

Heisenberg's Uncertainty Principle

HOME: [The Physics of Bruce Harvey](#)

Most students are introduced to Heisenberg's Uncertainty Principle through a discussion about the problems of observing small particles. In trying to observe the position of a small particle, we change its momentum. Oddly, the principle was not discovered through this line of reasoning, but emerged as Heisenberg analysed the relationship between his theory of quantum mechanics and the wave mechanics of Bohr's theory.

The uncertainty principle states that in attempting to observe the position of a particle, we impart momentum. If we localise the particle within an interval δx , then we are uncertain about its momentum by an amount δp . Position is not the only thing we might want to measure and a similar relationship is found between energy and time.

$$\delta x \delta p \approx h \rightarrow \delta E \delta t \approx h$$

A more formal definition based on a statistical analysis of repeated observations gives the relationship in terms of the standard deviations:

$$\Delta x \Delta p \geq \frac{\hbar}{2} \rightarrow \Delta E \Delta t = \frac{\hbar}{2}$$

So far, so good. We are talking real physics and real physical phenomena. The problems start when thinking becomes confused by existentialist concepts. If the particle exists in a Newtonian sense, whatever happens to it, it remains real and has an exact position and momentum at any instant of time. If on the other hand, the particle depends on the observation for its existence, then we are in trouble because now the position and momentum of the particle no longer have meaning. This is the crux of the matter. Physics as taught in university physics departments has sided with the Copenhagen interpretation. Only the observation is believed to be real. The uncertainty of an observation becomes a property of the particle.

Borrowing energy

It is an absolute article of faith of modern physics that the uncertainty principle can be restated in terms of energy and time

$$\delta x \delta p \approx h \rightarrow \delta E \delta t \approx h$$

and that this uncertainty allows energy to be borrowed. This forms the basis of Feynman's QED in which forces between particles are attributed to the exchange of virtual particles.

This is nonsense. Energy cannot be borrowed from nothing for however short a time. However, if in a controlled experiment where energy is measured at various times, the act of making the measurements interferes with the system and imparts energy to the system, it may give the appearance that an imbalance of energy occurred for a short period of time such that $\delta E \delta t \approx h$.

We utterly reject the idea that particles can be created from nothing, exist for a short time and then fade from existence so long as $\delta E \delta t \leq h$.

Tunnelling

Physicists reading the previous two paragraphs will laugh and quote a phenomenon called tunnelling adding that it is used in many practical applications, naming an electronic device called a tunnel diode as an obvious example.

Tunnelling applies in situations where, according to the laws of classical physics, a charged particle should not be able to pass a potential barrier because it should never have enough kinetic energy to overcome the potential. Quantum mechanics replaces the particle with a wave function and shows that the wave function has a finite value on the far side of the barrier. This is interpreted as implying a finite possibility of the particle passing through the barrier.

The essential ingredient needed to understand this phenomena was missing from classical physics because it had always tackled dynamic systems by forming and solving differential equations (or much more commonly quoting the resulting formula). Differential equations cannot be solved for complex systems and an iterative process of calculation must be used. Classical mechanics had to wait for the availability of high speed computers. Only then did it become possible to perform the calculations and make the discovery that complex systems may exhibit chaotic behaviour.

In the tunnel diode, conduction band electrons jump a potential barrier. Understanding that conduction band electrons are in a state of chaotic motion within the conductor, it is not hard to understand that some electrons approach the barrier with sufficient kinetic energy to pass through it. There was however a good reason to doubt that this could happen in such an obvious manner. The idea that conduction band electrons formed a sort of a gas within a metal had been explored in thermodynamics and rejected on the grounds that it predicted double the observed specific heat. If we have a gas which is a mixture of hydrogen and nitrogen, the much lighter hydrogen atoms acquire through collisions a much higher average velocity than the nitrogen atoms. This is because of an equipartitioning of energy in which each mole of hydrogen will possess the same energy as each mole of nitrogen. If the conduction band electrons are like a gas, then thermal collisions with atoms should give them an equal share of the energy doubling the specific heat, but this is not observed. Therefore, the conduction band electrons do not behave as a gas!

However, it is obvious from the conduction of electricity that in other ways, they do behave as a gas because the relationship between electric potential, current and resistance is exactly analogous to pressure, flow and resistance of a fluid flowing under pressure through a system of pipes. The missing element of understanding is that conduction band electrons do not collide with atoms, but with each other and with outer valency electrons. [Though "collide" is too emotive a word. We think of billiards balls colliding, cars crashing, or personal injury on bumping into a wall. Electrons strongly repel one another and never get near enough to touch each other.]

Our point is that in any real situation, there is always abundant energy available to be transferred from one particle to another as they dance in chaotic motion. We do not have to invent a magic source of energy.