Prof. Russell Stannard: The questions on everyone's minds
The Wave Particle Paradox

Russell: What is light? For a long time it was thought the answer was obvious. Light is made up of waves - electromagnetic waves - undulating electric and magnetic forces travelling through space, much like waves on the surface of a liquid. This seemed obvious for a number of reasons. For example, when waves pass through a narrow gap in a barrier, they spread out somewhat to the side rather than going straight on. And that's what light does.
Put two gaps close together and the humps and troughs from the two gaps overlap and interfere with each other. This gives rise to directions where the humps and troughs are in step and they reinforce each other. And then in between, the humps and troughs are out of step. They cancel each other out and we get very little activity. Now this is exactly the kind of behaviour that we get with light. Pass light through two parallel slits and we get bright beams going off in a number of directions, with little in between. And this is not what you'd expect if light were made up of particles. Such as this. Tiny droplets of liquid you get from a spray can for example. Okay I can demonstrate this like this. Actually this is going to get a bit messy. No, I'll leave it to my lab assistant to do it, he can do it outside. Okay, that's what you get with particles. Just two bands - one for each of the slits. So the fact that there are more than two bands demonstrates, quite conclusively, that light is made up of waves. Except, if you examine closely how light gives up its energy when it hits the screen, using a very weak beam, all you see at first are tiny dots, not the smoothed-out distribution you might expect if light were a gently undulating wave. As more and more light arrives on the screen, so you get more dots and the interference pattern begins to emerge. But note the energy is being given up as localised dots.
It's as though the screen had been hit by a hail of gunfire - a hail of tiny particles. We call these tiny bundles of energy: photons. So, what is light? Waves or particles? The fact that there are more than two patches of light can only be described in terms of light being made up of waves. But the fact that the light arrives and gives up its energy as dots can only be explained by saying light is particles. So the crucial question becomes: How can something be both a wave - spread-out over space with a succession of humps and troughs, and at the same time, not spread out - a tiny, localised point-like particle? This dilemma is known as the wave-particle paradox. This schizophrenic behaviour isn't confined to light. What about matter? What is matter?
Well, all the objects we see about us are made up of atoms, and atoms are made up of a nucleus surrounded by electrons, the nucleus is made up of neutrons and protons. So it seems pretty clear that we are dealing with particles. Take a beam of electrons - like the ones you get in the older-style TVs and computer monitors. The electrons are emitted from an electron gun at the back of the tube and then they travel to the screen, where they hit the screen here. There they give up their energy - energy that gets converted into the light that makes up the picture that we see. They hit the screen like a hail of tiny bullets. Fair enough. That's what we expect if electrons are tiny particles. The trouble is that while they are travelling from the gun to the screen they behave like waves.
Pass them through two slits in a barrier and we get this on the screen. An interference pattern - just as we got with light - a whole series of patches and nothing in between - and all this has to be due to the overlapping of humps and troughs. And this shows how those interference fringes are successively built up from individual electron impacts. It looks exactly like what we had for light. And what's more, it is not just electrons. The other constituents of matter: protons - they also exhibit wave-particle duality. Even beams of complete atoms or complete molecules. Everything is afflicted by wave/particle duality. So, what are we to make of it all? Well back in the 1920s, the Danish physicist Niels Bohr, he came up with a challenging suggestion. He declared that we are to stop asking questions of the sort: What is...? What is light? What is an electron? We have to redefine the question itself. Instead we are to talk only of observed behaviour. How are things observed to behave.
So for example, take the case of the electron in the TV tube. We can ask how the electron moves through space and hence where exactly we're likely eventually to find it on the screen.

Answer: it is observed to move through space like a wave. Or alternatively we can ask how it interacts when it gets to the screen. How does it give up its energy? Answer: We observe it to give up its energy as dots, tiny particles. Either we're asking how it moves through space or how it interacts when it gets to its destination. We can't be asking both questions at the same time. So there's never any call to have to use the concepts 'wave' and 'particle' at the same time. Depending on what type of observation we're talking about it's one or the other – it's never both. Hence the wave/particle paradox is solved - according to Bohr. But the solution comes at a price. The price is we're not allowed to ask questions of light - or of anything else - outside of the context of us observing the light, or observing the electron, or whatever.
Such questions are meaningless. Suppose, for example, out there in empty space there's an electron - on its own, not being observed, not interacting with anything. Under those circumstances, what is it? Is it a wave or is it a particle? No. You can't ask that question. It's meaningless. The very words 'wave', 'particle' - 'electron' even - they're all words used specifically to describe observations. It's a misuse of language to try and use those same words to describe what might exist in between observations. In effect what Bohr was saying is that we used to believe the job of the scientist was to describe the world - the world as it is. OK, in order to do that you have to look at it, through a microscope say on the small scale or through a telescope on the large scale, you have to experiment on it. But having done all that, having observed it, what you eventually write down in your science text book is a description of the world whether or not you are still looking at it. But Bohr. What Bohr says is: No. No. What you've written down here is a description of you looking at the world - what it's like to interact with the world. It's not about the world as it might be in itself. You've said nothing about that - and never will.
The German physicist, Wernher Heisenberg backed up Bohr and declared: 'It is possible to ask whether there is still concealed behind the statistical universe of perception a 'true' universe in which the law of causality would be valid. But such speculation seems to us to be without value and meaningless, for physics must confine itself to the description of the relationship between perceptions.' The relationship between perceptions. The relationship between observations. We can't say anything about the world in itself, the world that is not being observed. What a shocking idea. Not surprisingly, not everyone goes along with it. Einstein, in his discussions with Bohr for instance, Einstein maintained to his dying day that the goal of science remains what we always assumed it was: the description of an objective world out there independent of whether we happen to be observing it. But it has to be said that eighty years, eighty years of fruitless argument and we're still no closer to realising Einstein's dream today than he was then. And with each succeeding year it could be argued that it looks more and more as though Bohr was right. We really are up against the barrier of the knowable.
After piece
Russell: Tony, I was just wondering, I've been saying how when we're not being observed, you know it becomes meaningless okay. Well I was wondering whether I ought to add a bit because you know the viewer might be thinking that once they stop viewing the programme and I'm not being observed, I suddenly become you know meaningless. You know, or don't you think they're bothered or or?
Tony: Do you know what Russell? I really don't think they're bothered what's happening to you when they're not watching the programme.
Russell: Oh. Thank you, thank you. Well I'm bothered, in fact I think tonight I ought to sort of stay awake and keep observing myself, in fact that is probably why my dreams don't make sense, they are meaningless because I'm not being observed. I bet Freud, I bet Freud never thought about that.
Tony: Next series then?