QUANTUM MECHANICS.

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Annotation: This article gives a brief information to quantum mechanics. Quantum mechanics can be thought of roughly as the study of physics on very small length scales, although there are also certain macroscopic systems it directly applies to. The descriptor "quantum" arises because in contrast with classical mechanics, certain quantities take on only discrete values. However, some quantities still take on continuous values, as we'll see.
Key words: Physical Systems, Phenomenology, subatomic particles, double-slit experiment , quantum

In quantum mechanics, particles have wavelike properties, and a particular wave equation, the Schrodinger equation, governs how these waves behave. The Schrodinger equation is different in a few ways from the other wave equations we've seen in this book. But these differences won't keep us from applying all of our usual strategies for solving a wave equation and dealing with the resulting solutions. In some respect, quantum mechanics is just another example of a system governed by a wave equation. In fact, we will find below that some quantum mechanical systems have exact analogies to systems we've already studied in this book. So the results can be carried over, with no modifications whatsoever needed. However, although it is fairly straightforward to deal with the actual waves, there are many things about quantum mechanics that are a combination of subtle, perplexing, and bizarre. To name a few: the measurement problem, hidden variables along with Bell's theorem, and wave-particle duality. You'll learn all about these in an actual course on quantum mechanics.

Even though there are many things that are highly confusing about quantum mechanics, the nice thing is that it's relatively easy to apply quantum mechanics to a physical system to figure out how it behaves. There is fortunately no need to understand all of the subtleties about quantum mechanics in order to use it. Of course, in most cases this isn't the best strategy to take; it's usually not a good idea to blindly forge ahead with something if you don't understand what you're actually working with. But this lack of understanding can be forgiven in the case of quantum mechanics, because no one really understands it. (Well, maybe a couple people do, but they're few and far between.) If the world waited to use quantum mechanics until it understood it, then we'd be stuck back in the 1920's. The bottom line is that quantum mechanics can be used to make predictions that are consistent with experiment. It hasn't failed us yet. So it would be foolish not to use it.

The main purpose of this article is to demonstrate how similar certain results in quantum mechanics are to earlier results . You actually know a good deal of quantum mechanics already, whether you realize it or not.

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Quantum mechanics is the best tool we have to understand how the universe works on its smallest scales. Everything we can see around us, from far-off galaxies to our own bodies, is made up of subatomic particles, unimaginably tiny entities whose interactions produce the macroscopic effects we experience day-to-day. While it's tempting to imagine that these interactions obey the laws of physics that we're familiar with in our everyday lives, they are actually much much stranger.

One of the first physicists to confront this strangeness head-on was Max Planck. In order to explain unusual observations produced when objects were heated to high temperatures, he made a radical assumption. Instead of energy being emitted in a continuous stream, he assumed that there must be some indivisible base unit of energy that could be split no further. In other words, energy could only be exchanged in finite chunks, which he called quanta.

While Planck only came up with this idea in order to simplify his calculations, other physicists rapidly leaped on the real-world implications. Over the coming decades, Albert Einstein, Niels Bohr, Werner Heisenberg, Erwin Schrödinger and others completely restructured the standard picture of reality.

The new picture that emerged showed a world totally unlike the one we knew. A world where objects could travel through walls, particles led parallel lives as waves, and information appeared to be transmitted faster than the speed of light. Many of these apparent paradoxes are so mind-bending as to have entered popular culture. Perhaps most famous is the case of Schrödinger's cat, which imagines a cat trapped in a box that is both dead and alive until somebody bothers to look inside. Small wonder Nobel laureate Richard Feynman supposedly said: "If you think you understand quantum mechanics, you don't understand quantum mechanics."

Not that physicists have stopped trying. In their attempts to make sense of quantum weirdness, they have come up with a host of different interpretations of the mathematics at the theory's heart. As of the time of writing, it remains anyone's game.

The Development of Quantum Mechanics. Initial experimental evidence for the quantum nature of reality came from Planck's solution to the black-body radiation problem in 1900. According to physics as of the turn of the twentieth century, a black-body in thermal equilibrium with its environment should emit radiation with infinite power. Planck solved this problem by assuming that a black-body could only emit radiation with energy in discrete packets:

E = h \nuE=hν where \nuν was the frequency of the radiation and h \approx 6.626 \times 10^{-34} \text{ J}\cdot\text{s}h≈6.626×10−34 J·s was a constant now called the Planck constant.

Five years later, Albert Einstein would make the next step in clarifying Planck's claim in his examination of the photoelectric effect. In the photoelectric effect, shining light on metals causes them to emit electrons immediately provided that the light is of high enough frequency, without regard to the intensity of the light. Einstein's solution was the proposition that light came in "quantized packets of energy" that described a fundamental particle of light, the photon. However, the interference and diffraction of light observed over the previous century e.g. through Young's double-slit experiment supported the idea that light was a wave. Einstein unified the two ideas by suggesting that photons travel by the propagation of electromagnetic radiation (light waves), giving rise to the modern term wave-particle duality.

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In 1924, Louis de Broglie furthered the development of QM by making another bold claim: all particles possess wave-particle duality, where the momentum and energy of a particle are given by two relations:

p= \hbar k = \frac{h}{\lambda}p=ℏk=λhandE = \hbar \omega = \frac{{p}^{2}}{2m}E=ℏω=2mp2

where k = \frac{2 \pi}{\lambda}k=λ2π, \omega = 2 \pi \nuω=2πν, and the constant \hbar = \frac{h}{2\pi}ℏ=2πh is known as the reduced Planck constant.

de Broglie's hypothesis radically changed our understanding of matter. His "matter-waves" generalize Einstein's photon such that every particle we observe in the universe has the property of being both a particle and a wave. Interference and diffraction experiments performed with electrons have confirmed de Broglie's claim.

Lastly, experimental results from atomic physics also provided early evidence for quantum mechanics. The discrete spectral lines in the hydrogen emission spectrum showed that energy levels in atoms were quantized. This was initially explained by Bohr's atomic model in which the electrons were in circular orbits around the nucleus, although this theory was later shown to be inaccurate.

Throughout the remainder of the early twentieth century, a number of physicists and mathematicians like Dirac, Hilbert, von Neumann, Heisenberg, Schrödinger and others worked to solidify the theoretical underpinnings that explained these atomic and subatomic phenomena.

Physical Systems and Phenomenology. Although quantum mechanics is primarily applicable on the scale of atomic interactions, its effects and related phenomena are visible in a wide range of physical systems. One of the first successes of quantum mechanics was in explaining the emission spectrum of the hydrogen atom and similar atoms by correctly predicting the quantized energy levels of the electron. QM also correctly described how the electron could be bound to a nucleus without losing energy through radiation and inspiraling to the nucleus, and thus provided the first explanation for the stability of atoms.

Perhaps the most popularized example of a quantum effect due to its extreme defiance of classical intuition, still on the atomic scale, is quantum tunneling. Classically, a particle bound in a potential (i.e., stuck in a box) at low energy is trapped there, unable to escape. In QM, however, there is always a probability of measuring particles to have escaped the potential and thus "tunneled" through the walls of the box. As a result, there is a nonzero but inconceivably miniscule probability that if you were to attempt to walk through a wall, you would succeed! More practically, quantum tunneling is responsible for the \alphaα-decay of radioactive nuclei explained via the Gamow model, since the alpha particles must use quantum tunneling to escape the strong nuclear binding force.

.From the discovery of spin, the intrinsic angular momentum of particles, many new physical effects of quantum origin were understood. Particles are categorized into spins either in half-integer multiples of \hbarℏ, in which case they are called fermions, or integer multiples of \hbarℏ, in which case they are called bosons. Through quantum statistical mechanics and the Spin-Statistics Theorem, it was shown that populations of fermions and bosons behave differently from each other. In particular, no two fermions can occupy the same quantum state, a property called the Pauli exclusion principle in chemistry. The quantum statistical mechanics of particles has colossal influence throughout physics; for instance, it is responsible

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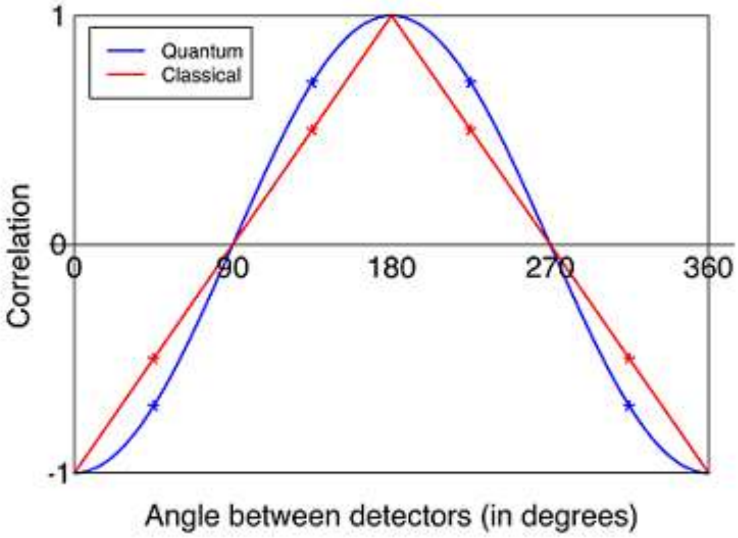
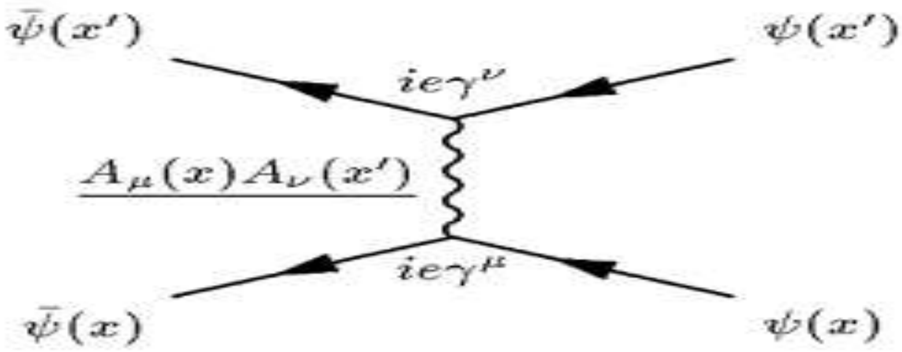
for the stability of neutron stars, the formation of "macroscopic" quantum states called Bose-Einstein condensates, and even the solid feeling of your desk.

A large body of work in quantum mechanics has gone towards understanding radiation. Classically, it was understood that atoms could both absorb and spontaneously emit light. Since the photon is a boson, Einstein was able to reproduce Planck's original distribution for the power spectrum of black-body radiation using the quantum statistics of bosons. Equally importantly, Einstein used his derivation to predict the stimulated emission of radiation from atoms, showing that the presence of spontaneously emitted photons could drive the further emission of photons at an exponentially growing pace. In other words, Einstein predicted the laser decades before its invention.



Spin has also been very important in quantum mechanics due to the discovery of quantum entanglement, which Einstein called "spooky action at a distance." It is possible to create two electrons so that their states are not independent; when the spins of these electrons are measured, there is a strong (anti-)correlation between the results, even if the electrons are separated by too large of a distance to influence each other! The fact that these correlations cannot be explained by some unseen variable hidden in the physical system is a theorem in quantum mechanics known as Bell's theorem. Entanglement, quantum teleportation and in general manipulation of super positions of spin states has enormous implications in cryptography and is the basis of the nascent field of quantum computing.

Quantum mechanics provides an elaborate theoretical framework for describing the interactions between particles via perturbation theory and scattering theory. At high energies such as those present in the Large Hadron Collider (LHC) at CERN, this framework is upgraded to relativistic quantum field theory and the Standard Model of particle physics. It is the hope that the LHC or similar particle colliders will reveal physics beyond our current knowledge of quantum theory.



Quantum effects can even be visible on enormous scales, like the size of the galaxy or even the universe. Quantum mechanics and quantum theories beyond the Standard Model such as string theory can have effects in cosmology and black hole physics. For instance, effects from string theory may alter how the early universe evolved, and leave a characteristic signature in the cosmic microwave background that permeates the universe. Black holes themselves are theorized to directly exhibit quantum effects through Hawking radiation, radiation which escapes black hole event horizons due to quantum vacuum fluctuations.

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