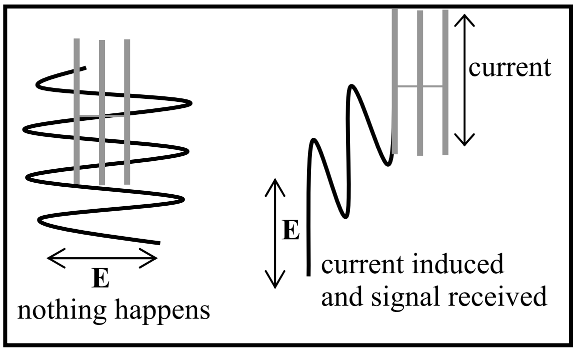
Workshop Tutorials for Physics

Solutions to WR5: **Electromagnetic Waves**

A. 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. Brent and Rebecca have bought a new TV antenna. Rebecca say's "Brent! You've set it up the wrong way! The bars should be horizontal!" The bars *should* be horizontal because the signals from the TV station's transmitting towers are horizontally polarised in Australia.
The electromagnetic waves which carry the signal have an oscillating electric and magnetic field. The oscillating electric field causes the electrons in the receiving antenna to oscillate, producing a current in the antenna, which is decoded into pictures and sound by the TV. If the antenna is vertical, the electrons cannot oscillate back and forth further than the width of the antenna, so no signal is received.



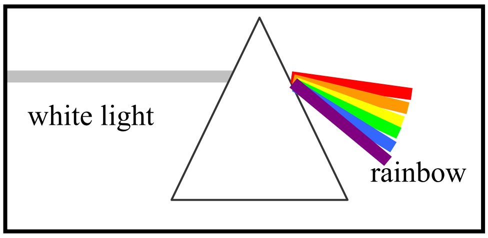
B. Activity Questions:

1. Speed of LightΔ

The melted patches occur at antinodes in the standing wave pattern inside the microwave. The distance between two antinodes is ½ λ. 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.

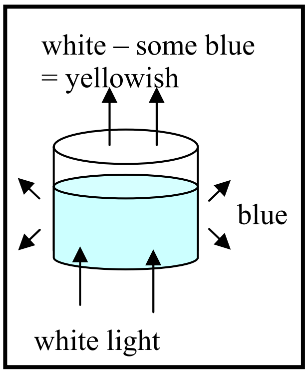
2. Prism

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 indexis greater for shorter wavelengths, and hence the blue component of the incident white light bends more than the red component.



3. 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 is black because there is no atmosphere to scatter any light – hence in the daytime you would see the sun, and other stars.



4. Polaroid glasses

A pair of polaroid glasses can be found by holding two pairs of glasses at right angles and looking at a light source. When a pair is found such that light does not pass through them when the lenses are at right angles, both are polaroids. Once one pair is identified, one of the sets of polaroid glasses can be used to test the others.

Sunglasses are useful for cutting out glare. Glare from water or shiny horizontal surfaces is effectively reduced by good sunglasses. The glare is due to light reflected from the horizontal surface, which is mostly horizontally polarised. Hence the transmission axis for the glasses must be vertical.

5. Stress lines

The molecules in the perspex are stretched by the applied stress, and align like the molecules in the sheets of polaroid. When viewed between two crossed polaroids, the light areas show where the material between is rotating the polarisation axis of the light coming through the first polaroid. This is a very useful technique, and is called optical stress analysis. Engineers use it to look for stress in models of structures. You will probably be able to see stress lines in the lenses of a pair of spectacles, showing the lenses have been stressed to fit them into the frames, or where the lenses are stressed due to damage to the frames, for example by dropping or sitting on the glasses.

C. Quantitative Question:

1. 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:

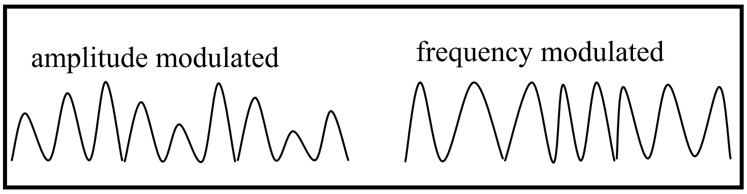
$\lambda = c/f = 3.0 \times 10^8$ m.s^{-1} / 106.5×10^6 Hz = 2.8 m.

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.



2. The refractive indices for ordinary and extraordinary waves traveling at right angles to the optic axis in quartz are $n_o = 1.544$ and $n_e = 1.553$. A quarter wave plate is one for which the two waves get exactly one quarter of a wavelength out of step after passing through it. The ordinary wave is one which passes straight through, the extraordinary is split off from the incident beam.

a. The thickness of the thinnest possible quarter wave plate corresponds to a path difference for the two beams of ¼ λ. The distance traveled will be the thickness, t, We require that if one beam goes through x wavelengths in this distance, then the other must travel through x + ¼ wavelengths. The number of wavelengths for a given thickness, t, is t/λ, so we require that:

$t/\lambda_o = x$ and $t/\lambda_e = x + ¼$, which gives $t/\lambda_e = t/\lambda_o + ¼$.

The wavelengths are related to the refractive indices for the waves: $\lambda_e = \lambda/n_e$ and $\lambda_o = \lambda/n_o$, putting this in to the expression for t gives: $tn_e/\lambda = tn_o/\lambda + ¼$,

which can be rearranged to give: $tn_e/\lambda - tn_o/\lambda = ¼$,

$t\,(n_e - n_o)/\lambda = ¼$ or $t = \lambda/\,4\,(n_e - n_o) = 600 \times 10^{-9}$ m / 4(1.553-1.544) = 1.7×10^{-5} m = 17 μm.

b. The thickness is proportional to the wavelength, so a smaller wavelength will require a thinner plate. A quarter wave plate will be thinner for light of wavelength 500 nm than for light of wavelength 600 nm.