

Perry, 6th grade

What is the reason light can travel so fast, the fastest speed we know?

Photons, the fundamental particles that mediate the electromagnetic force, are massless. You may know Einstein's famous equation $E = mc^2$, but the full equation actually goes

$$E^2 = (mc^2)^2 = (m_0c^2)^2 + (pc)^2$$

where p is momentum and m_0 is the mass of the particle at rest. Special relativity says that the so-called "relativistic mass" m actually changes with velocity, so as particles that start off with some finite mass accelerate to the speed of light, they get heavier. This is crazy but true! We have actually measured it. This is what prevents massive particles from reaching the speed of light: the faster those particles go, the heavier they get, and so we have to put even more work to accelerate them further, and it becomes a vicious cycle.

Photons, however, do not have this problem. Since they are massless ($m_0 = 0$), we can just simplify this equation to $E = pc$. This is what's called a dispersion relation $E(p)$, which is the equation that particles obey when you put together the laws of special relativity and quantum mechanics (a combination called quantum field theory). Applying the dispersion relation to all the coordinates of the particle in spacetime (three spatial coordinates and one time coordinate) tells you that massless particles travel at the speed of light. Particles with mass, like all quarks (the constituent particles of protons and neutrons), leptons (a class that includes particles like electrons and neutrinos), and the W and Z bosons (the carriers of the weak force), will travel below the speed of light, because their dispersion relation is not quite linear.