Workshop Tutorials for Introductory Physics

Solutions to WI5: **The Electromagnetic Spectrum**

A. Review of Basic Ideas:

Light and the Electromagnetic Spectrum

Have you ever stopped to think how it is that the information on this sheet reaches you? The answer lies with the waves that reflect off the sheet and into your eyes. These waves are electromagnetic in nature and your eyes respond to a particular range of frequencies – the visible segment of the electromagnetic **spectrum**.

Radio waves, **microwaves**, infrared radiation, visible light, ultraviolet, x-rays, gamma rays are just some of the common members of the electromagnetic spectrum. All these **electromagnetic** waves have the same nature – they are comprised of oscillating electric and magnetic fields. Electromagnetic waves travel (propagate) at a constant speed of $\mathbf{3 \times 10^8\ m.s^{-1}}$ in a vacuum. These waves do not need a medium, unlike **sound** waves they can move through a vacuum. The energy the earth receives from the sun is electromagnetic in nature and comes to us through space.

What then is the difference between the different parts of the spectrum? The answer is that different parts have different frequencies and so different **wavelengths** but they all travel with the speed of light.

Humans are sensitive to only a very small part of the electromagnetic spectrum. With our eyes we detect **visible** light, and with our skin we can detect infrared radiation, or **heat**. Human retinas have four types of detector cells, three types of **cones** for colour vision, and the **rods**. The rods are very sensitive and are used mainly for spotting movement in the peripheral vision and for **night** vision. The rods don't tell different colours apart, which is why everything looks sort of **grey** at night.

The three types of cones are sensitive to different wavelengths, or colours, one to blue, one to green and one to red. The sensitivities overlap so that we can see light from the **blue** end of the spectrum, around 400nm, to the **red**, around 700nm. We are most sensitive to the green/yellow around 550nm, which is now being used on emergency vehicles such as fire engines rather than the traditional red. This is also the frequency at which the **sun** radiates the most light.

Some animals don't have colour vision at all, such as **cows** and dogs. Others have very different colour vision, such as insects. Bees are sensitive to **ultraviolet**, and many **butterflies** see infrared.

Discussion Question

Humans are not sensitive to light in the x-ray region of the spectrum. However, Superman is not technically human, so he might have receptors to x-rays. However, natural light from the sun and artificial light does not contain x-rays, so there wouldn't be any normally for Superman to see. He would need a source of x-rays to shine through things to use his x-ray vision.

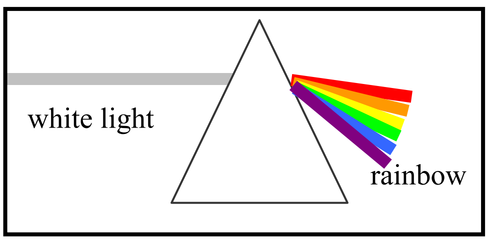
B. Activity Questions:

1. Speed of Light

The melted patches occur at antinodes in the standing wave pattern inside the microwave. The distance between two antinodes is ½λ. The speed of light can then be found using $c = \lambda f$, where the frequency, f, is read off the compliance plate on the back of the microwave.

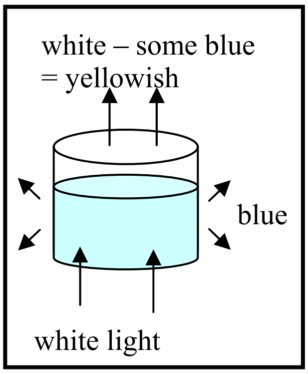
2. Prism

When light moves from air into the prism the light is refracted or bent, and it is bent again as it leaves the prism. The prism has a refractive index which varies for different wavelengths. The refractive index is greater for shorter wavelengths, and hence the blue component of the incident white light bends more than the red component.



3. Change the colour of your fruit (or See the World through Rose Coloured Glasses)
When white light falls on an object some of the light is reflected and some is absorbed. What we see is the reflected light, so the colour of the object is the colour of the light that it reflects. Looking through red glasses you will still see red objects as red, but objects that reflect no red light appear black. Hence a red apple looks almost normal, but a green apple looks black. A yellow banana looks reddish but very dark, because it reflects some red light, but not much.

4. Sunset in a jar
The milky water scatters the blue light more than other colours, so you should be able to see a faint blue tinge to the light coming from the sides of the beaker. This is like a very small but condensed version of the atmosphere scattering the light from the sun. The sky on Earth is blue because we are seeing light scattered by the atmosphere. If you looked directly at the sun (which you should never do!) it would look yellow, like the light coming out the top of the beaker. The sky on Mars (and the moon) is black because there is no atmosphere to scatter any light – hence in the daytime you would see the sun, and other stars.



C. Qualitative Questions:

1. Rebecca and Brent are sitting inside watching TV one evening when Brent notices a lightning flash. A few moments later they hear a peal of thunder. When there is a storm, lightning and thunder are emitted at the same time and from the same source. The lightning, which is light waves, travels much faster (around 3×10^8 m.s^{-1}) than thunder which is a sound wave (and travels at around 3×10^2 m.s^{-1}). So the light reaches Brent and Rebecca sooner than the sound. If the storm is far away the time difference between the arrival of the two is large. As the storm gets closer, the distance traveled by both waves is less, so the time difference gets smaller, and when the storm is right overhead the time difference is no longer noticeable. Brent has noticed that the time difference is getting smaller, so the storm is getting closer. If the time difference was getting greater the storm would be moving away.

2. When some people go shopping for clothes they try to look at the clothes in natural light, for example in the doorway of a shop. Natural light is close to white light, it contains all the different colours in the visible spectrum. Fluorescent light does not have as much red in it as sunlight, so clothes look different in fluorescent light to natural light or incandescent light. Many people find they look “less attractive” in fluorescent light because it is a “harsh” light. This is because it does not contain much red, and pink skin tones usually look healthier than pale white tones. If people feel they look less attractive when trying on clothing, they are less likely to buy it, hence expensive stores tend to use incandescent lights even though they are more expensive to run.

D. Quantitative Question:

FM radio stations broadcast signals which have frequencies in MHz, for example 106.5MHz.
a. To find the wavelength of the signal broadcast you use the relationship $c = \lambda f$. We know that the frequency is $f = 106.5 \times 10^6$ Hz, and $c = 3.0 \times 10^8$ m.s^{-1}, so:
$\lambda = c/f = 3.0 \times 10^8$ m.s^{-1} / 106.5×10^6 Hz = 2.8 m.
b. A wavelength of 521 m gives $f = c/\lambda = 3.0 \times 10^8$ m.s^{-1} / 521 m = 576×10^3 s^{-1} = 576kHz.
This is ABC radio national in Sydney.
c. See diagram opposite.
An FM signal carries information in the way the frequency varies, while the amplitude remains constant. An AM signal carries the information in the variation of the amplitude, while the frequency stays the same.