QUANTUM EXPLOITS

With the help of **Dr Jacob Dunningham** from the School of Physics and Astronomy, we take a take a cinematic look at one one of science's strangest theories.

Whatever would Messers Planck, Einstein or Bohr think? *Quantum of Solace?* The cryptic film title caused head scratching in cinema circles. With such a title, people thought, James Bond is in for a rough ride but owed a bit of comfort to his heart, broken in the last 007 adventure.

Physicists, with all due respect to Ian Fleming and company, chuckled – the last place to find solace would be at the quantum level.

The premise of quantum physics, the very nature of nature, is the stuff of blockbuster marketing: nothing is quite what it seems. Anything is possible in a realm where only a mutant would follow convention.

At the sub-atomic level, nothing stays still. Particles can be in two places at once. A cat can be both dead and alive. A single beam of light can behave like a discreet particle, but can also behave like a wave. Taking down an international cartel set on world domination? A mere lark compared to the plot twists of tiny science…

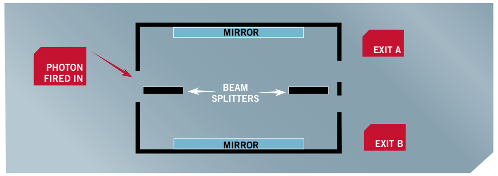
Picture the scene

Our favourite secret agent and Leeds alumnus, J Bond (Physics 2007) is at the games table, tuxedo on. It's a new game, created by the evil Quantum organisation. The game works like this: a single light photon is fired into a box. A photon is the smallest possible chunk of energy (a quantum – something that can't be divided). The light photon can emerge out of the box in one of two places, exit A or exit B, and the outcome is completely random. It's also all or nothing. There are five rounds, and Bond just has to bet on the outcome and get it right *every time* to win. If he loses… There is no cheating involved, however: he knows the game's not rigged. It's been designed by Physicists.

The outside of the box looks a bit like this:

Inside the box there is a beam-splitter device (it looks like a piece of glass) which the photon can either pass through or bounce off (it will be entirely random as to which this is). Whichever path the photon takes, the next thing it meets is a mirror, which will reflect the photon towards a second device it can also either randomly pass through or bounce off. After that there are two exits, depending which way the photon is travelling at this point.

The inside of the box looks like this:



The game starts

Roll 1: there's a 50-50 chance of getting this one right. The odds are tough – but Bond likes it that way. He takes a guess on Exit B....He's right. The light photon emerges at B

Roll 2: Bond looks surprisingly cool. He knows it's a random process, but after some thought sticks his bet on B…. There's light at B again

Roll 3: Without hesitating, Bond puts his money on B again. Will the photon emerge randomly at B again? Yes – B it is. Bond has two guesses left to win or lose everything.

Roll 4: Bond says B
The light photon emerges at B for a 4th time.

Roll 5: Bond thinks – then puts it all on B. Can the photon defy expectation and emerge at exit B for a fifth time?
It does. Mr Bond wins.

How have random actions always ended up with the photon exiting at B? That's an amazing 100 per cent probability. Like any hero, Bond has a secret trick. He defies logic.

This scene was based on a classic experiment in which physicists know that a photon of light will always yield the same result. The device through which a photon passes or bounces off is like a window. Think about how you can see a reflection and what's on the other side.

The photon's random behaviour always results in the same logic-defying outcome.

But, how? To get the most out of any action flick, you need to suspend your disbelief. You also need to accept a few quantum physics basics:

1 Energy does not flow constantly. It is divided into tiny discreet particles, or photons.

2 Each particle acts randomly but the probability of its different behaviours can be predicted.

3 A single photon can be in more than one place at a time. It can run into itself and interfere with itself. Not a twin, not an alter-ego, not a dream-based cop-out at the end of a plot. Exactly the same photon.

4 A photon has a split personality. It behaves like a particle but at other times it behaves like a wave. It's called wave-particle duality.

5 That particular characteristic means that photons behave just like waves approaching a beach or ripples in a pond. When a peak of one wave meets a dip in an adjacent one, they cancel each other out. When two peaks meet, their energy increases and forms a larger wave. This process is called interference.

6 We also know that a wave will shift by a quarter of a wavelength (a quarter of the distance between two peaks of a wave) whenever it is reflected.

Let's rewind to our scenario. Nothing emerges from exit A because, with the shift in wavelength, the two paths have cancelled each other out. At exit B, the peaks of two waves meet and a photon emerges.

We sent only one photon into the box and only one photon came out of it. Conclusion? The photon is in more than one place at a time and has interfered with itself. Like any good film, its surprising, shocking and leaves you shaking your head. You need to watch it again. The stuff of science fiction? No. Quantum physics.

This quantum physics theory offers many real life applications. Research at Leeds uses the fact that particles can be in more than one place to develop much faster computers. If a single particle is put into many different locations and performs a different calculation at each location, parallel computing can be carried out at a massive scale.

Then there's the concept of particles behaving differently in parallel universes…but that's another film plot.

Quantum physics – a handy plot summary:

1 The universe is made up of tiny particles

2 These particles behave randomly, but with predictable probabilities

3 Objects can be in different places at the same time

What's going on inside the box?

The photon is fired in and can only go in one direction until it gets to the first beam-splitter. At that point it has a random choice: the dotted and solid lines show the two alternative routes the photon could take. Yet always emerges at exit B. This is explained by the fact that the photon travels along both the upper and lower paths at the same time. At Exit A, the photon's wave-like behaviour means on the dotted route 3 reflections have shifted its wavelength by ¾ and on the solid route 1 reflection has shifted wavelength by ¼. The two photons are ½ a wavelength out, peak meets trough and cancels each other out. Similarly, the two routes to Exit B are each reflected twice. The waves match and so the photon emerges.