THE TAO OF PHYSICS

An Exploration of the Parallels Between Modern Physics and Eastern Mysticism

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Any path is only a path, and there is no affront, to oneself or to others, in dropping it if that is what your heart tells you ... Look at every path closely and deliberately. Try it as many times as you think necessary. Then ask yourself, and yourself alone, one question ... Does this path have a heart? If it does, the path is good; if it doesn't it is of no use.

Carlos Castaneda, The Teachings of Don Juan

1 MODERN PHYSICS
A Path with a Heart?

Modern physics has had a profound influence on almost all aspects of human society. It has become the basis of natural science, and the combination of natural and technical science has fundamentally changed the conditions of life on our earth, both in beneficial and detrimental ways. Today, there is hardly an industry that does not make use of the results of atomic physics, and the influence these have had on the political structure of the world through their application to atomic weaponry is well known. However, the influence of modern physics goes beyond technology. It extends to the realm of thought and culture where it has led to a deep revision in our conception of the universe and of our relation to it. The exploration of the atomic and subatomic world in the twentieth century has revealed an unsuspected limitation of classical ideas, and has necessitated a radical revision of many of our basic concepts. The concept of matter in subatomic physics, for example, is totally different from the traditional idea of a material substance in classical physics. The same is true for concepts like space, time, or cause and effect. These concepts, however, are fundamental to our outlook on the world around us and with their radical transformation our whole world view has begun to change.

These changes, brought about by modern physics, have been widely discussed by physicists and by philosphers over the past decades, but very seldom has it been realized that they all seem to lead in the same direction, towards a view of the world which is very similar to the views held in Eastern mysticism. The concepts of modern physics often show surprising parallels to the ideas expressed in the religious philo-

sophies of the Far East. Although these parallels have not, as yet, been discussed extensively, they have been noticed by some of the great physicists of our century when they came in contact with Far Eastern culture during their lecture tours to India, China and Japan. The following three quotations serve as examples:

> The general notions about human understanding ... which are illustrated by discoveries in atomic physics are not in the nature of things wholly unfamiliar, wholly unheard of, or new. Even in our own culture they have a history, and in Buddhist and Hindu thought a more considerable and central place. What we shall find is an exemplification, an encouragement, and a refinement of old wisdom.[1]
>
> *Julius Robert Oppenheimer*

> For a parallel to the lesson of atomic theory ... [we must turn] to those kinds of epistemological problems with which already thinkers like the Buddha and Lao Tzu have been confronted, when trying to harmonize our position as spectators and actors in the great drama of existence.[2]
>
> *Niels Bohr*

> The great scientific contribution in theoretical physics that has come from Japan since the last war may be an indication of a certain relationship between philosophical ideas in the tradition of the Far East and the philosophical substance of quantum theory.[3]
>
> *Werner Heisenberg*

The purpose of this book is to explore this relationship between the concepts of modern physics and the basic ideas in the philosophical and religious traditions of the Far East. We shall see how the two foundations of twentieth-century physics—quantum theory and relativity theory—both force us to see the world very much in the way a Hindu, Buddhist or Taoist sees it, and how this similarity strengthens when we look at the recent attempts to combine these two theories in order to describe the phenomena of the submicroscopic world: the properties and interactions of the subatomic particles of which all matter is made. Here the parallels between modern physics and Eastern mysticism are most striking, and we shall often encounter statements where it is almost impossible to say whether they have been made by physicists or by Eastern mystics.

When I refer to 'Eastern mysticism', I mean the religious philosophies of Hinduism, Buddhism and Taoism. Although these comprise a vast number of subtly interwoven spiritual disciplines and philosophical systems, the basic features of their world view are the same. This view is not limited to the East, but can be found to some degree in all mystically oriented philosophies. The argument of this book could therefore be phrased more generally, by saying that modern physics leads us to a view of the world which is very similar to the views held by mystics of all ages and traditions. Mystical traditions are present in all religions, and mystical elements can be found in many schools of Western philosophy. The parallels to modern physics appear not only in the *Vedas* of Hinduism, in the *I Ching*, or in the Buddhist *sutras*, but also in the fragments of Heraclitus, in the Sufism of Ibn Arabi, or in the teachings of the Yaqui sorcerer Don Juan. The difference between Eastern and Western mysticism is that mystical schools have always played a marginal role in the West, whereas they constitute the mainstream of Eastern philosophical and religious thought. I shall therefore, for the sake of simplicity, talk about the 'Eastern world view' and shall only occasionally mention other sources of mystical thought.

If physics leads us today to a world view which is essentially mystical, it returns, in a way, to its beginning, 2,500 years ago. It is interesting to follow the evolution of Western science along its spiral path, starting from the mystical philosophies of the early Greeks, rising and unfolding in an impressive development of intellectual thought that increasingly turned away from its mystical origins to develop a world view which is in sharp contrast to that of the Far East. In its most recent stages, Western science is finally overcoming this view and coming back to those of the early Greek and the Eastern philosophies. This time, however, it is not only based on intuition, but also on experiments of great precision and sophistication, and on a rigorous and consistent mathematical formalism.

The roots of physics, as of all Western science, are to be found in the first period of Greek philosophy in the sixth century B.C., in a culture where science, philosophy and religion were not separated. The sages of the Milesian school in Ionia were not concerned with such distinctions. Their aim was to discover the essential nature, or real constitution, of things which they called 'physis'. The term 'physics' is derived from this Greek word and meant therefore, originally, the endeavour of seeing the essential nature of all things.

This, of course, is also the central aim of all mystics, and the philosophy of the Milesian school did indeed have a strong mystical flavour. The Milesians were called 'hylozoists', or 'those who think matter is alive', by the later Greeks, because they saw no distinction between animate and inanimate, spirit and matter. In fact, they did not even have a word for matter, since they saw all forms of existence as manifestations of the 'physis', endowed with life and spirituality. Thus Thales declared all things to be full of gods and Anaximander saw the universe as a kind of organism which was supported by 'pneuma', the cosmic breath, in the same way as the human body is supported by air.

The monistic and organic view of the Milesians was very close to that of ancient Indian and Chinese philosophy, and the parallels to Eastern thought are even stronger in the philosophy of Heraclitus of Ephesus. Heraclitus believed in a world of perpetual change, of eternal 'Becoming'. For him, all static Being was based on deception and his universal principle was fire, a symbol for the continuous flow and change of all things. Heraclitus taught that all changes in the world arise from the dynamic and cyclic interplay of opposites and he saw any pair of opposites as a unity. This unity, which contains and transcends all opposing forces, he called the Logos.

The split of this unity began with the Eleatic school, which assumed a Divine Principle standing above all gods and men. This principle was first identified with the unity of the universe, but was later seen as an intelligent and personal God who stands above the world and directs it. Thus began a trend of thought which led, ultimately, to the separation of spirit and matter and to a dualism which became characteristic of Western philosophy.

A drastic step in this direction was taken by Parmenides of Elea who was in strong opposition to Heraclitus. He called his basic principle the Being and held that it was unique and invariable. He considered change to be impossible and regarded the changes we seem to perceive in the world as mere illusions of the senses. The concept of an indestructible substance as the subject of varying properties grew out of this philosophy and became one of the fundamental concepts of Western thought.

In the fifth century B.C., the Greek philosophers tried to overcome the sharp contrast between the views of Parmenides and Heraclitus. In order to reconcile the idea of unchangeable Being (of Parmenides) with that of eternal Becoming (of Heraclitus), they assumed that the Being is manifest in certain invariable substances, the mixture and separation of which gives rise to the changes in the world. This led to the concept of the atom, the smallest indivisible unit of matter, which found its clearest expression in the philosophy of Leucippus and Democritus. The Greek atomists drew a clear line between spirit and matter, picturing matter as being made of several 'basic building blocks'. These were purely passive and intrinsically dead particles moving in the void. The cause of their motion was not explained, but was often associated with external forces which were assumed to be of spiritual origin and fundamentally different from matter. In subsequent centuries, this image became an essential element of Western thought, of the dualism between mind and matter, between body and soul.

As the idea of a division between spirit and matter took hold, the philosophers turned their attention to the spiritual world, rather than the material, to the human soul and the problems of ethics. These questions were to occupy Western thought for more than two thousand years after the culmination of Greek science and culture in the fifth and fourth centuries B.C. The scientific knowledge of antiquity was systematized and organized by Aristotle, who created the scheme which was to be the basis of the Western view of the universe for two thousand years. But Aristotle himself believed that questions concerning the human soul and the contemplation of God's perfection were much more valuable than investigations of

the material world. The reason the Aristotelian model of the universe remained unchallenged for so long was precisely this lack of interest in the material world, and the strong hold of the Christian Church which supported Aristotle's doctrines throughout the Middle Ages.

Further development of Western science had to wait until the Renaissance, when men began to free themselves from the influence of Aristotle and the Church and showed a new interest in nature. In the late fifteenth century, the study of nature was approached, for the first time, in a truly scientific spirit and experiments were undertaken to test speculative ideas. As this development was paralleled by a growing interest in mathematics, it finally led to the formulation of proper scientific theories, based on experiment and expressed in mathematical language. Galileo was the first to combine empirical knowledge with mathematics and is therefore seen as the father of modern science.

The birth of modern science was preceded and accompanied by a development of philosophical thought which led to an extreme formulation of the spirit/matter dualism. This formulation appeared in the seventeenth century in the philosophy of René Descartes who based his view of nature on a fundamental division into two separate and independent realms; that of mind (*res cogitans*), and that of matter (*res extensa*). The 'Cartesian' division allowed scientists to treat matter as dead and completely separate from themselves, and to see the material world as a multitude of different objects assembled into a huge machine. Such a mechanistic world view was held by Isaac Newton who constructed his mechanics on its basis and made it the foundation of classical physics. From the second half of the seventeenth to the end of the nineteenth century, the mechanistic Newtonian model of the universe dominated all scientific thought. It was paralleled by the image of a monarchical God who ruled the world from above by imposing his divine law on it. The fundamental laws of nature searched for by the scientists were thus seen as the laws of God, invariable and eternal, to which the world was subjected.

The philosophy of Descartes was not only important for the development of classical physics, but also had a tremendous influence on the general Western way of thinking up to the present day. Descartes' famous sentence *'Cogito ergo sum'*—'I think, therefore I exist'—has led Westerners to equate their identity with their mind, instead of with their whole organism. As a consequence of the Cartesian division, most individuals are aware of themselves as isolated egos existing 'inside' their bodies. The mind has been separated from the body and given the futile task of controlling it, thus causing an apparent conflict between the conscious will and the involuntary instincts. Each individual has been split up further into a large number of separate compartments, according to his or her activities, talents, feelings, beliefs, etc., which are engaged in endless conflicts generating continuous metaphysical confusion and frustration.

This inner fragmentation mirrors our view of the world 'outside' which is seen as a multitude of separate objects and events. The natural environment is treated as if it consisted of separate parts to be exploited by different interest groups. The fragmented view is further extended to society which is split into different nations, races, religious and political groups. The belief that all these fragments—in ourselves, in our environment and in our society—are really separate can be seen as the essential reason for the present series of social, ecological and cultural crises. It has alienated us from nature and from our fellow human beings. It has brought a grossly unjust distribution of natural resources creating economic and political disorder; an ever rising wave of violence, both spontaneous and institutionalized, and an ugly, polluted environment in which life has often become physically and mentally unhealthy.

The Cartesian division and the mechanistic world view have thus been beneficial and detrimental at the same time. They were extremely successful in the development of classical physics and technology, but had many adverse consequences for our civilization. It is fascinating to see that twentieth-century science, which originated in the Cartesian split and in the mechanistic world view, and which indeed only became possible because of such a view, now overcomes this fragmentation and leads back to the idea of unity expressed in the early Greek and Eastern philosophies.

In contrast to the mechanistic Western view, the Eastern

view of the world is 'organic'. For the Eastern mystic, all things and events perceived by the senses are interrelated, 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 categorizing mentality. It is called *avidya*, or ignorance, in Buddhist philosophy and is seen as the state of a disturbed mind which has to be overcome:

> When the mind is disturbed, the multiplicity of things is produced, but when the mind is quieted, the multiplicity of things disappears.[4]

Although the various schools of Eastern mysticism differ in many details, they all emphasize the basic unity of the universe which is the central feature of their teachings. The highest aim for their followers—whether they are Hindus, Buddhists or Taoists—is to become aware of the unity and mutual interrelation of all things, to transcend the notion of an isolated individual self and to identify themselves with the ultimate reality. The emergence of this awareness—known as 'enlightenment'—is not only an intellectual act but is an experience which involves the whole person and is religious in its ultimate nature. For this reason, most Eastern philosophies are essentially religious philosophies.

In the Eastern view, then, the division of nature into separate objects is not fundamental and any such objects have a fluid and ever-changing character. The Eastern world view is therefore intrinsically dynamic and contains time and change as essential features. The cosmos is seen as one inseparable reality—for ever in motion, alive, organic; spiritual and material at the same time.

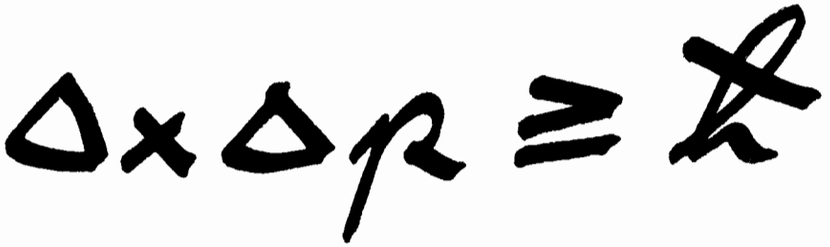
Since motion and change are essential properties of things, the forces causing the motion are not outside the objects, as in the classical Greek view, but are an intrinsic property of matter. Correspondingly, the Eastern image of the Divine is not that of a ruler who directs the world from above, but of a principle that controls everything from within:

> He who, dwelling in all things,
> Yet is other than all things,
> Whom all things do not know,
> Whose body all things are,
> Who controls all things from within—
> He is your Soul, the Inner Controller,
> The Immortal.[5]

The following chapters will show that the basic elements of the Eastern world view are also those of the world view emerging from modern physics. They are intended to suggest that Eastern thought and, more generally, mystical thought provide a consistent and relevant philosophical background to the theories of contemporary science; a conception of the world in which scientific discoveries can be in perfect harmony with spiritual aims and religious beliefs. The two basic themes of this conception are the unity and interrelation of all phenomena and the intrinsically dynamic nature of the universe. The further we penetrate into the submicroscopic world, the more we shall realize how the modern physicist, like the Eastern mystic, has come to see the world as a system of inseparable, interacting and ever-moving components with the observer being an integral part of this system.

The organic, 'ecological' world view of the Eastern philosophies is no doubt one of the main reasons for the immense popularity they have recently gained in the West, especially among young people. In our Western culture, which is still dominated by the mechanistic, fragmented view of the world, an increasing number of people have seen this as the underlying reason for the widespread dissatisfaction in our society, and many have turned to Eastern ways of liberation. It is interesting, and perhaps not too surprising, that those who are attracted by Eastern mysticism, who consult the *I Ching* and practise Yoga or other forms of meditation, in general have a marked anti-scientific attitude. They tend to see science, and physics in particular, as an unimaginative, narrow-minded discipline which is responsible for all the evils of modern technology.

This book aims at improving the image of science by showing that there is an essential harmony between the spirit of Eastern wisdom and Western science. It attempts to suggest that modern physics goes far beyond technology, that the way—or *Tao*—of physics can be a path with a heart, a way to spiritual knowledge and self-realization.



10 THE UNITY OF ALL THINGS

Although the spiritual traditions described in the last five chapters differ in many details, their view of the world is essentially the same. It is a view which is based on mystical experience—on a direct non-intellectual experience of reality—and this experience has a number of fundamental characteristics which are independent of the mystic's geographical, historical, or cultural background. A Hindu and a Taoist may stress different aspects of the experience; a Japanese Buddhist may interpret his or her experience in terms which are very different from those used by an Indian Buddhist; but the basic elements of the world view which has been developed in all these traditions are the same. These elements also seem to be the fundamental features of the world view emerging from modern physics.

The most important characteristic of the Eastern world view—one could almost say the essence of it—is the awareness of the unity and mutual interrelation of all things and events, the experience of all phenomena in the world as manifestations of a basic oneness. All things are seen as interdependent and inseparable parts of this cosmic whole; as different manifestations of the same ultimate reality. The Eastern traditions constantly refer to this ultimate, indivisible reality which manifests itself in all things, and of which all things are parts. It is called *Brahman* in Hinduism, *Dharmakaya* in Buddhism, *Tao* in Taoism. Because it transcends all concepts and categories, Buddhists also call it *Tathata*, or Suchness:

> What is meant by the soul as suchness, is the oneness of the totality of all things, the great all-including whole.[1]

In ordinary life, we are not aware of this unity of all things, but divide the world into separate objects and events. This division is, of course, useful and necessary to cope with our everyday environment, but it is not a fundamental feature of reality. It is an abstraction devised by our discriminating and categorizing intellect. To believe that our abstract concepts of separate 'things' and 'events' are realities of nature is an illusion. Hindus and Buddhists tell us that this illusion is based on *avidya*, or ignorance, produced by a mind under the spell of *maya*. The principal aim of the Eastern mystical traditions is therefore to readjust the mind by centering and quietening it through meditation. The Sanskrit term for meditation—*samadhi*—means literally 'mental equilibrium'. It refers to the balanced and tranquil state of mind in which the basic unity of the universe is experienced:

> Entering into the *samadhi* of purity, (one obtains) all-penetrating insight that enables one to become conscious of the absolute oneness of the universe.[2]

The basic oneness of the universe is not only the central characteristic of the mystical experience, but is also one of the most important revelations of modern physics. It becomes apparent at the atomic level and manifests itself more and more as one penetrates deeper into matter, down into the realm of subatomic particles. The unity of all things and events will be a recurring theme throughout our comparison of modern physics and Eastern philosophy. As we study the various models of subatomic physics we shall see that they express again and again, in different ways, the same insight—that the constituents of matter and the basic phenomena involving them are all interconnected, interrelated and interdependent; that they cannot be understood as isolated entities, but only as integrated parts of the whole.

In this chapter, I shall discuss how the notion of the basic interconnectedness of nature arises in quantum theory, the theory of atomic phenomena, through a careful analysis of the process of observation.* Before entering this discussion, I have to come back to the distinction between the mathematical framework of a theory and its verbal interpretation. The mathematical framework of quantum theory has passed countless successful tests and is now universally accepted as a consistent and accurate description of all atomic phenomena. The verbal interpretation, on the other hand—i.e. the metaphysics of quantum theory—is on far less solid ground. In fact, in more than forty years physicists have not been able to provide a clear metaphysical model.

The following discussion is based on the so-called Copenhagen interpretation of quantum theory which was developed by Bohr and Heisenberg in the late 1920s and is still the most widely accepted model. In my discussion I shall follow the presentation given by Henry Stapp of the University of California[3] which concentrates on certain aspects of the theory and on a certain type of experimental situation that is frequently encountered in subatomic physics.** Stapp's presentation shows most clearly how quantum theory implies an essential interconnectedness of nature, and it also puts the theory in a framework that can readily be extended to the relativistic models of subatomic particles to be discussed later on.

The starting point of the Copenhagen interpretation is the division of the physical world into an observed system ('object') and an observing system. The observed system can be an atom, a subatomic particle, an atomic process, etc. The observing system consists of the experimental apparatus and will include one or several human observers. A serious difficulty now arises from the fact that the two systems are treated in different ways. The observing system is described in the terms

*Although I have suppressed all the mathematics and simplified the analysis considerably, the following discussion may nevertheless appear to be rather dry and technical. It should perhaps be taken as 'yogic' exercise which—like many exercises in the spiritual training of the Eastern traditions—may not be much fun, but may lead to a profound and beautiful insight into the essential nature of things.

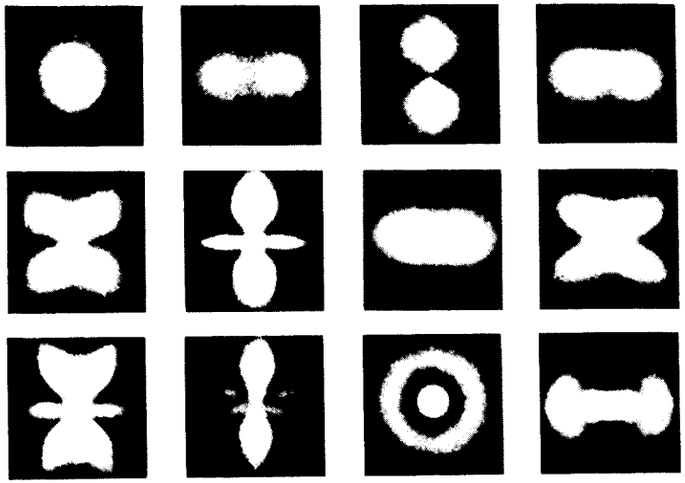
**Other aspects of quantum theory will be discussed in subsequent chapters.

of classical physics, but these terms cannot be used consistently for the description of the observed 'object'. We know that classical concepts are inadequate at the atomic level, yet we have to use them to describe our experiments and to state the results. There is no way we can escape this paradox. The technical language of classical physics is just a refinement of our everyday language and it is the only language we have to communicate our experimental results.

The observed systems are described in quantum theory in terms of probabilities. This means that we can never predict with certainty where a subatomic particle will be at a certain time, or how an atomic process will occur. All we can do is predict the odds. For example, most of the subatomic particles known today are unstable, that is, they distintegrate—or 'decay'—into other particles after a certain time. It is not possible, however, to predict this time exactly. We can only predict the probability of decay after a certain time or, in other words, the average lifetime of a great number of particles of the same kind. The same applies to the 'mode' of decay. In general, an unstable particle can decay into various combinations of other particles, and again we cannot predict which combination a particular particle will choose. All we can predict is that out of a large number of particles 60 per cent, say, will decay in one way, 30 per cent in another way, and 10 per cent in a third way. It is clear that such statistical predictions need many measurements to be verified. Indeed, in the collision experiments of high-energy physics tens of thousands of particle collisions are recorded and analysed to determine the probability for a particular process.

It is important to realize 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 recognize probability as a fundamental feature of the atomic reality which governs all processes, and even the existence of matter. Subatomic particles do not exist with certainty at definite places, but rather show 'tendencies to exist', and atomic events do not occur with certainty at definite times and in definite ways, but rather show 'tendencies to occur'.

It is not possible, for example, to say with certainty where an electron will be in an atom at a certain time. Its position



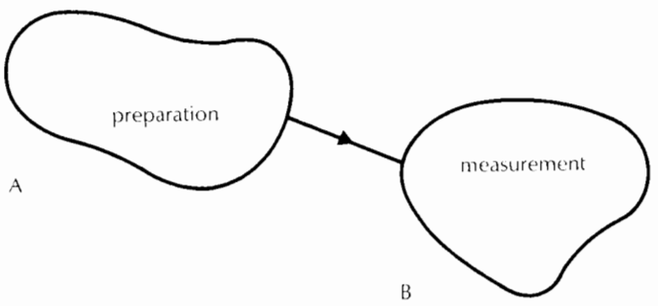
visual models of probability patterns

depends on the attractive force binding it to the atomic nucleus and on the influence of the other electrons in the atom. These conditions determine a probability pattern which represents the electron's tendencies to be in various regions of the atom. The picture above shows some visual models of such probability patterns. The electron is likely to be found where the patterns are bright and unlikely to be present where they are dark. The important point is that the entire pattern represents the electron at a given time. Within the pattern, we cannot speak about the electron's position, but only about its tendencies to be in certain regions. In the mathematical formalism of quantum theory, these tendencies, or probabilities, are represented by the so-called probability function, a mathematical quantity which is related to the probabilities of finding the electron in various places at various times.

The contrast between the two kinds of description—classical terms for the experimental arrangement and probability functions for the observed objects—leads to deep metaphysical problems which have not yet been resolved. In practice, however, these problems are circumvented by describing the observing system in operational terms, that is, in terms of instructions which permit scientists to set up and carry out their experiments. In this way, the measuring devices and the scientists are effectively joined into one complex system which has no distinct, well-defined parts, and the experimental apparatus does not have to be described as an isolated physical entity.

For the further discussion of the process of observation it will be useful to take a definite example, and the simplest physical entity that can be used is a subatomic particle, such as the electron. If we want to observe and measure such a particle, we must first isolate it, or even create it, in a process which can be called the preparation process. Once the particle has been prepared for observation, its properties can be measured, and this constitutes the process of measurement. The situation can be represented symbolically as follows. A particle is prepared in the region A, travels from A to B, and is measured in the region B. In practice, both the preparation and the measurement of the particle may consist of a whole series of quite complicated processes. In the collision experiments of high-energy physics, for example, the preparation of the particles used as projectiles consists in sending them around a circular track and accelerating them until their energy is sufficiently high. This process takes place in the particle accelerator. When the desired energy is reached, they are made to leave the accelerator (A) and travel to the target area (B) where they collide with other particles. These collisions take place in a bubble chamber where the particles produce visible tracks which are photographed. The properties of the particles are then deduced from a mathematical analysis of their tracks; such an analysis can be quite complex and is often carried out with the help of computers. All these processes and activities constitute the act of measurement.

The important point in this analysis of observation is that the particle constitutes an intermediate system connecting the processes at A and B. It exists and has meaning only in this context; not as an isolated entity, but as an interconnection between the processes of preparation and measurement. The properties of the particle cannot be defined independently of



observation of a particle in atomic physics

these processes. If the preparation or the measurement is modified, the properties of the particle will change too.

On the other hand, the fact that we speak about 'the particle', or any other observed system, shows that we have some independent physical entity in mind which is first prepared and then measured. The basic problem with observation in atomic physics is, then—in the words of Henry Stapp—that 'the observed system is required to be isolated in order to be defined, yet interacting in order to be observed.'[4] This problem is resolved in quantum theory in a pragmatic way by requiring that the observed system be free from the external disturbances caused by the process of observation during some interval between its preparation and subsequent measurement. Such a condition can be expected if the preparing and measuring devices are physically separated by a large distance, so that the observed object can travel from the region of preparation to the region of measurement.

How large, then, does this distance have to be? In principle, it must be infinite. In the framework of quantum theory, the concept of a distinct physical entity can be defined precisely only if this entity is infinitely far away from the agencies of observation. In practice, this is of course not possible; neither is it necessary. We have to remember, here, the basic attitude of modern science—that all its concepts and theories are approximate.* In the present case, this means that the concept

*See p. 41

of a distinct physical entity need not have a precise definition, but can be defined approximately. This is done in the following way.

The observed object is a manifestation of the interaction between the processes of preparation and measurement. This interaction is generally complex and involves various effects extending over different distances; it has various 'ranges', as we say in physics. Now, if the dominant part of the interaction has a long range, the manifestation of this long-range effect will travel over a large distance. It will then be free from external disturbances and can be referred to as a distinct physical entity. In the framework of quantum theory, distinct physical entities are therefore idealizations which are meaningful only to the extent that the main part of the interaction has a long range. Such a situation can be defined mathematically in a precise way. Physically, it means that the measuring devices are placed so far apart that their main interaction occurs through the exchange of a particle or, in more complicated cases, of a network of particles. There will always be other effects present as well, but as long as the separation of the measuring devices is large enough these effects can be neglected. Only when the devices are not placed far enough apart will the short-range effects become dominant. In such a case, the whole macroscopic system forms a unified whole and the notion of an observed object breaks down.

Quantum theory thus reveals an essential interconnectedness of the universe. It shows that we cannot decompose the world into independently existing smallest units.* As we penetrate into matter, we find that it is made of particles, but these are not the 'basic building blocks' in the sense of Democritus and Newton. They are merely idealizations which are useful from a practical point of view, but have no fundamental significance. In the words of Niels Bohr, 'Isolated material particles are abstractions, their properties being definable and observable only through their interaction with other systems.'[5]

The Copenhagen interpretation of quantum theory is not universally accepted. There are several counterproposals and the philosophical problems involved are far from being settled.

*See pp. 310ff for further discussion of this quantum interconnectedness in terms of 'nonlocal' connections implied by Bell's theorem.

The universal interconnectedness of things and events, however, seems to be a fundamental feature of the atomic reality which does not depend on a particular interpretation of the mathematical theory. The following passage from a recent article by David Bohm, one of the main opponents of the Copenhagen interpretation, confirms this fact most eloquently.

> One is led to a new notion of unbroken wholeness which denies the classical idea of analyzability of the world into separately and independently existing parts ... We have reversed the usual classical notion that the independent 'elementary parts' of the world are the fundamental reality, and that the various systems are merely particular contingent forms and arrangements of these parts. Rather, we say that inseparable quantum interconnectedness of the whole universe is the fundamental reality, and that relatively independently behaving parts are merely particular and contingent forms within this whole.[6]

At the atomic level, then, the solid material objects of classical physics dissolve into patterns of probabilities, and these patterns do not represent probabilities of things, but rather probabilities of interconnections. Quantum theory forces us to see the universe not as a collection of physical objects, but rather as a complicated web of relations between the various parts of a unified whole. This, however, is the way in which Eastern mystics have experienced the world, and some of them have expressed their experience in words which are almost identical with those used by atomic physicists. Here are two examples:

> The material object becomes ... something different from what we now see, not a separate object on the background or in the environment of the rest of nature but an indivisible part and even in a subtle way an expression of the unity of all that we see.[7]

> Things derive their being and nature by mutual dependence and are nothing in themselves.[8]

If these statements could be taken as an account of how nature appears in atomic physics, the following two statements from atomic physicists could, in turn, be read as a description of the mystical experience of nature:

> An elementary particle is not an independently existing unanalyzable entity. It is, in essence, a set of relationships that reach outward to other things.[9]

> 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.[10]

The picture of an interconnected cosmic web which emerges from modern atomic physics has been used extensively in the East to convey the mystical experience of nature. For the Hindus, *Brahman* is the unifying thread in the cosmic web, the ultimate ground of all being:

> He on whom the sky, the earth, and the atmosphere
> Are woven, and the wind, together with all life-breaths,
> Him alone know as the one Soul.[11]

In Buddhism, the image of the cosmic web plays an even greater role. The core of the *Avatamsaka Sutra*, one of the main scriptures of Mahayana Buddhism,* is the description of the world as a perfect network of mutual relations where all things and events interact with each other in an infinitely complicated way. Mahayana Buddhists have developed many parables and similes to illustrate this universal interrelatedness, some of which will be discussed later on, in connection with the relativistic version of the 'web philosophy' in modern physics. The cosmic web, finally, plays a central role in Tantric Buddhism, a branch of the Mahayana which originated in India around the third century A.D. and constitutes today the main school of Tibetan Buddhism. The scriptures of this school are called the *Tantras*, a word whose Sanskrit root means 'to weave' and which refers to the interwovenness and interdependence of all things and events.

*See p. 99

In Eastern mysticism, this universal interwovenness always includes the human observer and his or her consciousness, and this is also true in atomic physics. At the atomic level, 'objects' can only be understood in terms of the interaction between the processes of preparation and measurement. The end of this chain of processes lies always in the consciousness of the human observer. Measurements are interactions which create 'sensations' in our consciousness—for example, the visual sensation of a flash of light, or of a dark spot on a photographic plate—and the laws of atomic physics tell us with what probability an atomic object will give rise to a certain sensation if we let it interact with us. 'Natural science', says Heisenberg, 'does not simply describe and explain nature; it is part of the interplay between nature and ourselves.'[12]

The crucial feature of atomic physics is that the human observer is not only necessary to observe the properties of an object, but is necessary even to define these properties. In atomic physics, we cannot talk about the properties of an object as such. They are only meaningful in the context of the object's interaction with the observer. In the words of Heisenberg, 'What we observe is not nature itself, but nature exposed to our method of questioning.'[13] The observer decides how he is going to set up the measurement and this arrangement will determine, to some extent, the properties of the observed object. If the experimental arrangement is modified, the properties of the observed object will change in turn.

This can be illustrated with the simple case of a subatomic particle. When observing such a particle, one may choose to measure—among other quantities—the particle's position and its momentum (a quantity defined as the particle's mass times its velocity). We shall see in the next chapter that an important law of quantum theory—Heisenberg's uncertainty principle—says that these two quantities can never be measured simultaneously with precision. We can either obtain a precise knowledge about the particle's position and remain completely ignorant about its momentum (and thus about its velocity), or vice versa; or we can have a rough and imprecise knowledge about both quantities. The important point now is that this limitation has nothing to do with the imperfection of our measuring techniques. It is a principle limitation which is inherent in the atomic reality. If we decide to measure the particle's position precisely, the particle simply *does not have* a well-defined momentum, and if we decide to measure the momentum, it does not have a well-defined position.

In atomic physics, then, the scientist cannot play the role of a detached objective observer, but becomes involved in the world he observes to the extent that he influences the properties of the observed objects. John Wheeler sees this involvement of the observer as the most important feature of quantum theory and he has therefore suggested replacing the word 'observer' by the word 'participator'. In Wheeler's own words,

> Nothing is more important about the quantum principle than this, that it destroys the concept of the world as 'sitting out there', with the observer safely separated from it by a 20 centimeter slab of plate glass. Even to observe so miniscule an object as an electron, he must shatter the glass. He must reach in. He must install his chosen measuring equipment. It is up to him to decide whether he shall measure position or momentum. To install the equipment to measure the one prevents and excludes his installing the equipment to measure the other. Moreover, the measurement changes the state of the electron. The universe will never afterwards be the same. To describe what has happened, one has to cross out that old word 'observer' and put in its place the new word 'participator'. In some strange sense the universe is a participatory universe.[14]

The idea of 'participation instead of observation' has been formulated in modern physics only recently, but it is an idea which is well known to any student of mysticism. Mystical 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 crucial to the Eastern world view, and the Eastern mystics have pushed this notion to the extreme, to a point where observer and observed, subject and object, are not only inseparable but also become indistinguishable. The mystics are not satisfied with a situation analogous to

atomic physics, where the observer and the observed cannot be separated, but can still be distinguished. They go much further, and in deep meditation they arrive at a point where the distinction between observer and observed breaks down completely, where subject and object fuse into a unified undifferentiated whole. Thus the *Upanishads* say,

> Where there is a duality, as it were, there one sees another; there one smells another; there one tastes another ... But where everything has become just one's own self, then whereby and whom would one see? then whereby and whom would one smell? then whereby and whom would one taste?[15]

This, then, is the final apprehension of the unity of all things. It is reached— so the mystics tell us—in a state of consciousness where one's individuality dissolves into an undifferentiated oneness, where the world of the senses is transcended and the notion of 'things' is left behind. In the words of Chuang Tzu,

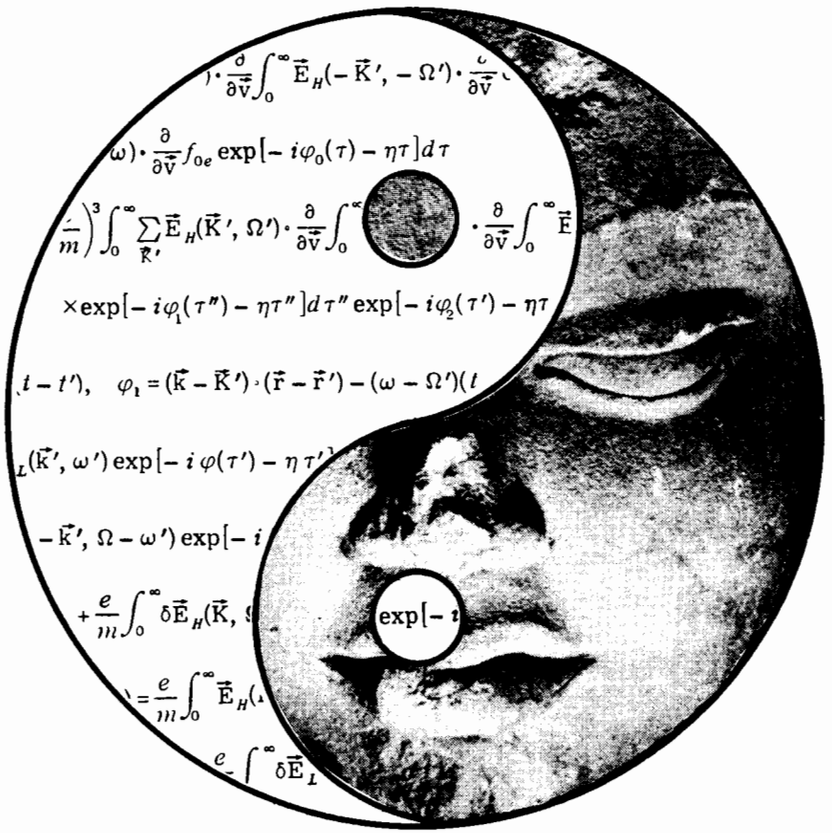
> My connection with the body and its parts is dissolved. My perceptive organs are discarded. Thus leaving my material form and bidding farewell to my knowledge, I become one with the Great Pervader. This I call sitting and forgetting all things.[16]

Modern physics, of course, works in a very different framework and cannot go that far in the experience of the unity of all things. But it has made a great step towards the world view of the Eastern mystics in atomic theory. Quantum theory has abolished the notion of fundamentally separated objects, has introduced the concept of the participator to replace that of the observer, and may even find it necessary to include the human consciousness in its description of the world.* It has come to see the universe as an interconnected web of physical and mental relations whose parts are only defined through their connections to the whole. To summarize the world view

*This point will be discussed further in Chapter 18.

emerging from atomic physics, the words of a Tantric Buddhist, Lama Anagarika Govinda, seem to be perfectly apropos:

> The Buddhist does not believe in an independent or separately existing external world, into whose dynamic forces he could insert himself. The external world and his inner world are for him 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.[17]



EPILOGUE

The Eastern religious philosophies are concerned with timeless mystical knowledge which lies beyond reasoning and cannot be adequately expressed in words. The relation of this knowledge to modern physics is but one of its many aspects and, like all the others, it cannot be demonstrated conclusively but has to be experienced in a direct intuitive way. What I hope to have achieved, to some extent, therefore, is not a rigorous demonstration, but rather to have given the reader an opportunity to relive, every now and then, an experience which has become for me a source of continuing joy and inspiration; that the principal theories and models of modern physics lead to a view of the world which is internally consistent and in perfect harmony with the views of Eastern mysticism.

For those who have experienced this harmony, the significance of the parallels between the world views of physicists and mystics is beyond any doubt. The interesting question, then, is not *whether* these parallels exist, but *why*; and, furthermore, what their existence implies.

In trying to understand the mystery of Life, men and women have followed many different approaches. Among them, there are the ways of the scientist and mystic, but there are many more; the ways of poets, children, clowns, shamans, to name but a few. These ways have resulted in different descriptions of the world, both verbal and non-verbal, wh ich emphasize different aspects. All are valid and useful in the context in which they arose. All of them, however, are only descriptions, or representations, of reality and are therefore limited. None can give a complete picture of the world.

The mechanistic world view of classical physics is useful for

the description of the kind of physical phenomena we encounter in our everyday life and thus appropriate for dealing with our daily environment, and it has also proved extremely successful as a basis for technology. It is inadequate, however, for the description of physical phenomena in the submicroscopic realm. Opposed to the mechanistic conception of the world is the view of the mystics which may be epitomized by the word 'organic', as it regards all phenomena in the universe as integral parts of an inseparable harmonious whole. This world view emerges in the mystical traditions from meditative states of consciousness. In their description of the world, the mystics use concepts which are derived from these non-ordinary experiences and are, in general, inappropriate for a scientific description of macroscopic phenomena. The organic world view is not advantageous for constructing machines, nor for coping with the technical problems in an overpopulated world.

In everyday life, then, both the mechanistic and the organic views of the universe are valid and useful; the one for science and technology, the other for a balanced and fulfilled spiritual life. Beyond the dimensions of our everyday environment, however, the mechanistic concepts lose their validity and have to be replaced by organic concepts which are very similar to those used by the mystics. This is the essential experience of modern physics which has been the subject of our discussion. Physics in the twentieth century has shown that the concepts of the organic world view, although of little value for science and technology on the human scale, become extremely useful at the atomic and subatomic level. The organic view, therefore, seems to be more fundamental than the mechanistic. Classical physics, which is based on the latter, can be derived from quantum theory, which implies the former, whereas the reverse is not possible. This seems to give a first indication why we might expect the world views of modern physics and Eastern mysticism to be similar. Both emerge when one enquires into the essential nature of things—into the deeper realms of matter in physics; into the deeper realms of consciousness in mysticism —when one discovers a different reality behind the superficial mechanistic appearance of everyday life.

The parallels between the views of physicists and mystics become even more plausible when we recall the other similarities which exist in spite of their different approaches. To begin with, their method is thoroughly empirical. Physicists derive their knowledge from experiments; mystics from meditative insights. Both are observations, and in both fields these observations are acknowledged as the only source of knowledge. The object of observation is of course very different in the two cases. The mystic looks within and explores his or her consciousness at its various levels, which include the body as the physical manifestation of the mind. The experience of one's body is, in fact, emphasized in many Eastern traditions and is often seen as the key to the mystical experience of the world. When we are healthy, we do not feel any separate parts in our body but are aware of it as an integrated whole, and this awareness generates a feeling of well-being and happiness. In a similar way, the mystic is aware of the wholeness of the entire cosmos which is experienced as an extension of the body. In the words of Lama Govinda,

> To the enlightened man ... whose consciousness embraces the universe, to him the universe becomes his 'body', while his physical body becomes a manifestation of the Universal Mind, his inner vision an expression of the highest reality, and his speech an expression of eternal truth and mantric power.[1]

In contrast to the mystic, the physicist begins his enquiry into the essential nature of things by studying the material world. Penetrating into ever deeper realms of matter, he has become aware of the essential unity of all things and events. More than that, he has also learnt that he himself and his consciousness are an integral part of this unity. Thus the mystic and the physicist arrive at the same conclusion; one starting from the inner realm, the other from the outer world. The harmony between their views confirms the ancient Indian wisdom that *Brahman*, the ultimate reality without, is identical to *Atman*, the reality within.

A further similarity between the ways of the physicist and mystic is the fact that their observations take place in realms which are inaccessible to the ordinary senses. In modern physics,

these are the realms of the atomic and subatomic world; in mysticism they are non-ordinary states of consciousness in which the sense world is transcended. Mystics often talk about experiencing higher dimensions in which impressions of different centres of consciousness are integrated into a harmonious whole. A similar situation exists in modern physics where a four-dimensional 'space-time' formalism has been developed which unifies concepts and observations belonging to different categories in the ordinary three-dimensional world. In both fields, the multi-dimensional experiences transcend the sensory world and are therefore almost impossible to express in ordinary language.

We see that the ways of the modern physicist and the Eastern mystic, which seem at first totally unrelated, have, in fact, much in common. It should not be too surprising, therefore, that there are striking parallels in their descriptions of the world. Once these paralleis between Western science and Eastern mysticism are accepted, a number of questions will arise concerning their implications. Is modern science, with all its sophisticated machinery, merely rediscovering ancient wisdom, known to the Eastern sages for thousands of years? Should physicists, therefore, abandon the scientific method and begin to meditate? Or can there be a mutual influence between science and mysticism; perhaps even a synthesis?

I think all these questions have to be answered in the negative. I see science and mysticism as two complementary manifestations of the human mind; of its rational and intuitive faculties. The modern physicist experiences the world through an extreme specialization of the rational mind; the mystic through an extreme specialization of the intuitive mind. The two approaches are entirely different and involve far more than a certain view of the physical world. However, they are complementary, as we have learned to say in physics. Neither is comprehended in the other, nor can either of them be reduced to the other, but both of them are necessary, supplementing one another for a fuller understanding of the world. To paraphrase an old Chinese saying, mystics understand the roots of the *Tao* but not its branches; scientists understand its branches but not its roots. Science does not need mysticism and mysticism does not need science; but men and women need both. Mystical experience is necessary to understand the deepest nature of things, and science is essential for modern life. What we need, therefore, is not a synthesis but a dynamic interplay between mystical intuition and scientific analysis.

So far, this has not been achieved in our society. At present, our attitude is too *yang*—to use again Chinese phraseology—too rational, male and aggressive. Scientists themselves are a typical example. Although their theories are leading to a world view which is similar to that of the mystics, it is striking how little this has affected the attitudes of most scientists. In mysticism, knowledge cannot be separated from a certain way of life which becomes its living manifestation. To acquire mystical knowledge means to undergo a transformation; one could even say that the knowledge *is* the transformation. Scientific knowledge, on the other hand, can often stay abstract and theoretical. Thus most of today's physicists do not seem to realize the philosophical, cultural and spiritual implications of their theories. Many of them actively support a society which is still based on the mechanistic, fragmented world view, without seeing that science points beyond such a view, towards a oneness of the universe which includes not only our natural environment but also our fellow human beings. I believe that the world view implied by modern physics is inconsistent with our present society, which does not reflect the harmonious interrelatedness we observe in nature. To achieve such a state of dynamic balance, a radically different social and economic structure will be needed: a cultural revolution in the true sense of the word. The survival of our whole civilization may depend on whether we can bring about such a change. It will depend, ultimately, on our ability to adopt some of the *yin* attitudes of Eastern mysticism; to experience the wholeness of nature and the art of living with it in harmony.

THE NEW PHYSICS REVISITED

Afterword to the Second Edition

Since the first publication of *The Tao of Physics*, there has been considerable progress in various areas of subatomic physics. As I have stated in the Preface to this edition, the new developments have not invalidated any of the parallels to Eastern thought but, on the contrary, have enforced them. In this Afterword, I would like to discuss the most relevant results of new research in atomic and subatomic physics up to the summer of 1982.

One of the strongest parallels to Eastern mysticism has been the realization that the constituents of matter and the basic phenomena involving them are all interconnected; that they cannot be understood as isolated entities but only as integral parts of a unified whole. The notion of a basic 'quantum interconnectedness', which I have discussed in great detail in Chapter 10, was emphasized by Bohr and Heisenberg throughout the history of quantum theory. However, it received renewed attention during the last two decades, when physicists came to realize that the universe, in fact, may be interconnected in much subtler ways than one had thought before. The new kind of interconnectedness that has recently emerged not only enforces the similarities between the views of physicists and mystics; it also raises the intriguing possibility of relating subatomic physics to Jungian psychology and, perhaps, even to parapsychology; and it sheds new light on the fundamental role of probability in quantum physics.

In classical physics, probability is used whenever the details involved in an event are unknown. For example, when we throw dice, we could—in principle—predict the outcome if we knew all the mechanical details involved in the operation:

the exact composition of the dice, of the surface on which they fall, and so on. These details are called local variables because they reside within the objects involved. In subatomic physics, local variables are represented by connections between spatially separated events through signals—particles and networks of particles—that respect the usual laws of spatial separation. For example, no signal can be transmitted faster than the speed of light. But beyond these local connections other, nonlocal connections have recently emerged; connections that are instantaneous and cannot be predicted, at present, in a precise mathematical way.

These nonlocal connections are seen by some physicists as the very essence of quantum reality. In quantum theory individual events do not always have a well-defined cause. For example, the jump of an electron from one atomic orbit to another, or the decay of a subatomic particle, may occur spontaneously without any single event causing it. We can never predict when and how such a phenomenon is going to happen; we can only predict its probability. This does not mean that atomic events occur in completely arbitrary fashion; it means only that they are not brought about by local causes. The behavior of any part is determined by its nonlocal connections to the whole, and since we do not know these connections precisely, we have to replace the narrow classical notion of cause and effect by the wider concept of statistical causality. The laws of atomic physics are statistical laws, according to which the probabilities for atomic events are determined by the dynamics of the whole system. Whereas in classical physics the properties and behaviour of the parts determine those of the whole, the situation is reversed in quantum physics: it is the whole that determines the behaviour of the parts.

Probability, then, is used in classical and quantum physics for similar reasons. In both cases there are 'hidden' variables, unknown to us, and this ignorance prevents us from making exact predictions. There is a crucial difference, however. Whereas the hidden variables in classical physics are local mechanisms, those in quantum physics are nonlocal; they are instantaneous connections to the universe as a whole. In the everyday, macroscopic world nonlocal connections are relatively unimportant, and thus we can speak of separate objects and formulate the laws describing their behaviour in terms of certainties. But as we go to smaller dimensions, the influence of nonlocal connections becomes stronger, the certainties give way to probabilities, and it becomes more and more difficult to separate any part of the universe from the whole.

The existence of nonlocal connections and the resulting fundamental role of probability is something that Einstein could never accept. This was the subject of his historic debate with Bohr in the 1920s, in which Einstein expressed his opposition to Bohr's interpretation of quantum theory in the famous metaphor 'God does not play dice.'[1] At the end of the debate, Einstein had to admit that quantum theory, as interpreted by Bohr and Heisenberg, formed a consistent system of thought, but he remained convinced that a deterministic interpretation in terms of local hidden variables would be found some time in the future.

The essence of Einstein's disagreement with Bohr was his firm belief in some external reality, consisting of independent spatially separated elements. In his attempt to show that Bohr's interpretation of quantum theory was inconsistent, Einstein devised a thought experiment that has become known as the Einstein-Podolsky-Rosen (EPR) experiment.[2] Three decades later John Bell derived a theorem, based on the EPR experiment, which proves that the existence of local hidden variables is inconsistent with the statistical predictions of quantum theory.[3] Bell's theorem dealt a shattering blow to Einstein's position by showing that the conception of reality as consisting of separate parts, joined by local connections, is incompatible with quantum theory.

In recent years the EPR experiment was repeatedly discussed and analyzed by physicists concerned with the interpretation of quantum theory, because it is ideally suited to show the difference between classical and quantum concepts.[4] For our purposes it will be sufficient to describe a simplified version of the experiment, involving two spinning electrons and based on the comprehensive discussion given by David Bohm.[5] To grasp the essence of the situation, it is necessary to understand some properties of electron spin. The classical image of a spinning tennis ball is not fully adequate to describe a spinning subatomic particle. In some sense particle spin is a rotation

about the particle's own axis, but, as always in subatomic physics, this classical concept is limited. In the case of an electron, the particle's spin is restricted to two values: the amount of spin is always the same, but the electron can spin in one or the other direction, clockwise or counterclockwise, for a given axis of rotation. Physicists often denote these two values of spin by 'up' and 'down'.

The crucial property of a spinning electron, which cannot be understood in classical terms, is the fact that its axis of rotation cannot always be defined with certainty. Just as electrons show tendencies to exist in certain places, they also show tendencies to spin about certain axes. Yet, whenever a measurement is performed for any axis of rotation, the electron will be found to spin in one or the other direction about that axis. In other words, the act of measurement gives the particle a definite axis of rotation, but before the measurement is taken, it cannot generally be said to spin about a definite axis; it merely has a certain tendency, or potentiality, to do so.

With this understanding of electron spin we can now examine the EPR experiment and Bell's theorem. The experiment involves two electrons spinning in opposite directions, so that their total spin is zero. There are several experimental methods that can be used to put two electrons in such a state, in which the directions of the individual spins are not known with certainty, but the combined spin of both electrons is definitely zero. Now suppose that these two particles are made to drift apart by some process that does not affect their spins. As they go off in opposite directions, their combined spin will still be zero, and once they are separated by a large distance , their individual spins are measured. An important aspect of the experiment is the fact that the distance between the two particles can be arbitrarily large; one particle may be in New York and the other in Paris, or one on the earth and the other on the moon.

Suppose now that the spin of particle 1 is measured along a vertical axis and is found to be 'up'. Because the combined spin of the two particles is zero, this measurement tells us that the spin of particle 2 must be 'down'. Thus, by measuring the spin of particle 1 we obtain an indirect measurement of the spin of particle 2 without in any way disturbing that particle.

The paradoxical aspect of the EPR experiment arises from the fact that the observer is free to choose the axis of measurement. Quantum theory tells us that the spins of the two electrons about any axis will always be opposite, but they will exist only as tendencies, or potentialities, before the measurement is taken. Once the observer has chosen a definite axis and has performed the measurement, this act will give both particles a definite axis of rotation. The crucial point is that we can choose our axis of measurement at the last minute, when the electrons are already far apart. At the instant we perform our measurement on particle 1, particle 2, which may be thousands of miles away, will acquire a definite spin along the chosen axis. How does particle 2 know which axis we have chosen? There is no time for it to receive that information by any conventional signal.

This is the crux of the EPR experiment, and this is where Einstein disagreed with Bohr. According to Einsten, since no signal can travel faster then the speed of light, it is impossible that the measurement performed on one electron will instantly determine the direction of the other electron's spin, thousands of miles away. According to Bohr, the two-particle system is an indivisible whole, even if the particles are separated by a great distance; the system cannot be analyzed in terms of independent parts. Even though the two electrons are far apart in space, they are nevertheless linked by instantaneous, nonlocal connections. These connections are not signals in the Einsteinian sense; they transcend our conventional notions of information transfer. Bell's theorem supports Bohr's position and proves rigorously that Einstein's view of physical reality as consisting of independent, spatially separated elements is incompatible with the laws of quantum theory. In other words, Bell's theorem demonstrates that the universe is fundamentally interconnected, interdependent, and inseparable. As the Buddhist sage Nagarjuna put it, hundreds of years ago,*

> Things derive their being and nature by mutual dependence and are nothing in themselves.

*See p. 138

Current research in physics aims at unifying our two basic theories, quantum theory and relativity theory, into a complete theory of subatomic particles. We have not yet been able to formulate such a complete theory, but we do have several partial theories and models, which describe certain aspects of subatomic phenomena very well. At present there are two different kinds of 'quantum-relativistic' theories in particle physics that have been successful in different areas. The first are a group of quantum field theories (see Chapter 14) which apply to electromagnetic and weak interactions; the second is the theory known as S-matrix theory (see Chapter 17), which has been successful in describing the strong interactions. A major problem that is still unsolved is the unification of quantum theory and general relativity theory into a quantum theory of gravity. Although the recent development of 'supergravity' theories[6] may represent a step towards solving this problem, no satisfactory theory has been found so far.

Quantum field theories, as described in detail in Chapter 14, are based on the concept of the quantum field, a fundamental entity that can exist in continuous form, as a field, and in discontinuous form, as particles, different kinds of particles being associated with different fields. These theories have replaced the notion of particles as fundamental objects by the much subtler notion of quantum fields. Nevertheless, they deal with fundamental entities and are thus, in a sense, semi-classical theories which do not exhibit the quantum-relativistic nature of subatomic matter to the fullest extent.

Quantum electrodynamics, the first of the quantum field theories, owes its success to the fact that the electromagnetic interactions are very weak and thus make it possible to maintain the classical distinction between matter and interaction forces to a large extent.* The same is true for the field theories dealing with the weak interactions. In fact, this similarity between electromagnetic and weak interactions has recently been strengthened enormously by the development of a new type of quantum field theories, called gauge theories, which have made it possible to unify both interactions. In the resulting unified field theory—known as the Weinberg-Salam theory after its two main architects, Steven Weinberg and Abdus Salam—the two interactions remain distinct but become mathematically intertwined and are referred to collectively as 'electroweak' interactions.[7]

*In technical terms, this means that the electromagnetic coupling constant is so small that a perturbation expansion gives an excellent approximation.

The gauge-theory approach has also been extended to the strong interactions with the development of a field theory called quantum chromodynamics (QCD), and many physicists are now attempting to achieve a 'grand unification' of QCD and the Weinberg-Salam theory.[8] However, the use of gauge theories for the description of strongly interacting particles is quite problematic. The interactions between hadrons are so strong that the distinction between particles and forces becomes blurred and, consequently, QCD has not been very successful in describing the processes involving strongly interacting particles. It works only for a few very special phenomena—the so-called 'deep inelastic' scattering processes—in which particles behave, for reasons that are not well understood, somewhat like classical objects. In spite of many great efforts physicists have not been able to apply QCD beyond this narrow range of phenomena, and the initial hopes in its role as a theoretical framework for deriving the properties of strongly interacting particles have, so far, not been fulfilled.[9]

Quantum chromodynamics represents the current mathematical formulation of the quark model (see Chapter 16), the fields being associated with quarks and the 'chromo' referring to the colour property of these quark fields. Like all gauge theories, QCD has been modelled after quantum electrodynamics (QED). Whereas in QED electromagnetic interactions are mediated by the exchange of photons between charged particles, in QCD the strong interactions are mediated by the exchange of 'gluons' between coloured quarks. These are not real particles but some kind of quanta that 'glue' quarks together to form mesons and baryons.[10]

During the last decade the quark model had to be expanded and refined considerably as many new particles were discovered in collision experiments of ever-increasing energies. As described in Chapter 16, each of the three quarks postulated originally and labeled by the flavours 'up', 'down', and 'strange'

was required to appear in three different colours, and then a fourth quark, again appearing in three colours and labeled by the flavour 'charm', was postulated. More recently, two new flavours were added to the model, denoted by *t* and *b* for 'top' and 'bottom' (or, more poetically, for 'true' and 'beautiful'), which brings the total number of quarks to eighteen—six flavours and three colours. Some physicists, not surprisingly, have found this large number of fundamental building blocks rather unattractive and have already suggested that the time was ripe to think of smaller, 'truly elementary' constituents out of which the quarks were made. . . .

While all this theorizing and model building went on, experimenters continued to look for free quarks but were never able to detect any, and this persistent absence of free quarks has become the main problem of the quark model. In the framework of QCD, the phenomenon has been given the name quark confinement, the idea being that quarks are, for some reason, permanently confined within the hadrons and thus will never be seen. Several mechanisms have been proposed to account for quark confinement, but so far no consistent theory has been formulated.

This, then, is the present state of the quark model: to account for the observed patterns in the hadron spectrum, at least eighteen quarks plus eight gluons seem to be needed; none of these have ever been observed as free particles and their existence as physical constituents of hadrons would lead to severe theoretical difficulties; various mechanisms have been developed to explain their permanent confinement but none of them represents a satisfactory dynamic theory, while QCD, the theoretical framework of the quark model, can only be applied to a very narrow range of phenomena. Yet, in spite of all these difficulties, most physicists still hang on to the idea of basic building blocks of matter which is so deeply ingrained in our Western scientific tradition.

The most impressive developments in particle physics, perhaps, have taken place recently in S-matrix theory and the bootstrap approach (see Chapters 17 and 18), which does not accept any fundamental entities but tries to understand nature entirely through its self-consistency. I have made it clear in this book that I consider the bootstrap philosophy as the culmination of current scientific thinking, and have also emphasized that it is the one that comes closest to Eastern thought, both in its general philosophy and its specific picture of matter. At the same time, it is a very difficult approach to physics which is, at present, pursued by only a small minority of physicists. For most members of the physics community the bootstrap philosophy is too foreign to their traditional ways of thinking to be seriously appreciated, and this lack of appreciation extends also to S-matrix theory. It is curious, and very significant, that although the basic concepts of the theory are used by all particle physicists whenever they analyze the results of scattering experiments and compare them to their theoretical predictions, not a single Nobel prize has so far been awarded to any of the outstanding physicists who contributed to the development of S-matrix theory over the past two decades.

The biggest challenge to S-matrix theory and the bootstrap has always been to account for the quark structure of subatomic particles. Although our present understanding of the subatomic world precludes the existence of quarks as physical particles, there can be no doubt that hadrons exhibit quark symmetries that will have to be explained by any successful theory of the strong interactions. Until recently the bootstrap approach could not explain these striking regularities, but within the last six years there has been a major breakthrough in S-matrix theory. This has resulted in a bootstrap theory of particles that can account for the observed quark structure without any need to postulate the existence of physical quarks. Moreover, the new bootstrap theory illuminates a number of questions not previously understood.[11]

To understand the essence of the new development it is necessary to clarify the meaning of quark structure within the context of S-matrix theory. Whereas in the quark model particles are pictured, essentially, as billiard balls containing smaller billiard balls, the S-matrix approach, being holistic and thoroughly dynamic, sees particles as interrelated energy patterns in an ongoing universal process—as correlations, or interconnections, between various parts of an inseparable cosmic web. In such a framework, the term 'quark structure' refers to the fact that the transfer of energy and the flow of information in

this network of events proceed along well-defined lines, producing the two-ness associated with mesons and the three-ness associated with baryons. This is the dynamic equivalent to the statement that hadrons consist of quarks. In S-matrix theory there are no distinct entities and no basic building blocks; there is only a flow of energy showing certain well-defined patterns.

The question, then, is: how do the specific quark patterns arise? The key element of the new bootstrap theory is the notion of order as a new and important aspect of particle physics. Order, in this context, means order in the interconnectedness of subatomic processes. There are various ways in which particle reactions can interconnect and, accordingly, one can define various categories of order. The language of topology—well known to mathematicians but never before applied to particle physics—is used to classify these categories of order. When this concept of order is incorporated into the mathematical framework of S-matrix theory, only a few special categories of ordered relationships turn out to be compatible with the well-known properties of the S matrix. These categories of order are precisely the quark patterns observed in nature. Thus, the quark structure appears as a manifestation of order and necessary consequence of self-consistency, without any need to postulate quarks as physical constituents of hadrons.

The emergence of order as a new and central concept in particle physics has not only led to a major breakthrough in S-matrix theory, but may well have far-reaching implications for science as a whole. At present, the significance of order in subatomic physics is still somewhat mysterious and not yet fully explored. However, it is intriguing to note that, like the three S-matrix principles,* the notion of order plays a very basic role in the scientific approach to reality and is a crucial aspect of our methods of observation. The ability to recognize order seems to be an essential aspect of the rational mind; every perception of a pattern is, in a sense, a perception of order. The clarification of the concept of order in a field of research where patterns of matter and patterns of mind are increasingly being recognized as reflections of one another promises thus to open fascinating frontiers of knowledge.

*See p. 275

According to Geoffrey Chew, who is the originator of the bootstrap idea and has been the unifying force and philosophical leader in S-matrix theory for the past two decades, the extension of the bootstrap approach beyond the description of hadrons may lead to the unprecedented possibility of being forced to include the study of human consciousness explicitly in our future theories of matter. 'Such a future step,' wrote Chew, 'would be immensely more profound than anything comprising the hadron bootstrap. . . . Our current struggle with the hadron bootstrap may thus be only a foretaste of a completely new form of human intellectual endeavor.'*

Since he wrote these words, almost fifteen years ago, the new developments in S-matrix theory have brought Chew considerably closer to dealing with consciousness explicitly. Moreover, he has not been the only physicist moving in this direction. Among recent research, one of the most exciting developments has been a new theory proposed by David Bohm who has, perhaps, gone further than anybody else in studying the relations between consciousness and matter in a scientific context. Bohm's approach is much more general and more ambitious than that of current S-matrix theory, and can be seen as an attempt to 'bootstrap' space-time, together with some fundamental concepts of quantum theory, in order to derive a consistent quantum-relativistic theory of matter.[12]

Bohm's starting point, as I have indicated in Chapter 10, is the notion of 'unbroken wholeness', and he sees the nonlocal connections that are exemplified by the EPR experiment as an essential aspect of this wholeness. Nonlocal connections now appear to be the source of the statistical formulation of the laws of quantum physics, but Bohm wants to go beyond probability and explore the order which he believes to be inherent in the cosmic web of relations at a deeper, 'nonmanifest' level. He calls this an 'implicate', or 'enfolded', order in which the interconnections of the whole have nothing to do with locality in space and time but exhibit an entirely different quality—that of enfoldment.

*See p. 301

Bohm uses the hologram as an analogy for this implicate order because of its property that each of its parts, in some sense, contains the whole.[13] If any part of a hologram is illuminated, the entire image will be reconstructed, although it will show less detail than the image obtained from the complete hologram. In Bohm's view, the real world is structured according to the same general principles, with the whole being enfolded in each of its parts.

Bohm realizes, of course, that the analogy of the hologram is too limited to be used as a scientific model for the implicate order at the subatomic level, and to express the essentially dynamic nature of reality at this level he has coined the term 'holomovement' for the ground of all manifest entities. The holomovement, in Bohm's view, is a dynamic phenomenon out of which all forms of the material universe flow. The aim of his approach is to study the order enfolded in this holomovement, not by dealing with the structure of objects, but rather with the structure of movement, thus taking into account both the unity and the dynamic nature of the universe.

According to Bohm, space and time, too, emerge as forms flowing out of the holomovement; they, too, are enfolded in its order. Bohm believes that the understanding of the implicate order will not only lead to a deeper understanding of probability in quantum physics, but will also make it possible to derive the basic properties of relativistic space-time. Thus, the theory of the implicate order should provide a common basis for both quantum theory and relativity theory.

To understand the implicate order, Bohm has found it necessary to regard consciousness as an essential feature of the holomovement and to take it into account explicitly in his theory. He sees mind and matter as being interdependent and correlated, but not causally connected. They are mutually enfolding projections of a higher reality which is neither matter no consciousness.

At present, Bohm's theory is still at a tentative stage and, although he is developing a mathematical formalism involving matrices and topology, most of his statements are qualitative rather than quantitative. Nevertheless, there seems to be an intriguing kinship, even at this preliminary stage, between his theory of the implicate order and Chew's bootstrap theory.

Both approaches are based on the same view of the world as a dynamic web of relations; both attribute a central role to the notion of order; both use matrices to represent change and transformation, and topology to classify categories of order. Finally, both approaches recognize that consciousness may be an essential aspect of the universe that will have to be included in a future theory of physical phenomena. Such a future theory may well arise from the merging of the theories of Bohm and Chew, which represent two of the most imaginative and philosophically profound approaches to physical reality.

THE FUTURE OF THE NEW PHYSICS

Afterword to the Fourth Edition

THE VISION

The origin of *The Tao of Physics* lies in the powerful experience I had in the summer of 1969 on a beach in Santa Cruz, described on the opening page of this book. One year later I left California to continue my research at Imperial College in London, and before leaving I designed a photomontage—a dancing Shiva superimposed on tracks of colliding particles in a bubble chamber—to illustrate my experience of the cosmic dance on the beach. This beautiful picture symbolized for me the parallels between physics and mysticism that I had just begun to discover. And one day, in the late fall of 1970, when I sat in my apartment near Imperial College and looked at the picture, I suddenly had a very clear realization. I knew with absolute certainty that the parallels between modern physics and Eastern mysticism would some day be common knowledge; and I also felt that I was best placed to explore these parallels thoroughly and to write a book about them.

Five years later, in the fall of 1975, *The Tao of Physics* was published by Wildwood House in London; in January of 1976 it was published in this country, by Shambhala Publications. Now, twenty-five years later, I want to ask several questions: Did my vision come true? Are the parallels between modern physics and Eastern mysticism indeed common knowledge today or, at least, are they becoming common knowledge? Is my original thesis still valid, or does it need to be reformulated? What has been the main criticism of my thesis and how would I answer that criticism today? And finally, what are my own views today, how are they evolving,

and where do I see the greatest potential for future work? In this afterword I will present my answers to these questions as carefully and as honestly as I can.

IMPACT OF THE BOOK

Over the past twenty-five years *The Tao of Physics* has been received with an enthusiasm that went beyond my wildest expectations. When I wrote it, friends in London told me that ten thousand copies sold would be a big success, and I secretly hoped that, eventually, fifty thousand copies would be sold. Today the sales figures add up to over one million worldwide; *The Tao of Physics* has been translated into more than two dozen languages; further translations are planned, and all editions are still in print and continue to sell well.

This tremendous response has had a strong impact on my life. During the past twenty-five years I have traveled extensively, lecturing to professional and lay audiences in the United States, Europe, and Asia, and discussing the implications of the "new physics" with women and men from all walks of life. These discussions have helped me enormously in understanding the broader cultural context of my work, and I now see that context as the main reason for its enthusiastic acceptance. Again and again I could witness how the book and my lectures generated a strong resonance in people. Again and again men and women would write to me or would tell me after a lecture: "You have expressed something I have felt for a long time without being able to put it into words." These were generally not scientists, nor were they mystics. They were ordinary people, and yet they were extraordinary: artists, grandmothers, businessmen, teachers, farmers, nurses; people of all ages, just as many over fifty as under. Quite a few were old people, and the most moving letters were from women and men over seventy, over eighty, and in two or three cases even over ninety!

What did *The Tao of Physics* touch off in all these people? What was it they had experienced themselves? I have come to believe that the recognition of the similarities between modern physics and Eastern mysticism is part of a much larger movement, of a fundamental change of worldviews, or paradigms, in science and society, which is now happening throughout Europe and North America and which amounts to a profound cultural transformation. This transformation, this profound change of consciousness, is what so many people have felt intuitively over the past two or three decades, and this is why *The Tao of Physics* has struck such a responsive cord.

THE PARADIGM SHIFT

In my second book, *The Turning Point,* I explored the social implications of the current shift of paradigms. My starting point for this exploration was the assertion that the major problems of our time cannot be understood in isolation. They are systemic problems—interconnected and interdependent. Stabilizing world population will only be possible when poverty is reduced worldwide. The extinction of animal and plant species on a massive scale will continue as long as the Third World is burdened by massive debts. Only if we stop the international arms trade will we have the resources to prevent the destruction of the biosphere and of human life.

In fact, the more we study the situation, the more we realize that, ultimately, these problems are just different facets of one single crisis, which is essentially a crisis of perception. It derives from the fact that most of us—and especially our large social institutions—subscribe to the concepts and values of an outdated worldview, to a paradigm that is inadequate for dealing with the problems of our overpopulated, globally interconnected world. At the same time, researchers at the leading edge of science, various social movements, and numerous alternative networks are developing a new vision of reality that will form the basis of our future technologies, economic systems, and social institutions.

The paradigm that is now receding has dominated our culture for several hundred years, during which it has shaped our modern Western society and has significantly influenced the rest of the world. This paradigm consists of a number of ideas and values, among them the view of the universe as a mechanical system composed of elementary building blocks, the view of the human body as a machine, the view of life as a competitive struggle for existence, the belief in unlimited material progress to be achieved through economic and technological growth, and—last, but not least—the belief that a society in which the female is everywhere subsumed under the male is one that is "natural." During recent

decades all of these assumptions have been found severely limited and in need of radical revision.

Such a revision is indeed taking place. The new paradigm that is now emerging can be described in various ways. It can be called a holistic worldview, seeing the world as an integrated whole rather than a dissociated collection of parts. It can also be called an ecological view, if the term "ecological" is used in a much broader and deeper sense than it is commonly used. This broader and deeper sense of "ecological" is associated with a specific philosophical school and, moreover, with a global, grassroots movement known as "deep ecology," which is rapidly gaining prominence. The philosophical school was founded by the Norwegian philosopher Arne Naess in the early seventies with his distinction between "shallow" and "deep" ecology. This distinction is now widely accepted as very useful terminology for referring to a major division within contemporary environmental thought.

Shallow ecology is anthropocentric. It views humans as above or outside of nature, as the source of all value, and ascribes only instrumental, or "use value" to nature. Deep ecology does not separate humans from the natural environment, nor does it separate anything else from it. It does not see the world as a collection of isolated objects but rather as a network of phenomena that are fundamentally interconnected and interdependent. Deep ecology recognizes the intrinsic values of all living beings and views humans as just one particular strand in the web of life. It recognizes that we are all embedded in, and ultimately dependent upon, the cyclical processes of nature. This deep ecological awareness is now emerging in various areas in our society, both within and outside of science.

The ecological paradigm is supported by modern science, but it is rooted in a perception of reality that goes beyond the scientific framework to an awareness of the oneness of all life, the interdependence of its multiple manifestations, and its cycles of change and transformation. Ultimately, such deep ecological awareness is spiritual awareness. When the concept of the human spirit is understood as the mode of consciousness in which the individual feels connected to the cosmos as a whole, it becomes clear that ecological awareness is spiritual in its deepest essence, and it is then not surprising that the new vision of reality is in harmony with the visions of spiritual traditions.

So now I can clearly spell out the broader context of *The Tao of Physics*. The new physics is an integral part of the new worldview that is now emerging in all the sciences and in society. The new worldview is an ecological worldview that is grounded, ultimately, in spiritual awareness. Therefore it is not surprising that the new paradigm, as it emerges in physics and in the other sciences, will be in harmony with many ideas in spiritual traditions.

My original thesis, then, is still valid and has also become much clearer by being reformulated and put in a larger conceptual context. At the same time, it has been confirmed by recent developments in other sciences, and therefore I now stand on much firmer ground. The exploration of systems concepts in biology, psychology, and in the social sciences, which I undertook in *The Turning Point* and *The Web of Life*, has shown me that the systems approach strongly enforces the parallels between modern physics and Eastern mysticism. In addition, the new systems biology and psychology point to other similarities with mystical thought that lie outside the subject matter of physics. These include certain ideas about free will; death and birth; and the nature of life, mind, consciousness, and evolution. The profound harmony between these concepts, as expressed in systems language, and the corresponding ideas in Eastern mysticism, is impressive evidence for my claim that the philosophy of mystical traditions provides a consistent philosophical background to the new scientific paradigm.

This recognition is not yet common knowledge, but it is certainly spreading, both within and outside of science. In the wake of *The Tao of Physics* there have been at least a dozen very successful books about the relationships between modern science and mystical traditions, and there have been several big international conferences on this subject featuring distinguished scientists, including several Nobel laureates, as well as eminent representatives of spiritual traditions. My orginal message has been vastly amplified by these events.

INFLUENCE OF HEISENBERG AND CHEW

I would now like to turn to the new paradigm in science and discuss its main characteristics. I have recently tried to identify a set of criteria for new-paradigm thinking in science. I suggest six criteria; the first two refer to our view of nature, the other four to our epistemology. I believe that these six criteria are common charac-

teristics of new-paradigm thinking in all the sciences, but since this is an afterword to *The Tao of Physics* I shall illustrate them with examples from physics, and I shall also briefly mention how they are reflected in Eastern mystical traditions.

Before I discuss the six criteria I would like to acknowledge with deep gratitude my debt to two outstanding physicists who have been my major sources of inspiration and have decisively influenced my scientific thinking: Werner Heisenberg and Geoffrey Chew. Heisenberg's book *Physics and Philosophy,* his classic account of the history and philosophy of quantum physics, exerted an enormous influence on me when I first read it as a young student. The book has remained my companion during my studies and my work as a physicist, and today I can see that it was Heisenberg who planted the seed of *The Tao of Physics.* I was fortunate to meet Heisenberg in the early seventies. I had several long discussions with him, and when I finished *The Tao of Physics* I went through the manuscript with him, chapter by chapter. It was Heisenberg's personal support and inspiration that carried me through those difficult years, when I went out on a limb to develop and present a radically new idea.

Geoffrey Chew belongs to a different generation than Heisenberg and the other great founders of quantum physics, and I have no doubt that future historians of science will judge his contribution to twentieth-century physics as significant as theirs. While Einstein revolutionized scientific thought with his theory of relativity, and Bohr and Heisenberg, with their interpretation of quantum mechanics, introduced changes so radical that even Einstein refused to accept them, Chew has made the third revolutionary step in twentieth-century physics. His bootstrap theory of particles unifies quantum mechanics and relativity theory into a theory that represents a radical break with the entire Western approach to fundamental science.

I have been fascinated by Chew's theory and philosophy of science ever since I met him about twenty years ago, and I have had the great privilege of a close association and continual interchange of ideas with him. Our regular discussions have been a source of continuing inspiration for me and have decisively shaped my entire outlook on science.

Let me now turn to my six criteria of new-paradigm thinking in science. The first criterion concerns the relationship between the part and the whole. In the mechanistic, classical scientific paradigm it was believed that in any complex system the dynamics of the whole could be understood from the properties of the parts. Once you knew the parts—their fundamental properties and the mechanisms through which they interact—you could derive, at least in principle, the dynamics of the whole. Therefore the rule was: in order to understand any complex system, you break it up into its pieces. The pieces themselves cannot be explained any further, except by splitting them into smaller pieces. But as far as you want to go in this procedure, you will always end up, at some stage, with fundamental building blocks: elements, substances, particles, and so on—with properties that you can no longer explain. From these fundamental building blocks with their fundamental laws of interaction you would then build up the larger whole and try to explain its dynamics in terms of the properties of the parts. This started with Democritus in ancient Greece; it was the procedure formalized by Descartes and Newton, and it has been the accepted scientific view until the twentieth century.

In the new paradigm, the relationship between the part and the whole is more symmetrical. We believe that while the properties of the parts certainly contribute to our understanding of the whole, at the same time the properties of the parts can only be fully understood through the dynamics of the whole. The whole is primary, and once you understand the dynamics of the whole, you can then derive, at least in principle, the properties and patterns of interactions of the parts. This change of the relationship between the part and the whole occurred in science first in physics, when quantum theory was developed. In those years, physicists found to their great amazement that they can no longer use the notion of a part—such as an atom, or a particle—in the classical sense. Parts could no longer be well defined. They would show different properties, depending on the experimental context.

Gradually, physicists began to realize that nature, at the atomic level, does not appear as a mechanical universe composed of fundamental building blocks, but rather as a network of relations, and

that, ultimately, there are no parts at all in this interconnected web. Whatever we call a part is merely a pattern that has some stability and therefore captures our attention. Heisenberg was so impressed by the new relationship between the part and the whole that he used it as the title for his autobiography, *Der Teil und das Ganze*.

The awareness of the unity and mutual interrelation of all things and events, the experience of all phenomena as manifestations of a basic oneness, is also the most important common characteristic of Eastern worldviews. One could say it is the very essence of those views, as it is of all mystical traditions. All things are seen as interdependent, inseparable, and as transient patterns of the same ultimate reality.

The second criterion of new-paradigm thinking in science concerns a shift from thinking in terms of structure to thinking in terms of process. In the old paradigm it was thought that there were fundamental structures, and then there were forces and mechanisms through which these interacted, which gave rise to processes. In the new paradigm, we think that process is primary, that every structure we observe is a manifestation of an underlying process.

This process thinking came into physics with Einstein's relativity theory. The recognition that mass is a form of energy eliminated the concept of a material substance from science and with it also that of a fundamental structure. Subatomic particles are not made of any material stuff; they are patterns of energy. Energy, however, is associated with activity, with processes, and this implies that the nature of subatomic particles is intrinsically dynamic. When we observe them, we never see any substance, nor any fundamental structure. What we observe are dynamic patterns continually changing into one another—a continuous dance of energy.

Process thinking is also a main characteristic of Eastern mystical traditions. Most of their concepts, images, and myths include time and change as essential elements. The more one studies the texts of Hindus, Buddhists, and Taoists, the more it becomes apparent that in all of them the world is conceived in terms of movement, flow, and change. Indeed, it was the image of the cosmic dance of Shiva, in which all forms are continually created and dissolved, that opened my eyes to the parallels between modern physics and Eastern mysticism.

In modern physics, the image of the universe as a machine has been replaced by that of an interconnected, dynamic whole whose parts are essentially interdependent and have to be understood as patterns of a cosmic process. In order to define an object in this interconnected web of relationships, we cut through some of the interconnections—conceptually, as well as physically with our instruments of observation—and in doing so we isolate certain patterns and interpret them as objects. Different observers may do so in different ways. For example, when you identify an electron you may do so by cutting through some of its connections to the rest of the world in different ways, by using different observational techniques. Accordingly, the electron may appear as a particle, or it may appear as a wave. What you see depends on how you look at it.

It was Heisenberg who brought this crucial role of the observer into quantum physics. According to Heisenberg, we can never speak about nature without, at the same time, speaking about ourselves. And this will be my third criterion of new-paradigm thinking in science. I believe that it is valid for all of modern science, and I want to call it the shift from objective science to *epistemic* science. In the old paradigm, scientific descriptions were believed to be objective, that is, independent of the human observer and the process of knowledge. In the new paradigm, we believe that epistemology—the understanding of the process of knowledge—has to be included explicitly in the description of natural phenomena. At this point, there is no consensus among scientists about what is the proper epistemology, but there is an emerging consensus that epistemology will have to be an integral part of every scientific theory.

The idea of the process of knowledge being an integral part of one's understanding of reality is well known to any student of mysticism. Mystical knowledge can never be obtained by detached, objective observation; it always involves full participation with one's whole being. In fact, mystics go far beyond Heisenberg's position. In quantum physics the observer and the observed can no longer be separated, but they can still be distinguished. Mystics in deep meditation arrive at a point where the distinction between observer and observed breaks down completely, where subject and object fuse.

The fourth criterion of new-paradigm thinking is maybe the

most profound of all and the most difficult for scientists to get used to. It concerns the age-old metaphor of knowledge as a building. Scientists speak about *fundamental* laws, referring to the *fundament,* or *basis,* of the building of knowledge. Knowledge has to be built on sound and firm *foundations;* there are *basic* building blocks of matter; there are *fundamental* equations, *fundamental* constants, *fundamental* principles. This metaphor of knowledge as a building with solid foundations has been used throughout Western science and philosophy for thousands of years.

The foundations of scientific knowledge, however, have not always remained solid. They have shifted repeatedly, and several times were completely shattered. Whenever major scientific revolutions occurred, it was felt that the foundations of science were moving. Thus Descartes wrote in his celebrated *Discourse on Method* about the science of his time: "I considered that nothing solid could be built on such shifting foundations." Descartes then set out to build a new science on firm foundations, but three hundred years later Einstein, in his autobiography, wrote the following comment on the development of quantum physics: "It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built."

So again and again, throughout the history of science, there has been a feeling that the foundations of knowledge were shifting, or even crumbling. The current paradigm shift in science again evokes such a feeling, but this time it may be the last time; not because there won't be any more progress or any more changes, but because there won't be any foundations in the future. We may not see it necessary in a future science to build our knowledge on firm foundations, and we may replace the metaphor of the building by the metaphor of the network. Just as we see reality around us as a network of relationships, our descriptions, too—our concepts, models, and theories—will form an interconnected network representing the observed phenomena. In such a network, there won't be anything primary and secondary, and there won't be any foundations.

The new metaphor of knowledge as a network with no firm foundation is extremely uncomfortable for scientists. It was stated explicitly for the first time by Geoffrey Chew more than thirty years ago in the so-called bootstrap theory of particles. According to the bootstrap theory, nature cannot be reduced to any fundamental entities, like fundamental building blocks of matter, but has to be understood entirely through self-consistency. Things exist by virtue of their mutually consistent relationships, and all of physics has to follow uniquely from the requirement that its components be consistent with one another and with themselves.

Over the past thirty years, Chew, together with his collaborators, has used the bootstrap approach to develop a comprehensive theory of subatomic particles, together with a more general philosophy of nature. This bootstrap philosophy not only abandons the idea of fundamental building blocks of matter but accepts no fundamental entities whatsoever—no fundamental constants, laws, or equations. The material universe is seen as a dynamic web of interrelated events. None of the properties of any part of this web is fundamental; they all follow from the properties of the other parts, and the overall consistency of their interrelations determines the structure of the entire web.

The fact that the bootstrap philosophy does not accept any fundamental entities makes it, in my opinion, one of the most profound systems of Western thought. At the same time, it is so foreign to our traditional scientific ways of thinking that it is pursued only by a small minority of physicists. However, the refusal to accept any fundamental entities is quite common in Eastern thought, especially in Buddhism. In fact, it can be said that the contrast between "fundamentalists" and "bootstrappers" in particle physics is paralleled by the contrast between the prevailing currents of Western and Eastern thought. The reduction of nature to fundamentals is basically a Greek approach, which arose in Greek philosophy together with the dualism between spirit and matter. The view of the universe as a web of relationships without any fundamental entities, on the other hand, is characteristic of Eastern thought. It has found its clearest expression and most far-reaching elaboration in Mahayana Buddhism, and when I wrote *The Tao of Physics* I made the close correspondence between bootstrap physics and Buddhist philosophy its high point and finale.

The four criteria for new-paradigm thinking I have presented so far are all interdependent. Nature is seen as an interconnected, dynamic network of relationships that include the human observer as an integral component. Any parts of this network are merely

relatively stable patterns. Correspondingly, natural phenomena are described in terms of a network of concepts, in which no part is more fundamental than any other part.

This new conceptual framework immediately raises an important question. If everything is connected to everything else, how can we ever hope to understand anything? Since all natural phenomena are ultimately interconnected, in order to explain any one of them we need to understand all the others, which is obviously impossible. What makes it possible to turn the bootstrap or web philosophy into a scientific theory is the fact that there is approximate knowledge. If one is satisfied with an approximate understanding of nature, one can describe selected groups of phenomena in this way, neglecting other phenomena that are less relevant. Thus one can explain many phenomena in terms of a few, and consequently understand different aspects of nature in an approximate way without having to understand everything at once.

This insight is crucial to all of modern science and represents my criterion number five: the shift from truth to approximate descriptions. The Cartesian paradigm was based on a belief in the certainty of scientific knowledge, which had been clearly stated by Descartes. In the new paradigm it is recognized that all scientific concepts and theories are limited and approximate. Science can never provide any complete and definitive understanding. Scientists do not deal with truth (in the sense of a precise correspondence between the description and the described phenomena); they deal with limited and approximate descriptions of reality. The most beautiful expression of this criterion I have found is one by Louis Pasteur: "Science advances through tentative answers to a series of more and more subtle questions which reach deeper and deeper into the essence of natural phenomena."

It is interesting, again, to compare this modern scientific attitude to the attitudes of mystics, and here we encounter one of the significant differences between scientists and mystics. Mystics are generally not interested in approximate knowledge. They are concerned with absolute knowledge involving an understanding of the totality of existence. Being well aware of the essential interrelationship of all aspects of the universe, they realize that to explain something means, ultimately, to show how it is connected to everything else. As this is impossible, the mystics often insist that no single phenomenon can be fully explained. They are generally not interested in explaining things but rather in the direct, nonintellectual experience of the unity of all things.

My last criterion, finally, does not express an observation but rather an advocacy. I believe that human survival in the face of the threat of nuclear holocaust and the devastation of our natural environment will be possible only if we are able to radically change the methods and values underlying our science and technology. As my last criterion I advocate the shift from an attitude of domination and control of nature, including human beings, to one of cooperation and nonviolence.

Our science and technology are based on the belief that an understanding of nature implies domination of nature by man. I use the word *man* here on purpose, because I am talking about a very important connection between the mechanistic worldview in science and the patriarchal value system, the male tendency of wanting to control everything. In the history of Western science and philosophy this connection is personified by Francis Bacon who, in the seventeenth century, advocated the new empirical method of science in passionate and often outright vicious terms. Nature has to be "hounded in her wanderings," wrote Bacon, "bound into service" and made a "slave." She is to be "put in constraint," and the aim of the scientist is to "torture nature's secrets from her." These violent images of nature as a female whose secrets have to be tortured from her with the help of mechanical devices is strongly suggestive of the torture of women in the witch trials of the seventeenth century, which were very familiar to Bacon, who was attorney general for King James I. So here we have a crucial and frightening connection between mechanistic science and patriarchal values, which had a tremendous impact on the further development of science and technology.

Before the seventeenth century, the goals of science were wisdom, understanding the natural order, and living in harmony with it. In the seventeenth century this attitude, which one could call an ecological attitude, changed into its opposite. Ever since Bacon the goal of science has been knowledge that can be used to dominate and control nature, and today both science and technology are used predominantly for purposes that are dangerous, harmful, and anti-ecological.

The change of worldview that is now occurring will have to in-

clude a profound change of values; in fact, a complete change of heart—from the intent to dominate and control nature to an attitude of cooperation and nonviolence. Such an attitude is deeply ecological and, not surprisingly, it is the attitude characteristic of spiritual traditions. The Chinese sages of old expressed it beautifully: "Those who follow the natural order flow in the current of the Tao."

CRITICISM OF THE TAO OF PHYSICS

I would now like to move on to the criticism *The Tao of Physics* has encountered over the years. One question I am frequently asked is: how did my colleagues in the physics community accept my basic thesis? As might be expected, most physicists were quite suspicious at first and many even felt threatened by the book. Those who were threatened typically would react with anger. They would make rather insulting and often outright vicious comments, either in reviews or in private conversations, which reflected their own insecurity.

The reason *The Tao of Physics* could be perceived as a threat lies in a widespread misunderstanding of the nature of mysticism. In the scientific community mysticism has generally been thought of as something very vague, fuzzy, nebulous, and highly unscientific. To see one's cherished theories compared with this vague, fuzzy, and suspect activity is naturally quite threatening to many physicists.

This erroneous view of mysticism is really very unfortunate, because when you look at the classic texts of mystical traditions, you will find that deep mystical experience is never described as vague or nebulous but, on the contrary, is always associated with clarity. Typical metaphors to describe the experience would be "lifting the veil of ignorance," "cutting through delusion," "cleansing the mirror of the mind, "perceiving the clear light," "unexcelled complete awakening"—all of which imply great clarity. Mystical experience does go beyond intellectual analysis, so the clarity is of a different kind, but there is certainly nothing vague or fuzzy about these experiences. In fact, the term *enlightenment,* which we use to describe the era of the new Cartesian, scientific approach in eighteenth-century Europe, is one of the oldest and most widely used terms to describe mystical experience.

Fortunately, the erroneous association of mysticism with things vague and unclear is now changing. As Eastern thought has begun to interest a significant number of people and meditation is no longer viewed with ridicule or suspicion, mysticism is being taken more seriously even within the scientific community.

Let me now review some of the most frequent criticisms of *The Tao of Physics,* which I have encountered again and again over the past twenty-five years. First of all, I have to say that I am very pleased that in all the criticism I have had from fellow physicists, not one of them has found any fault in my presentation of the concepts of modern physics. Some would disagree with the emphasis I placed on certain current developments, but to the best of my knowledge nobody has found any factual errors in *The Tao of Physics.* So that part has held up very well for twenty-five years.

There are two arguments that I have heard more than any others in criticism of my basic thesis. The first asserts that today's scientific facts will be invalidated by tomorrow's research. How, then, these critics ask, can something so transient as a model or theory in modern physics be compared to mystical experience, which is supposed to be timeless and eternal? Does this not mean that the truth of mysticism will stand or fall with the theories of modern physics?

This argument sounds very convincing, but it is based on a misunderstanding of the nature of scientific research. The argument is correct in that there is no absolute truth in science. Whatever scientists say is expressed in terms of limited and approximate descriptions, and these approximate descriptions are then improved in subsequent developments in successive steps. However, when theories or models are improved in successive steps, the knowledge does not change in an arbitrary way. Each new theory will be related to the preceding one in a well-defined way, although in a scientific revolution this may not be apparent for a long time. The new theory does not invalidate the old one in an absolute way; it merely improves the approximation. For example, quantum mechanics did not show that Newtonian mechanics is wrong; it merely showed that Newtonian physics is limited.

Now it is important to notice that when such an extension of a theory into new domains occurs, when the approximation is improved by the new theory, not all the concepts of the old theory are abandoned. And I believe that precisely those concepts in our

current theories that will not be invalidated, but will remain, are the ones related to ideas in mystical traditions.

I can say this even about Newtonian physics. One of Newton's key discoveries, maybe *the* key discovery, and certainly one of his most famous, was the discovery that there is a uniform order in the universe. As legend has it, Newton realized in a sudden flash of intuition, when an apple fell from a tree, that the force that pulls the apple toward the earth is the same force that pulls the planets toward the sun. That was the starting point of Newton's theory of gravity, and that insight—that there is uniform order in the universe—is not invalidated by quantum mechanics or relativity theory. On the contrary, it is confirmed and even enhanced by the new theories.

Similarly, I believe that the fundamental unity and interrelatedness of the universe and the intrinsically dynamic nature of its natural phenomena—the two grand themes of modern physics—will not be invalidated by future research. They will be reformulated, and many concepts we hold today will be replaced by a different set of concepts tomorrow. But this replacement will occur in an orderly way, and the basic themes that I use in my comparison with mystical traditions will be enforced, I believe, rather than invalidated. This belief is already being confirmed, not only by new developments in physics, but also by significant new developments in biology and psychology.

The second criticism, which I have also heard again and again, argues that physicists and mystics talk about two different worlds. Physicists deal with a quantum reality that is almost totally irrelevant to ordinary, everyday phenomena, so the argument goes, while mystics deal precisely with those large-scale phenomena, with things in the ordinary world that have almost nothing to do with the quantum world.

Well, first of all, one should realize that the quantum reality is not at all irrelevant to large-scale phenomena. For example, one of the most important physical phenomena in the ordinary world, the solidity of matter, is a direct consequence of certain quantum effects. So we should rephrase the argument and say that mystics do not deal explicitly with the quantum reality, whereas physicists do.

Now, as far as the notion of two different worlds is concerned, my view is that there is only one world—this awesome and mysterious world, as Carlos Castaneda calls it—but this one reality has multiple aspects, dimensions, and levels. Physicists and mystics deal with different aspects of reality. Physicists explore levels of matter, mystics level of mind. What their explorations have in common is that these levels, in both cases, lie beyond ordinary sensory perception. And, as Heisenberg has taught us, if the perception is nonordinary, then the reality is not ordinary.

So we have physicists probing into matter with the help of sophisticated instruments and mystics probing into consciousness with the help of sophisticated techniques of meditation. Both reach nonordinary levels of perception, and at these nonordinary levels the patterns and principles of organization they observe seem to be very similar. The way in which microscopic patterns are interrelated for physicists mirrors the way in which macroscopic patterns are interrelated for the mystics. It is only when we isolate those macroscopic patterns in our ordinary modes of perception that we identify them as ordinary, separate objects.

Another criticism, which has often been raised, agrees that physicists and mystics address themselves to different levels of reality, but argues that of mystics is a higher, spiritual level that includes the lower level of physical phenomena, while the physical level does not include the spiritual.

Well, to begin with, I would observe that calling one level higher and the other lower is a remnant of old-paradigm thinking—the metaphor of the building again, rather than that of the network. However, I agree that physics has nothing to say about other levels, or dimensions, or reality—life, mind, consciousness, spirit, and so on. *Physics* has nothing to say about these levels, but *science* does!

I have come to believe that the new paradigm in science, for which I proposed my six criteria, has found its most appropriate formulation in the now emerging theory of living, self-organizing systems, which I have discussed in detail in *The Web of Life*. It is a theory that applies to individual living organisms, social systems, and ecosystems and that promises to lead to a unified conception of life, mind, matter, and evolution. This systems approach confirms the parallels between physics and mysticism and adds others which go beyond the level of physics: the concept of free will, the concepts of life and death, the nature of mind, and so on. There is a profound harmony between these concepts, as expressed in

the theory of self-organizing systems and the corresponding concepts in mystical traditions.

CURRENT DEVELOPMENTS AND FUTURE POSSIBILITIES

This brings me to current developments and future possibilities in the formulation of the new scientific paradigm. Since I wrote *The Tao of Physics,* I have had an important change of perception regarding the role of physics in this development. When I began to study the paradigm shift in various sciences, I realized that they were all based on the mechanistic worldview of Newtonian physics, and I saw the new physics as the ideal model for new concepts and approaches in other disciplines. In the meantime, however, I have come to recognize that such a view implies that the physical level is, somehow, more fundamental than others. Today I see the new physics, and especially the bootstrap theory, as a special case of the systems approach, dealing with nonliving systems. Even though the paradigm shift in physics is still of special interest, since it was the first to occur in modern science, physics has lost its role as a model for other sciences.

Accordingly, I see future elaborations of the thesis I presented in *The Tao of Physics* not so much in future explorations of parallels between physics and mysticism, but rather in extending these parallels to the other sciences. In fact, this is already being done, and I would like to just mention some of that work. Regarding similarities between mysticism and neuroscience, the best source I know is Francisco Varela, one of the originators of the theory of self-organizing systems. In his book *The Embodied Mind* (1991), coauthored with Evan Thompson and Eleanor Rosch, Varela presents a detailed analysis of the contributions Buddhist theories of mind can make to cognitive science. More recently, Wes Nisker has explored the connections between Buddhist meditation practice and modern evolutionary thought in his book *Buddha's Nature* (1998).

In psychology, a lot of work has been done exploring the spiritual dimensions of psychology and psychotherapy. There is a special branch, transpersonal psychology, dedicated to this task. Stanislav Grof, Ken Wilber, Frances Vaughan, and many others have published books about this subject, many of them preceding *The Tao of Physics,* beginning way back with Carl Gustav Jung.

In the social sciences, the spiritual dimension emerged with E. F. Schumacher's essay "Buddhist Economics," first published in the late sixties and since explored by many groups and alternative networks, both in theory and in practice. Closely connected with these movements is a new form of ecologically oriented politics, known as Green politics, which I see as the political manifestation of the cultural shift to the new paradigm. Spiritual aspects of this political movement have been discussed by Charlene Spretnak in her book *The Spiritual Dimension of Green Politics.*

Finally, I would like to add a few words about my views on Eastern mysticism, which have also changed somewhat over the past twenty-five years. First of all, it was always clear to me, and I said so in *The Tao of Physics,* that parallels of the kind I drew between physics and *Eastern* mysticism could also be drawn to Western mystical traditions. My book *Belonging to the Universe,* coauthored with Brother David Steindl-Rast, discusses some of those parallels. Moreover, I no longer believe that we can adopt Eastern spiritual traditions in the West without changing them in many important ways to adapt them to our culture. My belief has been enforced by my encounters with many Eastern spiritual teachers who have been unable to understand some crucial aspects of the new paradigm that is now emerging in the West.

On the other hand, I also believe that our own spiritual traditions will have to undergo some radical changes in order to be in harmony with the values of the new paradigm. The spirituality corresponding to the new vision of reality I have been outlining here is likely to be an ecological, earth-oriented, postpatriarchal spirituality. This kind of new spirituality is now being developed by many groups and movements, both within and outside the churches. An example would be the creation-centered spirituality promoted by Matthew Fox and his colleagues at Holy Names College, Oakland, California.

These are just some of the developments that are now occurring in this process of emergence of a new paradigm. My own contribution over the past twenty-five years has been to offer a first synthesis of the emergent new paradigm and its social implications in *The Turning Point* and to refine that synthesis further in collaboration with many outstanding colleagues.

During those years I have met many extraordinary people to whom I owe a great deal. Many lasting friendships have resulted from these encounters. When I decided to write *The Tao of Physics*

thirty years ago, I took a step that involved considerable professional, emotional, and economic risks, and I was completely alone in taking it. So were many of my friends and colleagues who took similar steps in their fields. Today we all feel much stronger. We are embedded in the multiple alternative networks of what I have called the "rising culture"—a multitude of movements representing different facets of the same new vision of reality, gradually coalescing to form a powerful force of social transformation.

NOTES

1 THE WAY OF PHYSICS

Chapter 1: Modern Physics—A Path with a Heart?

1 J. R. Oppenheimer, *Science and the Common Understanding*, pp. 8-9.
2 N. Bohr, *Atomic Physics and Human Knowledge*, p. 20.
3 W. Heisenberg, *Physics and Philosophy*, p. 202.
4 Ashvaghosha, *The Awakening of Faith*, p. 78.
5 *Brihad-aranyaka Upanishad*, 3.7.15.

Chapter 2: Knowing and Seeing

1 W. Heisenberg, *Physics and Philosophy*, p. 125.
2 Chuang Tzu, trans. James Legge, ch. 26.
3 *Katha Upanishad*, 3.15.
4 *Kena Upanishad*, 3.
5 Quoted in J. Needham, *Science and Civilisation in China*, vol. II, p. 85.
6 W. James, *The Varieties of Religious Experience*, p. 388.
7 B. Russell, *History of Western Philosophy*, p. 37.
8 D. T. Suzuki, *On Indian Mahayana Buddhism*, p. 237.
9 J. Needham, op. cit., vol. II, p. 33.
10 From the *Zenrin kushu*, in I. Muira & R. Fuller Sasaki, *The Zen Koan*, p. 103.
11 D. T. Suzuki, *Outlines of Mahayana Buddhism*, p. 235.
12 In Carlos Castaneda, *A separate Reality*, p. 20.
13 Lao Tzu, *Tao Te Ching*, trans. Ch'u Ta-Kao, ch. 41.
14 Ibid., ch. 48.
15 Chuang Tzu, op. cit., ch. 13.
16 In P. Kapleau, *Three Pillars of Zen*, pp. 53-4.
17 A. K. Coomaraswamy, *Hinduism and Buddhism*, p. 33.
18 In A. W. Watts, *The Way of Zen*, p. 183.
19 Ibid., p. 187.

Chapter 3: Beyond Language

1 W. Heisenberg, *Physics and Philosophy*, p. 177.
2 D. T. Suzuki, *On Indian Mahayana Buddhism*, p. 239.
3 W. Heisenberg, op. cit., pp. 178-9.