Introduction To The Ideas Of The Quantum Theory

The Modern Viewpoint in Science

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CHAPTER I
THE EXISTENT AND THE KNOWABLE

The physics of the 20th century has forced philosophy beyond its traditional boundaries. Our notions about the universe have been reduced to uncomforting prejudices: among these one includes mass, energy, space, time, the criteria of objectivity, the relationship of the observer to the observed, and the role of experiment in the evolution of a scientific theory.

Few things have proven more insubstantial than substance itself. No dividing line now separates matter from energy ; particle and wave appear as the two faces of the same dual reality. Substance , once believed co-extensive with matter , has been supplanted by the *field* , a kind of localization of the potential of coming into being. Time itself , once considered so inherent to nature as to be in no need of description or analysis, now enters physics as a dependent variable only , linked to gravitation, relative velocity, and space.

It is therefore all the more surprising that our control over the environment is far more confident than ever in the past. From the incurable uncertainties of quantum theory come the flawless accuracy of the laser, the high speed computer, the transistor microchip. [1] The abolition of an uncontingent time and space by the special and general theories of relativity has not resulted in chaos in our daily lives. To the contrary , they have given us the power to peer billions of light-years into space, thereby taking in the full extent of the heavens, and to witness , as if unfolding before our very eyes, the split second of the creation of the universe , the dawn of time .

This new amplitude of vision, this grand perspective on encompassing reality is surrounded , much as a solid oak thickly coated in lichens and moss, by a cornucopia of ingenious world systems. Practical, applied and theoretical science have given rise to a richness of speculative science. The liberation of the intellect has catalyzed the liberation of the imagination: Big Bangs [2] , Big Crunches [1] , Cosmic

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[1] **"The entire microprocessor industry relies completely on a quantum mechanical foundation." David M. Clark "The EPR Paradox", pg. 1 (See Bibliography)**

[2] **<u>The Big Bang</u>: The theory, now well established by indirect evidence, that the universe originated in a stupendous explosion.**

Inflation [2] , Strings [3] , Quantum Foam [4] , Wormholes [5] , Non-Locality [6], Hidden Variables [7] , Anthropism [8] , Many Worlds [9] , etc .....

The bankruptcy of conventional ways of thinking about matter was apparent to most physicists in the period just before the turn of the century. The watershed years of the conceptual revolution, or in Thomas Kuhn's [10] vocabulary , the *paradigm shift* , occurred between 1900 , when Max Planck discovered his quantum of action , and 1905 , when Einstein put the finishing touches on the special theory of relativity.

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[1] The Big Crunch: The theory, for which there is no evidence, that in billions of years the universe may once again shrink to a point, crushing everything in it.

[2] Cosmic Inflation: A theory for which there is no direct evidence but which accounts for features of the Big Bang theory that are difficult to explain. This says that there was an enormous expansion almost immediately after the Big Bang. This caused all radiation and matter to freeze into fixed configurations. thus preparing the way for the universe as we see it. One of the dissatisfying features of this theory is that the field which produced this inflation is assumed to have completely disappeared, giving us no way to confirm its past existence.

[3] String Theory: A picture of matter at the fundamental level, useful in elementary particle theory, that replaces the 'point' particles' of classical mechanics by strings .

[4] Quantum Foam: A picture of the reality that may lie at the center of a Black Hole. Space, Time and Matter all engage in wild unpredictable fluctuations creating infinite instability, that yet remains trapped within the Black Hole.

[5] Wormholes: Rips in the fabric of space and time that might enable one to travel backwards and forwards in time.

[6] Non-Locality: A mysterious property of spontaneously created particle pairs (for example, electrons and positrons), which somehow 'stay in touch' across endless reaches of space. This may violate relativity theory. The phenomenon is not yet well understood.

[7] Hidden Variables : David Bohm's attempt to reconcile the claims of quantum theory with everyday experience. Hidden variables describe intrinsic properties in particles which we cannot detect , that propagate with infinite velocities .

[8] Anthropism: The view that we can only have knowledge of that tiny subset of universes in which life is possible. More specifically, because the evolution of the cosmos has brought us into being, many of the things we call natural laws are just accidents of our being here at this moment.

[9] Many Worlds: In certain situations, the quantum theory allows for several possible outcomes of the same event. The many-worlds model of Everett asserts that all of these outcomes are somehow being achieved in different worlds at the same time, ours being only one of them.

[10] sadly deceased last year

These radical theories emerged in response to contradictions within and between:

(I) The Maxwell-Lorentz theory of electromagnetism, and

(II) The theory of heat, (Thermodynamics) .

Electromagnetism : It was recognized that one could no longer give mechanistic interpretations , (in the sense of Newtonian mechanics) , to basic electromagnetic phenomena . In order to explain how light, radio waves, X rays and other forms of radiation travel across space, physicists had proposed a universal medium call the *ether* , a kind of infinitely refined substance with infinite tensile strength. Light rays were the undulations of this ether. The host of fantastic, even contradictory properties which the ether was required to possess grew beyond bounds. until the ether hypothesis was eliminated by special relativity.

Heat : The internal consistency of Thermodynamics has always been somewhat problematic . Although a statistical theory, its predictions are deterministic : heat always flows from a warmer to a colder body. Before becoming celebrated through the discovery of relativity, Einstein published 24 papers on aspects of this subject. There is also a lower limit to heat loss: it had been observed that it was impossible to reduce any substance to Absolute Zero, a state of complete absence of motion. This phenomenon was explained by Quantum Theory and became incorporated into Nernst's Law, otherwise known as the *Third Law of Thermodynamics* .

(III) Obstacles were encountered in attempts to understand the phenomenon known as *blackbody radiation* . All substances when

heated or set on fire change color: A poker in a brazier of burning coals will turn red, then blue, then white. The mechanism whereby heat converts to radiation raised difficulties (even today there are problems associated with it) ; two formulae had been devised to calculate the relationship between the intensity of the applied heat and the frequency of the emitted light. The first, the Rayleigh-Jeans Law, gave the correct predictions for low frequencies, while the other, Wien's Law, worked for very high frequencies.

Max Planck discovered that both laws could be derived from the same expression if the assumption were made that, for any given frequency ν , radiant energy was not released continuously but in discrete units proportional to ν . That is to say, E = Energy = $N \times \nu \times h$, where

N is the number of units,

ν is the frequency , and

h is the constant of proportionality, now known as Planck's constant, given by $h = 6.626 \times 10^{-27}$ erg secs .

Einstein's general theory of relativity was developed during World War I. Conceptually it was of such astounding difficulty for the times, so radical in its incorporation of advanced mathematical techniques, that he suffered a complete nervous collapse soon after its publication. Fortunately he recovered and lived on another 37 years. It is unusual insofar as it did not arise out of any anomaly or defect in prevailing theories. Instead it predicted things that no one had ever thought of looking for : the bending of light rays in the neighborhood of the sun, the slowing down of clocks in a gravitational field, a redshift in the light from distant stars produced by gravitational lensing , and others. The

one unsolved problem solved by General Relativity dropped out by accident : a correction to Newtonian theory that accounted a precession of 43 seconds of arc per century in the long axis (perihelion) of the orbit of Mercury .

Each of these new theories fashioned its primitive notions in terms of its own requirements, with no concern for the framework of the others. What was true then is still so today : Bring Relativity and Quantum Theory together and the harsh music coming from this combination is forbidding.
Since a statement of this sort may call anathema down upon me from professional physicists , a bit of space will be given over to clarifying it:

TIME **in relativity theory (both special and general) is treated as if it were exactly like any other dimension of spatial geometry . Velocity is interpreted as a rotation of time in the direction of space, or , as one should properly say, through** *space-time* **.**

TIME **in quantum theory, is treated as a** *parameter* **, while the spatial coordinates are treated as** *operators* **. This means that when an equation from classical physics is 'reinterpreted' or** *quantized* **at the subatomic level,** *length* **is replaced by a** *differential form* **, which is put into a special equation known as the** *Schrödinger wave equation* **, or simply 'the wave equation' . Time , on the other hand, undergoes no change. Both time and mass are treated as parameters, functioning essentially as constants of proportionality.**

MOMENTUM **in quantum mechanics is an irreducible primitive notion of the theory .**

MOMENTUM **in relativity is carried over unchanged from the older Newtonian theory and is defined as the product of two other** primitive notions, 'mass' and 'velocity'. Note that since time is treated spatially in relativity, velocity is dimensionless. This means that momentum is measured in units of mass alone.

What we have been learning is that , since 1900, every fundamental magnitude of physics has been redefined, not once but several times, and in different ways in different theories. It is because of this phenomenon , unique to the science of the modern world , that scientists are grappling with problems that had been by custom assigned to philosophy since approximately 100 B.S. [1] , the age of Heraclitus, Parmenides, Zeno , Pythagorus and Democritus. Then physics was a sub-division of philosophy, a second cousin to Metaphysics , Both physics and metaphysics became branches of theology at around 800 A.S. By the year 2000 , the two disciplines were fairly widely separated; Isaac Newton could smirk at the confusion of Bishop Berkeley over the calculus. A 23rd century physicist did not have to concern himself with the quarrels of Hume and Kant over the existence of cause and effect. . Little difference did it make to Maxwell what Hegel thought.

Deep foundational questions have been on the scientist's menu since the early 1900's A.C.E. Quantum theory emerged at the beginning of the century. After a break of about two decades it attained to its first synthesis with the Copenhagen Interpretation of 1926 . What began as one theory is now many: Relativistic Quantum Mechanics; Quantum Electrodynamics; Quantum Field Theory; Topological Quantum Field

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[1] B.S. : Before Socrates. Standard European dating conventions, to which we will not consistently adhere, places the above date at around 600 B.C. E. (Before Christian Era)

Theory; Axiomatic Quantum Theory; Quantum Thermodynamics; Quantum Chromodynamics; Quantum Gravity....

Only a small part of this vast subject can be touched on in the available space . In trying to get people interested in earlier versions of this book, I've often been told : "I've already read a book on that subject. I know all about quantum theory." My reply has been , "You know much more than I do." The field is enormous. For persons with enough background , it is advisable that they consult or study the standard textbooks, some of which are listed in the bibliography. There is still considerable value in a book like this one , which can be thought of as a kind of aerial reconnaissance photograph that gives an accurate , usable picture of the regional topography , without claiming to identify plant life, minerals or species of trees.

The Unknowable

The quantum theory is the most illuminating example of a particular philosophical perspective that has come to dominate all 20th century science: the acknowledge of the existence of phenomena, events, and causal connections which, by the structure of our relationship to nature, can never be known. Modern science is unique in history by the extent to which the *unknowable* has been elevated to a status comparable to that of the *unknown* .

We will be discussing the Copenhagen Interpretation, although we may find ourselves more interested in the rifts in this synthesis which opened up even during its formation : the debates between Max Planck, Werner Heisenberg , Max Born , Albert Einstein, Niels Bohr , and Erwin

Schrödinger as to its completeness , credibility, fidelity to nature , and internal consistency . The divergence in perspective between Bohr and Einstein is of particular significance : it led, in the 80's , to the discovery of non-locality . Though we will not be able to learn much about the numerous other branches of the theory , they will be referred to for examples as the occasion arises.

Quantum Theory Essentials

The phrases *quantum theory, quantum mechanics, wave mechanics,* and *matrix mechanics* , though signifying differing approaches , are synonyms . Quantum mechanics enters into the description of *all* phenomena at the atomic level : atoms, the strong and weak nuclear forces, the electromagnetic force , the elementary particles, light and radiation. There is as of yet no satisfactory theory of quantum gravity, a subject associated with Black Holes, the origins of the cosmos and the unification of all the forces of nature.

Paradoxes abound : every particle, the electron, proton , quark, and so forth, can also be interpreted as a wave. Every form of radiation can be interpreted as a particle. It was known by the 17th century that light beams behaves sometimes like wavefronts , sometimes like streams of particles. The mixing of colors, putting yellow and blue together to produce green, can only be explained by a wave model. Blackbody radiation is best understood thinking of light rays as particle streams . The principle whereby all physical entities behave like waves or particles depending on how one observes them, is known as *Complementarity* or *The Principle of Complementary Images* . It was first propounded by Niels Bohr at the physics conference in Como, Italy

in September, 1927. It went through several revisions over the course of his career.

There are neither certain locations nor momenta . Accuracy in the determination of either one of these magnitudes is always at the expense of accuracy in the other. An absolute determination of position would cause an infinite uncertainty in the momentum . It would also need an infinite amount of energy to make, so we can forget about it. For the same reasons, we can't hope for an absolute determination of the momentum.

These peculiarities of the quantum cosmos disappear, or fall below the threshold of perception , when the scale of our observations is at the level of day-to-day existence . This article of faith, which still encourages lively debate, is known as the *Correspondance Principle* and was also stated by Niels Bohr, in 1918.

Many would agree that the most controversial feature of quantum mechanics lies in the fact that its fundamental quantity, the range of values of the *Schrödinger wave function* ψ , corresponds to nothing one can measure in the observable universe. One might think of it as a kind of catalyst that, instead of going into some chemical reaction, gets put into an equation. Yet, from the form of the solutions to this equation we obtain all *that can possibly be known* about the behavior of a system at the atomic level. It therefore *establishes the boundaries of unknowability* . The wave function ψ does not itself correspond to a wave in the real world, but in an abstract mathematical construction known as *phase space* , or *configuration space* . To increase the confusion to the uninitiate, the *form* of the wave equation is elaborated in another mathematical construction, an infinite dimensional space known as

Hilbert space . **Fortunately the details need not concern us, save for one thing : its values are complex numbers, that is to say, they include a term in the square root of minus one, or i : $\psi = \psi_1 + i\psi_2$.**

It was the physicist Max Born who, in 1925, pointed out that the expression

$$\|\psi\|^2 = \psi_1^{\ 2} + \psi_2^{\ 2}$$

does **have an interpretation as the probability that some object may be in a certain place at a certain time.** [1]

The following mathematical digression is for the benefit of those who are interested in it, and can be skipped by other readers.
We start from the assumption that there is *something* **out there at all times, which we express by saying that the** *probability of its being somewhere* **is always 1. Since this probability is the square of the modulus of the wave function , we have the formula:**

$$\iiint_{Space} \psi\psi^* dxdydz = 1$$

[1] **Schrodinger himself pointed out the importance of Born's interpretation: Since the modulus of the wave equation for an electron expresses the probability of its being in some location, one does not have to imagine the possibility that *pieces* of the electron might be dispersed over all of space. Later he was not so sure: the ambiguity between the 'smear picture' and the 'precise location' picture led him to the invention of the Cat Paradox (see Chapter 3)**

For simplicity's sake, we can restrict ourselves to a single dimension, x. The expectation of finding this something in a specific region R is:

$$< x >= \int_R \psi^* x \psi dx$$ .The error is given by

$$(\Delta x)^2 = < x^2 > -(< x >)^2, where < x^2 >= \int_R \psi^* x^2 \psi dx.$$

The expectation for momentum is :

$$< p >= -ih / 2\pi \int_R \psi^* \frac{d\psi}{dt} dx. Again, (\Delta p)^2 = < p^2 > -(< p >)^2,$$

$$where < p^2 >= -h^2/4\pi^2 \int_R \psi^* \frac{d^2\psi}{dt^2} dx$$

The proof of the inequality, $\Delta q \bullet \Delta p \geq h / 4\pi$, (the letter q is substituted for position) , is straightforward. (Consult M. Jammer "The Philosophy of Quantum Mechanics" , Chap. 2. See bibliography)This is the *Heisenberg Uncertainty Principle* : *The product of the margin of error of position (Δq) with that of momentum (Δp) is always larger than Planck's constant divided by 4π* .

Knowledge about position is acquired at the expense of knowledge about momentum, and vice versa.

Unknowability in the Contemporary Sciences

Special Relativity:

Despite the paradoxical character of many of its conclusions, special relativity derives entirely from a single postulate: the speed of

light is independent of the uniform motion of the reference frame in which it is being measured. A *reference frame* is the collection of all objects motionless relative to an observer. Someone standing on a train platform measures the speed of light as the same universal constant as someone in the train moving past him :

$$c \approx 299{,}792.5 \, {}^{km}\!/_{\sec}$$

Conversely, no measurement of the speed of light can give any information about the speed at which one is moving. All material objects move in *relative motion* to each other at speeds *less* than light . From this one can show that ***if a light ray be beamed up to a distant object, such as a star, whose velocity is not know from independent observations, only the total time of its departure and return can be measured . The time at which it was reflected from the object is intrinsically unknowable.***

For if this time could be known, we would be measuring the speed of light to obtain the velocity of a material object.

An important category of phenomena which relativity identifies as intrinsically unknowable have to do with causation. Causality , also , cannot be propagated at a speed faster than that of light. This is often expressed by saying that no *signal* can travel faster than light . One can therefore identify regions of the universe that are causally independent of each other. If a galaxy that is estimated to be a billion light years distant , then a billion years must pass before what is happening on that galaxy now can have any effect on us.

The essential features of special relativity are **:**

(a) The speed of light is a universal constant, independent of reference frame.

(b) The apparent length of a moving object shrinks along its direction of motion.

(c) Clocks on a moving object appear to slow down

(d) The mass of a moving object appears to increase

(e) Energy and mass are equivalent. The total amount of energy in a quantity of mass , M , is given by $E = Mc^2$.

General Relativity:

General relativity leads us to expect that other features of the cosmos will be intrinsically unknowable. All the complexities of this theory comes , like the special theory , out of an observation and a principle . The observation is that the figure for mass that goes into Newton's equations for gravity, and the figure for mass that measures inertia , (the tendency of massive objects to persist in their motion) , is the same : gravitational mass equals inertial mass. This fact was determined by very precise experiments around the turn of the century by the Hungarian physicist Eötvös .

The *Principle of Equivalence* states that it is impossible to distinguish between free fall (weightlessness) in a gravitational field and rest. Stated differently, all accelerations can be interpreted as the presence of a gravitational field . Einstein used this to show that the path of a light beam curves under gravity . This was confirmed in 1919 by photographing the shifts in the apparent locations of stars during a solar eclipse.

There is another principle which Einstein considered central to his theory at the time of its development, known as *Mach's Principle* :

Mach's Principle: The weight of material object is determined by the relative distribution of mass throughout the entire cosmos .

The relativity of weight figures among the boldest of Einstein's assertions. It remains highly controversial. [1]

Relativity, both special and general, is based on measurement, on the effects on clocks and rulers of uniform motion and gravitational fields. These are combined in the fundamental concept of *the metric* , a differential equation involving 10 constants , { g_{ij} } ($i \leq j$, $i,j = 1,2,3,4$) . Once you know the values of these constants, you can, like a surveyor with his compass and sextant, determine both the topography of the universe as seen from your vantage point, and , since time has joined in its geometry , all of its future history.

By Mach's principle, these constants { g_{ij} } are functions of the distribution of matter over the entire universe. By the postulate of special relativity, no information can travel faster than light. Since it would take forever to detect and map this distribution, we can never know the value of the metric constants , which means that we can't measure the distances giving us the distribution of matter!

The practical consequences of this double-bind are minuscule , since knowledge of the mass distribution in our own neighborhood is sufficient for most purposes. Still, many of the difficulties associated with the determination of astronomical distances are related to the postulates of relativity, and it is reasonable to suggest that some of them may be intrinsically unknowable.

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[1]**Abraham Pais in his biography of Einstein, (pg. 288 ; see Bibliography), states that the distinguished German journal, the Zeitschrift für Physik , stopped accepting articles in general relativity because its editors were sick of all the feuding about Mach's principle !**

Cosmology:

Unknowability is pushed to its outer limits in the theoretical conception of the Black Hole:

The very substance of the Black Hole is formed from the destruction of information !

At the core of a Black Hole lies a point of infinite density into which has collapsed a star remnant of 3 or more solar masses . Any new matter sucked below the Event Horizon (the place beyond which nothing can escape from its gravitational attraction) loses *all* **of its characteristics. Even the distinction between matter and anti-matter completely disappears : physicists express this by saying that the conservation of the baryon number is lost. Likewise all the identifying characteristics of quarks, gluons, leptons , photons and gauge bosons, (now thought to be the essential building blocks of matter) are lost in the wash . All form and substance of that part of the universe which is sucked into a Black Hole is merged into an amorphous continuum. If you didn't know what this stuff looked like beforehand , it's too late to find out afterwards : something like our society's views on the stages of education. It is in that sense that the Black Hole really is a ' hole ' , sucking in all surrounding matter, information and structure .**

Another class of unknowable phenomena associated with Black Holes derive from the *Cosmic Censorship Hypothesis* **. In the Penrose - Hawking model of the Black Hole , knowledge is not only destroyed , it is also censored . Cause and effect breaks down in the neighborhood of the Black Hole's singular point. The metaphor of quantum foam has been used to express this phenomenon: time, matter, , energy space are**

driven , much like the leaves by Shelley's wild, west wind , in a frenzied cosmic dance , its fluctuations of so grand a scope that they may , for all purposes, be considered infinite.

However : not to worry ! By the Cosmological Censorship Hypothesis, this disruptive singularity is a ***trapped surface*** **: it can't escape to the rest of the universe to contaminate our sweet dreams of causation. There is no evidence for this one way or the other, and the question of whether 'naked singularities' can exist in our universe is still being debated.**

Mathematical Foundations:

What does Gödel 's Theorem really say? I will try to be brief, but there are so many confused mistreatments of the subject in today's literature that I must do my part in setting the record straight:

It is acknowledged by mathematicians that the laws of logic and set theory are adequately described in the Zermelo -Fraenkel axioms . The terminology used in these axioms was invented by B. Russell and A. Whitehead in a monumental and largely useless treatise called ***Principia Mathematica*** **. Finally, there is a set of postulates, the** ***Peano Postulates*** **, that capture all the properties of the arithmetic we all use in buying and selling , paying or evading taxes , running computers, adding up the days to retirement, or watching calories.**

With this machinery in the background, Kurt Gödel showed that every statement made within the language of arithmetic can be indexed by a positive integer , known as its' Gödel number . If this is done in a certain way, it is then an easy matter to decide if the statement is well-formed . Examples : the statement " 2+2=4 " is well formed , and true.

The statement " $1+2+3+.....+n = n^3$ " is well-formed but false, whereas the statement " $2+=(\sqrt{\log()})^{\%}$ " is not well-formed. One therefore makes the collection C of the Gödel numbers of all the well-formed statements of arithmetic .

One then asks the following question : ***Is there a machine or algorithm (decision procedure) for deciding if the Gödel number of any well-formed statement is that of a true or false statement?*** **There is, and this is called a proof: it consists of submitting it to the Zermelo-Fraenkel Axioms and the Peano Postulates and checking that no contradiction arises. Proofs themselves are well-formed statements. They therefore have Gödel numbers. And a statement of the form** ***"The statement with Gödel number X is a proof of the statement with Gödel number Y"*** **is also well-formed, with its own Gödel number.**

With great ingenuity, Gödel then constructed a statement whose truth or falsity could not be decided by decision procedures. Roughly speaking, he demonstrated the existence of the Gödel number of a statement that denies its own provability. This statement therefore is some sense stands outside arithmetic. Arithmetic is incomplete: one can make statements in its language whose truth or falsity cannot be decided by the axioms, indeed by any set of axioms that includes Peano's postulates.

Does this mean that arithmetic may be inconsistent? In his second theorem, Gödel shows that the statement

S: "Arithmetic is Consistent"

also stands outside arithmetic: it is undecidable.

This means that if a proof of its inconsistency, e.g. a contradiction, is ever discovered, then S will turn out to be decidable. But Gödel showed that it was not decidable. Therefore no contradiction will ever be found. Therefore arithmetic is consistent .[1] The proof of the consistency of arithmetic depends upon the fact that it is impossible to construct a proof of its inconsistency.[2]

Psychology :

Scientific psychology cannot draw a line of demarcation between free and determined conscious motivation . To the extent that one believes in the existence of an unconscious mind modifying or even overpowering rational behavior, one puts into question the very conception of the objective observer, the ground of all inductive science.

The existence of an unconscious mind has been known to Western psychology since the researches of Franz Anton Mesmer in the 18th century. We remain in the dark in our understanding of its mechanisms. Recent developments have lifted this dismal truth to high public visibility . The uncritical acceptance of the *false memory syndrome* **as legal evidence, based upon Freud's largely discredited repression hypothesis [3] , has been the basis for many severe judgments against innocent people .**

(No one is maintaining that all persons accused of child molesting are innocent.)

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[1] **!!??!**

[2] **For further clarification I refer the reader to the experts.**

[3] **Persons interested in this subject are encouraged to contact Pamela Freyd , False Memory Syndrome Foundation, 2020$^{1/2}$ Addison Philadelphia, PA., 19143**

Long prison terms have been handed down on the basis of uncorroborated evidence of persons who, prodded by lawyers and psychiatrists with little scruples, have come in all sincerity to imagine themselves victims.

The very concept of sincerity is put into doubt once one believes that the unconscious mind is strong enough to suppress , deny, or fabricate experience. A thorough-going critical skepticism is therefore required whenever one wishes to decide on the truth content of psychological impressions. In dealing with memory, one must always be aware that back-reconstruction is always very much more difficult than prediction in scientific work, since in the latter case, the future will eventually come along to prove one right or wrong.

Observing the Unknowable World

That there exist features of the universe we live in that , in some sense , are intrinsically unknowable , goes counter to the mentality that has prevailed over the whole history of science. The word "knowledge " means a kind of information that which can be reproduced and tested in other times and places, transmissible from one person to another, and to future generations. Distinguishing between subjective and objective belief has been a major pre-occupation of philosophy since Socrates, who suggested the separation of 'knowledge' from 'opinion'. The long evolution of this controversy led in the 17th century to the emergence of a doctrine which we now call the scientific method.

It is a measure of the strength of the scientific method that , when confronted with the evidence supplied by the quantum theory , it was able to give a precise description of its own limitations. Today we must modify or abandon the classical dichotomy between Consciousness as

the Knowing Principle , and Matter as the domain of Potential Knowledge. One thinks of a musician exercising mastery over the sounds coming from his piano. Should there be confusion between the performer and his instrument, we would no longer know what to make of the strange music coming from this strange combination. [1]

It is obvious that consciousness , unencumbered by the restrictions of space, time, the material body, energy and entropy , does not exist in a pure state. In the past it was believed that it was possible , in theory, to transcend these barriers . To some extent this is the very purpose of science. Yet it now appears that there is an upper bound to the objectivity of scientific investigation .

We have seen in our time the revival of the Heraclitean perspective , out of favor for over 2 millennia , and not only by Gerard Manley Hopkins. Heraclitus compared Nature to a river: one never steps into the same river twice. The traditional restrictions remain : neither observers nor events can be in two different places at the same time; two of these cannot be in the same place at the same time. Past experience can only be reconstructed, not witnessed; future events only predicted. Memory itself, as shown by recent research in cognitive science, is a complex psychic task of reconstruction, fallible at best, and undependable.

Quantum theory and Relativity now tell us that ***one cannot even be in the same place at two different times*** **! That electrons, or atoms, or light**

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[1]**As much as I hate to use this image , think of Holly Hunter in "The Piano" !**

quanta, have no independent identity. That all things exist all over the universe at once, at least until we start to look for them.

Even spatial dimension defines one of the limits of knowledge . Our minds perceive a 3-dimensional space and conclude that we live in that space. Immanuel Kant addressed this problem. He suggested that space , time and matter had not structure whatsoever, but that our minds organized our impressions of them into a coherent 3+1 dimensional picture.

Pure mathematics doesn't limit the number of spatial dimensions. In a world in which our bodies and brains were restricted to the surface of a plane, that was somehow embedded in what we normally call 3 - dimensional space, although we would not be able to make mental pictures of 3-dimensional objects, we could still use mathematics to prove all the theorems of Solid Geometry.

Imagine now that a huge meteor comes flying through 3-space. It hits our plane , does lots of damage in its passage, then flies away on the other side. Our astronomers and physicists would have to admit that the explanation for this phenomenon lies outside all known physical laws. The words "miracle", or "catastrophe" would be appropriate. Certain events obeying simple physical laws in 3-space would therefore be interpreted, in 2-space , in terms of divine intervention .

Transpose this image to a higher dimension. Our 3+1 space-time , S , may very well be embedded in a 4+1 dimensional universe, which we can label U. There could then exist normal events in U that would be interpreted as miraculous in S.

Our very existence as beings in 3-space sets up a category of unknowable realities. This is a small list of events which may belong

to it. Physicists may find that they are not able to explain them in terms of a self-contained 3+1 dimensional space-time:

(1) The Big Bang

(2) Cosmic Inflation

(3) The specific masses and energies of elementary particles

Is it possible , in a few words, to characterize that mysterious wilderness of things that we can know nothing about, save that they exist? I believe that we can. and wish to argue that unknowable entities are all reflections of the limitations imposed on us, as conscious observers, by virtue of the fact that we are obliged to live within the world that we are describing: limitations such as localization, instantaneity, finiteness, 3-dimensionality, ego definition, psychic fixations , unconscious mentation, quantum and relativistic limitations, entropy, decay. In the absence of these handicaps, inseparable from living itself, science could then claim that nothing was unknowable, either in theory or practice. From that ideal heaven, from which the observer need fear no interference with the observed, the Unknowable, either in theory or practice , would vanish.

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CHAPTER II
Science and Nature At The Interface
Planck and Heisenberg

A familiar litany , oft chanted in popularizer and solemn text about the "state of physics at the turn of the century", goes something like this:

Before 1900, classical physics was in chaos.

After 1904, physicists were in despair.

That is to say, quantum theory transmuted chaos to despair. Physical theory had made enormous advances in only two centuries :Newton had unveiled the laws of gravity, Huyghens had done the same for light, Carnot heat. Josiah Willard Gibbs had analysed the changes of state from solid to liquid to gas. Maxwell had hauled the electromagnetic field onto its mathematical pedestal . Dalton had vindicated the atoms of Democritus and Lucretius.

The deep contradictions that emerged were not so much within these fields as at their interface. Quantum Theory and Relativity, in giving answers to many open questions, raised as many of their own. This should not be seen in a negative way : it is not likely that scientists are about to put themselves out of work. Chaos in most disciplines outside of politics is rarely preferable to stagnation .

But this time there was a difference : Quantum Theory put limitations on the scientific method itself. If one could no longer conduct experiments, observe , or even use a normal vocabulary for the description of the universe , what hope could there be for the future of science ? It seemed indeed that chaos had given over to despair.

This crisis in objectivity, for it was no less than that, led to the elevation of the category of existent yet unknowable phenomena to the forefront of scientific discourse.

A brief history of the origins of the new physics **: Special Relativity arrived in 1905. It eliminated the arbitrary hypothesis of the** *ether* **, through the vibrations of which light and other forms of electro-magnetic radiation were imagined to propagate . The ether was replaced by the concept of the** *field* **, an entity no less mysterious yet, as it is**

defined entirely in terms of its mathematical properties, being a structure coming out of the differential equations describing the flow of forces, freed the propagation of light from all of the ether's pseudo-mechanical attributes. This was all to the good, since the fabulous properties which the ether were required to possess invariably broke down at every encounter with the real world.

In the same way that relativity comes into its own at the limit of enormous speeds, quantum theory claims the extremely small, or infinitesimal, as its proper domain. The way that one observes what happens at the sub-atomic level is by squirting concentrated energy into a tiny region and watching what comes out . When you hear the word *scattering* **in particle physics, that's what's being talked about. The commonly used expression** *scattering cross section* **means the ratio of what comes out to what goes in. Ordinary microscopes use light rays. Electron microscopes use beams of electrons which, by quantum theory, can behave like waves. Such procedures would normally be straightforward if the amount of radiant energy released did not depend on the frequency. A high frequency beam, such as an X-ray , has a short wave length. If the energy of the beam could also be made as small as desired , one could then use X-rays to observe atomic structures without disturbing their position or their momentum.**

Yet this turns out to be impossible. Max Planck, Albert Einstein and others discovered that energy not only correlates to frequency, it is proportional to it: if the frequency of a light particle is ν , then the lowest energy it can have is $h\nu$, where h is a universal constant, known as Planck's constant, given by $h = 6.626 \times 10^{-27}$ erg secs

Not only radiant energy, but all energy is emitted in discrete quanta. The energy in a ruby laser beam will be given by $E = Nh\rho$, where ρ is the frequency of red light, h is Planck's constant, and N is some enormous integer.

Though a theoretical physicist, Werner Heisenberg liked to invent pictures to help non-physicists understand the process of making observations at the quantum level. One of them is known as the 'Heisenberg microscope experiment'. The image is heuristic : it isn't accurate, yet very suggestive of what actually does take place.

In order to see an object under a microscope, light quanta are introduced into the aperture and focused by lenses. The object absorbs these quanta and spontaneously emits a returning stream. By Newton's Laws action equals reaction, so that the absorption and ejection of quantum produces a displacement in the object's position. The quanta themselves are of the same order of magnitude as the particles under observation, therefore this displacement can be as great or even greater than the breadth of the object itself. Hence the Uncertainty Principle.

Quantum Theory uses the terms ***observables*** **and** ***states*** **rather than magnitudes and quantities. Energy, mass, spin, momentum , position, time and other measurable entities are observables . It was Schrödinger who pointed out that the elementary particles also, were not particles in the sense that the term is used in quantum mechanics, but observables. States are the ranges of numerical values one can expect to find when making measurements on observables . States may be continuous or discrete. Discrete states are also called** ***eigenvalues*** **.**

Two observables A and B are called ***conjugate*** **when the measurement of the state of one does not disturb the measurement of**

the state of the other. They are *complementary* when such measurements do cause interference with one another.

Time and space are conjugate; position and momentum are complementary. Time and energy are complementary. Energy and momentum are conjugate . Quantum spin has the strange property that its states are all complementary to each other.

Time in quantum theory turns out to be anomalous . Conjugate to space and complementary to energy , it is referred to as a *parameter* rather than an observable. Theoretically, parameters can be measured without affecting anything else. Mass is also treated as a parameter. This confusing situation leads to actual contradictions when quantum theory is combined with relativity :

Special relativity states that mass and energy are equivalent. Yet the moment we go over into quantum theory, energy becomes an observable and mass a parameter. Every observable has associated with it a mathematical construct called an *operator* . In particular, the energy operator H is at the heart of the Heisenberg-Schrödinger theory. Yet mass, which by special relativity is equivalent to energy, is not complementary to anything else and has no operator.

In order to resolve such questions, not one, but 3 new branches of physics were created: the *relativistic quantum mechanics* of Louis de Broglie, the *quantum field theory* of Paul Dirac, and the *quantum electrodynamics* of Feynman, Schwinger and Tomanaga . To explore these in any depth would lead us too far afield. But it can be said that , to date , the fact that such fundamental quantities as mass, energy, time , and space relate differently in relativity than they do in quantum theory, continues to create serious difficulties at the foundations of physics.

For the moment we will stay within classical quantum mechanics. The following table is helpful : read from left to right, both across and/or diagonally :

Position				*Momentum*
is	*is*		*to*	*is*
Conjugate		*Complementary*		*Conjugate*
to	*is*		*to*	*to*
Time				*Energy*

TABLE I

Simultaneous measurements of *conjugate* quantities have no effect on one another. Simultaneous measurements of *complementary* quantities are related by mathematical inequalities known as Uncertainty Relations. There are two of them:

UNCERTAINTY RELATION I : $\Delta q \Delta p \geq h / 4\pi$

UNCERTAINTY RELATION I I: $\Delta t \Delta E \geq h / 4\pi$

TABLE II

In the first expression, q stands for position, p for momentum. [1]In the second expression t stands for time, E for total energy, E = K+V+H, where K is kinetic, V is potential, and H is the latent internal energy which, by the second law of thermodynamics, is unrecoverable. Respectively, these two formulae say:

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[1]This is the notation customary to physics although one would sometimes rather use the letter "p" to stand for position.

I: The error (Δq) in the simultaneous measurement of position times the error (Δp) in the measurement of momentum must always be assumed to be larger than or equal to Planck's constant h divided by 4π.

Since h =6.626x10^{-27} erg seconds

and 4π = 12.56636 , this quantity = 5.27 x 10^{-27} erg seconds , approximately. The expression h/2π occurs so often that one often uses the notation h (" h-cross ") . We will not do so only because our Microsoft software does not have an effective Strikethru operation.

II. A literal reading of the second uncertainty relation is :

"The "error" (Δt) in the simultaneous measurement of time , times the error (ΔE) in the measurement of Energy must always be assumed to be larger than or equal to Planck's constant h divided by 4π."

However, recalling the brief discussion on the anomalous status of time in quantum theory, and since it occurs twice in the above statement, both explicitly and in the use of the word "simultaneous", one has to modify this interpretation to allow for *exact time measurement* **, that is to say, treating time like a parameter. The usual interpretation of the second uncertainty relation is therefore:**

II : " The amount of time (Δt) needed for the observation of a energy gain (or loss) of an amount ΔE , is given by the expression in the second Uncertainty Relation"

This pronouncement has an uncanny way of rescuing the law of the conservation of energy, something like the little boy who saved the dikes of Holland. It is the basis of a 'trick' used in elementary particle theory, whereby it is allowed that particles, (gauge bosons for example), may spontaneously arise then disappear, provided that the time allotted for this event, times their energy , is less than the uncertainty limitation $h/4\pi$! For further clarification we recommend any good book on elementary particles and gauge theory.

Both uncertainty principles tell us that the interaction of the observer with the observed modifies the positions, momenta and energies of the systems under observation. By looking at the world around us we change it. It is very much like the experience of being watched by another person . The mere fact of knowing one is being watched influences one's behavior. However, the tiny disturbances of observations at the quantum level do not affect anything in the visible world . A tailor can still measure the length of a pant leg to a thousandth of a meter within disturbing the momenta of the other goods in his store. The indirect effects of quantum uncertainty however, are readily apparent in the elementary properties of light.

Science and Objectivity

Scientists may think of themselves as revealers of a self-evident world, but the meaning of the word 'science' itself is far from self-evident. In its various usages it may refer to the activities of a self-designated community ; or as a way of relating to the environment whose usefulness has only recently been acknowledged by the masses of mankind ; or as entirely co-extensive with technology ; or as a way of addressing ultimate questions ; or as a collection of writings sanctified

by authorities whom we have come to trust; or as a mental discipline, a kind of brain gymnastics for staying mentally fit; or as the correct way to think about things.

Common to all of these definitions is the fact that they always refer back to human consciousness and only indirectly to Nature. What we call "the universe" must always stand for an abbreviation of the phrase, "our impression of the universe". In recent years this modifier has motivated the development of a direction in cosmology known as Anthropism: we can only know about universes whose history bring about the creation of organic molecules that, under certain conditions, can combine together to produce intelligent life-forms.

The scientific outlook on the world is not comforting to us in the same way as were the older doctrines of revelation . But the two domains really have little to do with one another. No scientific theory or discovery can replace the fundamental religious and ethical creeds that have served humanity for millennia . One cannot prove "Thou shalt not steal", "Thou shalt not bear false witness", "Love thy neighbor", and so forth, from any combination of findings of cosmology, biochemistry, geophysics or any other science. On the other hand, when in trying to understand the universe around us , the structure of matter, the origin of the cosmos, the history of the earth, the origins of the species, or the composition of the DNA molecule, science has thoroughly displaced religion.

This is why , when a science as fundamental as the quantum theory , governing the dynamics of everything in the sub-atomic realm, is based on the premise that the accuracy of our information about one aspect of phenonema must be inversely proportional to any possibility

of knowing its other aspects, then the concept of science as the search for a certain kind of truth risks being severely undermined.

Refuge in a shallow solipsism - the view that we invent all that we see out of our own minds - is possible but pointless. You may have come across the story of the actor whose work obliges him to travel frequently between Los Angeles and New York. Somehow he's become convinced that Los Angeles disappears whenever he leaves it. He tells this to his psychiatrist in New York ."Nonsense", his psychiatrist reassures him, " That's solipsism; it's a shallow refuge. I assure you that L.A. is still there , just where you left it." Much relieved the patient pays him his $500 and drives off to the airport. As the car disappears around the corner, the psychiatrist picks up the phone, dials a number and leaves a message: 'He's returning. Start building up L.A."

This story recalls the behavior of the quantum spin of a particle singlet pair which , literally, take on the direction at which you measure it. Over the gates of Dante's Hell stands the inscription : ***Abandon All Hope, Ye Who Enter Here.*** **Over the gates of science one might imagine a comparable command:** ***A Universe Must Exist , Apart From Its Observers.*** **Since this has been called into question by quantum theory, how is science to be saved from its own inexorable logic? Physics, realizing itself inadequate to the task, turned once again to philosophy, from which it had already begun to diverge in the first century A.S. , when Alexander the Brute was funding the Lyceum of Aristotle.**

Speaking somewhat imprecisely, at times the way by which things are better said, physics might be defined as the study of the knowable universe, and philosophy that activity of the human mind which calls

all knowledge into question. The previous chapter has , I trust , shown that modern science has thoroughly muddled this distinction.

A History of Quantum Theory 1900-1927

Every major figure involved in the creation of quantum theory had serious disagreements with all the others as to the meaning of their joint invention. Most prominent among them were Max Planck, Albert Einstein, Niels Bohr, Erwin Schrödinger , Max Born and Werner Heisenberg.

In 1900 Max Planck published the correct formula for blackbody radiation. He arrived at this by assuming that radiation at any given frequency, (say the color red), was always released in discrete units. He did not then think in terms of an actual energy particle, now called the *photon* **. Curiously, the idea that energy may be quantized goes back to Aristotle: his quantum of action, or** *minima* **was debated all through the Middle Ages.**

It was Albert Einstein who advanced the photon hypothesis in 1905. He found that he could use it to explain the photo-electric effect : exposure of certain kinds of material, such as cadmium sulfide, to light, can cause the flow of an electric current. This phenomenon underlies the operation of the electronic eyes that open doors in supermarkets.

In 1913 Niels Bohr proposed a model for the atom that was successful in explaining the spectral lines of its emitted light . Any substance that is heated will glow at specific colors, (*in both the visible and invisible parts of the spectrum , where the word 'frequencies' is more appropriate* **) , that can be linked to the pure elements of which the substance is composed . The Bohr model placed electrons in orbits , or shells , around the nucleus. When making jumps between orbits, (the**

notorious quantum leaps) , the electrons emitted light quanta in exactly those frequencies associated with the atom to which they were bound.

The theory slumbered for about a dozen years, until the mid-20's, when many new ideas suddenly entered the arena . In 1925, the French physicist Louis de Broglie supplied mathematical arguments suggesting that not only light quanta, but any bit of matter , could be interpreted either as a wave or a particle. This was confirmed a few years later by the experiments of Elsasser , Davisson, Kunsmann and Germer. It is the basis for the electron microscope.

In that same year, Werner Heisenberg developed a formalism, known as matrix mechanics , which enabled one to make symbolic calculations at the quantum level analogous to those of the classical mechanics of Newton, D'Alembert , Lagrange , Hamilton and Jacobi . These ideas were further developed by Erwin Schrödinger , who replaced Heisenberg's matrices by a single function ψ that could be indirectly derived from a differential equation known as the Schrödinger wave equation. *Quantization* **was introduced as a systematic method for transforming classical equations to wave equations. Schrödinger showed that his formalism was mathematically identical to Heisenberg's . It turns out to be more practical for making calculations on complex systems.**

The wave function measures no physical quantity. In that same period , Max Born showed that its amplitude $\psi\psi^* = |\psi|^2$ could be interpreted as a probability density. That was the day that Einstein walked out of quantum mechanics! It was in the famous letter that he

wrote to Max Born in May , 1925 , that he scolded him , saying : "God doesn't play dice with the universe."

Heisenberg's *Uncertainty Principle* came along in 1927. It is , as mentioned above, in reality two principles which, although having a common origin, have two very different interpretations. With this final addition the so-called *Copenhagen Interpretation* - owing to the central role of Niels Bohr's Institute for Theoretical Physics - of quantum theory was complete.

The theory continued to develop , with further advances by W. Pauli, P. Dirac , P. Jordan and others. In 1955 the powerful mathematician, John von Neumann , (in many respects the 'Thomas Acquinas' of quantum theory) - situated all of the diverse components of the Copenhagen Interpretation within a comprehensive system based on the 3 fundamental notions of *linear operators* , *observables* and *states* . von Neumann's synthesis is employed in all modern treatments of quantum theory. Linear operators are general enough to include matrices, first degree differential equations, differential forms, integral transforms, orthogonal series, Hilbert spaces, and all the other formalisms that had been used to describe quantum theory in the past.

Quarrels began from the inception of the theory, and ran deep: Schrödinger quarreled with Bohr over his quantum leaps. Bohr and Einstein argued vehemently over the completeness of the theory. Planck didn't accept Einstein's photon. Heisenberg disagreed with Planck over the role of causation in the new physics. Einstein rejected Born's probabilistic interpretation of the wave function. The *group velocities* , *phase velocities* , *matter waves* , *pilot waves* , and *probability waves* of de Broglie have always had numerous supporters and detractors . von

Neumann claimed to have discredited David Bohm's theory of hidden variables; but a mistake were found in his proof . Finally John Stewart Bell showed that Bohm's ideas were not radical enough! Before Bell one could be either Bohmian or a Neumannite. Today no one knows what to think.[1]

These disputes have not died down in our own day. In the remainder of this chapter we will study the divergence of views between Planck and Heisenberg concerning the need for a coherent reality prior to observation. In the next chapter we will look at the more famous dispute between Niels Bohr and Albert Einstein and its modern re-emergence in the paradoxes of non-locality.

Saving Science

In a series of essays written in the 1930's , Max Planck developed the thesis that science could not be saved without incorporating a list of meta-scientific axioms asserting the existence of a universal or transcendent mind:

Planck's axioms:

If science is to survive one must assume the existence of :

I. A Universe apart from anyone's observations.

II. An Ideal Intellect capable of knowing everything, although not all of Its knowledge is accessible to us.

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[1] **But if we don't make up our minds quickly, the Inquisition will get us!**

III. A Rational Order which the human mind is capable of discovering and understanding.

Such axioms can be neither deduced , tested or refuted. They are indeed not part of physics, but of meta-physics [1] . Nevertheless they turn up frequently in conversations having nothing to do with physics. The third axiom is at the basis of every statement to the effect that some story is
" too far-fetched to be true." - as if truth ever cared if it were far-fetched or not. Axiom I supports our conviction that we are not all just living in a dream, that, as suggested above, Los Angeles does not disappear when we leave it. Up until recently it was thought that Axiom II was useful only to theologians, but quantum theory has brought it into science: see any of the recent pronouncements of Penrose, Tifler, Barrow, Hawking , etc....

Planck isn't saying that these things really exist ; only that science as an intellectual activity wouldn't make any sense without them. They are the ultimate grounds for intelligibility ; science can't function in an unintelligible world.

Is there a strategy proper to modern science? Planck attempts to define one in terms of two entities, the *sense image* **and the** *world image* **. The sense image consists of collections of raw sense data. These are utterly meaningless in themselves, (though perhaps useful for playing Trivial Pursuit) ; what structure they do have is , at this stage, as**

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[1]Note the hyphen: "Meta-physics" means the science of the foundations of physics. "Metaphysics", as it is used today, can mean anything from existentialism to the occult. Karl Popper uses it to refer to ideas that may someday turn into physics.

arbitrary as the information they encode. They are like stock market figures to people who know nothing about stocks.

The world image isn't derived from observation, although observation can be brought to testing it, modify it, or, during the dramatic paradigm shifts of Thomas Kuhn, bringing about its demise. The world image is essentially a framework for the understanding, a theoretical projection proposed by the scientific community. It only contains symbols. Even the constants of nature are expressed as letters, c, h, μ , etc. These symbols serve as the basis for a mathematical theory; they represent constants, variables, functions, operators, etc.

It is only when the figures of the sense image are substituted into the symbols of the world image that notions of predictability, testing, margins of error, closeness of fit, uncertainties, necessity , or simplicity arise.

There are two kinds of errors in Planck's model : Type I errors arise from the inaccuracies and mistakes in the substitution process. Type II errors arise from defects in the theory. Briefly:

Type I errors: Faulty measurements, faulty calculations

Type II errors: Faulty theories

Quantum Theory, for the first time in the history of science, blurs the distinction between Type I and Type II errors: the Uncertainty Principle obliges us to admit *theoretical* Type I errors .

Initiating a tradition that continues to divide quantum theorists into opposing camps, Planck believed that the quantum theory was not inconsistent with a deterministic universe:

(a) Position, momentum, spin, etc., can still be measured *individually* to any degree of accuracy. These things must therefore have some kind of absolute existence before they are observed.

(b) The constants of nature remain fixed through time and can be accurately measured.

Among those with viewpoints opposing Planck's were Werner Heisenberg , Max Born and, in modern times, Richard Feynman . Their view dominated the discourse in physics until experiments by Clauser, Aspect, Grangier, Horne, and Shimony showed that certain kinds of statistical correlations propagate instantaneously over arbitrary large reaches of space. Such faster than light , or *super-luminal* propagation narrowly escapes being a violation of relativity only because no energy is transferred in the process. No one is happy about this rationale , and it is generally thought that a revision of physical theory is needed.

Heisenberg criticizes Planck's 3 Axioms in an essay entitled "A Physicist's Conception of Nature".

Axiom I **: He could find no meaning in the phrase " natural world independent of observation." He was willing to concede that the universe may exist before we observe it; yet to him the essential point was that we can't *know* anything about it until we look at it.**

Walking through the forest I come across the trunk of a fallen tree: did its' fall make a sound? Planck says, "Of course". Heisenberg says, "The question is *scientifically* meaningless." , although he is more than willing to admit other ways of interacting with the world: "Science", he tells us, " is but a *single link* in the infinite chain of Man's argument with nature."

Axiom II : **Heisenberg wonders why there would be any need to cast beyond the Uncertainty Principle. Extraneous intelligences should be excluded because of a fundamental principle in scientific methodology known as "Occam's Razor" , literally the excision of superfluous (** *ad hoc* **) hypotheses.**

Axiom III : **Heisenberg didn't believe that a rational order of nature was required for doing science. He may have regretted this when he was forced to work for the Nazis in World War II, but he wasn't talking about the social order. Why should data be required to relate to anything beyond itself ? Rationality might just as well be replaced by the weaker concept of 'predictability", which means that if one is happy in the choice of one's equations, figures calculated from observations will correlate nicely with new observations. Whether these figures refer to mass, or space , or time, or causation, or waves or particles, is of little importance.**

He goes so far as to suggest that the word *reality* **itself should only refer to mathematical constructs: his matrices, or Schrödinger's wave functions, or Dirac's brackets, or Reichenbach's quantum logic , or von Neumann's operators. These should replace archaic notions such as mass, distance, duration, etc. He recognized that this disturbed some people, but he himself rather liked it: getting rid of 'naive rationalism' ought to be seen as a healthy development for science:**

"The Uncertainty Principle has given a strong check to an aimless and goalless traveling in circles, and ought to help us get rid of the equally unproductive notion of scientific progress." **, a term he later defines as ,** *"the naive conviction that everything could be known."*

This outmoded faith in a knowable universe is compared to reliance on a compass fixed to the deck of a ship made entirely of iron. The ship may travel all over the globe, but the compass points only to the ship. In a similar fashion, though Reason imagines that it is informing us about the universe, in fact it returns only to itself:

"Science, we find, is now focused on the network of relationships between Man and Nature, on the framework which makes us, as living beings, dependent parts of nature and which we, as human beings, have simultaneously made the objects of our thoughts and actions....By intervention, science alters and refashions the object of investigation... Thus, method and object can no longer be separated."

Given that most of the scientists involved in the creation of quantum mechanics were Germans, it seems appropriate to end this chapter with a quote from Goethe's Faust. When Faust tries to call upon Mephistopheles for his own ends, he is reminded that

"Du gleichst dem Geist , den du begreifst , Nicht mir!"

Just remember to pick on devils your own size.

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Chapter III
Dualism versus Completeness:
Albert Einstein and Niels Bohr

Does the Uncertainty Principle invalidate causation ? Is uncertainty built into Nature, or does it reside only in our experiments? This question, *which is far from being resolved today* **, has been at the origins of the 70-year civil war across the republic of theoretical physics.**

Erwin Schrödinger was one of the first to break with the Copenhagen Interpretation. We will be discussing his little horror story about the cat. Einstein parted company from the quantumists altogether. After clashing with Niels Bohr in 1927 and again in 1930 , he remained silent on these issues until 1935, when he once again disturbed the universe by designing a paradox, the *Einstein-Podolsky-Rosen (EPR) thought - experiment* .

Is the behavior of matter at the sub-atomic level completely random, or is this merely a constraint on the design of experiments? The differences in perspective can be considerable. Max Born's statistical interpretation was offset by the wave mechanics of Louis deBroglie, who thought that if every interaction could be expressed as a wave , one could return physics to a full determinism. Far more successful however, in terms of its practical applications , has been Richard Feynman's *quantum electrodynamics* . This has been called "the best theory we have". It is totally particulate, and totally statistical.

The Schrödinger Cat Paradox

Schrödinger's cat paradox highlights other difficulties in the statistical picture provided by the Copenhagen Interpretation.

To assemble the Schrödinger cat paradox, one needs :

(a) A box divided in half by a partition that can be raised through remote control.

(b) An electron trapped in the left half of the box.

(c) A cat trapped in the right half . This cat can be stolen from the house of the physicist you hate the most. This probably isn't fair : your

animosity towards the physicist is not the fault of the cat. Let's make it a cat infected with rabies, for whom death by gunshot might be considered merciful.

(d) A gun aimed at the cat. The diagram above , which is essentially equivalent to this description save in the details , shows a flask of cyanide. A string leads from the gun's trigger to :

(e) A mechanism hooked to a photocell in an upper corner of the cat's half of the box.

By raising the partition, the probability wave associated with the electron fills the box. The chances that the detector will 'observe' the electron are 50/ 50. The Schrödinger wave function therefore consists of two terms, "alive" and "dead" , each with probability 1/2 . But the cat cannot be half dead and half alive, no more than the American family can have 2.7 children . To the cat , its chances of being alive are either 100% or 0. The same becomes true for us when we look inside the box, which presumably changes nothing. ***Merely looking inside the box has "caused" the life or death of the cat !***

In line with the ideas of Chapter I , we can sharpen the argument by supposing that the gun will automatically go off if there is outside interference with the inside of the box. In particular, any attempt to see what is inside the box will kill the cat. Then the Copenhagen Interpretation of quantum theory tells that the state of the cat, living or dead, from the time the box is sealed until it is observed, is ***intrinsically unknowable*** **.**

Shifting the observers shifts the probabilities, but a complete description ought to be independent of specific observers. This was the issue that also divided Einstein from virtually all his other colleagues.

There are subtleties in the original presentation of the cat paradox that are difficult to convey, even for persons well versed in quantum theory. I've invented a situation equivalent in most respects to the cat paradox, which better conveys the substance of Schrödinger's criticism of the Copenhagen Interpretation :

We now imagine that our universe is divided into two regions, R and S. R is the inside of a building , S is the world outside. Inside the building one finds a laboratory directed by a scientist we might just as well call Einstein. There is only one door connecting R with S. Locks are placed on both sides of the door. Both locks must be opened before anyone can pass between the two regions. Outside the building is another laboratory directed by a scientist named, well, Bohr . When our story begins, it has been Open House for a week. Bohr's group is wandering freely about the building taking measurements, while Einstein's group is doing the same on the outside. By this time, Einstein and Bohr have compiled, and shared, detailed information about the physics of both their domains, and are in essential agreement about all their features.

That night , Einstein and his assistants return to their building. The locks are shut on both sides of the door. The mere act of doing this now produces a remarkable result. Although Einstein's picture of things happening inside the building is largely deterministic, in the sense that he can see what's happening around him, his picture of the outside world has become statistical, governed only by the uncertainties of the Schrödinger wave equation. The same is true for Bohr. If the contents of a can of red paint spill onto Einstein's face, he need only look in a mirror to know how he looks. Bohr ,however, is obliged to assign a certain

probability to the redness of Einstein's face and, in his reports to his colleagues, must use a model in which Einstein's face is both red and not red at the same time.

That the mere imposition of a box over a region, R, of space, should automatically produce two physical descriptions , the first being one in which R is determined and S statistical, while in the second S is determined and R statistical , continues to be unacceptable to many people. One can go to a higher level, and imagine someone in a different region of space, *who must work with two statistical equations for the door, that of the inside lock and that of the outside lock* **. Yet from the viewpoints of both Einstein and Bohr, the door is either open or it isn't.**

Too many observers with too many points of view does not make for an acceptable science.

The Use of Pictures in Scientific Explanation

Scientists, like the rest of us, think in pictures. Sometimes they are direct reproductions of visible objects; more often they are metaphors, similes, analogies , footholds for thought . The literary genre known as the science popularizer has always been severely criticized by professional physicists, (who frequently deplore the levels of public ignorance but rarely do anything about them) , because of the misleading character of its mental pictures . Often enough we have to agree with them. I have before me a copy of Douglas Hofstadter's *Gödel , Escher, Bach* . On page 82 one finds a picture of a phonograph that claims to be a "*visual rendition of the principle underlying Gödel 's Theorem .* " Whatever ideas one gets about the proof of Gödel 's First Theorem from an examination of this picture, are guaranteed to be more hopeless than any previous misconception .

Yet scientists at all levels think , and communicate , in pictorial images. The famous thought experiments of modern theoretical physics are all written in the language of pictures : Einstein's train going past a station platform to illustrate the postulate of special relativity; the man in the elevator illustrating the principle of equivalence; Heisenberg's explanation of the Uncertainty Principle in terms of a microscope experiment ; the elaborate cat story ; David Bohm's automobile windshield, where the quantum has to pause and decide whether it wants to be reflected or refracted ; the 'one-slit' and 'two-slit' experiments which, according to Richard Feynman, contain the essence of all the paradoxes of quantum theory; and the box camera

experiment which Einstein proposed to Bohr that we will be looking at in a moment .

One finds yet another decisive break between modern and classical physics in the extent to which it is impossible to picture the new concepts . The 'wave-particle' is not picturable. A 'particle' is a material object moving through empty space in a single direction ; a 'wave' is a disturbance through a material medium that propagates in every direction , though not always in the same way ; think of 'longitudinal' ocean breakers, versus 'spherical' light waves

The Schrödinger wave function is not picturable: it's not even a real number. The 4-dimensional geometry of relativity would not be picturable even if we could somehow see the 4th dimension! One of its dimensions , again, is a pure imaginary number.

Still, in some sense, these entities are all built up from things that we can imagine and see . The wave-particle , (sometimes, though rarely, called a 'wavicle'), refers to a mathematical construct that, under certain circumstances, produces wave-like behavior, and particle-like behavior under others . Light itself behaves this way, and if we can't see light we can't see anything.

Einstein's 4-dimensional space is however constructed from familiar spatial geometry , combined with a *metric form* (measurement grid) over this geometry that is a modification of the well-known Pythagorean Theorem. One speaks of 'light cones' , of contracting or expanding 'distances' , of 'clocks' which slow down or speed up. Velocities are measured with ordinary clocks and rulers. Even the absolute velocity of light is measured this way.

What then is the role of pictures? Should the ultimate constituents of reality be picturable? The issue is crucial: one might say that it is this, more than anything else, that divided Bohr from Einstein. There are, as one has come to expect , two schools of thought on the matter .

The first, exemplified by the philosopher of science, N. Hanson, is presented in his collection of essays , "Patterns of Discovery ". Hanson believes that the real difference between classical and contemporary physics has to do with the rejection of the fundamental notions that go into the framework of science: position, time, mass, energy, momentum. That the entities of atomic physics are not picturable is well known, he says. Then he points out that pictures are , at best , never more than useful analogies . If the elementary particles were picturable, they would not be elementary.

This insight is not new : Isaac Newton charged the scientists who explained the properties of matter by pictures of hooked atoms, with begging the question. One can hardly explain the sleep-inducing properties of opium by allusions to its soporific molecule! A classic example of such circular reasoning is the customary explanation of hypnosis by attributing it to 'suggestion'. What, then, is suggestion?

Without a doubt, the most interesting voice in the camp of those who would wish to rescue pictures is Niels Bohr, champion of the doctrine of ***complementarity*** **. Complementarity begins with the assumption that** ***there is a something*** **down there in the atomic world , yet the only way we can see or understand it is through its interaction with things at the scale of ordinary experience . The quantum phenomenon must somehow cross the barrier of the** ***correspondance***

principle ; the activity of bringing about this interaction is called an observation or experiment.

This being the case, it is incorrect to speak of atomic phenomena without also describing the experimental set-up by which one observes them . It is a little bit like the recognition that statements ought not be judged out of context, that when an actor struts across the stage and says, " *I am Henry , King of England!* " , the person in the audience who stands up and cries, *" No you're not! You're Richard Burton ! "* is making a mistake. Context is all.

Experiments, Bohr noted, divide into two categories: those that indicate the presence of waves , those that indicate the presence of particles . These are *complementary images* . It is these *pairs* of images which constitute reality . In isolation , each of them gives only partial information . One cannot design an experiment that records both aspects at the same time. By itself, each image is a clear and consistent picture . It is only their simultaneous combination which cannot be grasped intuitively.

Does momentum exist? Yes, says Bohr, *relative* to the experiment that measures it. Likewise for space, time, etc.

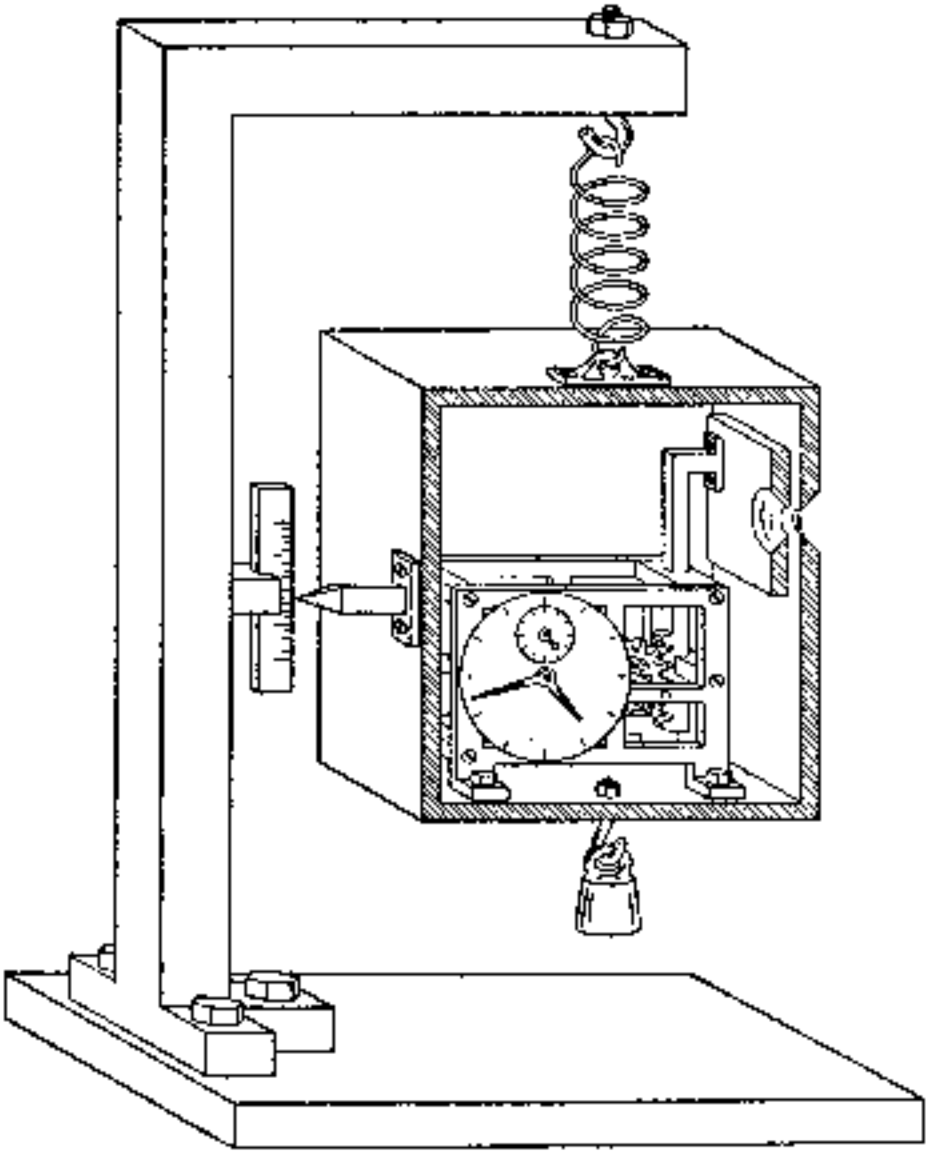
Einstein's disagreements with Niels Bohr revolved about complementarity . Between 1910 and 1935 , the Belgian physicist and entrepreneur, Ernest Solvay, financed a number of historically important conferences on theoretical physics . Physics, indeed all the sciences , at that time were still something in the nature of gentleman's clubs based on academic standing rather than peerage. Bohr and Einstein attended the Fifth Solvay Conference of 1927 in Brussels , although Einstein did not deliver a paper. For 5 days they jousted over

complementarity , the Uncertainty Principle and related issues during the meals served at the Hotel Metropole. These informal public debates were the highlight of the conference ; they have become known as the 'battle of the titans ' .

Both Einstein and Bohr came armed with pictures ! Neither elegant nor sophisticated , they were crude drawings of metal plates with cracks in them , bolted to tables or hanging from springs, boxes with camera shutters, clocks, Rube Goldberg mechanisms, pointers, scales ! Leave abstractions to the philosophers: they felt that they could best convey their ideas via things they could touch, build, see and, one must never forget, measure.

We can see what Einstein was getting at by reproducing and discussing the last of these pictorial thought-experiments . Einstein gave it to Bohr 3 years later at the Solvay conference of 1930 . It was the one that caused Bohr the most trouble, leading Einstein to conclude that he still hadn't answered all of his objections. Five years later he produced the revolutionary paper , co-authored with Boris Podolsky and Nathan Rosen : " ***Can a quantum mechanical description of nature be considered complete?*** **" We will come to this at the end of this chapter.**

Picture a hollow box. Its interior is absolutely black ; so much as a single quantum of light cannot be found within. A camera shutter mechanism is attached in front . The box dangles from a spring, while the pointer extending from the left touches a scale that records its weight.



The shutter flicks open for a split second . A handful of quanta stream inside the box. Special Relativity tells us that light has mass , given by

$$\Delta M = \Delta E / c^2$$

Since , from quantum theory

$$\Delta E = Nh\nu \quad \text{, we have}$$

$$\Delta M = N(h\nu / c^2) .$$

The quanta coming into the box will make it heavier. The box will sag and the pointer descend to a new reading for the weight

$$\Delta W = g(\Delta M) = gN(h\nu / c^2) .$$

The shutter was kept open during the time Δt . The added energy, which can be derived from knowing the weight, will be given by

$$\Delta E = \Delta W c^2 /g .$$

Since Δt and ΔE are independently derived , we should be able to make them so small that $\Delta t \times \Delta E < h / 4\pi$, thereby violating the 2nd Uncertainty Principle.

Niels Bohr eventually responded in a paper entitled ***"The Atomic Description of Nature "*** **, Physical Review , October 15th, 1935. What is interesting about this paper is that his** ***arguments use general relativity*** **to show that the 2nd Uncertainty Principle is in fact not violated. What he says, in effect, is that a real box must be built from real materials. In order to open a shutter for so short a time , there must be a corresponding violence with which the box is shaken. An increase in the rapidity of the shutter increases the uncertainty in the momentum of the box over that time interval. This energy of disturbance will transform itself into quanta that will be streaming out of the box while the new stream of quanta are entering in . There are no perfect containers. There are no ideal materials. The porosity of nature is measured by the Uncertainty Principle.**

Modern physical theories have placed limits not only on what can be observed or constructed, but on the imagination as well. Even our thought experiments must obey the rules of quantum reality.

The EPR Experiment

It was in 1935, safely settled in Princeton, New Jersey, with a lifetime chair endowed by the Institute for Advanced Study, that Einstein , in collaborations with co-workers Boris Podolsky and Nathan Rosen , produced his most famous quantum thought experiment.

The paper contrives a situation in which, in theory and ultimately by experiment, both the position and the momentum of a particle might be known to any degree of accuracy. The argument is quite general and applies to all pairs of complementary observables. In the experiments that have been carried out, the observable has been *quantum spin* , a essential magnitude of elementary particles which has the property that its differing *states* are complementary.

Since the existence and importance of uncertainty has always been recognized in all human interactions, it is not surprising to find that the situation described in the EPR paper can be effectively illustrated by a story [1] about journalists and politicians. Journalists will assume the role of 'observers' , the politicians are the 'observables' , while their political decisions are the 'states' , which it is the business of the journalists to find out and communicate to the rest of us.

Once upon a time, a number of key figures in the national government held a meeting . The strictest secrecy was maintained. All outside observers, including journalists, were excluded. The following things were known to the public:

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[1] which I cannot copyright without hindering the free flow of ideas, alas!

(1) The question being decided was whether or not to go to war with a certain hostile nation .

(2) One could know their decision if truthful answers were given to two questions:

(X) Will the army be mobilized?

(Y) Will weapons production be stepped up?

A "YES" answer to both of them meant that the nation was definitely going to war. A "NO" on both of them meant that there would definitely be peace. A mixture of "YES" and "NO" would mean that the decision had been tabled until further notice.

(3) The decision had been reached through consensus.

(4) Most of the politicians would give a truthful answer to either X or Y if asked, but that they were pledged to lie whenever (a) They were asked this question a second time, or (b) the question was followed by the complementary question . That is to say, they would answer only the first question truthfully, then tell lies in response to all subsequent questions.

Given assumptions (1) through (4) , it is an easy matter for the journalists to learn what happened at the meeting . They approach politician A and ask him question X . Then they approach politician B and ask him question Y. Then the journalists put the answers together to deduce the truth.

This is a direct translation of the EPR thought-experiment into daily life. Rosen , Einstein and Podolsky imagined two particles S and T that had spent some time in close interaction, so much so that they became thoroughly causally ***entangled*** **: knowing the behavior of S**

would give complete information about the behavior of T , provided that the state of S could be measured without disturbing the state of T .

The possibility of calculating T's position without having to disturb it satisfies *Einstein's criterion of reality* : A magnitude should only be considered real if it can be measured *without* altering its value .

This is clearly not possible when they are closely associated (the equivalent of the politicians' secret meeting) , but we now imagine a situation in which S and T fly apart until there is no longer any measurable interaction between them. One thinks, for example, of certain comets that come into the gravitational field of the sun, then fly out on a theoretically infinite parabolic path that never returns.

According to quantum mechanics, even though the particles are no longer entangled in the real world, *they are still entangled in the formal structure of the Schrödinger wave equation* . Einstein thought that there was something wrong with this: he pointed out that one could then, in theory, measure the position of S, use this to calculate the position of T via the wave equation , then measure the momentum of T directly. In this way, both the position and momentum of T could be exactly known.

Let us return to the politicians and journalists. The politicians might try to circumvent the prying inquiries of the journalists. After answering question X , politician A may pick up his telephone and notifies all the others who were present at the meeting. They will then be prepared with their lies when approached on question Y.

It then becomes a matter of getting to politician B before he has had a chance to receive a call from politician A. If politician A has a long list of calls to make , the reporters may be able to calculate the average amount of time it takes him to make a phone call, then use statistics to

estimate the most probable answer to question Y. The entire situation could be recast in statistical terms , so that even if the politicians sometimes lie and sometimes tell the truth , and even if they are in communication with one another, a clever statistician [1] could accurately estimate the probability that the country is going to war .

So what Podolsky , Rosen and Einstein said, was that there was an upper limit on communications between particles S and T , and that was given by the postulate of relativity which asserts that no signal can be transmitted faster than the speed of light. Anything else could be characterized as a "spooky action at a distance" , (*Gespenstersfeld* **) . Clearly the universe does not work that way.**

It turns out that they were both right and wrong. Einstein did once more launch a revolution in physics, but it did not go according to plan. The EPR thought experiment was refined by David Bohm to serve as a test case for his theory of hidden variables. In his great synthesis of quantum theory published in 1955 , John von Neumann thought he had proven that hidden variable theories were impossible ; but a mistake was discovered in his proof.[2] It was only in 1964 that John S. Bell proved a theorem that showed, by elementary arguments , that hidden variables were not sufficient to produce an EPR situation. However, one consequence of this is that correlations of certain quantities peculiar to the quantum world are instantaneously transmitted over arbitrarily long distances !

So that, on the one hand, EPR experiments , which by their nature violate Bell's Theorem , do not give a way to measure complementary

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[1] **of which there are unfortunately not many among journalists.**
[2] **For the technically-minded: the sum of two invertible matrices may be non-invertible.**

variables simultaneously , but that on the other hand, the completeness of quantum theory rests on a peculiar violation of the laws of relativity known as ***non-locality*** **! Certainly in 1935 no-one would have been prepared to accept this. Even today it is not well understood. Theorists argue that the principle of relativity only concerns energy transfers or signal transmission ; and in fact it can be shown that signals cannot be transmitted faster than light in situations which violation Bell's theorem. Such situations have been confirmed experimentally. Quantum theory has weathered the challenge, and we must give up our traditional notions of causal independence between differing regions of space.**

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