# 12.1: Einstein’s Theory of Relativity

Occasionally mainstream news, whether TV or internet, like to report on scientific phenomena and recent findings. However, they invariably simplify things to the point that the information is wrong. The two greatest victims of these unfortunate oversimplifications are the theories of relativity and quantum mechanics. For example, $E = mc^2$ anyone? Not hardly, Einstein derived the following:

$$E^2 = c^2p^2 + m^2c^4$$

where E is energy, m is mass, c is the speed of light, and p is momentum. The above is clearly a mouthful; however, if the particle isn’t moving (p=0), then $E^2 = m^2c^4$ which simplifies to:

$$E = mc^2$$

Thus, this ultra-famous equation is only correct for a particle at rest. And as you will see shortly, quantum mechanics stipulates that everything is always moving.

Einstein’s equation provides a launching point for the development of quantum mechanics. In this regard, let’s say that we are studying a particle with no mass such as a photon ($m = 0$ kg). In that case:

$$E^2 = c^2p^2 \rightarrow E = cp$$

The energy of a photon is known to be $hv$, where $h$ is Planck’s constant and $v$ is frequency which is: $v = \frac{c}{\lambda}$ and $\lambda$ is the wavelength. We can thus show that $E = h\frac{c}{\lambda} = cp$, which means that a massless particle such as a photon has a momentum: $p = \frac{h}{\lambda}$. Even though momentum is mass times velocity, and a photon has no mass, it still has a momentum. And now you should also know that many of the things you were told were absolutely true are, in fact, not true at all. Also, this is just our beginning of the discussion of Stranger Things.

## 12.1.1 Why waves?

The theory of small things introduces concepts that seem preposterous to those indoctrinated into classical mechanics, defined as Isaac Newton’s equation:

$$\text{force = mass} \times \text{acceleration.}$$

It should be made clear on the outset that the theory of quantum mechanics as formulated by the Schrödinger equation is known to be incorrect. However, for chemistry the form of quantum mechanics introduced here is as accurate as can be measured, so its “good enough” for developing a thorough understanding of chemical phenomena.

The most important concept is that small things (mostly electrons) often act more like waves than particles. For example, if a truck hits a wall, it will break through it if it is travelling fast enough (or faster than that!). However, if the truck is actually an electron, it may break through the wall even if it is going very slowly. Alternatively, if it has the right speed to break through the wall, it might instead just bounce off it. Confused yet? Here is a better analogy- an electron trying to get through a barrier is like light skimming off the surface of water. And that is because of the wave equation.