Some principles in quantum physics

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Introduction:

Quantum physics has radically changed our vision of the universe, it opens out a new world of probability, where nothing is absolute to the limit of our observations, it dethrones classical physics, and repaints the universe of its original colors.

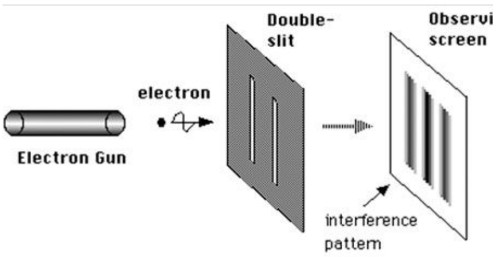
We haven't been able to break the universe's mystery, it is still obscure. However, quantum physics has made a step further towards the understanding of reality. How? It explains the strange behavior of quantum particles, which are really small particles including photons, electrons, atoms…

It sets numerous laws that decrypt the mystery of a particle's journey, since this one remains completely different from the familiar macroscopic world that we are used to.

Here are some quantum principles:

- **Quantum superposition:** it means that a particle can have many states; different velocities or be in different places at the same time. But when we measure the speed, for example, we are going to find one value. Of course by introducing this principle, we cannot ignore the extraordinary Schrödinger's cat, which is dead and alive at the same time. Imagine we put a cat in a box, which contains a device that would kill the cat within an hour, but we do not know if it actually worked, therefore we do not know either if the cat is dead or alive. Considering quantum physics principles, the cat is in both states unless we open the box, or, in other words, until we make measurements.

- **Everything is random, probabilistic:** nothing's absolute. Physicists, when predicting an outcome, only use probabilities. There is, for example, a 30% chance to find the particle in point A, and a 70% chance to find it in point B. It is an important concept, because we have always thought that nature was deterministic, which is rather staggering. And certainly the double slit experiment is the best way to explain it. As we see in the picture below, the electron beam gun is shooting one electron at a time.This electron has the choice to take one of the two possible paths. It is going to take both, even though on the screen it appears in one place, but before it lands in this place, it would have tried all the possible tracks. After shooting more of these strangely behaving particles, we can observe that the electrons had positioned themselves in many places. The mystery is that they acted as waves. Big waves tell us that there is a big chance to find the particle in this place, and the smaller one represents the small probability of finding it in the corner of the screen.



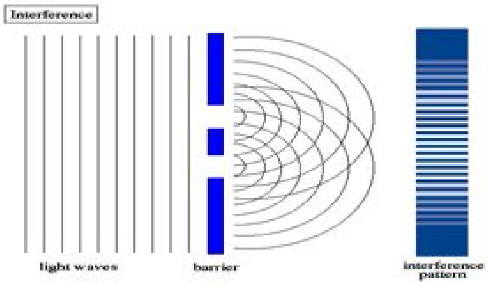


image 1 credit: File:Double-slit.PNG /Created: 16 December 2005 /source: commons.wikimedia.org

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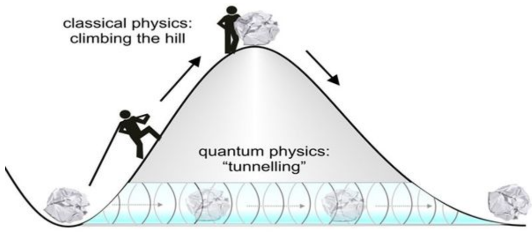
- **Quantized properties:** in classical mechanics, the quantities are continuous. When travelling by a car can change from the speed 30km/h to 20km/h, but in quantum mechanics it is no longer the case, there are well-defined values and they are quantified. For example, the lowest energy level of a hydrogen atom is -13.4 eV. To increase its energy, it is necessary to go up to -3.4 eV, there is no intermediate value.

- **Is light a particle or wave?** Here comes the particle wave-duality principle, it says that light can behave in both ways; as a particle and as a wave.It applies also to other small particles, such as electrons, when we talked about the double slit experiment we said that these particles try all the paths before hitting the screen. Let's imagine an electron, it will behave as a wave during its journey to the screen, but when it hits it, we see this one electron in one place and, therefore, as a particle. But why cannot we see that at our scale? The answer is that we are fat! Compared to electrons we are way bigger. So what do we mean by fat? The momentum is intrinsically connected to the wavelength, which we can see in this equation. p is the momentum and the lambda is the wavelength of the wave in question. We know that momentum equals velocity times mass and our mass is big, thus we have a big momentum, which corresponds to a really short wavelength. So small, in fact, that we are not able to notice this wave nature in everyday objects.

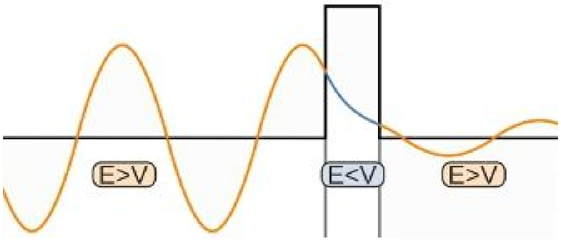
$$p = \frac{h}{\lambda}$$

- **Quantum tunneling effect:**



A diagram demonstrating the ball analogy of quantum tunneling: to climb the hill a ball would need sufficient energy, but with quantum tunneling there's a chance that the ball could randomly "tunnel" through the hill and appear on the other side(Credit: Max Planck Institute for Quantum Optics)

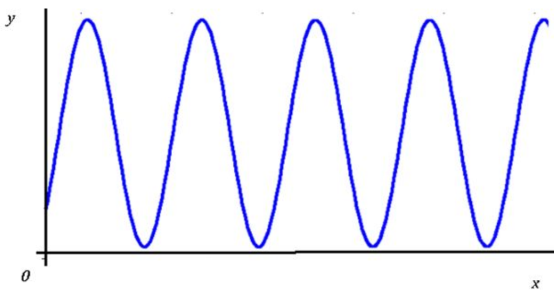
If this man wants to see the ball in the other part of the hill, he would have to push it so that it would have a kinetic energy greater than the potential energy of the hill. That is classical physics. But what about this other ball that is getting its way through the hill? Weird, right? Quantum physics describes a particle as a wave, and quantum tunneling says that this one has a slight probability of being on the other side. We already know that the waves are represented by wave functions, explaining the probability of finding the particle in certain places.



In regions where the potential energy is higher than the wave's energy, the amplitude of the wave decays exponentially. If the region is narrow enough, the wave can have a non-zero amplitude on the other side. Image Credit: Wikipedia

- **Heisenberg uncertainty:** Werner Heisenberg says that we cannot know with certainty the actual position and momentum of a particle simultaneously, and he also states that if we get to measure one of these properties accurately, we will lose certainty in terms of the other one. This idea was introduced by a previously mentioned eminent German physicist in 1927, where he himself tried to explain it through an experiment.

  Let's explain it this way, We said that the momentum is connected to the wavelength. This graph shows the position in terms of the probabilities of finding the particle at this



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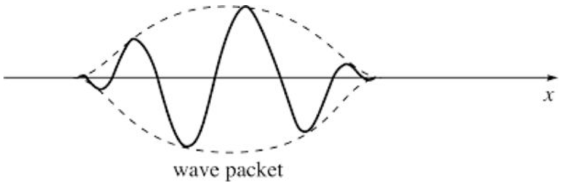
position. Here, because the wavelength is known, the momentum is well defined, whereas the location could be at any point, since the wavelength is infinitely long.

In order to know the location, we have to add several wavelengths, which correspond to different momentums. This creates an inference pattern as peaks of corresponding waves cancel the troughs of others. We refer to it as a wave packet, and the particle can begin to be localized. While we know that we have used several momentums, now we can be certain about the position, but unclear about the momentum.



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This principle extends to other pair of properties, which are called complementary variables.

- **Quantum entanglement:**

  As you may have a strong connection with your soulmate, little entangled particles could experience the same between themselves. They may maintain a connection which allows their properties to be interdependent, even if they are millions of miles apart.

  There's that strange correlation of cause and effect between two entangled electrons. Suppose we are going to measure their spin. One of them, when measured, will spontaneously affect the other, so if we find spin down in the first one, the second one will have spin up, according to quantum physics.

  For example, we have a pair of gloves, we send one of the two to Ali and Sara. If Sara finds the right handed glove, that automatically means that Ali has the left handed one.

  That is a vulgar example of what quantum mechanics could be. Actually, this quantum entanglement has raised a great debate between Niels Bohr and Einstein.

  If these two particles could affect each other simultaneously, Einstein would have rejected this idea, because it could mean that the information shared between the two particles travels faster than light. This affects his theory of relativity that states that nothing can travel faster than light. So he and two other physicists , Boris Podolsky and Nathan Rosen, collaborated to make a thought experiment called EPR (Einstein Podolsky Rosen), which gave birth to this mysterious quantum entanglement that Einstein thought was silly. Therefore, he came up with the idea of hidden variables, or particle's special plan, if you prefer. It means that before doing the act of measuring, the particles at the moment of creation already have a kind of plan, hidden variables programming their state, thereafter, when making the measurements, we are going to see a correlation. This is because the particles were once connected, , but not because they affect each other. On the other hand, Bohr said that particles were in a superposition state before the measurements were made, thus we understand that he maintained the idea of the strange simultaneous effect made by the act of measuring. This debate was finally ended by John Bell's inequalities, that we would expect to see if Einstein was right. If the entanglement experiment violates Bell's inequalities, that would mean that our dear Einstein is wrong. Later, this experiment was made by a French physicist Alain Aspect, who succeeded in making an entangled state of two photons, and it violated Bell's inequalities, thus Bohr was right. Nevertheless, it does not mean that relativity is broken, quantum physics stretches the normal laws without exceeding relativity, and causality, but still only affects locality.

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