

# Quantum Mechanics

*In the subatomic world,  
particles must be described  
by wave functions*

1900 • BLACK BODY  
RADIATION

1905 • PHOTOELECTRIC  
EFFECT

1905 • DE BROGLIE  
RELATION

1927 • QUANTUM  
MECHANICS

1927 • SCHRÖDINGER'S  
EQUATION

1927 • COMPTON EFFECT  
PRINCIPLE

1927 • DAVENPORT  
EXPERIMENT

1928 • HEISENBERG'S  
UNCERTAINTY PRINCIPLE

The word “quantum” comes from the Latin for “so much,” or “bundle.” “Mechanics” is the old-fashioned word for the science of motion. Quantum mechanics, then, is the study of the motion of things which come in bundles (or, to use the modern term, which are *quantized*). “Quantum” was first used by the German physicist Max Planck (see PLANCK CONSTANT) to describe the interaction of light with atoms.

Quantum mechanics often defies our commonsense expectations of how things should behave. This is because our “common sense” comes from our everyday experience with common, macroscopic objects, and things behave differently on an atomic scale. HEISENBERG'S UNCERTAINTY PRINCIPLE reveals some of these differences very clearly. In the macroscopic world, when we measure the position of something—this book, say—there is no ambiguity in the result. Whether we use a ruler, radar, or an acoustic “tape measure,” or take a photograph and measure its position on that, or use some other approach, the act of measuring does not affect the book's position (of course if you're clumsy with the ruler that might not be true!). There will be some uncertainty in the position we measure, determined by how accurate our measuring device is, but if we need a more accurate position then we simply use a more accurate device.

Now, if instead of this book it is an electron whose position we want to know, we find that we cannot ignore the interaction associated with the process of making the measurement. The force exerted on the book by the ruler or whatever is used to measure its position is negligible, but to determine where an electron is we have to bounce a photon, another electron, or some other particle off it, and then the force exerted on the electron is far from negligible. The very act of measuring the position of the electron therefore causes it to change its position, so there is an intrinsic uncertainty in the result—it has nothing at all to do with the quality of our measuring device. This, then, is the situation in the subatomic world. We cannot make a measurement without an interaction, and we cannot have interactions that do not affect the thing being measured.

A precise statement can be made about the effects of the interactions:

$$\text{uncertainty in position} \times \text{uncertainty in velocity} > h/m$$

or, in fully mathematical form,

$$\Delta x \times \Delta v > h/m$$

where  $\Delta x$  and  $\Delta v$  are respectively the uncertainties in position and velocity of the particle being measured. The symbol  $h$  on the right sides of these equations is the PLANCK CONSTANT, and  $m$  is the particle's mass.

So, it is not just the position of the electron that has an intrinsic uncertainty when it is measured, but also other properties of the electron, such as its velocity. The precision with which the value of one such pair of linked quantities can be found (another linked pair is the electron's energy and the instant of time at which the energy is measured) directly affects the precision that is possible for the other quantity. If we measure the position of an electron very accurately, then our measurement of its velocity *at the same instant* will be very ambiguous, and vice versa. In fact, if we were able to measure the position of the electron exactly, we would have absolutely no idea of its velocity, and an electron whose velocity we could measure exactly could be anywhere in the entire universe! Actual measurements fall between these two extremes. For example, if we can determine the position of an electron to within  $10^{-6}$  meter, we can at best only find its velocity to within 650 meters per second.

Because of the uncertainty principle, the way in which the state of some entity is described in the quantum world has to be different from the way objects are described in our everyday Newtonian world. Instead of using position and velocity, as you would for a billiard ball, for example, quantum objects are described by something called a *wave function*. The height of the "wave" at a point represents the probability that the particle would be found there if a measurement was made. The progression of this wave is described by SCHRÖDINGER'S EQUATION, which tells us how the state of a quantum system changes with time.

The picture of quantum events painted by Schrödinger's equation is that electrons and other particles are similar to tidal waves moving across the surface of the ocean. Over time, the peak of the wave (corresponding to the place where an electron, say, is most likely to be found) moves from place to place in the manner prescribed by the equation. What we think of as a particle, then, actually displays some of the characteristics of a wave in the quantum world.

The reconciliation of the wave and particle aspects of quantum objects (*see* DE BROGLIE RELATION) came when physicists accepted that quantum objects are neither particles nor waves, but some other entity that has properties similar to both but which has no analog in the Newtonian world. Although this resolution of quantum paradoxes still causes puzzlement (*see, e.g.,* BELL'S THEOREM), the theories that quantum mechanics has thrown up remain our best understanding of the subatomic world.

---