Appendix B

Mandatory Experiments Notes

B.1 Mechanics Experiments

B.1.1 To Measure Velocity and Acceleration

Theory:
Velocity is speed in a give direction, while acceleration is the rate of change of velocity with time.

$$v = \frac{s}{t}$$
$$a = \frac{v-u}{t}$$

Note that if the trolley starts from rest then $u = 0$ then

$$s = ut + \frac{1}{2}at^2$$
$$s = \frac{1}{2}at^2$$
$$2s = at^2$$
$$a = \frac{2s}{t}$$

hence we must measure the time t to travel a distance s.

Apparatus:
Ticker tape, ticker timer, trolley, adjustable slope, metre stick.

Method:

1. Run one end of the ticker tape through the ticker timer and attach to the trolley. Push the trolley.
2. Adjust the slope so that the distance between dots on the ticker tape is constant.
3. Measure the distance s between a set number of dots on the tape with a metre stick.

4. Calculate the time taken t by dividing the number of spaces n between the dots by the frequency of the timer, $t = \frac{n}{f}$.

5. Use $v = \frac{s}{t}$ (derived above) to find the velocity.

6. Use $a = \frac{2s}{t}$ (derived above) to find the accleration.

Result:
One obtains values for the velocity and acceleration of the trolley.

Precautions/Sources of error:

1. It is difficult to maintain constant velocity during the first part of the motion due to friction – raise the board just a little.

2. It is difficult to keep a constant force in the second part (which is needed to give uniform acceleration). There are two ways of doing this:-

   (a) Incline the board at a fairly large angle;

   (b) Practice pulling the trolley with a uniform length of elastic band.

3. For both parts friction is a problem. Eliminate it by :-

   (a) Oiling the wheels;

   (b) Incline the runway;

   (c) Make sure the runway is smooth and clean.

4. It is best practice to ignore the first few dots. These unevenly spaced dots were produced while the trolley was being pushed and thus they introduce a slight error into the calculations if included. (Over this interval the force was variable and hence the acceleration will be as well). The 'suvat' equations assume *constant* acceleration.

B.1.2 To Verify that the Acceleration of a Body is Directly Proportional to the Force Acting on it

Theory:
The change in linear momentum of a body is directly proportinal to the applied force causing it and takes place along the line of action of the force:

$$a \propto F$$

Apparatus:
Ticker tape, ticker timer, trolley, adjustable slope, metre stick, string, pulley, scale pan, and Newton weights.

Method:

1. Attach the ticker tape to the trolley through the ticker timer. Attach the other side of the trolley to the scale pan via the pulley using the string. Ensure all of the weights are placed on the trolley.

2. Adjust the slope so that the trolley will move with constant velocity if given an initial impulse.

3. Move one of the weights from the trolley to the pan. Note the weight in the pan–this is the force F which causes the trolley to aceclerate.

4. Measure the acceleration of the trolley as it moves down the slope (see previous experiment).

5. Move another weight from the trolley to the pan an repeat.

6. Repeat this process a number of times.

Result:
You should obtain a straight line through the origin when F is plotted against a.

Conclusion:
The acceleration is directly proportional to the force.

Precautions/Sources of Error:

1. Use more masses on the scale pan or a lighter trolley to reduce the percentage error by increasing the size of the acceleration.

2. Ensure the wheels of the trolley have been oiled to reduce friction.

3. Ensure that the string pulling the trolley is parallel to the slope so that all of the force acts in the same direction as the acceleration.

4. Ensure the slope is correct: the trolley should move with constant velocity down the slope when the scale pan is empty.

5. Moving weights from the trolley to the scale pan ensures that the mass of the system remains constant throughout the experiment.

B.1.3 To Verify the Principle of Conservation of Momentum

Theory:
The law states that when two bodies collide, their total momentum before collision is equal to their total momentum after, i.e., momentum is conserved. The momentum of a body is the product of its mass and velocity:

$$p = mv$$

The paper tape from a timer is attached to the moving body (trolley) so that the velocity of the latter can be measured, hence the momentum of the mass is known. In this experiment, trolley A is initially moving and trolley B at rest. Trolley A collides with

B, and their common velocity after impact is measured. Hence, their total momentum before and after collision can be calculated and compared.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 \implies m_1(u) + m_2(0) = m_1(v) + m_2(v)$$

$$m_1u = (m_1 + m_2)v$$

Apparatus:
Ticker tape, ticker timer, two trolleys, adjustable slope, metre stick, two magnets, electronic balance.

Method:

1. Find the mass of both trolleys using the electronic balance.
2. Attach ticker tape to trolley A through the timer. Place trolley B at rest on the slope.
3. Adjust the slope so that the trolleys will move with constant velocity if give an initial impulse.
4. Push trolley A and allow it to collide with trolley B.
5. Use the ticker tape and timer to measure the velocity of trolley A before the collision u.
6. Use the ticker tape and timer to measure the velocity of the combined trolleys after the collision v.
7. Calculate m_1u and $(m_1 + m_2)v$.

Result:

$$m_1u = (m_1 + m_2)v$$

Conclusion:
The total momentum before the collision is equal to the total momentum after the collision (provided no external forces act on the system).

Precautions/Sources of error:

1. Choose dots on the paper immediately before and after the collision to get a more accurate answer.
2. Oil the wheels of the trolleys to reduce friction.
3. Giving trolley A a greater initial velocity will reduce the percentage error.
4. Ensure the trolleys actually coalesce due to the collision using the magnets.
5. Ensure the slope is such that the trolleys will move off with constant velocity if given an initial impulse. This ensures that the frictional force is equal to the gravitational force.

B.1.4 To Verify Boyle's Law

Theory:
This law states that at constant temperature the volume of a fixed mass of gas is inversely proportional to its pressure: $P \propto \frac{1}{V} \implies PV = \text{constant}$.

Apparatus:
Boyle's law apparatus, air pump.

Method:

1. Set up the Boyle's law apparatus. Use the air pump to increase the pressure of the fixed mass of gas to its maximum value.
2. Allow time for the temperature of the gas to return to room temperature.
3. Note the volume V of the gas in the tube using the scale on the apparatus.
4. Note the pressure P at that volume using the pressure gauge.
5. Open the tap slowly to release some pressure, and repeat the process.

Result:
The graph of P vs. $\frac{1}{V}$ should be a straight line through the origin.

Conclusion:
The pressure of a fixed mass of gas at constant temperature is inversely proportional to the volume (Boyle's law).

Precautions/Sources of Error:

1. After changing the pressure wait a short time before taking readings to allow the temperature of the gas to return to room temperature. The increase in pressure causes an increase in temperature which would violate Boyle's law. Note that one could also simply release the pressure slowly to avoid temperature changes.
2. Read the volume of the oil from the bottom of the meniscus.
3. Increase the range of readings to reduce percentage error.

B.1.5 To Investigate the Laws of Equilibrium for a Set of Coplanar Forces

Theory:
A body is in equilibrium if:-

1. The vecor sum of the forces in any direction is zero, i.e. the sum of the upward forces and downward forces is zero, the sum of the forces to the right and to the left is zero.
2. The vector sum of the moments about any point is zero, i.e. the sum of the clockwise moments equal the sum of the anticlockwise moments.

Apparatus:
Metre stick, two spring balances, two retort stands and clamps, Newton weights, electronic balance, and a spirit level.

Method:

1. Find the mass of the metre stick using the electronic balance, and then get its weight using $W = mg$.

2. Find the centre of gravity of the metre stick by balancing it on a narrow fulcrum.

3. Attach one end of the spring balances to the clamps and the other to the metre stick. Hang three of the Newton weights from the metre stick. Adjust the locations until the stick is in equilibrium.

4. Note the forces on the spring balances (F_1 and F_2) and on each of the Newton weights (W_1, W_2 and W_3).

5. Note the position of the balances (d_1 and d_2) and weights (s_1, s_2 and s_3).

Results:

1. The forces up equal the forces F: $F_1 + F_2 = W + W_1 + W_2 + W_3$;

2. The sum of the moments about any point is zero: $F_1 d_1 + W_2 s_2 + W_3 s_3 = F_2 d_2 + W_1 s_1$.

The graph of P vs. $\frac{1}{V}$ should be a straight line through the origin.

Conclusion:
For a body in equilibrium: the forces up equal the forces down; the sum of the moments about any point is zero.

Precautions/Sources of Error:

1. Use a narrow fulcrum when finding the centre of gravity of the stick to get an accurate reading (e.g. use a wedge).

2. Make sure that the spring balances are hanging vertically to avoid friction and to ensure that the readings are parallel to the weights.

3. Ensure using a spirit level that the metre stick is horizontal so that forces are indeed perpendicular to the stick, and thus distances can be read directly from the stick.

4. Most metre sticks (and rulers) have excess material at one or both ends. This material is not included in the measurements on the stick, hence the centre of gravity may not be located at the 50cm mark. Use a 'cut' metre stick to obviate this potential difficulty.

5. Ensure to measure the perpendicular distances from the point about which moments are being taken–not the ends of the metre stick. It is convenient to take moments about the centre of gravity of the stick.

B.1.6 To Investigate the Relationship Between the Period and Length for a Simple Pendulum and Hence Calculate g

Theory:
The motion is simple harmonic and the periodic time is:

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

from which

$$T^2 = 4\pi^2\frac{\ell}{g}$$

divide across by ℓ

$$\frac{T^2}{\ell} = \frac{4\pi^2}{g} = \text{constant}$$

Therefore, if we plot on a graph of T^2 (on the x-axis) against ℓ (on the y-axis) we should obtain a straight line through the origin. From the slope of this graph, we can obtain a value for g:

$$gT^2 = 4\pi^2\ell$$
$$g = \frac{4\pi^2\ell}{T}$$

but $\frac{\ell}{T^2}$ = slope

$$g = 4\pi^2 \cdot \text{slope}$$

Apparatus:
Pendulum bob, string, retort stand, clamp, split cork, metre stick, stopwatch.

Method:

1. Attach the string to the pendulum bob and suspend from the split cork which is clamped onto the retort stand. Ensure the pendulum is as long as conveniently possible.
2. Measure the length ℓ of the pendulum, from the bottom of the split cork to the centre of the bob, using the metre stick.
3. Set the bob swinging through a small arc (less than 5° degrees from the vertical on either side) otherwise the motion will not be simple harmonic.
4. Start the timer as the bob moves through the lowest point. Stop the timer after a fixed number of oscillations. This gives us the time t from $T = \frac{1}{f}$.
5. Reduce the length of the pendulum and repeat process.
6. Repeat the procedure a number of times to get multiple readings.

Result:
A plot of ℓ vs. T^2 will be a straight line through the origin. Our observations will give us a value for g.

Conclusion:
The length of a pendulum is directly proportional to the square of the period. The acceleration due to gravity has a value of approximately 9.8 ms^{-2}.

Precautions/Sources of Error:

1. When counting, say ‘naught’ when the stopwatch is started. If you start counting at ‘one’ and stop at ‘twenty’, then only 19 oscillations will have been timed.

2. Be careful to count complete oscillations and not swings – these are only half-oscillations.

3. Vary the length of the pendulum between .3m and 1m, but not beyond these limits. Lengths above 1m are difficult to measure and the results become increasingly inaccurate the shorter the length of the pendulum due to increasing percentage error.

4. If oscillations become elliptical (i.e not in the same plane) then start the experiment again.

5. Make sure that the angle of the arc (amplitude) is no more than 5°. If it is greater than this then the mtion of the pendulum is not simple harmonic.

B.2 Heat Experiments

B.2.1 To Plot a Calibration Curve of a Thermometer Using the Laboratory Mercury Thermometer as a Standard

Theory:
A thermometric property is any physical property that changes measurably and uniformly with temperature.

Apparatus:
Ungraduated alcohol thermometer, ruler, mercury thermometer, hotplate, stirrer, ice, beaker.

Method:

1. Add ice to the beaker and allow it to melt.

2. Simultaneously, measure the length (ℓ) of the column of alcohol using a ruler and the temperature (θ) of the melted ice using the mercury thermometer.

3. Raise the temperature of the water by roughly 10°C and repeat the process so as to get a number of readings.

Result:
A graph of ℓ vs. θ will from the calibration curve.

Conclusion:
To use the alcohol thermometer, place the thermometer in thermal contact with the body whose temperature is to be found and measure its height, then find the corresponding temperature from the calibration curve.

Precautions/Sources of Error:

1. Heat the water slowly and stir to ensure a consistent temperature.
2. Take more readings to get a more accurate curve.
3. Make sure you take the temperature reading and the height at the same time.
4. Use a stirrer with low specific heat capacity, otherwise non-negligibe heat may be lost to the stirrer in heating it up.
5. Ensure that no parallax error occurs when reading the height of the column of alcohol.

B.2.2 To Find the Specific Heat Capacity of Water or a Metal

Theory:
This experiment is based on the fact that it takes a certain amount of heat (energy) to raise one unit of mass of a liquid (1Kg) through $1°C$, i.e. its specific heat capacity. Note that

$$\text{heat lost} = \text{heat gained}$$

The heat lost or gained is obtained by multiplying the mass by the specific heat by the change in temperature: $H = mc\Delta\theta$.

Apparatus:
Water, beaker, hotplate, thermometer, piece of aluminium, tongs, insulated calorimeter, electronic balance.

Method:

1. Find the mass of the empty calorimeter using the electronic balance.
2. Find the mass of a piece of aluminium using the electronic balance.
3. Place some water in a beaker along with the aluminium. Heat using the hotplate to 100°C. Measure the temperature of the water using a thermometer. This is the initial temperature of the aluminium θ_{al}.
4. Add some ice water (0°C) to the calorimeter. Find the mass of the calorimeter plus water (m_{cal+w}) using the electronic balance.
5. Insulate the calorimeter and measure the initial temperature of the water (θ_l) using the thermometer.

6. Move the aliminium from the beaker to the insulated calorimeter using tongs and place the lid on the calorimeter.

7. Stir the water until its temperature stops rising. Measure the final temperature (θ_F) using the thermometer.

Calculation:

$$\text{Heat lost} = \text{Heat gained}$$
$$(mc\Delta\theta)_{al} = (mc\Delta\theta)_w + (mc\Delta\theta)_{cal}$$

If given c_{al} solve for c_w. Conversely, if given c_w solve for c_{al}.

Result:
Water has a specific heat capacity of approximately 4180 $Jkg^{-1}K^{-1}$ (that of aluminium is approximately 910 $Jkg^{-1}K^{-1}$).

Precautions/Sources of Error:

1. Note the following assumptions:-
   (a) That all electrical energy is converted to internal energy in the water and calorimeter.
   (b) That there is no heat lost to the surroundings.
   (c) That the specific heat capacity of copper is known. If not, then use an aeroboard container, which may be assumed to absorb no heat energy.

2. Make sure to lag the calorimeter well.

3. When reading the final temperature wait for a short time after switching off the calorimeter to allow the heat in the element to be relaxed and spread evenly throughout the liquid.

4. Make sure to stir the liquid before taking the final temperature.

5. The current in the coil should be fairly high so that heating will be fairly rapid, and thus the time for heat loss small.

B.2.3 To Measure the Specific Latent Heat of Fusion of Ice

Theory:
Here we are trying to find the amount of heat needed to change the state of the substance (i.e. ice water). It is called the specific latent heat of fusion of ice.

Apparatus:
Ice, mortar and pestle, blotting paper, water, thermometer, insulated calorimeter, electronic balance.

Method:

1. Find the mass of the empty calorimeter (m_{cal}) using the electronic balance.

2. Half fill the calorimeter with warm water. Find the mass of the calorimeter plus water (m_{cal+w}) using the electronic balance.

3. Insulate the calorimeter and measure the initial temperature of the water (θ_I) using the thermometer.

4. Crush some ice using the mortar and pestle. Dry it on the blotting paper, and then gently add it to the water in the calorimeter.

5. Allow time for all the ice to melt and measure the lowest temperature (θ_F) reached by the water using the thermometer.

6. Find the mass of the calorimeter plus water plus melted ice ($\theta_{cal+w+ice}$) using the electronic balance.

Calculation:

$$\begin{aligned} \text{Heat lost} &= \text{Heat gained} \\ (mc\Delta\theta)_w + (mc\Delta\theta)_{cal} &= (ml)_{ice} + (mc\Delta\theta)_{ice} \\ m_w c_w(\theta_I - \theta_F) + m_{cal}c_{cal}(\theta_I - \theta_F) &= m_{ice}l_{ice} + m_{ice}c_w(\theta_F - \theta_I) \end{aligned}$$

Solve for l_{ice}.

Result:
Water has a specific latent heat of fusion of approximately 328341 $Jkg^{-1}K^{-1}$.

Precautions/Sources of Error:

1. Note that we make two basic assumptions:
   (a) The ice cubes are at 0°, they may be lower.
   (b) All the heat needed to melt the ice is taken from the water and the calorimeter.

2. Ensure the ice is dry, otherwise you will be adding water at 0° as well as ice and this will be an inaccurate result.

3. Make sure that the calorimeter is well lagged, otherwise the ice in melting will absorb heat from the surroundings, producing a poor result.

B.2.4 To Measure the Specific Latent Heat of Vaporisation of Water

Theory:
Here we are trying to find the amount of heat needed to change the state of a substance , i.e. water to steam. It is called the specific latent heat of vaporization.

Apparatus:

Conical flask, water, hotplate, steam trap, glass tubing, thermometer, insulated calorimeter, electronic balance.

Method:

1. Find the mass of the empty calorimeter (m_{cal}) using the electronic balance.
2. Insulate the calorimeter and measure the temperature of the water (θ_I) using the thermometer.
3. Boil the water so that steam flows from the conical flask through the steam trap into the water in the calorimeter. Note that the steam trap should only be placed into the water once steam flows freely from the trap.
4. Allow the steam to cause a $20°C$ rise in temperature. Remove the calorimeter and measure the final temperature of the water (θ_F) using the thermometer.
5. Find the mass of the calorimeter plus water plus condensed steam using the electronic balance.

Calculation:

$$\text{Heat lost} = \text{Heat gained}$$
$$(ml)_{steam} + (mc\Delta\theta)_{steam} = (mc\Delta\theta)_w + (mc\Delta\theta)_{cal}$$
$$m_{steam}l_{water} + m_{steam}c_w(100 - \theta_F) = m_wc_w(\theta_I - \theta_F) + m_{cal}c_w(\theta_I - \theta_F)$$

Solve for l_{water}.

Result:
Water has a specific latent heat of vaporisation of approximately $2.3 \times 10^6\ Jkg^{-1}$.

Precautions/Sources of Error:

1. Note that the following assumptions are made:-
   (a) That the steam is at $100°C$ – it may be at a higher temperature.
   (b) That the heat given out by the steam in condensing is the same as that required to change the water back into steam.
   (c) That no heat is lost or gained from the surroundings.
2. Lage the calorimeter well to prevent heat being lost or gained from the surroundings.
3. "Dry" the steam by passing it through a steam trap. This will ensure that only steam and no water will enter the calorimeter.
4. Stir well before reading the final temperature.
5. If you pre-cool the water before adding the steam, the final temperature will be around room temperature. Thus less heat will be lost to the surroundings than if the water was at a higher temperature.

6. Leave the water boil for a few minutes to get rid of the oxygen and other gases from the water. These gases make the result less accurate as they have different specific heat capacities.

B.3 Light and Sound Experiments

B.3.1 To Measure the Speed of Sound in Air

Theory:
This experiment is based on resonance, i.e. the length of an air column in a pipe closed at one end is an odd number of quarter wavelengths when resonance occurs. If a tube of diameter d is used and the distance from the top of the water to the top of the resonance tube is ℓ, then the wavelength of the sound λ is given by

$$\lambda = 4(\ell + .3d)$$

where the $.3d$ term is called the *end correction* term. It accounts for the fact that the antinode does not end exactly at the edge of the tube, but extends beyond it slightly. The speed of sound in air is thus computed from the forumla

$$v = f\lambda$$

Apparatus:
Resonance tube, graduated cylinder, water, tuning forks, metre stick, Vernier callipers.

Method:

1. Measure the internal diameter of the resonance tube (d) using the Vernier callipers.
2. Fill the graduated cylinder with water and immerse the resonance tube so that the portion of tube above the surface of the water is quite small.
3. Strike the tuning fork of highest frequency and position it above the pipe. Note that the frequency of the tuning fork (f) is written on it.
4. Raise the pipe until resonance occurs in the pipe. Measure the length (ℓ) using a metre stick.
5. Repeat the process using tuning forks of different frequencies to get a number of readings.
6. Calculate the speed of sound in air using $c = 4f(\ell + .3d)$.

Result:
A plot of ℓ vs. $\frac{1}{f}$ gives a straight line (not through the origin). $c = 4 \times \text{slope}$ since

$$c = 4f(\ell + .3d) \Longrightarrow \ell = \frac{c}{4}\left(\frac{1}{f}\right) - 0.3d$$

so that $-0.3d$ is the y-intercept and $c = 4 \times \text{slope}$.

Alternatively one can simply use the formula on each of the readings and then get the average of all the c values obtained.

Conclusion:
The speed of sound in air is approximately 340 ms^{-1}.

Precautions/Sources of Error:

1. Do not use tuning forks of too high a frequency. If you do, the wavelength is decreased and therefore the distance between the antinodes is shorter because they are closer together and therefore harder to measure – antinodes could easily be skipped. It is also difficult to set up a standing wave in a tube when the wavelength is very short.

2. If the water in the cylinder is replaced by another liquid of different density, parrafin say, it would make no difference since almost all of the sound is reflected from the surface.

3. One method for the detection of nodes and antinodes is the fact that a note is given out when resonance occurs.

B.3.2 To Investigate the Variation of the Frequency of a Stretched String or Wire with Length and Tension

Theory:
This experiment is based on the fact that the frequency of a stretched string:

- is inversely proportional to its length: $f \propto \frac{1}{\ell}$
- is directly proportional to the square root of the tension: $f \propto \sqrt{T}$

Apparatus:
Sonometer, paper rider, spring balance, tuning forks, metre stick.

Method: Variation with Length (Tension Fixed)

1. By moving the bridges of the sonometer, make the wire as long as possible.

2. Strike the tuning fork of highest frequency and position it on the fixed bridge. The frequency (f) of the tuning fork is written on it.

3. Slowly slide one of the movable bridges until resonance occurs in the wire. Measure the distance (ℓ) between the bridges using a metre stick. The paper rider will jump off the wire when resonance occurs.

4. Repeat using tuning forks of different frequencies to get a number of readings.

Result:
A graph of f vs. $\frac{1}{\ell}$ is a straight line through the origin.

Conclusion:

The frequency of a stretched string is inversely proportional to its length, provided the tension and mas per unit length are constant.

Method: Variation with Tension (Length Fixed)

1. By moving the bridges, make the wire about $\frac{1}{3}$ of its maximum length. The length must not be changed for the rest of the experiment.

2. Strike the tuning fork of highest frequency and position it on one of the bridges. The frequency (f) of the tuning fork is written on it.

3. Vary the tension (T) of the wire by adjusting the tension control key until resonance occurs.

4. The paper rider will jump off the wire when resonance occurs. Measure the tension using a spring balance.

5. Repeat the process using tuning forks of different frequencies to get a number of readings.

Result:
A graph of f vs. $\sqrt{T}$ is a straight line through the origin.

Conclusion:
The frequency of a stretched string is directly proportional to the square root of its tension, provided the length and mas per unit length are constant.

Precautions/Sources of Error:

1. For the first part of the experiment, tension should be fixed, while for the second part length should be fixed.

2. Ensure to place the paper rider at the midpoint between the two brudges as this is where the antinode will be located.

3. Ensure to avoid parallax error when using the metre stick to measure lengths.

4. One could repeat each step a number of times to compute an average length/tension at each frequency.

B.3.3 To Measure the Focal Length of a Concave Mirror

Theory:
Using the formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, the focal length of a concave mirror is obtained by direct observation of the image produced.

Apparatus:
Concave mirror, screen, ray box with cross threads, metre stick.

Method:

1. Find the approximate focal length of the mirror by focusing the image of a distant object on a piece of paper. The distance from the mirror to the paper is the focal length.

2. Place the ray box outside this approximate focal length and focus a clear image of the cross hairs onto a screen using the mirror. Measure the distance from the ray box to the mirror (u) and the distance of the screen from the mirror (v) using the metre stick.

3. Repeat the procedure a number of times to get several readings.

Results:
Compute f from the formula: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. Alternatively, a graph of $\frac{1}{v}$ vs. $\frac{1}{u}$ will cut the axes at points equidistant from the origin. This distance is $\frac{1}{f}$; simply invert this to find f.

Precautions/Sources of Error:

1. Ensure to avoid parallax error when taking measurements using the metre stick.

2. Ensure that when an image is formed on the screen that it is a *sharp* image.

3. One could repeat each step a number of times to find an average v fro each u.

4. Ensure to find the approximate focal length first. This allows one to place the ray box outside the actual focus so that a real image can be formed in the main part of the experiment.

B.3.4 To Measure the Focal length of a Converging Lens

Theory:
Using the formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, the focal length of a concave mirror is obtained by direct observation of the image produced.

Apparatus:
Converging lens, screen, ray box, metre stick.

Method:

1. Find the approximate focal length of the lens by focusing the image of a distant object on a piece of paper. The distance from the lens to the paper is the focal length.

2. Place the ray box outside this approximate focal length and focus a clear image of the cross hairs onto a screen using the mirror. Measure the distance from the ray box to the mirror (u) and the distance of the screen from the mirror (v) using the metre stick.

3. Repeat the procedure a number of times to get several readings.

Results:
Compute f from the formula: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. Alternatively, a graph of $\frac{1}{v}$ vs. $\frac{1}{u}$ will cut the axes at points equidistant from the origin. This distance is $\frac{1}{f}$; simply invert this to find f.

Precautions/Sources of Error:

1. Ensure to measure distance from the screen to the *centre* of the lens.
2. Ensure to avoid parallax error when taking measurements using the metre stick.
3. Ensure that when an image is formed on the screen that it is a sharp image.
4. One could repeat each step a number of times to find an average v fro each u.
5. Ensure to find the approximate focal length first. This allows one to place the ray box outside the actual focus so that a real image can be formed in the main part of the experiment.

B.3.5 To Measure the Refractive Index of a Liquid (Water)

Theory:
This experiment is based on the formula $\mu = \frac{\text{real depth}}{\text{apparent depth}}$

Apparatus:
Plane mirror, two pins, cork, retort stand and two clamps, beaker, water.

Method:

1. Place the pin at the bottom of the full beaker of water. Clamp the mirror to the stand at the top of the beaker with the reflective side facing up. Stick the pin into the cork which is clamped to the top of the stand.
2. Afjust the height of the search pin (one at the top) above the mirror until there is no parallax between its image in the mirror and the image of the pin in the liquid.
3. Measure the distance from the search pin to the back of the mirror using the metre stick. This is the apparent depth.
4. Measure the depth of the beaker, using a metre stick. This is the real depth.
5. Remove some water from the beaker and repeat this procedure a number of times to get multiple readings. Each time the mirror should be adjusted so that the back of the mirror is in line with the top of the water.

Results:
A graph of real depth vs. apparent depth will be a straight line through the origin. The slope of the line of best fit gives the refractive index of the water.

Precautions/Sources of Error:

1. Make sure the container is completely full, i.e. that the water touches the back of the mirror. Otherwise the value for the apparent depth will be incorrect.

2. Be sure to take measurements from the back of the mirror rather than the front – it is the back that actually reflects the light.

3. To get a more accurate result use beakers of different depths as otherwise it can be difficult to ensure that the back of the mirror is in line with the top of the water.

B.3.6 To Verify Snell's Law and Hence Find the Refractive Index of a Solid (Glass)

Theory:
Snell's law states that the ratio of the sine of the angle of incidence is poportional to the angle of refraction: $\frac{\sin i}{\sin r} = n$, where n is a constant referred to as the refractive index of the second medium with respect to the first.

Apparatus:
Rectangular prism, four pins, protractor, pencil, paper.

Method:

1. Place the prism on a page and trace its outline. Remove the prism and draw a normal through one side of the outline. Draw a line representing the incident ray.

2. Measure the angle of incidence (i) with the protractor.

3. Place two pins (A & B)on the incident ray. Reposition the prism as before.

4. View the pins through the prism. PLace two pins (C & D) in line with the images of A and B as seen through the prism.

5. Remove the prism and draw a line from the point of emergence to the point of incidence. This line represents the refracted ray.

6. Measure the angle of refraction (r) with the protractor.

7. Repeat the procedure a number of times to get several readings.

Results:
A graph of $sini$ vs. $\sin r$ will be a straight line through the origin. The refractive index of the glass is the slope of the line of best fit.

Conclusion:
The sine of the angle of incidence is directly proportional to the sine of the angle of refraction.

Precautions/Sources of Error:

1. Make sure to look through the glass block when arranging the pins.

2. Place a book or a hand over the glass block when lining up the pins.

3. If using a light beam instead of pins the ray of light emerging from the glass is a dividing beam because dispersion has occurred within the glass due to the fact that the glass has a slightly different refractive index for each colour. The problem is overcome by using monochromatic light, i.e. light of one colour.

4. Increasing the angle of incidence will reduce the percentage error.

B.3.7 To measure the Wavelength of Monochromatic Light

Theory:
This experiment is based on the grating equation $n\lambda = d \sin\theta$.

Apparatus:
Spectrometer, monochromatic light source, diffraction grating.

Method:

1. Look through the eyepiece of the telescope to view the image of the light source directly opposite the collimator (the zero order image).

2. Rotate the telescope left until the first bright fringe is in focus in the centre of the cross threads. Note the angle θ_L on the scale.

3. Rotate the telescope right until the first bright fringe is in focus in the centre of the cross threads. Note the angle θ_R on the scale.

4. Repeat the process, getting values of θ_L and θ_R for the second, third, and higher order images.

Calculations:

- Calculate the grating constant d from the number of lines per millimetre: $d = \frac{1}{N} \times 10^{-3}\ m$.

- For each order of image (n) subtract θ_L from θ_R to get 2θ. and then divide by 2 to get θ.

- Calculate the wavelength from the formula: $n\lambda = d \sin\theta$.

- Calculate an average value of λ.

Precautions/Sources of Error:

1. When rotating the telescope be careful not to skip one of the bright images.

2. The method for adjusting the spectrometer is as follows:-

   (a) Adjust the eyepiece until the crosswires are clearly seen;
   (b) Focus the telescope on a distant object in order to focus it for parallel light;
   (c) Illuminate the slit. Place the telescope in line with the collimator. Adjust the collimator lens until the image of the slit coincides with the crosswires;

   (d) Adjust the width of the slit;
   (e) Level the table by adjusting the levelling screws underneath.

   Once it has been adjusted, the slit must now be at the focus of the converging lens in the collimator since the telescope was originally focused for parallel light.

3. Ensure to avoid parallax error when measuring angles using the Vernier scale.

B.4 Electricity Experiments

B.4.1 To Investigate How the Resistance of a Metallic Conductor Varies with Temperature

Theory:
The resistance of a material varies with temperature. For most metals the resistance increases with temperature. However, for semiconductors, such as silicon and germanium, the resistance decreases with temperature.

Apparatus:
Coil of wire, boiling tube containing glycerol, beaker with water, hotplate, thermometer, ohmmeter.

Method:

1. Connect the ohmmeter to the boiling tube using a wire that forms a circuit. The portion of wire immersed in the glycerol forms a coil. Connect the boiling tube to the digital thermometer.

2. Measure the temperature of the coil of wire Rusing the ohmmeter.

3. Increase the temperature of the wire by $10°C$ by heating the beaker of water with the hotplate.

4. Repeat the process a number of times to get several readings.

Results:
A graph of R vs. $\Delta\theta$ is a straight line not through the origin.

Conclusion:
There is a linear relationship between the resistance of a metallic conductor and temperature.

Precautions/Sources of Error:

1. Heat slowly.

2. Never use water in the test tube as it has a very high specific heat capacity.

3. Always stir the paraffin between readings because a rise in temperature may not correspond to a rise in resistance.

4. Keep any leads away from the bunsen burners as this could add more resistance and give a false reading.

5. Ohmmeters do not measure small rises in resistance.

6. Wait for the paraffin (or glycerol) to have the same temperature as the heating coil before taking readings.

B.4.2 To Investigate the Variation of the Resistance of a Thermistor with Temperature

Theory:
The thermistor is a device used for measuring temperature. Its resistance changes uniformly with temperature: its resistance is high when cold and drops uniformly with an increase in temperature.

Apparatus:
Thermistor, boiling tube containing glycerol, beaker, water, hotplate, thermometer, ohmmeter.

Method:

1. Connect the ohmmeter to the boiling tube using a wire that forms a circuit. The portion of wire immersed in the glycerol will contain the thermistor connected in series. Connect the boiling tube to the digital thermometer.

2. Measure the temperature of the thermistor (θ) using the thermometer in the glycerol.

3. Measure the resistance of the thermistor (R) using the ohmmeter.

4. Increase the temperature of the wire by $10°C$ by heating the beaker of water with the hotplate.

5. Repeat the process a number of times to get several readings.

Results:
A graph of R vs. θ shows that as temperature increases resistance of the thermistor decreases.

Precautions/Sources of Error:

1. Make sure there is enough glycerol to cover the thermistor.

2. Heat the wire slowly, so as to ensure that the thermistor is the same temperature as the glycerol, or start at a high temperature and take readings as the wire cools.

3. The more readings one takes the more accurate the graph will be.

4. Ensure the temperature and resistance are measured simultaneously.

B.4.3 To Measure the Resistivity of the Material of a Wire

Theory:
Resistivity is the resistance of a piece of wire of unit length and unit cross sectional area. It depends on the material of the wire and may be used to compare, for example, two pieces of wire of different materials.

Apparatus:
Nichrome wire, micrometer, ohmmeter, leads and crocodile clips, metre stick.

Method:

1. Make a note of the zero error on the micrometer.
2. Measure the diameter at different points along the wire, using the micrometer. Subtract the zero error on each occasion. Compute the average diameter (d).
3. Measure the resistance of the leads when the crocodile clips are connected together, using the ohmeter.
4. Stretch the wire to remove any slackness and then connect it to the the ohmmeter using the clips.
5. Measure the distance (ℓ) between the clips using the metre stick.
6. Measure the resistance pf the wire plus clips using the ohmmeter. Subtract the value for the clips alone to get the resistance of the wire.
7. Decrease the distance between the clips and repeat the process a number of times to get several readings.

Calculations:
The resistivity is calculated using:

$$\rho = \frac{RA}{\ell} = \frac{R\pi d^2}{4\ell}$$

Precautions/Sources of Error:

1. When measuring the length, ℓ, make sure the wire is taut.
2. Measure the diamter at a number of points along the wire and then get an avergage.
3. Ensure that current flows only through the measured length of wire – use crocodile clips – and do not include the part wrapped around the terminals.
4. When measuring the resistance, keep the current small.

B.4.4 To Verify Joule's Law

Theory:
The heat produced by electric current is directly porportional to the square of the current: $H \propto \Delta\theta \propto I^2$. Note that the heat produced each time is gotten by multiplying the mass by the specific heat capacity by the rise in temperature ($H = mc\theta$). Since the mass and the specific heat capacity are constant we can say that $H \propto \theta$. Thus it is not necessary to know the mass of water used.

Apparatus:
Ammeter, heating coil, thermometer, insulated calorimeter, variable power supply, electronic balance, stirrer, water.

Method:

1. Half fill the calorimeter with a known mass of water (use the electronic balance).
2. Attach the power supply to the ammeter, the wire in the lagged calorimeter, and to the digital thermometer in order to form a circuit.
3. Measure the intitial temperature of the water (θ_I) using the thermometer.
4. Switch on the power and simultaneously start the stopwatch.
5. Measure the current (I) passing through the coil using the ammeter. Use a small current ($0.5\ A$) for the first set of readings.
6. Allow the current to flow for a fixed time (t).

Results:

- Calculate $\Delta\theta = \theta_F - \theta_I$
- Calculate I^2 from $W = I^2Rt$.
- A graph of $\Delta\theta$ vs. I^2 is a straight line through the origin.

Results:
The change in termperature is directly proportional to the current squared (Joule's law).

Precautions/Sources of Error:

1. Use a coil of manganin or constantin since the resistance of these alloys varies very little with temperature.
2. Lag the calorimeter well to prevent heat loss to the surroundings.
3. The current should be fairly high so that heating will be fairly rapid and therefore the time for heat loss small.
4. It is vital to stir before taking each temperature reading – if you don't the error involved may be up to $10°C$.
5. If the current flowed for a shorter period then $\Delta\theta$ in each case would be much smaller, thus points on the graph would be much closer, causing inaccuracies.

B.4.5 To Investigate the Variation of Current with Potential Difference for a Metallic Conductor, Filament Bulb, Copper Sulphate Solution with Copper Electrodes, a Semiconductor Diode

Apparatus:
Ammeter, voltmeter, leads, power supply with potential divider, metallic conductor, filament bulb, copper sulphate solution with copper electrodes, semiconductor diode.

Method:

1. Set up the apparatus consisting of the power source in series with the ammeter and the voltmeter in parallel with the metallic conducto/fialment bulb, etc.
2. Set the potential dividerso that there is a small voltage (1 V) across the conductor.
3. Measure the voltage V using the voltmeter. Simultaneously measure the current I using the ammeter.
4. Increase the voltage by 1 V by adjusting the potential divider and repeat the procedure to get a number of readings.

Results:

- For a metallic conductor a graph of I vs. V will be a straight line through the origin, thus $V \propto I$ in the given temperature range.
- For a filament bulb a graph of I vs. V will be a smooth increasing curve showing that as voltage increases so does current.
- For the ionic solution (copper sulphate with copper electrodes) a graph of I vs. V will be a straight line through the origin, thus $V \propto I$ in the given temperature range.
- For a semiconductor diode a graph of I vs. V will be a smooth increasing curve showing that as voltage increases so does current while in forward bias, while in reverse bias only a tiny current flows.

Precautions/Sources of Error:

1. Use a digital thermometer to get more accurate readings.
2. The more readings one takes the more accurate the plots will be.
3. Ensure that there are clean connections in all parts of the circuits.