taken to be positive in this case. With the two graphs displayed, it is clear that when the toy changes its direction of travel the sign of the velocity changes. The video can be played and the motion of the toy and its velocity is tracked as the video plays.

The maximum gravitational potential energy of the toy can be found by reading the maximum height reached from the graph of position against time. The maximum height for this jump was 0.374 m. The gravitational potential energy transferred to the toy is:

Mass of toy × acceleration due to gravity × change in height

$= 0.0060 \times 9.81 \times 0.374 = 0.022\,\text{J}$

Using the energy stored in the spring, students can find out how efficient the spring was at transferring its stored energy to the jumping toy. Students can then discuss the energy transfers involved.

Students found this activity very engaging. While completing the activity they became familiar with applying the formulae and the fact that springs can be used to store energy. The standard experiments involve stretching springs; this activity uses the compression of a spring, something they might not be so familiar with.

These two experiments require little preparation yet they illustrate some important concepts. Students who I have done these experiments with were very engaged and had a good understanding of the topics covered, as was shown by their answers to a summative assessment.

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Helpdesk

Doppler shift in light: help needed

Tim Tranquada

The Doppler (Johann Doppler 1803–1853) shift is well understood when applied to sound waves produced by a source emitting a continuous constant-frequency sound wave, for example one produced by a loudspeaker driven by an amplifier and playing a note of frequency 256 Hz.

In Figure 1, the observer and transmitter are not moving relative to each other so the observer hears a series of compressions at the transmitted frequency of 256 Hz.

In Figure 2, the transmitter is moving towards the observer and the emitted compressions and rarefactions become ‘bunched up’ so that the observer now hears a higher frequency sound.

In Figure 3, the transmitter is moving away from the observer and the emitted compressions and rarefactions become more ‘spaced apart’ so that the observer now hears a lower frequency sound.

Doppler shift in light

In many science textbooks, it is then said that the perceived red shift in light means that the emitting source must be moving away from the observer.

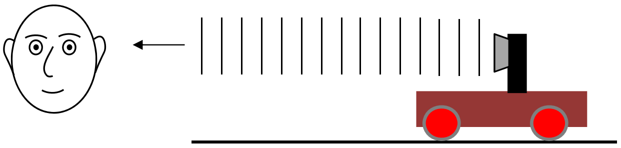

Figure 1 Illustration of a constant sound travelling towards an observer from a stationary source

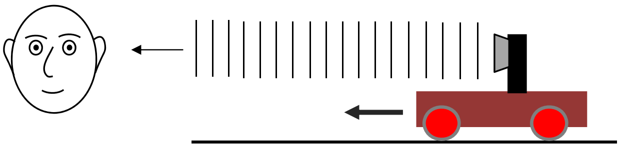

Figure 2 Illustration of a constant sound travelling towards an observer from a source moving towards the observer

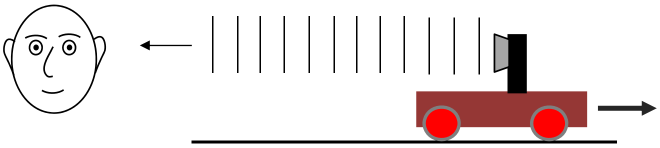

Figure 3 Illustration of a constant sound travelling towards an observer from a source moving away from the observer

But we give our students a model of how light is produced and travels that makes the red shift in light hard to fully grasp; **this is where I would appreciate a suitable model to help**.

Light, we say, is not produced as a continuous wave, such as a continually vibrating loudspeaker cone, but arises from distinct electron transitions from a higher ‘orbit/energy level’ to a lower ‘orbit/energy level’. The difference in the energy levels manifests itself as a lump or photon of energy of value hf, where h is the Planck constant and f is the frequency of the emitted bundle of oscillating electric and magnetic fields (Figure 4). This then implies that the photon is localised in space–time and has a ‘beginning’ and ‘end’ to correspond to the time taken for the transition from one energy level to the other to take place. An acceptable model for the photon is that of a ‘wavicle’, which is drawn as a ‘lump’ with a start and an end, and contains inside it the wave nature of the oscillating electromagnetic fields.

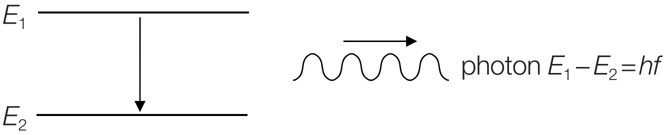

Figure 4 Representation of output of a photon in consequence of a change in energy level

How can we reconcile this model of light with the Doppler shift?

In Figure 5, the transmitter can be set up (thought experiment) to emit a train of photons, at equal intervals (like a machine gun) of energy $= hf$. The photons are observed and are ‘seen’ as light of frequency f Hz. The observed frequency is that ‘contained’ in the photon package and is not the frequency of the production of the photons, which would be the intensity (number received per second).

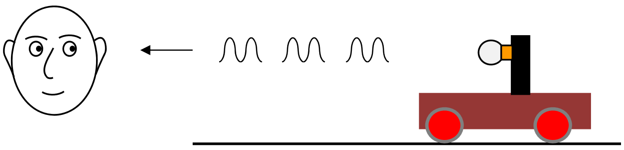

Figure 5 Illustration of light waves travelling towards an observer from a stationary source

What happens, using these models, when the transmitter moves towards the observer? In Figure 6, the observer still receives the same energy lump of $E = hf$ but would receive more photons per second. The observer would say that the light is still of frequency f but the light is more intense.

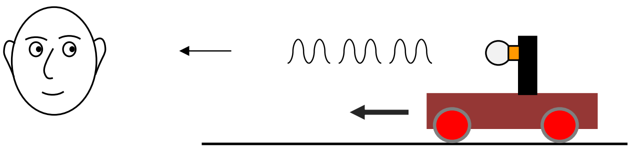

Figure 6 Illustration of light waves travelling towards an observer from a source moving towards the observer

In a similar way, in Figure 7 the transmitter is moving away from the observer and the ‘lumps’ are more spaced apart so giving a lower intensity but still light of frequency f. So where are the red and blue shifts?

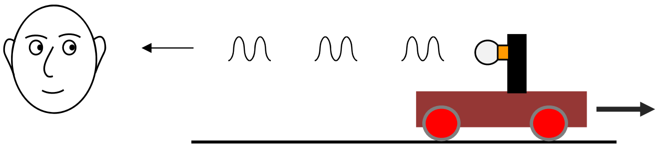

Figure 7 Illustration of light waves travelling towards an observer from a source receding from the observer

I can understand that a stream of photons (with an associated mass) can be affected in ‘flight’ by a large gravitational field and can follow curved gravitational field lines such as those, for example, around our own Sun. Most scientists believe that the red shift is due to the universe expanding, but what model can we use to show how gravitational fields affect the rate of oscillation of an electromagnetic field? Do we have to say to our students that the ‘next-level’ explanation can be found at university with a deeper study of relativity?

We should be clear that models have their uses at the appropriate level of complexity but do not at all times give the final complete picture.

H. E. Ives and G. R. Stilwell (1938) carried out an experiment using a beam of hydrogen atoms to measure the ‘predicted’ (by relativity) shift in frequencies. The data seemed to support the theory.

What next? We provide models in science to help others to understand difficult concepts. The models we use need to be good enough at a particular stage of development and should also indicate, if possible, a bridge to the next deeper level of understanding. Does anyone have a suggestion for a ‘bridge’ to understand red shift in light?

Reference

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