with some of them below, always taking up a critical dialogue centering on a given theme.

The issue of certainty.

One of the central problems in modern physics is the tangled issue of determinism, a probabilistic account of physical states. Here scientific considerations par excellence become indistinguishable from moral-religious issues and even from a deep psychological craving for certainty which seems to be inherent in the human being. Is it indeed so? Where does our quest for certainty come from? Is there anything specifically scientific in our preference for a deductive proof over an inductively reached conclusion? Is indeed a Laplacian deterministic world an unreachable ideal, in comparison to which all our present theories are only a second-best?

The 17th century sources of the quest for certainty we have just seen: all the three polar answers promised certainty. Religious certainty by revelation separated out of the world of knowledge and became a different branch of human consciousness. To us this will be of little concern for the next two hundred years. The Cartesian programme of certainty by ratiocination failed as a scientific research programme aimed at understanding the physical world, and by the mid-18th century it yielded to the Newtonian research programme which claimed to be following Bacon directly. As far as the Cartesians' social image of science goes, namely that the aim of science was the mathematization of all fields of enquiry, it was taken up by the Newtonians and became the dominant force in science for a hundred and fifty years. But this is true only of one of the Newtonian traditions. The Newtonian Research Programme split into two parts: the one based on the Principia, and it was mathematical and reductionistic; the other based on the Opticks, and it represented a programme of developing a theory of matter which would explain chemistry and biology and fit the 17th century image of God. The hard-core metaphysics of the one was that the world consists of discrete particles between which central forces are acting at a distance, the other a programme at the core of which was the nutshell theory of matter [1]. This second was taken up by natural philosophers — materialists who all believed in an all-pervasive

1. See A. Thackray, «Matter in a Nut-Shell: Newton's Opticks and 18th Century Chemistry», Ambix 15 (1968), pp. 28-53, and also his: «Quantified Chemistry — The Newtonian Dream» in D. S. L. Cardwell (ed.): «John Dalton and the Progress of Science», Manchester U.P., 1968, pp. 92-108.

æther in which they saw a vehicle of transmission of various forces.

From the point of view of the history of critical dialogues it is interesting that the Cartesian Scientific Research Programme failed, while the Cartesian image of science prevailed. The two Newtonian traditions fared very differently. The mechanistic tradition ruled supreme and, on having accomplished its task by 1800, simply merged with another theory, creating the field concept. The other Newtonian tradition became a participant in all critical dialogues in the 18th century on theory of matter, and finally merged in the 19th century with the Naturphilosophie, yielding the theory of energy (to these I shall return below).

However, the non-polar, non-dogmatic answers to 16th century scepticism did not take up the banner of certainty. Their contributions were of a different kind. Though all these non-polar trends were connected, for clarity's sake it is easier to talk separately of the Hermetic philosophers, the Paracelsians and of Leibniz.

As was seen above, I do not accept the conception of science and the history of its growth as represented by the Weber-Merton theses. That conception is mainly the Victorian image of science, generalized into a time-independent truth which, according to that thesis, was born in the 17th century.

For me the seventeenth century is an unhappy age of religious strife and mutual destruction, and a time when, after 200 years of such religious controversy, the intellectuals were seeking a non-controversial field of intellectual activity, everybody was for consensus. As I have shown above, that non-controversial answer they hoped to have found either in revelation, or in fact, or in ratiocination. True, the believers in each of these answers disagreed among themselves, but these were at least three great consensus groups, and, secondly, the discussion between these two groups was a rational dialogue and no scholastic disputatio or, what is worse, religious partisanship. The Baconians and the Cartesians diasagreed in salons - not in university aulas among cheering wild crowds (the disputatio style) nor on the battlefield (as did the religious partisans). Actually, what we, with our Victorian image of knowledge, try to see as experiment vs. theory distinction, did not exist in the 17th century. Even Bacon, in spite of the interpretation of the 19th century vulgar Baconians, never imagined a science without a theory [1], nor did Descartes preach a science

1. See P. Rossi, «Bacon» (University of Chicago Press, 1968).

without experiments. The real enemy of both was the *disputatio*: it was against the disputatio that Bacon wanted the inductive method and Descartes the extreme rationalization and mathematization of all fields of knowledge. It was the disputatio which embodied the schoolmen's image of knowledge, and it was a critical dialogue between these two competing images of knowledge of the schoolmen on the hand and the representatives of the 'new science' on the other. It is in this light that the mythical story about the 'obscurantist' Aristotelians who refused to look through the telescope of Galileo has to be understood. They were not afraid of seeing the evidence which would damn their theory, but simply refused to accept the evidence of the senses as a criterion for solving a dispute: to them, whatever was seen at the other end (or perhaps inside)[1] was not relevant to the solution of the problem whether any other heavenly body but the earth can have satellites.

Thus science was a happy solution for the many gentlemen of leisure who were tired of religious strife. They grouped around their masters and spent their leisure in deciphering the book of nature: some by collecting facts, some by looking inward, and the synthesizers and mystics by looking for great general principles of nature to be discovered or to be revealed. What united all of them was that they were tolerant people - our science was born of the latitudinarian spirit.

This thesis is best defended for the English scene by Barbara J. Shapiro[2]: «It is not difficult to see why scientific activities attracted so many during this period of religious and political upheaval. Science provided a respite, a non-controversial topic of conversation, where men might have «the satisfaction of breathing a freer air, and of conversing in quiet one with another, without being engaged in the

1. See the articles by P. Feyerabend: «Problems of Empiricism, Parts I, II», in: R. G. Colodny (ed.) «Beyond the Edge of Certainty» Prentice-Hall, 1965; and Colodny (ed.) «The Nature and Function of Scientific Theories», U. Pittsburgh Press, 1970; also «Realism and Instrumentalism» in: M. Bunge (ed.), «The Critical Approach to Science», Free Press, 1964. The story in its modern-good-science against 'the Aristotelian fools' interpretation serves as a central dramatic scene in Brecht's «Galileo».

2. Both quotations are from her «Latitudinarianism and Science» Past and Present, No. 40, July 1969, pp. 16 - 41, and her intellectual biography «John Wilkins 1614 - 1672», Calif. U. Press, 1969. The whole problem of the Founders of the Royal Society was taken up by Marjorie Purver, «The Royal Society, Concept and Creation», M.I.T. Press, 1967, and J. Agassi, «The Origins of the Royal Society» (Organon, 7, 1970).

passions and madness of that dismal Age». As Thomas Sprat wrote: «For such a candid, and unpassionate company, ...and for such a gloomy season, what could have been a fitter subject to pitch upon than Natural Philosophy? To have been always tossing about some Theological question, which would have been, to have made that their private diversion, the excess of which they themselves disliked in the publick: ...It was Nature alone, which could pleasantly entertain them in that estate. The contemplating of that, draws our minds off from past or present misfortunes, ...that never separates us into mortal Factions; that gives us room to differ, without animosity; and permits us to raise contrary imaginations upon it, without any danger of a Civil War».

And also:

«The alliance between latitudinarianism and science, however, went far deeper than a common core of pracitioners and a mutual distaste for dogmatism. For the two movements also shared a common theory of knowledge, and members of both became the principal proponents of a rationalized religion and natural theology. In their respective areas both scientists and theologians sought a via media between scepticism and dogmatism. On the scientific side this search resulted in an emphasis on hypothesis and a science without overt metaphysics. In spiritual matters it led to an emphasis on broad fundamentals and the eschewing of any detailed, orthodox theology claiming infallibility».

This view also relieves the tension between those who see in 17th century science mainly an intellectual activity, and the others who see in it a utilitarian puzzle-solving activity to help industry, navigation, mining or agriculture. For those gentlemen of leisure who were indulging in these noncontroversial topics did not distinguish so sharply between experiment and theory, nor did they want either to understand nature *or* to rule it. They, unlike their 19th century vulgarizers, read their Bacon very carefully and found as much sense in performing *experimenta lucifera* as in *experimenta fructifera*. All problems amused them and interested them, and they discovered God's greatness in Nature in all its wonderful manifestations; enlightenment could come from the artisan as well as from the astronomer.

The Cartesians were Catholics (but there were also many Huguenots) and also religious tolerants. They found their anchor in philosophical introspection, not, however, by eliminating experience but by fixing the criterion of relevance and of truth in what is arrived at by such introspection rather than by relying on the senses. Much less is known about the Cartesian Scientific Research Programme than, let us say, about the Baconian or the Newtonian, for in the Cartesian-Newtonian critical dialogue Newton had the upper hand, and with the 19th century image of science as a continuous success-story, Descartes and the Cartesians were exorcised [1].

It is not the place here to elaborate on the great synthesizing movements of the Hermetic philosophers, the Rosicrucians, Paracelsians and Helmontians with their iatrochemistry, alchemical dream, as universal social and educational reforms. I shall confine myself to quoting three passages: Van Helmont: «I praise my bountiful God, who hath called me into the Art of the fire, out of the dregs of other profession. For truly Chymistry, hath its principles not gotten by discourses, but those which are known by nature and evident by the fire: and it prepares the understanding to pierce the secrets of nature, and causeth a further searching out in nature, than all other Sciences being put together: and it pierceth even unto the utmost depths of real truth...».

«And all those things, not indeed by a naked description of discourse, but by handicraft demonstration of the fire. For truly nature measureth her works by distilling, moystening, drying, calcining, resolving, plainly by the same means, whereby glasses do accomplish those same operations. And so the Artificer, by changing the operations of nature, obtains the properties and knowledge of the same. For however natural a wit, and sharpness of judgement the Philosopher may have, yet he is never admitted to the Root, or radical knowledge of natural things, without the fire. And so every one is deluded with a thousand thoughts or doubts, the which he unfoldeth not to himself, but by the help of the fire. Therefore I confess, nothing doth more fully bring a man that is greedy of knowing, to the knowledge of all things knowable, than the fire. Therefore a young man at length, returning out of these Schooles, truly it is a wonder to see how much he shall ascend above the Phylosophers of the University, and the vain reasoning of the Schooles» [2].

«In short, the Scientific Revolution was not simply the forward march of a new experimental method coupled with the powerful tool of mathematical abstraction. For some the two were incompatible and

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1. See A. I. Sabra's admirable «Theories of Light from Descartes to Newton», London 1967.

2. Both from Van Helmont, «Oriatribe» as quoted by Allen G. Debus, «The Chemical Dream of the Renaissance», Heffer, Cambridge 1968.

the growing predominance of mathematical abstraction. For some the two were incompatible and the growing predominance of mathematical abstraction could be interpreted as a step backward - a step away from a truly experimental study of nature. For these men the purely experimental studies of chemistry seemed the best answer to the training of the logic ridden universities. We have seen this in the glorification of Paracelsus in the Rosicrucian texts and in the chemically orientated laboratory science of the utopian Christianopolis. And with the two chemists we have touched on, Fludd and van Helmont, we note a similar hope for educational change - a hope dominated by their belief that chemistry was the true key to nature»[1].

The Newtonian Research Programme is too well-known to be repeated here. I shall return later to the main elements in the 18th century critical dialogues about it. However, what is much less known, and even less admitted as relevant to the history of physics is the Scientific Research Programme of Leibniz, and to this I shall now turn.

The Scientific Research Programme of Leibniz.

Leibniz's programme was to unify body and mind, man and nature, and God, and to establish such overall principles as would point to such unity. In Leibniz's world there is no reduction of all explanations to faith *or* to experience *or* to ratiocination. His pre-established harmony is supported by all three, and he sees no incoherence in that. Then the scientific metaphysics at the core of his research programme is the unity of the world, focused in one fundamental entity: first force and then this entity becomes the monad. To this world conservation laws apply. His image of knowledge is shared by the Paracelsians, Rosicrucians, Hermetic philosophers and the great humanists of his age: it is to help man to understand, to feel, to empathise with God in all-pervading harmony. The aim of knowledge is not explanation, nor prediction, nor certainty: its aim is empathy with God. The important aspect of Leibniz's work is that it contributed at least as much to what we accept today as positive knowledge, as did the dogmatic polar reductionists. And the critical dialogue between these two world views (the reductionists and the synthesizers) and the different images of knowledge kept science steadily progressing. Let us look at Leibniz in some detail.

There is no serious historical treatment of Leibniz's monad

1. Ibid., p. 37.

as a scientific concept, attempting to understand it as a generalization of his concept of force; yet Leibniz made it very clear that this generalization was the connection between the two concepts. Leibniz pointed clearly to the connection between his concept of force and his concept of the monad [1]; and so we have to presuppose that there is coherence among the various aspects of man's thought. This is not a coherence of a strict logical kind [2] - it may be that the choice

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1. Leibniz himself says in his letters to De Volder: (Leroy E. Loemker (ed.), «G. E. Leibniz - Philosophical Papers and Letters», D. Reidel Publ. Co., Dordrecht, Holland, 1969): ...«you are already tacitly assuming what matter would be except through monads, since it would always be an aggregate, or rather the result of a plurality of phenomena, until we arrived at these simple beings» (p. 534) and «...It is essential to substance that its present state involves its future states and vice versa. And there is nowhere else that force is to be found or a basis for the transition to new perceptions... It is also obvious that in actual bodies there is only a discrete quantity, that is a multitude of monads or of simple substances, though in any sensible aggregate or our corresponding to phenomena, this may be greater than any given number», p. 539. In his «Reply to the Thoughts on the System of Pre-Established Harmony» contained in the second edition of «Mr. Bayle's Critical Dictionary, Article Rorarius» 1702 Leibniz repeats: «And I do in fact regard souls, or rather monads as the atoms of substance since there are no material atoms in nature according to my view and the smallest particle of matter still has parts. Since an atom such as Epicurus imagined has a moving force which gives it a certain direction, it will carry out this direction without hindrance and uniformly if it encounters no other atom», op.cit., p. 579. Finally in «The Monadology» (1714) he says «It follows from what I have said that the natural changes in monads come from an *internal principle* since an external cause could not influence (influer dans) their interior», op.cit., pp. 643 - 644. Loemker himself (op.cit.) also draws attention to the close relationship between monad and force: «All monads are temporal series of active force and passive content, representative of the universe and striving toward the purposes defined in the individualized law from which they proceed» - Introduction, op.cit., p. 45) and in his annotation to «matter» he says «...secondary matter, as matter is phenomenal, and only the aggregated monads whose passive force is expressed as resistance or inertia are substantial (op.cit., p. 508, note 12).

2. Anthropologists wrote extensively on coherence which is not of a logical kind. Lévy-Bruhl in his «Les Carnets de L. Lévy-Bruhl», Paris 1948, writes that mystical thought is organized into a coherent system with a logic of its own (p. 61). According to Evans-Pritchard in a review essay on Lévy-Bruhl, (E. E. Evans-Pritchard: Lévy-Bruhl's Theory of Primitive Mentality, Bull. of the Faculty of Arts, II, 1934 1 - 36) mystical thought is 'intellectually consistent even if it is not logically consistent, and 'primitive thought is eminently coherent, perhaps over-coherent. (...) Beliefs are coordinated with other beliefs and behaviour into an organized system. Both quotations are brought by Steven Lucas in his paper «Some Problems about Rationality» which

of the term 'coherence' is unfortunate. It is rather like the coherence between different works of art by the same artist [1].

A unifying principle goes through the work of Leibniz like a 'Leitmotif'. In his early dynamical works [2] he spoke of such a fundamental principle as conservation of force. It is nothing like the Newtonian force-vector. It is certainly not energy as some modern commentators would like to translate it [3]. What Leibniz actually tells us himself is that force has *an effect* mv^2, *or* mv, *or* the height reached by a body thrown upward, as the case may be, while in later works he says that it is a 'metaphysical entity', 'the essence of matter' or 'the main attribute of a monad'...

The monad serves as a final generalization of his concept of force, now uniting in it not only all the physical effects of this fundamental entity which is conserved in nature, but also the physical and the spiritual: mind and matter. To us, all this may sound rather confused; but the importance of vague concepts like Leibniz's force of monad for creating science is enormous [4]. Like most scientific concepts at the early stages of their evolution (as well as of the theories in which they occur) the concept of the monad defies any attempt at exact definition. Historical research in the evolution of such vague concepts and half-formulated theories will contribute to our understanding of those elements in science which, by contemporary standards, look irrational. If we do not follow the Leibnizian Scientific Research Programme

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appeared in Bryan R. Wilson (ed.) «Rationality», Oxford, Basil Blackwell 1970, p. 202. See also G. Holton: «Science and New Styles of Thought». The Graduate Journal 7 (1967), pp. 399 - 422. The motto to this article is «not in logic alone».

1. There is a sense in which the man who composed the *Razumowsky* quartets must be the same man who wrote also *Fidelio*. The question is how to translate such a vague insight into practical terms - into fruitful historical research. What a commitment to such a belief in coherence implies is that the works of the philosopher-scientists must be treated as a whole.

2. The New Physical Hypothesis (1671) which appeared in two parts:
   1) The Theory of Abstract Motion, and
   2) The Theory of Concrete Motion.

3. On the problem of translation of terms into modern terminology see my «Helmholtz' Kraft», op.cit.

4. There is a famous quotation by H. A. Kramers which is so poignant that it is worth repeating:

«In the world of human thought generally and in physical science particularly, the most fruitful concepts are those to which it is impossible to attach a well-defined meaning».

through to the mid-nineteenth century, we can easily be puzzled by the obscure origin of conservative ideas which burst 'suddenly' on the scene from so many quarters [1].

Following this line of thought we come to a central issue in the 18th century history of thought. What is to count as Newtonian and what as anti-Newtonian? This is not a rhetorical question but a historiographical problem of fundamental importance, any reasonable answer to which would presuppose a comprehensive knowledge of the growth of science from the 17th century onwards. To describe the world in terms of discrete particles between which central forces are acting at a distance is certainly Newtonian - this is the metaphysical core of the «*Principia*». The programme of mathematization of mechanics, as perfected by the French school of rational mechanics is also Newtonian. The various matter theories of the 18th century first presented in the Queries and in the letters to Bentley, are characteristically Newtonian. The idea of chemical affinities is Newtonian but so was the Daltonian revolution which rejected the affinities. Lavoisier was a Newtonian of sorts and so was Priestly whom Lavoisier rejected and so was Humphrey Davy who refuted Lavoisier's central doctrine, namely that all 'elements' contain oxygen. Some of these great natural philosophers called themselves Newtonians because they adhered to a world-view where the most important force was gravitation acting-at-a-distance; some others accepted a material substratum, the ether, which transmits all physical action and this was the reason why they considered themselves Newtonians; some others again made the same claim because they believed to be doing scientific work in the hypothetico-deductive way, which they considered to be the hallmark of Newtonianism. Needless to say there is very little similarity between Newton's thoughts and speculations and the conceptual framework which they thought to be Newtonian. In addition to those who thought themselves bona fide Newtonians, there are others who used the label 'Newtonian' politically, for legitimization of their theories; an example is Thomas Young, a disciple of Euler and Huygens, who introduced his famous paper on interferences of light by attributing the main ideas to Newton. Finally there were the continental natural philosophers, all of whom accepted Newtonian mechanics and attempted to blend it into their Cartesian or Leibnizian con-

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1. See also J. Agassi, «Leibniz's Place in the History of Physics», J. Hist. Ideas, XXX (1969), pp. 331 - 344.

ceptual frameworks; later historians in their positivistic whitewashing exercises called them Newtonians; such were, to name only a few, Boscovich, Euler and Kant.

But, allowing for the moment that we could sufficiently refine our notion of Newtonianism, it still seems to me that to attempt to describe the main lines of the development of 18th century science (even if we restrict ourselves to England and to matter theory of chemistry) in terms of the struggle of the Newtonian and anti-Newtonian traditions is to put ourselves into a conceptual straightjacket.

In my opinion there were at least three great traditions or scientific research programmes competing for primacy in eighteenth-century science. These are the Cartesian, Newtonian and Leibnizian research programmes. The critical dialogue between these three was conducted in pairs: Newtonianism v. Leibnizianism; Newtonianism v. Cartesianism and again separately Leibnizianism v. Cartesianism, or rarely when two joined forces against the third. To lump all general explanatory hypotheses which are not Newtonian together under the heading 'anti-Newtonianism' is an oversimplification. Those conceptual frameworks which can justly be labelled as anti-Newtonian focus their opposition either on Newtonian science or Newtonian methodology. Yet anti-Newtonians proper and Newtonians share a fundamental problem-situation: Should or could one describe the universe in terms of discrete particles with forces acting between them; can force act through a vacuum; are forces essential properties of matter? On the other hand the 18th century Leibnizians and the two different brands of Cartesians (which separated out of the original Cartesian framework at the turn of the century) had to face different problem situations and had a different scientific research programme than the 18th century Newtonians. The two Cartesian groups were the Cartesian mathematical rationalists like d'Alembert, Diderot and later Lagrange and the Cartesian matter-theorists like Maupertuis, Euler and Johann Bernoulli. Cartesian mathematical rationalism developed a programme aimed at subsuming all phenomena under mathematically formulated laws. Here there was no discussion of fundamental concepts, no search for underlying principles, and the criterion of truth was rarely empirical. Rather, mathematical formalizability and elegance became signs of truth. These Cartesians were occupied in developing mechanics as a branch of mathematics and concentrated on attacking the Liebnizians rather than the Newtonians.

The main argument between the matter-theorist Cartesians and the Newtonians centered on the primacy of the concept of force. These Cartesians too accepted Newton's results, that is, the laws of mechanics and the law of gravitation, but they insisted that there are essential qualities of bodies to which forces can be reduced. If forces were introduced into the Cartesian programme they were considered as mathematical abstractions useful for smooth calculations - an attitude somewhat similar to Heinrich Hertz's a hundred and fifty years later.

The mind-body dichotomy was part of the Cartesian tradition but it played only a very minor role in the controversy with the Newtonians. This problem was, however, the core of the Cartesian-Leibnizian critical dialogue. The Cartesians separated mind and body, and also scientific metaphysics (That is, those views on the structure and genesis of the physical world which are on principle untestable, but form the core of their research programme) from theology. Both the Newtonians and the Leibnizians, on the other hand, attempted to justify their scientific metaphysics by their theology. This justification became one of the foci of the Newtonian-Leibnizian critical dialogue, as exemplified in the Leibniz-Clarke correspondence and as continued by Euler in the 'Letters to a German Princess' written in the 1770s.

The central Newtonian conception is that of force, whether acting at a distance or at a short range by contact. Newtonian physics, astronomy, chemistry and physiology all involve forces. Whether the forces are inherent in matter or reducible to their relational properties is another focus of the dialogue between Newtonians and Leibnizians. On the other hand, the concept of force is as foreign to the Cartesian as it is inseparable from both the Newtonian and the Leibnizian Research Programmes.

Another difference between Newtonians and Leibnizians is that conservation principles are alien to the former but fundamental to the latter. Even though an anti-conservation-principles attitude is not explicit in Newton's writing it seems to me one of his deep-seated anti-Cartesian biases. He, unlike Descartes, will not address himself to questions like - 'what are fundamental entities?' 'are they conserved?' etc. He takes four 'fundamental notions': space, time, mass and force for granted and operates with them. For Leibniz, too, the concept of force is fundamental, but it is rather its conservation which is at the core of his scientific metaphysics. It is the idea of conservation of force which served Leibniz in doing away with the Cartesian mind-body dualism and helped him develop his monistic theory.

In short, in order to gain any reliable picture of eighteenth-century science one has to explore at least three competing traditions; all three left their indelible mark on the development of science in the nineteenth and even the twentieth century, each at times had the upper hand in the long critical dialogues between them. Newtonianism is the paradigm of success in terms of positive scientific results. The positivistic attitude does not find room for either the Cartesians or the Leibnizians in the history of science. Thus 'Newtonian' v. 'anti-Newtonian' covers the ground adequately only if we judge the development of science presupposing that science grows by accumulation. If we view the growth of knowledge as a result of a dialogue between competing *research programmes*, we must think in terms of at least the above mentioned three traditions. Perhaps one could add to these three also the Paracelsian tradition but it seems to me that as far as problem-situations are emphasized the Newtonian and Leibnizian conceptual frameworks will cover Paracelsianism too.

When looked at in the framework suggested here, eighteenth century matter-theory will look different; it will be clearly seen that chemistry of affinities is Newtonian in its emphasis on quantification and search for a general law. In other words the problems of the chemistry of affinities belongs to the Cartesian-Newtonian critical dialogue. On the other hand, S t a h l and the phlogistonians emphasized that not forces but rather primary principles which are present in finite quantities and which obey conservation laws, like the principles of heat, electricity, chemical affinity, etc., are the ultimate entities to which all phenomena have to be reduced. This conceptual framework is Leibnizian even if the chemical concepts are traceable to the great alchemical schools and the later Paracelsians, Rosicrucians and Helmontians. Yet the Stahlians who rejected the Newtonian kind of forces fully endorsed the Newtonian empirical attitude. Thus the whole Stahlian chemistry can be seen much more clearly against the background of the Newtonian-Leibnizian dialogue. Actually, the argument between the Stahlians and the Newtonian affinity chemists concentrated on the nature of heat, for and against the Stahlian theory of the phlogiston.

Moreover, in order to see the connection between D a l t o n and his predecessors it is not enough to reach back to the Scottish common sense philosophers, the Edinburgh chemists (P l u m m e r, C u l l e n and B l a c k) and to B o e r h a a v e, all from the point of view of Newtonianism; but we have to view the emergence of D a l t o n's work as against the fierce dispute between the late 18th century Newtonians and the followers of Kant, whose growing influence introduced many Leibnizian elements into English and even more into Scottish natural philosophy. Boerhaave himself cannot be seen clearly without the Newtonian-Leibnizian dialogue in the background. In the same vein, it does not seem to me acceptable to claim that «during the 19th century mechanism again reached ascendency but with explanations quite unlike those which had characterized the dynamic corpuscularity of 18th century mechanical philosophy; ...the emphasis was on forces and energy... next to nothing was said (or believed) of a material substratum in which such forces might inhere» [1]. This is unilluminating. The concepts of force and energy cannot be disentangled from the ideas of conservation and their emergence does not belong to the dispute between Newtonian mechanists and Newtonian materialists but rather to the joint Cartesian-Leibnizian attack on the Newtonian research programme as it developed in the work of Leibniz, Euler, Kant and Helmholtz who all belonged to this tradition.

There is an important link which should not be omitted in a description of 18th century theory of matter. I have in mind the influence of Euler, the man who did more than any other to embed Newtonian science in the Leibnizian programme. He developed a matter theory of contact-forces derivable from the property of impenetrability. He reformulated the '*Principia*' in modern mathematical terms and made possible its absorption of the conservation laws. He rejected Newtonian optics and combined Newtonian ether theory with Huygensian optics and prepared the ground for Young and Fresnel. His was the major scientific influence on Kant; in short it was Euler's influence which reintroduced the core of the Cartesian-Leibnizian research programme into the body of science on the Continent and in England. I shall turn to him now briefly.

Euler was a Cartesian in his metaphysics, a Newtonian in his methodology; his image of science was heavily influenced by Leibniz and by the tone of the Enlightenment as it was expressed by the Berlin and St. Petersburg Academies, and he was a major influence on Immanuel Kant.

At the centre of our discussion of Euler's theory of matter, the halfdistinct concept of impenetrability will be found. Euler was

1. Robert E. Schofield, «Mechanism and Materialism: British Natural Philosophy in Age of Reason», London 1970, p. 227.

trying to construct a physics which would suit his scientific metaphysics. He took for granted an attitude towards science and towards metaphysics which was new and which later cost Kant a lifetime of hard labour to put on a strong foundation. Euler discovered a discrepancy between his metaphysics, the central pillar of which was the tenet that there are no forces acting-at-a-distance, and the usual interpretation of the successful Newtonian physics; this constituted a serious problem for him. In trying to overcome the difficulty he reached back to the Cartesian and Leibnizian heritage which he transmitted to the coming generations. From Descartes and Leibniz he took the rational rejection of action-at-a-distance and from Leibniz the wish of harmonizing and synthetizing. Though he failed in his theory of the ether and in his theory of gravitation, both resulting from his attempted synthesis, he was so eminently successful in his mechanics of solids and mechanics of fluid bodies that he became a central figure in the development of that kind of science which flourished in Germany in the 19th century and harked back to Eulerian and Leibnizian syntheses of conservation ideas and unitary principle. He was also an ardent supporter of the *wave* theory, or rather of the anti-corpuscularean theory of light. Moreover, in the development of that attitude to science which is best described as 'essentialistic' [1], Euler serves as an important link.

The concept of impenetrability occurs from Descartes onward almost in every treatise on the theory of matter — be it corpuscular or dynamic in approach, or a combination of both. 'Corpuscular' theories treat mass and motion as fundamental entities; the 'dynamicist' theories use force and motion, while there is a third approach which uses both the concepts of force and mass.

Descartes, Leibniz, Boscovich, Kant, as well as Euler and many others on the other hand, began asking 'what is the essence of matter?' Some of them were corpusculareans, others were dynamicists, but all were system-builders, concept-creators.

Euler and Boscovich [2] were followers of Leibniz. They too asked first of all what was the essential property of matter, and both considered the Leibnizian 'impenetrability' and 'force' as the essential properties of matter. But their solutions were complementary.

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1. K. R. Popper, «The Aim of Science», Ratio 1 (1957), pp. 24-35.
2. As to Boscovich and Kant see: M. Oster, «R. J. Boscovich als Naturphilosoph, Cöln 1909 and, my op.cit., p. 111, on Kant.

Euler found that the fundamental quality was impenetrability. It was fundamental insofar as Euler thought he could 'derive' — in those days 'derive' had a much less mathematical meaning than nowadays — all other properties and fundamental laws from it. Force was for Euler only an effect of impenetrability.

For Boscovich the essence of matter was force, and impenetrability was its effect. As a result of these different metaphysics, for Euler all action was by impact; that is, only contact-forces existed, while for Boscovich, all action was due to forces acting-at-a-distance. Yet he was not a proper corpusculareau, for his system dispensed even with the concept of mass as a fundamental property.

Kant, as we shall see, was influenced by Euler and opposed the corpusculareau view. As mentioned above, he first accepted action-at-a-distance, while in his old age he became even more Eulerian and he rejected action-at-a-distance. It was only Newton, and even more his followers in England and later in France, who, not having asked 'what is the essence of matter?' could say that some forces were contact forces while others acted-at-a-distance.

Euler's essentialism and theory of matter influenced Kant and Helmholtz in Germany, and Thomas Young and through him Faraday in England. Euler proved that important and successful work can be done when motivated by his metaphysics, and this became one of the important sources for the continuum theory of matter which developed in the late 18th and 19th century, very often through the mediation of Kant. If founded the scalar formulation of mechanics, the mathematical study of fluid mechanics; it motivated Helmholtz in developing the theory of energy, and gave a scientific support to the revival of the various vortex theories in the mid-19th century. Finally it was to Euler's metaphysics that the anti-atomistic tradition in the late 19th century referred.

Kant mentions Euler very often and in highly praising words, but it so happens that in the all-important first 'critique' Euler is not mentioned at all. The 'Critique' so overshadowed all other works of Kant, that even the 'Metaphysical Foundations' was mostly ignored, at least until the Kant-renaissance which began in the 1870's. Kant's last work, the posthumously published 'On the Transition from the Metaphysical Foundations of Natural Science to Physics' [1],

1. Vom Übergange..., op.cit.

which is the least Newtonian and most Eulerian of all his works, has been ignored as being a work of senility.

Yet it seems to me that Kant was directly influenced by Euler's concepts of space, time, impenetrability — in short by Euler's theory of matter. These concepts, half-distinct as they were in Euler's system, became the building blocks of that physics, on which Kant, by a further step of abstraction, constructed his metaphysics [1]. By its very formulation, and choice of words, Kant's metaphysics, as is well known, became the chief support of the hostile attitude towards all metaphysics which characterized philosophy of science until the days of Einstein.

As I wish to concentrate here on Euler's influence on Kant's theory of matter [2], I mention only briefly that Kant's theory of absolute space and his theory of time are based on Euler's. The way I read Kant it seems to me that he was impressed by Euler's complete separation between the state of rest and the state of uniform motion. It was this separation which made his absolute space more absolute than Newton's; his further abstraction of it, by elevating it into the world of the physically unattainable ideas, did not make it less real than Euler's absolute space from which it started. The influence can be detected in Kant's theory of physical time, which is simply 'a measure of the duration of things'. The Kantian conception of place is again based on Euler. The idea here is that the concept of place is not formed except by removing the body which occupied it.

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1. In Methodology there is positive progress from Euler to Kant. Euler was one of the first scientist-philosophers who became very uneasy about the Leibnizian mathematical ideal. His certainty that metaphysics is harmonious with mathematically demonstrated truths originating in a priori principles was shaken. Kant, his true disciple in this too, gave up the Leibnizian ideal totally and he was after the genuine scientific metaphysics which links our transcendental notions with the experimental data in a unique way. That methodologically Euler influenced Kant so much is easily seen when we deal with Kant's attitude towards the Berlin Academy of Sciences of which Euler was the unofficial but most important spokesman. Moreover, as we shall see below, their image of science and their view on the role of the scientist were very similar.

2. With the exception of Cassirer, most historians of science look for the scientific roots of Kant only in positive distinct science; it is small wonder that they thought they discovered these in Newton's work. The renaissance which rescued Newton's philosophy from the strait-jacket of positivism has not yet reached Euler and Kant. Kant's half-distinct ideas were made distinct by hindsight, after having been amputated from the body of a coherent system on which they had grown.

It was on this that Kant based his well-known and erroneous theory of the difference between a body and its mirror image.

As to the nature of these all-important forces, Kant went through a whole cycle of opinions. While a young man, he hesitated between the Newtonian and the Leibnizian conceptions of forces. Later, he tried to unite the two by giving a Leibnizian, metaphysical importance to the concept of force, but as its physical nature he chose the Newtonian action-at-a-distance. This is the well-known Newtonian element in the 'Metaphysical Foundations' which led into internal difficulties mainly because of Kant's opposition to ultimate atomic units of matter. Here, in the Metaphysical Foundations, which could be called the second stage in Kant's theory of matter, he accepted the Newtonian gravitational force as action-at-a-distance. But even here Kant did not reject completely the possibility of contact forces, and when he talks about these, not surprisingly it is in connection with impenetrability:

'Contact in the physical sense is the immediate action and reaction of impenetrability' [1].

Later, Kant tended to reject the Newtonian type of gravitation and adopted the Eulerian theory of contact forces. For both Euler and Kant, whatever the nature of the forces that are active in the world, it is impenetrability which, expressed through forces, makes a body capable of filling space. The empirical concept of matter, for both of them, rests on the concept of impenetrability.

Kant's Physics, Scientific Metaphysics and View of the Task of Knowledge.

Again I shall outline a theory very briefly. During his University studies, Kant became thoroughly familiar with the Leibnizian system through its Wolffian indoctrination, and under the influence of his mentor, the Professor of Physics M. Knutzen, with the works of Newton. He followed with keen interest the preoccupations and problem-choices of the Berlin Academy and having good enough mathematical training, was acquainted with the most recent works, like the *Rational Mechanics* of Euler and his contemporaries. The prize-essays of the Berlin Academy occasioned numerous works of Kant and created a lively competition between himself and his most distinguished contemporaries like Moses Mendelssohn and Jo-

1. I. Kant, M.A.D.N., op.cit.

hann Heinrich Lambert. Some of Kant's most interesting works were the three papers reacting to the Lisbon Earthquake, «The Examination of the Question whether the Earth has Undergone an Alteration of its Axial Rotation», «On the Theory of Winds», and the «Inquiry Concerning the Distinctness of the Fundamental Principles of Natural Theology and Morals», 1764, written as an essay for a Berlin Academy question in 1763 (called the «Prize Essay») and for which Mendelssohn won the prize. In this work Kant finally breaks with the Leibnizian mathematical ideal in philosophy. He actually answers the doubts raised by Euler, whether one can combine metaphysics and mathematics by separating the two and by considering metaphysics more and more as half-science which lays the foundations on which physics has to be built. Already in his earliest essay on «Living Forces» and in the «Monadologia Physica», Kant rejected the Newtonian dismissal of metaphysics and developed his own most important contribution to science and to metaphysics by initiating his search for scientific *metaphysics*.

From his first work, «Living Forces», we know that Kant was well acquinted with the whole history of the debate around the true measure of living forces and the only solution which he had missed was d'Alembert's, incidentally, the only correct solution. This work is often described as an attempt to bridge the gap between Newtonian and Leibnizian science while trying to accommodate both the Cartesian solution that the measure of vis viva is mv (not vector $\overline{mv}$) and the Leibnizian mv^2. In view of the three parallel critical dialogues mentioned above, such a formulation is meaningless; furthermore Leibniz himself had taught that vis viva can have three different kinds of effect or measure, depending on circumstances: sometimes its effect is mv, at others mgh, and again in other circumstances it is mv^2. On the other hand, Kant belonged to and did work in the intellectual framework of the Newton-Leibniz dialogue, trying to harmonize Newton's mathematical-physical formal results (which he always fully accepted) and the underlying Leibnizian scientific metaphysics of the continuum, the impossibility of action-at-a-distance and the central role of the idea of conservation which is completely missing in Newton. This view is in direct contradiction to Adickes, Vleeschauwer, and others. The idea of a fundamental principle of conservation of force — the great unifying element in Nature for which Leibniz, Euler and now Kant had been looking, penetrated Kant's physics from the first work through his last, the *Opus Posthumum*.

It was this idea which the later Kantians (the Naturphilosophen and Helmholtz) inherited. It is in this sense that the work before us is a work of reconciliation. Kant reaches a wrong conclusion because he rejects here the idea of the conservation of the vis viva. He maintains that living forces can disappear in given circumstances, be implicitly present in bodies at rest, and be recreated by bodies in rest (p. 136). This is what sounds to so many commentators as an anti-conservationist position and is often ascribed to M. Knutzen's influence. However, as it becomes apparent in later works, when Kant (under the influence of Boscovich and even more of Euler) introduced the force of impenetrability in the «Metaphysiche Anfangsgründe der Naturwissenschaft» («M.A.d.N.») and the *Op. Post* as a creative cause which in bodies at rest is the source of all motion in the world, Kant maintains a much broader principle of conservation nearer in spirit to Leibniz's intentions and identical with Euler's scientific metaphysics. (L. Euler, Anleitung zur Naturlehre), which in all probability was widely known in academic circles long before its publication. It was written around 1745. Kant was also well acquainted with Euler's «Letters to a German Princess» which repeated these views. Kant differs here from many of his elder colleagues among philosopher-scientists, in recoiling from over-mechanization; in a science in the stages of formation he allows, or even prefers, vague concepts as guides in the inquiry. The Eulerian attitude and the fundamental role of the force of impenetrability from which all science can be later reduced became the cornerstone of the *Opus Posthumum.*

The chief point of interest of this early essay is the attempt to prove that science, without any underlying metaphysics, is useless, insofar as a metaphysical theoretical foundation is necessary for understanding basic concepts like «force» before they can be scientifically treated. This was the image of science of the young Kant and of many generations of Kantians after him. The concept of force which Kant inherited from Newton was, in spite of many current formulæ in which it was embedded, too crude to give a picture of the world both describing it and explaining its history. For this, Leibniz's concept of «force» seemed more promising but this had to be developed further.

By the year 1770, Kant's thought had matured. This is felt in his style, mode of argumentation, and choice of priorities. Yet the fundamental problems developed coherently from pure physics to pure metaphysics and back. Kant claimed that the year 1769 «brought great light» and that then his recollection of Hume «interrupted his dogmatic slumber» (Prolegomena to Any Future Metaphysics, «Prolegomena», p. 9). Many interpreters see here a breaking point and the starting point of his critical period. It is often mentioned that at the time of his death, Kant's library did not include a single work of his own written work before 1770. This may be true, but it is amenable to widely different interpretations. When checking carefully, neither was his earlier work non-critical nor was Kant previously a dogmatist. Rather what happened now was that Kant chose as his methodological fulcrum the critical mode as against both the dogmatic and the sceptical attitudes. This he learned from his work in science: the only possibility for a realist not to turn into a primitive empiricist, nor to abandon realism for a dogmatic a-priorism was to apply the critical mode in order to balance the empirical evidence from a real world with the competence of human reason to form the epistemological framework in which this world is perceived. This task before him from now on was to draw the lessons from science and to establish a metaphysics which deals with the physical world and relies on a methodology which is scientific: he set out to create *a scientific metaphysics*.

An important contribution of Kant's both to physics and to philosophy was his elucidation of the relation between the Newtonian description of the physical world and the right kind of geometry in harmony with it. Had it even been true, as is so often claimed, that Kant found the only possible geometry suitable to the real world to be the Euclidean geometry, even then his contribution would be enormous; his very emphasis of this relation should have seen to that. Actually this was not his claim, as we shall see. His elucidation resulted in two different schools or world-views. The late 19th century «conventionalism» of Poincaré and his followers can be traced back to that interpretation of Kant's view according to which all fundamental theories of nature are pure man-made straight-jackets to be forced on nature. This view led to mid-20th century instrumentalism: theories serve as mere tools of prediction and have nothing to do with descriptions of reality. Whether this philosophy of science ever contributed to human knowledge is questionable. The other view, namely, the present one, of scientists who do not deny the reality of the world, yet accept inherent uncertainties in its description (the very source of the idea of complementarity) is unimaginable without Kant's elucidation.

Kant never claimed the impossibility of other geometries. Already in the *Living Forces* we find a clear statement that if Newton's empirical laws were different, space would not behave in a Euclidian way, but non-Euclidian geometries would have to be developed. It is in this sense that the transcendental criticism has indirectly influenced the development of science.

In the M.A.d.N. and even more in the opus posthumum, Kant expressed doubts in the entire intelligibility of nature and tried to trace the limit between what in science is derived from deduction and what is due to experiment. He found reality partially intelligible and tried to formulate a rule of demarcation. This again became the source of the Popperian problem of demarcation between science and metaphysics which Popper called Kant's Problem. Yet the place accorded by Kant to pure deduction seems to have been over-estimated. His many followers among the «Naturphilosophs» and their absurd mistakes (like Schelling's deductions of a theory of condensation and evaporation, or Hegel's of polarization and the nature of light) will testify to that. Finally, he started out from conservation laws and ended up in the opus posthumum with an even stronger affirmation of an underlying principle of conservation of matter and forces in Nature. The concept tying together all these ideas: conservation, impenetrability, space, time and cause, contact forces as against action-at-a-distance is the concept of the ether which fills all space in nature and many of the pages of the opus posthumum. In the M. A. d. N. Kant had started from empirical concepts and went on to establish an a priori scientific metaphysics. Now he went back in order to establish empirical detail in conformity with his metaphysics.

Kant's Influence on His and the Next Generations.

Kant died at a time when several philosophical, scientific and social movements were being formed. Most of the greatest intellectual figures of the time had been directly or indirectly his disciples. The philosophy and literature of German Romanticism was spreading rapidly, and all its chief representatives claimed Kantian parentage. They saw in him only Kant the idealist or transcendentalist. Even Goethe who resented the fact that Kant had ignored him did consider his own science (Metamorphose der Pflanze) and his philosophy as Kantian. In science, and in the scientific metaphysics of the «Naturphilosophie», Kant was the great conservationalist who elevated forces to become the action principles of matter and by their conservation a way was found to unite Nature with Man, body and mind. Kant's