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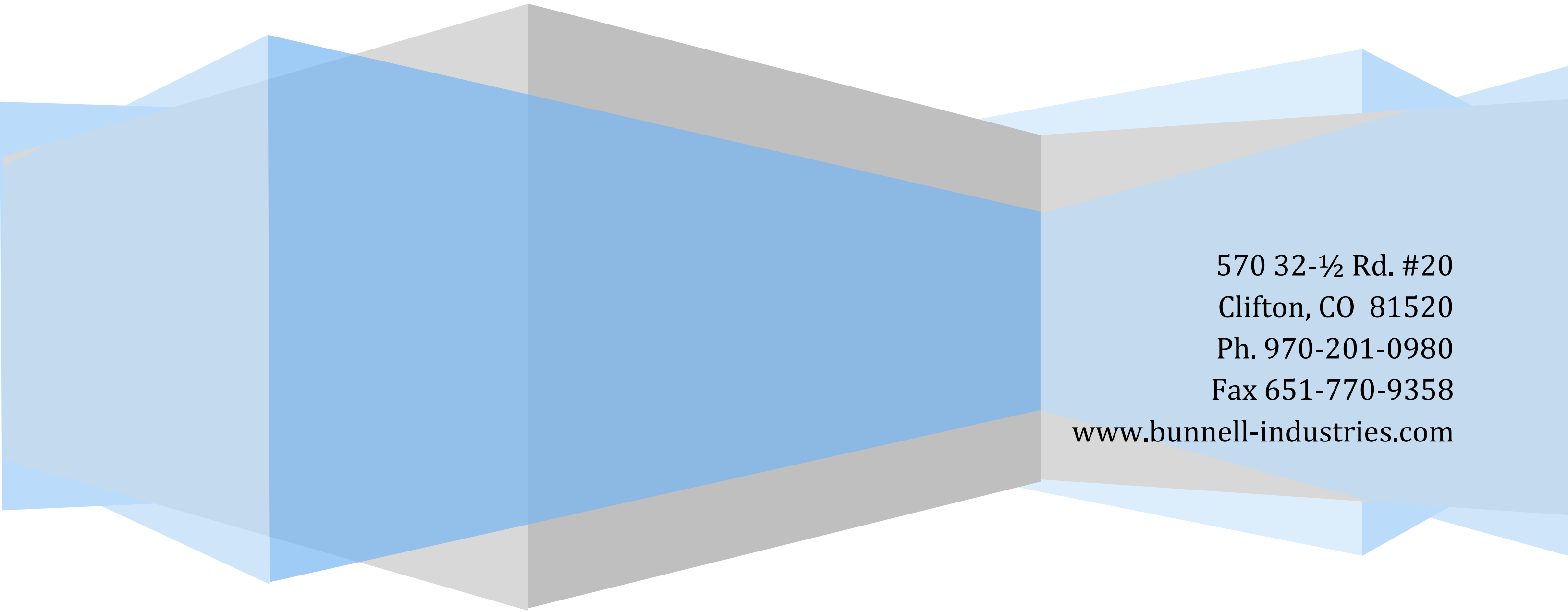
Proof of Schrödinger’s Equation



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Proof of Schrödinger's Equation

Dr. Marvin D. Bunnell

In Schrödinger's equation, the basis of quantum mechanics, in my opinion, the hypothetical cat which must be dead and alive at the same time for all of the other universes to exist in a quantum state does exist in this reality.

The cat is dead and alive at the same time. When the cat is declared dead it only means that some of its body functions have stopped working, but in actuality the atoms in the cells continue to function until the atoms are turned into another form of matter.

Medical doctors call the time of death, but even in their opinions it is relative then, that the cat can be dead and alive at the same time in this reality.

Therefore the conditions surrounding the proof of Schrödinger's equation is real in this reality and can be viewed in a physical from. At the present Roger Penrose appears to believe that the quantum state and quantum mechanics does not apply unless they can be proven in this reality.

I have just supplied the proof that the equation is correct, and quantum mechanics and the quantum state are real.

Also, by my testing with APM (All-Purpose Medicine), I have determined that the quantum state and other realities exist in the 95% of matter and energy we do not see with the limited senses which most lifeforms have at their disposal. Each lifeform has different senses available to them.

Roger Penrose and quantum physicists and particle physicists all want to agree that the quantum state, other universes, other realities and string energy are real.

I am in concurrence with the above statement and I have developed my own proofs from experimentation with my APM compound.

Even atoms, protons and electrons in metals and all matter are moving at high rate of speed. They appear solid to the eye.

My structure of the cell in the twelve (12) stages of construction and the formation of the neurons and energy involved in the communications, even after a physical reality, death still can maintain a coherence in the tublins of the cells, even after they have been disbursed into another form.

My procedures for re-instituting life into a body after death has been called by medical personnel, also proves that the cat can be dead and alive at the same time.

Quantum state material; APM, can maintain a coherence.

Schrödinger Equation

$$E\Psi = \hat{H}\Psi$$

$$i\hbar\frac{\partial}{\partial t}\Psi = \hat{H}\Psi$$

Two forms of the Schrödinger equation

In physics, specifically quantum mechanics, the **Schrödinger equation** is an equation that describes how the quantum state of a physical system changes in time. It is as central to quantum mechanics as Newton's laws are to classical mechanics.

In the standard interpretation of quantum mechanics, the quantum state, also called a wavefunction or state vector, is the most complete description that can be given to a physical system.
Solutions to Schrödinger's equation describe not only molecular, atomic and subatomic systems, but also macroscopic systems, possibly even the whole universe. The equation is named after Erwin Schrödinger, who constructed it in 1926.[1]

The most general form is the time-dependant Schrödinger equation, which gives a description of a system evolving with time. For systems in a stationary state, the time-independent Schrödinger equation is sufficient. Approximate solutions to the time-independent Schrödinger equation are commonly used to calculate the energy levels and other properties of atoms and molecules.

Schrödinger's equation can be mathematically transformed into Werner Heisenberg's matrix mechanics, and into Richard Feynman's path integral formulation. The Schrödinger equation describes time in a way that is inconvenient for relativistic theories, a problem which is not as severe in matrix mechanics and completely absent in the path integral formulation.

Contents

The Schrödinger equation

The Schrödinger equation takes several different forms, depending on the physical situation. This section presents the equation for the general case and for the simple case encountered in many textbooks.

General quantum system

For a general quantum system:[2]

$$i\hbar\frac{\partial}{\partial t}\Psi = \hat{H}\Psi$$

where

- Ψ is the wave function; the probability amplitude for different configurations of the system at different times,
- $i\hbar\frac{\partial}{\partial t}$ is the energy operator (here, *i* is the imaginary unit and $\hbar$ is the reduced Planck constant),
- $\hat{H}$ is the Hamiltonian operator.

Single particle in a potential

For a single particle with potential energy *V*, the Schrödinger equation takes the form:[3]

$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},\,t) = -\frac{\hbar^2}{2m}\nabla^2\Psi(\mathbf{r},\,t) + V(\mathbf{r})\Psi(\mathbf{r},\,t)$$

where

- $-\frac{\hbar^2}{2m}\nabla^2$ is the kinetic energy operator, where *m* is the mass of the particle.
- ∇^2 is the Laplace operator. In three dimension, the Laplace operator is $\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}$, where *x*, *y*, and *z* are the Cartesian coordinates of space.
- $V(\mathbf{r})$ is the time-independent potential energy at the position **r**.
- $\Psi(\mathbf{r},\, t)$ is the probability amplitude for the particle to be found at position **r** at time *t*.

Time independent equation

The time independent equation, again for a single particle with potential energy *V* takes the form:[4]

$$E\psi(r) = -\frac{\hbar^2}{2m}\nabla^2\psi(r) + V(r)\psi(r).$$

This equation describes the standing wave solutions of the time-dependent equation, which are the states with definite energy.

Historical background and development

Following Max Planck's quantization of light (see black body radiation), Albert Einstein interpreted Planck's quantum to be photons, particles of light, and proposed that the energy of a photon is proportional to its frequency, one of the first signs of wave–particle duality. Since energy and momentum are related in the same way as frequency and wavenumber in special relativity, it followed that the momentum *p* of a photon is proportional to its wavenumber *k*.

$$p = \frac{h}{\lambda} = \hbar k$$

Louis de Broglie hypothesized that this is true for all particles, even particles such as electrons. Assuming that the waves travel roughly along classical paths,[*clarification needed*] he showed that they form standing waves for certain discrete frequencies. These correspond to discrete energy levels, which reproduced the old quantum condition. [5]

Following up on these ideas, Schrödinger decided to find a proper wave equation for the electron. He was guided by William R. Hamilton's analogy between mechanics and optics, encoded in the observation that the zero-wavelength limit of optics resembles a mechanical system—the trajectories of light rays become sharp tracks which obey Fermat's principle, an analog of the principle of least action.[6] A modern version of his reasoning is reproduced in the next section. The equation he found is:

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = -\frac{\hbar^2}{2m}\nabla^2\Psi(x,t) + V(x)\Psi(x,t).$$

Using this equation, Schrödinger computed the Hydrogen spectral series by treating a hydrogen atom's electron as a wave $\Psi(x, t)$, moving in a potential well V, created by the proton. This computation accurately reproduced the energy levels of the Bohr model.

However, by that time, Arnold Sommerfeld had refined the Bohr model with relativistic corrections.[7][8] Schrödinger used the relativistic energy momentum relation to find what is now known as the Klein–Gordon equation in a Coulomb potential (in natural units):

$$\left(E + \frac{e^2}{r}\right)^2 \psi(x) = -\nabla^2\psi(x) + m^2\psi(x).$$

He found the standing waves of this relativistic equation, but the relativistic corrections disagreed with Sommerfeld's formula. Discouraged, he put away his calculations and secluded himself in an isolated mountain cabin with a lover.[9]

While at the cabin, Schrödinger decided that his earlier non-relativistic calculations were novel enough to publish, and decided to leave off the problem of relativistic corrections for the future. He put together his wave equation and the spectral analysis of hydrogen in a paper in 1926.[10] The paper was enthusiastically endorsed by Einstein, who saw the matter-waves as an intuitive depiction of nature, as opposed to Heisenberg's matrix mechanics, which he considered overly formal.[11]

The Schrödinger equation details the behaviour of ψ but says nothing of its *nature*. Schrödinger tried to interpret it as a charge density in his fourth paper, but he was unsuccessful.[12] In 1926, Just a few days after Schrödinger's fourth and final paper was published, Max Born successfully interpreted ψ as a probability amplitude.[13] Schrödinger, though, always opposed a statistical or probabilistic approach, with its associated discontinuities—much like Einstein, who believed that quantum mechanics was a statistical approximation to an underlying deterministic theory— and never reconciled with the Copenhagen interpretation.[14]

Derivation

Short heuristic derivation

Schrödinger's equation can be derived in the following short heuristic way.

Assumptions

1. The total energy *E* of a particle is

   $$E = T + V = \frac{p^2}{2m} + V.$$

   This is the classical expression for a particle with mass *m* where the total energy *E* is the sum of the kinetic energy *T*, and the potential energy *V* (which can vary with position, and time). *p* and *m* are respectively the momentum and the mass of the particle.

2. Einstein's light quanta hypothesis of 1905, which asserts that the energy *E* of a photon is proportional to the frequency *v* (or angular frequency, *ω* = 2π*v*) of the corresponding electromagnetic wave:

   $$E = h\nu = \hbar\omega \ ,$$

3. The de Broglie hypothesis of 1924, which states that any particle can be associated with a wave, and that the momentum *p* of the particle is related to the wavelength *λ* (or wavenumber *k*) of such a wave by:

   $$p = \frac{h}{\lambda} = \hbar k \ ,$$

   Expressing **p** and **k** as vectors, we have

   $$\mathbf{p} = \hbar\mathbf{k} \ .$$

4. The three assumptions above allow one to derive the equation for plane waves only. To conclude that it is true in general requires the superposition principle, and thus, one must separately postulate that the Schrödinger equation is linear.

Expressing the wave function as a complex plane wave

Schrödinger's idea was to express the phase of a plane wave as a complex phase factor:

$$\Psi(\mathbf{x},t) = Ae^{i(\mathbf{k}\cdot\mathbf{x}-\omega t)}$$

and to realize that since

$$\frac{\partial}{\partial t}\Psi = -i\omega\Psi$$

then

$$E\Psi = \hbar\omega\Psi = i\hbar\frac{\partial}{\partial t}\Psi$$

and similarly since

$$\frac{\partial}{\partial x}\Psi = ik_x\Psi$$

and

$$\frac{\partial^2}{\partial x^2}\Psi = -k_x^2\Psi$$

we find:

$$p_x^2\Psi = (\hbar k_x)^2\Psi = -\hbar^2\frac{\partial^2}{\partial x^2}\Psi$$

so that, again for a plane wave, he obtained:

$$p^2\Psi = (p_x^2 + p_y^2 + p_z^2)\Psi = -\hbar^2\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)\Psi = -\hbar^2\nabla^2\Psi$$

And, by inserting these expressions for the energy and momentum into the classical formula we started with, we get Schrödinger's famed equation, for a single particle in the 3-dimensional case in the presence of a potential *V*:

$$i\hbar\frac{\partial}{\partial t}\Psi = -\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi$$

Versions

There are several equations which go by Schrödinger's name:

Time dependent equation

This is the equation of motion for the quantum state. In the most general form, it is written:[15]

$$i\hbar\frac{\partial}{\partial t}\Psi(x,\,t) = \hat{H}\Psi(x,\,t)$$

where $\hat{H}$ is a linear operator acting on the wavefunction Ψ. For the specific case of a single particle in one dimension moving under the influence of a potential V.[15]

$$i\hbar\frac{\partial}{\partial t}\Psi(x,\,t) = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\Psi(x,\,t) + V(x)\Psi(x,\,t)$$

and the operator $\hat{H}$ can be read off:

$$\hat{H} = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x).$$

For a particle in three dimensions, the only difference is more derivatives:

$$i\hbar\frac{\partial}{\partial t}\Psi(x,y,z,\,t) = -\frac{\hbar^2}{2m}\nabla^2\Psi(x,y,z,\,t) + V(x)\Psi(x,y,z,\,t)$$

and for N particles, the difference is that the wavefunction is in $3N$-dimensional configuration space, the space of all possible particle positions.[16]

$$i\hbar\frac{\partial}{\partial t}\Psi(x_1,...,x_n,t) = \hbar^2(-\frac{\nabla_1^2}{2m_1}-\frac{\nabla_2^2}{2m_2}...-\frac{\nabla_N^2}{2m_N})\Psi(x_1,...,x_n,t)+V(x_1,..,x_n,t)\Psi(x_1,...,x_n,t).$$

This last equation is in a very high dimension, so that the solutions are not easy to visualize.

Time independent equation

This is the equation for the standing waves, the eigenvalue equation for $\hat{H}$. In abstract form, for a general quantum system, it is written:[15]

$$\hat{H}\psi = E\psi.$$

For a particle in one dimension,

$$E\psi = -\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + V(x)\psi.$$

But there is a further restriction—the solution must not grow at infinity, so that it has a either a finite ***L*²-norm** (if it is a bound state) or a slowly diverging norm (if it is part of a continuum):[17]

$$\|\psi\|^2 = \int |\psi(x)|^2\, dx.$$

For example, when there is no potential, the equation reads:[18]

$$-E\psi = \frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2}$$

which has oscillatory solutions for $E > 0$ (the C_n are arbitrary constants):

$$\psi_E(x) = C_1 e^{i\sqrt{2mE/\hbar^2}\,x} + C_2 e^{-i\sqrt{2mE/\hbar^2}\,x}$$

and exponential solutions for $E < 0$

$$\psi_{-|E|}(x) = C_1 e^{\sqrt{2m|E|/\hbar^2}\,x} + C_2 e^{-\sqrt{2m|E|/\hbar^2}\,x}.$$

The exponentially growing solutions have an infinite norm, and are not physical. They are not allowed in a finite volume with periodic or fixed boundary conditions.

For a constant potential V the solution is oscillatory for $E > V$ and exponential for $E < V$, corresponding to energies which are allowed or disallowed in classical mechanics. Oscillatory solutions have a classically allowed energy and correspond to actual classical motions, while the exponential solutions have a disallowed energy and describe a small amount of quantum bleeding into the classically disallowed region, to quantum tunneling. If the potential V grows at infinity, the motion is classically confined to a finite region, which means that in quantum mechanics every solution becomes an exponential far enough away. The condition that the exponential is decreasing restricts the energy levels to a discrete set, called the allowed energies.

Nonlinear equation

The nonlinear Schrödinger equation is the partial differential equation (in natural units)

$$i\partial_t\psi = -\frac{1}{2}\partial_x^2\psi + \kappa|\psi|^2\psi$$

for the complex field ψ.

This equation arises from the Hamiltonian

$$H = \int \mathrm{d}x \left[\frac{1}{2}|\partial_x\psi|^2 + \frac{\kappa}{2}|\psi|^4\right]$$

with the Poisson brackets

$$\{\psi(x), \psi(y)\} = \{\psi^*(x), \psi^*(y)\} = 0$$

$$\{\psi^*(x), \psi(y)\} = i\delta(x-y).$$

It must be noted that this is a classical field equation. Unlike its linear counterpart, it never describes the time evolution of a quantum state.

Properties

The Schrödinger equation has certain properties.

Local conservation of probability

The probability density of a particle is $\Psi^*(x,\,t)\Psi(x,\,t)$. The probability flux is defined as [in units of (probability)/(area × time)]:

$$\mathbf{j} = -\frac{i\hbar^2}{2m}\left(\Psi^*\nabla\Psi - \Psi\nabla\Psi^*\right) = \frac{\hbar}{m}\mathrm{Im}\left(\Psi^*\nabla\Psi\right).$$

The probability flux satisfies the continuity equation:

$$\frac{\partial}{\partial t}P\left(x,t\right) + \nabla\cdot\mathbf{j} = 0$$

where $P\left(x,t\right)$is the probability density [measured in units of (probability)/(volume)]. This equation is the mathematical equivalent of the probability conservation law.

For a plane wave:

$$\Psi(x,t) = Ae^{\mathrm{i}(kx-\omega t)}$$

$$j\,(x,t) = |A|^2\,\frac{\hbar k}{m}.$$

So that not only is the probability of finding the particle the same everywhere, but the probability flux is as expected from an object moving at the classical velocity *p*/*m*. The reason that the Schrödinger equation admits a probability flux is because all the hopping is local and forward in time.

Relativity

The Schrödinger equation does not take into account relativistic effects; as a wave equation, it is invariant under a Galilean transformation, but not under a Lorentz transformation. But in order to include relativity, the physical picture must be altered.

The Klein–Gordon equation uses the relativistic mass-energy relation:

$$E^2 = p^2c^2 + m^2c^4$$

to produce the differential equation:

$$-\frac{1}{c}\frac{\partial^2}{\partial t^2}\psi = -\nabla^2\psi + \frac{m^2c^2}{\hbar^2}\psi$$

which is relativistically invariant.

Solutions

Some general techniques are:

- Perturbation theory
- The variational method
- Quantum Monte Carlo methods
- Density functional theory
- The WKB approximation and semi-classical expansion

In some special cases, special methods can be used:

- List of quantum-mechanical systems with analytical solutions
- Hartree-Fock method and post Hartree-Fock methods
- Discrete delta-potential method

Notes

1. **^** Schrödinger, E. (1926). "An Undulatory Theory of the Mechanics of Atoms and Molecules". *Physical Review* **28** (6): 1049–1070. doi:10.1103/PhysRev.28.1049. http://home.tiscali.nl/physis/HistoricPaper/Schroedinger/Schroedinger1926c.pdf.
2. **^** Shankar, R. (1994). *Principles of Quantum Mechanics* (2nd ed.). Kluwer Academic/Plenum Publishers. p. 143. ISBN 978-0-306-44790-7.
3. **^** Shankar, R. (1994). *Principles of Quantum Mechanics* (2nd ed.). Kluwer Academic/Plenum Publishers. p. 143ff. ISBN 978-0-306-44790-7.
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5. **^** de Broglie, L. (1925). "Recherches sur la théorie des quanta [On the Theory of Quanta]". *Annales de Physique* **10** (3): 22–128. http://tel.archives-ouvertes.fr/docs/00/04/70/78/PDF/tel-00006807.pdf. Translated version.
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11. **^** Einstein, A.; *et. al*.. *Letters on Wave Mechanics: Schrodinger-Planck-Einstein-Lorentz*.
12. **^** Moore, W.J. (1992). *Schrödinger: Life and Thought*. Cambridge University Press. p. 219. ISBN 0-521-43767-9.
13. **^** Moore, W.J. (1992). *Schrödinger: Life and Thought*. Cambridge University Press. p. 220. ISBN 0-521-43767-9.
14. **^** It is clear that even in his last year of life, as shown in a letter to Max Born, that Schrödinger never accepted the Copenhagen interpretation. cf p. 220 Moore, W.J. (1992). *Schrödinger: Life and Thought*. Cambridge University Press. p. 479. ISBN 0-521-43767-9.
15. ^ ***a b c*** Shankar, R. (1994). *Principles of Quantum Mechanics*. Kluwer Academic/Plenum Publishers. pp. 143*ff*. ISBN 978-0-306-44790-7.
16. **^** Shankar, R. (1994). *Principles of Quantum Mechanics*. Kluwer Academic/Plenum Publishers. p. 141. ISBN 978-0-306-44790-7.
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External links

- Quantum Physics - a textbook with a treatment of the time-independent Schrödinger equation
- Linear Schrödinger Equation at EqWorld: The World of Mathematical Equations.
- Nonlinear Schrödinger Equation at EqWorld: The World of Mathematical Equations.
- The Schrödinger Equation in One Dimension as well as the directory of the book.
- All about 3D Schrödinger Equation
- Mathematical aspects of Schrödinger equations are discussed on the Dispersive PDE Wiki.
- Web-Schrödinger: Interactive solution of the 2D time dependent Schrödinger equation
- An alternate derivation of the Schrödinger Equation

Retrieved from "http://en.wikipedia.org/wiki/Schr%C3%B6dinger_equation"

Discover Interview: Roger Penrose Says Physics Is Wrong, From String Theory to Quantum Mechanics

September 2009 Issue

Please visit the Discover Magazine website[1] to read the complete interview with Roger Penrose on quantum mechanics, Schrodinger equation and Schrodinger's hypothetical dead and alive cat.

Q: In quantum mechanics an object can exist in many states at once, which sounds crazy. The quantum description of the world seems completely contrary to the world as we experience it.

Roger Penrose:
"It doesn't make any sense, and there is a simple reason. You see, the mathematics of quantum mechanics has two parts to it. One is the evolution of a quantum system, which is described extremely precisely and accurately by the Schrödinger equation. That equation tells you this: If you know what the state of the system is now, you can calculate what it will be doing 10 minutes from now. However, there is the second part of quantum mechanics—the thing that happens when you want to make a measurement. Instead of getting a single answer, you use the equation to work out the probabilities of certain outcomes. The results don't say, "This is what the world is doing." Instead, they just describe the probability of its doing any one thing. The equation should describe the world in a completely deterministic way, but it doesn't."

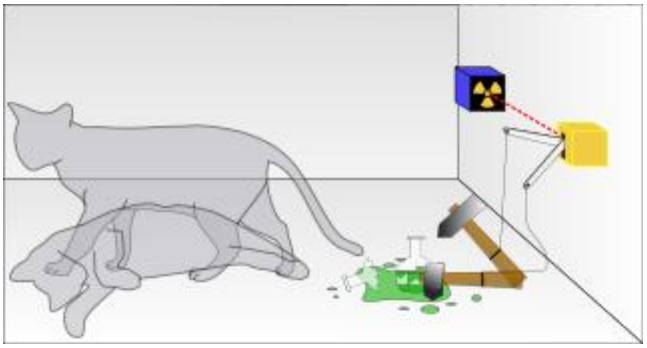
Q: Erwin Schrödinger, who created that equation, was considered a genius. Surely he appreciated that conflict.

Roger Penrose:
"Schrödinger was as aware of this as anybody. He talks about his hypothetical cat and says, more or less, "Okay, if you believe what my equation says, you must believe that this cat is dead and alive at the same time." He says, "That's obviously nonsense, because it's not like that. Therefore, my equation can't be right for a cat. So there must be some other factor involved."

Reference:

1. Discover Magazine Interview by Susan Kruglinski
http://discovermagazine.com/2009/sep/06-discover-interview-roger-penrose-says-physics-is-wrong-string-theory-quantum-mechanics

Schrödinger's Cat



Schrödinger's Cat: A cat, along with a flask containing a poison and a radioactive source, is placed in a sealed box shielded against environmentally induced quantum decoherence. If an internal Geiger counter detects radiation, the flask is shattered, releasing the poison that kills the cat. The Copenhagen interpretation of quantum mechanics implies that after a while, the cat is *simultaneously* alive *and* dead. Yet, when we look in the box, we see the cat *either* alive *or* dead, not both alive *and* dead.

Schrödinger's cat is a thought experiment, often described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935. It illustrates what he saw as the problem of the Copenhagen interpretation of quantum mechanics applied to everyday objects. The thought experiment presents a cat that might be alive or dead, depending on an earlier random event. In the course of developing this experiment, he coined the term **Verschränkung** — literally, entanglement.[1]

Contents

Origin and motivation

Schrödinger's thought experiment was intended as a discussion of the EPR article, named after its authors — Einstein, Podolsky, and Rosen — in 1935.[2] The EPR article had highlighted the strange nature of quantum superpositions. Broadly stated, a quantum superposition is the combination of all the possible states of a system (for example, the possible positions of a subatomic particle). The Copenhagen interpretation implies that the superposition undergoes collapse into a definite state only at the exact moment of quantum measurement.

Schrödinger and Einstein had exchanged letters about Einstein's EPR article, in the course of which Einstein had pointed out that the quantum superposition of an unstable keg of gunpowder will, after a while, contain both exploded and unexploded components.

To further illustrate the putative incompleteness of quantum mechanics, Schrödinger applied quantum mechanics to a living entity that may or may not be conscious. In Schrödinger's original thought experiment, he describes how one could, in principle, transpose the superposition of an atom to large-scale systems of a live and dead cat by coupling cat and atom with the help of a "diabolical mechanism". He proposed a scenario with a cat in a sealed box, wherein the cat's life or death was dependent on the state of a subatomic particle. According to Schrödinger, the Copenhagen interpretation implies that *the cat remains both alive and dead* (to the universe outside the box) until the box is opened.

Schrödinger did *not* wish to promote the idea of dead-and-alive cats as a serious possibility; quite the reverse, the paradox is a classic reductio ad absurdum. The thought experiment serves to illustrate the bizarreness of quantum mechanics and the mathematics necessary to describe quantum states. Intended as a critique of just the Copenhagen interpretation (the prevailing orthodoxy in 1935), the Schrödinger cat thought experiment remains a topical touchstone for all interpretations of quantum mechanics. How each interpretation deals with Schrödinger's cat is often used as a way of illustrating and comparing each interpretation's particular features, strengths, and weaknesses.

The thought experiment

Schrödinger wrote:

> *One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter, there is a tiny bit of radioactive substance, so small that perhaps in the course of the hour, one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges, and through a relay releases a hammer that shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts.*
>
> *It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naively accepting as valid a "blurred model" for representing reality. In itself, it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks.*[3]

The above text is a translation of two paragraphs from a much larger original article that appeared in the German magazine *Naturwissenschaften* ("Natural Sciences") in 1935.[4]

Schrödinger's famous thought experiment poses the question, *when* does a quantum system stop existing as a mixture of states and become one or the other? (More technically, when does the actual quantum state stop being a linear combination of states, each of which resembles different classical states, and instead begins to have a unique classical description?) If the cat survives, it remembers only being alive. But explanations of the EPR experiments that are consistent with standard microscopic quantum mechanics require that macroscopic objects, such as cats and notebooks, do not always have unique classical descriptions. The purpose of the thought experiment is to illustrate this apparent paradox. Our intuition says that no observer can be in a mixture of states; yet the cat, it seems from the thought experiment, can be such a mixture. Is the cat required to be an observer, or does its existence in a single well-defined classical state require another external observer? Each alternative seemed absurd to Albert Einstein, who was impressed by the ability of the thought experiment to highlight these issues. In a letter to Schrödinger dated 1950, he wrote:

> *You are the only contemporary physicist, besides Laue, who sees that one cannot get around the assumption of reality, if only one is honest. Most of them simply do not see what sort of risky game they are playing with reality—reality as something independent of what is experimentally established. Their interpretation is, however, refuted most elegantly by your system of radioactive atom + amplifier + charge of gunpowder + cat in a box, in which the psi-function of the system contains both the cat alive and blown to bits. Nobody really doubts that the presence or absence of the cat is something independent of the act of observation.*[5]

Note that no charge of gunpowder is mentioned in Schrödinger's setup, which uses a Geiger counter as an amplifier and hydrocyanic poison instead of gunpowder. The gunpowder had been mentioned in Einstein's original suggestion to Schrödinger 15 years before, and apparently Einstein had carried it forward to the present discussion.

Interpretations of the experiment

Since Schrodinger's time, other interpretations of quantum mechanics have been proposed that give different answers to the questions posed by Schrodinger's cat of how long superpositions last and when (or *if*) they collapse.

Copenhagen interpretation

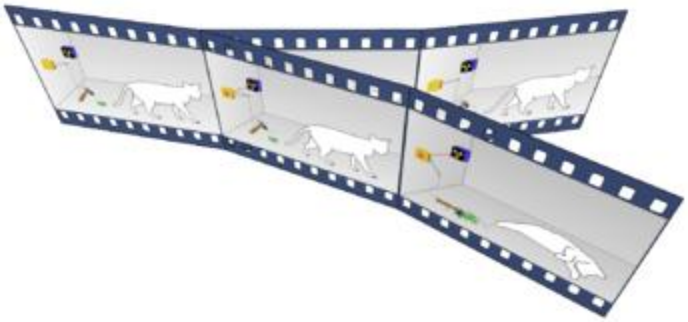
In the Copenhagen interpretation of quantum mechanics, a system stops being a superposition of states and becomes either one or the other when an observation takes place. This experiment makes apparent the fact that the nature of measurement, or observation, is not well-defined in this interpretation. The experiment can be interpreted to mean that while the box is closed, the system simultaneously exists in a superposition of the states "decayed nucleus/dead cat" and "undecayed nucleus/living cat", and that only when the box is opened and an observation performed does the wave function collapse into one of the two states. An alternate view is that the "observation" is taken when a particle from the nucleus hits the detector. This line of thinking can be developed into objective collapse theories. In contrast, the many worlds approach denies that collapse ever occurs.

Steven Weinberg said:

> *All this familiar story is true, but it leaves out an irony. Bohr's version of quantum mechanics was deeply flawed, but not for the reason Einstein thought. The Copenhagen*

> *interpretation describes what happens when an observer makes a measurement, but the observer and the act of measurement are themselves treated classically. This is surely wrong; physicists and their apparatus must be governed by the same quantum mechanical rules that govern everything else in the universe. But these rules are expressed in terms of a wave function (or, more precisely, a state vector) that evolves in a perfectly deterministic way. So where do the probabilistic rules of the Copenhagen interpretation come from?*
>
> *Considerable progress has been made in recent years toward the resolution of the problem, which I cannot go into here. It is enough to say that neither Bohr nor Einstein had focused on the real problem with quantum mechanics. The Copenhagen rules clearly work, so they have to be accepted. But this leaves the task of explaining them by applying the deterministic equation for the evolution of the wave function, the Schrödinger equation, to observers and their apparatus.*[6]

Many-worlds interpretation & consistent histories



The quantum-mechanical "**Schrödinger's cat**" paradox according to the many-worlds interpretation. In this interpretation every event is a branch point; the cat is both alive and dead, irrespective of whether the box is opened, but the "alive" and "dead" cats are in different branches of the universe, both of which are equally real, but which cannot interact with each other.

In 1957, Hugh Everett formulated the many-worlds interpretation of quantum mechanics, which does not single out observation as a special process. In the many-worlds interpretation, both alive and dead states of the cat persist after the box is opened, but are decoherent from each other. In other words, when the box is opened, the observer and the already-split cat split into an observer looking at a box with a dead cat, and an observer looking at a box with a live cat. But since the dead and alive states are decoherent, there is no effective communication or interaction between them.

When opening the box, the observer becomes entangled with the cat, so "observer states" corresponding to the cat's being alive and dead are formed; each observer state is entangled or linked with the cat so that the "observation of the cat's state" and the "cat's state" correspond with each other. Quantum decoherence ensures that the different outcomes have no interaction with the other. The same mechanism of quantum decoherence is also important for the interpretation in terms of consistent histories. Only the "dead cat" or "alive cat" can be a part of a consistent history in this interpretation.

Roger Penrose criticises this:

> *"I wish to make it clear that, as it stands, this is far from a resolution of the cat paradox. For there is nothing in the formalism of quantum mechanics that demands that a state of consciousness cannot involve the simultaneous perception of a live and a dead cat",*[7]

although the mainstream view (without necessarily endorsing many-worlds) is that decoherence is the mechanism that forbids such simultaneous perception.[8][9]

A variant of the Schrödinger's Cat experiment, known as the quantum suicide machine, has been proposed by cosmologist Max Tegmark. It examines the Schrödinger's Cat experiment from the point of view of the cat, and argues that by using this approach, one may be able to distinguish between the Copenhagen interpretation and many-worlds.

Ensemble interpretation

The ensemble interpretation states that superpositions are nothing but subensembles of a larger statistical ensemble. That being the case, the state vector would not apply to individual cat experiments, but only to the statistics of many similarly prepared cat experiments. Proponents of this interpretation state that this makes the Schrödinger's Cat paradox a trivial non-issue.[*who?*]

This interpretation serves to discard the idea that a single physical system in quantum mechanics has a mathematical description that corresponds to it in any way.

Relational interpretation

The relational interpretation makes no fundamental distinction between the human experimenter, the cat, or the apparatus, or between animate and inanimate systems; all are quantum systems governed by the same rules of wavefunction evolution, and all may be considered "observers." But the relational interpretation allows that different observers can give different accounts of the same series of events, depending on the information they have about the system.[10] The cat can be considered an observer of the apparatus; meanwhile, the experimenter can be considered another observer of the system in the box (the cat plus the apparatus). Before the box is opened, the cat, by nature of it being alive or dead, has information about the state of the apparatus (the atom has either decayed or not decayed); but the experimenter does not have information about the state of the box contents. In this way, the two observers simultaneously have different accounts of the situation: To the cat, the wavefunction of the apparatus has appeared to "collapse"; to the experimenter, the contents of the box appear to be in superposition. Not until the box is opened, and both observers have the same information about what happened, do both system states appear to "collapse" into the same definite result, a cat that is either alive or dead.

Objective collapse theories

According to objective collapse theories, superpositions are destroyed spontaneously (irrespective of external observation) when some objective physical threshold (of time, mass, temperature, irreversibility, etc.) is reached. Thus, the cat would be expected to have settled into a definite state long before the box is opened. This could loosely be phrased as "the cat observes itself", or "the environment observes the cat".

Objective collapse theories require a modification of standard quantum mechanics to allow superpositions to be destroyed by the process of time evolution.

Practical applications

The experiment is a purely theoretical one, and the machine proposed is not known to have been constructed. Analogous effects, however, have some practical use in quantum computing and quantum cryptography. It is possible to send light that is in a superposition of states down a fiber optic cable. Placing a wiretap in the middle of the cable that intercepts and retransmits the transmission will collapse the wave function (in the Copenhagen interpretation, "perform an observation") and cause the light to fall into one state or another. By performing statistical tests on the light received at the other end of the cable, one can tell whether it remains in the superposition of states or has already been observed and retransmitted. In principle, this allows the development of communication systems that cannot be tapped without the tap being noticed at the other end. This experiment can be argued to illustrate that "observation" in the Copenhagen interpretation has nothing to do with consciousness (unless some version of panpsychism is true), in that a perfectly unconscious wiretap will cause the statistics at the end of the wire to be different. Such a test would only work if the collapse occurs after (as opposed to before) observation; otherwise, it would appear collapsed whether it had been wiretapped or not.

In quantum computing, the phrase "cat state" often refers to the special entanglement of qubits wherein the qubits are in an equal superposition of all being 0 and all being 1; i.e., $|00...0\rangle + |11...1\rangle$.

Extensions

Although discussion of this thought experiment talks about two possible states (cat alive and cat dead), in reality, there would be a huge number of possible states, since the temperature and degree and state of decomposition of the cat would depend on exactly when and how (as well as if) the mechanism was triggered, as well as the state of the cat prior to death.

In another extension, prominent physicists have gone so far as to suggest that astronomers observing dark energy in the universe in 1998 may have "reduced its life expectancy" through a pseudo-Schrödinger's Cat scenario, although this is a controversial viewpoint.[11][12]

Another variant on the experiment is Wigner's friend, in which there are two external observers, the first of whom opens and inspects the box and then communicates his observations to a second observer. The issue here is, does the wave function collapse when the first observer opens the box, or only when the second observer is informed of the first observer's observations? Another extension is a scenario wherein the inside of the box is videotaped and played to an audience at a later time, or played back to the cat while in the box. If dead, there would be no observer to cause disentanglement; if alive, disentanglement would occur.

In popular culture

See also

- Schrödinger's cat in popular culture
- Measurement problem
- Basis function
- Double-slit experiment
- Interpretations of quantum mechanics
- Quantum Zeno effect
- Elitzur-Vaidman bomb-tester
- Wigner's friend
- Quantum suicide
- Schroedinbug
- Observer (quantum physics)

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External links

- Erwin Schrödinger, The Present Situation in Quantum Mechanics (Translation)
- The EPR paper
- Viennese Meow (the cat's perspective - short story)
- The story of Schrodinger's cat (an epic poem); The Straight Dope
- Tom Leggett (Aug. 1, 2000) New life for Schrödinger's cat, Physics World, UK Experiments at two universities claim to observe superposition in large scale systems
- [2] A good popular account of the puzzle.
- Size matters for Schrödinger's cat An easy to understand resolution to the apparent paradox.
- Information Philosopher on Schrödinger's cat More diagrams and an information creation explanation.
- A YouTube video explaining Schrödingers cat

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