Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *The quantum vacuum... or not*.

You will often hear people say that the apparent vacuum of empty space-time is actually filled with virtual particles that appear out of nowhere, persist for a time that is just not quite long enough for us to detect or measure them - and then they wink out of existence again. They are called virtual particles because of this ephemeral behaviour. The word virtual is meant to distinguish them from other more conventional particles like photons, electrons and all the rest which are, well… *real* particles.

Some people doubt the reality of virtual particles, saying they are just mathematical expressions of the inherent uncertainty that is required within quantum physics. Others are convinced they are real and that they give the vacuum of empty space-time a sort of fuzzy, granular substructure.

Whether or not they are real, virtual particles play an important role in quantum physics calculations and are routinely added to Feynman diagrams to model a force that is acting at a distance. For example, if two particles with the same charge approach each other, a Feynman diagram will show them exchanging virtual photons. Those virtual photons represent the electromagnetic force that makes those two same-charged particles repel each other. There is no loss of energy in this process because the virtual photons are just virtual – they appear and then they disappear. So the first law of thermodynamics, the one about the conservation of energy, is not violated.

However, there is some, at least circumstantial, evidence for the reality of virtual particles that *can* pop out of nowhere and do violate the first law. If you position two metallic plates micrometers from each other within a vacuum, they are attracted to each other. This is called the Casimir effect.

The Casimir effect could be caused by virtual particles and the physics of the quantum vacuum. For example, the effect can be mimicked by placing the two of the same plates in a medium, like water. If you generate a vibration that propagates ripples through the water – you will find that bigger ripples are sustained outside the two plates than can fit between them. This creates a nett imbalance of forces and consequently the plates are pushed together.

If the Casimir effect does result from vacuum fluctuations, which are the result of virtual particles popping in and out of existence and hence causing ripples in the vacuum – then we should conclude that virtual particles are real and that the vacuum behaves a bit like a fluid.

But, the fact that energy has been derived from the vacuum to do the work of pushing the two plates together, represents a violation of the first law of thermodynamics – since energy is drawn from the virtual world to do measurable work in the real world.

To avoid this problem, there are physicists who offer other interpretations of the underlying cause of the Casimir effect. Casimir himself had initially assumed it was the result of van der Waal forces – although he was apparently persuaded towards the quantum vacuum interpretation later on.

Some theorists suggest that you could explain the Casimir effect as a relativistic van der Waal effect – though a full explanation of this is beyond the scope of this podcast. The relevant Wikipedia page on the Casimir effect provides a brief outline of this alternate interpretation.

But the case for the reality of virtual particles was further strengthened in 2011, when experimental physicists demonstrated what is called the dynamical Casimir effect. This involves a mirror moving near the speed of light. In that inertial frame of reference the mirror is able to 'observe' and hence reflect virtual photons that have been amplified into real photons due to the relativistic motion of the mirror. This is also getting a bit beyond the scope of this podcast, but hopefully you get the general idea.

Nonetheless, there is source of counter-evidence, which is not circumstantial, but involves direct observation. Consider the Earth's atmosphere, it's almost transparent to optical light and to radio waves, but any light frequencies above ultraviolet are scattered by the particles of gas. This is because the atmosphere is a medium – and a medium will diffract light of certain wavelengths – although it may still be transparent to other wavelengths.

We generally assume that a vacuum should allow light of all wavelengths to pass through it – but very energetic gamma rays can have a wavelength so small that they would be disturbed by fluctuations and ripples smaller than a Planck length. And is there an astronomical source of such high energy gamma rays with such short wavelengths? You bet ya.

Gamma ray bursts may be produced by hypernovae – which are really big supernovae or they may be produced by colliding black holes. In either case these are hugely energetic events that radiate light across the whole spectrum but with strong peaks in the gamma ray region of the spectrum. Indeed, the more energetic the event, the shorter the wavelength of gamma ray light produced.

This gamma ray burst light, may come from distant galaxies and cross hundreds of millions of light years of empty vacuum before it reaches Earth. And can you guess to what extent those extreme short wavelength gamma ray bursts are perturbed, diffracted or even polarised after passing through millions of light years of vacuum which is allegedly bubbling with virtual particles and fluctuating vacuum ripples? Zip, zilch and zero - not even a flicker. A hundred million light years of vacuum seems to behave exactly as you'd expect a hundred million light years of vacuum to behave. It just sits there, cold, empty and still – as though it's just a vacuum.

In the grand scheme of things, this observation is kind of reassuring. If you allow the vacuum to have some kind of substructure that is full of bubbling virtual particles you risk recreating the nineteenth century physics problem of the luminiferous ether. This pre-Einstein notion sought to grapple with the problem that although you might think you are sitting still in a chair – that chair is on the surface of the Earth with an equatorial rotation of 1,700 kilometers an hour, the Earth is orbiting the Sun at 30 kilometers a second, and the Sun is dragging the Solar System around the centre of the galaxy at 220 kilometers a second.

Prior to Einstein, people assumed that there must be some common background against which all these different speeds can be referenced so that we can absolutely describe our real speed. Well, no. After Einstein we know that we can only describe our state of motion by referring it to a particular frame of reference. There is no single, definitive answer to the question of what your speed is. But if you give the vacuum a substructure, so that it becomes a stationary background like the imagined luminiferous ether, then you may need to reconfigure relativity physics.

In any case, the gamma ray burst findings have not derailed the quantum vacuum hypothesis. Current work is underway at Fermilab, in the US, to build a ground-based experiment which will fire laser light through long stretches of evacuated tubing – once again looking for signs of the light being perturbed, diffraction or polarised. And this is good science, testing the hypothesis again in a more controlled environment where we know the exact wavelength of the light we use and the exact nature of the vacuum that it will move through.

As it happens, these researchers aren't really looking for virtual particles. They hope to find a substructure of the vacuum that is proposed to be able to store information. This is a part of a hypothesis known as the holographic universe – which is, once again, a bit beyond the scope of this podcast. But, in any case, if Fermilab don't find anything – or in other words, if they do find nothing – well, that could be that for both the holographic universe and for virtual particles. We should see some results of this work in the next five or ten years. Stay tuned.

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