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The Interpretation of Quantum Mechanics:
Dublin Seminars(1949-1955)
and other unpublished essays
Erwin Schrödinger:
edited and with an Introduction by Michel Bitbol
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Curiosity Killed the Cat – But Which of its 9 Lives?

"I am opposing, as it were, the whole of quantum mechanics." - -**Erwin Schrodinger, op. cit., page 19**

Although the theories of Special and General Relativity are *technically* much more difficult than the Quantum Theory, the *conceptual* challenges posed by the latter surpass - with one exception- those of any other modern scientific theory.[1] The Quantum quandries continue to bedevil us up to the most recent issues of Science, Scientific American, or Discover magazines. Although the subtle ramifications of the Quantum Theory are as timely as tomorrow's scientific journals, they have not, in essence, brought us much closer to their resolution since they were first elaborated in the 1920's and 30's.

[1] **The exception is mathematical set theory with its paradoxes, Gödelian proscriptions , and hierarchies of transfinite numbers.**

It is a matter of no little consequence that two of the principal architects of the theory, Albert Einstein and Erwin Schrödinger, both in the first rank of scientists, rejected the equilibrium form of the theory that stabilized in the 20's under the name of the *Copenhagen Interpretation* . Each did more than merely criticize the prevailing orthodoxy: both worked out thought experiments , communicated to posterity in the form of Zen koans, to show us what's wrong with it.

Einstein's koan is collaborative. It is known as the "Einstein, Podolsky, Rosen" (EPR) thought experiment. Stated in 1935, it was officially refuted by Niels Bohr. A modified form involving hidden variables was put forth by David Bohm in 1938. Then John von Neumann proved that hidden variable theories were prohibited by the axioms of his operator algebras. Then a mistake was found in his proof. In 1962, EPR was vengefully vindicated by Bell's Theorems , then translated into (real life) ,experiments that have confirmed it. Bell's theorems, and these experiments, are telling us that space is either non-local (something *can* be in two places at the same time), or non-separable (a measurement anywhere in the universe can *instantaneously* affect all measurements everywhere else.)

Around the same time, 1935, Erwin Schrödinger gave us the story of a cat that, following quantum logic, is both dead and alive simultaneously. This in itself is not so surprising: most humans are in such a state almost always. Schrödinger's Cat Paradox says that if we try to find out if the cat is dead or alive, we not only kill it but may cause it to vanish altogether! [2]

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[2]The cat is in 2 "eigenstates", *alive* and *dead* , that are 'superimposed' before measurement. The observation or measurment pushes the system into the dead state. However, there is also a positive probability that the cat will not even be inside the box when its opened.

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In this collection of his profound seminars and letters: *The Interpretation of Quantum Mechanics* , Schrödinger doesn't talk very much about his cat. He is too busy telling us about everything else that is wrong with just about *all* of the traditional formulations of quantum mechanics.

And there are so many of them! I cannot think of any other scientific theory in which an identical intuition has been recast into so many different mathematical languages, each with its own machinery, formalisms and algorithms: Heisenberg's matrices, Bohr's complementary experiments, Born's probabilities, De Broglie's pilot waves, Schrödinger's waves, Dirac's brackets (*literally <bras- and -kets>*) ,Popper's scattering distributions, von Neumann's operators, Reichenbach's 3-valued logics ,Feynman's path integrals, Mackey's axioms, Birkhoff's lattices, Jordan's algebras, Gleason and Piron's quantum logics.............

Schrödinger rejected almost everything - including his own wave, ψ ! He did this at least four times in his career. The private interpretation of ψ 's connection to physical reality that is the subject of all of the lectures in this book was arrived at in the late 1950's .

The stages in his thinking are presented in the excellent introduction written by Michel Bitbol. To summarize them briefly: in 1926, Schrödinger imagined that his wave, a function that ranges over an abstract mathematical construction known as complex phase space, (but evolves in real time) , could also represent something that really existed within atomic structure, a kind of "standing wave" similar to the pilot waves of Louis deBroglie. By 1928 he had come to consider his wave-function as merely a kind of shorthand, a "Hilfbegriff" [3], that entered into calculations, like the minus

[3] Such a word merits such a font registration

signs we use to figure out how much money we are worth, although everybody who does not work in the federal government knows that there is no such thing as anti-money.

Shortly after that he allowed himself to be persuaded to believe in the Copenhagen Interpretation. This codification, completed in the mid 50's, which many people still think of when they hear the words, *The Quantum Theory* **,has 5 components:**

(1) *Heisenberg's Uncertainty Principle* **: Accuracy in the measurement of position varies inversely with the accuracy in the measurement of momentum, (mass times velocity).**

(2) *The Complementarity Principle of Niels Bohr* **: there are two mutually exclusive kinds of experimental arrangement: those which indicate the presence of particles ; those which indicate waves.**

(3) *Schrödinger's wave equation,(ψ)* **: This is an ingenious construction which allows one to translate physical laws from the visible world to the microscopic or quantum world. ψ has no direct physical interpretation, but in some sense contains all the information it is possible to extract from a given system.**

(4) *Max Born's statistical interpretation* **: $\psi\psi^*$ does have physical meaning, and can be treated, (when normalized), as a probability density.**

(5) *John von Neumann's operator algebras* **: this brilliant mathematical reformulation of the whole of quantum theory was completed in the mid 50's. One can with justice call his textbook the Bible of modern quantum mechanics.[4] Even Schrödinger's critique is couched in its language.**

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[4]Mathematical Foundations of Quantum Mechanics. Princeton University Press 1955

Schrödinger's definitive break with Copenhagen came in 1935 with the publication of his cat paper[5]. Quoting from Bitbol's introduction:

"The year 1935 marked a noticeable change. A few weeks after the appearance of the Einstein-Podolsky-Rosen paper.....Schrödinger published both his 'cat-paper' and a more technical article about the 'entanglement' of wave-functions. In these two pieces of work, Schrödinger expressed a well-documented skepticism about the current interpretation of quantum mechanics, even though he was admittedly unable to offer any satisfactory alternative."

It has generally been assumed that in his final years Schrödinger had made his peace with Copenhagen. These lecture notes from the 50's show that his radical rejection of commonly accepted ideas about the meaning of quantum mechanics continued to develop up to his death in 1961 at the age of 73.

This collection of his lecture notes prepared for colloquia in Dublin, Ireland and Cambridge, U.S.A. between 1940 and 1955 is filled with insights and criticisms, combined with a host of 'thought experiments' that make his already very clear expositions particularly lucid: this is material for both the abstract intellectual and the pictorial-intuitive mind. He worries about everything, although two convenient fictions give him the most trouble: the Gestalt of *the particle* , and the theatrical format of the *collapse of the wave packet* .

(A.) Particles:

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[5]**"Die gegenwärtige Situation in der Quantenmechanik"** ***Naturwissenschaften*** **23, 807-812, 823-828, 844-849; 1935, This paper is reprinted in English in the indispensable reference work "Quantum Mechanics and measurement", editors J.A. Wheeler and W.K. Zurek, Princeton UP, 1983**

One discovers sooner or later that Schrödinger really wants us to give up the concept of particle entirely. He observes that the identification of observables as *particles* requires four assumptions:

(1) A list of attributes that give it identity: mass, location, charge, spin, etc.

(2) A way of distinguishing between one particle and another.

(3) A way of re-identifying the particle at different moments of time as being in some sense the same object.

(4) Virtuality: in some sense the particle "exists" even when we are not looking at it.[6] This is the essence of the cat paradox: Things must be there even when they aren't in the eigenstates.

In his judgment this is asking too much of the natural order. Quantum theory forces us to abandon conditions (2), (3) and (4), and even make serious modifications in (1) . Modern physics considers all electrons , for example, to be absolutely identical in mass, shape , density and charge. Since they are what are technically known as fermions, their aggregate behavior cannot be described by normal statistics, but by Fermi-Dirac statistics, which are based on the assumption that, treated as a gas or cloud, electrons cannot be distinguished, even theoretically. There must then be some other way of distinguishing them, and that can only be the chronicle of their past histories, that is to say, their paths or trajectories. But once again, quantum theory, particularly in the extreme formulation of Richard Feynman, denies them the right to have continuous trajectories. To quote Schrödinger:

"To me, giving up the path seems giving up the particle." [7]

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[6]Bishop Berkeley has not once stopped turning over in his grave since 1900 ,when Max Planck midwifed his quantum.
[7]Letter to H. Margenau, 4/12/55 AHQP,microfilm 37,sec 9

Again from Bitbol's introduction (page 7) :

"It is at this point that Schrödinger's hyper-revolutionary attitude arises. Is it coherent to keep speaking of "particles" if they have nothing like a trajectory? Schrödinger's answer is a definite **no.** *When he asked "what is a particle which has no trajectory or no path?" it was just a somewhat ironical way of emphasizing that(...) the particles, in the naive sense of the old days,* **do not exist."**

Rejecting the particle is but the prelude to his grander agenda: raising the "wave" to total ontological hegemony. Schrödinger maintains that a strict adherence to the interpretation of all sub-atomic data as wave phenomena can, if properly carried out, (i) resolve all the paradoxes, (ii) satisfy the two sides of Bohr's complementarity, (iii) do away with Born's statistical interpretation, and (iv) replace the 'schizophrenia' , if you like , of the "intervention model" of the collapse of the wave packet, by a continuous picture of the natural order in which there is no necessity for positing a line of demarcation between the observable and the measuring instrument.[8]

There are at least 4 arguments, he says, which ought to convince us that we need to replace our particle metaphors by wave language:

(1) Whenever we speak of particles our minds form pictures of objects which possess many traits that don't exist in quantum-mechanical descriptions: shape, trajectories, locality, etc.

(2) The notion of "physical reality" has nothing at all to do with the contents of static moments--always essentially particulate in character. What we should mean by the *real* **is the** *law-like ordering of nature* **. In quantum**

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[8]**Schrödinger's concept of the 'entanglement' of wave-fronts, described with thoroughness in his second Dublin lecture , pgs. 39-54**

terms this is given by the evolution of the ψ-function through time, exclusively a wave phenomenon.

(3) Since wavefronts interact independently, (*the acoustic phenomenon that allows us to distinguish between different conversations, a rumbling truck , and a juke box all active together* **) , the wave picture can be adapted to the Principle of Superposition of States, which he believes is a fundamental of nature. Schrödinger was probably the first expositor, at his level of authority, of the Everett model of "all possible worlds" that now monopolizes popular science writing:**

" The idea that they be not alternatives but all really happening simultaneously seems lunatic to [a conventional quantum theorist] , just impossible." **(pg.19)**

(4) The ψ-functions, in contrast to particles, can be distinguished. They have 'individuality'.[9]

As already stated, the second Dublin lecture is devoted largely to his objections to the concept of the *collapse of the wave packet.* **This expression is a convenient slogan for von Neumann's complex interpretation of** *the* ***central experience of quantum mechanics****(!).*[10] **Roughly speaking, by observing a sub-atomic system, the scientist ruptures its causal continuity. This interference with nature causes the observed event/object to "collapse" all of its modes of vibration into a single one , registered on the measuring instrument as some actual phenomenon.**

For example, any heated natural element gives off spectral lines. The Bohr model of the atom leads us to interpret these as the transition frequencies of electrons jumping across atomic orbits. Each element has a

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[9]But only in abstract phase space!
[10]Supra-mystical Anthropism?

characteristic light spectrum that identifies it more infallibly than a fingerprint. It is because of these spectra that we know the relative proportions of the quantities of the natural elements in stars. These transitions are the "eigenstates", and when an electron is not making such a transition, it is, in some sense, in all of the eigenstates at once. However, we only "see" the transitional states when we pass the light from the heated element through a spectrometer that picks up only the transition frequencies and no others: we "collapse the wave packet" , reducing a *continuous* underlying reality to the appearance of *discrete* energy particles, called quanta.

On page 45, Schrödinger indicates that he wants to replace the collapse model by a Causal Algebra,[11] structured by functional composition, that would preserve the universality and continuity of the wave function before, during, and after the experiment. The interaction between the "(mathematical) operator of the observable" and the "(mathematical) operator of the instrument", leads to an "entanglement of wave-functions" that causes the continuous, even differentiable content of the eigenvalue set of the observable to be absorbed into a discontinuous or discrete spectrum that we see. He shows us how this programme might be carried out, but confesses that he cannot come up with good examples that could be applied to real experimental situations. In fact, he describes a construction given by John von Neumann himself , but as he himself admits: "*It does not refer to any actual experiment, it is purely analytic.*" (pg.83)

It would take too long to detail the wealth of observations that fill this small 151 page paperback, the many evidences of Erwin Schrödinger's

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[11]**See *Causal Algebras : Mathematical Models for Philosophical Choices* , Dr. Roy Lisker, Ferment Press,$8.00**

shrewdness, wisdom and acumen. On pages 33 to 35 he makes several remarks that raise the same issues as my 1992 paper that follows this review. On page 42 he points out that the term "eigenfunction" in quantum mechanics has a very different meaning from the way it is used in mathematics, which leads to all sorts of problems when we want to go freely from one to the other. His basic objection to the Copenhagen Interpretation is summed up in a single sentence on page 53: *"You have to assume explicitly that the system can never be found in a non-eigenstate, when this quantity is measured!"*

On page 70 he points out that the formalism of the ψ - function, which he himself invented, is such that it is *theoretically* **impossible to back-construct a wave function from any amount of data. This is further elaborated on page 82:**

"With all the milliards of dollars and pounds the governments now lavish on the promotion of physics, I maintain that nobody has ever yet been able to procure a physical system whose wave-function was known to him or to anybody else."

On page 97 he points out that the *particles* **of quantum theory have not one thing to do with the** *elementary particles* **of modern physics. In fact, he says, elementary particles relate neither to** *waves* **nor** *particles* **, but to the more basic notions of** *observables* **and** *states* **.**

These are only a few of the riches to be found in this rewarding text. It comes out at a good time, when traditional quantum theory is being subjected to heavy criticism from all sides: when, that is to say, the field is thriving.

The Ox Bow edition is deficient in certain respects. A brief account of Erwin Schrödinger's life and career would have helped us in placing these lectures in context. According to an encyclopedia I have in front of me, the Dublin Institute for Advanced Study, created by Eamon deValera to shelter

Schrödinger and other refugee scientists during WWII, always maintained a sizable roster of famous scientists. These were not talks designed only for graduate students only, but also for important scientists including Dirac, Born, Thirring, Mautner, Peng and others. None of this is given any mention in the book.

Nor is any information given about Michel Bitbol, an interesting writer about whom we would like to learn more. It lacks an index; always a plus in a scientific text. The book also lacks what one might call "connective tissue", some sort of on-going historical commentary that would relate what Schrödinger was thinking to the research and thought of his immediate contemporaries .

The paperback version is very attractive, designed for readability, and sturdy. All in all OxBow has done a good job.

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