Department of Physics

Physics Practicals

Book 1

Content

About this work

Most of this work is based on the laboratory sheets prepared by Professor Alfred Micallef. Subsequently, many others have contributed.

Experiment 1: Using the Vernier caliper

1.1. Introduction

The Vernier caliper is a measuring instrument capable of measuring lengths smaller than one millimetre. This is carried out using a specially designed scale known as a Vernier scale. Such a scale is found on many measuring instruments including spectrometers and travelling microscopes. Hence the knowledge of its use is quite important.

This experiment is meant to train you on how to read such a scale using a Vernier caliper. The laboratory demonstrator will give you a detailed tutorial on how to do it. Please make sure to understand well how to use the scale and take any notes necessary for you to remember how it works. In later experiments you will be asked to recall what you need to do in order to make other measurements.

1.2. Apparatus and setup

For this experiment you will be provided with a Vernier caliper, a metre rule, a rod of brass (which is brownish in colour), two rods of aluminium, one of which has a hole in it, a PVC tubing, and a mass balance. The apparatus does not need to be set up as only measurements using the Vernier caliper will be made.

1.3. Experimental procedure

1. Use the metre rule to measure the length of each rod and tabulate them as indicated below.

		Aluminium cylinder without hole	Aluminium cylinder with hole	PVC tube	Brass cylinder
l / m	±0.001				

Note that the stated uncertainty is based on the least count of the instrument.

2. Measure the masses of each rod and tabulate the results with those of the lengths. Note the uncertainty in the mass balance is 0.1 g. (Make sure you learn how to find the uncertainty of each instrument.)
3. Ask your laboratory demonstrator on how to use the Vernier caliper. You might need to wait for this as the laboratory demonstrator might need to help other students before he can dedicate himself to you.
4. Determine the least count and hence the uncertainty in the Vernier caliper.
5. Measure the external diameter of each rod using the Vernier caliper. You should do this at three different locations, each time taking two readings at right angles to each other. Thus you need to have a set of <u>six readings</u> for each object at the end.
6. Measure the inner diameter of the PVC tubing from both ends. You should make at least two measurements at right angles to each other at each end.

7. Measure the inner diameter of the hole in one of the aluminium rods. Remember to make at least two measurements.
8. Tabulate the results for the diameter as indicated below. Remember to include the average diameter at the end of the table.

		Aluminium cylinder without hole	Aluminium cylinder with hole		PVC tube		Brass cylinder
			Inner diameter	Outer diameter	Inner diameter	Outer diameter	
d_1 / 10^{-3} m	±0.05						
d_2 / 10^{-3} m	±0.05						

Note that the stated uncertainty is based on the least count of the instrument.

1.4. Data analysis

In this part you are going to determine the densities of the aluminium, brass and PVC. Then you will be asked to find the length of the hole.

First determine the volume of the solid aluminium rod, the brass rod and the PVC tube. For a solid circular rod the equation for the volume is,

$$\text{Volume} = \text{Area} \times \text{Height} = \pi R^2 l,$$

where R is the radius and l is the length. In order to determine the volume of PVC tubing you need to subtract the internal volume (obtained by the internal radius) from that of the total volume (obtained from the external radius).

You can now determine the density from the equation,

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}.$$

In order to present your results for the volume and the density in a nice way you should use a table. Remember that you have three materials for which to determine the density, namely aluminium, brass and PVC.

Use the density of the aluminium to calculate the depth of the hole in the given cylinder. State any assumption you have used in working out this part. Do you think this assumption will hold in practice? (*Hint*: Start by find the volume of the hole using the total volume of the cylinder and that due to the aluminium.)

Why do you think you had to read the diameter at different points and at each point you had to take readings at right angle to each other?

The objects used to calculate the density in this experiment had a regular shape, thus simplifying the procedure and the calculations. However, not all objects have such a regular shape. Propose a simple procedure that can be used to get a rough estimate of the density of an object that does not have a regular shape.

Additional information: You can take the density of PVC as $0.9\ \mathrm{g\ cm^{-3}}$. The density of the other materials can be obtained from the data book available in the lab.

Experiment 2: Using the micrometer screw gauge

2.1. Introduction

The micrometer screw gauge is an instrument that is used to measure lengths with very high accuracy. In fact the least count of the instrument is just 10^{-5} m. Such precision is attained by having a very cleverly deceived system of scales that work together. Given that in physics we often have to measure lengths that are smaller than one millimetre, such as in the case of wires, the use of such an instrument is very important.

In this experiment you will learn how to use the micrometer screw gauge and how to read its scale. The laboratory demonstrator will give you a detailed tutorial about how to use the instrument. Please make sure to understand well how to use the scale and take any notes necessary for you to remember how it works. In later experiments you will be asked to recall what you need to do in order use the instrument.

2.2. Safety precautions

- Do not move your fingers on sharp edges as you can hurt yourself.

2.3. Apparatus and setup

For this experiment you will be provided with a micrometer screw gauge, a set of aluminium disks of different height and an electronic balance. The apparatus does not need to be set up.

2.4. Experimental procedure

1. Ask your laboratory demonstrator to explain how to use the micrometer screw gauge. You might need to wait for this as the laboratory demonstrator might need to help other students before he can dedicate himself to you.
2. Determine the least count and hence the uncertainty in the micrometer screw gauge. (Make sure you learn how to find the uncertainty of each instrument.)
3. Measure the height of each disk using the micrometer screw gauge. You should do this at four different locations. Thus, at the end, you need to have a set of four reading for each disk.
4. Tabulate the results for the thickness t as indicated below.

t_1 / 10^{-3} m	t_2 / 10^{-3} m	t_3 / 10^{-3} m	t_4 / 10^{-3} m	t / 10^{-3} m
±0.01	±0.01	±0.01	±0.01	

Note that the stated uncertainty is based on the least count of the instrument.

5. Determine the mass m of each disk using the electronic balance and tabulate the results as indicated below.

t / 10^{-3} m	m / 10^{-3} kg
	± 0.1

Note that the stated uncertainty is based on the least count of the instrument.

6. Plot a graph of m on the y-axis and t on the x-axis.

2.5. Data analysis

From the equation for the density ρ and the equation for the volume of a cylinder the following equation can be derived,

$$m = \frac{\pi d^2 \rho}{4} t,$$

where d is the diameter of the disk which should be taken to be 5.075±0.001 cm.

Set the given equation in the form $Y = MX + C$ and hence determine a value for the density of aluminium.

It is also possible to find the density of aluminium using just the dimensions of one cylinder without plotting a graph. Do you think that such an experiment will give you a better, a worse or an equivalent result to that obtained in this work? Explain your answer.

In order to measure a length, the precision of the instrument we choose is related to the dimension we want to measure. Thus for example, while we could have used a meter rule to measure the thicknesses, the resultant relative uncertainty would have been too large. Hence the use of a micrometer screw gauge.

Now suppose that we want to measure the thickness of a sheet of paper. This is of the same order of magnitude of the uncertainty in the micrometer screw gauge. Can you propose a procedure that can be used in order to overcome this problem?

Experiment 3: Discharging a capacitor

3.1. Introduction

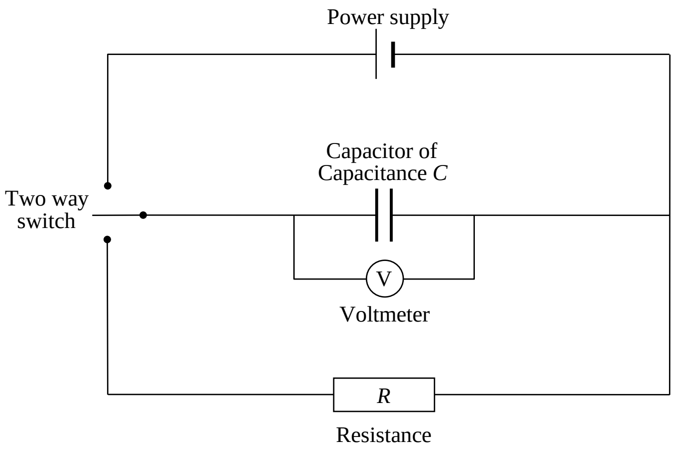
A capacitor is a device that can store charge. Due to depletion of charge the rate at which a capacitor discharges changes with time. In fact it can be shown that the process follows an exponential decay.

A very important aspect in such a problem is the time taken for discharging to take place. Given that the process occurs through an exponential decay, we can anticipate that it will take a very long time for the capacitor to be fully discharged. Since a very large number is not practical to use, we have defined the time constants T as the time taken for the voltage, current or charge to fall to $1/e$ $(\approx 37\ \%)$ of their initial value and use it as the representative quantity in defining how long the discharge process takes.

In this experiment we are going to use the measurements made during a discharge process and the definition of the time constant to determine its value.

3.2. Apparatus and setup

For this experiment you will be provided with a power supply or battery, a capacitor, a two way switch, a voltmeter, a known resistance and a stopwatch. The apparatus should be set up as shown below:



3.3. Experimental procedure

1. Setup the apparatus as shown in the diagram:
   Note I: To connect the apparatus you can follow these steps:
   - Start by connect the upper part of the circuit, i.e. the capacitor to the battery and the two way switch.
   - Then connect the resistor to the capacitor and the two way switch, i.e. complete the bottom part of the circuit.
   - Finally connect the voltmeter (multimeter) to the capacitor.

   Note II: The multimeter has to be connected by inserting one pin into the "common" and another pin where there is "V". Then set the multimeter to read up till 20 V direct current by *rotating* the function/range selector.

Note III: Before charging the capacitor make sure you have connected the positive terminal of the capacitor with the positive terminal of the battery and the negative terminal of the capacitor with the negative terminal of the battery.
Note IV: Ask the demonstrator to check the setup before switching it on.

2. Charge the capacitor by turning the two way switch upwards.
3. Note the maximum voltage across the capacitor.
4. Start discharging the capacitor by turning the two way switch downwards and at the same time start the stopwatch.
5. Note the readings on the voltmeter at intervals of 20 seconds until the voltage stops changing significantly (say until it is about 1 V or less).
6. Repeat the whole procedure again to obtain repeated readings.
7. Copy and complete the table below.

t_1 / s	V_1 / V	t_2 / s	V_2 / V	t / s	V / V
±0.3	±0.001	±0.3	±0.001		

Remember to include the voltage when $t = 0$ s. Note that the stated uncertainty in the stopwatch reflect the human reaction time. The uncertainty of the voltage it is based on the expected least count of the instrument. This might change from voltmeter to voltmeter. Ask if you are not sure.

8. Plot a graph of V on the y-axis against t on the x-axis.
9. Plot a second graph with ln(V) on the y-axis against t on the x-axis.

3.4. Data analysis

Analysis of the circuit gives that during discharge the voltage across the capacitor is related to time through the equation,

$$V = V_0 \exp\left(-\frac{t}{T}\right),$$

where V_0 is the initial current and T is the time constant. Use the definition of T to obtain a value for the time constant from the graph of V against t. Make sure to show how the measurements were taken from the graph. Check the notes or ask the demonstrators if in doubt.

Set the given equation in a straight line format using natural logarithms. Hence, find a second value for T.

Finally, T is related to the resistance R and capacitance C through the equation,

$$T = RC.$$

The factory values of the resistance and the capacitance are written on the apparatus. Use them to determine another value for the time constant. Calculate the accuracy using the theoretical value as the reference value.

Which of the three values derived should be considered to give the best result? Explain.

Discuss how capacitors are able to store charge. Explain also why the rate of discharge changes with time.

Experiment 4: The mass-spring system

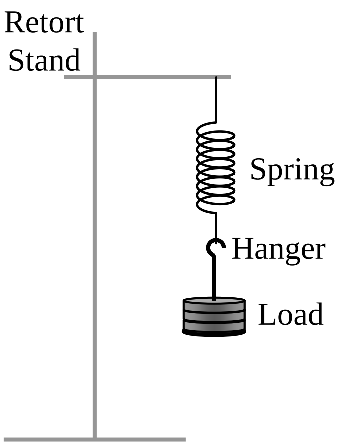
4.1. Introduction

Whenever you pull or compress a spring, this will exert a force in such a way that it will try to get back to its original length. If a mass is attached to the spring, the restoring force will cause the system to oscillate whenever the spring is pulled or compressed.

Analysis of the system using Newton's second law and Hooke's law reveals that the type of oscillations that the mass-spring system will undergo are such that the acceleration is always proportional to the displacement and is always directed toward the equilibrium position. In other words, the mass-spring system is an example of a system that can perform simple harmonic oscillations (SHM). Thus, this experiment is meant to illustrate some of the common features of systems that can perform this type of motion.

4.2. Apparatus and setup

For this experiment you will be provided with a stopwatch, a retort stand, a spring, a holder for the spring, a hanger equipped with a load of 100 g and a set of 20 g loads. The apparatus should be set up as shown below:



4.3. Experimental procedure

1. Setup the apparatus as shown in the diagram. Note that the hanger has a 100 g mass attached to it.
2. Place one 20 g mass on the hanger.
3. Set the system into small vertical oscillations.
4. Determine the time for twenty oscillations. Call this ${}_{20}t$.
5. Repeat the procedure each time increasing the mass by 20 g until you obtain a total of five readings.
6. Determine the periodic time T.
7. Tabulate the results in an appropriate manner.

m / kg	${}_{20}t_1$ / s	${}_{20}t_2$ / s	${}_{20}\bar{t}$ / s	T / s	T^2 / s^2
	±0.3	±0.3			

Note that the stated uncertainty in the stopwatch reflect the human reaction time. The uncertainty of the mass is not given.

8. Plot a graph of T^2 on the *y*-axis against *m* on the *x*-axis.

4.4. Data analysis

Using Newton's laws of motion and Hooke's law it is possible to show that the periodic time T is linked to the load m and the stiffness constant k of the spring through the equation,

$$T = 2\pi\sqrt{\frac{m}{k}}.$$

Set the above equation in the form $Y = MX + C$ and hence determine a value for the stiffness constant. Note you can take the quoted value of the stiffness constant to be 25 kg s^{-2}.

Determine also the value of the intercept (including its units). The above equation suggests that the intercept is zero. Did you confirm this from the results? If not, can you explain the difference?

In your study of physics, you might be surprised on the emphasis that is given to harmonic oscillators. The reason is that they can serve as a reasonable approximation provided that the displacement is not large. Explain why this is so (*Hint*: see for example the initial part of the section *The Harmonic Oscillator* in Griffiths J.D., *Introduction to quantum mechanics*, Prentice-Hall, 1995.)

Experiment 5: Fusing current of wire conductors

5.1. Introduction

The aim of this experiment is to investigate the relationship between the fusing current and the diameter for wire conductors.

In 1884, William Henry Preece derived a fundamental law of fusing by considering the balance of heat generation (I^2R) with the heat loss (πhdl), which is approximately valid near the fusing threshold. Here it is assumed that the wire current is constant. The symbols used represent the following, I for the wire current, R for the wire resistance, σ is the wire electrical conductivity, h is heat loss per unit area from radiation or convection, d is for the wire diameter, and l is the wire length. Thus,

$$I_f^2 R = I_f^2 \frac{4l}{\sigma \pi d^2} = \pi hdl \tag{2.1}$$

or

$$I_f = Bd^{3/2} \text{ and } B = \tfrac{1}{2}\pi\sqrt{\sigma h}. \tag{2.2}$$

where I_f denotes the fusing current. Preece's law states that the wire fusing current is proportional to the wire diameter to the three halves power. Note that this effect is independent of length (However for practical purposes the length of wire should be just loose due to internal resistances).

5.2. Apparatus and setup

D.C. voltage source, ammeter, rheostat, commercial fuse wires, circuit switch and a micrometer.

5.3. Experimental procedure

1. Connect the circuit such that the power supply, rheostat, ammeter, switch and terminal block are all in series. Note that, the terminal block is that device, across which the wire under test, is stressed.
   - Note: Please ask the demonstrator to check the circuit before you switch it on.

2. Order the wires available in decreasing diameter values. Shave off the protective skin surrounding the ends of the length of wire with sandpaper. For each length of wire used, measuring the diameter twice at one single point using a micrometer screw gauge.

3. Attach the length of wire to the terminal block, making sure to keep the switch turned off so as to avoid electric shocks.

4. With the switch turned off increase the supply voltage so that is around 4 V. Note that you should not exceed 5 V or go below 2 V as otherwise the amount of current will not be enough to fuse the wires.

5. Turn the switch on and gradually increase the current from zero, making sure to keep note of the current reading. This is equivalent to reducing the resistance of the rheostat in the power supply. Take note of the maximum current passed just before the fuse blows. This will be the fusing current I_f.

6. Repeat this procedure for the other lengths of wire.

5.4. Data analysis

The relation between the fusion current I_{F} and the diameter d of the wire can be written in the form,

$$I_{\mathrm{F}} = kd^{a}.$$

where a is a constant that according to theoretical calculations is equal to 3/2. Use logarithms to set the above equation in a straight line format. Hence, plot a suitable graph to determine the value of a that can be obtained from your measurements.

Explain the mechanism through which the electric energy of the electrons flowing through the wire is dissipated as heat. In your discussion, you should mention any factor that affects the rate of dissipation of heat.

Experiment 6: Linear and nonlinear resistances

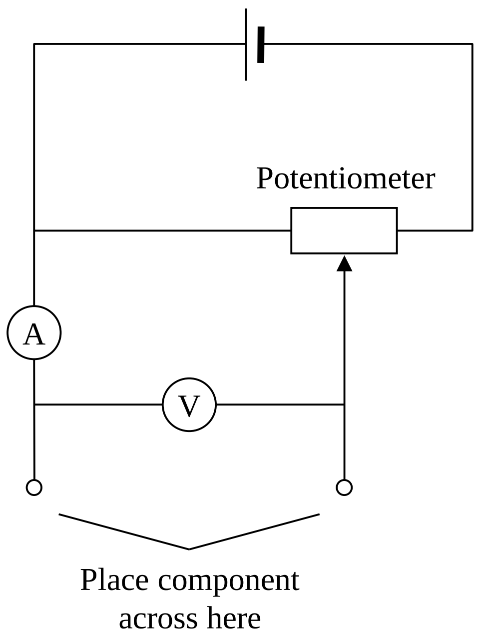
6.1. Introduction

The aim of this experiment is to determine the *I-V* characteristics of a variety of components.

Linear or Ohmic resistances obey Ohm's law independent of the magnitude of the current. In practice, materials have non-linear characteristics in the limit of very high currents, while some materials have marked non-linear characteristics even at low currents. The resistance of some other materials can furthermore be changed by external conditions, e.g. light radiation.

6.2. Apparatus and setup

12 V and 4 A DC power supply, 40 ohm and 4 A rheostat (or potentiometer) , two multimeter to be used as a voltmeter and an ammeter, a wire resistance, a 12 V tungsten filament bulb, a negative temperature coefficient (NTC) thermistor and a light-dependent resistor (0 R P12). The apparatus should be set up as shown below.



6.3. Experimental procedure

1. Set up the circuit as shown above leaving the terminals open for the devices to be tested.

2. Connection one of the available devices to the terminals.
   - Note: Please ask the demonstrator to check the circuit before you switch it on.

3. Choose at least six suitable potential differences in the available range. (Much more should be taken in the case of non-ohmic components.) By

setting the resistance such that these values are realised over the device under test, take note of the resulting current over the device.

4. Repeat the above procedure for the other devices. The LDR changes its characteristic graph depending on how much light is falling on it. Take two readings for this device, one illuminated and one when kept in the dark, i.e. it is covered in some way.

<u>Experimental Suggestions:</u>

Always start the experiment with zero volts across the load with the ammeter set to the 1 Amp range. Turn the voltage up slowly and then set the ammeter to give a readable indication on the scale (i.e. change range down from 1 A scale). **Do not overload the ammeter.**

6.4. Data analysis

Plot the IV-characteristic graph (having *I* on the *y*-axis and *V* on the *x*-axis) for each component. Hence set state which are the ohmic and which are the non-ohmic devises. Present your statements in an appropriate table format.

The resistance at a point is defined as the ratio,

$$R = \frac{V}{I}.$$

Using this definition and the IV-characteristics graphs determine:

- The resistance of the resistance wire and compare it with the one given.
- The resistance of the light bulb when the voltage is 2.5 V, 5 V, 7.5 V and 10 V.

Explain the process through which negative temperature coefficient (NTC) thermistor and light dependent diodes achieve the variation of current with voltage that you have obtained in this experiment. Describe also some practical applications for which these types of components are used.

Experiment 7: The field-effect transistor (JFET)

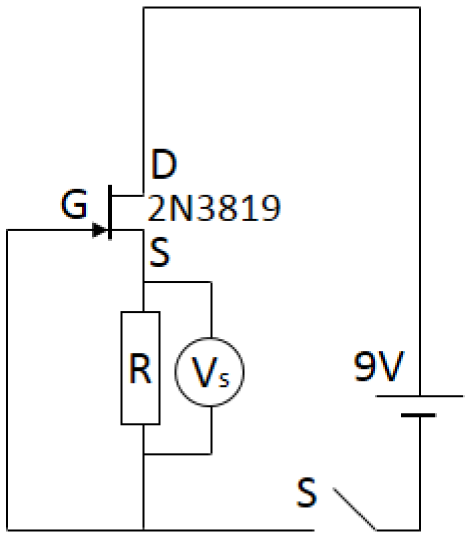
7.1. Introduction

To determine the IV characteristics of a JFET.

A junction gate field-effect transistor (JFET) is the simplest type of field transistor. Electrons flow between Source and Drain terminals, while applying a potential difference over the gate impedes this flow. Thus reducing the current.

7.2. Apparatus and setup

For this experiment you will be provided with a 2N3819 JFET, a 9 V battery, a resistance box and a multimeter. The apparatus is to be set up as shown below.



7.3. Experimental procedure

1. Connect the JFET circuit shown in the figure, keeping the switch turned off while doing this.
   - Note: Please ask the demonstrator to check the circuit before you switch it on.

2. When you are sure that the circuit is connected correctly, turn the switch on. Vary the resistance over the range 100 to 10000 Ω. Take readings every 100 Ω between 100 Ω to 1000 Ω and then at every 1000 Ω up to 10000 Ω.

3. Disconnect the battery and the rest of the circuit when the readings are taken.

4. Determine the current I_d by finding the ratio of V_S and R for each resistance reading, where I_d is the current flowing across the resistor.

Safety:

Connecting the FET incorrectly will short circuit the transistor and burn it out thus making it useless. **Be sure that it is connected correctly before closing the circuit**. The diagram in Fig.(1.4) shows how the gate (G), drain (D) and source (S) should be connected. Connect the circuit exactly as shown, if in doubt ask a technician or demonstrator to check the circuit setting.

7.4. Data analysis

Theory suggests that,

$$I_d \propto \left(V_T - V_S\right)^a$$

where V_T is the source-drain potential difference when I_d is zero and $a = 2$. In order to investigate this relation, first plot a graph of V_S against I_d. Draw by hand a suitable graph and extrapolate it to $I_d = 0$ A in order to obtain a value for V_T. Then use the value of V_T to plot a second graph from which you can obtain a value for *a*.

Explain in detail how a JFET works.

Experiment 8: The surface tension of water

8.1. Introduction

To determine the surface tension of water and Ethanol by the drop-weight and break-away methods.

The drop-weight method involves letting a drop fall at the end of a tube by means of gravity alone. Rayleigh showed that an approximation for surface tension γ is given by the following formula

$$\gamma = \frac{mg}{3.8r}, \tag{8.1}$$

where m is the mass of the drop, r is the inner radius of the tube and g is the acceleration due to gravity. It is important that other sources of drop formation are subdued.

The break-away method on the other hand is conducted by first submerging a metal ring into a liquid and then putting it out. The breakaway force is then measured by subtracting the weight from the maximum force read when the ring breaks from the surface. Together with the ring radius this can be used to determine the surface tension of the liquid as explained below.

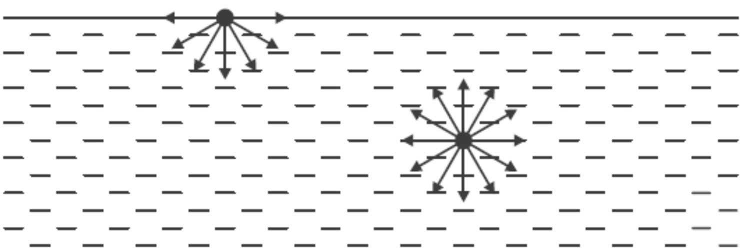


Figure 7.1: Water molecules under tension.

The surface tension of a liquid arises by means of attractive forces due to adjacent molecules to its sides. It occurs due energy being supplied to move molecules to enlarge the surface. Its definition is given by the maximum energy supplied ΔE to move the molecules per unit surface area ΔA at constant temperature, i.e.

$$\gamma = \frac{\Delta E}{\Delta A}.$$

The maximum energy supplied can be related to the breakaway force by means of the well-known relation

$$F = \frac{\Delta E}{\Delta x}.$$

The surface area change can be calculated by noting that a thin layer of water forms when the ring is pulled up slowly. The outside and inside surface of the liquid therefore changes by

$$\Delta A = 2 \times 2\pi R \Delta x.$$

Hence the surface area can be calculated through the equation,

$$\gamma = \frac{\Delta E / \Delta x}{\Delta A / \Delta x} = \frac{F}{4\pi R}.$$

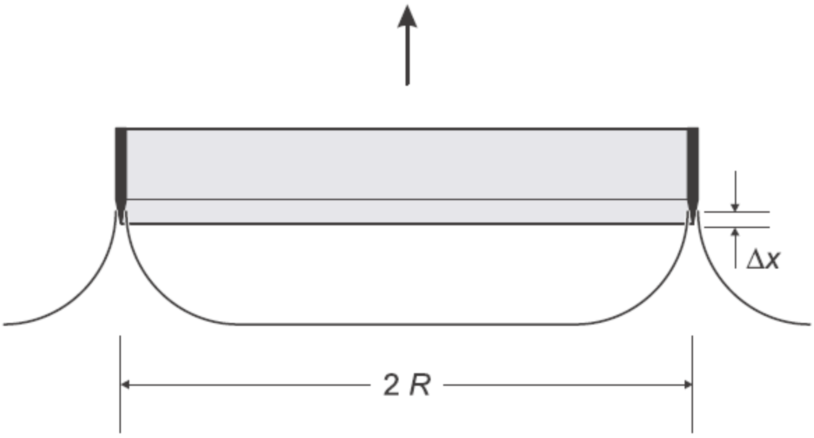


Figure 7.2: Thin layer formed around ring.

8.2. Apparatus and setup

Drop-weight method: Funnel to which is attached by means of rubber tubing a short glass tube of diameter 4 or 5 mm, screw clip, beaker and a travelling microscope.

Break-away method: Dynamometer, vernier callipers, dish, stand, metal ring with hook, adjustable stand.

8.3. Experimental procedure

1. Measure the temperature of the fluid.

First the drop-weight method will be conducted. This part involves the pipe with the funnel attached on top.

2. Close the stopcock at the middle of the pipe. Place water in the funnel at a rate which allows for a drop to fall every 15 s or so. This is to ensure that drop formation is due to gravity alone. The drop should be allowed to form slowly.

3. Use the beaker to measure the average mass of a drops (let 20 or 30 drops fall).

4. Measure the mean internal diameter of the tube using the travelling microscope. The Rayleigh equation can later be used to find the surface tension.

Next the break-away method will be employed. This can be found next to the drop-weight apparatus.

5. Determine the diameter of the ring using the vernier callipers

6. Fill the beaker with water and place on the adjustable stand

7. Attach the ring onto the end of the dynamometer such that the ring is horizontal

8. Elevate the adjustable stand until the ring is completely submerged

9. Cautiously lower the stand taking note of the maximum downward force on the dynamometer

10. The surface tension can then be determine.

8.4. Data analysis

Use the given equations to determine a value for the surface tension for each method. Note that in order to calculate the accuracy you should use linear interpolation in order to obtain the surface tension at the working temperature of the experiment.

Explain how surface tension arises. In your discussion explain why the shape of the water droplet in the weight drop method is expected to be spherical.

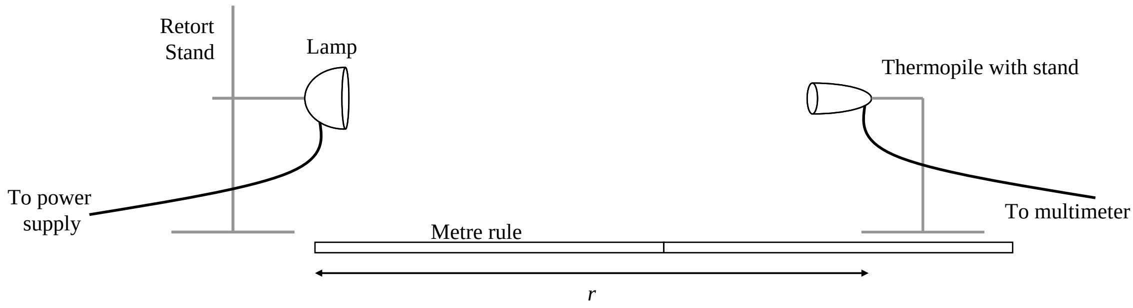
Experiment 9: Inverse square law of radiant energy

9.1. Introduction

The inverse square law simply states that a quantity I is inversely proportional to the square of the distance r from some fixed point. In physics there are many laws that follow this relation including Newton's law of gravitation and Coulomb's law of electrostatics. In this work we are going to investigate how this law applies to the energy radiated from a lamp decreases with distance from the source.

9.2. Apparatus and setup

For this experiment you will be provided with a retort stand, two metre rules, a lamp together with a holder, a thermopile (that is used to measure heat) complete with stand, a multimeter and a power supply. The apparatus should be set up as shown below:



9.3. Experimental procedure

1. Setup the apparatus as shown in the diagram. Make sure that the thermopile and the lamp are aligned.
2. Set the multimeter to read direct current with a maximum value of 200 mV.
3. Switch on the lamp.
4. Set the distance between the lamp and the thermopile r to 2 m using the metre rules provided. Record this distance.
5. Measure the maximum voltage recorded on the multimeter. You will have to wait a couple of minutes before taking the reading.
6. Decrease r by 10 cm and repeat Steps 4 and 5. Make sure you only move the thermopile as moving the lamp might break the filament.
7. Repeat Step 5 until the thermopile cannot be moved any further.
8. Then repeat the whole procedure this time increasing the distance r by 10 cm.

9.4. Data analysis

Theory indicates that the voltage decreases with distance according to an inverse square law,

$$V \propto \frac{1}{r^a},$$

where $a = 2$. Hence, plot a suitable graph to show that this relation hold. Hence, determine a value for *a* from your measurements.

Explain why:

- You needed to wait some time in Step 5.
- It is better to take one set of measurements by decreasing the distance and another one by increasing the distance between the lamp and the thermopile rather than having two set where the distance is only increase or decreased.

Do you results *proof* that the inverse square law is obeyed? Discuss this by making reference to the scientific method. (*Hint*: Check Chapter 1 of your notes.)

Experiment 10: The Young's modulus of a beam

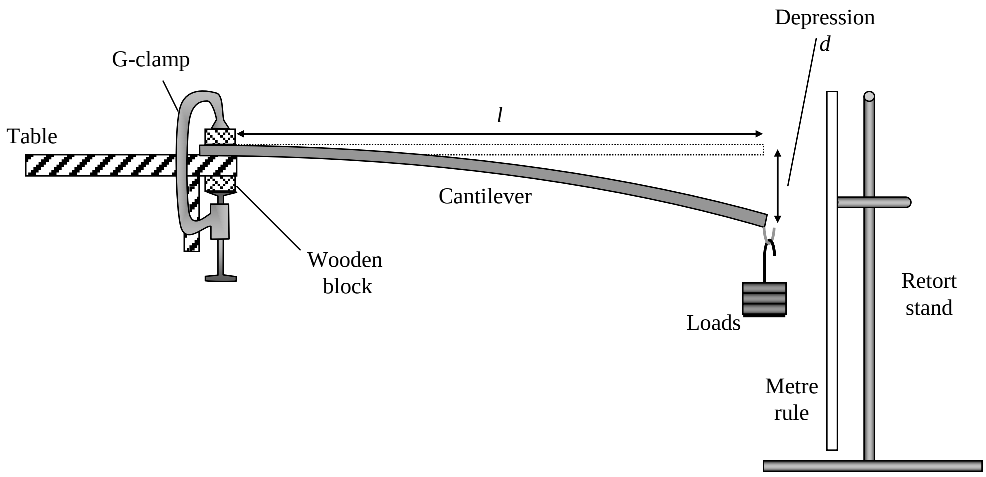
10.1. Introduction

A cantilever is a beam that is fixed at one end but is able to move at the other end. Such structures are widely found especially in the buildings. A simple example is a skyscraper. Apart from this it is used in balconies and bridges. Referring to aeroplanes, the wings and the tail can be modelled as cantilevers.

Given its wide usage, it is important to investigate its properties. In this experiment the behaviour of a wooden beam that is anchored at one end will be investigated. The work will consider how much the beam bends for a given load. This will lead to the determination of the Young's modulus, a very important parameter in elasticity that gives an idea of how stiff the material is. (Stiffness refers to how difficult it is to deform – change the shape of – an object.)

10.2. Apparatus and setup

For this experiment you will be provided with a retort stand, a beam made of oak to serve as cantilever, a metre rule, a micrometer screw gauge, a Vernier caliper, two wooden blocks, a G-clamp, a hook, a hanger and a number of 20 g loads. The apparatus should be set up as shown below:



10.3. Experimental procedure

1. Setup the apparatus as shown in the diagram. Make sure that the metre rule is vertical.
2. Set the length of the cantilever l to half a metre.
3. Record the initial position of the cantilever without loads (but with the hook and the hanger attached). Call this x_0.
4. Place a load of 20 g on the hanger and record the new position x.
5. Repeat Step 4 until you have obtained a total of five sets of readings.
6. Repeat the procedure for unloading.

7. Measure the thickness t of the cantilever at three points using the micrometer screw gauge and tabulate your results including the uncertainty. Remember to calculate the average value.
8. Measure the width w of the cantilever at three points using the Vernier caliper and tabulate your results including the uncertainty. Remember to calculate the average value.

10.4. Data analysis

Elasticity theory gives that the depression $d = |x - x_0|$ is related to the applied mass by the equation,

$$d = \frac{4mgl^3}{Ewt^3},$$

where g is the acceleration due to gravity that should be taken equal to $9.81\,\mathrm{m\,s^{-2}}$ while E is a constant called the Young's constant. Set the above equation in a straight line form and plot the corresponding graph. Hence calculate the value for E.

Explain why you have been asked to use a metre rule to measure the length, a vernier to measure the width and a micrometer screw gauge to measure the thickness rather than using the metre rule to measure all these lengths.

A number of structures that we use can be thought of as cantilevers. Discuss the use of a number of these structures.

Experiment 11: The Young's modulus of a wire

11.1. Introduction

To determine Young's modulus of a thin wire using Gravesend's method.

11.2. Apparatus and setup

For this experiment you will be provided with a wire (thinned copper), a set of 20 g masses, a travelling microscope, a metre ruler and a hanger.

11.3. Experimental procedure

1. Place the hanger in the middle of the stretched wire.
2. Align the cross wires of the moving telescope with the point of contact between the hanger and the wire.
3. Record the position x_0 of the moving telescope.
4. Place a mass m on the hanger and use the moving telescope to measure the new position x of the contact point.
5. Repeat Step 4 for all the given masses.
6. Repeat the procedure for unloading.
7. Measure the length L of the wire.
8. Measure the diameter d of the wire at three different position, each time taking two readings at right angles to each other.

11.4. Data analysis

Newtonian mechanics and elasticity theory can be used to show that for the system under consideration the following equation holds,

$$\frac{m}{y} = \frac{8\pi r^2 Y y^2}{gL^3} + \frac{4T_0}{Lg}$$

where $y = |x - x_0|$ is the depression of the wire due to the applied mass, g is the acceleration due to gravity that is taken to be $9.81\ \mathrm{m\ s^{-2}}$, r is the radius of the wire, T_0 is the initial tension in the wire and Y is the Young's modules of the material. Set the above equation in a straight line format and plot the corresponding graph. Hence, find a value for the Young's modulus of the material.

The above equation has been derived under the assumption that assumes that the force is proportional to the extension, i.e. that Hooke's law holds. However, if you stretch a wire beyond a certain point it will distort. Hence, Hooke's law has a limited range of applicability. Explain the various phases a stretched wire passes through until it finally snaps. Link these to what happens at the atomic or molecular level. Your discussion should include various materials such as a metal, glass, rubber and a polymer such as polythene.

Experiment 12: The line spacing of a diffraction grating

12.1. Introduction

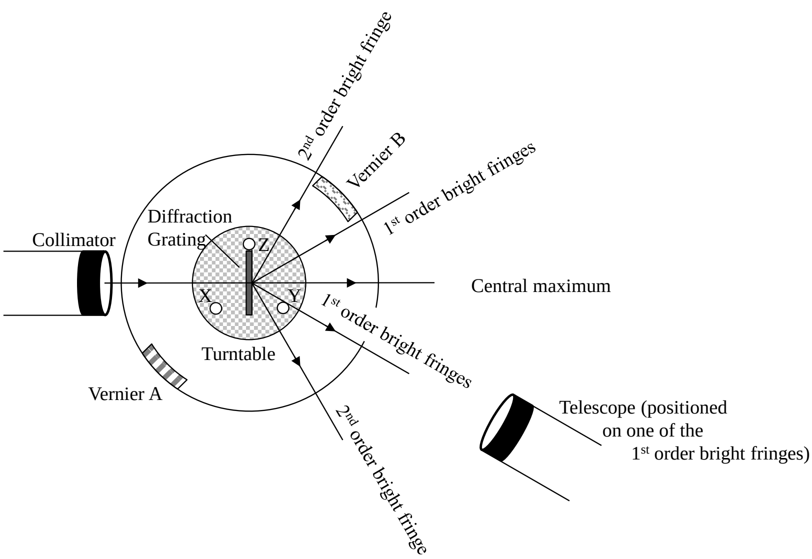
By now you should be familiar with Young's double slit experiment, whereby, coherent light passing through two slits interferes to produce fringes. However, there is nothing special about two slits and in fact interference can be observed when coherent light passes through any number of slits.

The particular case when the number of slits is very large is of special practical importance in physics. It turns out that when light passes through such an instrument, which is called a diffraction grating, the angular separation between successive maxima (i.e. positions of constructive interference) depends not only on the wavelength but also on the spacing between the slits. Thus, no matter how close two distinct wavelengths might be, in principle, it should still be possible to separate them by adjusting the distance between the splits.

This experiment is meant to show you how you how to use a diffraction grating. Rather than using the diffraction grating to identify the wavelengths of a given beam, you will use known wavelengths to determine the distance between the slits. In the process, you are also going to learn how to use a spectrometer.

12.2. Apparatus and setup

For this experiment you are provided with a mercury lamp with power supply, a spectrometer and a diffraction grating with a mounting. In order to help you read the scale on the spectrometer, you are also being provided with a lens and a lamp.



12.3. Experimental procedure

Important note: The detailed use of the spectrometer is discussed in your notes. You are expected to read through this information at home in preparation for the experiment. <u>Please note that while you are setting up the spectrometer you are expected:</u>

- To ask one of your tutors to check that you have properly focused the telescope on the Chemistry building.
- Not to change the settings of the collimator (which includes the slit).

Marks will be allocated for properly following the instructions given.

1. Adjust the focus of the eyepiece and the moving telescope. (Detailed instructions are found in your notes.) As your tutor to check the focusing of the telescope before proceeding.
2. Position the diffraction grating perpendicularly to the collimator. (Detailed instructions are found in your notes.)
3. Align the moving telescope with the collimator until the central maximum is in the field of view. This should have the same colour as the lamp.
4. Move the telescope to the right and ensure that you see the fringes coloured violet, blue, green and two yellow-orange in the stated order.
5. Repeat for the left hand side.
6. Moved the moving telescope until the first order violet bright fringes is at the centre of the cross-wires as shown in the figure. Then lock the telescope in position and fine adjust if required.
   Note: There will be more than one violet bright fringes. You should only consider the one that is farthest away from the central maximum.
7. Note the readings on the two telescope's verniers. Let these be A and B.
8. Unlock the telescope and rotate it until the other first order violet bright fringe is in the centre of the cross-wires. (Note that a number of violet lines could be observed. In such a case you should choose the one farthest from the central maximum.) Lock the telescope in position and fine adjust if required.
9. Record the new positions of the verniers, says A' and B'. Note A and A' correspond to the same vernier scale as do B and B'.
10. The angular difference between A and A' or B and B' correspond to 2θ, where θ is the angle between the central maximum and bright fringe. This gives two reading for θ as,

$$\theta_1 = \frac{|A - A'|}{2} \text{ and } \theta_2 = \frac{|B - B'|}{2}.$$

    Note: It may occur that on moving the telescope the reading exceeds $360°$ or goes below $0°$. In such cases you should add or subtract $360°$ as necessary to determine a value for θ_1 or θ_2. You can easily determine if this is the case if θ_1 and θ_2 are not approximately equal.
11. The average angle between the central maximum and the fringe can now be found as,

$$\overline{\theta} = \frac{\theta_1 + \theta_2}{2}.$$

12. Repeat the procedure for all the first and second order of coloured fringes.
13. Tabulate all the results using the format degree and minutes. The format degrees, minutes and seconds will also be accepted.

12.4. Data analysis

An analysis of diffraction grating shows that the wavelength λ, the order *n*, the spacing between the slits *d* and the angle of deviation θ are related through the equation,

$$n\lambda = d\sin(\theta)$$

Set the equation in the form $Y = MX + C$ and plot the corresponding linear graph. Value for the wavelength can be found in the table below.

Colour	Wavelength / nm
Violet	435.8
Blue	491.6
Green	546.1
Yellow-orange	577.0
Yellow-orange	579.1

Use the graph that you have plotted to find a value for *d*. Hence, determine the number of lines per millimetre *N* of this diffraction grating.

When we view a mixture of blue and yellow light, the resultant colour that we see is green. Thus, the question naturally arises whether the colour green exist or is simply a mixture of two colours? Discuss this in relation to the experiment that you have just conducted.

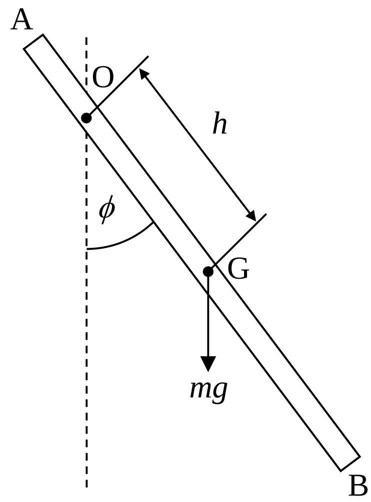
Experiment 13: The compound pendulum A

13.1. Introduction

To investigate the properties of a compound pendulum.

13.2. Apparatus and setup

For this experiment you are provided with an iron bar that will be used as a compound pendulum, a stopwatch and two types of pivots.



13.3. Experimental procedure

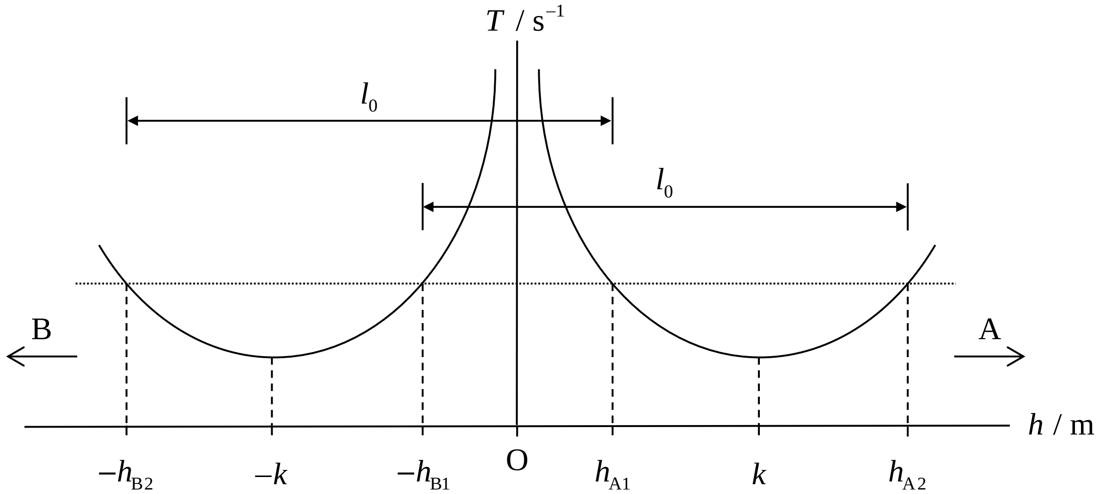
1. Find the centre of mass G of the iron bar by balancing it on the appropriate pivot. Mark its position using a piece of chalk.
2. Attach the second pivot to the iron bar at a distance of around 5 cm from one end.
3. Set the compound pendulum into small planar oscillations about the pivot point O and measure the time for twenty oscillations.
4. Hence determine the periodic time.
5. Decrease the distance h between the pivot point and G by 5 cm and repeat Steps 2 and 4.
6. Repeat Step 5 until you about 5 cm from the other end. Note that you should take h to be positive on one side of G and negative on the other. Also, you will need to turn the bar upside down each time you move across G.
7. Measure the length L of the rod.

13.4. Data analysis

Analysis of the compound pendulum indicates that the periodic time T is related to the distance from the centre of mass through the equation,

$$T = 2\pi\sqrt{\frac{k^2+h^2}{gh}} = 2\pi\sqrt{\frac{l_0}{g}}$$

where g is the acceleration due to gravity, k is the radius of gyration, i.e. the distance from the pivoting a point mass needs to be in order to have the same moment of inertia and $l_0 = \left(k^2+h^2\right)/h$ is the equivalent length a simple pendulum would have in order for it to have the same periodic time.



Start by plotting a graph of a graph of T against h as shown above. This will have two branches, one for the side GA (which has been assigned positive values of h) and one for the side GB (which has given negative values of h).

Now it is easy to see from the definition of l_0 that provided $h \neq 0$,

$$h^2 - hl_0 + k^2 = 0.$$

This is a quadratic in h, that has two roots, namely,

$$h_1 = \tfrac{1}{2}l_0 + \tfrac{1}{2}\sqrt{l_0^2 - 4k^2} \text{ and } h_2 = \tfrac{1}{2}l_0 - \tfrac{1}{2}\sqrt{l_0^2 - 4k^2}.$$

Thus for each value of the length l_0 there are two values of h that would give the same periodic time. However, due to the square root in the expression for T there will effectively be four such roots as shown in the figure above. Also shown is the equivalent length l_0 that is obtained by combining the results from the two branches.

Draw a line parallel to the h-axis and determine a set of four roots h_i. Knowing the roots, allows us to write,

$$h^2 - hl_0 + k^2 = \left(h - h_1\right)\left(h - h_2\right) = 0.$$

From this it easily follows that,

$$k = \sqrt{h_1 h_2},$$

where the roots h_1 and h_2 are paired so that they have the same sign, i.e. $h_1 h_2 > 0$, or equivalently, they are within the same branch. Use this equation to determine two values for *k*. Estimate the uncertainty in their values by using the grid spacing to obtain the uncertainty in each h_i.

The graph shows that the periodic time reaches a minimum when $h = k$. This follows from the fact that for $h^2 - hl_0 + k^2 = 0$ to have real roots the discriminant $\sqrt{l_0^2 - 4k^2} \geq 0$. Use this information to obtain another pair of values for *k* together with their uncertainty.

Plot a second graph of $|T^2 h|$ against h^2 and hence determine another value for *k*. Finally, if the rod is perfectly uniform, then it can be shown that the radius of gyration can be found from,

$$k = \frac{L}{\sqrt{12}},$$

where *L* is the length of the rod. Use this equation to determine another value for *k*. Take this value to be the one expected and compare with the others. Hence determine if the rod can be considered as uniform.

In this experiment, you should have seen that if the bar used for a compound pendulum is not uniform, the theoretically predicted value of *k* would be different from the real one. This in turn would affect the expected periodic time of the pendulum. Such differences between predicted and real values can lead to inaccuracies if the pendulum is used to measure time. In fact, while the introduction of pendulums in clocks managed to improve time keeping in mechanical clocks, there were practical limitations that limited their accuracy. Discuss some of these practical limitations. Where possible, indicate how they were addressed.

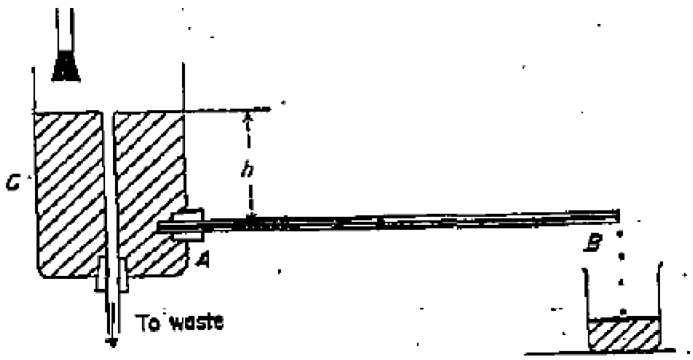
Experiment 14: Poiseuille's formula

14.1. Introduction

To determine the coefficient of viscosity for water.

14.2. Apparatus and setup

For this experiment you are provided with a constant head device, a length of capillary tubing, beaker, a retort stand, a metre ruler, a thermometer, a balance and a travelling microscope. A schematic illustration of the setup is shown below,



14.3. Experimental procedure

1. Setup the apparatus as shown making sure to set the water flow such that it will be suitable for all the heights to be considered during the experiment, i.e. make sure that water will flow and not drop for at least six height (not necessarily regularly spaced). Remember that the flow of water should be due to the pressure and not the gravitational pull on the water, for this reason avoid a low rate drop flow and aim for a fast drop flow. The stopcock should be set once to help in this need but it cannot be readjusted after the experiment has begun. If this is readjusted at any point during the experiment then the data must be discarded and the experiment started again

2. By raising or lowering the constant head apparatus, the head of water is adjusted so that the water emerges slowly as drops from B. Note that a little grease smeared over the end of the capillary tube will prevent the water running back along the outside of the tube. The water is collected in a pre-weighed beaker, and the *volume* flow rate determined by weighing the amount of water collected in a set time (the same for all measurements). The pressure head h is also measured

3. Take at least six volume flow rate readings, taking note of their respective heights by measuring the height of both components from the common table.

4. Note the temperature before and after each measurement.

5. The length l of the capillary tube is to be measured.

6. Use the travelling microscope to determine the diameter d of the tube. Hence determine a value for the radius r.

14.4. Data analysis

Analysis of the static fluid motion give following equation, called Poiseuille's formula, for the system under consideration.

$$Q = \frac{P\pi r^4}{8\eta l},$$

where Q is the volume flow rate of water through capillary tube, η is the coefficient of viscosity and P is pressure difference between the pressure head and the outlet of the capillary that can be calculated using $\rho gh,$ with g being the acceleration due to gravity taken to be $9.81\,\mathrm{m\,s^{-2}}$ and ρ is the density of water that can be taken to be $1\,\mathrm{g\,cm^{-3}}$.

Set the above equation in the form of a straight line and plot the corresponding graph. Hence, determine the coefficient of viscosity η. Note that the viscosity depends on the temperature. You should hence compare the experimental value with the one expected for the average temperature of water during the experiment. In case your temperature lies between two quoted values, you can use linear interpolation, i.e. you should assume that the viscosity varies approximately linearly with temperature between the quoted values. (*Hint*: You need to find the straight line $y = mx + c$ that passes through the end points of the interval. Since you have two unknowns, m and c, you can set up two equations using the value of the viscosity at the end points.)

What is the viscosity of a fluid? How does it arise?

Experiment 15: Calibration of thermocouples

15.1. Introduction

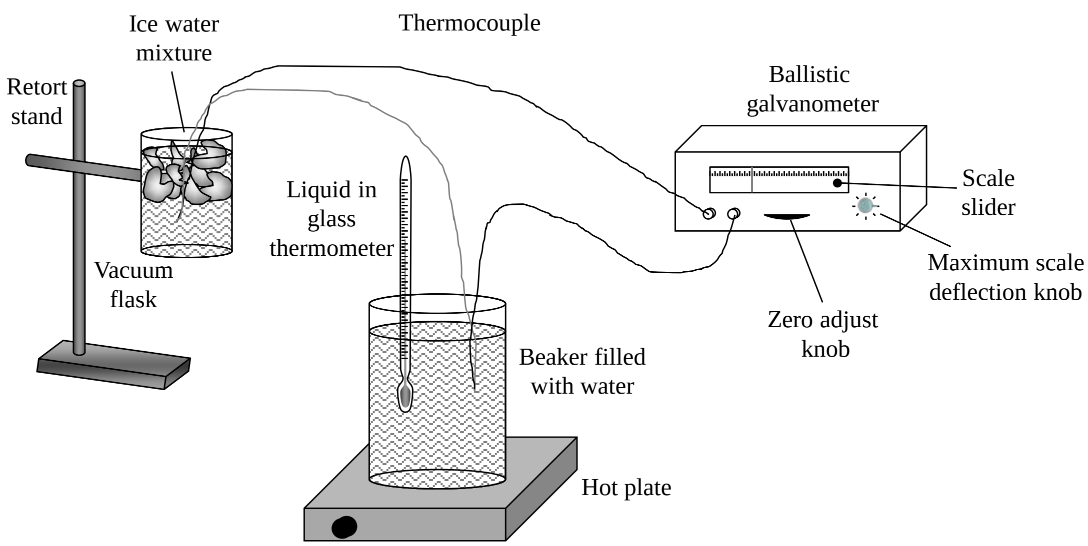
A thermometer is an instrument that can measure temperature. Such instrument needs to rely of a physical property that changes whenever there is a temperature change. This property that changes is called a thermometric property.

There are various properties that can be used to build thermometers. One that is of very practical importance relies on the establishment of a potential difference between the ends points of two connected wires that are made of different materials when these are placed at different temperatures. The resultant thermometer is called a thermocouple.

One of the disadvantages of a thermocouple is that the measured potential difference needs to be converted in some way to an equivalent temperature. There are various ways of doing this. However, in this experiment a very simple approach will be taken. This consists in the setting up of a calibration curve relating the temperature with potential difference. The technique that will be used is commonly used to calibrate instruments for which a direct reading cannot be obtained.

15.2. Apparatus and setup

For this experiment you will be provided with two wires made of different materials that will be used a thermocouples, a ballistic galvanometer, a retort stand, a vacuum (Dewar) flask, a beaker, water, ice, a liquid in glass thermometer and a hot plate. The apparatus is to be set up as shown below.



15.3. Safety precautions

- Make sure to keep your hand off heated parts.
- Make sure that no water is spilled over electronic components.
- Make sure that your hands are dry before touching any electronic component.

15.4. Experimental procedure

1. Set up the apparatus as shown above where initially both junctions should be placed in the ice-water mixture.
2. Move the scale slider so as to set the scale to zero at this point.
   Note 1: The ballistic galvanometer should already have been set so as to have a maximum scale reading of 5 mV. Do not change this setting.
   Note 2: The ballistic galvanometer is very sensitive and can be easily broken if you move the indicator beyond its scale. For this reason you should never touch the zero adjust knob.
3. Place one of the junctions in the beaker filled with water.
4. Note the temperature θ on the liquid in glass thermometer and the voltage V on the ballistic galvanometer. In the case of the voltage, read the bottom scale (which has a maximum of 50) and adjust the value in accordance with the maximum scale reading.
5. Switch on the hotplate
6. Stir the water with the liquid in glass thermometer to ensure a uniform temperature.
7. Note the readings on the liquid glass thermometer every $5\ ^\circ\mathrm{C}$ together with the corresponding reading on the ballistic galvanometer until you reach boiling point.
8. Replace the boiling water with cold water and take a second set of measurements.

15.5. Data analysis

Start by plotting a graph of voltage against temperature. The voltage across the junctions should vary linearly in this region. This will allow you to fit a straight line. Provide the gradient and the intercept of such line. Hence, use them to determine,

- The temperature when $V = 2.5\ \mathrm{mV}$ and
- The voltage when the temperature is $50\ ^\circ\mathrm{C}$.

Use the uncertainty in the gradient and the intercept to determine the uncertainty in the calculated quantities.

Explain why you have been asked to replace the water in the beaker rather than wait for it to cool down in order to get a second reading. Which of the two methods, replacing the water or letting it cool down, in your opinion would be the ideal one to use?

Both the liquid in glass thermometer and the thermocouple have their advantages and their disadvantages. List and discuss these advantages and disadvantages.

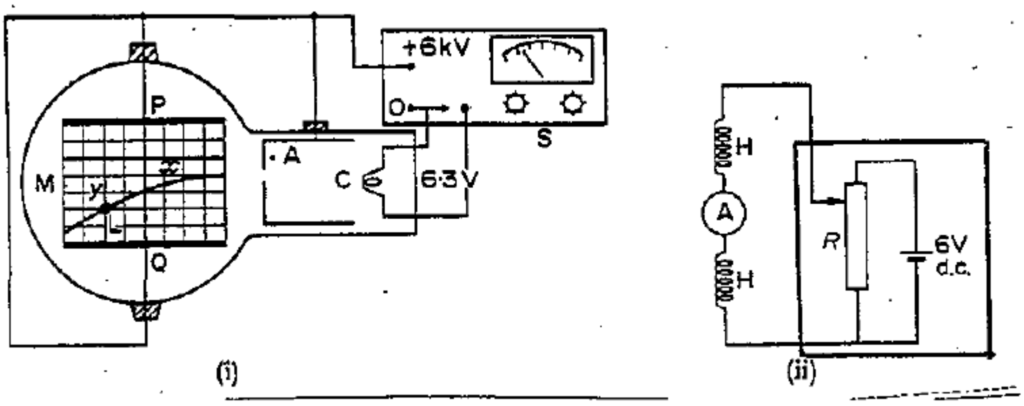
Experiment 16: The specific charge of electrons

16.1. Introduction

To determine the specific charge of electrons by magnetic deflection.

16.2. Apparatus and setup

For this experiment you will be provided with a teltron tube (consisting of an electron gun - cathode C and anode A-fluorescent graduated scale M and plates P and Q), a Helmholtz coil (H, H), an extra high tension (EHT) electrical supply (0-6 kV) combined with a low-voltage supply (6.3 V) a.c., a variable d.c. voltage supply and an ammeter (0-l A). The apparatus is to be set up as shown below.



16.3. Experimental procedure

SAFETY PRECAUTIONS: You should find the experiment already set up. Never attempt to set up the experiment on your own. Do not touch any of the connecting plugs since you will be using very high voltages. Wear the protective spectacles while the experiment is running. Do not dismantle any of the circuitry!

Switch the heater supply of 6.3 V on, then the anode voltage V of say 1.5 kV. A horizontal luminous beam should be seen on the graduated screen M along the x-axis.

1. Switch the heater supply of 6.3 V on, then the anode voltage V of say 1.5 kV. A horizontal luminous beam should be seen on the graduated screen M along the x-axis.

2. Switch on the circuit supplying current for the Helmholtz coils. The beam should be deflected along a circular arc.

3. Adjust the current in the coils until the circular trace passes through a point such that the vertical and horizontal lines cross. The coordinates of such points can be accurately read by noting both the *x-component* – the horizontal distance from the origin, and the *y-component* – the vertical distance from the

origin. Record the coordinates of all possible points and the current I in the Helmholtz coils, up to a Helmholtz current of 0.75 A.

4. The experiment should be repeated twice again. One reducing the current and then again increasing the current.

5. Plot a suitable linear graph to determine the specific charge of electrons.

6. Take repeated readings of the anode voltage V, as this will fluctuate through the experiment.

16.4. Data analysis

The deflection of the electrons in the above experiment is such that the following equation is obeyed,

$$\frac{e}{m_e} = \frac{2Vr_H^2}{0.72^2 \mu_0^2 N^2}\left[\frac{1}{I}\left(\frac{2y}{x^2+y^2}\right)\right]^2, \tag{16.1}$$

where e/m_e, is the specific charge of electrons (charge per unit mass) V is the anode voltage, r_H is the radius of the Helmholtz coils that in this case is 0.065 m, N is the number of turns of the coils that in this case is 320, μ_0 is the permeability of vacuum, I is the current through the Helmholtz coils and x, y are the coordinates of deflection.

Set the above equation in a straight line format and plot the corresponding graph. Hence determine the value for the specific charge of electrons e/m_e.

This experiment relies on the fine beam tube method to determine the specific charge of an electron. Explain how this method works. There is no need to include any derivation. A description of how each component works will suffice.

Experiment 17: The internal electrical resistance

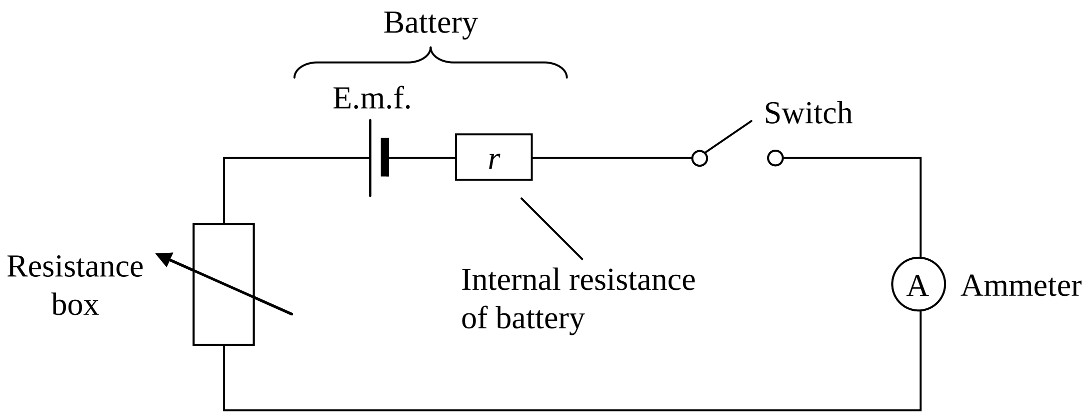
17.1. Introduction

When we consider a power supply usually we only think of it in terms of the voltage it supplies. However, no power supply is ideal, converting all input energy to output voltage. In practice some energy is lost in the conversion. To model this loss we think of the power supply as having some internal resistance across which we have a voltage drop (which is equivalent to a loss of energy). This allows us to think of the real power supply as being made up of an ideal voltage supply placed in series with an ideal resistor.

In this experiment we are going to explore how we can determine the internal resistance of a battery. Such resistance is usually very small and hence in principle would require an advanced setup. The use of such setup would be beyond the scope of this course.

17.2. Apparatus and setup

For this experiment you will be provided with a battery having an internal resistance, a resistance box, an ammeter (in the form of multimeter) and a switch. The apparatus should be set up as shown below:



17.3. Experimental procedure

1. Setup the apparatus as shown in the diagram with the resistance R of the resistance box set to $10\ \Omega$ and the ammeter to read up till 200 mA.
   Note: Ask your demonstrator to check the circuit before you switch it on.
2. Close the switch.
3. Determine the current flowing through the ammeter.
4. Increase the resistance of the resistance box by $10\ \Omega$ and record the value of the current on the ammeter.
5. Repeat Step 4 until the resistance box has a resistance of $90\ \Omega$.
6. Repeat the procedure this time decreasing the resistance on the resistance box by $10\ \Omega$ each time.
7. Plot a graph of $1/I$ on the y-axis against R on the x-axis.

17.4. Data analysis

Simple circuitry theory gives that the electro motive force (e.m.f.) of the system is related to the resistances and the current through the equation,

$$\text{E.m.f.} = I\left(R + r\right).$$

Rearrange the equation so that it represents the graph that you have plotted and hence set it in the form of $y = mx + c.$ Use the graph to determine a value for the e.m.f. and the internal resistance.

Derive the equation that gives the maximum current from a non-ideal power supply (i.e. one that has internal resistance). What is its value in this case? *Hint*: Consider that in order to obtain the maximum current we have to use the smallest possible resistance.

Discuss the practical importance of internal resistances. In your discussion you should make particular reference to its effect on a car batteries and its use in high voltage supplies.

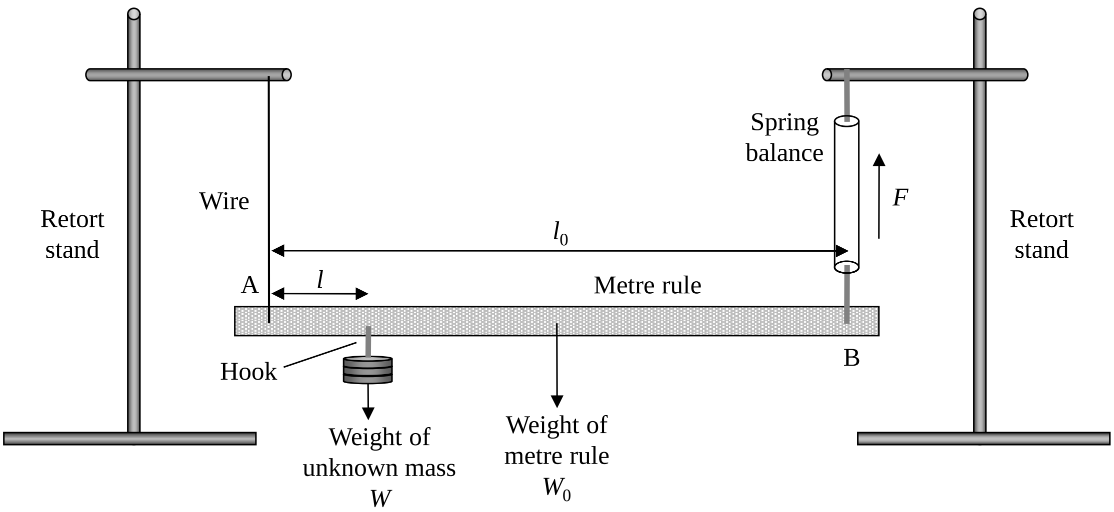
Experiment 18: Mechanical equilibrium

18.1. Introduction

Mechanical equilibrium is a term used to indicate that the total sum of the forces as well as the total sum of the torques is zero. This means that the system undergoes no linear or circular acceleration and hence it will retain its state of motion. Such a fact is often used in mechanics to determine unknown forces or torques from some other known forces and torques. In fact this is what we are going to do in this experiment.

18.2. Apparatus and setup

For this experiment you are provided with two retort stands, a metre rule, an unknown weight, a spring balance, a hook, a wire and a spirit level. The apparatus should be set up as shown below:



18.3. Experimental procedure

1. Setup the apparatus as shown in the diagram. The wire and the spring balance should be placed at about 5 cm from the edge of the metre rule.
2. Record the value of l_0.
3. Set l to be around 10 cm. Record its value.
4. Move the hands of the retort stands up and down until the metre rule is *horizontal* and the wire and the spring balance are *vertical*. The spirit level should be used to make sure the metre rule is as horizontal as possible.
5. Record the force F indicated on the spring balance.
6. Increase the length l and repeat Steps 4 and 5. Make sure not to change the distance l_0.
7. Repeat Step 6 until you obtain a total of five readings.
8. Plot a graph of F on the y-axis against l on the x-axis.

18.4. Data analysis

Let W and W_0 be respectively the weight of the unknown mass and the metre rule. Take moments about Point A and show that the following equation holds,

$$F = \tfrac{1}{2}W_0 + \frac{Wl}{l_0}.$$

Set the above equation in the form $y = mx + c$ and hence find a value of the masses of unknown mass and the metre rule.

Explain why it is important to ensure that the spring balance is vertical before reading the value of F.

The mechanical equilibrium (or equilibria) that a system can attain might turn out to be “stable”, “unstable”, “neutral” or even “metastable”. Discuss why the type of equilibrium attained is important and the difference between the possible types of equilibrium states.