The Tao of Physics
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Modern physics has had a profound influence on general philosophical thought because it has revealed a surprising limitation of classical ideas and has led to a profound revision of many of our basic concepts about reality. Concepts like matter, object, space, time, cause and effect, etc., are totally different in atomic and subatomic physics from the corresponding classical ideas and with their radical transformation our whole world view has begun to change. Out of these changes, a new world view is now emerging which turns out to be closely related to the views of mystics; especially to those of the mystical traditions of the Far East (Hinduism, Buddhism, Taoism). The dramatic changes in the philosophy of physics will necessarily affect the other sciences, both the natural sciences and the humanities and social sciences, because all these sciences have modelled themselves after physics. To be more precise, they have taken the classical, Newtonian physics as their model, and now that physicists have gone far beyond the Newtonian model it will be time for the other sciences to become aware of this development and to expand their underlying philosophies.

In this paper, I would like to give you an overview over the parallels between the fundamental concepts of modern physics and the basic ideas in the religious philosophies of the Far East.

The Mechanistic Newtonian View.

To begin with, let me briefly describe the world view which was changed by the discoveries of modern physics. This view had been a mechanistic view of the world. It had its roots in the philosophy of the Greek atomists who saw matter as being made of several “basic building blocks”, the atoms, which are purely passive and intrinsically dead. They were thought to be moved by some external force which was often assumed to be of spiritual origin, and thus fundamentally different from matter. This image became an essential part of the Eastern way of thinking. It gave rise to the dualism between spirit and matter, between the mind and the body, which is characteristic of Western thought. This dualism was formulated in its sharpest form in the philosophy of Descartes who based his view of nature on the fundamental division between spirit and matter, between the I and the world. The “Cartesian” division allowed scientists to treat matter as dead and completely separate from themselves, and to see the material world as a mu1titude of different objects assembled into a huge machine. Such a mechanistic world view was held by Newton who constructed his mechanics on its basis and made it the foundation of classical physics. From the second half of the seventeenth century to the end of the nineteenth, the mechanistic Newtonian model of the universe dominated all scientific thought.

The Eastern View

In contrast to the mechanistic view, the Eastern view of the world is an "organic" one. For the Eastern mystic, all things and phenomena we perceive with our senses are interrelated, are connected, and are but different aspects or manifestations of the same ultimate reality. Our tendency to divide the perceived world into individual and separate things and to experience ourselves as isolated egos in this world is seen as an illusion which comes from our measuring and categorising mentality. The division of nature into separate objects is, of course, useful and necessary to cope with our everyday environment, but it is not a fundamental feature of reality. For the Eastern mystic, any such objects have therefore a fluid and ever changing character. The Eastern world view is always a dynamic world view which contains time and change as essential features. The cosmos is seen as one inseparable reality which is forever in motion, alive, organic, spiritual and material at the same time. I shall now try to show how the main features of this picture appear in modern physics.

Atomic Physics

At the beginning of our century, the experimental investigation of atoms gave sensational and totally unexpected results. Far from being the hard and solid particles they were believed to be since antiquity, the atoms turned out to consist of vast regions of empty space in which extremely small particles the electrons, moved around the nucleus. When quantum theory, the theoretical foundation of atomic physics, was worked out in the 1920's, it became clear that even the subatomic particles, i.e. the electrons and the protons and neutrons in the nucleus, were nothing like the solid objects of classical physics. The subatomic units of matter are very abstract entities. Depending on how we look at them, they appear sometimes as particles, sometimes as waves. This dual aspect of matter was extremely puzzling. The picture of a wave which is always spread out in space is fundamentally different from the particle picture which implies a sharp location.

The apparent contradiction between the two pictures was finally solved in a completely unexpected way which gave a blow to the very foundation of the mechanistic world view, to the concept of the reality of matter. At the subatomic level, matter does not exist with certainty at definite places, but rather shows "tendencies to exist". These tendencies are expressed, in quantum theory, as probabilities and the corresponding mathematical quantities take the form of waves. This is why particles can be waves at the same time. They are not "real' three dimensional waves like sound or water waves. They are "probability waves", abstract mathematical quantities with all the characteristic properties of waves which are related to the probabilities of finding the particles at particular points in space and at particular times.

It is important to realise that the statistical formulation of the laws of atomic and subatomic physics does not reflect our ignorance of the physical situation, like the use of probabilities by insurance companies or gamblers. In quantum

theory, we have come to recognise probability as a fundamental feature of the atomic reality which governs all atomic and subatomic phenomena.

This fundamental role of probability implies a new notion of causality. In quantum theory, individual events do not have a well defined cause. For example, the jump of an electron from one atomic orbit to the other, or the disintegration of a subatomic particle, will occur spontaneously without any single event causing it. We can only predict the probability for the event to happen. This does not mean that atomic events occur in completely arbitrary fashion; they are governed by statistical laws. The narrow classical notion of causality is thus replaced by the wider concept of statistical causality in which the probabilities for atomic events are determined by the dynamics of the whole system.

The Cosmic Web

At the atomic level, then, the solid material objects of classical physics dissolve into wave like patterns of probabilities. These patterns, furthermore, do not represent probabilities of things, but rather probabilities of interconnections. A careful analysis of the process of observation in atomic physics shows that the subatomic particles have no meaning as isolated entities, but can only be understood as interconnections between the preparation of an experiment and the subsequent measurement. Subatomic particles are not “things” but interconnections between things and these “things” are interconnections between other things, and so on. In atomic physics, you never end up with any “things” at all; you always end up with interconnections. This is how quantum theory reveals a basic oneness of the universe. It shows that we cannot decompose the world into independently existing smallest units. As we penetrate into matter, nature does not show us any isolated basic building blocks, but rather appears as a complicated web of relations between the various parts of a unified whole. In the words of Werner Heisenberg:

“The world thus appears as a complicated tissue of events, in which connections of different kinds alternate or overlap or combine and thereby determine the texture of the whole.”

This, however, is the way in which the Eastern mystics experience the world, and they often express their experience in words which are almost identical to the words used by atomic physicists. Take, for example, the following quotation from a Tibetan Buddhist, Lama Govinda:

“The external world and his inner world are for (the Buddhist) only two sides of the same fabric, in which the threads of all forces and of all events, of all forms of consciousness and of their objects, are woven into an inseparable net of endless, mutually conditioned relations.”

These words by Lama Govinda bring out another feature which is of fundamental importance both in modern physics and in Eastern mysticism. The universal interconnectedness of nature always includes the human

observer and his or her consciousness in an essential way. In quantum theory, the observed “objects” can only be understood in terms of the interaction between the processes of preparation and measurement, and the end of this chain of processes lies always in the consciousness of the human observer. The crucial feature of quantum theory is that the human observer is not only necessary to observe the properties of an object, but is necessary even to bring about these properties. My conscious decision about how to observe, say, an electron; whether I decide to use my apparatus in one way or another will determine the electron’s properties to some extent. In other words, the electron does not have objective properties independent of my mind. In atomic physics, the sharp Cartesian split between mind and matter, between the “I” and the world, is no longer valid. We can never speak about nature without, at the same time, speaking about ourselves. In the words of Heisenberg:

“Natural science does not simply describe and explain nature it is a part of the interplay between nature and ourselves”.

In modern physics, then, the scientist cannot play the role of a detached observer, but gets involved in the world he or she observes. John Wheeler sees this involvement of the observer as the most important feature of quantum theory, and he has therefore suggested to replace the word “observer” by the word “participator”, But this, again, is an idea which is well known to any student of a mystical tradition. Mystica1 knowledge can never be obtained just by observation, but only by full participation with one’s whole being. The notion of the participator is thus basic to the mystical traditions of the Far East.

The Restlessness of Matter

The fact that matter, at the atomic level, appears as particles and as wave patterns implies not only an essential interconnectedness of all phenomena, but also a very peculiar behaviour pattern of subatomic particles. Whenever they are confined to some region in space, they react to this confinement by moving around. The smaller the region of confinement, the faster the particle “jiggles” around in it. This implies, however, that atomic and subatomic matter is fundamentally “restless”. Most of the material particles are confined by the molecular, atomic, and nuclear structures, and therefore they are never completely at rest. According to quantum theory, matter is never quiescent, but always in a state of motion. The closer we look at it, the more alive it appears: the molecules vibrating according to their temperature and in harmony with the thermal vibrations of their environment. The electrons whirl around in the atoms and in the nuclei the protons and neutrons race about with fantastic velocities. Modern physics thus pictures matter not at all as inert, but as being in a continuous dancing and vibrating motion whose rhythmic patterns are determined by the molecular, atomic, and nuclear structures. How much this picture is in the spirit of Eastern thought is best shown by the following quotation from a Taoist text :

“The stillness in stillness is not the real stillness. Only when there is stillness in movement can the spiritual rhythm appear which pervades heaven and earth”.

For the Taoists, the real stillness is stillness in movement or to put it less poetically, the basic equilibrium in nature is not static, but is a dynamic equilibrium and this is exactly the message we get from quantum theory. In the nucleus, the velocities of the protons and neutrons are often so high that they come close to the speed of light. This fact is crucial for the description of nuclear phenomena because any description of natural phenomena involving such high velocities has to take Einstein’s relativity theory into account. It has to be, as we say, a “relativistic” description. This brings me now to the second basic theory of modern physics, relativity theory.

Relativity theory

As you probably know, relativity theory has brought about a drastic change in our concepts of space and time. It showed us that space is not three dimensional and that time is not a separate entity. Both are intimately connected and form a four dimensional continuum called “space time”. In relativity theory, therefore, we can never talk about space without talking about time, and we can never talk about time without talking also about space. We have now been living with relativity theory for a long time, and we have become thoroughly familiar with its mathematical formalism. But this has not helped our intuition very much. We have no direct sensory experience of the four dimensional space time, and whenever this relativistic reality manifests itself — i.e. in all situations where high velocities are involved we find it very hard to deal with it at the level of intuition and ordinary language.

A similar situation seems to exist in Eastern mysticism. The mystics seem to be able to attain non-ordinary states of consciousness in which they transcend the three dimensional world of everyday life to experience a higher, multidimensional reality; a reality which, like that of relativity theory, is impossible to describe in ordinary language. Lama Govinda talks about this experience when he writes:

“An experience of higher dimensionality is achieved by integration of experiences of different centres and levels of consciousness. Hence the indescribability of certain experiences of meditation on the plane of three dimensional consciousness.

The dimensions of these states of consciousness may not be the same as the ones we are dealing with in relativity theory, but it is striking that they have led the mystics towards notions of space and time which are very similar to those implied by relativity theory. Throughout Eastern mysticism, there seems to be a strong intuition for the “space - time” character of reality. The fact that space and time are inseparably linked, which is so characteristic of relativistic physics, is stressed again and again. The Buddhist scholar D.T. Suzuki, for example, writes :

“As a fact of pure experience, there is no space without time, no time without space.”

In physics, the concepts of space and time are so basic for the description of natural phenomena that their modification entails a modification of the whole framework we use to describe nature. The most important consequence of this modification is the realisation that mass is nothing but a form of energy. Even an object at rest has energy stored in its mass, and the relation between the two is given by Einstein’s famous equation $E=mc^2$

These developments the unification of space and time and the equivalence of mass and energy have had a profound influence on our picture of matter and have forced us to modify our concept of a particle in an essential way. In modern physics, mass is no longer associated with a material substance, and hence particles are not seen as consisting of any basic “stuff”, but as bundles of energy. Energy, however, is associated with activity, with processes, and this implies that the nature of subatomic particles is intrinsically dynamic.

To understand this better, we must remember that these particles can only be pictured within the framework of relativity theory where space and time are fused into a four dimensional continuum. In such a framework, the particles can no longer be pictured as static three dimensional objects, like billiard balls or grains of sand, but must be conceived as four dimensional entities in space and time. Their forms have to be understood dynamically, as forms in space and time. Subatomic particles are dynamic patterns which have a space aspect and a time aspect. Their space aspect makes them appear as objects with a certain mass, their time aspect as processes involving the equivalent energy. Relativity theory thus gives the constituents of matter an intrinsically dynamic aspect. The particles of the subatomic world are not only active by moving around very fast; they themselves are processes; the being of matter and its activity cannot be separated. They are but different aspects of the same space time reality.

The Eastern mystics have developed ways of experiencing the “space time” character of reality intuitively. Thus most of their concepts, images and myths contain time and change as essential elements. The “maya” doctrine in Hinduism, for example, sees all forms in the world as fluid and ever changing, and the same idea is found in ancient Chinese philosophy. The Chinese saw flow and change as the very essence of the universe. The notion of absolute rest was practically absent from their philosophy and all things were seen as being merely stages in one big cosmic process which they called the Tao. These are the ideas lying at the basjs of the I Ching - one of the foundations of Chinese thought, the title of which, characteristically, means the “Book of Changes”.

Buddhists, too, are well aware of the dynamic character of matter. D.T. Suzuki writes in one of his books on Buddhism:

“Buddhists have conceived an object as an event and not as a thing or substance.”

The two basic theories of modern physics thus exhibit all the main features of the Eastern world view. Quantum theory has abolished the notion of fundamentally separated objects, has introduced the concept of the participator to replace that of the observer, and has come to see the universe as an interconnected web of relations whose parts are only defined through their connections to the whole. Relativity theory, so to speak, has made the cosmic web come alive by revealing its intrinsically dynamic character: by showing that its activity is the very essence of its being.

Current research in physics aims at unifying quantum theory and relativity theory into a complete theory of the subatomic world. We have not yet been able to formulate such a complete theory, but we do have several partial theories, or "models", which describe certain aspects of subatomic phenomena very well. In the remaining part of my article, I shall now concentrate on one of these models, called the "bootstrap model", which is perhaps the most ambitious of them all and which shows, as you will see, the most striking parallels to Eastern thought.

The bootstrap idea

The basis of the bootstrap model is the idea that nature cannot be reduced to fundamental entities, like fundamental building blocks of matter, but has to be understood entirely through self-consistency. All of physics has to follow uniquely from the requirement that its components be consistent with one another and with themselves. This idea constitutes a radical departure from the traditional spirit of basic research in physics which had always been bent on finding the fundamental constituents of matter. At the same time, it is the culmination of the conception of particles as an interconnected web of relations. The bootstrap philosophy abandons not only the idea of fundamental building blocks of matter, but accepts no fundamental entities whatsoever, no fundamental laws, equations, or principles.

The universe is seen as a dynamic web of interrelated events. None of the properties of any part of this web are fundamental they all follow from the properties of the other parts, and the overall consistency of their mutual interrelations determines the structure of the entire web. We see immediately that this idea is very much in the spirit of Eastern thought which regards all forms in the universe as fluid and ever changing and has no room for any fixed fundamental quantity. We might also say that the principle of self-consistency which forms the basis of the bootstrap model, and the unity and interrelation of all phenomena which is so strongly emphasised in Eastern mysticism are just different ways of expressing the same idea. This becomes particularly clear in Chinese philosophy.

Joseph Needham has pointed out in his thorough study of Chinese science and civilisation, that the Chinese never had the idea of fundamental laws of nature. The term which comes closest to our "law of nature" in Chinese is Li which Needham translates as "dynamic pattern". He says that, in the Chinese view,

“The cosmic organisation is, in fact, a Great Pattern in which all lesser patterns are included, and the ‘laws’ which are involved in it are intrinsic to these patterns.”

This is exactly the idea of the bootstrap philosophy: everything in the universe is connected to everything else and no part of it is fundamental. The properties of any part are determined, not by some fundamental law, but by the properties of all the other parts. Therefore, in order to really understand any phenomenon, we have to understand all the others. This is obviously impossible, and here physicists and mystics take different attitudes.

Physicists are satisfied with an approximate understanding of nature. They try to describe selected groups of phenomena in an approximate way, neglecting other phenomena which are considered less relevant. In this way, they are able to explain many phenomena in terms of a few and thus to understand different aspects of nature in an approximate way without having to understand everything at once. This is the scientific method. The notion that all scientific theories and models are approximations to the true nature of things is basic to modern scientific research.

The Eastern mystics, on the other hand, are not interested in approximate knowledge, which Buddhists call “relative knowledge”. They are concerned with absolute knowledge involving an understanding of the totality of life. Being well aware of the unity and interconnectedness of the universe, they realise that to explain something means, ultimately, to show how it is connected to everything else. This is, of course, impossible and the Eastern mystics insist therefore that no single phenomenon can be explained. For this reason, they are generally not interested in explaining things, but rather in the direct mystical experience of the unity of all things.

The Hadron Bootstrap

What, then, is the picture of particles in the bootstrap model? Well, it can be summed up in the provocative phrase: every particle consists of all other particles. Let me, now give you a more detailed description of the picture.

Like all other scientific models, the bootstrap model can only be approximate, and its main approximation consists in the fact that it describes only a certain kind of subatomic particles, the so-called “hadrons” or “strongly interacting particles”. These are particles like the proton and the neutron which interact through the strong nuclear force. In the bootstrap model all hadrons are composite structures whose components are again hadrons. The essential feature of the model is the picture of the binding forces holding these structures together. The forces between the constituent particles are pictured as the exchange of other particles. This is a general feature of subatomic physics: the forces between particles i.e. their mutual attraction or repulsion manifest themselves as the exchange of other particles. This concept is extremely hard to visualise. It is a consequence of the four dimensional space - time character of the subatomic world and neither our intuition nor our language can deal with this image very well. But it is crucial for the picture of

particles in the bootstrap model. The constituents which make up, for example, a proton are particles; but the forces which hold them together are also particles, and therefore the distinction between the constituent particles and the particles representing the binding forces becomes blurred. The whole notion of an object consisting of constituent parts breaks down.

In the hadron bootstrap, then, all hadrons are composite structures whose components are again hadrons. The binding forces holding these structures together manifest themselves through the exchange of particles, and these exchanged particles are again hadrons. Each hadron plays therefore three roles: it is a composite structure, it may be a constituent of another hadron, and it may be exchanged between constituents and thus contribute to the forces holding the structure together. Each particle thus helps to generate other particles which, in turn, generate it. The whole set of hadrons generates itself in this way, or "pulls itself up by its own bootstraps", which is the origin of the model's name.

You will realise that this concept of every particle containing all other particles is extremely hard to visualise. This is because it arises in the four dimensional framework of relativity theory. The hadrons are dynamic "space - time" patterns which do not "contain" one another, but rather "involve" one another in a certain way which can be given a precise mathematical meaning, but cannot easily be expressed in words.

Given our difficulties in visualising this model, it is fascinating to see that the idea of each particle containing all the others has also arisen in Eastern mysticism. It is to be found in Mahayana Buddhism where it is known as "interpenetration". In the words of DT Suzuki:

"When the one is set against all the others, the one is seen as pervading them all and at the same time embracing them all in itself."

This concept is illustrated in Buddhist texts by many parables. Here is one of them which uses the image of a network of pearls to illustrate the idea of the interconnected web:

"In the heaven of Indra, there is said to be a network of pearls, so arranged that if you look at one you see all the others reflected in it. In the same way each object in the world is not merely itself but involves every other object and in fact is everything else."

The similarity of this image with that of the hadron bootstrap is indeed striking. The metaphor of Indra's net may justly be called the first bootstrap model, created by the Eastern sages some 2,500 years before the beginning of particle physics.

The bootstrap idea of an interconnected web of relations, in which particles are dynamically composed of one another, represents the culmination of a view of nature that arose in quantum theory with the realisation of an essential interconnectedness, and was further shaped by relativity theory when it was

recognised that the cosmic web is intrinsically dynamic; that its activity is the very essence of its being. At the same time, this view of nature came ever closer to the Eastern world view and is now, with the bootstrap, in harmony with Eastern mysticism both in its general philosophy and in its specific picture of matter.