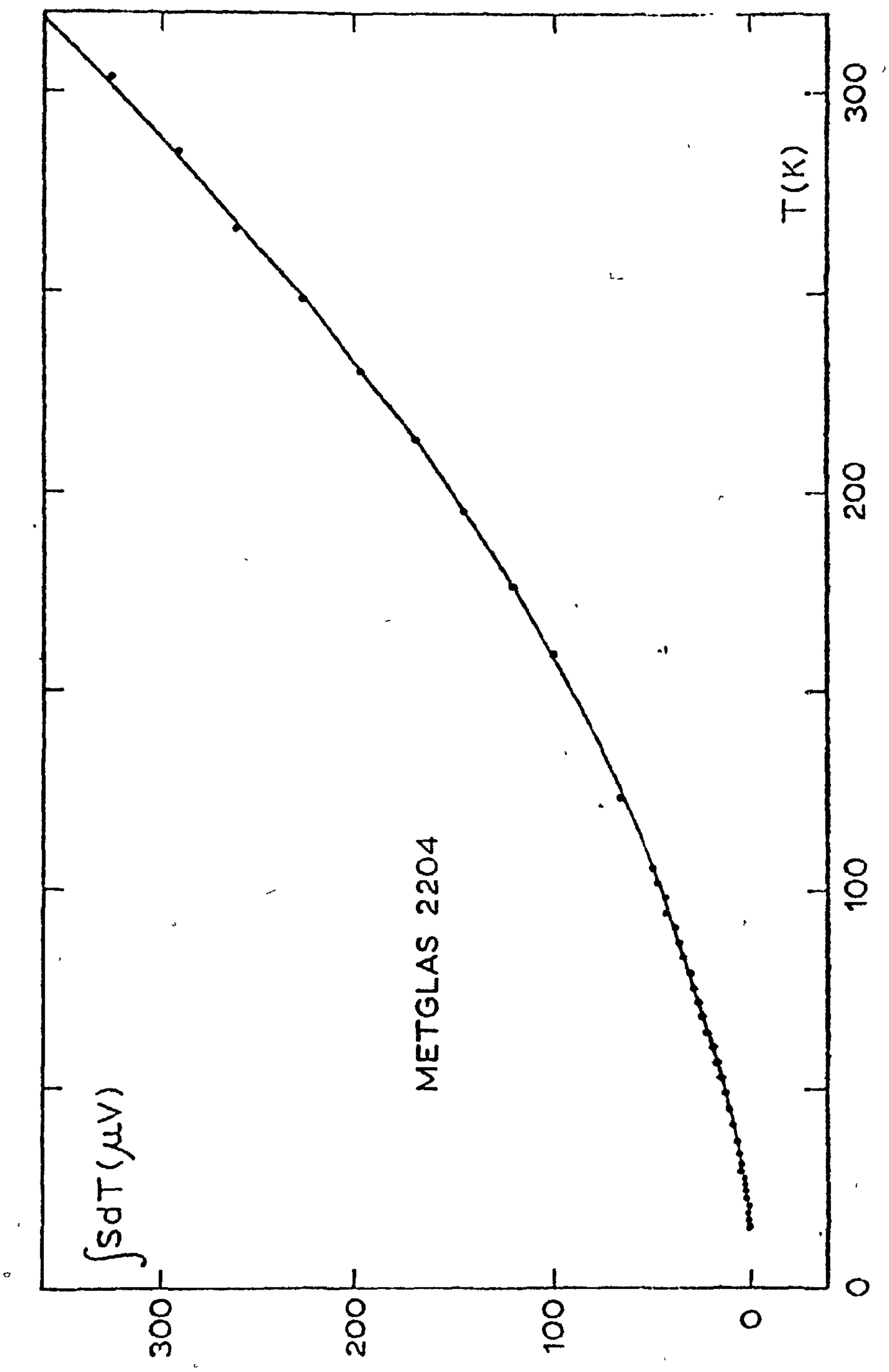
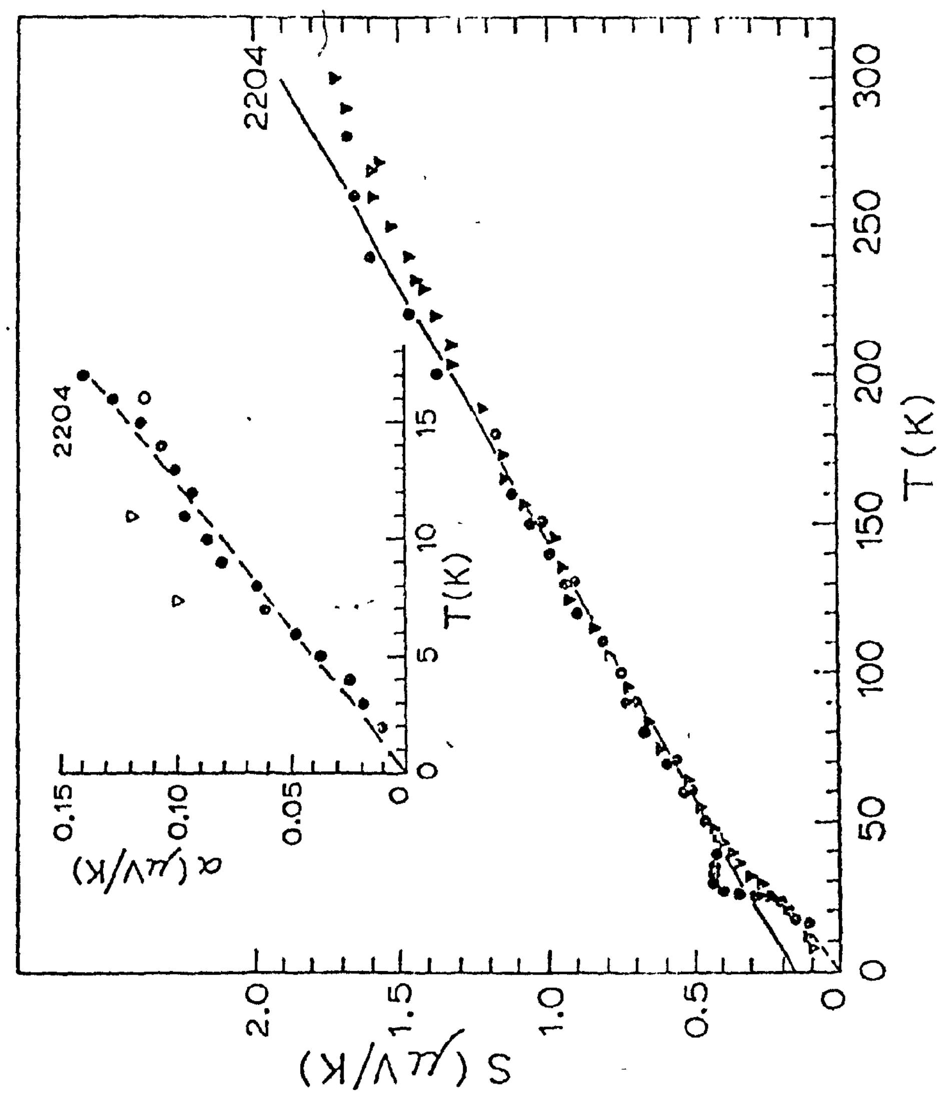

R
1
H
2
METGLAS 2826
1 x: 0.1 V/in
y: 3 μV/in
2 x: 0.1 V/in
y: 10 μV/in
1in

FIGURE 15 - "Integrated thermoelectric power for Metglas 2204".
(Reproduced from BAIBICH, 1979a; p.25)



∫SdT (μV)
METGLAS 2204
T(K)
0
100
200
300
0
100
200
300

FIGURE 16 - "Thermoelectric power for Metglas 2204. The data obtained in this work is represented by solid dots. The solid triangles are the results obtained by Elzinga and Schoeder. The insert shows the reults obtained in another independent experiment with He cryostat, see BAIBICH 1979b."
(Reproduced from BAIBICH, 1979a; p.30)


2204
S (μV/K)
T (K)
α (μV/K)
T(K)
2204

sample.

Using the same apparatus and a similar technique, a graphic for the resistivity of the samples as a function of T can be obtained. In the case of R, we do not need to form a thermo-couple. We measure P by passing a known current and measuring the voltage. The variation of T is accomplished by the same method. The experiments made to measure R were also performed by the same group of experimental scientists. I present here their results in order to analyse them together with the measurements of S. In reality, as I will explain in the next section, these experiments were made with the aim of testing the models presented to explain the results obtained for the measurements of R. As Baibich points out,

> We have measured the thermoelectric power of a series of metallic glasses between 4K and 300K and compare the results to the predictions of the...theories advanced to explain the behaviour of the resistivity... The study of the thermoelectric power was chosen as a technique because it is, for crystalline materials, generally a more sensitive probe of the scattering processes than is the electrical resistivity.
>
> (BAIBICH, 1979a; p.4)

I pass now to the presentation of these models advanced to explain the behaviour of the resistivity.

IV.G THE THEORETICAL MODELS

1 - Extended Ziman Theory

As I have stated in the last section, in order to explain the behaviour of R of the MG's, theoretical models were advanced. These models are based upon an adaptation of general theories to explain the electronic transport of the MG's. In order to test these theories, this series of measurements of S was made and the results, compared with the predictions obtained from the theoretical models. Let me now present these models.

The first model — derived from **Ziman Theory** postulates that the metallic glasses are merely a frozen liquid and therefore all the expressions derived for the liquid are valid for the MG's. In this model, the only source of electrons's scattering is the electrical potential of the ions of the liquid. Since the frozen liquid does not present a periodic structure as do the crystals, another physical property is introduced in order to described the interaction electrons-ions, namely, **the liquid factor.** The liquid factor is inferred from X-ray and neutron diffraction experiments and it describes the scattering of the electrons by the ions's core. Then, with the expression of the electrical potential and the expression of the liquid structure factor, an expression for the resistivity of the frozen liquids can be obtained according to Ziman Theory. Given the expression for the resistivity, we obtain the expression for S.

The application of this model to the MG requires auxiliary assumption. The model predicts that the resistivity will decrease with increasing temperature — i.e. the curve RxT will present a negative temperature coefficient. Under the same model and same assumptions, we derive that S should be a linear function of T with the sign dependent on the magnitude of two physical parameters. In most cases, a positive S is expected when the electrons are charge carriers[11].

Let us summarize the results predicted from this application of Ziman Theory:

PREDICTION 1 - The curve RxT for MG's should present a negative temperature coefficient.

PREDICTION 2 - The curve SxT for MG's should present a linear function of the temperature with a positive sign in most cases.

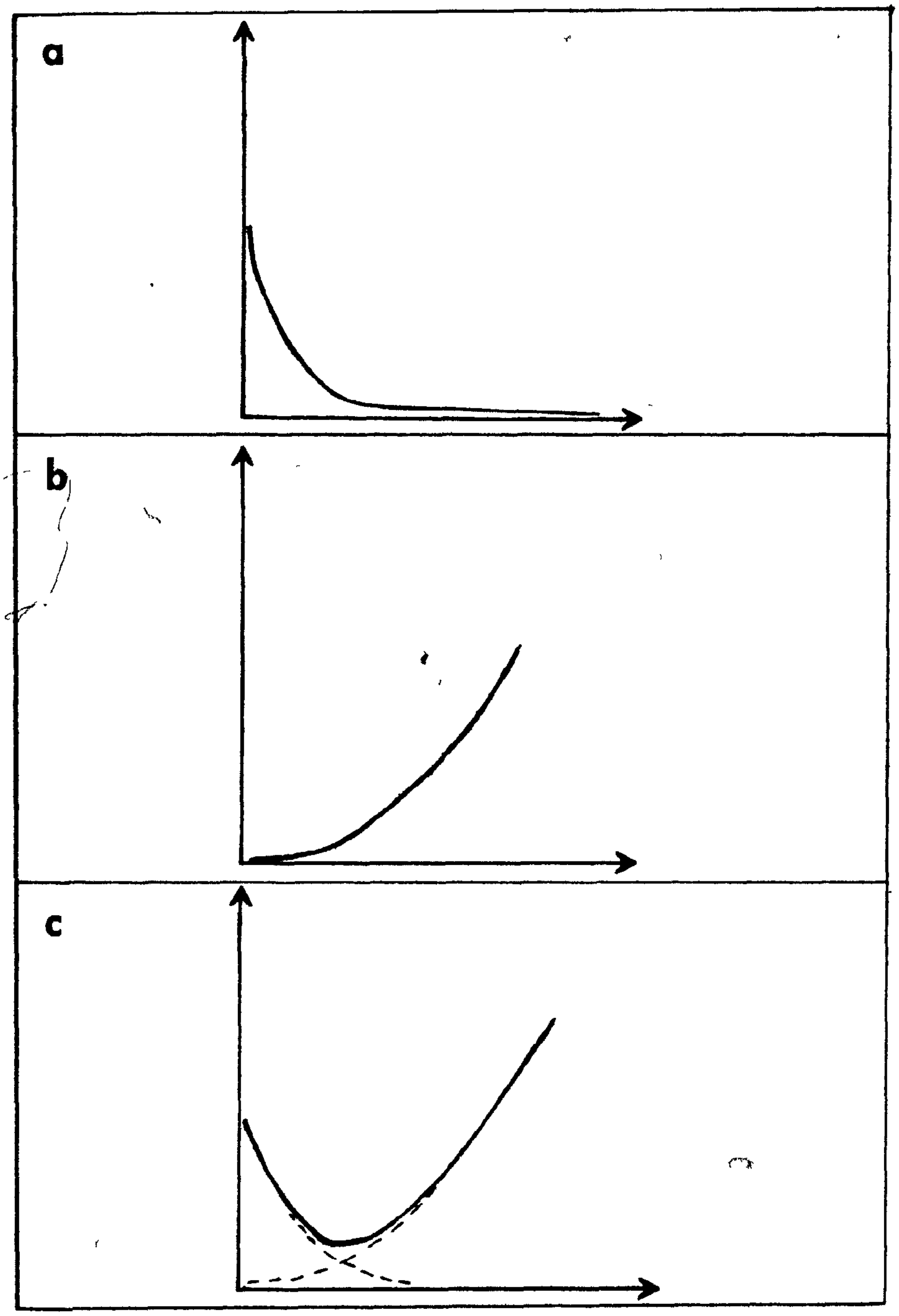
2. KONDO THEORY

Another group of models presented to explain the behaviour of R of MG is based on the extensions of the Kondo Theory (KT) of the resistivity of dilute magnetic impurities in metals.

KT was originally elaborated to explain the existence of a minimum in the resistivity in the curve RxT of some metals. For most metals, as T increases, R increases as well. This fact can be explained in terms of the vibration of the atoms of the lattice: as T increases, the vibrations of the atoms increases and therefore they offer a larger obstacle to the conduction of electrons. Nevertheless, for some metals, at low temperatures (less than roughly 20 K), we find a region of negative temperature coefficients followed by one of positive temperature resulting in a minimum in R. The essence of KT is to explain this minimum in R: the theory postulates the existence of an extra-scattering process which is relevant at low temperature and becomes less relevant as T is raised. Then, if we consider the normal behaviour of the resistivity together with this extra scattering process, we obtain the minimum in R. FIGURE 17 shows how the graphic RxT may be obtained if we add the two curves which represent the two scattering processes.

The theoretical problem we face now is to explain the nature of this scattering process. A first interpretation of the Kondo effect (KE), as this process is called, explains the existence of this scattering in terms of the the existence of small concentrations of magnetic impurities in the metal. The extra scattering process needed to form the minimum in R at low temperature arises from the transitions between spin states of the magnetic ions, i.e. the electrons not only lose energy through the

FIGURE 17 - Kondo Effect
a. Kondo effect contribution to the electronic resistivity
b. Normal result for RxT
c. The addition of the two effects



a
b
c

electrical interaction with the lattice ions, but they also transfer energy to the magnetic impurities to allow the transitions between spin states through the magnetic interaction electrons-impurities.

Two physicists, Tsuei and Hasegawa (TSUEI, 1969), first proposed that the minimum in R for the MG could be explain in terms of the KE explained above, i.e.

PREDICTION 3 - At low temperature, a minimum in R is expected because of the magnetic interaction electrons-impurities, which gives the transitions between the spin states of these magnetic impurities.

Before we derive the prediction for S within this model, let us derive a further theorem which will suggest a serious objection to the model:

PREDICTION 4 - If the negative temperature coefficient is explained in terms of the transitions between the spin states of the magnetic impurities, then, when the sample under examination is submitted to a fairly high magnetic field, the KE decribed above should be completly suppressed, and the minimum in R should disappear.

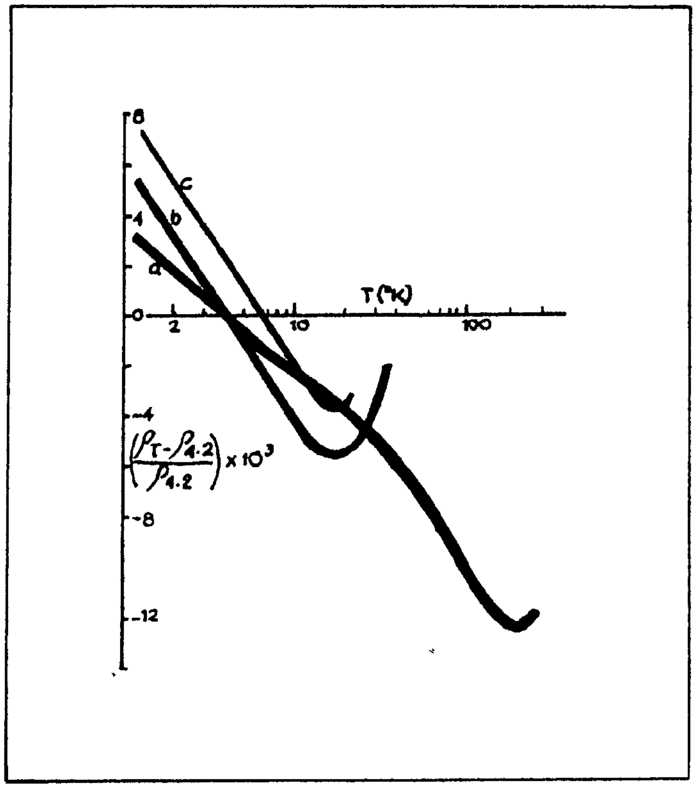
This conclusion is obtained because the high magnetic field will fix the spin orientation of the magnetic ions and therefore suppress the magnetic interaction electrons-impurities. This is a theoretical prediction based in QM. However, a detailed examination of R's behaviour of some MG's has shown that the shape of the RxT curves is unchanged when fairly high magnetic fields (COCHRANE, 1975). These experiments suggest that the negative temperature coefficient of R is not due to the magnetic and that another extra scattering process must be hypothesized if we want to maintain a model based on the KT (FIGURE 18).

I view of this objection, another extension of KT has been presented (COCHRANE, 1975). In this model the minimum in R is supposed to be caused by electrons scattering due to structural degrees of freedom inherent in the lack of atomic periodicity in the material, i.e. it is assumed that since the ions are not distributed in a periodic structure as in the crystals, they are able to occupy either of two equivalent sites. Therefore, the electrons will lose energy by allowing the ions to pass from one site to another, a process known as the **tunneling effect.** This scattering mechanism replaced the spin orientation suggested in the original KT. Then,

PREDICTION 5 - At low temperatures, a minimum in R is expected because of the transitions between the two equivalent sites which can be occupied by the ions of the material.

In terms of S, these two extensions of KT allow us to

FIGURE 18 - Magnetic influence in the curve RxT
"Resistivity versus lnT for (curve a) Metglas 2826A at H=0 and H=45KOe; (curve b) NiP at H=0; and (curve c) NiP at H=45K0e. For b and c, scale x10".
(Reproduced from COCHRANE, 1975; p.677)


8
4
0
-4
-8
-12
2
10
100
T (°K)
a
b
c
$\left(\frac{\rho_T - \rho_{4.2}}{\rho_{4.2}}\right) \times 10^3$

derive the same prediction since the equations describing the extra scattering processes are the same and we have only to give different interpretation to the variables involved in the calculations[12].

PREDICTION 6 - The thermoelectric power should present an **extremum** value around the equivalent of the Kondo temperature — the temperature in which the minimum in R occurs.

An important remark concerning the validity of the above predictions must be made before we present the experimental results. As I have stated, the predictions of the extensions of KT refer to effects at low temperatures (temperatures less than roughly 20 K). On the other hand, the validity of ZT has been shown to be restricted to intervals of temperature above 50 K. Therefore, we have to restrict the tests of each group of models to these T intervals.

IV.H THE RESULTS AND ANALYSIS

The experimental scientists arrive now at the most exciting moment: the empirical information has finally been produced in such way that they can apply it to the evaluation and development of the theories. It is only now, after a lot of manipulation of empirical data that the scientists can say: "We have the results. Let us decide whether our hypotheses have anything to do with real events or whether we have dreamed too much".

The curves of RxT for some of the samples under examination were obtained from previous experiments. They are shown in FIGURE 19. TABLE I presents information concerning the five samples which are relevant to the analysis of the results. The data obtained from the measurements in question are shown in FIGURE 16 (Metglas 2204), FIGURE 20 (metglas 2605 and 2605A), and FIGURE 21 (Metglas 2826 and 2826A). Finally, FIGURE 22 presents the five curves produced from these data, i.e. the graphic SxT for each sample. Let us now discuss these results.

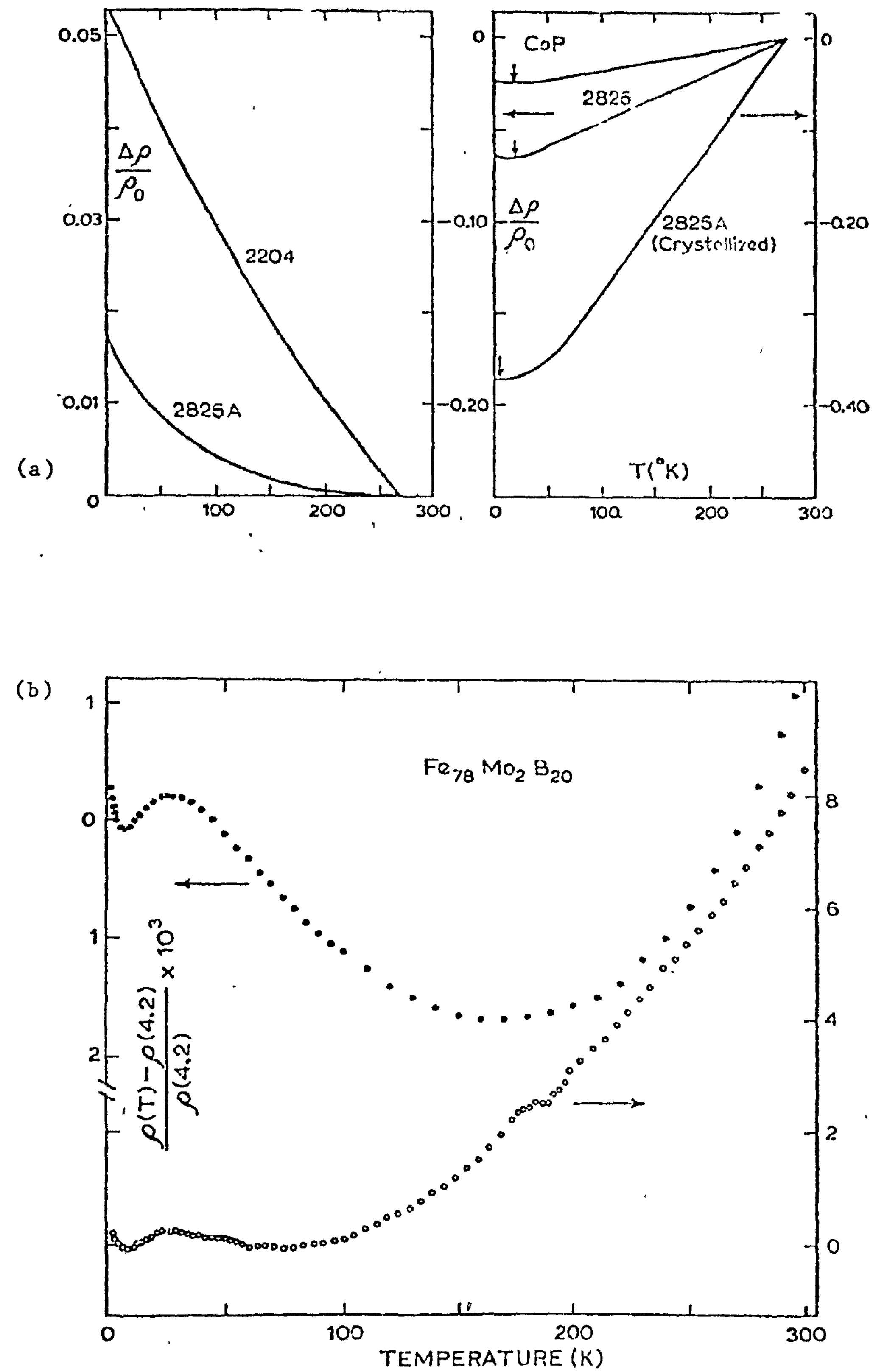
Let me first comment on the result for each sample separately. This first analysis consists of the examination of the geometrical features of the curves obtained.

Metglas 2204 - The curve obtained for this sample is linear above 40 K. This straight line does not intercept the origin. At low T (below 15 K) the curve is again linear, and it seems to approach zero with that slope, at least down to 0.3 K.

TABLE I

METGLAS ALLOY	COMPOSITION	ρ_{273} ($\mu\Omega$cm)	$\frac{1}{\rho}\frac{d\rho}{dt}$ at 200K	T_{min} (K)	FERROMAGNETIC T_c(K)
2204	$Ti_{50}Be_{40}Zr_{10}$	300	$-2x10^{-4}$	300	non magnetic
2826	$Fe_{40}Ni_{40}P_{14}B_6$	180	$+2.3x10^{-4}$	20	>300
2826A	$Fe_{32}Ni_{36}Cr_{14}P_{12}B_6$	180	$-2.5x10^{-5}$	270	249
2605	$Fe_{80}B_{20}$	140	$+1.0x10^{-4}$	70	375
2605A	$Fe_{78}Mo_2B_{20}$	120	$+1.0x10^{-4}$	10 & 70	>300

FIGURE 19 - "The electrical resistivity of some Metallic glasses
(a) the resistivity of some Metglas alloys and CoP, after R.W. Cocchrane and J.O. Strom-Olsen, J. Phys. F7, no.9, 1799 (1977).
(b) the resistivity of two samples of Metglas 2605A, after R.W. Cochrane".
(Reproduced from BAIBICH, 1979a; p.3)



0.05
0.03
0.01
0
$\frac{\Delta\rho}{\rho_0}$
2204
2826A
(a)
100
200
300
0
CoP
2826
$\frac{\Delta\rho}{\rho_0}$
2825A
(Crystallized)
-0.10
-0.20
-0.20
-0.40
T(°K)
(b)
$Fe_{78}\,Mo_2\,B_{20}$
$\frac{\rho(T)-\rho(4.2)}{\rho(4.2)} \times 10^3$
TEMPERATURE (K)

FIGURE 20 - "The following convention was used:
●- data obtained in this work
▲- data obtained by Belanger and Destry (Université de Montréal)
▼- data obtained by Elzinga and Schroeder (Michigan State University)"
(Reproduced from BAIBICH, 1979a; p.31)

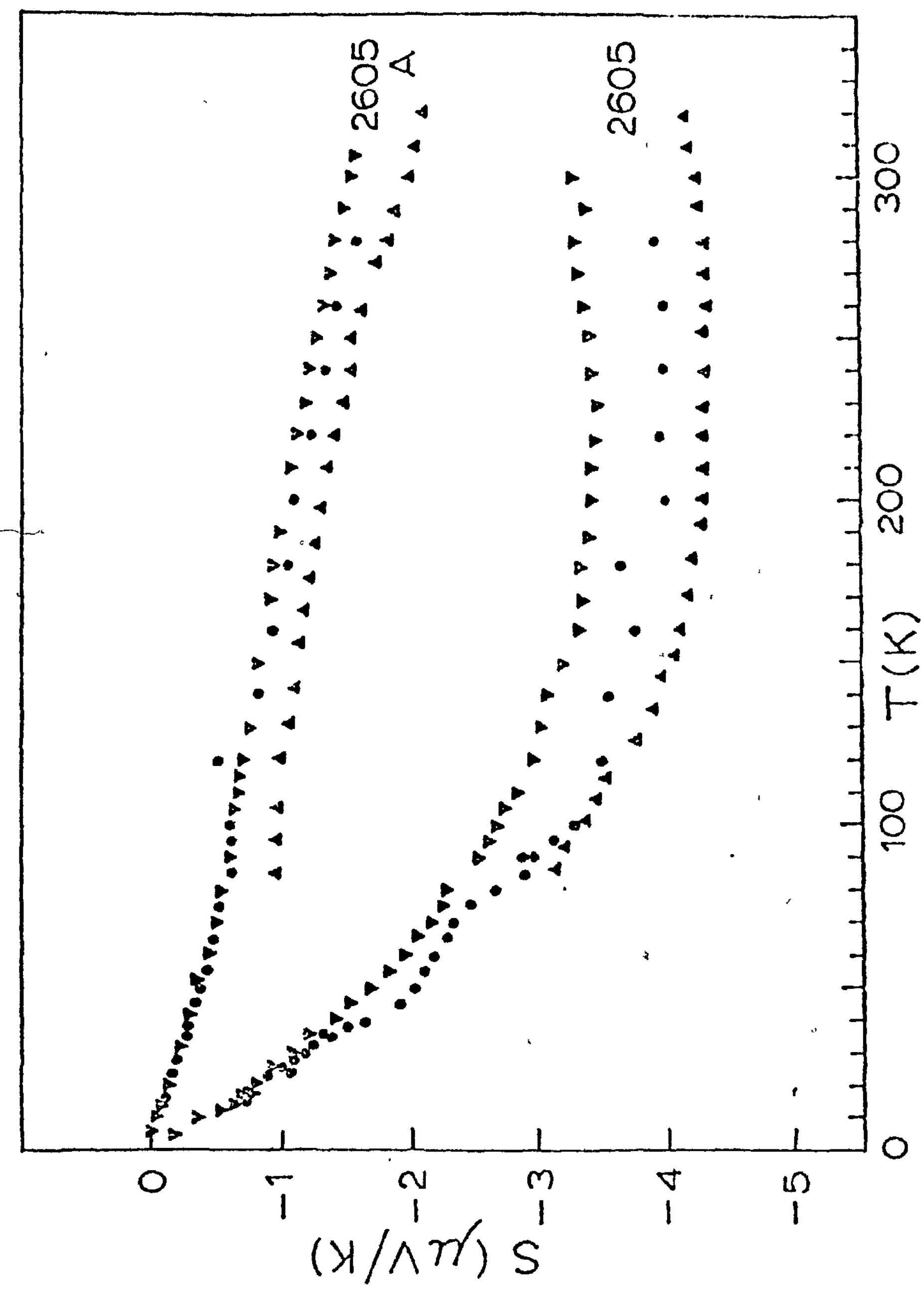

2605
A
2605
T(K)
S (μV/K)
0
100
200
300
0
−1
−2
−3
−4
−5

FIGURE 21 - "The following convention was used:
●- data obtained in this work
▲- data obtained by Belanger and Destry (Université de Montréal)
▼- data obtained by Elzinga and Schroeder (Michigan State University)"
(Reproduced from BAIBICH, 1979a; p.32)

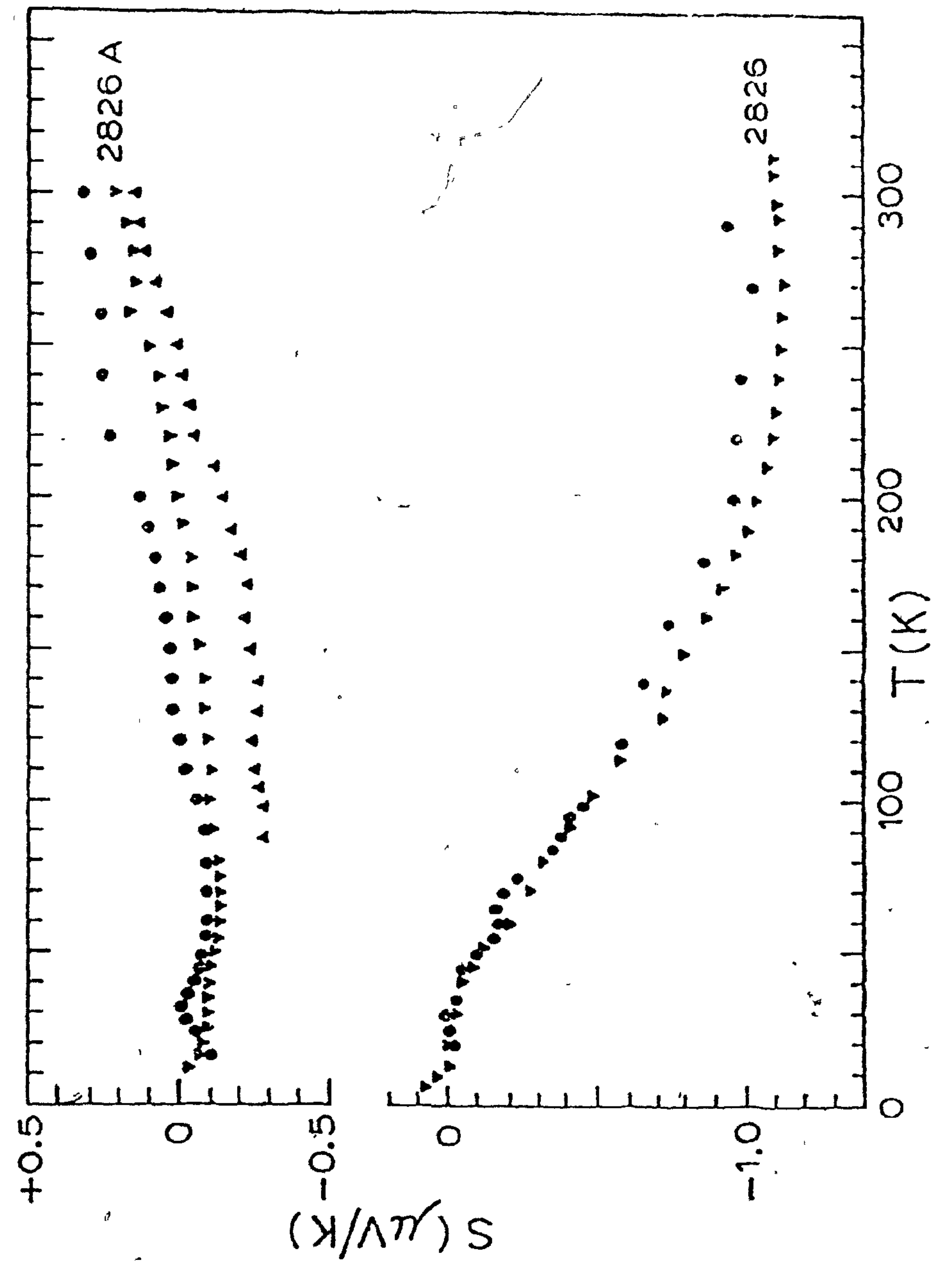
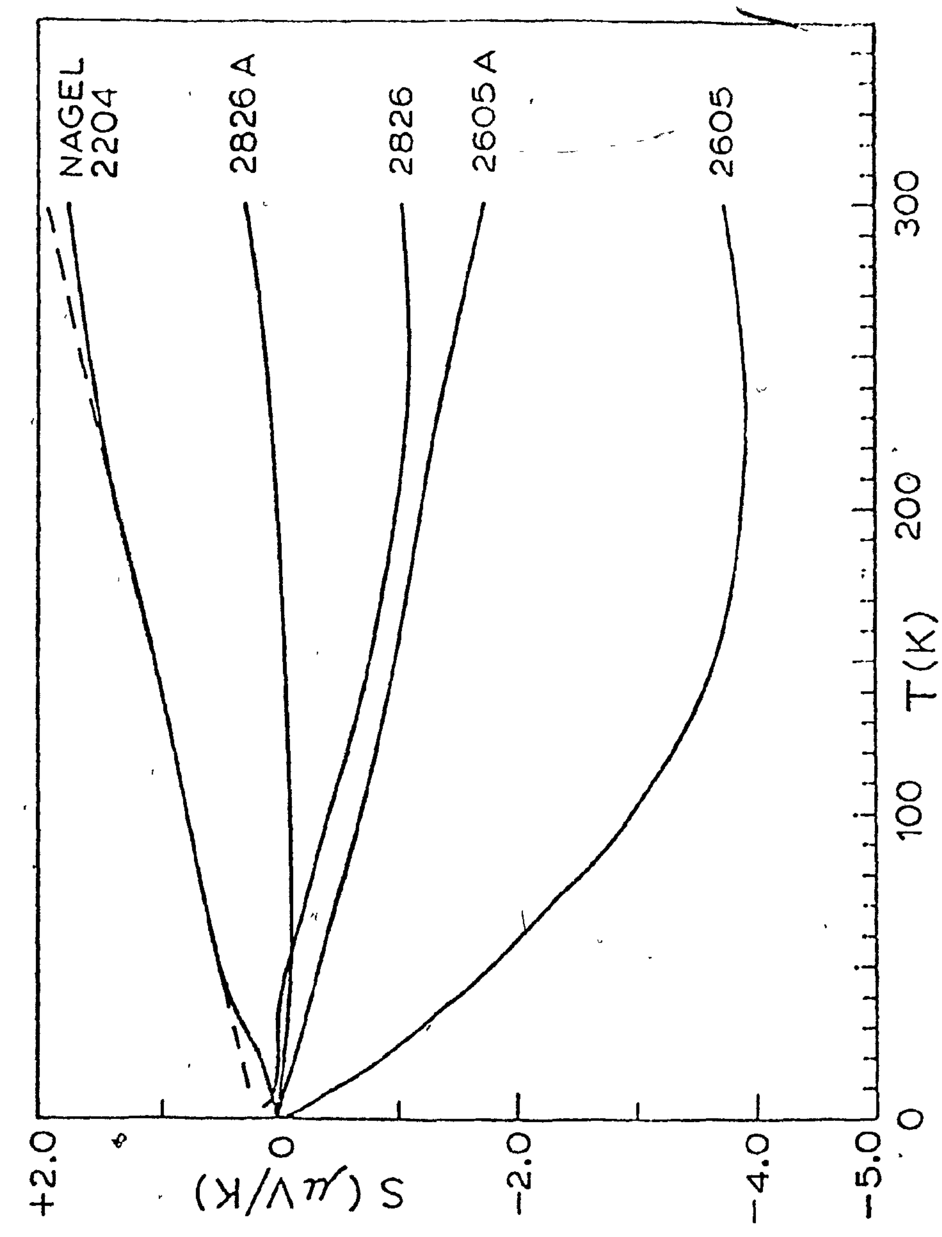

2826 A
2826
T (K)
S (μV/K)
+0.5
0
-0.5
0
-1.0
0
100
200
300

FIGURE 22 - "The solid lines represented the average of the results obtained by three independent groups. The dotted line reproduces the data published by Nagel". (Reproduced from BAIBICH, 1979a; p.35)


NAGEL
2204
2826 A
2826
2605 A
2605
+2.0
0
-2.0
-4.0
-5.0
S (μV/K)
0
100
200
300
T(K)

Metglas 2605 - The curve obtained for this sample is clearly not linear, showing a minimum at approximately 234 K.

Metglas 2605A - The curve obtained for this sample is nearly linear, always negative in this temperature range.

Metglas 2826 - The curve obtained for this sample is not linear. There is a change in sign at approximately 25 K and a minimum at approximately 250 K.

Metglas 2826A - The curve obtained for this sample is not linear. There is a change in sign at approximately 123 K and a minimum appears at approximately 70 K.

TABLE II summarizes the conclusions of the geometrical analysis together with the temperature minimum in the resistivity (Tmin). Let us now consider the theoretical predictions in the light of these results.

Consider first ZT. As I stressed in the end of last section, this theory is best applied to amorphous metals whose characteristic temperature for the minimum in the resistivity is relatively high. From TABLE II we infer that among the samples in question, Metglas 2204, 2826A, and perhaps 2605 fulfill this requirement. From the same table we can conclude that neither

TABLE II The relevant featúres of the curves SxT obtained.

SAMPLE	LINEAR	SIGN	MINIMUM	Tmin
2204	YES	+	NO	300K
2605	NO	-	234K	70K
2605A	YES	-	NO	10K & 70K
2826	NO	-/+(25K)	250K	20K
2826A	NO	+/-(123K)	70K	270K

Metglas 2826A nor Metglas 2605 presents the curve predicted from ZT (PREDICTION 1). It then becomes clear that Metglas 2204 is the only sample from this group to have S in reasonable agreement with the prediction of ZT. The fact that below 40 K S does not follow the straight line predicted by this model is not surprising since this theory becomes of doubtful value below 50 K as I have previously mentioned.

On the other hand, if we consider first S and we look at R, we should expect that a linear S would imply a high Tmin. FOr Metglas 2204 this is true as we have just seen. Looking back at TABLE II, we note that Metglas 2605A also presents a linear S; as Baibich points out (BAIBICH, 1979a; p.29), two other experimental scientists, Rayne and Levy (RAYNE, 1977), have shown that the Metglas 2605A presents a double minimum in resistivity, both **minima** below 70 K.

Let us pass now to the Kondo or Pseudo-Kondo models; all these models are valid for low temperatures, thus suggesting that the best results will be obtained for the samples with low Tmin. Form TABLE II we infer that Metglas 2826 and perhaps 2605 and 2605A fulfill this requirement. Now, from PREDICTION 6, we should expect an **extremum** value for S. Considering FIGURES 21 and 22 we find out that Metglas 2605 and 2605A do not present such an **extremum** value. We also infer that only Metglas 2826 might show a maximum at low T. Baibich suggests that this apparent complete failure of the models based on KT may be attributed to the limitations of the experimental resolution available to him and he provides theoretical arguments to support this possiblity. From these theoretical considerations, he concludes that,

> The thermoelectric power of amorphous metals will be sensitive only to the mechanism that produces the predominant scattering because of the weight of the total resistivity in metallic glasses. This made it difficult if not impossible to detect the Kondo-type contribution to the thermoelectric power with the experimental resolution available to us...
>
> (BAIBICH, 1979a; pp.37-8)

We see then that instead of accepting the negative results as evidence against the models based on KT, Baibich shows, on theoretical basis, that these empirical results cannot support any conclusive position because of the low experimental resolution.

We conclude then that Ziman's theory seems to account only for the results of Metglas 2204 over a limited temperature interval (40 to 250 K). The existence of a Kondo or Kondo-like contribution to the thermoelectric power of the MG's is still in doubt because of the argument presenting in the preceding paragraph. In view of this analysis, Baibich is led the following conclusion:

> Analysing the experimental results obtained and the predictions of the several theories proposed we are led to say that not one

> individual theory can explain all of the features presented... In order to assess the physical consistency of this assumption, further studies of thermoelectric powers of metallic glasses should be undertaken.
>
> (BAIBICH, 1979a; p.36)

In order to gain further insights from these results, two other remarks are in order. In terms of the structure of MG, it is interesting to realize that for crystalline metals the existence of structure in the resistivity — i.e. resistivity **minima** and/or **maxima** — usually is followed by a more pronounced structure in the thermoelectric power. In terms of the results obtained, we observe that: a) Metglas 2204 is consistent in not showing structure in both resistivity and thermoelectric power; b) Metglas 2826 has some structure in S and a minimum in R; finally, c) Metglas 2605A has two **minima** and a **maximum** in R and nearly linear S. Obviously, these observations do not allow any definite conclusion. Thus Baibich suggests that 'to better understand the behaviour of metallic glasses, the thermoelectric power for recrystallized samples should be measured and compared to the amorphous results'.

Finally it should be pointed out that the composition of the MG is an important variable in the study of the thermoelectric power of these materials. In the case in question, we observe that the change of composition — Metglas 2826 and 2826A (addition of Cr) on the one hand, and Metglas 2605 and 2605A (addition of Mo) on another hand — has implied a regular change in S. In both cases we have a reduction in the magnitude of S. Baibich points out that this effect may be explained by a suggestion made by Conchrane **et. al.** (COCHRANE, 1978) and Rayne and Levy (RAYNE, 1977 and 1978), but he concludes that this problem cannot be answered definitely with the set of samples available and that 'the thermoelectric power of a series of amorphous alloys with the same components but varied proportions should be measured'.

These are the experimental results, the scientific analysis of them, and the main conclusions derived by Baibich.

With this section I end this chapter which I expect has provided some scientific knowledge concerning the metallic glasses. It is in the light of the material presented in this chapter that I will return now to the philosophical dimension of this dissertation, specifically I would like to examine the two problems presented in CHAPTER II: the theoretical basis of scientific experiments and the factual truth of scientific theories.

Notes

[1]The importance of this new assumption becomes clear when we read K. Popper analysis's of **the pre-Socratic theory of change:**

> Thus what exists is **atoms** and **the void.** In this way the atomits arrived at a theory of change — a theory that dominated scientific thought until 1900. It is the theory that **all change, and especially all qualitative change has to be explained by the spatial movement of unchanging bits of matter — by atoms in the void...**
> The next great step in our cosmology and the theory of change was made when Maxwell, developing certain ideas of Faraday's, replaced this theory by a theory of changing intensities of fields.
>
> (POPPER, 1963; p.146)

[2]As Hertz pointed out:

> It is in empty space, in the free ether, that the process which we have described takes place...it is...certain that the wave theory of light is true...but whereas our knowledge of the geometrical relations of the process in this substance is clear and definite, our conception of the physical nature of these processes is vague, and the assumptions made as the properties of the substance itself are not altogether consistent.
>
> (HERTZ , 1896; p.314)

[3]In terms of the physical world, we can say that the assumption of the existence of fields is one of the most important elements in any contemporary theory about the ontology of physics. As Bunge has recently pointed out, a materialistic ontology which

wants to be in accordance with contemporary science cannot assume a concept of material object synonymous with bodies. Fields are also material objects, even though they are massless. This point led Bunge to search for an alternative definition of material objects, beyond the notion of bodies. His suggestion is to identify a material object as a object as a thing which can undergo processes in which <u>at least one of its properties is changed</u>. In this sense, any object which change its actual state is a material object. For a detailed discussion of this interesting debate concerning a revision of <u>materialism</u> see BUNGE, 1977, 1979a and 1980a.

[4]This is indeed the major assumption we make here. It makes the model very simplified since we do not consider other existent conduction processes.

[5]To put this assumption as an axiom may appear odd to eyes of the scientists. Nevertheless, I believe that the purpose and informal character of the axiomatics I present here justify the inclusion of this assumption as an axiom.

[6]E.H. Wichman in his book on QM (WICHMAN, 1972; p.41) suggests the order of 10 seconds, such a small period of time which would imply the impossibility of a stable material world underlying our perceptual experience with material objects.

[7]Insted of **atoms of the lattice,** we should now say **ions of the lattice** since the atoms have a positive charge because of the valence electron they share with one another.

[8]We have consider the lenght of the sample. If we consider the cross-sectional area of the sample, we will reach the same conclusion.

[9]As Kittel points out:

> The ideal crystal of classical crystallographers is formed by the periodic repetition in space of identical units. But no general proof exists that the ideal crystal is the state of minimum energy of the atoms at absolute zero. Many structures that occurs in nature are regular without being entirely periodic. The crystallographers's ideal is not necessarily a law of nature. Some of the aperiodic structures may only be metastable with very long lifetimes.
>
> (KITTEL, 1976; p.28)

[10]Another interesting example which I want just to mention here consists of the search for positive evidence of <u>quarks</u>. In a recent article by A. Pickering (PICKERING, 1981), we find a deep and detailed analysis of the importance of the theoretical basis of the construction of instruments for the interpretation of the results. Pickering shows that the very acceptance of the <u>Stanford experiments</u> as evidence for quarks partially depends on the

debate concerning the theoretical basis of the instruments used in such experiments.

[11]/Given the complexity of these deductions, I will omit the details which are not essential to my analysis. A more detailed derivation can be found in NAGEL 1975,1978, SHIMOJI 1977, and ZIMAN 1961,1965.

[12]Again, I omit the detail of the deductions. The reader can find a more complete presentation in TSUEI 1969 and COCHRANE 1975.

CHAPTER IV

ANALYSIS OF THE PHILOSOPHICAL THESES

After this long adventure in the wonderland of experimental and theoretical physics where we have attained some new insights on the electronic transport through the metallic glasses, I return now to the philosophical problems raised in CHAPTER II. Following BUNGE[1], I believe that there is always a philosophical basis which underlies any piece of concrete research, in particular the measurements of the thermoelectric power we have discussed in the last chapter. The philosophical presuppositions underlying any piece of research are, in most cases, not explicitly mentioned by the scientists when they publish their results. And when they are mentioned, the philosophical references made by the scientists might not be right. My task now is to contrast the philosophical theses of CHAPTER II with the actual piece of scientific research presented in CHAPTER III.

I start by presenting a review of the main points discussed in chapter II:

THE THEORETICAL BASIS OF SCIENTIFIC EXPERIMENTS:

THESIS 1 - Scientific experiments are theory-free.

THESIS 2 - An experiment is objective if and only if it is theory-free.

THESIS 3 - Factual science is based on experiment alone.

THESIS 4 - All scientific experiment are theory-dependent.

(Substantiation of THESIS 4)

T4.A The conception of the experiment: the theoretical context of experiments.

T4.B The design and plan of scientific experiments: the auxiliary theories.

T4.C The reading of the data: the interpretation of the empirical information.

T4.D The analysis of the results.

THESIS 5 - The factual referents of a scientific theory are the objects which are assumed to exist in the real world independently of the human experience of them.

THESIS 6 - The real world is a system of actual entities which exist independently of the human experience of them.

THE FACTUAL TRUTH OF SCIENTIFIC THEORIES

THESIS 7 - A scientific proposition is valid if and only if it is verified by empirical evidence.

THESIS 8 - All scientific propositions refer to empirical observations or empirical operations.

THESIS 9 - "An axiomatic system is never true or false, but only more or less useful".

THESIS 10 - The real world can be partially represented and explained by means of scientific theories.

THESIS 11 - The adequacy or truth of a factual theory is evaluated by the comparasion of the theoretical predictions derived from the theory with the help of auxiliary assumptions and the empirical results which are also produced with the help of many auxiliary theories.

(Remarks on THESIS 11)

T11.A The factual truth values are attributed to scientific propositions when two predicates are compared.

T11.B The evaluation of the degree of factual truth of a scientific theory does not consist in the attempt to verify the correspondence between the model and the actual object which the model is supposed to represent.

T11.C The factual truth of a scientific theory or hypothesis is very far away from the notion of the <u>absolute</u> <u>and</u> <u>final</u> <u>truth</u>.

Let us start with **the theoretical basis of scientific experiments** In order to refute THESIS 1 and at the same time to defend THESIS 4, I present now four modes of the theory-dependence of the experiments discussed (T4.A-D).

Consider first the conception of the experiments discussed. Even at the informal and incomplete level of the THEORETICAL BACKGROUND I have presented — section III.B — we can realize that the study of the electronic properties of any material presupposes a complex system of hypotheses concerning atomic properties and atomic structures. While it is true that these atomic theories have already received support from previous experiments, e.g. the case of the Rutherford Model discussed in CHAPTER I, it is not true that these atomic theories are derived from experiments. The models presuppose hypotheses which are postulates, such as the idea of an atomic nucleus or the idea of discrete states of energy for the atoms. The measurements of the thermoelectric power of the metallic glasses aim to better understand the processes through which the electrons move in the material. This aim can only be conceived within a theoretical context of atomic models, i.e. **a theoretical context.** This first comment stresses the general theoretical background need for the very conception of the experiments discussed. On a more specific level, we see that the models advanced to explain the resistivity of metallic glasses were not received without doubts, doubts which led to further empirical tests of these models (the extension of Ziman Theory and the Kondo or Pseudo-Kondo Models). It was with this aim that Baibich proposed to measure the thermoelectric power. Again, the study of the electronic properties of the metallic glasses was performed within a theoretical context, and the experiments discussed were conceived from this context[2].

This first remark does not seem to be enough to refute the positivist position. It could be argued: "true that the conception of the experiment is theory-dependent; but, once the experimentalists have decided what they want to measure, **the pure collection of empirical data start to take place"**. Let me then pass to the second and more definite argument: the design of the experiments.

As I have shown in section III.E — EXPERIMENTAL INSTRUMENTS — there is not a single instrument used in the experiments presented which is theory-free. If we take, for instance, the thermometer used, we realize that without the theoretical knowledge contained in quantum theories, a silicon diode would never be used as a thermometer. If we review pages 91 to 99, we will find the evidence that just as the thermometer cannot be conceived and used without theory, so all the other instruments used in the measurement of the thermoelectric power of MG are also theory-dependent. The text refered to above is explicit and I do not think it is necessary to repeat the theoretical basis of the instruments. The important philosophical conclusion to be derived from this remark, is that the very collection of the empirical information is extremely based on theory, and as the experiment I have presented here suggested, **without auxiliary theories the very accomplishment of the measurements would become, in practice, impossible.**

The theory-dependence of the measuremants is not only evident in the nature of the instruments, but also in the indirect manner by which we measure the properties under examination. In the case we have analysed, we see that neither the electronic resistivity nor the thermoelectric power can be directly observed. It is only with the help of theoretical considerations that empirical evidences could be produced for the tests of the models in question (see the whole section III.C — HOW CAN THESE PROPERTIES BE MEASURED? — and section III.E EXPERIMENTAL INSTRUMENTS — p.97, THE Pb WIRE). Those theoretical considerations become particulary relevant when the empirical data first obtained have to be further elaborated in order to attain the desired results. This step of the experimental work is the best evidence of the theoretical basis of the scientific experiments: the reading of the values of the voltmeters do not directly provide the data concerning the thermoelectric power of the sample. The experimentalists have to work with these data in order to produce the empirical results they want. This is the mode of the theoretical basis which I have called **the reading of the data** (T4.C). In the case we have analysed we can observed all the calculations and considerations Baibich had to make at the theoretical level before he obtained the curves for the samples (FIGURE 22). This is, I believe, the main refutation of the positivist thesis, or the best defense of the conceptualist alternative. If the empirical results are not the direct collection of data, but the result of a long process which involves both theory — in reality many theories — and experience of actual objects, how can we speak of the pure empirical data as the last word in factual science? My answer is obvious: this talk is non sense, or, in a more moderate consideration, it only makes sense in reference to an abstract science which has never existed in reality; a science which is neither true abstract science — e.g. mathematics — nor concrete factual sciences — e.g. physics, but only the science imagined by the positivist philosopher of science.

Last, but not least, we have the analysis of the results which also requires a theoretical approach to empirical results. This is in fact what Baibich did: after obtaining the curves, he began his analysis of them. First he produced the curves from the points obtained after the caLculations with the empirical data; then he made the geometrical analysis, which allowed him to obtain the relevant information about the curves (see section III.H — THE RESULTS AND ANALYSIS). Both these steps are far away from the mere collection of sense-data: Baibich worked with the data in order to obtain the points, with the points to obtain the curves, and with the curves to obtain the relevant results.

Each of these operations presupposes hypotheses: from the data to the points, we have the theoretical considerations involved in the design of the experiments; from the points to the curves, it is assumed that the processes under examination are continuous; finally, from the curves to the relevant informations, the very theories to be tested are used. Baibich tried hard to obtain either a linear function or an **extremum** value, because these are the expected behaviour derived from the models to be tested. (I am not saying that Baibich had deliberately forced the results in the perspective of positive evidences for the theoretical models. I think that the whole section III.H is a clear evidence against this idea. What I am suggesting here is that the theoretical expectations are an important factor in the analysis of the results, since they help the to know what they should look for.) Even after the relevant data are obtained, the work of interpretation of the results is not finished. At this point, the results are compared with the theoretical predictions, and as I have suggested before, a review of the empirical results may be required. In the experiments with the MG, we have seen that the lack of evidence for the Kondo Models led Baibich to the evaluation of the experimental resolution and to the conclusion that the curves obtained are not fine enough to testify against these predictions. Once more, the empirical information is deeply elaborated from theoretical considerations.

I pass now to the second philosophical problem raised in CHAPTER II: THE FACTUAL TRUTH OF SCIENTIFIC THEORIES. Let me first refute the empiricist view. The piece of scientific research we have studied offers several evidences that the positivist postulate that all scientific propositions refer to empirical observations or operations, THESIS 8, is completely wrong. Let us take for instance the two mechanisms used to apply Kondo Theory to the study of the MG: spin orientation and tunnelling effect of the ions of the material atoms. Both are quantum processes which occur in the interaction of sub-atomic elements (electrons-ions). Neither can these processes be directly observed nor can they be defined operationally. As in any application of quantum mechanics, by postulating quantum processes we can derive some effects which can be tested empirically. In the study of MG, the postulate of one of these two quantum processes allowed the scientists to derive minimum of the temperature for the restivity and to expect an **extremum** value for the thermoelectric power. These two predictions can be evaluated experimentally as I have shown in last chapter, but the quantum processes themselves cannot be tested — or "verified" as the positivists prefer — by any direct experiment. This impossibility of direct testing does not imply that these hypotheses are not scientific or not valid as the positivist philosophers would state. In actual science, we face a situation in which most of the postulates presented do not refer to empirical objects — objects of direct experience — as in most of the statements of atomic theories.

If the positivist THESIS 8 has been refuted in favor of the conceptualist THESIS 5, we have already a first problem concerning THESIS 7, the positivist notion to replace the factual truth of scientific theories. Since not all scientific hypotheses can be "verified" by empirical evidence, we cannot decide about the "validity" of all scientific propositions. To this objections, the positivist philosopher would answer that the propositions which do not refer to experience are just auxiliary devices without any real "physical meaning". (Remember the theory of meaning proposed by the positivists which I have mentioned on page 41) Without entering into this positivist talk about **propositions without meaning,** we can realize that even the propositions which indeed refer to objects of experience are not really "verified" in the positivist sense. Let me explain this in terms of concrete research.

First, what is the positivist sense of "verification"? Suppose someone says: "My book is blue". Now,suppose that we want to now if this is true. The empirical verication consists in looking at the book and checking its colour. If we perform this empirical operation or observation under normal conditions, says the positivist rule, we cannot be wrong for the sense data is never wrong[3]. This is the model of verification the positivist doctrine tries to impose on factual science.

If we turn back to the experiments presented in this paper, we do not find any test of the kind "blue books". Baibich did not develop the models for the transport of electrons first and afterwards "take picture of the electrons in motion" to verify the models. As we have seen, the testing process is much more complex than the positivist philosophers have ever dreamed. But enough of the positivist position. Let me pass to the alternative view.

As I have exhibited, the conceptualist alternative is based on the concept of **the partial degree of factual truth of scientific theories or hypotheses** (THESIS 11). IN the experiments in question, we obseve that the evaluation of the theories under examination is made by the comparasion of, on the one hand, some specific predictions, PREDICTION 1-6, which were derived from general theories with the help of auxiliary theories and a number of specific assumptions, and, on the other hand, the results produced from the experiments which were also produced with the help of many auxiliary theories as I have just shown. Both the extension of ZT and the modified KT's received a partial support from the measurement of the electronic resistivity. In terms of the thermoelectric power, Metglas 2204 provides evidence for the model based on the extension of ZT, i.e. the analysis of this sample gives a higher degree of factual truth for this model. However, the lack of evidence for the prediction of KT's is not taken as a refutation of the models based on this theory since it is suggested that the data are not fine enough to prove or disprove the existence of <u>extrema</u> in the thermoelectric power.

These considerations lead us to the following conclusions:

1. The conceptualist position is right in denying the concept of final and absolute truth in factual science. The experiments analysed clearly show that the most we can obtained from empirical tests is a partial evaluation of the truth or adequacy of the theoretical models, without any absolute conclusion. Even we are faced with negative results, we have seen that we cannot guarantee an absolute refutation of the hypotheses under test. This last conclusion shows that the criticism of positivism elaborated by the philosopher of science K. Popper[4] — a critique of the positivist <u>verification</u> in favour of the popperian <u>falsification</u> <u>or</u> <u>refutation</u> — is also inadequate when compared with actual pieces of concrete scientific research.

2. The evaluation of the factual truth of scientific hypotheses consists of the confrontation of two predicates — the theoretical prediction and the empirical results. The naive positivist notion of verification does not take place in concrete factual science. Furthermore, empirical tests do not consist of the direct comparison of the processes described theoretically and the actual interactions in the real world; on the contrary, by

postulating certain actual processes — e.g. the mechaninsms of the Kondo Models — we derive predictions — e.g. the behaviour of the thermoelectric power — and it is only these predictions that can be tested, i.e. for which we can obtain empirical refutation or confirmation — the curves produced by Baibich.

The analysis of a piece of concrete scientific research has provided a number of elements for the evaluation or testing of philosophical theses. That is the way philosophy and science can be unified into a unique inquiry.

Notes

1 So much so that the mere word philosophy is apt to evoke an ironic or even contemptuous smile in him (the physicist). He knows better than to indulge in free wheeling in the void. However, the neglect of philosophy will not stave if off. Indeed, when we say that we do not care for philosophy, what we are likely to do is substitute an implicit, hence immature and uncontroled philosophy for the explicit one. In short, the physicist is not philosophically neutral...

(BUNGE, 1973b; pp.1 and 2)

[2] Furthermore, we should no forget that the very material under examination, the metallic glasses, could not be obtained without a series of developments of contemporary physics as I have shown in section III.D — THE METALLIC GLASSES. This point may appear as a peculiarity of the piece of concrete research i question, but it is relevant to stress that this is a very common situation in advanced physics where artificial materials have been studied more and more.

[3] An example of this fruitless discussion of this kind can be found in any of Sellars's books; see Sellars, 1968 and1971).

[4] See POPPER, 1935, 1963.

CHAPTER V CONCLUSIONS

The philosophical journey made in these pages has taken us from the thoughts of Giordano Bruno and Mario Bunge, through the philosophical problems associated with scientific research, into the scientific investigations of metallic glasses. The perspective of such a voyage offers us a new view of "philosophy" and "science", a synthetic landscape wherein we see that scientific and philosophical inquiries are mutually dependent and determinant.

Our path has been long and tortuous , but what can we expect from a dissertation which aims to be a point of meeting between philosophy and science? To pursue this path requires the courage to ask questions like: 'Is the universe infinite?', 'Is it possible to know if the universe is infinite?', or 'How can we know if the universe is infinite?'. These are theoretical questions which I think we, as humans, should try to answer. I support the view which answers the first of these questions positively: **the universe is actually infinite.** And I also believe that this answer, as any scientific proposition, has a meaning within the context of contemporary physics — e.g. general relativity ; it has an actual reference class — e.g. the whole universe; and it also has a partial degree of factual truth — e.g. evidence produced in experiments of general relativity. This scientific proposition and its theoretical and experimental basis can be critized. This criticism must be rigorous and challenging for only in this way we can accept that this thesis is a scientific proposition.

In terms of the research programme analysed here, I conclude that the material called metallic glasses are composed of atoms and atomic elements. The actual processes through which these atoms change their states are represented and explained in part through the scientific studies which I have discussed here. These studies show me that:

1. Science is a complex human activity which involves both theoretical and experimental work. Both these levels of activity play an equal role in the actual research of scientists.

2. The philosophical approach to actual science should not start from either one of these levels and neglect the other; otherwise, this approach would become a creative exercise rather than a critical reflection on actual sciences.

3. The logical positivist view which tries to isolate experiment from theory is shown to be incorrect and to refer to an abstract factual science which has nothing to say about actual scientific research.

4. We should start to re-orientate the philosophy of science, pursuing a FACTUAL PHILOSOPHY, as I have called the new

approach, so that we can refute logical positivism and offer a new philosophical orientation which tries to scientifically reflect upon concrete science. The conceptualist theses presented are shown to represent the first steps in this direction.

5. The experiments to measure the thermoelectric power of some metallic glasses do not suggest the search for a final and absolute truth. On the contrary, they suggest that scientific research is a lengthy and complicated process involving constant criticism both from theoretical perspective and from experimental perspective. This work results in the production of a scientific picture or representation of real events. The analysis of the case has given us a deeper insight into the electronic transport through MG, but do we know in absolute terms those transport processes? Surely not! Do we have any knowledge concerning those scientific problems? Surely, we do! Surely the work of Baibich and his co-workers has advanced our knowledge concerning these new materials invented in the 60's.

In the same way that scientists have improved our knowledge concerning the MG, we can expect that the new philosophical approach to scientific research may very soon give us a much deeper understanding of the actual work of scientists. What we must is do to develop this new philosophical methodology which requires us to be philosophers and scientists at the same time. That is indeed our job.

APPENDIX A METALLIC GLASS: ITS PRODUCTION AND APPLICATION

> In composotion they are metallic, but they have the noncrystalline atomic structure typical of a glass. Such a material can be prepared by booling a molten alloy at a rate of a million degrees per second.
>
> (CHAUDHARI, 1980; p.98)

> Many application are likely for these materials that exhibit the favorable properties of metals and the manufacturing and economical advantages of conventional glasses.
>
> (GILMAN, 1975; p.46)

In order to complement the presentation of the metallic glasses given in section III.D, I exhibit now this appendix concerning one technique used to produce such material and some of the possible technological applications of the material. This appendix aims not only at offering a more detailed view of the MG but it can also be taken as an argument for the **the decisive role played by pure or basic science in the development of technological devices.** The defense of the importance and priority of **pure or basic science** — which aims at producing scientific knowledge about real events — as an area of research distinct from **technology** — which aims at producing scientific knowledge with practical use — has been philosophically present in recent years — e.g. BUNGE, 1967b and 1979c. The case which we analyse now is a clear defense of this position since we can observe that the very conception of the metallic glasses could occur only in light of theoretical and experimental background which I have partially presented here and which is beyond any doubt a chapter of pure or basic science.

In terms of the production of the MG, the main technique which has been used and rapidly developed in the few last years is the method called melt-spinning. As I have explained in section III.D, the main problem to the production of a MG is that the **glass temperature** of the metals is too close to the temperature of crystallization To be more precise, the glass temperature of these materials lies right below the liquidus temperature, where the liquid and the crystal phases can exist in equilibrium. As a result, when the liquid is cooled, it crystallizes long before the glass has a chance to form, so that the MG cannot be obtained. The method used for making MG economically on a large scale overcomes that problem by a simple strategy. The technique is based on some hypotheses concerning the processes of crystallization of these materials, which Chaudhari describes in the following words:

> When a liquid is cooled throu the liquidus temperature, crystallization does not begin everywhere at once. Aggregates of a few atoms each, called nucleation centers, must first be assembled in the crystalline configuration. These centers then grow by

accretion until the entire volume of the material has solidified. The formation and growth of nucleation centers requires a certain amount of time. The strategy for creating the metallic glass is to cool the liquid rapidly from above the liquidus temperature to below the glass temperature. If the passage through the intervening region is fast enough, there will not be time for crystals to form.

(CHAUDHARI, 1980; p.98)

Before I describe the usual strategy to let the MG to attain the solid state without giving time for the formation of crystals, I think that we have here a remarkable opportunity to stress the priority of pure science. The formation of crystal described by Chaudhari is a typical example of a mechanism which is theoretically postulated and cannot be directly observe. The factual truth of this model can only be evaluate in the way presented in this dissetation, i.e. empirical evidence produced with the help of auxiliary theories may provide the attribution of a partial degree of factual truth to theoretical models; the attribution is not definitive: further empirical or non-empirical tests may change our opinions about the models. As Strom-Olsen has recently stated in a conference on amorphous metals (Ecole d'ete sur la physique de l'etat amorphe metaux et semi-conducteurs. Universite de Montreal, 1981), the models advanced to explain the formation of the metallic glasses require a lot of fantasy. In Strom-Olsen's view this is not suprising since in theoretical physics we indeed need to use an number of models which can only be conceived with a strong help of imagination. Strom-Olsen opposed this situation to the applications of pure science where the needs imposed by the 'real or practical world' (technological demands) do not allow such flies of fantasy.

Let me then describe the technique in the words of Chaudhari:

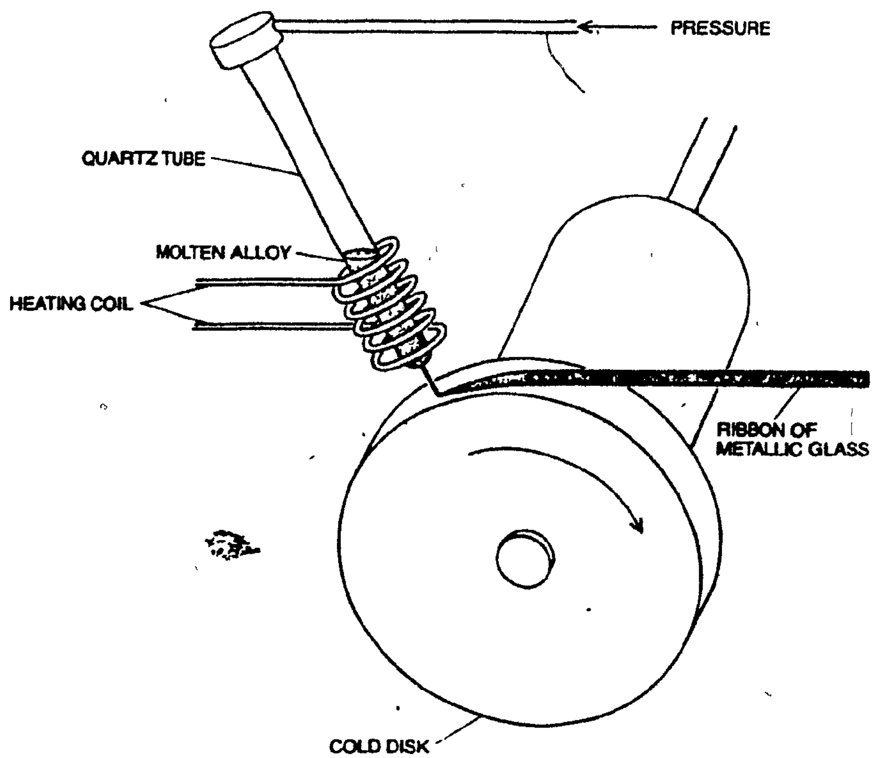
> A jet of molten metal is driven onto the surface of a rotating metal disk or cylinder, which is held at room temperature or below. The liquid is thereby drawn into a film no thicker than a few ten-thousandths of an inch. Because the film is so thin, because it is in intimate contact with a heat sink of comparatively large volume and because metals have an inherently high thermal conductivity, the metal cools an solidifies extremely fast. In round numbers, the metal can be cooled in a millisecond, which is equivalent to a rate of a million degrees per second.
>
> (CHAUDHARI, 1980; p.99)

By means of such rapid cooling many scientists and technologists have produced a great variety of MG. FIGURE 23 shows a diagram of the apparatus used.

The main characteristics which make the MG candidates for the technological applications, are rarely related to the investigation of electronic transport through MG and most of the potential applications are restricted to the magnetic, mechanical, and chemical properties of the MG. For this reason, I am not able to provide a detailed discription of the main applications without

FIGURE 23 - " MELT-SPINNING of a alloy is the predominant method of achieving the high rate of cooling needed to form a metallic glass. The film of the metal on the surface of the rotor cools quickly because it is thin, bacause the rotor provides a heat sink of large volume and because metals are good conductors. Cooling rates of a million degrees Kelvin per second have been attained. Similar techniques have been adopted for commercial preparation of metallic glasses".

(Reproduced from CHAUDHARI, 1980; p.104)


PRESSURE
QUARTZ TUBE
MOLTEN ALLOY
HEATING COIL
RIBBON OF
METALLIC GLASS
COLD DISK

entering into new theoretical developments beyond the scope and aim of this appendix. In this situation I will only outline some of the technological applications of MG. For a more detailed exposition of these applications, the reader is refered to CHAUDHARI 1978, 1980, GILMAN 1975, and POLK 1978.

I now mention some of the conclusions drawn from the texts presented in these articles:

1. High strengths (up to 245Kg/mm2/ or more) combined with thoughness make these glasses contenders as reinforcing filaments in automobile tires, transmission belts, high-pressure tubing, and related mechanical components.

2. A property that parallels strength is hardness. This is useful for various types of cutting devices if a material can be readily sharpened — and metallic glasses can be.

3. Another property that parallels strength is low attenuation of acoustic waves, which means that devices such as delay lines and mechanical oscillators can be constructed effectively.

4. The combination of very high permeability with high hardness makes metallic glasses useful for tape recorder heads.

5. Amorphous alloys combining superior corrosion resistance, high hardness and high elastic limit may be useful as razor blades.

Since the study of all these properties of the MG have been accomplished by research programmes which in essence are not different from the one analysed here, we can conclude that contemporary technologies deeply dependend on basic or pure science. To say that technological research is all we need is very short sighted. If we ignore pure science in defense of technology, we will soon find that in reality we are ignoring both. Without the basis of pure science, we are not able to develop contemporary technological research.

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