UNL2206, Nature's Threads: Tutorial 6

1) Is it possible in principle that there could be a universe in which there were charged bodies, but no electric fields?

a) yes, it is possible
b) no, it is impossible for such a universe to exist.

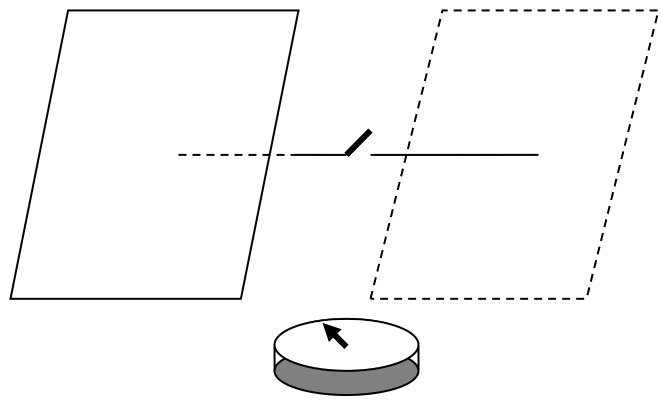
2) Faraday's law of electromagnetic induction states that a voltage and a resulting electric current will be induced in a conducting loop through which a magnetic field is changing with time. Maxwell re-expressed this purely in terms of fields, stating that a changing magnetic field will induce an electric field. Is the dual situation true as well ie will a changing electric field induce a magnetic field?

a) yes, always
b) yes it can, but not always
c) no, it cannot.

3) Is it possible that there could be a universe in which there were electric fields, but no charged bodies?

a) yes, it is possible
b) no, it is impossible for such a universe to exist.

4) A wire with a switch connects two oppositely charged capacitor plates and a small magnetic compass is located just outside the plates as shown below.



When the switch is closed, allowing the plates to discharge through the wire, there will be a momentary current in the wire. You might expect therefore that the magnetic compass pointer would be deflected. Will it?

a) Yes, it will
b) No, it won't

5) Calculate the displacement current I_D between the square plates, 2.8cm on each side, of a capacitor if the electric field is changing at a rate of 2.0×10^6 V/m.s.

6) Will an electric shield that shields the inside of a volume from an external electric field also shield against an incident electromagnetic wave?

7) The electric field in an EM wave traveling north oscillates in an east-west plane. What is the direction of the magnetic field vector in this wave?

8) In the electromagnetic spectrum, what type of EM wave would have a wavelength of 10^3 km? 1 km? 1m? 1cm? 1mm? 1μm?

9) Calculate the wavelength of: (a) a 60 Hz EM wave, (b) a 93.3 MHz FM radio wave, and (c) a beam of visible red light from a laser operating at a frequency of 4.74×10^{14} Hz.

10) Show that, at any instant, the total energy stored per unit volume in a region of space through which an electromagnetic wave is propagating can be written in the following equivalent ways:

$$U = \tfrac{1}{2}(\varepsilon_o E^2 + B^2/\mu_o) = \varepsilon_o E^2 = B^2/\mu_o = \sqrt{(\varepsilon_o/\mu_o)}\, E\, B \quad \text{joules/m}^3$$

11) The rate at which energy is transported by an electromagnetic wave <u>at any instant</u> is given by:

$$S = \varepsilon_o\, c\, E^2 = c\, B^2 / \mu_o = E\, B / \mu_o \quad \text{watts per m}^2$$

Assuming that the e-m wave is sinusoidal, what is the average energy transported over an extended period of time?

12) Solar radiation reaches the Earth (above its atmosphere) at a rate of about 1350 joules/sec m^2. Assuming that this radiation is in the form of a single e-m wave, calculate

a) the maximum values of the electric and magnetic fields;

b) the energy density due to the electric and magnetic contributions.

13) **Measuring the speed of light for yourself.** The *accepted value* for the speed of light is 2.99792458×10^8 m/s.

Measuring the speed of electromagnetic radiation or light normally requires delicate experiments involving expensive equipment. However, you can actually find a value for the speed of light to within an accuracy of about 5% from a simple experiment done at home using your microwave oven and a bag of marshmallows! You will also need a microwave-proof rectangular pyrex dish and a ruler. This is how: fill the whole dish with the marshmallows, placing them one layer thick, side by side with the flat side down. If your microwave has rotating turn-table, first remove this. Next, place your pyrex dish with the marshmallows arranged in it within the microwave oven.

Now cook the marshmallows on low heat. The marshmallows do not melt evenly and you will find there are certain 'hot-spots' within the oven. Heat the marshmallows gradually (at the lowest possible power setting of the microwave) and check the result every 10-15 seconds, until they <u>begin to melt at four or five spots at least</u> which you should mark (with either a felt tip pen or by inserting toothpicks at the appropriate points in the marshmallows). Remove the dish from the microwave oven and observe carefully the pattern of melted spots. With a ruler, measure the distance between the centres of each pair of melted spots; try to <u>identify the centre of a spot as accurately as possible</u>. You should find that one distance repeats more often than others. What is your *best estimate* (ie the average), X_{best}, for this distance? How do you account for the uncertainty in identifying the 'centre' of a given 'hot-spot' and are you able to reduce this particular uncertainty? Your measured value should therefore be quoted as $X_{best} \pm \delta x$ (meaning that the 'true' value of your measurement lies in the probable range $X_{best} + \delta x$ to $X_{best} - \delta x$). Given the way in which you have identified the 'hot-spots', what is a reasonable estimate for the *uncertainty*, δX, of your measurements?

Microwave ovens cook unevenly because a pattern of standing waves form inside the oven chamber. The pattern creates an array of hot-spots throughout the oven's volume. An operating frequency of around 2000 MHz will produce a wavelength of around 10cm, and the hotspots should be at half a wavelength apart, or about every 5-6 cm, but in a complex 3D pattern. Now, turn the microwave around and look for a small sign that tells you the frequency of the microwave. Most commercial microwaves operate at 2450 MHz (so if you cannot find the rating of your particular oven, assume this value for the frequency). Realistically, the frequency will also have a corresponding uncertainty associated to it, and we will assume this to be 2450 ± 50 MHz (meaning that the probable frequency of the microwave oven lies somewhere in the range 2400 MHz to 2500 MHz).

Your group should do one complete trial, and compile your measurements in a table listing the wavelengths, microwave oven frequency as well as their respective uncertainties.

The speed of light is given by the product of the frequency (f) and wavelength (λ). To obtain the experimental uncertainty in the product of two measured quantities requires the *fractional* or *percentage error,* $\delta\lambda/\lambda_{best}$, to be first determined. Your measured probable value for the speed of light then lies somewhere within the range:

$$\lambda_{best}\, f\,\{1 + \delta\lambda / \lambda_{best} + \delta f/f\} \text{ to } \lambda_{best}\, f\,\{1 - (\delta\lambda / \lambda_{best} + \delta f/f)\}$$

Therefore you are now able to compare the measured value for the speed of light determined by ***your*** experiment with the accepted value for this speed. Firstly, is your measured value *consistent* with the accepted value? Secondly, as a measure of the 'accuracy' of your result, compute the percentage difference between the two by taking the actual speed of light as 3.00×10^8 m/s and determining the % error as follows:

% difference = | (Accepted Value - Measured Value) / Accepted Value | x100

Note that the 'experimental error' or uncertainty of your result is in fact *distinct* from the accuracy of your experiment.

Finally, you can view a simulation of this experiment at
http://demonstrations.wolfram.com/MeasuringTheSpeedOfLightWithMarshmallows/

OPTIONAL QUESTIONS

12) **Particle vs. Wave Theory of Light –** Huygens' Principle states that *every point on a wave front can be considered as a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself. The new wave front is the envelope of all the wavelets* – that is, the tangent of all of them.

a) Use Huygens' Principle to discuss the diffraction of a plane wave as it impinges on an obstacle that partially interrupts the wave fronts.

b) Use Huygens' Principle to explain (Snell's) Law of Refraction.

c) Does Huygens' Principle apply to sound waves? To water waves?

13) Discuss the phenomenon of *interference* of waves.

14) Why doesn't the light from the two headlights of a distant car produce an interference pattern?

15) What evidence is there that sound is not electromagnetic radiation?

16) Discuss the photo-electric effect and explain how it provides clear evidence in favour of the *photon theory* of light.