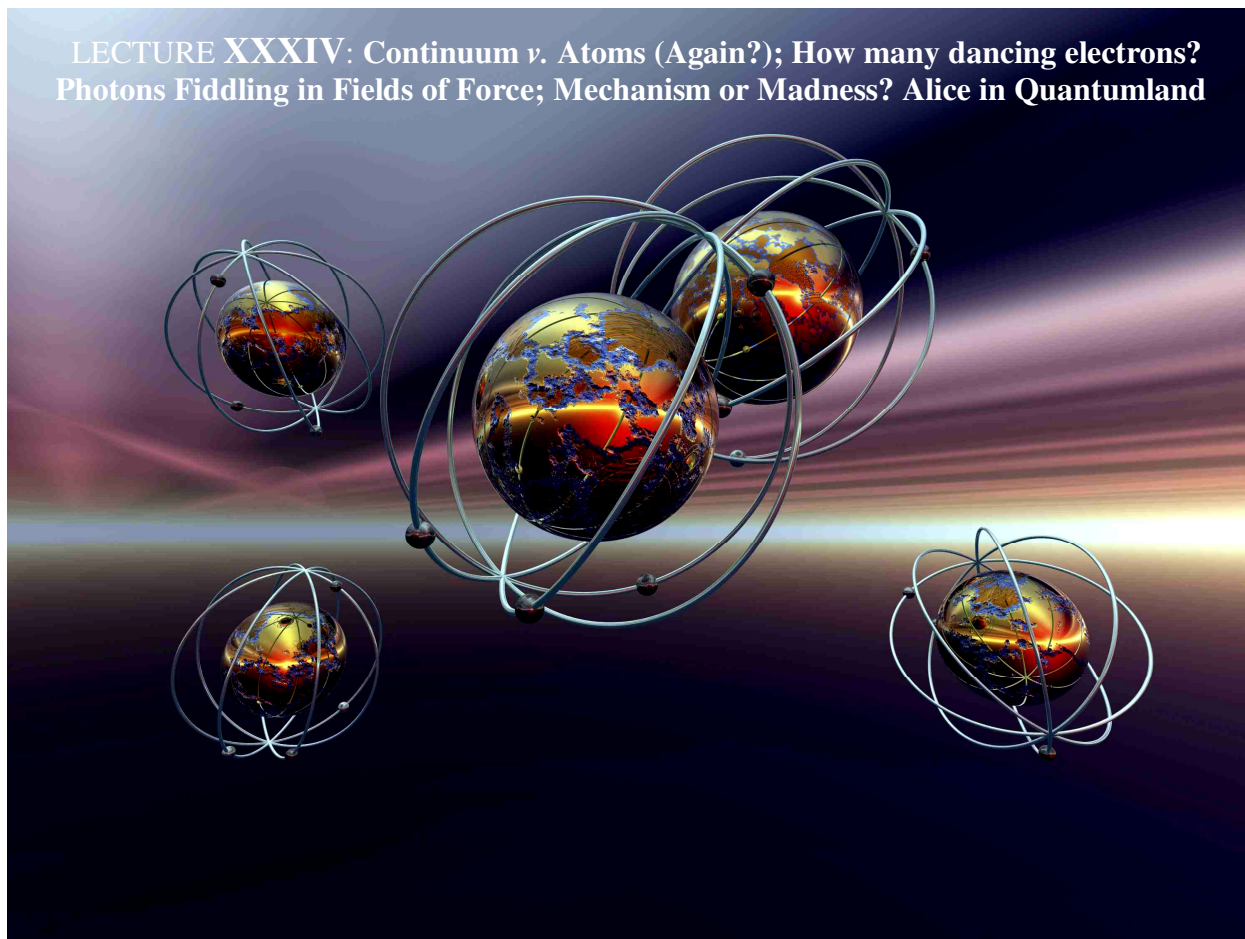


COSMOLOGY without HEADACHES

(Lecture Series)

(compiling, transcribing, researching, editing always in progress)

LECTURE XXXIV: Continuum v. Atoms (Again?); How many dancing electrons?
Photons Fiddling in Fields of Force; Mechanism or Madness? Alice in Quantumland



Atoms and the Ether—Particles of Light and Waves of Iron:

In this discussion we are going to meet with an unusual group of gifted thinkers, all of them contemporaries of the most famous man of modern science, Albert Einstein. These are the forward-looking theorists whose ideas and interactions shaped modern physics, transforming the world while also directing us toward what has been called the ‘crisis of modernity’; individuals whose names and accomplishments should be known and remembered by all intelligent and educated people born and reared under the auspices of Western Civilization and living with the advantages and challenges engendered by today’s advanced technology.

Until the mid-nineteenth century science had made progress by the dedication of talented and brilliant amateurs. Universities did not have departments of chemistry and physics with tricked out laboratories in which to do research and pass on new information and ideas. The great new age was spawned in part by a German chemist named Justus Liebig, who convinced the Grand Duke of Hesse in 1824 to provide some space and some funds for equipment for an organic chemistry laboratory at the University of Giessen, mostly in the interest of advancing pharmacy; a facility that would attract many students interested generally in science and set them on their various paths of discovery.

Soon afterward Robert Bunsen urged the Duke of Baden to put together a more industrial-oriented chemical laboratory in an old monastery at Heidelberg. These not only provided returns in the realm of inventions and products, but became centers of instruction for a new breed of scientist. The movement toward fully staffed departments is often marked from the date of the appointment of Helmholtz at Berlin. Theoretical physics began to develop alongside modern philosophy and medicine, and Germany took the lead in science and industry, as well as in precision engineering and technology.

The general (if unsettled but rarely questioned) understanding of the world near the end of the 19th century was somewhat paradoxical. It had long been considered or assumed in chemistry that atoms were real, though there was nothing in chemistry resembling a deep atomic theory and little thought was given by chemists as to how the atom might be revealed. This was probably because, from a chemist's point of view, there seemed no reason to question the atom's existence since theory or supposition was working just fine in practice. Though it was merely a useful hypothesis, most chemists had come to believe in its truth and were not much concerned that it was unexplainable. After all, physics had hardly done more: In regard to the consistency of matter, a not at all deeply examined sort of atomic theory was widely but not universally accepted.

There were still highly respected scientists, however, who did not believe the atomic scenario. In terms of light and electricity and magnetism Maxwell's field theory was now becoming the thing to think. Paradoxically, a magnetic or electric field was considered immaterial and wave theory seemed to dominate as far as the means of transmission of energy was concerned. It was unclear and seldom debated as to what exactly were these fields or how the waves of light and electromagnetism actually traveled. Was there a continually changing and renewing continuum through empty space (though that seemed impossible in terms of the contemporary mechanical theory) or was energy carried along in real-time waves: vibrations set up in a kind of infinitely wispy but unified medium called ether (in the manner that sound is propagated through a gaseous atmosphere). Here is the simplified conundrum: experiments on light had 'proved' it was made up of particles, if that was what you were trying to discover; but also 'proved' it was a wave, if that was the sort of test you were conducting. Thus the paradox:

- (a) *If light is a particle*, it needs mostly empty space—a void—if it is to travel from source to observer. If space is not a vacuum; especially if it is some sort of all-pervading gas, however thin it might be, there will be hindrance to the passage of particles (not to mention resistance to the great masses of planetary and stellar dimensions) and thus an easily detectable scattering of photons. Needing to travel over millions and millions of parsecs, photons from distant stars and galaxies would hardly be able to reach us at all if space were to any degree substantial. If space is void, that would preclude the wave hypothesis.
- (b) *If light is a wave* it needs space to be not only substantial, but infinitely dense and rigid in order to act as a medium—to 'wave' sufficiently so as to transport the energy of electromagnetism, thus precluding the particle concept.
- (c) Therefore *both ideas must be wrong*. Yet experiments seem to show *both ideas to be correct*, thus precluding 'space' from being either substantial or insubstantial—*neither ether nor void*.

The King of Siam might have exclaimed “It’s a puzzlement!” Light as granular must have seemed the least likely of the two visions, especially on the heels of Maxwell’s field equations. If only by default, it was the *ether* version of ‘space’ that continued to be generally accepted as the only reasonable means of energy transmission. How else could waves of light be formed? I.e., space was considered as completely filled with ether—or perhaps more accurately, there exists infinite ether rather than empty space. Assuming the ether, how can massive things like planets and stars and whole galaxies move through it without apparent resistance? Perhaps the ether, some speculated, is very fine in its nature: so light and wispy that it is pushed aside without noticeable expenditure of energy; without friction, much as we push the air aside with a wave of our hand experiencing no noticeable resistance. If so, ether must actually clump around matter as it is pushed aside and we ought to be able to notice a difference in its density. We ought to be able to at least detect it. Not only that, since it is everywhere, it could provide an inertial state: an all pervading substance at absolute rest, relative to which we might find our own absolute velocity through the Universe. But it might be so fine as to be inter-penetrable with matter: so that it passes through the tiny spaces even in atoms themselves, just as certain electromagnetic fields had proved able to do by radiating through material that was opaque to light, thus passing unnoticed even through our finest instruments of detection. But that would mean that atoms, or even electrons, were not the smallest of ‘things’. Also, the ether itself would have to include space between its tiny particles—if the ether were actually considered to be substantial. And of course *it must be substantial*. If it were not substantial, it could not be set into the motion of waves by light-energy and electrical charge. So ether must be ‘something’: some sort of pseudo-material that extends through (or *is*) space. It must be stationary relative to both atomic and cosmic scale things, so that it coincides with the Newtonian concept of absolute space and so that light can travel in straight lines. That being the case, and since it clearly reacts to light and electromagnetic energy by carrying those waves, there simply must be some degree of resistance to motion of mass through it—an ether ‘drag’ that should be somehow detectable.

The Michelson-Morley Experiment:

Enter experimental physicist Albert A. Michelson [1852-1931] & chemist Edward Wm. Morley [1838-1923] who devised one of the most famous enterprises in the physics of the 19th century: the **Michelson-Morley Experiment** [Cleveland; 1887]. Using Michelson’s invention, the interferometer, and splitting a beam of light into two beams traveling at right angles to one another and then reflecting them back together again where they would enter a specially designed detector. Directing one beam in the direction of the Earth’s considerable velocity through space and the other perpendicular to that movement, when the beams were brought back together their waves should be out of phase (due to the ‘drag’ of the stationary ether having very slightly slowed one of the beams in its course) and thus ought to display interference patterns that could be measured by the *interfere-o-meter*. Despite all precautions to prevent any chance of experimental skewing, no matter how they arranged their equipment and how often and how carefully they performed the experiment, the expected difference of interference between the beams did not occur. They concluded, therefore, they had proved there was no ‘drag’; thus the ether was non-existent and should be considered a falsified hypothesis. For this work, Albert Michelson became the first US Nobel Prize winner in 1908.

The ether, however, would not be so swiftly dismissed. Though it showed no resistance whatever to masses in motion, not unlike insubstantial angels and deities or, perhaps in this case, more in the manner of a demon, it mightily resisted exorcism from the world of ideas. A great effort was made by those who cared about consistency in logic (an increasing new breed called ‘theoretical physicists’, many of whom had a stake in the reality of a wave-carrying medium—not to mention salvaging materialism itself) to explain away the Michelson & Morley results while preserving their precious ether.

Ingenious hypotheses were constructed hoping to restore the classical integrity of physics but to no avail. One of the best of those flights of fancy, the *Fitzgerald-Lorentz contractions*, must have seemed the least likely when it was floated. Here was a fantasy presented, perhaps first, by **George Francis Fitzgerald** [1851-1901] that the length of a measuring rod, or any material item in motion, is actually shortened in the direction of its movement in a direct relationship with the increase of velocity of the moving system—and then by Dutch physicist, **Hendrik Antoon Lorentz** [1853-1928] who, in trying to save the ether from the Michelson-Morley result, refined this formula by adding the concept of ‘local time’ [in his paper: *Simplified Theory of Electrical and Optical Phenomena in Moving Systems* of 1899], differing from but still depending on Newton’s absolute or universal time. Thus, by contracting space and stretching time proportionately to motion and velocity, one could say Michelson & Morley had been ‘tricked’ by Nature into thinking the ether did not exist. What had really happened in their experiment was that all the measuring devices and instruments and, presumably, the light-waves themselves had been altered, ‘contracted’ in the direction of the Earth’s movement by exactly the amount necessary to compensate for the ether drag—and that this, as a newly discovered law of physics, meant no experiment could ever detect the ether or its affect (apart from the implication of its existence due to the surmise that light-waves could not be set in motion without it).

It was not easy to accept this explanation as actually true. The highly respected French mathematician, cosmologist, and science philosopher, Poincaré, called it a “wonderful invention”, and to this formula for preserving the laws of motion and electromagnetism when moving from one frame of reference to another of different direction or velocity he gave the name *Lorentz transformations*. Here Lorentz actually stood on the very threshold of ‘special relativity’—so close that when that concept was refined and first announced in Einstein’s paper *Elektrodynamik* [1905] it was called the *Lorentz-Einstein theory*. “For me personally” Einstein said later “he [Lorentz] meant more than all the others I have met on my life’s journey”. Einstein himself, since his relativity theory was in part an outgrowth of the Fitzgerald-Lorentz contractions, did not assume Michelson & Morley had negated the ether. Instead, *special relativity* nullified their experiment and indicated that, whether it existed or not, ether could not be discovered by the methods of physics. Contrary to popular belief and what is generally taught in introductory science and astrophysics courses, not all physicists agree over the ether question. It has been suggested by some, in fact, that the curved or warped space described by the *general* theory of relativity actually requires that space must have substance. More on that will be entertained later on, when we discuss relativity theory.



The Divisible Atom:

At this time, very near the 20th century (and ever since their conception by Democritus or Leucippus), atoms were thought, by those who believed in them, to be the smallest possible particles of reality: indivisible kernels of existence and perhaps eternal. In 1897, however, **J.J. Thomson** [1856-1940] showed that cathode rays were negatively charged particles with mass much smaller than a hydrogen atom: the first indication of sub-atomic entities. These he called **electrons** and proposed that they were associated with atoms and had to do with atomic number per the Mendeleev periodic table of elements. Based on this discovery he envisioned the atom as something like a tiny bread pudding with the electrons as raisins lodged here and there throughout the mass. The pudding was positively charged while electrons are negative, so electrons and ‘pudding’ are mutually attracted, but electrons are repulsive to each other so the atom was thought to exist in a kind of quivering equilibrium, with the electrons still liable to coaxing out by sufficient electric or magnetic or maybe even brute mechanical forces.

A young physicist, Neils Bohr, having just earned his Ph.D., came from Denmark to work with Thomson at Cambridge.

Neils Bohr [1885-1962]

Presenting problems that could not be solved using what George Gamow referred to as Thomson’s ‘watermelon’ version of the atom, Bohr’s seemingly heretical views tended to engender heated debates rather than an explanation of heat.

Disappointed with Cambridge, Bohr found a more bendable ear in **Ernst Rutherford** [1871-1937] and moved to Manchester where Rutherford was already engaged in his famous scattering experiments: studying the internal structure of atoms by bombarding them with what were known as alpha particles emitted by the newly discovered radioactive elements. The results indicated the atoms were not spread out evenly, as equilibrium would have it, but were condensed into a hard central core—not a pudding but a kernel: a *nucleus*. Considering that Coulomb’s law concerning electrical attraction is identical to Newton’s gravitational law (the ‘forces’ being inversely proportional to the square of the distance between their sources), Rutherford’s version of the atom took shape as a tiny solar system, with the nucleus as the sun and separate but captured electrons orbiting about as its planets.

There was, however, a problem here, too: the planets of the Solar System are electrically neutral whereas an atom is charged—electrons negatively so, and the much more massive nucleus is positive (though it was not yet understood as being made up of neutral neutrons and charged protons). The interacting of electrical fields causes emission of light waves (or photons), which if continuous, George Gamow explains, would “take away into space all of the electron’s energy within about one hundred-millionth of a second. Having lost all their energy, the orbiting electrons must fall into the nucleus and the atom cease to exist!” [THIRTY YEARS THAT SHOOK PHYSICS] A universe could not be built out of such incoherence, and of course atoms do not destabilize and disappear. As far as anyone knew, they seemed to exist forever.



It was then that Dr. Planck had a flash of insight and threw in a suggestion that seemed so crazy that he refused to believe it himself. [see GAMOW: THIRTY YEARS THAT SHOOK PHYSICS: *The Story of Quantum Theory*; Dover Publications, NY, 1985 (republication of Doubleday, NY, 1966); p.36]



Max Karl Ernst Ludwig Planck [1858-1947]

The Quantum Idea:

Max Planck was a hardened classicist, having studied with the reigning king of positivists, Helmholtz. He also had a deep interest in thermodynamics as presented to him by two of its discoverers: Clausius and Kirchoff at the University of Berlin. Before he chose physics as a career an early teacher tried to dissuade him, advising that physics was coming to an end—soon to be dead, theoretically. Only a few problems remained to be solved and then there would be nothing more exciting to do in that branch of science. He urged Planck to pursue his alternate career choice: the enviable life of concert pianist. Instead, against all the classical rules by which his mind remained bound—while studying black-body radiation rather than the ‘Black Key Etude’—he proposed that energy is not a continuous field-like thing that can be reduced infinitesimally by eternally dividing its intensity, but that it exists in limited tiny packets which he called **quanta**, presumably finite and so, theoretically, they might even be counted. Thus an atom could reach a lowest energy state—not absolute zero but a minimum level—which could not be further reduced. That idea solved the problem of atomic endurance mathematically, but it had no empirical basis.

At the time, many of the stalwarts of science still saw the radiation problem as a weakness in the argument for atomic theory. After all, atoms cannot be seen directly and the whole hypothesis might well be a house of cards ready to collapse were it not for such mad ideas as this *Planck Radiation Formula* acting as a kind of temporary scotch tape. Not only was there no suggestive basis in science or reality for Planck’s quantum trick but it seemed that it could never be verified by experiment. It had just dawned on Planck as the only possible answer. Remaining as trained, however, a staunch classicist, he could not bring himself to believe that it was anything but an artificial, mathematical deception.

Here’s the deal in my best-mustered layman’s terms: There is a lower limit, both in size (volume or length or the amplitude of a wave—i.e., extension) and in time (duration/frequency/rhythm) beyond or ‘below’ which there can be no reality; or where mechanistic-materialist ‘reality’ ceases. One of the best expressions of this concept is the notion that an electromagnetic wavelength has a minimum size or expression, as there is also a minimum lapse of time in relation to its full-length expression. No wave or particle or expression of energy can exist in any smaller unit; no further division is possible. Think of the limited harmonics available on a violin or guitar string—or of the series of overtones if one is a wind instrumentalist. On the low/long end, the size of waves is limited by the length of the string or tube (the fundamental pitch). On the high/short end the wavelength, even using harmonics, becomes irreducible well before it reaches the limit where the diameter of the string equals or exceeds the length of the wave, or where thickness of the reed prevents a higher frequency, or where one’s lips can no longer buzz in response to increasing air pressure. Similarly there is a size/frequency limitation on

electromagnetic waves—i.e., a smallest possible wave. Incidentally, there also may be a longest possible wave: the fundamental pitch of the Cosmos, so to speak, which would be limited by the diameter of the Universe (unless infinite), the modern estimate of which gives us about 400 octaves in which to express our creativity—a limitation even on God.

Depending on the scale used in measurement, the minimum wave-length or frequency and/or spatial extension and/or duration of energy quanta have become known as the *Planck length* and/or the *Planck moment* (sometimes called the *Planck second*), together expressed as the ‘*Planck constant*’, symbolically shown as h ($= 6.6256 \times 10^{-34} \text{J}\cdot\text{s}$ [that is: Joule-seconds]) or, later, as the ‘reduced Planck constant’ called “h-bar”, shown as \hbar . But we have no hope of describing or getting much of a grasp on **quantum theory** within the limitations of this course, so we will leave Planck’s contribution at this: a formula or means of ‘understanding’ that rescues (at least it did temporarily) the law of conservation of energy and allows, theoretically, for the obvious endurance of elements of matter despite the otherwise thermodynamic expectation that *all* energy would be quickly lost to entropy. And all of this was accomplished by considering energy to exist only in discrete, minimally limited units called *quanta*.

It was Max Planck, then, who first gave sufficient thought to the paradoxical nature of the problems raised by this lack of resolution to the atomic scenario of matter and who was first to attack the problem. His resolution was sufficiently radical to be a principal cause of the modern revolution in science: *energy must not exist as a continuum*. It appears and acts only in separate, minimal quanta. The lowest energy level, then, would be one quantum, represented by a single quasi-particle-like entity. Thus, though he never thought such subparticles could be real and never swerved from his classical physics orientation, it was Planck, in announcing the graininess of the material world at its sub-microscopic level with this first expression of *quantum theory*, who, it might be said, established a substructure for the

...modernist...conceptual insight: that the objects of our knowledge are—contrary to the evolutionary seamlessness of nineteenth century thought—discrete, atomistic, and discontinuous. The gray matter was found to be made out of neurons, poems out of disjunctive images, and paintings out of dots of color, all by innovators whose worlds were just beginning to align.

[quotation from dust-jacket blurb for Wm. R. Everdell; THE FIRST MODERNS; Univ. of Chicago, 1997]

Einstein took Planck’s quantum idea seriously and used the tiny, light-energy packet it in one of his landmark papers of 1905 to explain the *photoelectric effect*, after which it became known as a ‘photon’. Niels Bohr found it to answer his new description of the atom, hence upgrading the Rutherford solar system model and engendering at Copenhagen a veritable fraternity of young geniuses devoted to the complete recasting of physics, developing a quantum-based hypothesis as a sorely needed replacement for the crumbling structure of classical mechanics. Bohr’s model now, after Einstein’s photoelectric paper, had the electrons orbiting in ellipses and jumping to higher or lower orbits when the atom was excited by absorbing new energy such as a photon or when it was relaxed by loss of energy by emitting a photon. These electron orbits were separated in accordance with Planck’s constant so that there was no continuum between them—no free-falling toward the nucleus into a closer orbit or sliding gradually away from an inner orbit to one further out—because ‘in-between’ orbits, according to quantum theory, could not exist. Thus the famous *quantum jump* or ‘quantum leap’. An electron simply ceased

to exist in the initial orbit and re-appeared instantaneously in the adjacent one or in any available higher or lower orbit or ‘state’, depending on the frequency of the energy absorbed or emitted by the atom as a unit—or was it even the same electron? In any case,



this was a strong argument for *discontinuity* in both motion and matter: the mischievous shade of Zeno still conjuring the old conundrums while obscuring the resolution.

Wolfgang Ernst Pauli [1900-1958]

Native Viennese physicist, Wolfgang Pauli, had studied with Sommerfeld and Max Born before joining Neils Bohr at Copenhagen. He limited Bohr’s electrons at first to only one per orbit, a finding now called the *Pauli exclusion principle*, but later, when the attribute of spin was added, he allowed two per orbit, providing they had opposite spin. The ‘non-relativistic spin’ idea would add an unexpected complication to the attempt at completion of the quantum view when it was discovered that the angular velocity resulting from the calculated rate of ‘spin’ violated Einstein’s absolute limit on the velocity of light—but that’s another story; one we probably will not entertain further in our current survey.

The Pauli Principle, incidentally, should not be confused with the *Pauli effect*, a kind of metaphysical phenomenon that particularly haunts theoretical physicists; one so prominently displayed in the person of Wolfgang Pauli that it was named after him. The effect has to do with the natural clash of theory with practice such that it acts as a kind of extension of Murphy’s Law: ‘whatever can go wrong will go wrong—especially with the work or the apparatus of an experimental physicist at the touch or merely the approach of a theoretician’. Pauli was a remarkable personification of this symptom, taking great delight in discovering he didn’t need to be even in the same room to wreak havoc on experiments. In a case related by Gamow, certain experimentalists, exasperated with some unexplainable malfunction, mentioned that ‘Pauli must be nearby’. It was a joke, of course, but when the story was related to Pauli he realized that he had indeed been enroute that very afternoon and, at the time of the incident in question, his train had made an unscheduled stop for some undisclosed reason, delaying him for several minutes at the station nearest the effected physics lab. Unexplainable? The ‘twilight zone’? Perhaps—but hardly more so than the logic-cracking quantum world he was helping to expose.

The discrete atomic universe concept—now descending into the sub-atomic realm—was hard enough to accept, though experiment and mathematics seemed to demand it. Proponents of what one might call neo-Cartesianism, the world as a continuum, were desperate to salvage their quasi-membranous vision. The strangeness that was being uncovered by the new subatomic concepts demanded a much more rigorous theory than the speculative views engendered by Planck’s quantum suggestion—even as supported by Einstein’s photoelectric paper. Although it was Einstein whose photons illuminated the door that opened into the quantum world, he refused to pass through that portal himself, warning his fellow physicists, in effect, that behind that door was an abyss: an Alice-in-Wonderland world not reconcilable with normal logic. Reason would be of little use in negotiating that realm. Bohr and his growing circle of young geniuses, however, having got this bizarre notion of it in advance, saw it as a great adventure and plunged in without hesitation.

The Exploration of Quantumland:



The first to come to grips with formulating an ‘explanation’ of quantum mechanics was Bohr’s favorite among his youthful acolytes **Werner Heisenberg** [1901-1976], a mathematics whiz fresh from studies with Sommerfeld in Munich and time spent at Göttingen with the famous mathematician David Hilbert and renowned physicist Max Born, who remarked on his student’s “unbelievable quickness and precision of understanding.” “He had the first truly quantum-mechanical mind”, said American physicist Jeremy Bernstein, “the ability to take the leap beyond the classical visualizing pictures into the abstract, all-but-impossible-to-visualize world of the subatomic ...” [Above quotes from *Postscript to the play,*

COPENHAGEN by Michael Frayn; Anchor Books (Random House), NY, 2000; pp.104-105].

It was Sommerfeld who took Heisenberg to the Bohr Festival in Göttingen and introduced him to Bohr, beginning a long and variable relationship with the recognized dean of quantum physics. A fellowship award [mid-1920s] allowed him to do research at the Institute of Theoretical Physics in Copenhagen. Heisenberg returned to Göttingen to work out, with Born and Pascual Jordan, the mathematical ideas that were boiling in his head, resulting in his *matrix version of quantum mechanics*. Bohr invited him back to take a salaried position in Copenhagen as his assistant, occasioning many long hikes deep in conversation about the meaning of this new quantum concept and the development of the *principle of uncertainty* that bears his name [1927].

Though Bohr resisted Heisenberg’s contention that not only was the former’s ‘improved’ model of the atom incorrect but that no such visualization could ever elucidate the workings of the atomic world, he came to accept the idea that it could only be described mathematically. But matrix mechanics is so esoteric that few beyond Heisenberg’s close colleagues understood it—if it can be understood at all. So we will not spend time, here, trying to explain the unexplainable. We will simply remember Heisenberg for his proof of uncertainty [1927], showing that, unlike the macro-world situation, measurements taken in the quantum world were limited by the nature of interference by the observer. When we see things in the macro-world, billions of photons (several wave-fronts, if you prefer) bombard our retina exciting the optic nerve, etc. The original light source, say a lamp or the Sun, does not generate intensity sufficient to noticeably affect inertia or the location of objects large enough to be illuminated and observed directly, so the quantum effect goes unnoticed in the macro-world. But if we wish to ‘observe’ something on the quantum scale, like an electron, we would have to bounce another sub-atomic particle or a stream of subparticles off of it—particles as massive as, or even more massive than the object of our observation—both of which are moving at or near light speed thus severely disturbing the object in its motion or location. In fact, by simply finding an electron—that is, in detecting it with our instruments—we have drastically altered its nature or its ‘state’. Some say that, by thus collapsing the wave that otherwise masks its particle nature, we actually ‘create’ the electron by our observation. However that may be, observation on a quantum scale acts in such a way that the *momentum* and *location* of a subatomic particle cannot both be known with accuracy. The *Heisenberg uncertainty principle* holds that the more one knows about its

momentum, the more one is denied knowledge of its place, and the reverse. This has led to some serious philosophical difficulties regarding ‘What is reality?’ since it implies that existence seems to require an observer—e.g., the proverbial tree falling in a remote forest with no one around to hear: Does it make a sound?—Does it even exist? And perhaps you have heard of the adventures of Schrödinger’s cat in quantum land. But before we open that box, we need to get back to Copenhagen and see how all this strangeness is being organized conceptually: how does quantum mechanics relate to reality; to the macroworld.

Louis Victor Pierre Raymond, Prince de Broglie
[1892-1987]



In the interest of promoting the non-corpuseular understanding of energy, Louis de Broglie dropped a suggestion into the pond that stirred up what amounted to a theoretical tsunami. As a Ph.D. candidate in physics, Broglie wrote a dissertation contending that all particles included a wave function that acted as a useful visualization of the restrictive nature of Planck’s constant. The inner-most orbit of an electron, he proposed, acts in the nature of a curved violin string sounding the fundamental [draw diagram]. In other words, the orbit would display a full wave with two nodes. The next orbit outward from the nucleus would ‘sound’ the second partial, a split wave (3-nodes). The next orbit outward would represent the third partial (4-nodes), etc., etc., to the outermost electron orbit of the most complex element. Since there can be no intermediate harmonics (which is why they can only ring at certain precise points on your string), there could be no intermediate orbits, another way of visualizing the quantum jump—i.e., to the next harmonic or ‘partial’. So the atom could be imagined as a miniature musical instrument, despite the fact that it is so tiny that it can not be seen and the waves it produces are well beneath the visible spectrum, let alone beyond the range of human hearing. But reflect back for a moment: recall Kepler and Pythagoras and their suggestions of a kind of symphonic cosmos. Now we have an orchestra of atoms.

The young Broglie’s mathematical descriptions were formidable but seemed to work. The oddity of the idea, however, and his use of as yet unfamiliar elements from Planck’s quantum theory and Einstein’s photoelectric paper, propelled his thesis into the *avant garde* and beyond the confidence level of his academic committee. So, to properly evaluate it, they actually sent Broglie’s paper to Einstein, asking his impression. Einstein was enthusiastic, hence all subatomic particles became associated with what came to be called pilot waves. The next logical step in this direction was to imagine that all particles, and in fact everyday things of all sorts, have corresponding wave functions. Things of macro-size and larger (your house; your car; you; Earth; the Sun) have such a huge mass-over-velocity ratio that their inertia dwarfs the wave function such that it has no discernable affect. The electron and its subparticle cousins, while they have great velocity in comparison to the things in our naturally observed world, have such minute momentum or inertia due to their near masslessness that their associated wave function becomes a dominant factor in shaping their existence or ‘realizing their state’ in the quantum realm. In fact some physicists view the wave aspect as the natural or normal ‘existence’ or *tao* of unobserved, undetected quanta.

Erwin Schrödinger, Viennese physicist/philosopher and Nobel laureate [1935, shared with Paul Dirac] and free-thinker, was the inventor of *wave mechanics*.



Erwin Rudolf Josef Alexander Schrödinger [1887-1961]

Influenced by reading Schopenhauer at an early age, he became interested also in Eastern religions, particularly the Vedanta. He also, apparently, was subject (if not victimized) by an unusually active libido. Though he married at twenty-three and kept his wife through life, they had an ‘understanding’ about love, both having affairs from time to time. In fact Schrödinger lived much of the time with two women, even though one was married to another man, and had affairs with many others, even fathering several out of wedlock children, while his legal wife, Annemarie, was having her own affairs, most notably with another famous physicist, Hermann Weyl. This lifestyle, about forty years ahead of its time, proved problematic. Contrary to

what one might expect, however, it was much more problematic from the point of view of others than for Anny and Erwin. When he felt the need to leave Austria in the early 1930s due to threatening NAZIism, he was offered positions in England (Oxford) and America (Princeton), but found adversity in both communities to his extra-marital arrangements. In the 1940s, invited by Ireland’s Taoiseach Eamon de Valera to help establish a theoretical physics program at Dublin, he accepted and remained in Ireland until his retirement in 1955. He and Anny then returned to Vienna where he died in 1961.

Perhaps his most important contribution to the new physics was a paper published in 1926 concerning wave mechanics which included the *Schrödinger equation* considered to be one of the major achievements of twentieth century physics. Three more papers followed rapidly, including a demonstration that his *wave mechanics* was actually Heisenberg’s *matrix mechanics* from a different perspective—somewhat more visualizable and thus was exposed (or, more accurately, appearing diaphanously clothed, was ‘revealed’) rather than obscured behind Heisenberg’s dense blocks of numbers.

Like everyone else involved in the physics revolution he visited Bohr to make his case before the recognized patriarch of quantum mechanics. Bohr argued so vehemently against wave mechanics that Schrödinger hastily retreated from Copenhagen—but did not retreat from his theory, which became a central feature of the new quantum mechanics. Bohr would ultimately have to accept it—and a lot more.

In 1930 *PRINCIPLES OF QUANTUM MECHANICS* appeared, by Paul Dirac. The book incorporated the theories of Heisenberg and Schrödinger into a third version of quantum mechanics. It became a favorite textbook for introducing quantum mechanics and is still in use today.

Paul Adrian Maurice Dirac [1902-1984]

So now we have Heisenberg’s matrix theory; Schrödinger’s wave function theory; and Dirac’s mathematical correlation of the two. Later we will encounter Richard Feynman’s sum over history—or ‘point particle’ theory of quantum mechanics.



Dirac was the consummate nerd among this pack of mostly youthful egg-heads. If you look up ‘geek’ in the encyclopedia there ought to be a picture of Paul Dirac as prime example. While highly respected as a mathematician and theoretical physicist (if ‘physics’ is the proper word for what was going on among ‘quantists’), recipient of many awards (including a Nobel Prize), and occupying the Lucasian Chair of Mathematics in England (once held by Newton and now by Stephen Hawking), he was socially rather inept. As if displaying the negative image of Schrödinger, who seemed to attract females by the bunch, Dirac exhibited little charm and no understanding whatever of the opposite sex. Once on a cruise with Heisenberg, who was himself quite a ladies man, Dirac asked him about dancing and why he engaged in it. Heisenberg told him it was enjoyable, explaining “when there are nice girls, it is a pleasure”. Dirac pondered this notion, then blurted out: “But, Heisenberg, how do you know beforehand that the girls are nice”? [from a review of *THE STRANGEST MAN* in *THE OBSERVER*, 1 Feb. 2009—found in Wikipedia: *Paul Dirac*]

Dirac did, however, manage to find a wife: the sister of another theoretical physicist and mathematician Eugene Wigner [1902-1995]. Wigner and his close colleague Hermann Weyl [1885-1955] (who was currently wife-swapping with Schrödinger) are chiefly responsible for the introduction of group theory into quantum physics (which we will not get into here, except to mention it has nothing to do with orgies). Due to Wigner’s ‘membership’, as it were, in the quantist association, his sister, Margit, was well known to the club, but none of them, despite their off-the-scale IQs, seemed able to remember her name, referring to her almost universally simply as ‘Wigner’s sister’. This was so common, and Dirac was such a social incompetent, that shortly after his marriage when a visitor noticed with some surprise the presence of an attractive woman in Dirac’s house, Dirac stammered, “This is...this is Wigner’s sister”. Margit Dirac told both George Gamow and Anton Capri in the 1960s that her husband had actually said, “Allow me to present Wigner’s sister, who is now my wife.” [George GAMOW in *THIRTY YEARS THAT SHOOK PHYSICS: The Story of Quantum Theory*; Courier Dover Publications, 1966 ed., p. 121]

In addition to his mathematical solution/description of quantum mechanics, Dirac has garnered certain notoriety in cosmology for his ‘large numbers hypothesis’. We will not have time, nor do we have sufficient expertise, to explore this in depth. Here we must be satisfied to say ‘large numbers hypotheses’, of which there are now several (most of which have no relationship to the particular number comparisons that influenced Dirac), take notice of certain enormous numbers that fall out of cosmological and/or quantum level formulae as tending toward similar orders of magnitude. Notably for Dirac:

- (a) *The strength of gravity, as represented by the gravitational constant, is inversely proportional to the age of the Universe; and*
- (b) *The mass of the Universe is proportional to the square of the Universe’s age.*

Here is an example of the sort of thing that influences such hypotheses:

$$\frac{ct}{r_e} \approx 10^{40} \text{ where } t \text{ is the age of the Universe, } c \text{ is the speed of light and } r_e \text{ is the electron radius,}$$

in atomic units, if $c=1$ and $r_e=1$, the age of the Universe is 10^{40} atomic units of time.

$$\frac{4\pi\epsilon_0 G m_p m_e}{e^2} \approx 10^{-40} \text{ With } e \text{ (charge of the electron), } m_p/m_e \text{ (the mass of the proton/electron),}$$

and $4\pi\epsilon_0$ (‘permittivity factor’) in atomic units equal to 1, this gives the gravitational constant.

This is only one example of several such unexplainable matchings or opposings or mirror images of such gigantic numbers that crop up in the mathematics of quantum and cosmological descriptions. Another example, perhaps easier to understand, is that of Pascual Jordan, when in 1947 he “noted that mass ratio for a typical star and an electron approximates to 10^{60} .” Dirac-inspired large-numbers-hypothesis promoters see such things as more than coincidence, leading to intense examination and hotly debatable theories as to why this should be the case and what it might mean in the search for the infinitely elusive Theory of Everything [*Jordan example from Die Herkunft der Stern, quotes and above formulae found in Wikipedia.org/wiki/Dirac_large_numbers_hypothesis*]. When you get right down to it, though, it’s not that much different from Kepler’s obsession with the musical spheres and his nesting polygons as somehow (coincidentally?) connected to the planetary positions in the solar system or Pythagoras with his magic number theories. In fact, some physicists, in this regard, have accused Dirac of practicing numerology.

In another reaction, American Physicist Robert Dicke [MIT and Princeton] thought the reason we see such coincidences is that they are necessary for the rise and sustenance of intelligent life in the Universe. At other times, when these numbers are out of sync, there could exist no sentient beings to notice it. This is often referred to as the ‘weak anthropic principle’. This seems to be linked to Dirac’s idea that the gravitational constant, G , must not actually be constant but must instead adjust over the eons to keep its correlation—its large number relationship—with the age of the Universe. One might see that as a stronger anthropic principle if one believes the Universe adjusts in such manner as to protect and sustain humans or intelligent life—or any living things. Dicke, however, disagrees, expecting that G will remain constant and that particular number correlation (and many if not all others) will eventually be lost as the Universe evolves, such that many (if not all) contemporary ‘laws of physics’ will be altered or overturned, ultimately making life and maybe even a material Universe impossible. Or maybe (just guessing) many, if not all, of these coincidental relations of large numbers have no meaning—no inter-relationship at all; that the large numbers hypothesis is just another of those mathematical games God plays with upstart scientists and philosophers who think they can outsmart him and find him out—like trying to resolve π , squaring the circle, and finding the square root of 2, etc. —and that the loss of such seeming correlations of the large but purely abstract numbers will have no more effect on the nature of the Universe than does Achilles in passing the tortoise.

We have digressed, as usual, and stepped beyond our subject: quantum mechanics. We must get quickly back to it to complete the planned topic of this lecture: the quantum mystery.

The Double Slit Experiment: (*Set up the ‘Dr. Quantum Double Slit Experiment’ from internet*)

There is no better means of showing the paradoxical nature of the quantum world, the dual nature of light (and even of the basic particles of matter), and the reason behind the Bohr theory of complementarity than the now classic *double slit experiment*. The basic experiment is about as elementary as one can get in physics, next to dropping golf balls together with canon balls from the Leaning Tower of Pisa. Nothing expensive is required in the way of equipment for the initial experiment, no fine-tuning of complicated apparatus, no dangerous levels of radiation or high voltage bursts of electrical energy. All you need is a light source, an opaque barrier with two narrow slits to filter the light rays

and a screen upon which to project the result of the light's passage through the slits. What we hope to determine, once and for all, is whether light comes in waves or particles. When we turn on the light source and open the slits, what shall we expect to see on the screen?

If light is an ocean of separate photons we would expect to see two long patches of light directly opposite the slits. They won't be perfect rectangles but will have some fading around the edges where we will find fewer and fewer 'hits' as we look farther from the centers of the light patches, and a few stragglers, perhaps, further off, where they ended up after bouncing off the edge of a slit when squeezing through with the billions of other photons.

If light comes in waves, the waves might bend as they go through the slits and expand as they emerge. With two slits open the two separate wave fronts created as light emerges should expand again so that they might light the whole screen—or at least make large spots with overlapping edges. Maybe the pattern will be brighter where the edges of both slit-images overlap in the center of the screen.

What we actually see is a pattern of light and dark lines, parallel to the slits, naturally, but spread out across the screen. Someone knowledgeable in wave action will explain that the dark spots, which we might not have expected, are caused by the peaks and troughs of the crossing wave fronts being out of step with each other and cancelling. This distinct pattern might be more than we had previously expected from the wave theory, but it absolutely could *not* be the product of light as tiny billiards balls. So we seem to have proved light comes in waves.

Not so fast, say those of the particle persuasion. What about those isolated hits on the screen—the ones appearing farthest from the centers of the light bars. There are clearly points where only one photon struck. Maybe many of the billions of photons crowding through the slit are interfering with each other—knocking each other off course. How would a tiny wavelet disconnect itself from the front and take its own course? Let us see what happens when we close one of the slits.

The wave-backers explain that such interference between particles would not be expected to make the clear and symmetric pattern we observed. Surely it would be more random in nature and changing continually if light were made up of individual particles. How would those insentient particles know how to form such a pattern, and how to decide which particles would go where to make it happen—and to make it endure? But they agree to close one of the slits and repeat the experiment.

Now, if light is particles they should make a somewhat larger but still thin image of the slit on the screen, again with rough edges and some random hits away from the center where the bright area fades to darkness on each side.

If light is waves, the spreading wave front upon emerging from the single slit should expand pretty evenly across the screen. Though the single image is likely to be noticeably brighter in the center, the dark interference lines resulting from the two slit configuration should no longer be displayed.

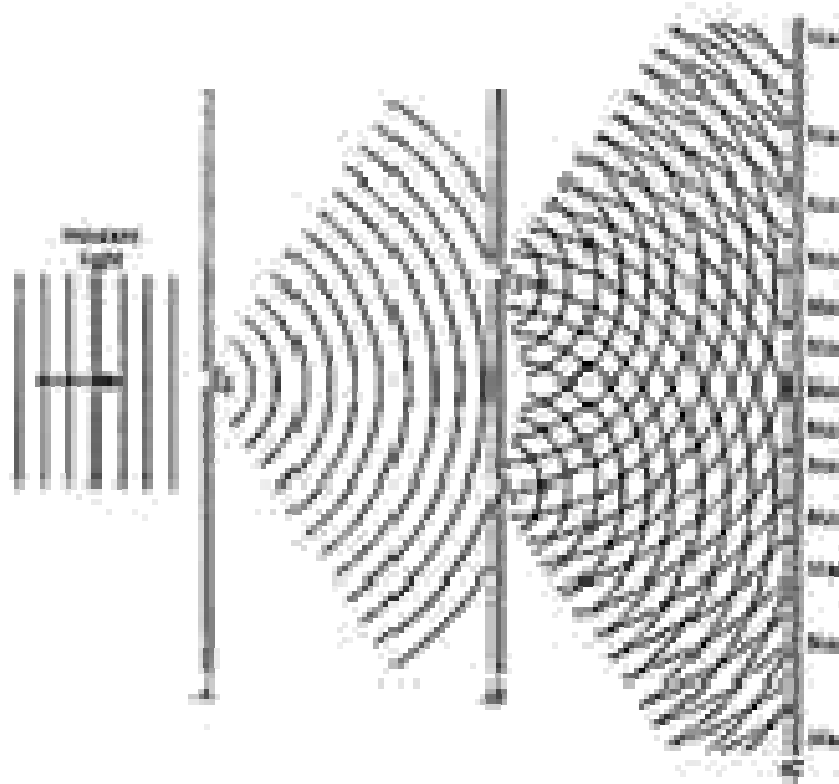
One slit is closed and a new pattern is observed. The wave expectation (the latter description) again prevails. Light is certainly waves, therefore not particles. So the photon hypothesis, however helpful it may be in mathematics solutions or in explaining heat transfer, is obviously wrong.

The photon favorers, somehow, are not totally convinced. They asked for another experiment after they have been granted some time to tweak the apparatus. They replace the continuous light source with a device whose energy output can be dimmed down, reducing the emissions so much that only a single quanta of light, one at a time, is allowed to emerge and pass through the slit.

With only one slit still open the photons, for the most part, should travel straight through, but a few of them might deflect off the edges of the slit and strike the receptor screen well outside the expected target area. The experiment is started. Most of the photons, the overwhelming majority of hits do begin to gather near the middle of the screen, assembling in the shape of the slit, but after a while the accumulated hits begin to form the same, spread-out pattern made by what we proved were light waves in the last experiment. Now even the wave supporters are surprised, since it was hard for them to imagine single photons making a pattern that would be expected only from waves. How could that be? Let us open the second slit and see what happens.

The second slit is opened and the photon emitter is activated. One at a time the photons, presumably, find their way through one slit or the other and begin to accumulate on the receptor screen. Little by little, quanta by quanta, the wave interference pattern of bright and dark lines begins to form. What could explain this? How could a single photon interfere with itself?

PLAY THE 'Dr. QUANTUM' ANIMATION



So some of the quantists want to say the particle is a wave before it becomes a particle, and that it only transforms itself when detected—or that the wave is transformed or collapsed into a particle by being observed. From the understanding of Broglie and Schrödinger each particle has a wave function: the pilot wave idea. But it is unclear whether the particle actually exists continually surrounded by and/or participating in its wave, or that it only comes into being when the wave collapses. The language of most quantum physicists seems to indicate the former, as they speak of the varying probability of ‘finding the particle’ at particular locations in its field. Since the wave pattern in the experiment is caused by widening waves that are broken up by interference and by passing through the slits only to spread out again, each particle must have a wave at least as wide as the whole screen each of which collapses into a single tiny photon when it meets the photo plate detector screen.

This is not at all like ocean waves. Waves of water are, of course, made up of hundreds of trillions of H₂O molecules that inundate the beach when the wave hits the shore. Quantum waves, however, are not a series of giant waves, one after another washing up against the phosphorescent screen, but billions of separate waves each of which, perhaps, becomes a particle when it hits. But if the pattern of each wave is like those shown in the diagram: a widening half-circle, why don't all the waves collapse into particles at the center of the screen where they first strike the detector screen? Those who say the particles already exist somewhere in their wave claim the probability of location argument: some particles are not at the front of their waves but off to one side or another. But then, one would like to know: Why are most of the particles located at the wave front instead of being equally scattered all over the wave area?—and How is it that the waves seem to interfere with each other when there is only one quantum of energy or ‘wave packet’ at a time allowed to pass through the slits. How can a single particle pass through both slits and interfere with itself on the opposite side before its wave collapses on the screen?—or is it now two waves?

This seems an irresolvable paradox: a chicken/egg sort of debate that cannot be resolved. So quantists want to have it both ways: Each particle has a wave function that somehow accompanies it or represents it, such that it does not reveal its alternate particle nature until it is observed, detected, or collapsed by being deflected or absorbed or by whatever means it enters into the material world of cause and effect. Wave nature or particle nature?—Which is correct? It seems anybody's guess, but Bohr's fudged compromise is the more widely accepted answer: the duality called complementarity.

It gets worse: If two such entities should interact to form a system they become ‘entangled’ in a way by which they become as one: a new system. If they remain unobserved and their state is unknown (if they can be said to exist at all in such a state), no matter how remote they may recede from one another they remain one: a single unit, and observation or measurement of the state of one part of this unit (one of the former entities prior to their entanglement) resolves the other simultaneously into the same state (or perhaps a mirror image or negative state, depending on the sort of entanglement), which might imply observer entanglement as well.

In 1935, Einstein, together with Boris Podolsky and Nathan Rosen, proposed that this necessary entanglement of observer with an observed reality was paradoxical. In a paper called the EPR experiment (a thought experiment), they declared quantum mechanics to be an incomplete description of reality:

[A. Einstein](#), [B. Podolsky](#), and [N. Rosen](#)

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Received 25 March 1935; published in the issue dated May 1935

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.

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URL: <http://link.aps.org/doi/10.1103/PhysRev.47.777>

DOI: 10.1103/PhysRev.47.777

Einstein mentioned that, according to the probability and entanglement approach of quantum mechanics in its description of reality, a keg of gunpowder left alone would, after a while, attain to a mixture of exploded and unexploded states. Schrödinger took up Einstein's cause reminding the Copenhagen quantists that we know that a lump of uranium, for instance, slowly gives off radiation as it transforms itself into lead, and that its half-life is the period over which exactly half of its atoms have been transformed but, in accordance with quantum mechanics, we cannot predict which of the atoms will be so transformed and which not—only that half of them will be. He suggested that this probability feature of atomic radiation, connected with the collapsing of the probability waves by observation, should have a real-world effect. He proposed a thought experiment whereby a cyanide capsule would be placed in a box along with an atom of uranium and a Geiger counter that, if activated by radiation, would trip a hammer set to crush the cyanide capsule. A cat is put into the box with the cyanide and radiation activated hammer, and the physicists wait for a prescribed amount of time. With many atoms, one can know the continuous rate of radiation and the half-life is always the same. With only one atom the cat is at the mercy of chance. The atom might be one that radiates immediately, or it might be one that waits a few moments, or hours, or a century. The longer the cat is in the box, the more likely it will be killed, but until the event is observed by opening the box, according to quantum theory, nothing has happened. The cat is in a state of limbo, neither dead or alive—or more accurately in a state of dead *and* alive—until the wave is collapsed by a measurement or an observation.

Physicists outside the Copenhagen circle, like Einstein (most prominent of the resistance) and Schrödinger and Planck, including the dark genius Nikolai Tesla, and many others, found it difficult to accept that position. They could not make sense out of entanglement. A world based on sheer probability was anathema to them—recall Einstein's comment that surely 'God does not play dice with the Universe'. And as for 'complementarity', experiments do not actually affirm either the wave or particle understanding. Or, perhaps by seeming to affirm both sides of the paradox, the double-slit experiment actually falsifies both views. Anyway, according to science philosopher Karl Popper [1902-1994], experiments can never finally verify anything but the increased *probability* of hypotheses being true. But they can—facts eventually do—falsify theory.

Therefore, *the only real knowledge we can have about the world is negative in nature*: we can know with certainty only what is not [see POPPER: THE LOGIC OF SCIENTIFIC DISCOVERY; Routledge, London/NY, 1959]. It seems it was easy enough for astute quantists, however, to consider that, in logic, language, and mathematics, *two negatives make a positive*:

(-) *not* particles + (-) *not* waves = (+) particlewaves!

thus, introducing (possibly unwittingly) a world of negative reality: the world of anti-matter—soon to be confirmed by the discovery of positrons. And, now, it is accepted dogma that every particle has its anti-particle. So we have something like equivalence between negative numbers and negative charge and, now, negative matter—the makings of a negative universe where even time runs backwards. But if particles are also waves, what could be the meaning of a negative wave?

However that may be, unlike the ocean, where waves are made up of trillions of particles of water, these *particlewaves* are particles that are somehow made of waves—or are created out of them! But of what might these waves consist? Since the particle is only probably here or improbably there before we observe it, the waves must simply be probability waves. ... Yes? ... No? ... Improbable?

“...[T]hinking about quantum particles as ordinary objects” warns theoretical physicist Heinz Pagels “is in conflict with experiment” [THE COSMIC CODE: *Quantum Physics as the Language of Nature*; Simon & Schuster, NY, 1982; p.64]. But if sheer probability is seriously considered to be at the bottom of macro-reality, what is it that holds up our ‘classical’ castle?—What is the foundation of the sensible world in which we live? There are several answers given by various quantists and their acolytes:

Mechanism or Madness?—*The Eightfold Way*:

Quantum Reality #1: There is no deep reality (Copenhagen interpretation, Part I—*Bohr*);

Quantum Reality #2: Reality is created by observation (Copenhagen, Part II—*Wheeler*);

Quantum Reality #3: Reality is an undivided wholeness (*Walter Heitler, David Bohm*);

Quantum Reality #4: Reality consists of a steadily increasing number of parallel universes (the ‘many worlds’ interpretation—*Hugh Everett, 1957*);

Quantum Reality #5: Reality obeys a non-human, non-Boolean logic (the quantum logic solution—*David Finklestein*);

Quantum Reality #6: Neo-realism (the world is made of ordinary objects—*Einstein; Planck; Schrödinger; Broglie*—seen as Neanderthal physics by quantists);

Quantum Reality #7: Consciousness creates reality *Fritz London; H.P. Stapp; Wigner; John von Neumann* [in THE MATHEMATICAL FOUNDATIONS OF QUANTUM MECHANICS];

Quantum Reality #8: Duplex reality, a variation of the Copenhagen view (potentials and actualities co-exist—*Heisenberg*).

Karl Popper said he worried about this discussion over what is essentially the impossibility of knowing more: There can be no piercing through of the Planck-second; no surpassing the velocity of light; no splitting the photon or neutron or neutrino; no unbending of spacetime, etc. He would like to dismiss not the quantum world, exactly, but the various quantum theories as being what he would term unfalsifiable, thus not quite up to Popper’s definition of a scientific hypothesis. The fact that quantum mechanics works consistently may not be enough to establish its truth. It’s not that experiments are restricted or wanting. It’s that no hypothesis can ever be verified, Popper

explained, even by a perfect record of experimental success. No matter how many experiments are performed, it cannot be guaranteed that the next clever test of this particular theory won't change everything. So there are things we can know for certain. There is truth, he seems to have thought, but we can see only its negative image. Certainty can only be achieved through falsification. We can come to know only what is not. And yet it was he, the very knave of negativity, who professed to be concerned over the barrenness of these quantum scenes—especially that of Heisenberg. If things were to be understood so negatively (as that there are limits to our knowledge, and that they had already been reached), it might have an adverse effect on scientific progress, retarding research and reducing interest in science—and it would certainly reflect poorly on a modern philosophy that remained dependent on and supportive of the physics priests. Limitations on knowledge, however, do not affect our need to know. Since we can only have this negative sort of knowledge, it is incumbent upon science, he believed, that its theories be stated carefully and purposefully in such a manner as to be liable to falsification. He insisted that they must invite disproof.

It might be argued that these quantum theories; these quantum mechanical views (particularly Heisenberg's uncertainly principle) are, in a sense, already negative hypotheses—restricting what we can know rather than revealing what we do know, or think (or hope) we might come to know. If that is the case, falsifying them is the ticket to success: a plus!—suggesting the mathematicians are right in that, if carefully arranged and analyzed and exploited, several negatives can be made to actually add up to something positive—maybe even something 'real'.

It could be that none of these unlikely sounding ideas are correct and that there are even more ways not yet invented or discovered or conceived (and all equally wrong). As John Wheeler imagines: "There may be no such thing as the 'glittering central mechanism of the universe' to be seen behind a glass wall at the end of the trail. Not machinery but magic may be the better description of the treasure that is waiting".

[List above and quotes from Nick Herbert; QUANTUM REALITY: *Beyond the New Physics*; Anchor Press (Doubleday), NY, 1985; pp.15-29]

As the quantum strangeness has amplified over time instead of fading, the ever expanding world of 'big physics' has been erected on this quicksand—the linear accelerators and cyclotrons with their miles of concrete tunnels and now the great hadron collider in Switzerland and the search for gravity waves, etc.—all to keep the experimentalists in step with the challenges of rapidly advancing theory in spite of the paradoxical absurdities. In a lecture given in the early 1960s it was admitted by Paul Dirac, one of the founding fathers of quantum mechanics, that "It may be that our method of passing from classical physics to quantum mechanics is not yet correct"—a quote, incidentally, from the subject of a biography entitled *THE STRANGEST MAN*.

[LECTURES ON QUANTUM MECHANICS; Dover, NY, 2001: p.86
(*Republication of original of Belfer Graduate School of Science, Yeshiva University, NY, 1964*)]

In our next session we will give our minds a break from quantum theory—before it breaks our minds—by taking up Einstein and his relativity theory and entertaining the question: *Compared to what?*

HANDOUT: A. Einstein, *Autobiographical Notes*; from Paul Schilpp (ed.), ALBERT EINSTEIN; pp.3-95 (*odd pages only, as German orig. is on facing pages*); Harper Torchbooks, NY, 1959
and
Douglas R. Hoffstadter; METAMAGICAL THEMAS: *Questing for the Essence of Mind & Pattern*; ch.20, "Heisenberg's Uncertainty Principle and the Many-Worlds Interpretation of Quantum Mechanics" (July, 1981); Basic Books, NY, 1985; pp.455-477