ONE HUNDRED YEARS OF QUANTUM PHYSICS

Ulrich Mohrhoff
Sri Aurobindo International Centre of Education
Pondicherry 605002 India

(Talk presented at SAICE, 5 May 2001.)

In 1894, one year after Sri Aurobindo's return from England, the physicist Albert Michelson confidently declared that "the more important fundamental laws and facts of physical science have all been discovered". In the physics section of the 1898-99 catalogue of the University of Chicago one reads the following: "It seems probable that most of the grand underlying principles have been firmly established and that further advances are to be sought chiefly in the rigorous application of these principles to all the phenomena which come under our notice." The mood prevalent at the end of the 19th century was that the then known laws of physics are capable of explaining all past and future experimental findings.

Let's take a look at some of the things that were known but not understood at the time. There was much evidence for the existence of atoms, but it was indirect, and the question of their existence was not yet completely settled. At any rate, the structure of the atom was completely unknown. The Periodic Table of the elements had no theoretical foundation. The spectral lines associated with each chemical element—thousands of pages of collected data—were a mystery. Radioactivity was a cause of considerable bafflement. So was the photoelectric effect and the spectrum of a glowing hot object. In the last decade of the 19th century the journals of physics were filled with papers on essentially every measurable property of matter (atomic spectra, viscosity, elasticity, electrical and thermal conductivity, indices of refraction, etc. etc.), and nobody knew how to explain these data.

Then, exactly in 1900, Max Planck found the law that perfectly describes the spectrum of a glowing hot object. This law was absolutely irreconcilable with the physics of his time, which is now called "classical physics". All attempts to explain the spectrum of a glowing object by classical means had met with spectacular failure. If classical physics were right, you would get blinded by ultraviolet light whenever you looked at the burner of your stove! Thank God, classical physics is wrong. Planck not only found the right law, he also hit on the right explanation: Matter, when heated, emits electromagnetic radiation (including light) not continuously but in small chunks that were dubbed "quanta". This is how quantum physics was born.

The next great embarrassment for physics came in 1911, when Ernest Rutherford demonstrated that the positive charge in an atom, as well as most of the atom's mass, was concentrated in a tiny nucleus, about 50 000 times smaller than the entire atom. It was then assumed that the atomic electrons orbit the nucleus

much like planets orbit a star. Yet classical electromagnetic theory predicts that such orbiting electrons would radiate away their energy, and would spiral inward until they got sucked into the atomic nucleus after about a millionth of a millionth of a second. Luckily for us, the atoms out of which, among other things, our bodies are made, are eminently stable. In short, when applied to the atom, classical physics turned out to be a complete failure.

Two years later, in 1913, Niels Bohr postulated that the angular momentum of an atom was quantized, which meant that it could change only discontinuously, and that it could take on only certain discrete values. This simple but from a classical point of view outrageous assumption explained why atoms emit and absorb light only in discrete packets now known as “photons”, and why atoms are stable. It also made it possible to predict, with remarkable accuracy, the form of the hydrogen spectrum, which till then had been a complete mystery.

The next great idea came ten years later, in 1923. If electromagnetic waves can behave like particles (photons) then, so the French physicist Louis de Broglie reasoned, why should not particles behave like waves? It was a time when the most crazy ideas proved to be the most fruitful. Bohr’s comment on an idea proposed at the time was: “Crazy, but not crazy enough to be true.” Here is de Broglie’s argument: Suppose the electron in a hydrogen atom is a wave that propagates around the nucleus. As it goes round and round, it catches up with itself, and so it interferes with itself. If it is not to obliterate itself, it must interfere with itself constructively. This leads at once to the simple condition that the circumference of the electron’s orbit must be an integral multiple of the electron’s wavelength. In this way de Broglie explained what Bohr had left unexplained: Why the angular momentum of the atom was quantized in the first place.

Then a tumultuous series of events occurred that culminated in the greatest scientific revolution of all time. Here are some of those events: In 1924 Satyendra Bose found the correct statistical law for the particles that are now called “bosons”. In 1925 Uhlenbeck and Goudsmit discovered the spin of the electron, a most curious property that has no classical analogue. In the same year Werner Heisenberg, helped by Max Born and Pascual Jordan, discovered matrix mechanics, the first full-fledged version of nonrelativistic quantum mechanics. In 1926 Erwin Schrödinger invented wave mechanics, which turned out to be another formulation of the same theory, and which explained the electron waves postulated by de Broglie. In 1927 Wolfgang Pauli extended wave mechanics to include particles with spin, and in 1928 Paul Dirac formulated the relativistic version of quantum mechanics, which implies the existence of anti-matter and explains why the electron has a spin. The first anti-matter particle, the positron, was discovered four years later.

The crucial year of this revolution was 1926. I suppose you are aware that in the same year Sri Aurobindo arrived at a turning point in his yoga. On the 24th of November the light and the power of the overmind descended into his physical

being. Subsequently he withdrew from outer contacts to concentrate on the more difficult task of “bringing down the supermind”. The timing perhaps is no mere coincidence.

A key role in the creation of quantum mechanics was played by the Danish physicist Niels Bohr. His vision guided the quantum revolution. In 1913 he rejected classical physics wholesale, initiated the creation of an entirely new physics, and rallied physicists to complete it. His vision was eventually fulfilled, though it took twelve years and a new generation of young physicists. Most of the key players in the creation of quantum mechanics (Pauli, Heisenberg, Dirac, Jordan, Fermi) were in their early twenties. Schrödinger, ten years older, would not accept the philosophical implications of his own theory. Planck never took his quantum hypothesis seriously. Einstein, having himself invented some of the key concepts of quantum mechanics, rejected quantum mechanics as a fundamental and complete theory. Lord Kelvin, in a letter congratulating Bohr on his explanation of the hydrogen spectrum, admitted that he would never understand it. He recognized that the radically new physics Bohr was after would need to come from unfettered minds.

Those were fabulous years to be a physicist. Whatever problem one tackled with the new tool of quantum mechanics could be successfully solved, and hundreds of problems from the experimental work of decades were around, asking to be tackled.

In the 75 years since 1926 many discoveries have been made, but not a single one that did not fit neatly into the theoretical framework of quantum mechanics. No experiment or observation has ever given the lie to quantum mechanics. Which is why you may be asking yourself: Then why should I learn the old classical physics? Here is why: Classical physics is an excellent approximation to quantum physics whenever you are dealing with things that are huge compared to the size of an atom. To calculate the trajectory of a bullet, a planet, or a billiard ball you don’t need quantum physics. On the other hand, the technical applications of classical physics are rather limited. Presently as much as 30 percent of the gross national product of the USA involves technology that is based on quantum mechanics. For instance, without quantum mechanics there would be no lasers and therefore no CD players; there would be no microchips and therefore no personal computers, and so on.

More importantly, if we want to understand the true nature of matter, we must study the exact laws that govern the behavior of matter, and these are the laws of quantum mechanics. We get nonrelativistic physics out of relativistic physics if we pretend that the velocity of light is infinite, and we get classical physics out of quantum physics if we pretend that the radius of an atom is zero. It is clear that a true knowledge of matter cannot be built on such patently false assumptions. If we base our understanding on approximate laws, we will not obtain an approximate understanding; we will get nowhere.

At the beginning of the 20th century a mass of empirical data were waiting to be explained, but there wasn't any theory to explain them. Now, at the beginning of the 21st century we have a theory that appears to be able to successfully account for every physical experiment carried out to date. So what remains to be done, apart from collecting more experimental data and explaining them with the help of this theory? What remains is the biggest task of all: making sense of it. The 20th century gave us the right formulas. It may be hoped that in the 21st century physicists will come to understand what they mean.

Currently the majority of physicists would agree with Richard Feynman, who in 1965 shared the Nobel price for taming the mathematical complexities of quantum electrodynamics. He wrote: "I think it is safe to say that no one understands quantum mechanics". Why is that so? I can give you the answer straight-away: Because physicists think in materialistic terms. If you try to understand quantum mechanics in these terms, it truly makes no sense. If on the other hand you adopt a spiritual world view, quantum mechanics makes perfect sense. This is easier said than done, however, for we are all by nature materialists.

The essential feature that makes a world view materialistic is that it takes the multiplicity of things for the ultimate truth or fact. But this is also the essential characteristic of our mental consciousness, as Sri Aurobindo has told us in so many words. For the mind, multiplicity comes first. It understands unity only in terms of agglomeration or aggregation. It neither perceives nor understands the essential oneness of things. We are materialists for the simple reason that our consciousness is mental rather than supramental.

The essential feature of a spiritual world view is the opposite: oneness. There is only one thing, one single reality out of which everything is made and in which everything is contained. Here in India this is called Brahman. The nature of Brahman is absolutely beyond human comprehension. Considering that all our words refer to particular manifestations of Brahman, what could we possibly say about Brahman itself, except that ultimately everything is Brahman and everything is contained in Brahman?

Now listen to what quantum mechanics has to say—if we allow it to say what it has to say and do not force it into a conceptual framework that renders it incomprehensible. It tells us that the original truth or fact is oneness rather than multiplicity. It describes a world that is created top-down, by the differentiation of one thing, one single reality, rather than bottom-up, by a process of agglomeration or aggregation. It tells us that by entering into spatial relations with itself, or by adopting positions relative to itself, this single formless reality created space and acquired the aspect of a multiplicity of particles. It tells us that the forms of things are made of the positions of formless particles relative to formless particles, and that at bottom all particles are one and the same thing. It tells us that space consists of relations between this one thing and itself, and that space therefore exists inside this one thing. In short, quantum mechanics tells us that everything in

the world not only is made of but also is contained in one single reality, for which it doesn't yet have a name.

Now I ask you, what is quantum mechanics talking about? What is this single reality if not the Brahman of Indian philosophy? quantum mechanics explains nothing less than how Brahman went about manifesting the material world. Do not expect the creation of the world to bear any similarity to the way we humans create things. We create inside the world, one thing out of other things. Quantum mechanics deals with the creation of everything out of something that is both everything and unlike everything. No wonder that only the craziest of ideas were acceptable to Bohr! Also do not expect the creation of forms out of—and inside—a formless reality to be something that you can visualize or imagine. You can imagine only the result—this world of forms. Heisenberg was helped in his discovery of the mathematical formalism of quantum mechanics by an extraordinary insight: He argued that if atoms are to explain what the world looks like, they cannot look like anything in the world. If you really want to understand atoms, you must think of them as bridges between formless Brahman and this world of forms.

Let’s take a closer look a the humble hydrogen atom, which has proved so fertile a testing ground for the emergent quantum theory. A single proton forms the nucleus, which is made up of three formless particles—three quarks. The form of the nucleus consists of the positions of the quarks relative to each other. The form of the hydrogen atom consists of this form plus the position of a formless electron relative to the nucleus. So we have four formless entities and their relative positions. Then where is matter? Where is this stuff that seems to fill out all so-called material things—things whose forms seem to be boundaries or surfaces rather than sets of relative positions? If this is your idea of matter—a stuff that is extended in space and enclosed within surfaces,—then I must tell you that it exists only in your minds. The real stuff of the world is formless Brahman plus the spatial relations that exist between Brahman and Brahman.

You must realize that what you see—the world as it appears to you—is made up by your mind and your brain out of exceedingly scanty information: The photons that impinge on the retinas of your eyes, the sound waves that jiggle your ear drums, etc. If you study how the brain processes visual information, you come to understand why the world appears to you made up of objects that are filled with some extended stuff and enclosed within surfaces. It’s the brain’s doing. It has nothing to do with the world as it is in itself, the world investigated by science. The real reason why a material object is extended in space—why it has a volume—is not that it is made of some stuff that is extended in space. What “fluffs out” material things is the spatial relations that constitute the shapes of material things—the relative positions of matter's formless constituents.

This way of fluffing out matter works only because the spatial relations between its constituent particles are fuzzy—they lack precise values. If you are

Brahman, and if you want to create material forms by entering into spatial relations with yourself, you have no choice but to let these relations have fuzzy values. The proper language for talking about fuzzy values is the language of statistics, and for this reason quantum mechanics is formally a statistical theory—a theory that at bottom does nothing but assign probabilities to the possible results of possible measurements.

The deeper reason why the world appears to us as it does is to be found in the nature of mental consciousness, for the brain works as it does because the mind works as it does—not the other way round, as we are prone to think. As Sri Aurobindo says, "the brain is not the creator of thought, but itself the creation, the instrument and here a necessary convenience of the cosmic Mind". Here is how Sri Aurobindo describes the characteristic working of the mind:

Mind in its essence is a consciousness which measures, limits, cuts out forms of things from the indivisible whole and contains them as if each were a separate integer. Even with what exists only as obvious parts and fractions, mind establishes this fiction of its ordinary commerce that they are things with which it can deal separately and not merely as aspects of a whole.... It is this essential characteristic of Mind which conditions the workings of all its operative powers, whether conception, perception, sensation or the dealings of creative thought. It conceives, perceives, senses things as if rigidly cut out from a background or a mass....

That is why things appear to us as if they had been cut out from some extended stuff with the help of three-dimensional cookie cutters, and why the forms of things appear to be surfaces, and why inside these surfaces there seems to be an impenetrable stuff, and why it seems impossible for two things to be in the same place, and why the matter in one thing appears to be different from the matter in another thing, and so on. Quantum mechanics tells us that all of these appearances are deceptive. There is no extended stuff from which things are cut out, stuff that comes packaged inside surfaces. There is no impenetrable stuff—it is quite possible for two particles to be in the same place. Nor is the stuff in one thing different from the stuff in another thing. The only stuff there is is Brahman, and this is absolutely the same in every particle; it doesn't get parceled out.

The moral of this story is that the original creative principle—the conscious power that created the world, or by which Brahman created the world—cannot be mental. If the world were created by a mental consciousness, it would be more or less as it looks to our consciousness. Quantum mechanics tells us that the world was created both out of Brahman and inside Brahman, as a web of spatial relations between Brahman and Brahman. It couldn't be more different from how it appears to us. Quantum mechanics thus confirms what Sri Aurobindo has been telling us in so many words: The original creative principle is supramental rather than mental. The creation proceeds from the One, by a process of differentiation that creates relations between the One and the One. This is not how the mind works, but it is

exactly how the supermind works.

Unlike classical physics, quantum physics is therefore in perfect agreement with Sri Aurobindo's explanation of the origin and nature of matter. Sri Aurobindo's concept of matter and quantum mechanics complement each other beautifully. We are here, in this school, in the unique position of being able to study both. Neither the chapters on matter in *The Life Divine* nor quantum mechanics are easy, but we aren't here to do easy things. If you study them both, you will find how beautifully they illuminate each other. Sometimes what Sri Aurobindo wrote throws light on a difficult quantum-mechanical concept, and sometimes quantum mechanics makes you understand a difficult passage in *The Life Divine*.