Physics with Synno – Light-Matter – Lesson 4

L & M 7 Heisenberg Uncertainty Principle

Quantum physics (not classical physics), assumes that a matter wave, like a light wave, is a probability wave. Therefore the probability (per unit time) of detecting a particle in a small volume centered on a given point in a matter wave is proportional to the value of the probability density squared at that point. (Erwin Schrödinger 1926).

In 1927 Werner Heisenberg proposed that measured values cannot be given to both the position (x) and momentum (p) of a particle with unlimited precision.

This uncertainty is not related to the measurement techniques, or limitations on measurement devices, but it is an outcome of both wave-particle duality and the interactions between the object being observed and the effect of the observation on that object.

For the normal 'nonquantum' world Δx and Δp_x are so small they are considered insignificant, but at the atomic scale, this level of uncertainty is significant.

To measure the precise location of a free particle (e.g. electron), it needs to be hit with another particle (e.g. photon). This will cause the electron to move (or move differently) as energy is transferred from the photon. Therefore the act of measuring causes a change in the value of what is being measured.

If Δx is position uncertainty, and Δp momentum uncertainty then $\Delta x \times \Delta p_x \geq \frac{h}{4\pi}$.

(Where h is Planck's constant 6.63×10^{-34} J s). If one uncertainty is small ($\rightarrow 0$) then the other is large ($\rightarrow \infty$) to maintain $\geq \frac{h}{4\pi}$.

To find the minimum uncertainty allowed, use $\Delta x \times \Delta p_x = \frac{h}{4\pi}$.

As Δx decreases Δp_x has to increase.

Summarising - According to Heisenberg's uncertainty principle,

The **more** exactly the position of a particle is known, the **less** is known about its momentum.

Conversely

The **more** precisely the momentum of a particle is measured, the **less** certain its exact position.

L & M 7.1 Single Slit Diffraction

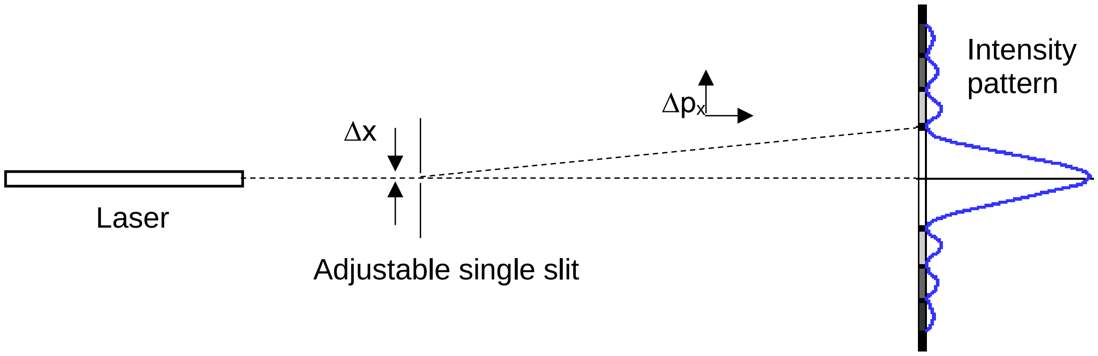
In 1909, G I Taylor, carried out the single slit experiment using light so feeble that only one photon passed randomly through the slit at a time.

Diffraction fringes built up on the screen (over 3 months), even though the photons could not have been interacting with each other.

As the photon passes through the slit, Δx is the slit width, its position is **known with some certainty**. Heisenberg says that this **introduces uncertainty** in momentum Δp_x, so beam the spreads out, hence the diffraction pattern.

If Δx is **smaller** (very thin slit), Δp_x must be **greater** so beam spreads out **more**.

Note: Momentum = mass × velocity. Velocity has a direction, uncertainty in the direction is responsible for the spreading out of the beam.



Davisson and Germer (1928) demonstrated the wave nature of electrons. Single slit diffraction can also be observed with particles, e.g. electrons, protons, neutrons etc.

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with Dr Karl Kruszelnicki

The 'truth' about Santa

COME CHRISTMAS EVE, how does Santa deliver presents to millions of children around the world?

About 2 billion kids are under the age of 18. But only about one-quarter are Christian so, officially, Santa has to visit only 500 million kids. Santa, however, visits ALL children.

On *average*, 3.5 children live in each house, so Santa visit s about 140 million separate homes.

Luckily, Santa has about 30 hours of darkness to deliver the presents - because the Earth rotates! Suppose Santa travels east to west, start s at the leading edge of sunset and then gradually allows the t railing edge of dawn to catch up with him. In this case, Santa's Christmas night lasts for 30 hours (24 + 6). There are 108,000 seconds in this 30-hour 'night'. Santa has to visit 1000 houses each second!

But there are about 150 million square kilometres of land on our planet. So, on *average*, the households are about 1km apart. Santa has to travel a total distance of 150 million kilometres. His average speed is about l000km/s.

Santa has to accelerate from zero to l000km/s and back to zero, and do this 1000 times each second. His acceleration is about 400 million g (where g is acceleration due to gravity) - but the average person goes unconscious after *five* seconds at 5g. Under this ferocious acceleration, Santa's 100kg body would 'weigh' 40million tonnes. Santa would disintegrate into a chunky red mush!

The payload is another problem. Suppose each of the 500 million children gets 1kg of presents. Then the reindeer pull 500,000 tonnes.

The combination of enormous speed, large payload and wind resistance that the lead pair of reindeer dissipate (on their bodies) is about 15 million million million Watts of power. That's roughly one million times more power than the human race dissipates *over* our planet!

So how does he do it? The solution is easy - Quantum Physics. On Christmas Eve, Santa is everywhere on the planet, and at the same time - and that proves he is real!

DRKARL is a prolific broadcaster, author and Julius Sumner Miller fellow in the School of Physics **at** the University of Sydney. His latest book, *Karl, the* Universe *and Everything* , is published by Pan Macmillan. Follow him on Twitter: @Doctor Karl