Ideas of the Natural Philosophy of Ancient Times in Modern Physics[1]

Modern science has followed many trends of early Greek natural philosophy by reconsidering the problems with which that philosophy had grappled in a first attempt to understand the surrounding world. Hence it may be well worth considering which of those early ideas have retained their creative power in modern physics, and what shape they have acquired by absorbing the scientific experiences of the intervening two thousand years. There are, especially, two ideas of early Greek philosophy which today still determine the course of science, and which are therefore of special interest to us: the conviction that matter consists of minute indivisible units, the atoms, and the belief in the purposely directive power of mathematical structures.

The thesis of the existence of atoms was the natural consequence of the development of the concept of matter, the classification of which was the first endeavour of ancient natural philosophy. The conviction that, in the transience of phenomena, there must be something permanent which is subjected to change, led to the teaching of the existence of some 'fundamental matter'. For Thales, this fundamental substance was simply water, on which all life appeared to depend. His successors defined this concept more accurately and attributed to it the characteristics of entity (Einheitlichkeit) and indestructibility. Thus, to make intelligible the variety of phenomena, several kinds of 'fundamental matter' had later to be postulated whose mixture and separation is the cause of the manifold changes of events, unless of course these permanent elements were to be something beyond the material world. Thus Earth, Fire, Air and Water appeared to be the natural elements of which the world was constructed. To make these ideas into a real explanation of phenomena, the process of mixing had to be clearly described. It seemed obvious to interpret the mixing of two liquids essentially like that of a mixture of water and sand, and to assume that the smallest particle of the liquid would retain its initial qualities unchanged and that these particles are present in the

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mixture in a random distribution. Thus originated, as if of its own accord, the idea of the smallest indivisible unit of matter and in the teachings of Leucippus and Democritus the 'atoms' appeared as the real carriers of material and spiritual evolution.

According to this view, the atoms differed no longer through their inherent qualities, but only through shape, position and movement. The protagonists of these 'atomic' ideas believed that such geometrical properties would suffice to explain all the diversity of natural phenomena. The atoms were the essential reality, between them was 'nothing', empty space. Larger composite bodies were formed by the compounding of like atoms, and their properties in turn were determined by the type of arrangement. The atoms themselves were eternal and indestructible. We shall now compare modern atomic theory with the corresponding ideas of antiquity, based on the principles I have outlined.

Modern atomic theory, too, assumes indivisible elementary particles of matter called 'electrons, neutrons and protons', and it, too, endeavours to trace back all perceptible qualities of substances to the dynamics of the atoms. However, the necessity of explaining the most delicately executed experiments to the last detail, has made it obvious that there was in ancient atomic theory a peculiar contradiction, an inner inconsistency. The basic idea of atomic theory had to be carried to its logical conclusion. Democritus's atomic theory, on the one hand, realizes that it is impossible to explain rationally the perceptible qualities of matter except by tracing these back to the behaviour of entities who themselves no longer possess these qualities. If atoms are really to explain the origin of colour and smell of visible material bodies, then they cannot possess properties like colour and smell. Thus ancient atomic theory consistently denies the atom any such perceptible qualities. On the other hand they are left with the quality of taking up space so that one may speak of position, arrangement and size of atoms. Democritus, here, patently goes beyond the opinion of his predecessors. The fundamental concept of previous philosophy, that of *being* (*Seiend*) and *non-being* (*Nichtseiend*) he brings down to earth by making it *full* and *empty*. To him, empty space is a reasonable (*sinnvoll*) concept. He thus creates the possibility of explaining the different perceptible qualities of substances by means of variable arrangements of atoms in space. But, at the same time, he has to give up the idea of linking space and time with the existence of matter, to *explain* space and time. The old and great idea that space and time are, so to speak, stretched out by matter and in essence akin to it, has no room in Democritus's teachings.

Modern atomic theory shares *this* fundamental thought with ancient counterpart: It tries to explain the qualitative variety of external physical events by relating it to a variety of forms, which can be surveyed and analysed. Of such forms the Greek philosophers had at their disposal only the geometrical configurations, and hence ancient atomic theory explained qualities by varying groupings of the atoms in space. The preference for one particular perceptible quality – the taking up of space as a quality of atoms – does however seem to show a lack of consistency, and it is obvious that modern theory will have to differ fundamentally at this point. The indivisible elementary particle of modern physics possesses the quality of taking up space in no higher measure than other properties, say colour and strength of material. In its essence, it is not a material particle in space and time but, in a way, only a symbol on whose introduction the laws of nature assume an especially simple form. Modern atomic theory is thus essentially different from that of antiquity in that it no longer allows any reinterpretation or elaboration to make it fit into a naive materialistic concept of the universe. For atoms are no longer material bodies in the proper sense of the word, and we are probably justified in claiming that in this respect modern theory embodies the principal and basic idea of atomic theory in a purer form than did ancient theory. Without going into detail it is naturally difficult to convey a picture of the place the atom occupies in modern science, and of the mathematical forms whose variety present us with a picture, faithful to the last detail, of the diversity of phenomena. A parallel may, perhaps, illuminate the symbolic character of the present-day concept of the atom. The atom of modern physics shows a distant formal similarity to the $\sqrt{-1}$ in mathematics. Though elementary mathematics maintains that among the ordinary numbers no such square root exists, yet the most important mathematical propositions only achieve their simplest form on the introduction of this square root as a new symbol. Its justification thus rests in the propositions themselves. In a similar way the experiences of present-day physics show us that atoms do not exist as simple material objects. However, only the introduction of the concept 'atom' makes possible a simple formulation of the laws governing all physical and chemical processes.

The abstract nature of the modern concept 'atom', and those mathematical forms which, in modern theory, serve to express the imagery for the variety of atomic phenomena, do already lead us to the second fundamental principle which our science has taken over from antiquity; that is the idea of a purposeful and directive force inherent in mathematical formulations.

We meet this idea, stated clearly for the first time, in the teachings of the school of Pythagoras, expressed by their discovery of the mathematical conditions of harmony. In investigating the vibrations of strings, they found that the condition for two strings to sound in harmony (all other properties being equal) was that their length must be in simple ratio. This means that a totality of sound appears to the human ear to be in harmony only if certain simple mathematical relations are realized, though the listener may not be conscious of this. This discovery represents one of the strongest impulses of human science, and its effects, in nature as well as in art, can constantly be seen, once the creative force of mathematical order has been appreciated. I would mention the kaleidoscope as a specially simple and obvious example. Here, something beautiful and orderly arises from a random picture, through simple mathematical symmetry. More valuable and important examples can be found in an analysis of any work of art or, in nature, in the study of crystals. If the essence of a musical harmony or a form of fine art can be discovered in its mathematical structure, then the rational order of surrounding nature must have its basis in the mathematical nucleus of the laws of nature. Such a conviction found its first expression in the Pythagorean teaching of spherical harmony, in the attribution of regular shapes to the elements. Thus in *Timaeus* Plato explains the atoms of earth, fire and water as cube, tetrahedron, octahedron and icosahedron respectively. But in the last resort the whole of mathematical natural science is based on such a conviction.

Modern science has thus accepted from antiquity the idea of a pattern capable of mathematical description, but it carries it out in a different manner, rigorous and, we believe, determined for all time. The realm of mathematical forms at the disposal of ancient science was still comparatively limited. They were primarily geometrical forms which were related to natural phenomena. Hence Greek science searched for static patterns and relationships. The subjects of its investigations were the unchangeable orbits of the stars, or the forms of the everlasting and indestructable atom. However, the laws that could be derived from those assumptions could not accommodate the experiences of later centuries based on the use of more delicate apparatus. Modern science has demonstrated that in the real world surrounding us, it is not the geometric forms but the dynamic laws governing movement (coming into being and passing away) which are permanent. Even Kepler thought he had found in the orbits of the stars the harmonies of Pythagoras's school. Science since Newton has attempted to see them in the mathematical structure of the law of dynamics, and in the equation of formulating this law.

This change does represent a consistent execution of the programme of the Pythagoreans inasmuch as the infinite variety of natural events finds here its faithful mathematical replica in the infinite number of solutions to an equation. Newton's differential equation of mechanics serves as a good example. The demand that there should arise from the one natural law, already formulated, an infinite variety of phenomena accessible to experimental investigation, does at the same time provide the guarantee for the correct formulation of the law, which is then valid for all time. An equation formulating such a law expresses in the first instance only the simplest physical circumstances: it defines the dynamic concepts necessary for an understanding of the natural phenomena concerned. Beyond that, it contains some general expressions about the world of our experiences, like the fact that in empty space direction and position cannot be defined. Yet it encompasses, as a possible development, an infinite variety of phenomena, just as a fugue of many parts can be developed from the few notes of a musical theme. Thus, while ancient philosophy attributed regular shapes to the atoms of elements, a mathematic equation must belong to the elementary particle of modern physics. This equation formulates the natural law governing the structure of matter. It embraces the progress of, say, a chemical reaction, as well as the regular shapes of crystals or the pitch of a vibrating string. It develops logically, from the accidental initial conditions, the physical phenomena of the surrounding world, like a kaleidoscope which creates an ingenious pattern from an accidental conglomeration of coloured glass.

The successes of this method have confirmed the beliefs of the Pythagoreans to an unforeseen extent. It has partly resulted in a real mastery over the forces of nature, and thus decisively intervened in the development of mankind. Hence modern science has retained confidence in a simple mathematical basis for all regular interrelations of nature, even of those which we cannot as yet grasp. Mathematical simplicity ranks as the highest heuristic principle in exploring the natural laws in any field opened up as a result of new experiments. In such a case the inner relations seem to be understood only when the determining laws have been formulated in a simple mathematical way.

This search for the mathematical structure of phenomena, as taken over from antiquity has, however, given rise to an accusation. It is said that it illuminates only certain and, at that, not the most essential aspects of nature and, rather than being of help in an immediate and general understanding of nature, it is actually a hindrance. This complaint can best be answered by drawing attention to the starting point of Pythagoras's teachings. It is the conscious understanding of the rational numerical relations underlying musical harmonies which make possible both the construction and use in performance of a musical instrument. It is, however, in the unconscious mental acceptance of these rational relations that we can grasp the real content of music. Similarly, the precondition for an active, practical intervention in the material world, is just this conscious knowledge of mathematically formulated natural laws. Behind this, however, there is a direct understanding of nature unconsciously accepting these mathematical structures and mentally recreating them. All human beings are capable of this understanding if they are willing to enter into a more intimate receptive relation with nature.

Information and Announcements

Planetary Exploration Programme

Physical Research Laboratory, Ahmedabad 380 009

Fifth Workshop on Moon & Meteorites

November 5 – 10, 2004

With the aim of creating awareness amongst scientists, particularly in universities and national laboratories and attract bright talented students to take up research work in the challenging area of Planetary Science/Exploration, the PLANEX programme of ISRO has been organizing periodic workshops and training programmes. The main features of this workshop are listed below:

The workshop will consist of lectures by experts, group discussion and laboratory visits.

Three or four bright participants will be selected for further intensive training in specialized fields related to the thrust areas in Planetary Sciences.

Post-doctoral Fellows, Research Scholars working towards their Ph.D. Degree and final year M.Sc. students in Physics, Chemistry and Earth Sciences may apply. Selected participants (about 30) will be provided travel support, accommodation and boarding for the duration of the workshop.

Interested scientists/students may write or send e-mail to the following address before **15 September 2004**, enclosing a brief bio-data, research interests (in ~ 200 words) and a reference letter from Department Head/Research Supervisor.

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