2. FURTHER EXPERIMENTS AND INVESTIGATIONS

Testing microwaves (Textbook p19)

Fig 2A Testing microwaves

Use a microwave transmitter and receiver to investigate

1. absorption of microwaves by different materials
2. reflection of microwaves by a metal plate
3. diffraction of microwaves at a gap between two metal plates
4. polarisation of microwaves.

Polarisation tests (Textbook p20)

1. Use a single polaroid filter to find out

(a) if light from a candle flame or discharge lamp is polarised,

(b) if light reflected from glass is polarised.

2. Observe the LCD display of a calculator through a polaroid filter. Observe and explain what happens when the filter is turned through 360^0.

3. Use two polaroid filters, a strong light source and a lens to find out if light scattered by milky water is polarised.

Click here for answers to Polarisation tests

Absorption of sound by materials (Textbook p25)

Test different materials for absorption of sound. For example, place a cushion over a microphone and see if any sound from the loudspeaker reaches the microphone. You could place the microphone in a box surrounded by cushions , allowing sound to reach the microphone only through a suitable hole in the side of the box. Different materials could then be placed over the hole to see what effect each material has on the microphone. In general , soft materials such as fabrics will absorb the sound if the material is thick enough.

Measuring the speed of sound in a pipe (Textbook p33)

Fig 2B An air column of variable length

The length of the air column in Fig 2B can be changed by allowing water to enter or leave the pipe.

Method 1 Using a tuning fork of known frequency f, the water level is gradually lowered from the top. The air in the pipe resonates when the water level is at certain positions. These positions are located and the length of the air column for each resonance is measured.

The shortest length L_o corresponds to the fundamental pattern of vibration.,

$L_o + e = {}^1/_4\ \lambda$,where λ is the wavelength of sound in the pipe and e is the end-correction of the pipe.

The next longest length for resonance , L_1 , corresponds to the first overtone,

$$L_1 + e = {}^3/_4\ \lambda$$

$$\therefore\ L_1 - L_o = {}^1/_2\ \lambda$$

$\therefore$ The speed of sound in the pipe, $\upsilon = f\lambda = 2f(L_1 - L_o)$

Method 2 Using a tuning fork of known frequency f, the water level is gradually lowered from the top until the air in the pipe resonates. This should be the shortest length for resonance in accordance with the equation above. The test is repeated for different tuning forks, each of known frequency f.

Since the 'fundamental length' L_0 is given by the equation

$$L_o + e = {}^1/_4\ \lambda$$

then using the equation $\upsilon = f\lambda$ for the speed of sound in the pipe gives ,

$L_o + e = \upsilon / 4f$,where e is the end-correction of the pipe.

Therefore a graph of L_0 on the y-axis against 1/f on the x-axis should give a straight line of gradient $\upsilon / 4$ and a y-intercept equal to -e. Hence the speed of sound in the pipe can be calculated.

Measurement of the wavelength of laser light using double slits (Textbook p38)

Use double slits of known spacing d , a laser and a white screen as shown in the diagram.

Laser safety goggles must be worn when a laser is in use. Under no circumstances look along the laser beam.

Fig 2C Using a laser

1. The fringe spacing , y , should be measured using a mm rule. Measure across as many fringes as possible and divide the distance measured by the number of fringe spacings to obtain a value for y.

2. The slit-screen distance X should be measured using a millimetre rule.

3. The slit spacing d can be measured using a travelling microscope. The position of each edge of each slit should be measured to enable the position of the centre of each slit to be determined accurately. The slit spacing , d , is the distance between the centres.

Calculate the wavelength λ of the light from the laser using the equation

$$\frac{\lambda}{d} = \frac{y}{X}$$

Determination of the focal length of a convex lens by measuring object and image distances

(Textbook p45)

Fig 2 D Measuring object and image distances

The convex lens is used to project an image of the illuminated cross wires onto a white screen. The image distance is measured for different object distances.

1. The focal length can be calculated directly for each pair of measurements of u and v using the lens formula $1/u + 1/v = 1/f$. An average value for f can then be calculated.

2. Alternatively, a graph of 1/u on the y-axis against 1/v on the x-axis can be plotted. This should be a straight line of gradient -1 (since $1/u = -1/v + 1/f$) which intercepts both axes at 1/f . Calculate f using the average value of the intercept.

Fig 2E 1/u against 1/v

Estimate of the size of an oil molecule (Textbook p71)

Fig 2F Estimating the size of an oil molecule

A tiny oil drop placed on a clean water surface spreads out into a circular patch just one molecule thick. A V-shaped thin wire is dipped into the oil and shaken so just one droplet remains on the wire. The diameter, d, of this droplet can be estimated by using a magnifying glass and a millimetre scale. The water surface is sprinkled with very light powder after being cleaned. When the droplet is placed on the water surface, the oil spreads into a circular patch , pushing the powder away. The diameter , D, of the patch can then be measured.

The thickness, t, of the patch can be estimated by assuming the volume of the droplet ($= 4\pi r^3/3$, where its radius r= d/2) equals the volume of the patch ($= \pi D^2 t/4$).

Further notes; The experiment is an estimate not an accurate determination of the size of an oil molecule. An oil molecule is a chain of atoms and it is assumed that the thickness of the patch is equal to the length of a molecule. The number of atoms in an oil molecule depends on the type of oil . Note that a single carbon atom has a diameter of about 0.3 nanometres so a patch thickness of 1.6 nanometres would correspond to a molecule of length equal to about 5 atom diameters.

Investigation of convection of air (Textbook p85)

1. Natural convection

Fig 2G Cooling curves

Measure the temperature of a hot object at regular intervals as it cools naturally in air. The measurements may be plotted as a temperature v time graph, as in Fig 2G. The gradient of this graph at any point is the rate of temperature loss of the object at that point. The results show that the rate of temperature loss decreases as the excess temperature of the object above its surroundings increases.

2. Forced convection

Repeat the measurements in the presence of an airstream from a hair dryer or fan. The temperature decreases more rapidly than without a fan.

Further notes

See if your results for natural convection fit Newton's law of cooling which states that the rate of heat loss is in proportion to the temperature difference between the object and the surroundings. Assuming no loss of mass during cooling, the rate of loss of heat is in proportion to the rate of fall of temperature. Therefore if Newton's law of cooling is correct,

the rate of change of temperature $d\theta = -k(\theta - \theta_o)$

dt

where θ is the temperature of the object and θ_o is the temperature of the surroundings.

The solution of the above differential equation is

$$\theta - \theta_o = (\theta_1 - \theta_o)\, e^{-kt}$$, where θ_1 is

the initial temperature of the object. The temperature thus decreases exponentially towards θ_o.

Taking natural logarithms of both sides of the above solution gives

$$\ln(\theta - \theta_o) = \ln(\theta_1 - \theta_o) - kt$$

Therefore a graph of $y = \ln(\theta - \theta_o)$ against $x = t$ should give a straight line of gradient $-k$ if Newton's Law of Cooling applies. Note that Newton's Law of Cooling only applies to natural cooling, not forced cooling.

Fig 2H A graph of $\ln(\theta - \theta_o)$ against t

Measurement of the thermal conductivity of copper (Textbook p87)

One end of an insulated copper bar is heated electrically, as shown in Fig 2I. The heat conducted along the bar is removed by water flow through the copper cooling coils wrapped round the cold end of the bar. Steady heat flow along the bar is attained when the temperature readings of the thermometers becomes steady.

Fig 2I Measuring the thermal conductivity of copper

1. The temperature gradient is measured using the thermometers T_1 and T_2 at measured distance L apart.

2. The diameter d of the bar is measured and used to calculate the area of cross-section using $A = \pi d^2 / 4$,

3. The rate of flow of heat along the bar Q/t is determined by measuring the water flow rate through the cooling coils and the inflow and outflow temperatures T_3 and T_4. If m is the mass of water flowing through the coils in time t, the heat flow Q/t = the energy removed per second by the water

$$= \frac{m}{t} c (T_4 - T_3),$$

where c is the specific heat capacity of water.

The thermal conductivity k can then be calculated using the equation

$$\frac{Q}{t} = k A \frac{(T_1 - T_2)}{L}$$

More about measuring stress and strain (Textbook p95 and 96)

The relationship between stress and strain for a wire can be investigated using the arrangement in Fig 2J.

Fig 2J Measuring stress and strain

The control wire supports a micrometer which is used to measure the change of length of the test wire when the test wire is loaded and unloaded. Each time a measurement is made, the micrometer is adjusted so the spirit level is horizontal before the micrometer reading is taken.

1. The two wires are loaded sufficiently to ensure each wire is straight. The micrometer is adjusted as explained above and its reading noted.

Safety note; Always wear impact-resistant safety spectacles when carrying out stretching tests in case the wire snaps and flies up.

2. The initial length L of the test wire is then measured using a metre rule with a millimetre scale.
3. The diameter of the wire at several points along the wire is also measured using a micrometer to give an average value , d, for the diameter of the wire. The area of cross-section, A, of the wire is calculated using $A = \pi d^2 / 4$
4. The test wire is then loaded with a known weight W and its micrometer is adjusted as above and its reading noted. The procedure is repeated as the weight W is increased in steps and then decreased in steps to zero. The tension in the wire at each step is equal to the weight W.
5. The extension e from the initial length L is calculated from the test wire micrometer readings.

For a wire of unstretched length L and area of cross-section A under tension T,

the Young modulus of the wire material , E = $\frac{\text{stress}}{\ } = \frac{T / A}{\ } = \frac{T L}{\ }$

strain e / L A e

$$\therefore \quad T = \frac{AE}{L} e$$

A graph of Tension T on the vertical axis against extension e on the horizontal axis therefore gives a straight line through the origin with a gradient = $\frac{AE}{L}$.

Hence E = gradient (of T v e line) x $\frac{L}{A}$

Further notes Test your data analysis skills by estimating the uncertainties in the measurements to obtain an overall uncertainty for your value of the Young modulus. To estimate the % uncertainty of the gradient of the line plotted on the graph of y = tension against x = extension , add the % uncertainties of the highest reading of tension and of extension .

The % uncertainty in the calculated value of the Young modulus

= % uncertainty in the length of the wire

\+ % uncertainty in the area of cross-section of the wire

\+ % uncertainty in the gradient of the above graph.

Note that the % uncertainty in the area of cross-section = 2 x the % uncertainty in the wire diameter .

See **Data analysis** for more about uncertainties.

Investigating motion (Textbook p135)

Use a motion sensor linked to a microcomputer to record and display the speed of a dynamics cart on a smooth runway. It should be possible to display a graph of speed v time on the microcomputer display screen. Test the effect of different inclinations for the runway and find out how the mass of the cart affects its motion.

Design and carry out an experiment using the conservation of momentum to measure the mass of an object. (Textbook p153)

Fig 2K A controlled explosion

Use the arrangement shown in the diagram to make two dynamics carts initially at rest fly apart . For two carts of different masses, they move away from each other at different speeds. Place a brick at a measured distance from each cart so the carts hit the bricks simultaneously.

Since the carts carry away equal and opposite momentum,

$$\frac{\text{the speed of cart X}}{\text{the speed of cart Y}} = \frac{\text{the mass of cart Y}}{\text{the mass of cart X}}$$

Because the distance travelled by each cart in the time from release to impact is proportional to its speed, the speed ratio is equal to the ratio of the measured distances. Hence the mass ratio can be determined from the distance ratio. If one of the masses in known and the other is unknown, the unknown mass can then be determined.

Experiment to calibrate a voltmeter (Textbook p179**)**

Fig 2L Calibrating a voltmeter

Use the circuit in Fig 2L to measure the electrical energy E supplied to a low voltage light bulb for a measured time t and a known constant current I.

Calculate the charge supplied Q using the equation $Q = I\,t$.

The potential difference V across the light bulb can then be worked out using

$V = E / Q$.

If the voltmeter scale is already calibrated, compare the calculated p.d. with the voltmeter reading.

Repeat the test for different potential differences.

More on the measurement of the resistivity of a wire (Textbook p197)

Fig 2M Comparing two resistances

Use a Wheatstone bridge as in Fig 2M to measure the resistance of different measured lengths of the wire under test. Use a micrometer to measure the diameter of the wire at different points to obtain an average value d. Calculate the area of cross-section A using the equation $A = \pi d^2 / 4$.

Plot a graph of resistance R on the vertical axis against length L on the horizontal axis.

The graph should be a straight line through the origin, in accordance with the equation $R = \frac{\rho}{A} L$

Since the gradient of the line = ρ / A , the resisitivity can be calculated from ρ = gradient x A

Further notes

Use your data analysis skills to determine the uncertainty in your calculated value of resistivity.

The % uncertainty of the resistivity = % uncertainty in the area of cross-section of the wire

+ % uncertainty of the gradient of the line

1. The % uncertainty of the area of cross-section of the wire = 2 x the % uncertainty of the diameter of the wire ,

2. The % uncertainty of the gradient of the line of y = resistance against x = length can be estimated by adding together the percentage uncertainty of the resistance and of the length for the longest length measured.

Worked example

Use the following data about a wire to calculate

(a) the resistivity of the wire, and

(b) the uncertainty in the calculated value of resistivity.

Wire diameter = 0.31 $\pm$ 0.01 mm ,

Resistance = 21.1 $\pm$ 0.3 Ω,

Length = 1.100 $\pm$ 0.002 m,

Solution

(a) Resistivity = $\frac{\text{resistance x area of cross-section}}{\text{length}} = \frac{21.1 \times \pi (0.31 \times 10^{-3})^2}{1.100 \times 4} = 4.61 \times 10^{-7}\ \Omega\ \text{m}$

(b) % uncertainty of diameter = $\frac{0.02}{0.31}$ = 3.23 %

$\therefore$ % uncertainty of area of cross-section = 2 x 3.23 = 6.46 %

% uncertainty of resistance = $\frac{0.3}{21.1}$ = 1.42 %

% uncertainty of length = $\frac{0.002}{1.100}$ = 0.18 %

.'. % uncertainty of resistance per unit length = 1.42 + 0.18 = 1.60%

.'. % uncertainty of resistivity = 6.46 + 1.60 = 8.06 %

.'. Uncertainty of resistivity = $\frac{8.06}{100}$ x 4.61 x 10^{-7} Ω m = 0.37 x 10^{-7} Ω m

(Note ; .'. Resistivity = 4.61 x 10^{-7} Ω m ± 0.37 x 10^{-7} Ω m)

An experiment to measure the energy stored by a capacitor (Textbook p210)

Fig 2N Measuring the energy stored in a capacitor

The energy stored by a capacitor can be measured using a joulemeter, as shown in the circuit diagram below. The capacitor is charged to a known voltage by connecting switch S to the voltage supply. When the switch is reset from X to Y, the capacitor is then discharged through the low voltage light bulb via the joulemeter. The light bulb lights briefly and as it does so, the joulemeter records the energy transferred from the capacitor to the light bulb. The joulemeter reading gives the energy stored, provided there is no heating effect in the connecting wires. The measurement can be compared with the calculated value given by the formula 'Energy stored = $^1/_2$ CV^2 '.

Further notes;

1. Because the battery supplies charge Q at potential difference V, the energy supplied by the battery = QV = CV^2

2. The energy transferred to the capacitor = $^1/_2$ QV = $^1/_2$ CV^2 as explained on p 210 of the textbook.

3. The charging current dissipates heat in the connecting wires due to their resistance. This accounts for the fact that only 50% of the energy transferred from the battery is stored in the capacitor.

4. When the capacitor is discharged through a resistor, all the energy stored is dissipated as heat in the resistance and the connecting wires.

Experiment to investigate an astable multivibrator (Textbook p232)

Fig 2 P An astable multivibrator

Display the output waveform of the astable multivibrator shown in Fig 2P using an oscilloscope.

1. Use the time scale of the oscilloscope to measure the time period of the waveform. Compare the measured time period with the value calculated from the time constant.

2. Replace one of the capacitors and one of the resistors and observe the effect on the output waveform.

Investigating the effect of a uniform magnetic field on a beam of electrons (Textbook p258)

Fig2Q The fine beam tube

The force on an electron moving at speed υ in a uniform magnetic field of flux density B in a direction at right angles to the field = $B e \upsilon$, where e is the charge of the electron.

As explained on p258, this force is at right angles to the direction of motion of the electron and therefore the electron moves on a circular path. The force is towards the centre of curvature of the circular path and therefore so too is the acceleration of the electron. This acceleration, referred to as 'centripetal' because it acts towards the centre of the circular path, is equal to υ^2 / r, where r is the radius of curvature of the circular path. See p391 for more about circular motion.

Using Newton's 2nd Law in the form F = ma therefore gives $B e \upsilon = m \upsilon^2 / r$

Hence the radius of curvature of the beam, $r = \frac{m \upsilon}{B e}$

Fig 2Q shows a tube in which a beam of electrons is created and made visible. The tube contains a gas at low pressure and some of the electrons in the beam collide with gas molecules and make the molecules emit light. The beam is produced from an electron gun, as explained on p305 of the textbook.

A controlled magnetic field is applied to the tube by means of two current-carrying coils in series with each other, either side of the tube.

1. If the initial direction of the beam is perpendicular to the lines of force of the magnetic field, the

beam is forced round in a circle. This is because the force is always at right angles to the direction of motion of the particle just like the force of gravity on a satellite in orbit is always at right angles to the direction of motion of the satellite. The force does no work on the particle because it is perpendicular to its direction of motion. Hence the particle's speed remains constant.

2. The magnetic flux density in the tube can be increased by increasing the current in the coils. The result is to force the beam into a tighter circle because the force is made larger.

The speed of the electrons in the beam is controlled by the anode voltage (ie. the voltage of the electron gun). Therefore , if the anode voltage is not changed, the radius of curvature of the beam is inversely proportional to the magnetic flux density ie. $r \propto 1/B$.

This relationship can be tested by altering B by changing the coil current I and measuring the beam diameter. Because B is proportional to the coil current, then the beam diameter should be inversely proportional to the coil current. For example, if the coil current is doubled, then the beam diameter should be halved.

Measure the beam diameter for different values of the coil current and then plot a graph of y = beam diameter against x = 1 / coil current. The graph should be a straight line through the origin.

<u>Further investigations of flux changes using a data recorder</u> (Textbook p273)

1. Repeat the test on p273 with the same magnet but at a different speed. You should find that the curve is higher and thinner for greater speed but the area is just the same.

2. Arrange a bar magnet attached to a length of thread as a simple pendulum so that the bar magnet oscillates about a fixed point in a fixed plane. Fix a flat coil of wire in a horizontal position just below the midpoint (ie. lowest point) of the oscillations of the bar magnet. Connect the coil to a data recorder and record the induced voltage in the coil as the bar magnet swings across.

Fig 2R Using a bar magnet

The induced voltage varies with time as shown in the diagram. Note that the midpoint of the swing corresponds to where the voltage reverses polarity. This is because the flux is at a maximum at this point and therefore the rate of change of flux is zero at this instant. The area under the trace before the midpoint is equal to the area after the midpoint because the growth of flux through the coil before the midpoint is equal to the decrease of flux after the midpoint. Test this 'area' rule by measuring the area in each half. Use your measurement and any further necessary measurements to determine the magnetic flux density of the magnet, given that the change of magnetic flux from the midpoint (in volt seconds) is equal to BAN, where N is the number of turns of the coil and A is the coil area.

Investigating self-inductance (Textbook p281)

Fig 2S Using a data recorder

Use an ammeter sensor and a data recorder as shown in Fig 2S to measure the growth of current in a d.c. circuit containing an coil of large inductance. Use the readings or a printer to plot a graph of the current v time. If the data recorder is linked to a microcomputer, the results can be displayed automatically as a graph by selecting the appropriate options. Use the graph to measure the initial rate of growth of the current and hence calculate the self-inductance of the coil (= battery voltage / initial rate of growth of current).

Measuring the reactance of a coil (Textbook p295)

Fig 2T Measuring the reacrance of a coil

For a coil of resistance R and self inductance L in an a.c. circuit, the rms voltage V_{rms} across its terminals depends on the rms current I_{rms}, the coil resistance and the a.c. frequency f in accordance with the equation

$V_{rms} = I_{rms} (R^2 + X_L^2)^{1/2}$, where X_L is the coil's reactance and is equal to $2\pi fL$

Use the circuit shown in the diagram to measure the rms voltage for different values of frequency, keeping the rms current constant. Use the oscilloscope to measure the time period of the alternating current and the peak voltage and hence determine the rms voltage and the frequency.

Since

$V^2_{rms} = I^2_{rms} (R^2 + (2\pi fL)^2)$, then $V^2_{rms} = (2\pi LI_{rms})^2 f^2 + I^2_{rms}R^2$.

Therefore a graph of $y = V^2_{rms}$ against $x = f^2$ should be a straight line of gradient $(2\pi LI_{rms})^2$ with a y-intercept of $I^2_{rms}R^2$. Use your measurements to plot the graph and to determine the self-inductance and the resistance of the coil.

Experiment to measure the spectrum of the hydrogen atom (Textbook p318)

Use a spectrometer and a diffraction grating to measure the wavelengths of light emitted by a hydrogen discharge tube. See p54 for the use of the spectrometer and **More about using a spectrometer** for setting up a spectrometer.

The energy levels of the hydrogen atom are given by the formula $E = -\frac{13.6}{n^2}$ eV

where n is a positive integer, referred to as the principal quantum number. Use this formula to determine the electron transitions responsible for the photon wavelengths measured using the spectrometer.

Experiment to test the inverse square law for gamma radiation from from a point source.
(Textbook p330)

Use a geiger tube to measure the count rate at different distance from a source of gamma radiation. Note that the source should be transferred to and from its storage box using a handling tool designed for the purpose. For each distance, measure the distance ,d , from the front of the source to the geiger tube and measure the number of counts in five minutes three times to give an average value for the count rate. Without the source present, measure the number of counts in 10 minutes to determine the background count rate which should then be subtracted from the average count rate for each distance to give the corrected count rate C.

The corrected count rate C depends on the distance r from the source in accordance with the inverse square law $C = k / r^2$, as explained on p330. However, the measured distance d is from the geiger tube to the front of the source holder . Hence distance $r = d + d_0$, where d_0 is the unknown distance from the front of the source holder to the source inside the holder.

Rearranging $C = k / r^2$ gives $r = k^{1/2} / C^{1/2}$ thus $d = k^{1/2} / C^{1/2} - d_0$ so a graph of $y = d$ against $x = 1 / C^{1/2}$ should give a straight line with a positive gradient and a y-intercept equal to $-d_0$, as shown below .

Fig 2U d v $1/ C^{1/2}$

More about using a spectrometer (Textbook p54**)**

Fig 2V Using a spectrometer

To set up the spectrometer with the diffraction grating in the correct position;-

1. Look through the spectrometer telescope and focus it on a distant object, thus ensuring the telescope is set to receive parallel light.

2. Observe the slit of the collimator through the telescope and focus the collimator so its slit is in focus. This ensures the collimator gives parallel light from the slit. Then adjust the slit width so the slit appears as a narrow line when the light source to be observed is placed next to the slit.

3. Ensure the turntable is horizontal by using a spirit level. To do this, place the spirit level along the line between any two of the three turntable levelling screws. Adjust one of the two screws so the spirit level is horizontal. Then place the spirit level along a line perpendicular to its previous alignment and adjust the other levelling screw until the spirit level is once more horizontal. The turntable is then horizontal.

Fig 2W Levelling the spectrometer

4. Place the diffraction grating in the grating holder on the turntable. To ensure the grating is perpendicular to the incident beam (from the collimator), move the telescope from the 'straight through' position exactly in line with the collimator position (where the slit image is observed on the centre of the

telescope eyepiece crosswires) through exactly 90^0 so it is then perpendicular to the incident beam. Then unlock the turntable and turn the turntable until an image of the slit can be seen by reflection off the grating through the telescope at the centre of the field of view. The grating is then exactly at 45^0 to the incident beam. Turning the turntable through exactly 45^0 then position the grating at exactly 90^0 to the incident beam. The turntable should then be locked into this position. The spectrometer is now set up ready for measurements to be made. See p 54.

Answers to Polarisation tests.

1. (a) No, (b) Complete polarisation occurs at a certain angle of incidence referred to as the 'Brewster' angle. At this angle of incidence , the refracted ray is at 90^0 to the incident ray. Therefore , using Snell's Law of refraction (sin i / sin r = n) , because r = 90 - i and so sin r = sin (90 -i) = cos i , then tan i = n at the Brewster angle . For glass of refractive index n = 1.5, the Brewster angle is 57^o .

2. The display becomes dark at a certain position and again when the filter is turned through 180^0.

3. Light scattered through 90^0 by milky water is polarised.