Heisenberg and Schrodinger Famous Physicists of the 20th and its Contributions - An Overview

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Abstract

This paper deals with works of Heisenberg and Schrodinger famous physicists of the 20th century and their contribution to the society. By its very nature, inventive thought usually requires breaking away from the status quo. Usually something unanticipated, innovation can mark the death of old methods and the starting point of new paradigms. Theoretical physicists are the shooting stars of science. They do their best work in their 20's, then seemingly burn out. Theorists commonly retire, intellectually speaking, by their 30's to become "elder statesmen" of physics. Four of the giants of quantum mechanics - Paul Dirac, Werner Heisenberg, Wolfgang Pauli and Niels Bohr - all crafted their greatest theories as very young men. (Dirac and Heisenberg, in fact, were accompanied by their mothers to Stockholm to accept their Nobel Prizes.) Dirac summed up the phenomenon in a poem he once wrote, the sentiment of which is that a physicist is better off dead once past his 30th birthday.Heisenberg introduced his famous relations in an article of 1927, entitled Ueber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. A (partial) translation of this title is: "On the anschaulich content of quantum theoretical kinematics and mechanics". Here, the term anschaulich is particularly notable. Apparently, it is one of those German words that defy an unambiguous translation into other languages. Heisenberg's title is translated as "On the physical content …" by Wheeler and Zurek (1983). His collected works translate it as "On the perceptible content …", while Cassidy's biography of Heisenberg, refers to the paper as "On the perceptual content …". Literally, the closest translation of the term anschaulich is "visualizable". But, as in most languages, words that make reference to vision are not always intended literally. Seeing is widely used as a metaphor for understanding, especially for immediate understanding. Hence, anschaulich also means "intelligible" or "intuitive"

How, then, does one explain Erwin Schrodinger? At the age of 38, positively geriatric for a theorist, Schrodinger changed forever the face of physics with four exquisite papers, all written and published in a six-month period of theoretical research that is without parallel in the history of science.They are interpretable independently of these concepts and, further, their validity on the empirical level still provides the physical content of the theory. During this time he discovered wave mechanics, which greatly accelerated the progress of quantum theory. J. Robert Oppenheimer called Schrodinger's theory "perhaps one of the most perfect, most accurate, and most lovely man has discovered," and the great physicist and mathematician Arnold Sommerfeld said wave mechanics "was the most astonishing among all the astonishing discoveries of the twentieth century.'

Key words: quantum theory, Schrodinger, Heisenberg, quantum mechanics, Paul Dirac.

Introduction

By 1925 quantum theory had already modified, if not supplanted, the classical Newtonian view that everything was a continuum: that energy could be emitted in an infinite range of amounts, that light undulated in continuous waves, and so forth. Quantum theory, on the other hand, held that everything is quantized, or expressed in multiples of a basic unit. Energy and matter are distributed in discrete amounts; you must have multiples of certain minimum quantities. The universe is lumpy - a pile of rice as opposed to a scoop of mashed potatoes. Niels Bohr had extrapolated this theory to the arena of the atom. The electrons in an atom, he said, occupy quantized orbits. They can leap from one fixed orbit to another, but may not rest between these states. This made the theorists uneasy. Where, for instance, do the electrons go between orbits? And what are the rules that govern their quantum leaps?

Enter Werner Heisenberg, at the age of 24 already considered, next to Einstein, the most brilliant physicist in the world. Heisenberg, with help from Max Born and Pascual Jordan, came up with a matrix theory, which supposedly explained the travels of the electron by a complex form of mathematics called matrices. There remained some problems, however. Heisenberg's solution did not allow one to visualize what was happening inside the atom. Also, the smartest physicists in the world found the equations impossible to solve.Along came Louis de Broglie. This young French physicist presented a most unusual thesis for his doctoral degree at the University of Paris. He put forth the proposition that, at certain velocities, an electron behaves more like a wave than a particle. De Broglie's thesis examiners couldn't make head or tail out of this concept and neither could most theorists, with the exception of two: Albert Einstein, who applauded it, and Erwin Schrodinger, who exploited it.

A few days before Christmas, 1925, Schrodinger, a Viennese-born professor of physics at the University of Zurich, took off for a two-and-a-half-week vacation at a villa in the Swiss Alpine town of Arosa. Leaving his wife in Zurich, he took along de Broglie's thesis, an old Viennese girlfriend (whose identity remains a mystery) and two pearls. Placing a pearl in each ear to screen out any distracting noise, and the woman in bed for inspiration, Schrodinger set to work on wave mechanics. When he and the mystery lady emerged from the rigors of their holiday on Jan. 9, 1926, the great discovery was firmly in hand. Schrodinger's wave equation, published only a few weeks later, was immediately accepted as "a mathematical tool of unprecedented power in dealing with problems of the structure of matter," according to Mr. Moore. By 1960, more than 100,000 scientific papers had appeared based on the application of the equation. Schrodinger lavishly thanked his physicist friend Hermann Weyl for his help with the mathematics. (He was perhaps indebted to Weyl for an even greater favor: Weyl regularly bedded down Schrodinger's wife, Anny, so that Schrodinger was free to seek elsewhere the erotic inspiration he needed for his work.) Three more papers followed in quick succession, each an arrow to the hearts of the likes of Heisenberg, Born and Bohr, who had labored so long and so unsuccessfully on the problem. Schrodinger's equations were easy for physicists to solve. More important, for the first time, one could visualize what was happening to particles in the atom.

The physical basis of Schrodinger's theory was this: Ordinarily, one can think of a particle as a dot; but one should really visualize it as a little clump of waves, a "standing wave" in today's parlance. Don't bother thinking of electrons as particles, Schrodinger said, and forget about this quantum-leap business. Just apply rules of wave interactions. Beyond constructing a mechanism for particle interactions, Schrodinger linked the quantum world of the microscopic to the classical world of macroscopic objects. Waves now existed, figuratively speaking, in atoms as well as in oceans. Physicists could understand waves, which they had endlessly studied. Schrodinger's wave mechanics saved quantum theory and at the same time threatened its underpinnings. It utilized continuous phenomena, waves, to explain the discontinuous quantum world of the atom.

For this, Schrodinger earned the Nobel Prize in Physics (in 1933) and the undying enmity of the great Werner Heisenberg. Schrodinger had destroyed Heisenberg's precious matrices. Schrodinger was old. He was an outsider from Zurich, not part of the Gottingen-Copenhagen quantum clique. Worst of all, he was right. The clique felt compelled to retaliate. Pauli referred to Schrodinger's views as "Zurich superstitions." Heisenberg was less charitable, calling the theory "abominable" and worse. Heisenberg would later eat his words. In 1927 he incorporated Schrodinger's wave functions as an integral part of his uncertainty principle.

Objective:

This paper intends to understand the works of Schrodinger and Heisenberg and their contribution to the society. From artists and determined dreamers to daredevils and studious scientists, here we look at 10 of humanity’s greatest innovators, and the special attributes which helped them to help the world progress.

Schrodinger and Heisenberg competent, undistinguished physicists

Schrodinger was nothing more than a competent, undistinguished physicist who had revealed no hint of his extraordinary brilliance early in his career. After his great discovery, he never again exhibited this brilliance. And in the 1920's world of theoretical physics in which collaboration was the norm, Schrodinger chose to work alone. Moreover, he had no love for the branch of physics he had saved. He was the Lone Ranger of quantum mechanics - a stranger who rode into town, saw a problem, solved it, then virtually rode away from it all.

Walter Moore has written an admirable book about this intriguing man. Mr. Moore, an emeritus professor of physical chemistry at the University of Sydney, Australia, and the author of the textbook "Physical Chemistry," sets out to do more than chronicle Schrodinger's life and work. He attempts to find the roots of genius in a man's life; in this case, he is searching for the secret behind the greatest six-month burst of creativity in scientific history. How does one explain Schrodinger's sudden burst of genius, uncommon even in that post-World War I era of uncommon geniuses? The man appears to have been extraordinarily common. The picture of Schrodinger that emerges from Mr. Moore's book is one of a conceited, selfish, childish, hopelessly middle-class nerd, one who worried about his awards and medals and was obsessed with his pension and salary.

Mr. Moore informs us that Schrodinger kept a series of "little black books" in which he recorded the names of all his loves with a code to indicate "the denouement," as the author puts it, of each affair. He unbuttons Schrodinger's code and reveals a life of stunning promiscuity. Schrodinger admitted he detested his wife, Anny, sexually, and took on a series of mistresses, three of whom bore him illegitimate daughters. Immediately after his triumph in wave mechanics, he agreed to tutor 14-year-old twin girls named Withi and Ithi Junger. Schrodinger called the latter "Ithy-bitty" and regularly fondled her during their math lessons. He finally seduced her when she was 17, assuring her she wouldn't get pregnant. She did, Schrodinger immediately lost interest in her, and the girl underwent a disastrous abortion that left her sterile. He then took on Hilde March, the wife of his assistant Arthur March, as his mistress, and she bore him a daughter. March, ever the dutiful assistant, agreed to be named the father, while his wife moved eventually into the Schrodinger household to serve as Schrodinger's "second wife." Well, the great man's sordid affairs go on and on, and Mr. Moore faithfully serves up all of the titillating details. He concludes that Schrodinger needed "tempestuous sexual adventures" to inspire his great discoveries. Unfortunately, the notebook for the critical year 1925 has disappeared, so the woman who erotically guided Schrodinger to his famous wave equation, "like the dark lady who inspired Shakespeare's sonnets," the biographer tells us, "may remain forever mysterious."

Quantum world and Vedanta

As for Vedanta, the recent rash of new-age physics writers will be chagrined to learn that Schrodinger himself rejected the idea that philosophical conclusions can be drawn from wave mechanics or any work in theoretical physics. But Mr. Moore believes that Vedanta - which holds that through the Self one can comprehend the essence of the universe - may have been instrumental in Schrodinger's discovery of wave mechanics. Much has been written about Schrodinger's insistence that the electron is not a particle; it doesn't just behave like a wave, he said, but rather is a wave, as real as a radio wave or an ocean wave. This belief of Schrodinger's, soon discarded by other physicists, is played down by Mr. Moore, who points out that Schrodinger actually wavered on this point very early on.

After wave mechanics, Schrodinger attempted, and failed (as did Einstein), to forge a unified field theory, but he did write a bizarre and wonderful book entitled "What Is Life?" in which he was the first to suggest that a chromosome is nothing more than a message written in code. The book inspired at least two young scientists to seek careers in biology - James Watson and Francis Crick, who eventually were given the Nobel Prize in Physiology or Medicine for decoding DNA.

It came as a big surprise, therefore, when one year later, Erwin Schrödinger presented an alternative theory, that became known as wave mechanics. Schrödinger assumed that an electron in an atom could be represented as an oscillating charge cloud, evolving continuously in space and time according to a wave equation. The discrete frequencies in the atomic spectra were not due to discontinuous transitions (quantum jumps) as in matrix mechanics, but to a resonance phenomenon. Schrödinger also showed that the two theories were equivalent.

Even so, the two approaches differed greatly in interpretation and spirit. Whereas Heisenberg eschewed the use of visualizable pictures, and accepted discontinuous transitions as a primitive notion, Schrödinger claimed as an advantage of his theory that it was *anschaulich*. In Schrödinger's vocabulary, this meant that the theory represented the observational data by means of continuously evolving causal processes in space and time. He considered this condition of *Anschaulichkeit* to be an essential requirement on any acceptable physical theory. Schrödinger was not alone in appreciating this aspect of his theory. Many other leading physicists were attracted to wave mechanics for the same reason. For a while, in 1926, before it emerged that wave mechanics had serious problems of its own, Schrödinger's approach seemed to gather more support in the physics community than matrix mechanics.

Heisenberg on Schrödinger's theory

Understandably, Heisenberg was unhappy about this development. In a letter of 8 June 1926 to Pauli he confessed that "The more I think about the physical part of Schrödinger's theory, the more disgusting I find it", and: "What Schrödinger writes about the *Anschaulichkeit* of his theory, … I consider *Mist*" (Pauli 1979: 328). Again, this last German term is translated differently by various commentators: as "junk" (Miller 1982) "rubbish" (Beller 1999) "crap" (Cassidy 1992), "poppycock" (Bacciagaluppi & Valentini 2009) and perhaps more literally, as "bullshit" (Moore 1989; de Regt 1997). Nevertheless, in published writings, Heisenberg voiced a more balanced opinion. In a paper in *Die Naturwissenschaften* (1926) he summarized the peculiar situation that the simultaneous development of two competing theories had brought about. Although he argued that Schrödinger's interpretation was untenable, he admitted that matrix mechanics did not provide the *Anschaulichkeit* which made wave mechanics so attractive. He concluded:

to obtain a contradiction-free anschaulich interpretation, we still lack some essential feature in our image of the structure of matter.

The purpose of his 1927 paper was to provide exactly this lacking feature.

Heisenberg's argument

Let us now look at the argument that led Heisenberg to his uncertainty relations. He started by redefining the notion of *Anschaulichkeit*. Whereas Schrödinger associated this term with the provision of a causal space-time picture of the phenomena, Heisenberg, by contrast, declared:

We believe we have gained anschaulich understanding of a physical theory, if in all simple cases, we can grasp the experimental consequences qualitatively and see that the theory does not lead to any contradictions. Heisenberg 1927: 172)

His goal was, of course, to show that, in this new sense of the word, matrix mechanics could lay the same claim to *Anschaulichkeit* as wave mechanics.

To do this, he adopted an operational assumption: terms like "the position of a particle" have meaning only if one specifies a suitable experiment by which "the position of a particle" can be measured. We will call this assumption the "measurement=meaning principle". In general, there is no lack of such experiments, even in the domain of atomic physics. However, experiments are never completely accurate. We should be prepared to accept, therefore, that in general the meaning of these quantities is also determined only up to some characteristic inaccuracy.

As an example, he considered the measurement of the position of an electron by a microscope. The accuracy of such a measurement is limited by the wave length of the light illuminating the electron. Thus, it is possible, in principle, to make such a position measurement as accurate as one wishes, by using light of a very short wave length, e.g., \(\gamma\)-rays. But for \(\gamma\)-rays, the Compton effect cannot be ignored: the interaction of the electron and the illuminating light should then be considered as a collision of at least one photon with the electron. In such a collision, the electron suffers a recoil which disturbs its momentum. Moreover, the shorter the wave length, the larger is this change in momentum. Thus, at the moment when the position of the particle is accurately known, Heisenberg argued, its momentum cannot be accurately known:

At the instant of time when the position is determined, that is, at the instant when the photon is scattered by the electron, the electron undergoes a discontinuous change in momentum. This change is the greater the smaller the wavelength of the light employed, i.e., the more exact the determination of the position. At the instant at which the position of the electron is known, its momentum therefore can be known only up to magnitudes which correspond to that discontinuous change; thus, the more precisely the position is determined, the less precisely the momentum is known, and conversely. (Heisenberg 1927: 174–5)

The interpretation of Heisenberg's uncertainty relations

Heisenberg's relations were soon considered to be a cornerstone of the Copenhagen interpretation of quantum mechanics. Just a few months later, Kennard (1927) already called them the "essential core" of the new theory. Taken together with Heisenberg's contention that they provide the intuitive content of the theory and their prominent role in later discussions on the Copenhagen interpretation, a dominant view emerged in which the uncertainty relations were regarded as a fundamental principle of the theory.

The interpretation of these relations has often been debated. Do Heisenberg's relations express restrictions on the experiments we can perform on quantum systems, and, therefore, restrictions on the information we can gather about such systems; or do they express restrictions on the meaning of the concepts we use to describe quantum systems? Or else, are they restrictions of an ontological nature, i.e., do they assert that a quantum system simply does not possess a definite value for its position and momentum at the same time? The difference between these interpretations is partly reflected in the various names by which the relations are known, e.g., as "inaccuracy relations", or: "uncertainty", "indeterminacy" or "unsharpness relations". The debate between these views has been addressed by many authors, but it has never been settled completely. Let it suffice here to make only two general observations.

First, it is clear that in Heisenberg's own view all the above questions stand or fall together. Indeed, we have seen that he adopted an operational "measurement=meaning" principle according to which the meaningfulness of a physical quantity was equivalent to the existence of an experiment purporting to measure that quantity. Similarly, his "measurement=creation" principle allowed him to attribute physical reality to such quantities. Hence, Heisenberg's discussions moved rather freely and quickly from talk about experimental inaccuracies to epistemological or ontological issues and back again.

However, ontological questions seemed to be of somewhat less interest to him. For example, there is a passage (Heisenberg 1927: 197), where he discusses the idea that, behind our observational data, there might still exist a hidden reality in which quantum systems have definite values for position and momentum, unaffected by the uncertainty relations. He emphatically dismisses this conception as an unfruitful and meaningless speculation, because, as he says, the aim of physics is only to describe observable data. Similarly, in the Chicago Lectures, he warns against the fact that the human language permits the utterance of statements which have no empirical content, but nevertheless produce a picture in our imagination. He notes,

One should be especially careful in using the words "reality", "actually", etc., since these words very often lead to statements of the type just mentioned. (Heisenberg 1930: 11)

So, Heisenberg also endorsed an interpretation of his relations as rejecting a reality in which particles have simultaneous definite values for position and momentum.

Uncertainty relations or uncertainty principle?

Let us now move to another question about Heisenberg's relations: do they express a *principle* of quantum theory? Probably the first influential author to call these relations a "principle" was Eddington, who, in his Gifford Lectures of 1928 referred to them as the "Principle of Indeterminacy". In the English literature the name uncertainty principle became most common. It is used both by Condon and Robertson in 1929, and also in the English version of Heisenberg's Chicago Lectures (Heisenberg 1930), although, remarkably, nowhere in the original German version of the same book (see also Cassidy 1998). Indeed, Heisenberg never seems to have endorsed the name "principle" for his relations. His favourite terminology was "inaccuracy relations" (*Ungenauigkeitsrelationen*) or "indeterminacy relations" (*Unbestimmtheitsrelationen*). We know only one passage, in Heisenberg's own Gifford lectures, delivered in 1955–56 (Heisenberg 1958: 43), where he mentioned that his relations "are usually called relations of uncertainty or principle of indeterminacy". But this can well be read as his yielding to common practice rather than his own preference.

But does the relation qualify as a principle of quantum mechanics? Several authors, foremost Karl Popper (1967), have contested this view. Popper argued that the uncertainty relations cannot be granted the status of a principle on the grounds that they are derivable from the theory, whereas one cannot obtain the theory from the uncertainty relations. (The argument being that one can never derive any equation, say, the Schrödinger equation, or the commutation relation, from an inequality.)

Popper's argument is, of course, correct but we think it misses the point. There are many statements in physical theories which are called principles even though they are in fact derivable from other statements in the theory in question. A more appropriate departing point for this issue is not the question of logical priority but rather Einstein's distinction between "constructive theories" and "principle theories".

Einstein proposed this famous classification in Einstein 1919. Constructive theories are theories which postulate the existence of simple entities behind the phenomena. They endeavour to reconstruct the phenomena by framing hypotheses about these entities. Principle theories, on the other hand, start from empirical principles, i.e., general statements of empirical regularities, employing no or only a bare minimum of theoretical terms. The purpose is to build up the theory from such principles. That is, one aims to show how these empirical principles provide sufficient conditions for the introduction of further theoretical concepts and structure.

The prime example of a theory of principle is thermodynamics. Here the role of the empirical principles is played by the statements of the impossibility of various kinds of perpetual motion machines. These are regarded as expressions of brute empirical fact, providing the appropriate conditions for the introduction of the concepts of energy and entropy and their properties.

Conclusion

Schrodinger never accomplished his greatest dream, to reinstate classical physics with its almost Vedantic continuity over the lumpiness of quantum mechanics. Perhaps as a revenge against his quantum enemies, he did leave behind a paradox that torments scientists to this day. The paradox of Schrodinger's cat links the squishy quantum microworld, with its statistical probabilities that replace cause and effect, to the Newtonian macroworld of everyday objects that obey hard-and-fast rules of causality. Put a cat in a box, Schrodinger said, with a flask of lethal acid. In a Geiger tube, place a small quantity of radioactive material, so little that in the course of an hour one atom has a 50-50 chance of disintegrating, setting off the Geiger counter, which will trigger a hammer that shatters the flask of acid that will kill the cat. So, after one hour is the cat dead or alive? Schrodinger said that if one used the quantum wave function to describe the entire system, "the living and the dead cat" would be "smeared out (pardon the expression) in equal parts." Schrodinger intended his paradox as a sarcastic comment on quantum probability or "blurred variables." One can resolve the uncertainty, he explained, by looking in the box.

Schrodinger himself, however, must always remain somewhat blurred, despite Walter Moore's heroic efforts in this important book about the century's most enigmatic scientist. For the average reader, "Schrodinger" may be tough going, but it serves up a wonderfully frank and unglamorized, albeit narrow, history of the development of quantum mechanics. Much of the science in this book is only opaquely explained, but explaining science is not the book's main function. It is an attempt to analyze a soul, and in that respect, it surpasses even "The Double Helix" by James Watson in its examination of the most visceral drives of a great scientist.

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