Discussion note

Popular science communication

May 23, 2022

Imagine that the year is 1959: with the MS Princess of Tasmania making its first voyage across Bass Strait, you enthusiastically receive your copy of your favourite popular science magazine. You read the cover story: something about a "metal-oxide-semiconductor field-effect transistor"? That doesn't pique your interest, but then you turn the page:

Photons falling to Earth

Dropping an egg can be a (minor) disaster, but intuitively one knows that the effect of the impact will depend on the height from which the egg is dropped. The principle which undergirds this intuition is gravity, namely that there exists a force between masses, and the outcome in this case is that the egg falls towards the Earth - and the Earth towards the egg, but we don't really notice this! To construct a framework to understand why an egg dropped from a greater height will hit the ground with a greater velocity, or equivalently, with more energy, it is useful to introduce the concept of *potential energy*: the energy stored by an object due to the existence of forces. This is best encapsulated by the phrase "energy can neither be created nor destroyed, but rather only converted from one form to another", which in the case of our egg, gravitational potential energy - which an object has when it is raised to a height - can be exchanged for kinetic energy, which is the energy associated with movement gained as the object falls - thus loosing gravitational potential energy.

The applications of energy transfer have been known since concepts of energy have been appreciated since humans first appeared, if not before, in cases such as combustion of materials proving heat, and our conception of energy was largely completed during the 19$^{\text{th}}$ century. That was, until new theories of the universe on both the small- and large-scale were introduced: quantum mechanics and relativity respectively, with quantum mechanics specifying how energy could be stored and transported, and the theory of general relativity fundamentally entwining space and time, and ultimately energy. It is therefore unsurprising that one might ask: do our intuitions about dropping an egg hold firm when I drop an infinitely small egg in a region of curved space time?

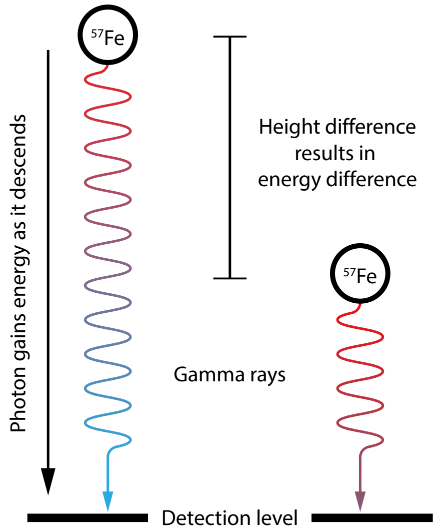

Figure 1: A gamma-ray photon which is emitted from a greater height will have more energy than a gamma-ray photon emitted from lower down, much like a ball dropped from a greater height will have a greater velocity when it hits the ground

In an experiment conducted Jefferson Lab, some physicists devised a way to do just this: by placing two samples of the radioactive element iron-57 at different heights - one atop the building and the other in the basement - they were able to have a 22.5 metre height difference between the between the radiation that is emitted from the radioactive decay of the iron: gamma rays. Gamma rays are photons, which are little pieces of energy, which due to the *gravitational redshift* will have their energy changed with height: increased as they move closer, or decreased if they move farther, from the Earth. The effect is valid for all photons, so in principle, this could be observed with visible light, which are also photons, and would manifest as red light becoming more blue as it got closer to the ground. Unfortunately, the change in colour, or equivalently frequency, is so small here on Earth, we need to use very high frequency photons to have sufficient sensitivity to detect the small change in frequency, and thus the use of gamma rays.

The researchers had a long list of technical problems to solve, for example, ensuring the photons would travel the required distance, but coupled with rigorous experiment design and analysis, they were able for the first time to measure a gravitational redshift, which is consistent with the predicted redshift as calculated from general relativity. The result, which is not explained by any pre-existing theory, is yet another indication that general relativity well describes our universe, and who knows, perhaps these incredibly minor changes in frequency might one day be important should we ever put vast numbers of satellites into space and try to accurately determine a surface position from said satellite array.