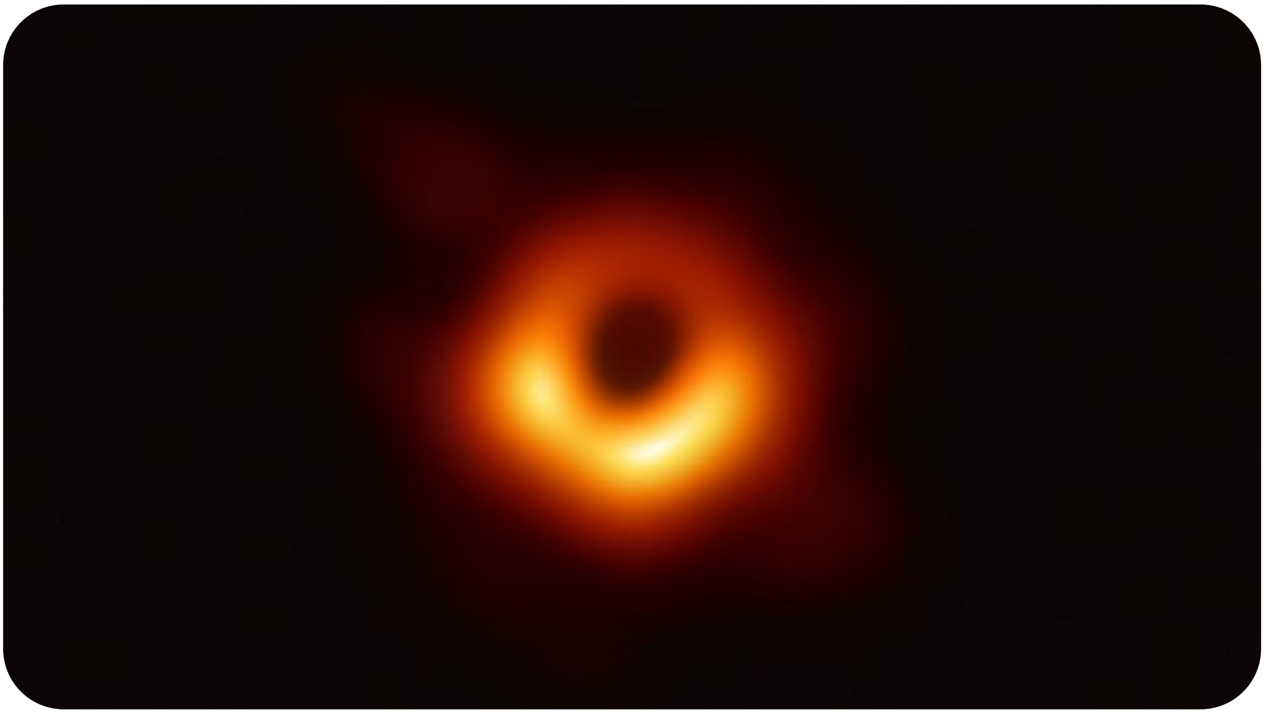
EDEXCEL International Advanced Level



Edexcel IAL Physics Unit 6

Summary©

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HS

Introduction

A scientific investigation goes through the following phases:

- Planning
  - Apparatus
  - Instruments and techniques
  - Method

- Implementation and measurements
  - Significant figures
  - Readings

- Analysis
  - Graph
  - Error and uncertainty
  - Conclusion

A. PLANNING

Apparatus

- You should produce a list of all the apparatus you will need to take all necessary measurements. Your list must include both the item under investigation and the means to experiment on it.
- A diagram will help, so this is a good place to draw your diagram. Make sure that your diagram is clear. Your diagram should show the apparatus assembled as a scientific diagram not an illustration.

Instruments and techniques

Measurement	Instrument	Technique(s)
Length of rubber band	Metre rule	Place rule close to band Lay the rubber band out straight without stretching it Read the position of each end of the band and subtract
Diameter of a wire	Micrometer screw gauge	Take a pair of readings at right angles to make sure it is circular and find the mean Take readings at several places down the length and find the mean
Time for a model car to roll down a ramp	Stopwatch	Draw clearly defined start and stop points on a ramp Make sure the car starts from rest Repeat and find the mean
Temperature of water in a water bath	Thermometer	Place thermometer close to object being heated Stop heating before reading Stir water
Potential difference	Multimeter	Use the most sensitive voltage range Check connections are secure
Length of a simple pendulum	Metre rule	Clamp rule alongside Record the position of the bottom of support (top of string) and the centre of mass of the bob Read the rule with your eyes at the same horizontal level as the position recorded
Diameter of a test tube	Callipers	Repeat readings in different orientations Repeat readings at different places down the tube

Digital Multimeter vs Analogue Ammeter + Voltmeter

Idea	Analogue		Digital
Equipment /cost	two meters needed / may be more expensive	Or	only one meter needed / may be cheaper option
Ease of reading	two readings must be taken	Or	one reading only / fluctuates
Parallax	needs to be considered	Or	digital display / no parallax error
Systematic errors	zero errors contact resistance	Or	zero error contact resistance
Scales	fixed/ requires interpolation	Or	variable/can be changed / numeric reading
Sensitivity	limited by size of scale divisions	Or	two decimal places
Setting up	requires both series and parallel connections / additional apparatus	Or	only requires series connection / must set function switch / use correct terminals
Heating effect of current	heating may change resistance of wire	Or	unlikely to be much heating effect
Power supply	meters do not require individual batteries / but circuit needs a power supply	Or	internal battery required
Uncertainties	greater since two readings	Or	smaller since only one reading
Data	needs calculation from two readings	Or	no calculation required/direct reading
Graphical method	possible	Or	less simple for a fixed wire

Stopwatch vs light gates or sensors and a data logger

Idea	Datalogger/light gates		Stopwatch
Comparison of errors	Advantage - fewer errors	or	Disadvantage - more errors e.g. random, systematic or parallax (not just human error)
Reaction time	No need to account for reaction time	or	Disadvantage - effect of reaction time
Precision	e.g. readings to nearest millisecond	or	e.g. insufficient precision for shortest times
Power supply	Disadvantage - power supply (or electricity) needed.	or	Advantage - no power supply required
Complexity	Needs 'training' setting up, alignment issues, time needed to set up	or	Simple to operate or to set up
Graph	Advantage - any graph could be drawn automatically	or	Any graph would have to be drawn manually
Availability, cost or transport	Not easily available Expensive Not easily transportable	or	Readily available Cheaper Easily transportable

Method

- Write out your method using bullet points.
- You should identify the dependent and independent variables.
- You should describe the graph you will plot and how you will use to find the value you require.
- You should identify any factors that might affect the outcome and state how you will control these variables. You should not be too ambitious here but consider only those things that are likely to have a real effect on your work.

B. Interpretation and measurements

You should follow your plan but keep in mind what you are trying to find out.

- Draw up a table and head each column with the quantity and the unit.

Significant figures

- You are going to record what your instruments read and this is usually to 3 s.f.
- You should use the least number of significant figures when calculating values for derived quantities.
- Your graph should be as precise as possible. In general, 3 s.f. are needed for plotting the points, so gradient calculations should also be given to 3 s.f.

Readings

- You need to take enough readings to plot a reliable graph. If you expect your graph to be a straight line then you should have six readings. For a curved graph you should take more readings where the graph curves and the readings change rapidly, and take fewer readings when it is straight.
- You do not always need to use equal increments of the independent variable.

Critising measurements

- Units present or missing in the table
- Repetition / at least 6 readings
- Inconsistent precision / Inconsistent significant figures
- Precision of readings too low

C. Analysis

- First, plot your readings on a graph. You must do this by hand without using a software programme.
- You then evaluate your findings and move towards a conclusion.

Graph

- Your graph should have the correct axes, as described in your plan, and for giving the axes correct units. The gradient of a graph has no units because the axes are labelled with units and, therefore, you plot pure numbers. Independent variable is usually plotted on the x-axis and the dependent variable on the y-axis. You should have a good reason for plotting the independent variable on the y-axis.
- One purpose of a graph is to display data. The data points should occupy at least half of both axes of your graph; you should not include the origin unless you can do so without confirming the points to one corner. The other purpose of a graph is to enable you to take

readings from intermediate points (interpolate), so make sure your scale is sensible and easy to read.

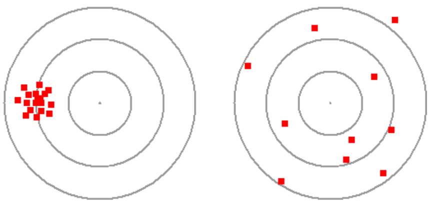
- Plotting should be accurate.
- The best-fit line should have points above and below it and should not necessarily pass through the origin.
- You should describe your graph using appropriate vocabulary. If the graph is a straight line through the origin then the two variables are directly proportional; if the y-intercept is not zero then you can say there is a linear relationship between the variables. You should also note how close the points are to a straight line.

Error and uncertainty

Error in a reading may be systematic or random. The value of a derived quantity will have an uncertainty that comes from the readings used in the calculation.

Error

- A systematic error is caused when something affects all of the readings of an instrument in the same way. Systematic errors can be minimised by taking sensible precautions, such as checking for zero errors and avoiding parallax errors, and by drawing a suitable graph. A systematic error has poor accuracy, definite causes and is reproducible.
- A random error results from variability in what you are reading. Random error is shown by the spread in repeated readings, which might also come about because what you are reading is difficult to measure. Random errors can be minimised by taking the average of a number of repeat measurements and by drawing a graph, that, in effect, averages a range of values. A random error has poor precision, non-specific causes and is not reproducible.



Systematic Error   Random Error

Uncertainty

Uncertainty arises when you consider the effect of the errors in the context of the actual measurement. There are two ways to take this into account.

- Uncertainty in measurements is unavoidable and estimates the range within which the answer is likely to lie. This is usually expressed as an absolute vale, but can be given as a percentage. The normal way of expressing a measurement x_0 with its uncertainty, u, is:

$$x_0 \pm u$$

- Absolute uncertainty and percentage uncertainty are calculated by using the following equations:

$$mean = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

$$u = \frac{x_{max} - x_{min}}{2}$$

,where x_{max} is the maximum and x_{min} the minimum reading of x. (Ignoring any anomalous readings)

$$Percentage\ uncertainty = \frac{Uncertainty}{Mean\ value} \times 100\%$$

- Uncertainties can be combined when 2 or more values with absolute uncertainties are treated.

1-) Multiplying and dividing: The percentage uncertainty in a quantity, formed when two or more quantities are combined by either multiplication or division, is the sum of the uncertainties in the quantities which are combined.

2-) Raising to a power: The percentage uncertainty in x^n is n times the percentage uncertainty in x.

Note: The percentage uncertainty in $\frac{1}{x^n}$ is again times the percentage uncertainty in x.

Note: The percentage uncertainty in $\sqrt{x}$ is half the percentage uncertainty in x.

3-) Multiplying by a constant: The percentage uncertainty is unchanged.

- The other way to consider uncertainty is to use a graph. Plot error bars on the graph – these are lines drawn vertically and horizontally from the plot and indicate how much error there is in the reading. Now draw a best-fit line through the data points on the graph and then draw a worst-fit line that just fits through all the error bars. The uncertainty in the gradient is given by the difference between the two gradients.

Conclusion

The aim of the uncertainty calculation is to give a measure of the confidence you can have in your conclusion. The conclusion is the answer to the question in the hypothesis and the uncertainty, informed by your thoughts on errors, will give your results some validity.

As part of your conclusion you need to think about how you might improve the experiment. Your suggestions should reduce the uncertainty and improve your final answer in terms of accuracy and precision.

Glossary

Term	Definition or meaning
Accepted value	The accepted value of a measurement is the value of the most *accurate measurement* available. It is sometimes referred to as the 'true' value.
Accuracy	Accuracy is a measure of confidence in an *accurate measurement*, often expressed as an upper and lower limit of the measurement based on the *uncertainty* in the measurement (eg $g = 9.8 \pm 0.3\,\text{m}\,\text{s}^{-2}$).
Accurate measurements	A measurement which can be described as accurate is one that has been obtained using accurately calibrated instruments correctly and where no systematic errors arise.
Dependent variable	Dependent variables are those variable physical quantities whose values change as a result of a change of value of another variable quantity. The dependent variable is usually plotted on the vertical or y-axis of a graph.
Error	The difference between a measurement and its accepted value. Often a misnomer suggesting that a mistake was made in taking a reading.
Independent variable	Independent variables are those variable physical quantities whose values are controlled or selected by the experimenter. Changing the value of an independent variable usually results in a change of value of a dependent variable. The independent variable is usually plotted on the horizontal or x-axis of a graph.
Linearity	This is a design feature of many instruments and it means that the readings are directly proportional to the magnitude of the variable being measured. *The scale of a moving coil meter is linear if it has evenly spaced graduations on its scale each representing equal increases in current.*
Mean value	The mean value of a set of readings is calculated by adding the readings together and dividing by the number of readings.
Percentage uncertainty (of a mean value)	$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{mean value}} \times 100$
Precision	The precision of a measurement is the degree of exactness (sometimes the number of significant figures) to which the measurement of a quantity or value can be obtained and reproduced consistently. • If a reading is constant when repeated, the precision of the measurement will be the precision of the instrument. • If a reading fluctuates the precision of the measurement (its mean value) is given by half the maximum range of the readings.
Precision of an instrument	The precision of an instrument is the smallest non-zero reading that can be measured using the instrument.
Probable error	See 'uncertainty'.
Random error	Random errors are errors with no pattern or bias. Readings with random errors vary in an unpredictable manner with no discernable pattern or trend. The effect of random variations in measurements of a quantity is reduced by taking more readings and finding a mean value.
Range	The range of a set of readings or calculated values is the difference between the smallest and the largest values.
Reliability	Reliability is the extent to which the measurements of a quantity remain consistent over repeated measurements of the same quantity under identical conditions. • An experiment is reliable it if yields consistent results of the same measurement. • An experiment or investigation is unreliable if repeated measurements give different results or if the scatter of measurements on a line graph is too great to establish the line. • Reliability is higher when random errors are reduced. • The reliability of data can be improved by carrying out repeat measurements and calculating a mean value.

A2 Physics Experiments

1. Conservation of linear momentum
2. Force and change of momentum
3. Centripetal force
4. Demonstrating a uniform electric field
5. Measuring the force between two charges
6. Measuring the capacitance of a capacitor
7. The efficiency of energy transfer from a capacitor
8. Charging and discharging a capacitor
9. The force on a current-carrying conductor
10. Deflecting electron beams
11. Capturing an induced emf
12. Measuring the specific heat capacity of a solid
13. Measuring the specific heat capacity of a liquid
14. Demonstrating the pressure law
15. Demonstrating Boyle's law
16. Measuring background radiation
17. Modelling radioactive decay
18. Measuring the activity of a radioactive substance
19. Generating graphs of SHM
20. Forced oscillations
21. Investigating damped oscillations
22. Standard candles

1-) Conservation of linear momentum

A. Introduction

The principle of conservation of linear momentum states that in any interaction between bodies, **linear momentum is conserved**, provided that no external force acts on the bodies. Therefore, the following equation can be applied to two colliding bodies:

$$m_a u_a + m_b u_b = m_a v_a + m_b v_b$$

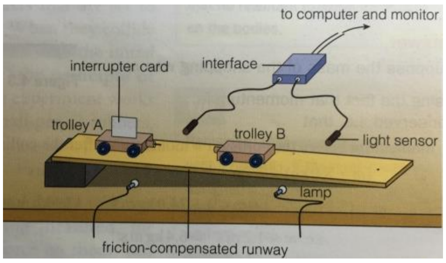
The purpose of this experiment is to test on this principle using two trolleys (Trolley A and Trolley B) and a friction-compensated slope. As trolley B is stationary initially, and after the collision A and B move off together as a single object the general equation stated above becomes:

$$m_a u_a = (m_a + m_b)v$$

Therefore, to say that momentum is conserved, the initial momentum of A must be equal to the final momentum of A and B which couple together.

B. Safety

- Lift the wooden support with care.
- To reduce the danger of trolleys falling off the bench, a means of stopping them safely at the bottom of the runway is needed. An enclosed area or piece of sponge would suffice. The area around the equipment should be kept free of bags, books.



C. Apparatus

- Two trolleys
- Two light gates
- 0.2 m interrupter card
- Pin and cork
- Wooden runway
- Means of compensating the runway for friction.

D. Procedure

- Compensate for friction by tilting the runway slightly. Check by giving one trolley a small push and confirming that it runs down the runway with constant speed.
- Trolley A of mass m_A is given a push so that, after its release, its interrupter card cuts through a light beam with the trolley moving at a constant velocity down the friction-

compensated slope. The time in the light beam is interrupted is recorded electronically and the (constant) velocity, u, of trolley A is calculated.

- Trolley A has a cork attached with a pin sticking out of it that couples to a cork attached to trolley B of mass m_B when A hits B.
- The two now move off together at a constant velocity, v, down the slope; a velocity that is calculated as the interrupter card on trolley A passes through the second light beam.
- The experiment is repeated for differing initial speeds and trolley masses.

E. Data

t_1/s	t_2/s	u/m s^{-1}	v/m s^{-1}	Initial momentum/N s	Final momentum/N s
0.64	1.28	0.31	0.16	0.27	0.27
0.73	1.45	0.27	0.14	0.24	0.23
0.48	0.95	0.42	0.21	0.36	0.36
0.60	1.20	0.33	0.17	0.29	0.28

F. Validity of the Study and Improvements

The values of the initial and final momentum are the same ($\pm 1\%$) in each case, indicating that the total momentum has been conserved. The uncertainty is most likely a result of an external resultant force acting on the system which includes air resistance.

The reason behind using an inclined plane: There should be no resultant external forces acting on the system for the momentum to be conserved. There will usually be resistive forces acting on the trolley. These forces can be compensated for by raising the end of the runway so that there is a component of the weight of the trolley acting down the plane. When this force is equal to the frictional forces, the resultant force on the trolley is zero. If the trolley is given a gentle push, it will continue to move down the runway at constant speed, just as it would on a horizontal track with no friction.

- ➔ If the runway were horizontal, the frictional forces would lead to a change in momentum – the total momentum after the collision would be less than that before the collision.

G. Conclusion

Initial momentum equals final momentum within reasonable accuracy, therefore this experiment has shown that momentum had been conserved in the collision of trolleys.

2-) Force and change of momentum

A. Introduction

Newton's second law establishes the relationship between the resultant force acting on an object and the change of momentum that it causes. An important result that follows from the second law and the definition of the Newton is F = m x a.

Newton's second law states that:

The rate of change of momentum of an object is proportional to the resultant force acting on it and acts in the direction of the resultant force.

$$\frac{\Delta p}{\Delta t} \propto F$$

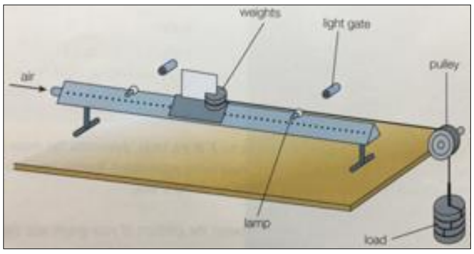
The definition of the size of the Newton fixes the **proportionality constant at one**.

The aim of this experiment is to investigate rate of change of momentum using a linear air track.

B. Safety

- Place a padded box beneath the load so that the floor and masses do not get damaged.
- To avoid injuries to feet, do not stand under falling masses.

C. Apparatus



- Linear air track
- Air blower
- Rider
- Two light gates
- Pulley suitable for fixing to the air track
- Thread
- Set of slotted masses

D. Procedure

The light gates are connected to a suitable data logger and the results can either be interpreted manually or can be fed into a suitable computer programme. They are interpreted manually in this experiment. The following data is required:

- The length l of the card: 200 mm in this experiment
- The times for the card to pass through each light gate, t_1 and t_2
- The time for the car to travel from the first light gate to the second light gate Δt
- The mass of the trolley m_T: 450 g in this experiment

Method

- Measure the length of the card.
- Carry out the experiment for a particular force and record t_1, t_2 and Δt.
- Repeat the experiment a couple of times for the same force and calculate the average.
- Repeat the experiment for increasing magnitude of forces at 0.1N intervals.
  - ➔ We need to think carefully about m. The force, which is the weight of the masses hanging over the pulley has to accelerate the combined mass of the trolley, the masses on the trolley and the masses hanging over the pulley. In order to vary the force and at the same time keep m constant we have to take one of the masses off the trolley and add it to the load each time.

E. Data

The velocity through the first light gate is calculated using the equation: $v_1 = \frac{l}{t_1}$

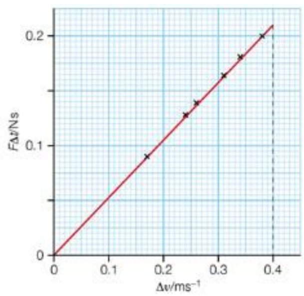
The velocity through the second light gate is calculated using the equation: $v_2 = \frac{l}{t_2}$

The change in momentum is then $\Delta p = m(v_2 - v_1) = m\Delta v$ where m is the mass being accelerated.

F/N	Δt/s	$F\Delta t$/N s	t_1/s	t_2/s	v_1/m s^{-1}	v_2/m s^{-1}	Δv/m s^{-1}
0.10	0.90	0.090	0.51	0.36	0.39	0.56	0.17
0.20	0.64	0.128	0.38	0.26	0.53	0.77	0.24
0.29	0.48	0.139	0.29	0.21	0.69	0.95	0.26
0.39	0.42	0.164	0.25	0.18	0.80	1.11	0.31
0.49	0.37	0.181	0.22	0.16	0.91	1.25	0.34
0.59	0.34	0.200	0.19	0.14	1.05	1.43	0.38

F. REPRESENTATION OF DATA

a graph of $F\Delta t$ on the y-axis against Δv on the x-axis is plotted.



G. VALIDITY OF THE STUDY AND IMPROVEMENTS

Using a linear air track minimises friction.

The experiment should be repeated at each different load combination.

In order to draw a line of best fit, at least 6 points are needed.

H. CONCLUSION

A graph of $F\Delta t$ on the y-axis against Δv on the x-axis is plotted and a straight line through the origin shows that $\Delta v \propto F$. The gradient is found to be m, then we can say that

$F\Delta t = m\Delta v$ or $F = \frac{m\Delta v}{\Delta t} = rate\ of\ change\ of\ momentum$

3-) Centripetal force

A. Introduction

Consider a body of mass m moving in a circle of radius r at constant speed. While the magnitude of v is constant, its direction is continuously changing; in other words, although the linear speed is constant, the velocity, which is a vector quantity, is always changing.

- The change in velocity means that the mass is accelerating.
- Since the magnitude of v remains unchanged, the acceleration must always be directed at right angles to v, **towards the centre of the circle**.
- The magnitude of the acceleration is given by:

This acceleration is known as the centripetal acceleration.

Using the relation $v = \omega r$, centripetal acceleration can also be expressed in terms of the angular speed:

$$a = \omega^2 r$$

By Newton's second law, a resultant force is required to produce the centripetal acceleration. This resultant force, called the centripetal force, is directed towards the centre of the circle and has a magnitude given by:

$$F = ma = \frac{mv^2}{r} = m\omega^2 r$$

The aim of this experiment is to verify the equation for centripetal force using a whirling bung.

$$F = \frac{mv^2}{r}$$

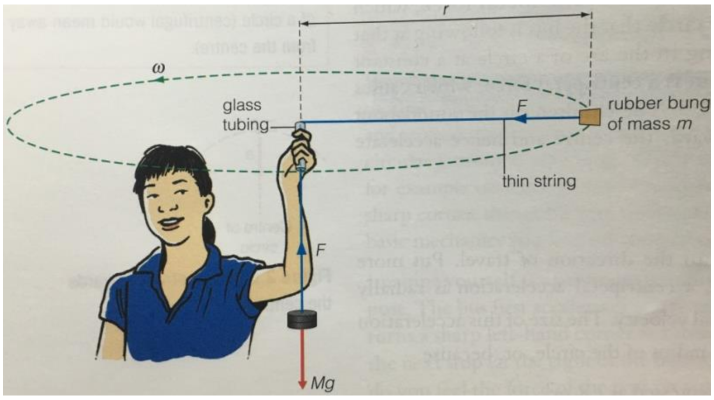
B. Safety

- Glass tubing should be smoothed by heat treatment in a Bunsen flame.
- Eye protection should be worn, even if the experiment is carried out outdoors.

C. Apparatus

- Rubber bung with a hole through it (mass 75g)
- Length of string
- Washers
- Stopwatch
- Metre ruler
- Short length of glass tube with ends burred over

- Access to a balance
- Eye protection



D. PROCEDURE

- Tie the piece of string to a rubber bung and then thread it through a short length of glass tube.
- Fix a small weight to the lower end of the string.
- Whirl the bung round in a horizontal circle while holding the glass tube so that the radius of the bung's orbit is constant.
- Measure the mass of the bung (m), the total mass of the washers (M), the radius of the orbit (R) and the time for ten orbits.
- Repeat the experiment with different numbers of washers or Repeat the experiment with different orbit radii or Repeat the experiment with bungs of different masses.

E. DATA - ANALYSIS

Calculate the period of the orbit (T), the velocity of the bung in the orbit $(v = \frac{2\pi R}{T})$ and then work out the centripetal force $(F = \frac{mv^2}{R})$.

Compare this value with the weight of the washers (Mg).

M (g)	F = Mg (N)	10T (s)	T (s)	R (m)	v = 2πR/T (m/s)	mv^2/R
50	0,49	21,9	2,19	0,83	2,38	0,51
100	0,98	16,2	1,62	0,80	3,10	0,90
150	1,47	13,5	1,35	0,93	4,33	1,51
200	1,96	11,2	1,12	0,79	4,43	1,86
250	2,45	10,7	1,07	0,99	5,81	2,56

F. Representation of data

A graph v squared against r can be drawn and that can be used to find the mass of the bung if it is unknown.

G. Validity of the study and improvements

Assumptions

When the supported mass M is in equilibrium,

- There is negligible friction between the glass tube and the string
- That the string to the whirling rubber bund is effectively horizontal

Note: Time for 10 rotations is measured instead of 1 in order to reduce the percentage uncertainty in the measurement of the period.

H. Conclusion

The tension in the string is known. T is equal to the weight of the supported mass M. Tension acts as the centripetal force in this experiment resulting in the circular motion of the rubber bung. The equation for centripetal force is used to calculate the force acting on the bung. In theory tension and centripetal force is equal thus the columns 2 and 6 in the table must be equal. Some values agree. As M gets larger, the agreement between the second and the sixth column becomes weaker which suggests that the system is not frictionless.

4-) Demonstrating a uniform electric field

A. Introduction

An electric field is a region in space in which a charged object will experience a force. An electric field is generally represented by drawing field lines or lines of force. Electric field lines are drawn always pointing from positive to negative, like the flow of current. Just like magnetic and gravitational fields, the separation of the lines tells us the relative strength.

Electric field strength can be calculated:

$$E = \frac{F}{Q}$$

,where F is the force that would act on a positive charge Q placed in the electric field. It should be noted that E is a vector quantity whose direction is that of the force F.

Between a pair of parallel conducting plates that have a potential difference applied across them, the field is uniform, with all field lines perpendicular to the plates. As E is constant, F acting on a charged object should also be uniform.

The aim of this experiment is to demonstrate a uniform electric field using a rod with aluminium foil attached to on of its ends.

B. Procedure

- Cut a test strip of aluminium foil, about 20 mm by 5 mm.
- Attach it to the bottom of an uncharged insulating rod.
- Hold the ruler vertical and lower the end with its foil into the space between two charged plates.
- Move the ruler so that the aluminium foil is at different places between the charged plates.

C. Conclusion

If the yield is uniform, the force on the foil will be constant and the aluminium foil will hang at the same angle to the vertical wherever it is placed in the field. If the charges on the plates are reversed, the test strip swings to the same angle the other way.

5-) Measuring the force between two charges

A. Introduction

The basic law describing the size of the force F between two point charges Q_1 and Q_2 is an inverse square law that depends on the distance r between the charges and the size and sign of the charges Q_1 and Q_2.

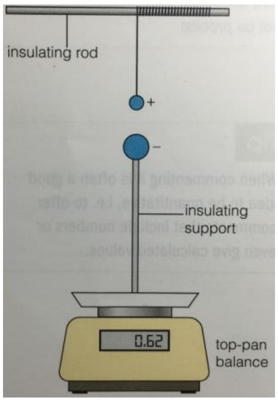
$$F = \frac{kQ_1Q_2}{r^2}$$

The aim of this experiment to measure this force F between two charges.

B. Safety

- Use a low potential difference.

C. Apparatus



D. Procedure

- The forces are going to be very small, so a sensitive measuring device is required to register changes in the force as the distance between the charges is changed.
- Two conducting spheres, shown in blue, are charged by flicking the negative lower sphere with woollen cloth and using the positive terminal of a d.c. supply set at about 30V to charge the upper sphere. Spheres are insulated so that they do not lose their charge.
- Readings on the top-pan balance should now be taken for different distances r between the centres of the spheres. One way of recording how this distance changes without touching the charged spheres is to project a shadow of them onto a nearby screen.

E. DATA

m/g	0.11	0.38	0.62	0.83	1.14
r/cm	12.0	6.4	5.0	4.3	3.7

F. VALIDITY OF THE STUDY AND IMPROVEMENTS

One difficulty is that some of the charge on one or both of the spheres may leak away during the experiment.

Another difficulty is the difficulty in measuring the distance r between the centres of the charged spheres.

G. CONCLUSION

If $m \propto {}^{1}/_{y^2}$, then the product my^2 should be constant. Taking values from the table gives the following values:

16, 16, 16, 15 and 16 to 2 SF

Hence the product is approximately constant and m is proportional to ${}^{1}/_{y^2}$.

6-) Measuring the capacitance of a capacitor

A. Introduction

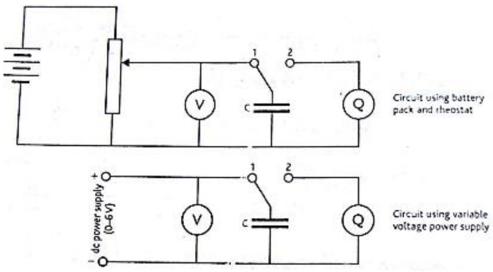
The capacitance of a capacitor is defined as Q/V where Q is the size of the charge on the plates of the capacitor and V is the potential difference between the plates.

The aim of this experiment is to measure the capacitance on different capacitors.

B. Safety

Capacitors of more than 1.0 Mf usually have a plus sign marked at one end and a maximum voltage written on them. It is very important in any activity to be sure that the + end of such a capacitor is connected to the positive terminal of the supply and that the maximum p.d. is not exceeded.

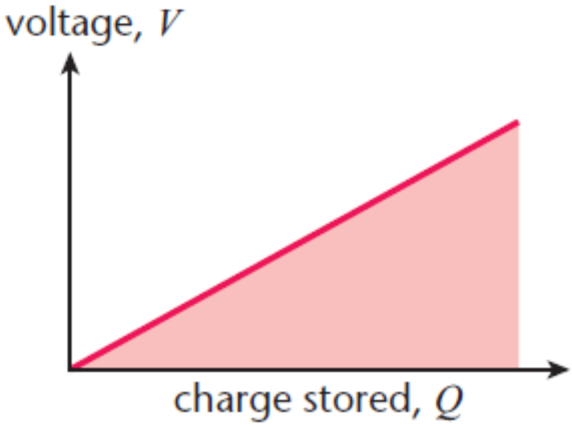
C. Apparatus



D. Procedure

- Connect up the circuit in the diagram using the 0.1 micro Farad capacitor with the switch in position 1. Switch on the power supply and adjust the output so that the voltmeter reads 0.5 V.
- Move the switch to position 2 and record the reading of charge on the coulombmeter.
- Return the switch to position 1 and adjust the voltmeter to read 1.0 V. Move the switch to position 2 and again record the charge.
- Repeat the procedure in 0.5 V steps up to a maximum of 6.0 V. Record all your results in the table showing capacitor voltage and charge.
- Repeat for different values of capacitance.
- For each capacitor plot a graph of capacitor voltage against charge. Calculate the gradient of each of your graph and compare this with the stated value of the capacitor.

E. DATA



7-) The efficiency of energy transfer from a capacitor

A. Introduction

Capacitors store energy. The energy transferred, or work done, when a charge ΔQ moves across a potential difference of V is given by $\Delta W = V\Delta Q$. When charging capacitors there is a problem in calculating the energy transferred using this formula because the p.d. changes as the capacitor charges!

Fortunately, V is proportional to Q, so the average p.d. is exactly half the final p.d., and we can use:

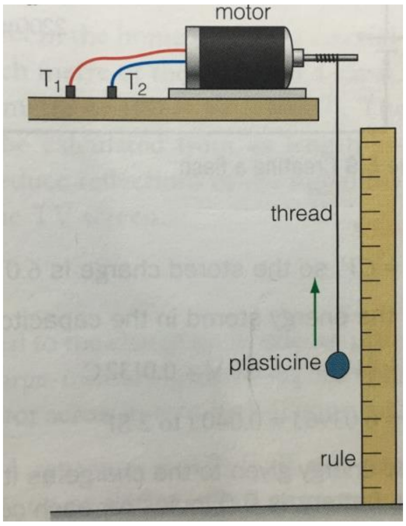
$$W = V_{av}Q = \frac{1}{2}V_{max}Q$$

The aim of this experiment is to use this formula and exploit the principle of conservation of energy in order to calculate the efficiency of energy transfer from a capacitor to a motor which lifts a mass.

B. Safety

- Fix the motor on the table.
- Do not exceed the voltage limit of the capacitor.

C. Apparatus



D. PROCEDURE

- The electrical potential energy (EPE) stored in a 10000 μF capacitor can be transferred to gravitational potential energy (GPE) by discharging the capacitor through a small electric motor. As the capacitor discharges the current in the motor raises a small mass.
- The mass to be lifted could be a small ball of plasticine with a mass of, say, 8.0 g. the cotton is wound round the spindle of the electric motor and a vertical rule arranged to measure how far the plasticine is lifted. The gain of GPE by the plasticine is mgh so m must be small for measure values of h to be obtained. The capacitance of the capacitor C must, however, be large.
- A series of readings of V the charging voltage and h should be taken as the capacitor is first charged from the variable d.c. power supply and then discharged through the motor.

E. DATA

V/V	7.5	9.0	10.5	12.0
h/m	0.27	0.40	0.53	0.71

F. REPRESENTATION OF DATA

A graph of mgh (the gain of GPE in joules) against $\frac{1}{2}CV^2$(the loss of EPE in joules), or simply a graph of h against V^2, could be plotted. If the graph is a straight line through the origin, then $h \propto V^2$, or Δ(GPE) is proportional to Δ(EPE).

G. VALIDITY OF THE STUDY

The values of mgh and $\frac{1}{2}CV^2$ will not be equal because the efficiency of the energy transfer is not 100%. Some energy is inevitably lost to internal energy in heating the wires of the circuit and in working against friction in the motor. Over a wide range of values, the efficiency may not be constant and so Δ(GPE) may not proportional to Δ(EPE).

H. CONCLUSION

Ideally, Δ(GPE) must be proportional to Δ(EPE). However, there are energy losses from the system due to friction and other forces so this is not the case.

8-) Charging and discharging a capacitor

A. Introduction

The charging and discharging of a capacitor follows curved graphs in which the current is constantly changing, and so the rate of change of charge and pd are also constantly changing. These graphs are known as exponential curves. The shapes can be produced by plotting mathematical formulae which have power functions in them.

A data logger must be used in this experiment to display and analyse the potential difference across a capacitor as it charges and discharges through a resistor. Time is too small to collect data as you go.

The purpose of this experiment is to investigate charging and discharging capacitors and their graphs.

B. Safety

- Ensure that the voltage rating of the capacitor is not exceeded.
- Ensure that the electrolytic capacitor has the correct polarity in the circuit.

C. Apparatus

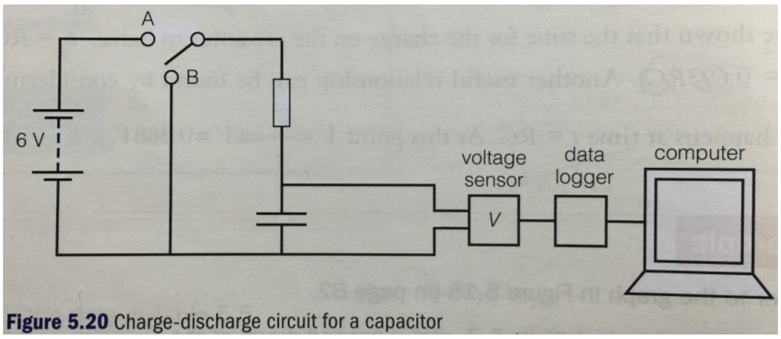
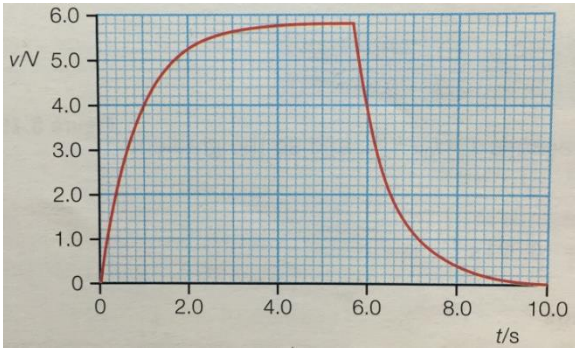


Figure 5.20 Charge-discharge circuit for a capacitor

D. Procedure

- The capacitor is charged through the resistor by connecting the switch to contact A. The capacitor is then discharged through the same resistor by moving the switch to contact B. The p.d. across the capacitor is measured by the voltage sensor and recorded by the data logger. The data can then be analysed by the computer.

E. DATA



F. ANALYSIS OF DATA

During the first 6 seconds (approximately) the capacitor is being charged through the resistor and the p.d. rises exponentially from zero to just under 6 V. The capacitor then discharges exponentially, becoming almost completely discharged after about 10 seconds.

Equations for the graph:

Charging: $V = V_0 (1 - e^{-t/RC})$

Discharging: $V = V_0 e^{-t/RC}$

Estimating the capacitance and the uncertainty in the estimate

There are various ways of finding the time constant *RC*. We can use

Charging: CR = time (from 0) for $V \rightarrow 0.632V_0$
Discharging: CR = time (after start of discharge) for $V \rightarrow 0.368V_0$
Charging or discharging: $CR = 0.693\, t_{½}$

You should determine at least 2 values and take an average. You should then find that *CR* is approximately 0.72 ± 0.05 s, bearing in mind the difficulty in reading off values from the graphs.

For $CR = 0.67$ s $\Rightarrow C = 0.67\text{ s} / R = 0.67\text{ s} / 6.9 \times 10^3\ \Omega = 9.71 \times 10^{-5}$ F
= 97 μF to 2 SF

For $CR = 0.77$ s $\Rightarrow C = 0.77\text{ s} / R = 0.77\text{ s} / 6.9 \times 10^3\ \Omega = 1.12 \times 10^{-4}$ F
= 110 μF to 2 SF

The capacitance is therefore estimated to be in the range 97–110 μF

This suggests the capacitor is probably a 100-μF capacitor (this is a 'preferred value')

G. VALIDITY OF THE STUDY AND IMPROVEMENTS

The value for the capacitance is only an estimate as it is difficult to read off the times with any accuracy from the graphs. This could be improved by expanding, say, the charging part of the graph so that the time scale was larger, thereby making the times easier to read off.

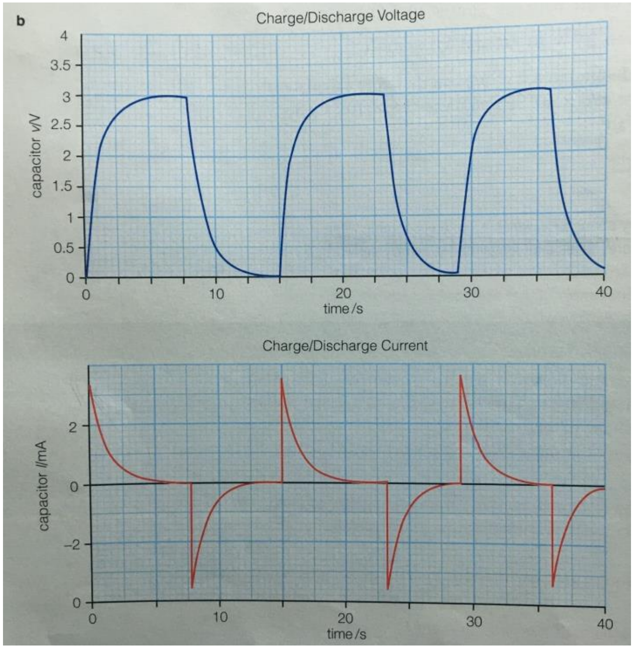
H. CONCLUSION

The following equations can be used to calculate the potential difference across a charging and discharging capacitor:

Charging: $V = V_0 (1 - e^{-t/RC})$

Discharging: $V = V_0 e^{-t/RC}$

Explaining the shape of the following graphs



At $t = 0$, at the moment the switch is connected to contact A, there is no charge on the capacitor and so no p.d. across it. The full supply voltage is across the resistor, so the current is a maximum. As the capacitor begins to charge up, the p.d. across it increases and so the p.d. across the resistor, and therefore the current, decrease. Both curves are exponential and 'mirror' each other. When the capacitor is fully charged, the p.d. reaches a maximum and the current is zero – no more charge is flowing.

After about 8 seconds, the switch is switched to contact B and the capacitor now starts to discharge through the resistor. As the capacitor is discharging, the charge flow in the *opposite direction* to that when charging and so the current appears negative on the graph. The current is initially large when the capacitor is fully charged. Then, as the charge on the capacitor gets less, so the p.d. across the capacitor falls exponentially, as does the current.

9-) The force on a current-carrying conductor

A. Introduction

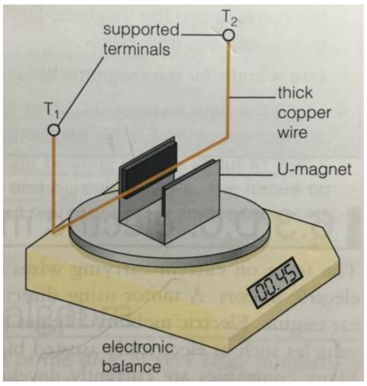
The force acting on a current-carrying conductor is perpendicular to both the direction of magnetic field and the direction of current.

The aim of this experiment is to measure the magnitude of this magnetic force with varied current.

B. Safety

- The power supply should be switched off between readings to avoid the copper wire getting too hot.

C. Apparatus



D. Procedure

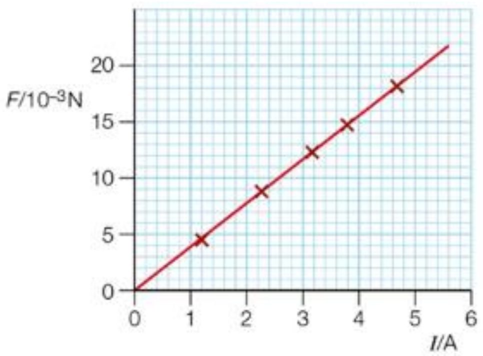
- The balance is first zeroed and the current is then switched on. Having made sure the horizontal piece of the wire carrying the current lies between the poles of the U-magnet and that the wire is perpendicular to the magnetic field, a series of balance readings m, in grams can be taken for a range of currents I.
- The magnetic force on the wire is, by Newton's third law, equal in size but opposite direction to the magnetic force on the magnet – and it is this latter force that is registered by a change in the balance reading. The force can then be calculated using F = mg.
- A graph plotted of F against the current I enables a value for the magnetic field strength between the poles of the U-magnet to be deduced. (It is also possible to alter the length l of the horizontal wire in the magnetic field by using a second U-

magnet, but such an experiment gives only a rough test of how the force varies with I.)

E. Data

I/A	1.2	2.5	3.4	4.2	5.0
m/g	0.45	0.90	1.25	1.50	1.85
F/10^{-3} N	4.4	8.8	12.3	14.7	18.1

F. Representation of Data



G. Validity of the Study and Improvements

The slope of this graph = $\frac{F}{I} = \frac{21.5\times10^{-3}N}{5.5A} = 3.8\times10^{-3}NA^{-1}$

Using $F = B_{\perp}I\ell$ with ℓ = 0.045 m

$$B_{\perp} = \frac{3.8\times10^{-3}NA^{-1}}{0.045m}$$ = 0.09 N A^{-1} m^{-1} or 0.09 T

The region over which the magnetic field is uniform cannot be determined for certain – it gets less near each end of the magnets - so the value of $B_{\perp}$ can only be approximate, e.g. to ± 5 %, or here to 1 SF.

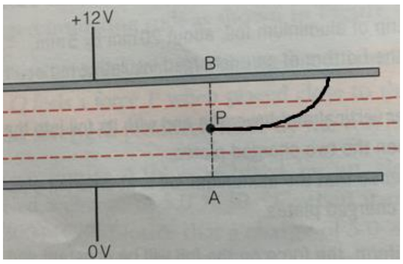
H. Conclusion

As the graph is a straight line through the origin, the current in a wire in a magnetic field is directly proportional to the conventional current flowing through it.

10-) Deflecting electron beams

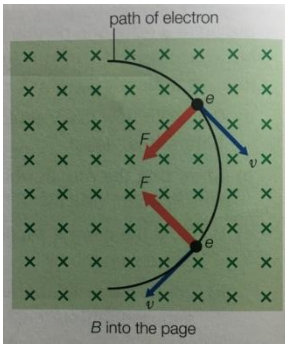
A. Introduction

Electric fields



As simple as it is, like charges repel and unlike charges attract. Charges in an electric field will experience force acting on them and the direction of this force will depend on the charge of the particle. Suppose, for example, that a charges particle is moving parallel to two parallel plates which produce a uniform electric field between them. The particle will experience a force towards either of the plates and provided that its mass is negligible, the only force acting on this particle will be the electric force. Therefore, it will have acceleration in the vertical direction but no acceleration in the horizontal direction, thus it will follow a parabolic path.

Magnetic fields



Moving charges constitute an electric current, and so will experience a force when they move at a non-zero angle to a magnetic field. Beams of electrons or ions will therefore be deflected as they pass through a magnetic field, as will fast mobbing charged sub-atomic particles.

The force on a particle carrying a charge q moving with velocity v at an angle θ to a field of flux density B is given by the expression:

$$F = Bqv\sin\theta$$

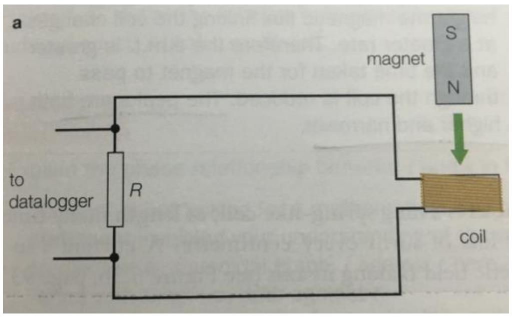
Note that since the force is always at right angles to the direction of motion of the charges, particles moving perpendicular to the field will travel along circular paths, with the magnetic force providing the centripetal acceleration.

11-) Capturing an induced e.m.f.

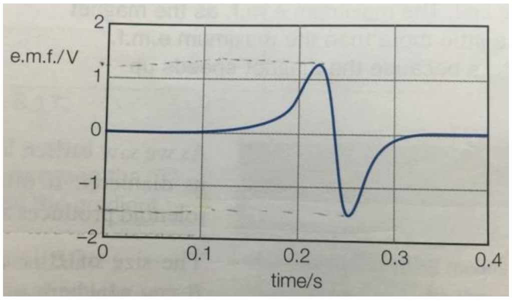
A short bar magnet is dropped through a coil connected in series with a resistor. A data logger (a device that can capture a changing p.d. thousands of times per second) is connected across this resistor.

The data logger will record the potential difference as it varies across the resistor. The p.d. is equal in size at all times to the e.m.f. induced in the coil.

Apparatus



Data



Explanation of the shape of the graph

- Changing of flux / Cutting of field
- Induced e.m.f. is proportional to the rate of change of flux (equation)
- Initial increase in e.m.f. as the magnet gets closer to the coil
- Negative gradient is when magnet is going through the coil
- Magnet's speed increases as it falls
- Negative maximum value is greater than the positive maximum value
- Time for second pulse is shorter
- The areas of the two parts of the graph will be the same (since $N\varphi$ is constant)

Some questions

Q1 – Explain why the acceleration of the falling magnet is not quite 9.8 m s^{-2}.

The induced e.m.f. produces a current in the coil-resistor circuit. This current in turn produces a magnetic field that will be up out of the coil as the magnet approaches, so repelling the falling magnet – Lenz's law. Similarly, the falling magnet will be attracted back into the coil as the magnet exits the coil. Both these effects are producing upward forces on the magnet so its acceleration is not quite as big as the free fall acceleration.

Q2 – Describe how the output of the data logger would differ if:

a-) the coil is replaced by a coil with double the number of turns, and

Double the number of turns means that the induced magnetic flux through the coil is doubled. The induced e.m.f. is doubled at each stage of the fall, and so the peaks are each twice as high as they were.

b-) the magnet is dropped from a greater height.

When the magnet is dropped from a greater height the magnetic flux linking the coil changes at a greater rate. Therefore the e.m.f. , is greater and time taken for the magnet to pass through the coil is reduced. The peaks are both higher and narrower.

12-) Measuring the specific heat capacity of a solid

A. Introduction

Transferring the same amount of energy to two different objects will increase their internal energy by the same amount. However, this will not necessarily cause the same rise in temperature in both. The increase in temperature can be calculated using the equation:

$$\Delta E = mc\Delta\theta$$

c, in the equation is the specific heat capacity of the object. This is defined as the amount of energy needed to raise the temperature of 1 kg of a particular substance by 1 K. Different materials have different specific heat capacities because their molecular structures are different and so their molecules will be affected to different degrees by additional heat energy.

The aim of this experiment is to measure the specific heat capacity of a solid using an electrical method.

B. Safety

Use low voltages.

C. Apparatus

- Aluminium
- Heat-resistant mat
- Low-voltage heater and a suitable power supply
- Ammeter and voltmeter
- Thermometer
- Stopclock
- Insulating jacket with a hole for the thermometer or sensor
- Silicone grease

A temperature sensor and a data logger can be used instead of the thermometer and stop clock.

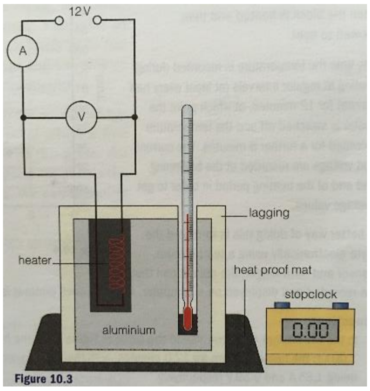


Figure 10.3

D. PROCEDURE

- Measure the mass of metal block (m).
- Put the thermometer in the small hole in the metal block. Place the heater in the large hole in the block and switch it on. A small amount of silicone grease in the holes in the block can improve thermal contact. Place the insulating jacket around the apparatus.
- Set the voltage (V) to a convenient value and record this with the value of the current (I).
- Measure the initial temperature and start the stopclock (or use a temperature sensor and data logger).
- Record the temperature at one-minute intervals. Switch off the heater when the temperature reaches 50 °C.

(You may need to adjust the value of I during the experiment so that the power input remains constant.)

E. ANALYSIS

Plot a graph of temperature against time and choose a section of the graph where the temperature is rising steadily. In this area find the temperature rise $\Delta\theta$ in a time Δt.

Calculate the electrical energy supplied to the heater ($VI\Delta t$).

Calculate the specific heat capacity (c) of the metal of your block using the formula:

$$c = \frac{VI\Delta t}{m\Delta\theta}$$

where m is the mass of the block.

F. DATA

m = 993 g	V = 10.3 V	θi = 21.4°C
I = 3.10 A	Δt = 3.00 minutes	θf = 27.3°C

G. VALIDITY OF THE STUDY AND IMPROVEMENTS

Although this quick and practical method provides an accurate estimate of the specific heat capacity, there are **several sources of error**:

- Energy is absorbed by the heater itself; this is the main source of error and will make the value of c too large because it means that not all the energy supplied is used to raise the temperature of the block of metal.

- Energy is transferred to the surroundings, despite the lagging (also making c too large).
- A little energy will be taken by the lagging and the thermometer (again making c too large).
- Inaccuracy of the thermometer, especially $\Delta\theta$ is fairly small (this could make c too large if $\Delta\theta$ were too small or too small if $\Delta\theta$ were too large).
- Inaccuracy of the meters (again, this could affect the value of c either way).

H. CONCLUSION

13-) Measuring the specific heat capacity of a liquid

A. Introduction

The aim of this experiment is to measure the specific heat capacity of a liquid using two different experimental set-ups.

B. Safety

Do not heat the contents of the calorimeter above 50°C.

C. Apparatus

First set-up

- A copper or aluminium calorimeter with a volume between 250 and 400 ml
- Insulating jacket with a hole for the thermometer or sensor
- Electrical immersion heater
- Voltmeter and ammeter
- Low-voltage power supply (0-12V)
- Thermometer (0-50°C)
- Stopclock

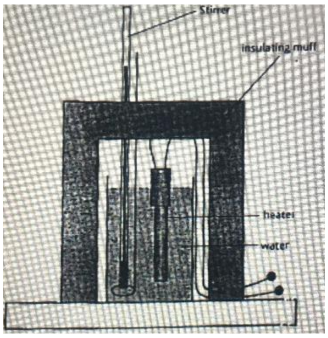
(A temperature sensor and datalogger can be used instead of the thermometer and stopclock.)

Second set-up

- Expanded polystyrene cup
- Thermometer
- Heater
- Ammeter and voltmeter
- Stopclock

D. Procedure

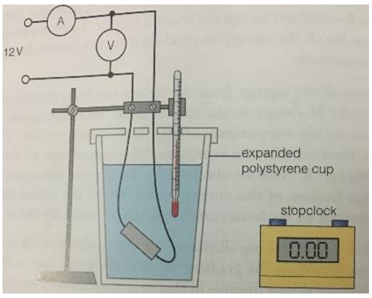
First set-up



- Set up the apparatus as shown in the diagram.
- Measure the mass of the calorimeter (m_c) and fill it with a known mass of water (m_w). There must be enough water to cover he immersion heater when it is put in the calorimeter. Place the muff over the calorimeter.
- Switch on the heater. Set the voltage (V) to a convenient value and record this with the value of the current (I).
- Measure the initial water temperature (θ) using a thermometer and start the stopclock (or use a temperature sensor and datalogger).

- Record the temperature at one-minute intervals, stirring just before the thermometer is read.
- Switch off the heater when the temperature reaches 50°C.

Second set-up



- The heater is a 15Ω, 11W ceramic body, wire-wound resistor. A 12 V power supply is used, with digital meters set on the 20V and 2A ranges respectively.
- Using a measuring cylinder, 120 ml of water is poured into the expanded polystyrene cup.
- The initial temperature θ_i of the water is taken. The power supply is then switched on and, at the same time, the stopclock is started. The current I and V are recorded.
- After a time Δt of 5.0 minutes has elapsed, the heater is switched off, the water is stirred thoroughly and the highest steady temperature θ_f reached by the water is recorded.

The specific heat capacity c of the water can be calculated from:

$$c = \frac{IV\Delta t}{m(\theta_f - \theta_i)}$$

E. SOURCES OF ERROR

- Energy is absorbed by the heater itself (making the value of c too large).
- Energy is transferred to the surroundings, mainly from the top of the cup (also making c too large).
- A little energy will be taken by the cup and the thermometer (making c too large).
- Inaccuracy of the thermometer, especially $\Delta\theta$ is fairly small (this could make c too large if $\Delta\theta$ were too small or too small if $\Delta\theta$ were too large).
- Inaccuracy of the meters (again, this could affect the value of c either way).

F. CONCLUSION

14-) Demonstrating the pressure law

A. Introduction

When we are looking at the behaviour of gases we have **four variables** to consider – the mass, pressure, volume and temperature of the gas. These four variables are related by the ideal gas law equation:

$$pV = nRT$$

In order to investigate how these quantities are related, we need to keep two constant while we see how the other two vary with one another.

The aim of this experiment is to investigate how the pressure of a gas changes when it is heated at a constant volume, thus two factors investigated are pressure and temperature.

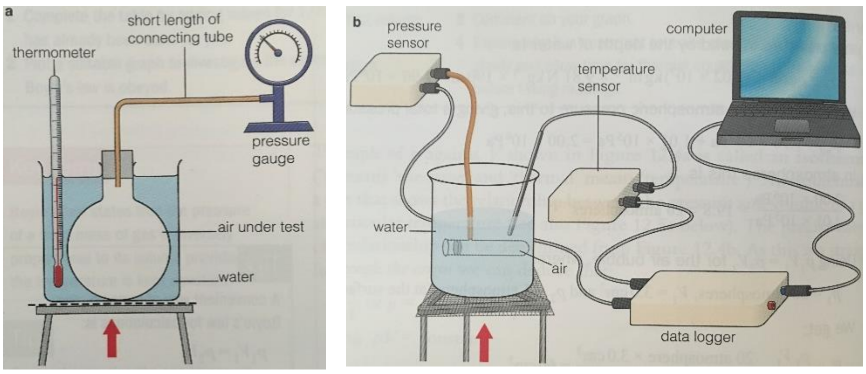
B. Safety

Wear eye protection if your face is to be close to the hot water.

C. Apparatus

- Round-bottomed flask
- Temperature sensor and probe
- Rubber bung with a short length of glass tube fitted through it
- Length of rubber tubing
- Pressure sensor
- Bunsen burner, tripod, gauze and mat
- Glass beaker
- Water
- Ice
- Eye protection

This experiment can be performed either using a thermometer and a pressure gauge or using temperature and pressure sensors with a suitable datalogger. Note that the tube connecting the container of air to the pressure gauge/sensor should be as short and of small an internal diameter as possible to reduce the volume of air inside the tube to a minimum, because this air will not be at the same temperature as that in the flask.



D. PROCEDURE

- Initially the beaker is packed with ice to get low a starting temperature as possible.
- Record the temperature of the water (effectively the temperature of air in the flask) and the pressure of the air.
- Light the Bunsen burner and heat the water slowly.
- Record the pressure and temperature of the air at 10-degree intervals until the water temperature reaches 80°C.

E. ANALYSIS

Plot a graph of the pressure of the trapped air (y-axis) against the temperature of the trapped air (x-axis). (Make sure that the pressure you record is the pressure of the trapped air, not just the excess above atmospheric pressure. It is assumed that the temperature of the trapped air will be the same as that of the water in the beaker.

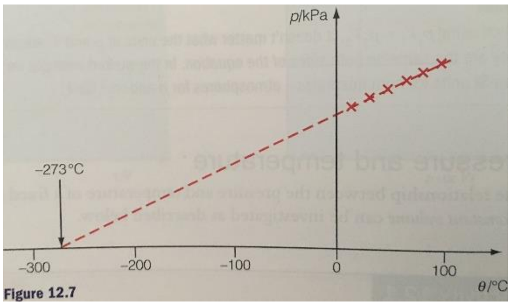


Figure 12.7

Draw a second graph with the temperature axis showing -300°C to +100°C and find the intercept on the pressure axis. This should be at absolute zero.

Record your value for absolute zero, suggesting any inaccuracies in your experiment and how they might be reduced.

F. VALIDITY OF THE STUDY AND IMPROVEMENTS

- Extrapolation
- Inaccuracy in thermometer
- Uneven heat distribution

G. CONCLUSION

As the graph is a straight line through the origin, it shows that

$$p \propto T \text{ or } \frac{p}{T} = constant$$

for a fixed mass of gas at constant volume.

15-) Demonstrating Boyle's law

A. Introduction

Boyle's law states that:

For a constant mass of gas at a constant temperature, the pressure exerted by the gas is inversely proportional to the volume it occupies.

This relationship can be derived from the ideal gas law equation as was the case in the previous experiment.

The aim of this experiment is to verify the relationship between the pressure and volume for a gas.

$$p \alpha \frac{1}{V}$$

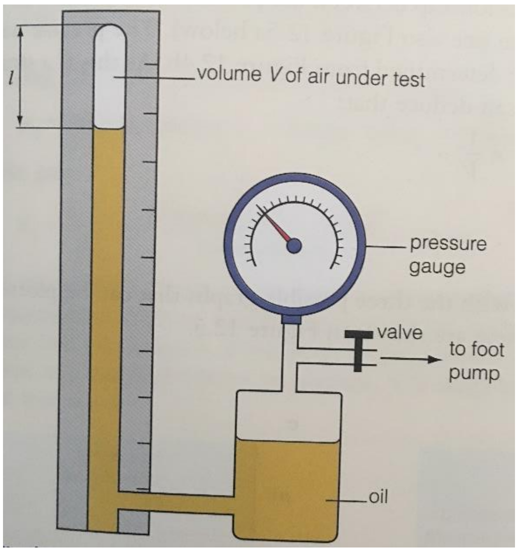
B. Safety

The apparatus should include a protective plastic screen around the glass tube. However, a safety screen is advisable.

Do not increase the pressure to more than 300 kPa.

C. Apparatus

- Boyle's law apparatus
- Bicycle pump
- Length of thick-walled rubber tubing
- Thermometer
- Safety screen



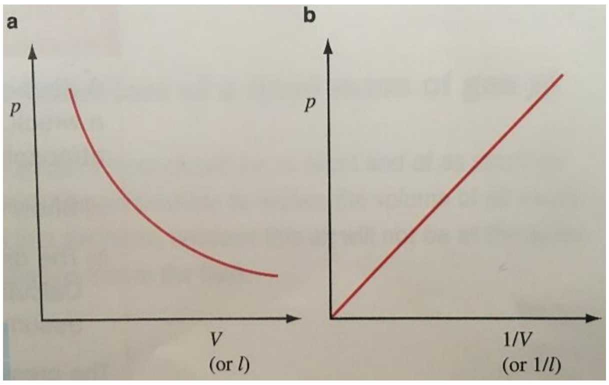
D. PROCEDURE

- The simple apparatus shown can be used.
- The volume V of the fixed mass or air under test is given by the length l of the column air multiplied by the area of cross section of the glass tube. If the tube is uniform, this area will be constant, so we can assume that $V \propto l$.
- The total pressure of the air is read straight off the pressure gauge.
- The valve is opened so that the air starts at atmospheric pressure and then the pressure is increased by means of the foot pump. This pressure is transmitted through the oil and compresses the air.
- The pressure p and the corresponding length l of the air column are recorded for as wide a range of values as possible. --- It is important to leave sufficient time after each change in pressure for the air to reach thermal equilibrium with its surroundings so that its temperature remains constant.
- The measurements of p and l are tabulates, together with values of 1/l.

E. DATA

p/kPa	100	120	140	160	180	200	220	240
V/cm^3	20.1	16.6	14.4	12.4	11.2	9.9	9.1	8.4
$(1/V)$cm^{-3}	0.050	0.060	0.070	0.081	0.089	0.101	0.110	0.119
$(1/V)/10^3$ m^{-3}	50	60	70	81	89	101	110	119

F. REPRESENTATION OF DATA



G. VALIDITY OF THE STUDY AND IMPROVEMENTS

- Constant temperature must be ensured.
- Gas should not escape.

H. Conclusion

The graph of p against V is called an isothermal. An isothermal is a curve that shows the relationship between the pressure and volume of a gas at a particular temperature. As this is a straight line through the origin we can deduce that:

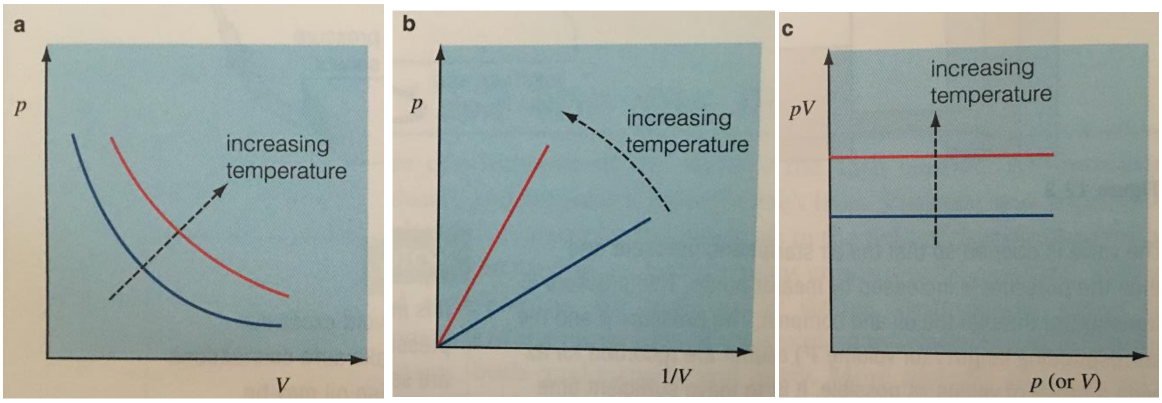
$$p = \frac{1}{V} \text{or} p = constant \times \frac{1}{V}$$

Giving pV = constant

A convenient way of remembering Boyle's law for calculations is:

$$p_1V_1 = p_2V_2$$

Three different graphs may be drawn which illustrate Boyle's law and these are shown below along with how each graph would be altered with an increase in temperature.



16-) Measuring background radiation

A. Introduction

We live in a radioactive environment and the radiation, which is constantly present in our environment, is called background radiation. There are various sources of background activity. The main natural sources of background radiation are:

- Radioactive gases (mainly radon) emitted from the ground
- Radioactive elements in the Earth's crust – mainly uranium and the isotopes it forms
- Cosmic rays from outer space which bombard the Earth's atmosphere producing showers of lower-energy particles such as muons, neutrons and electrons
- Naturally occurring radioactive isotopes present in our food and drink, and in the air we breathe

The aim of this experiment is to measure the background count rate.

B. Apparatus

- Geiger – Müller tube and counter
- Stopclock

C. Procedure

The Geiger-Muller tube detects radiation. Each time it absorbs radiation, it transmits an electrical pulse to a counting machine. This makes a clicking sound or displays the count rate. The greater the frequency of clicks, or the higher the count rate, the more radiation the Geiger-Muller tube is absorbing.

It is easy to determine the average background radiation in your area using a Geiger-Müller tube and counter. As radioactive decay is a random and spontaneous process, the activity in your lab must be measured over a long period of time (30 minutes or more) and then an average calculated. Otherwise, you may find that the measurement is, by chance, particularly high or particularly low and thus does not truly indicate the average over time. For example, if the G – M tube and counter are set to counting for two hours, and the final count is then divided by 7200 seconds, this will give a good approximation to the average over time as the count time is long compared with the typical average count of about 0.5Bq.

17-) Modelling radioactive decay

D. APPARATUS

- Large beaker
- 24 dice

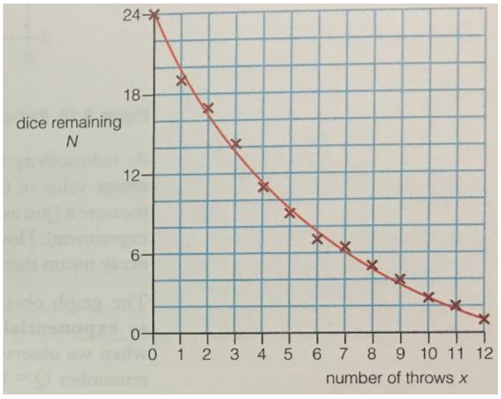
E. PROCEDURE

- Twenty-four dice (or small cubes of wood with one face marked with a cross) are shaken in a beaker and tipped onto the bench.
- All the dice that have landed with six uppermost are removed – these are deemed to have decayed.
- The number N of dice remaining are then counted.
- This process is repeated until all the dice have decayed.
- A graph of N against x (the number of throws) is plotted.

F. DATA

Number of throws, *x*	0	1	2	3	4	5	6	7	8
Dice remaining, *N*	48	41	32	27	23	18	15	14	10

G. REPRESENTATION OF DATA



H. ANALYSIS

The curve is <u>not smooth</u> because whether or not a six is thrown is a random event, just like radioactivity. It is instructive to repeat the experiment and average the results, or else combine the results with those of one or more classmates. It will be found that the more results that are combined, the smoother the curve will become.

Radioactivity is a random process similar to throwing dice, although it differs from this dice-throwing model insomuch as it is a continuous process and the numbers involved are much, much larger.

"Decay constant" → Half-life

The rate of decay is proportional to the number of radioactive nuclei, which gives us the defining equation for radioactive decay, $-\frac{dN}{dt} = \lambda N$. The decay constant λ is therefore the probability of decay, which is 1 in 6 for throwing a six in our model.

$$x_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.693}{1/(6\,\text{throws})} = 4.2\,\text{throws} \approx 4\,\text{throws}$$

% difference between experimental and theoretical values

$$= \frac{4.2 - 3.7}{4.2} \times 100\% = 12\%$$

(Note that the theoretical value is used as the denominator)

I. CONCLUSION AND MODEL OF RADIOACTIVE DECAY

Radioactivity differs from the dice-throwing model as it is continuous. The concept of half-life is used to model radioactive decay. **Half-life of a particular isotope is the average time for a given number of radioactive nuclei of that isotope to decay to half that number**.

As radioactivity is an entirely random process, we can only ever determine an average value of the half-life because it will be slightly different each time we measure it. However, the very large number of nuclei involved in radioactive decay means that our defining equation, $-dN/dt = \lambda N$ is statistically valid.

The graph for radioactive decay is an exponential curve and the equation is:

$$N = N_0 e^{-\lambda t}$$

From this equation it can be deduced mathematically that the half-life, $t_{1/2}$, is related to the decay constant, λ, by the expression:

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

18-) Investigating the absorption of γ-radiation by lead

A. Introduction

Different types of radiation have different penetrating powers and can be stopped by different materials of various length. The absorption of any type of radiation is modelled as an exponential curve and the equation $N = N_0 e^{-\mu x}$.

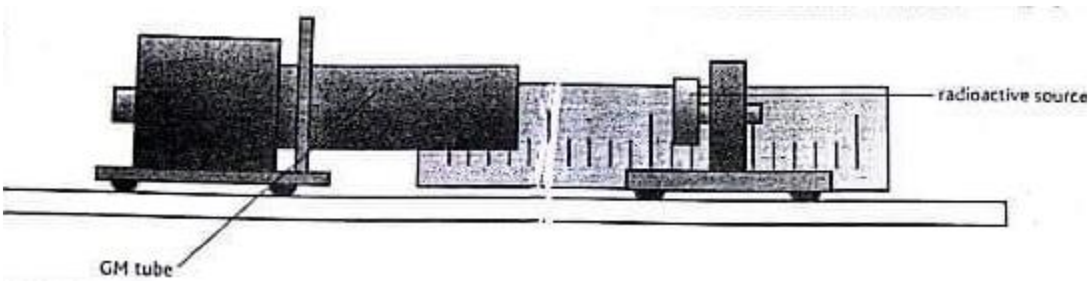
The aim of this experiment is to investigate the absorption of gamma radiation by several thicknesses of lead.

B. Safety

- A sealed source should always be used.
- The source must be kept in a lead-lined box in a special locked metal cupboard in a separate store room, labelled with the radioactivity symbol.
- Protective gloves should be worn.
- Always handle the source with tongs.
- Keep as far away from the source as possible.
- Keep exposure time to a minimum.

C. Apparatus

- Geiger – Müller (GM) tube, lead and stand
- Source holder
- Beta source
- Pair of long forceps
- Counter/scalar and stopclock
- Ruler



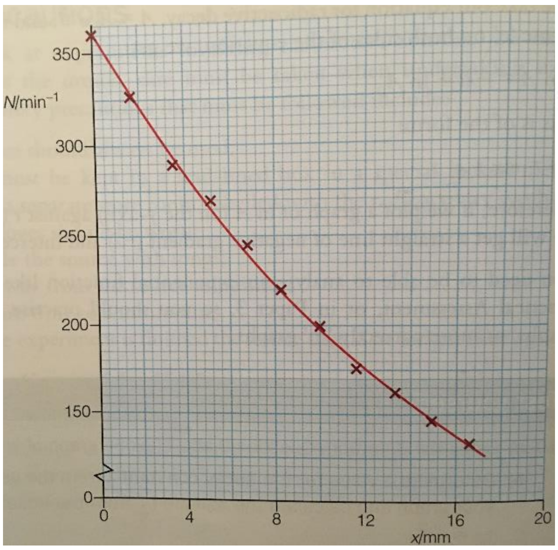
D. PROCEDURE

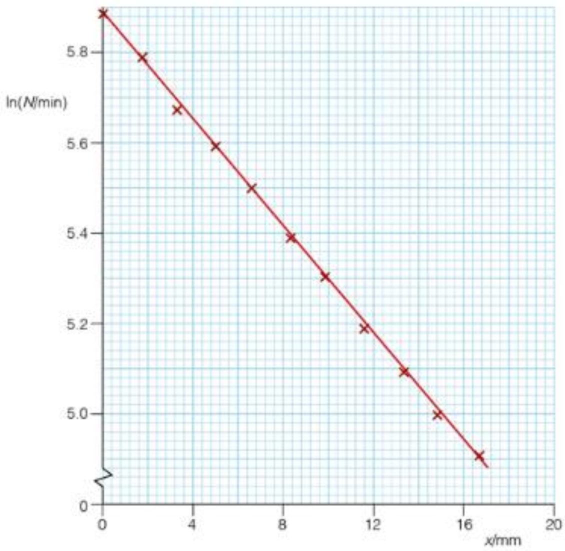
- The thickness of each of the discs is measured with Vernier callipers or a micrometre.
- The background count rate is recorded for 5 minutes. This is repeated and the average value subtracted from subsequent readings.
- Once this has been done, the source is put in position and the count N_0 with no lead discs in place is recorded.
- The count N is then taken for several thicknesses of x of lead by using the discs, either singly or in combination, as absorbers. Care must be taken to keep the distance between the source and G-M tube constant.
- A graph of the count rate N against absorber thickness x is initially plotted.
- To test whether the graph is an exponential curve, a graph of ln N against x should be plotted.

E. DATA

Total thickness of lead/mm	0.0	1.7	3.3	5.0	6.6	8.3	9.9	11.6	13.3	14.9	16.6
Counts/minute	372	342	304	283	259	234	216	194	178	162	150
Corrected counts/minute	358	328	290	269	245	220	202	180	164	148	136
ln (N/min^{-1})	5.88	5.79	5.67	5.59	5.50	5.39	5.31	5.19	5.10	5.00	4.91

F. REPRESENTATION OF DATA





G. Conclusion

The suggested relationship between N and x was:

$$N = N_0 e^{-\mu x}$$

Taking logs of both sides gives,

$$\ln N = -\mu x + ln\, N_0$$

This is equivalent to y = mx + c. Allowing for a bit of scatter, which is to be expected because of the random nature of radioactive emission, the **graph is a straight line of negative gradient, with intercept ln N_0**. This confirms that the absorption of the gamma radiation varies exponentially with the thickness of the absorber as proposed.

19-) Generating graphs of SHM

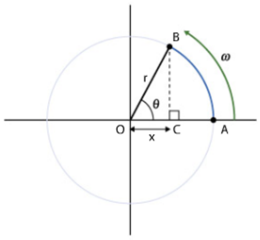
A. Introduction

Simple harmonic motion is periodic motion about an equilibrium position and all SHMs share two common characteristics:

- The resultant force acting on the oscillating body, and therefore its acceleration, is proportional to the displacement of the body.
- The resultant force, and therefore the acceleration, always acts in a direction towards the equilibrium position.

These conditions are combined into a simple equation:

$$F = -kx$$

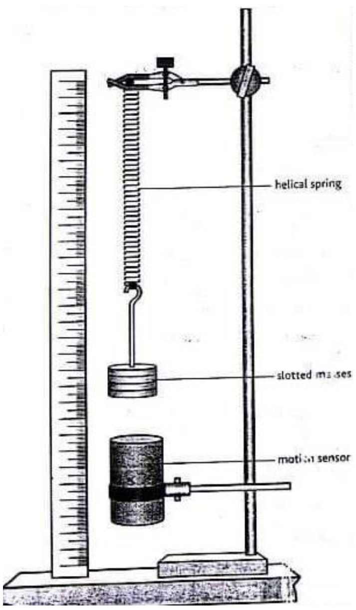


X is the horizontal distance from the centre. **The motion is a projection of a circular motion** so the equations for angular velocity, displacement, frequency and time are equally valid for simple harmonic motion.

When the object is at position A, this projected distance x is equal to the radius of the circle, r, but at position B this distance is shown by OC. This distance can be calculated from:

$$x = r\cos\theta$$

Or: $x = r\cos(\omega t)$



In this experiment a spring is used therefore r is replaced with A which denotes the displacement. The equation for SHM is then:

$$F = -kA\cos(\omega t)$$

The aim of this experiment is to generate graphs of some of the different properties of a system undergoing simple harmonic motion and interpret the graphs mathematically.

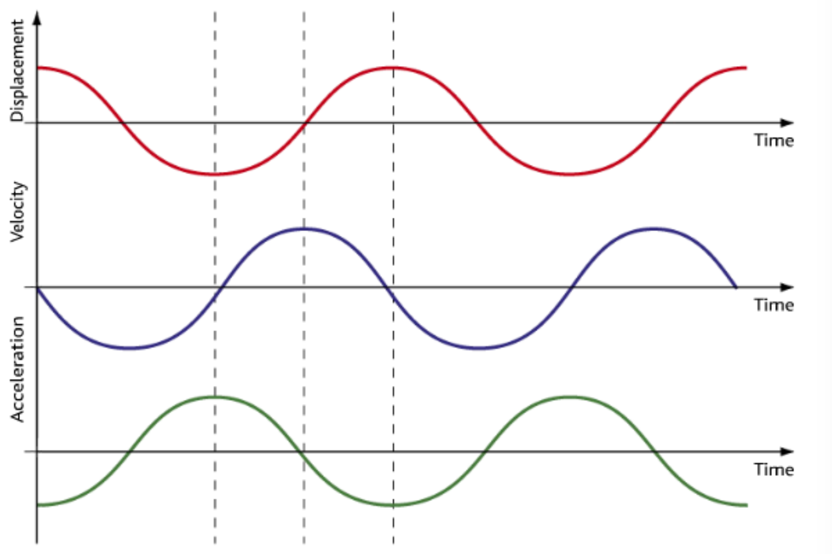
B. Procedure

This experiment is very simple as a motion sensor and a data logger are used. The set-up shown is arranged. A card is attached to the masses to give a good reflective surface, but may not be needed if the base of the masses is large enough. Typically the data logger might be set to record for 10 seconds at a sampling rate of 100 per second. The computer is programmed to plot the following graphs:

- Displacement against time
- Velocity against time
- Acceleration against time
- Acceleration against distance from the centre of oscillation
- Velocity against distance from the centre of oscillation

A graph showing the changes in kinetic and potential energy could also be plotted.

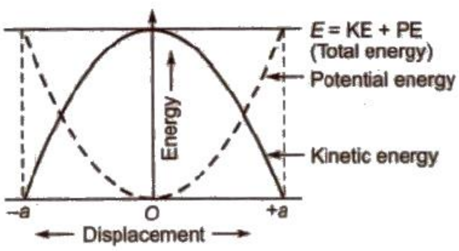
C. GRAPHS



Acceleration against distance from the centre of oscillation

Velocity against distance from the centre of oscillation

Energy



D. INTERPRETATION OF GRAPHS AND CONCLUSION

Displacement – time graph

The graph is a typical cosine graph. The equation of the graph is $\boldsymbol{x = A\cos(\omega t)}$:

Velocity – time graph

We can calculate the velocity of an oscillator at any moment from the gradient of the displacement – time graph.

Differentiating $x = A\cos(\omega t)$ gives:

$$\boldsymbol{\frac{dx}{dt} = -A\omega \sin(\omega t)}$$

This is the equation of the velocity – time graph. **It is sine graph reflected in the x-axis**.

Acceleration – time graph

Differentiating the function which represents the velocity – time graph gives the equation of the acceleration – time graph.

$$\boldsymbol{\frac{d^2x}{dt^2} = -A\omega^2 \cos(\omega t)}$$

Therefore, the **acceleration – time graph is a cosine function reflected in the x-axis**.

Acceleration against distance from the centre of oscillation

Velocity against distance from the centre of oscillation

Energy graph

Total mechanical **energy is conserved** and is exchanged between gravitational potential energy and kinetic energy.

20-) Forced oscillations

A. Introduction

A **free oscillation** is one in which no external force acts on the oscillating system except the force that gives rise to the oscillation. **Forced oscillations** occur if a force is continually or repeatedly applied to keep the oscillation going so that the system is made to vibrate at the frequency of the vibrating source and not at its own natural frequency of vibration.

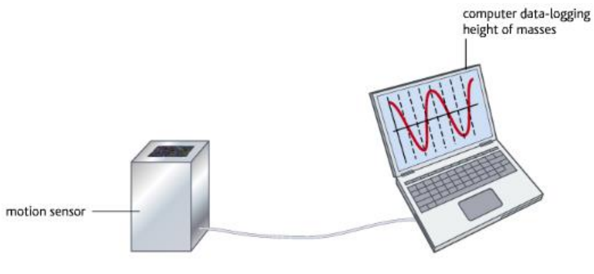
The aim of this experiment is to investigate how the amplitude of a system subjected to a forced oscillation varies with the driving frequency.

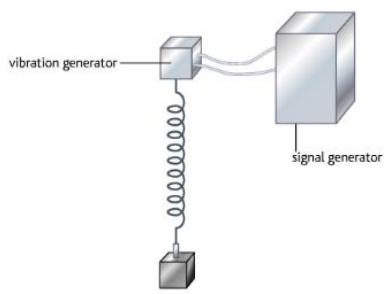
B. Safety

Wear eye protection.

C. Apparatus

- Spring
- Hanging masses
- Clamp and stand
- Datalogging laptop
- Motion sensor
- Signal generator
- Vibration generator





21-) Investigating damped oscillations

A. Introduction

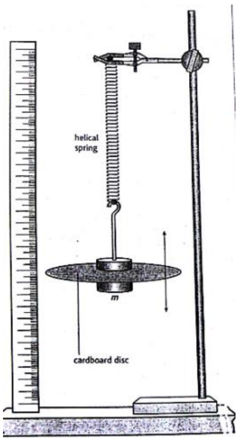
A **damped oscillation** is one in which energy is being transferred to the surroundings, resulting in oscillations of reduced amplitude and energy. An oscillating system does work against the external forces acting on it, such as air resistance, and so uses up some of its energy. This transfer of energy from the oscillating system to internal energy of the surrounding air causes the oscillations to slow down and eventually die away.

The aim of this experiment is to investigate the oscillations of an air-damped mass-spring system.

B. Safety

Take care masses do not fall and cause injury.

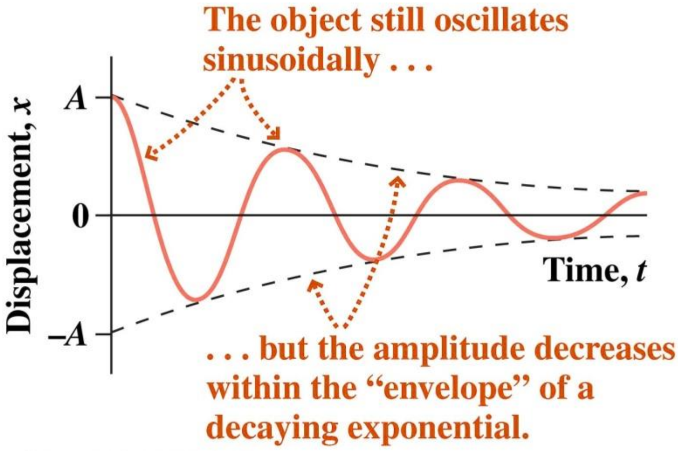
C. Apparatus



D. Procedure

- Set up the apparatus as shown in the diagram.
- The mass on the end of the spring (m) should be chosen so that the period is as long as possible without damaging the spring.
- Record the rest position of the mass.
- Pull the mass downwards (by about half the original extension) and release, allowing it to oscillate.
- Record the position of maximum displacement of the mass every 5 oscillations and hence calculate the amplitude (A) of oscillation each time.
- Repeat and take an average for each amplitude.

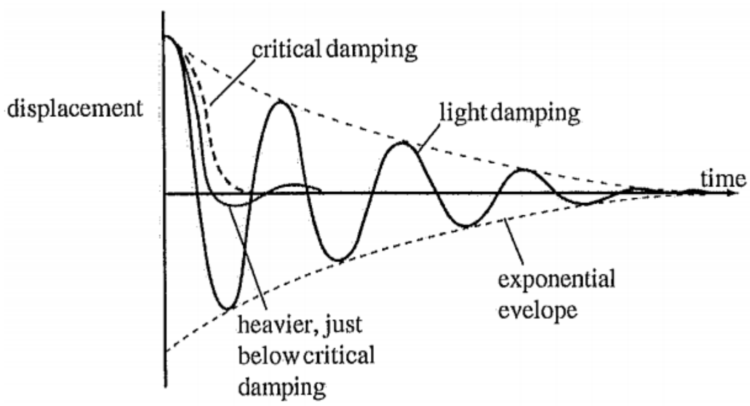
E. GRAPHS



F. SOURCES OF ERROR

- Parallax error in amplitude measurement
- The stand not perpendicular to the surface

G. CONCLUSION



22-) Standard candles

Luminosity and flux

Luminosity is the word astrophysicists use to describe the total output power of a star, unit W.

The electromagnetic wave energy per second per unit area from a star reaching us on Earth is called the radiation flux from the star, symbol F, unit W m^{-2}.

Luminosity (L) and radiation flux (F) are linked by the **inverse-square law**:

$$F \; or \; I = \frac{L}{4\pi d^2}$$

d is the distance from Earth to the star.

Therefore, the following equation can be used to calculate the distance of a star from Earth:

$$4\pi d^2 = \frac{L}{F} = \frac{luminosity}{radiation\; flux}$$

Standard candles

The problem in using the equation to measure how far it is to a star is how to determine the star's full power output – its luminosity L.

A type of star now called a Cepheid was discovered by Henrietta Leavitt. A Cepheid star has a luminosity that varies with time. Such stars appear more bright and less bright with periods of the order of days. Further, she was able to establish that the maximum luminosity L of a Cepheid star was related to the period T of its luminosity variation. For the first time it was thus possible, by measuring T for a Cepheid star that it is too far away to show any parallax wobble, to know the star's luminosity. Such stars are valuable standard candles.

A standard candle is a distant star of known (maximum) luminosity.

The process to find the distance d from Earth to a star is therefore:

- Locate a Cepheid variable star
- Measure its period T
- Find the star's luminosity L using Leavitt's T – L data
- Measure the radiation flux F from the star at Earth
- Calculate d using $d = \sqrt{\frac{L}{4\pi F}}$