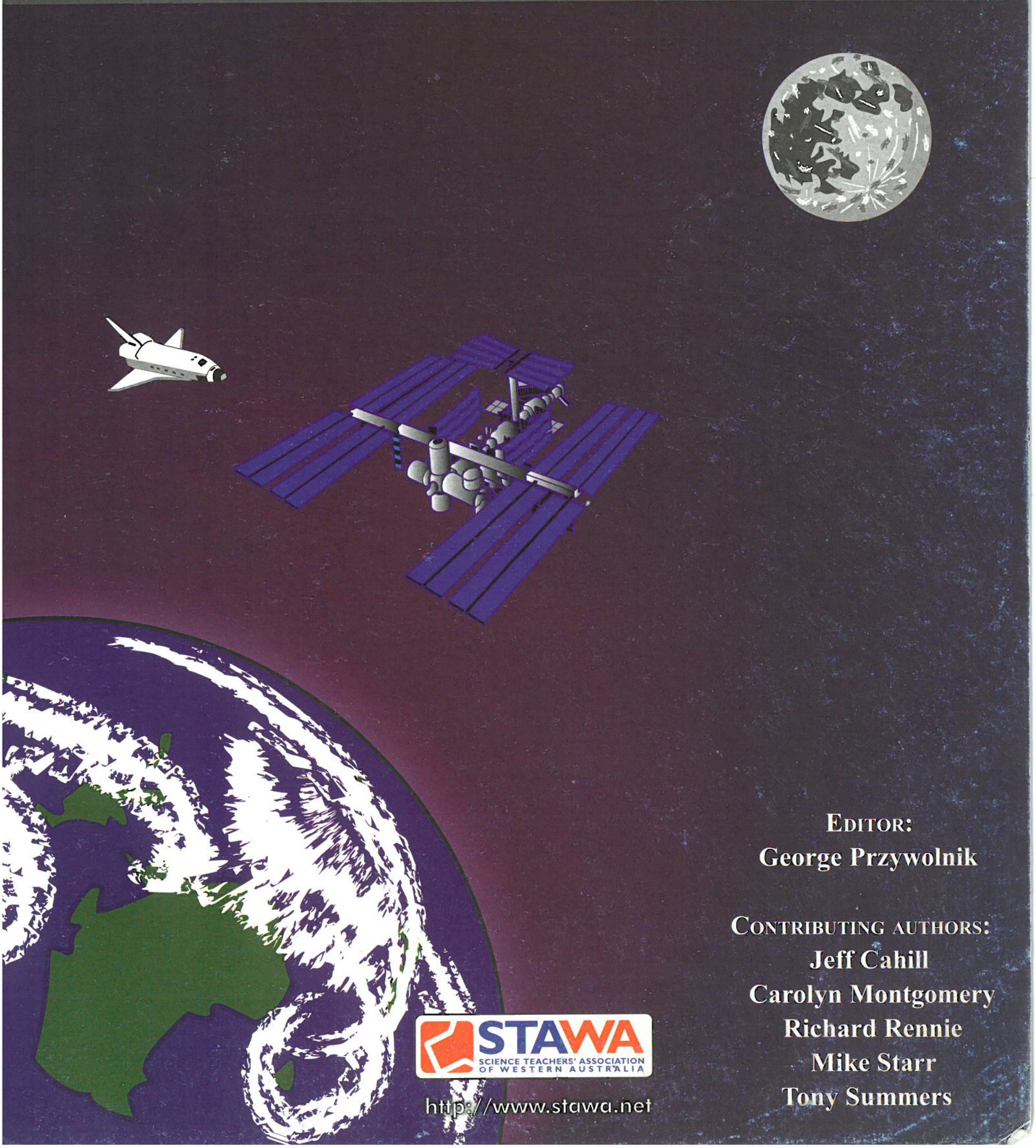
Exploring
PHYSICS

Stage 3

Second Edition



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SCIENCE TEACHERS' ASSOCIATION OF WESTERN AUSTRALIA
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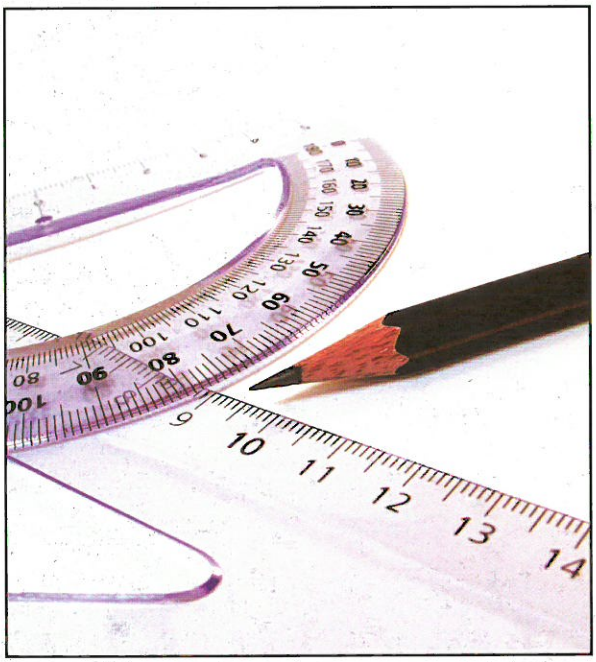
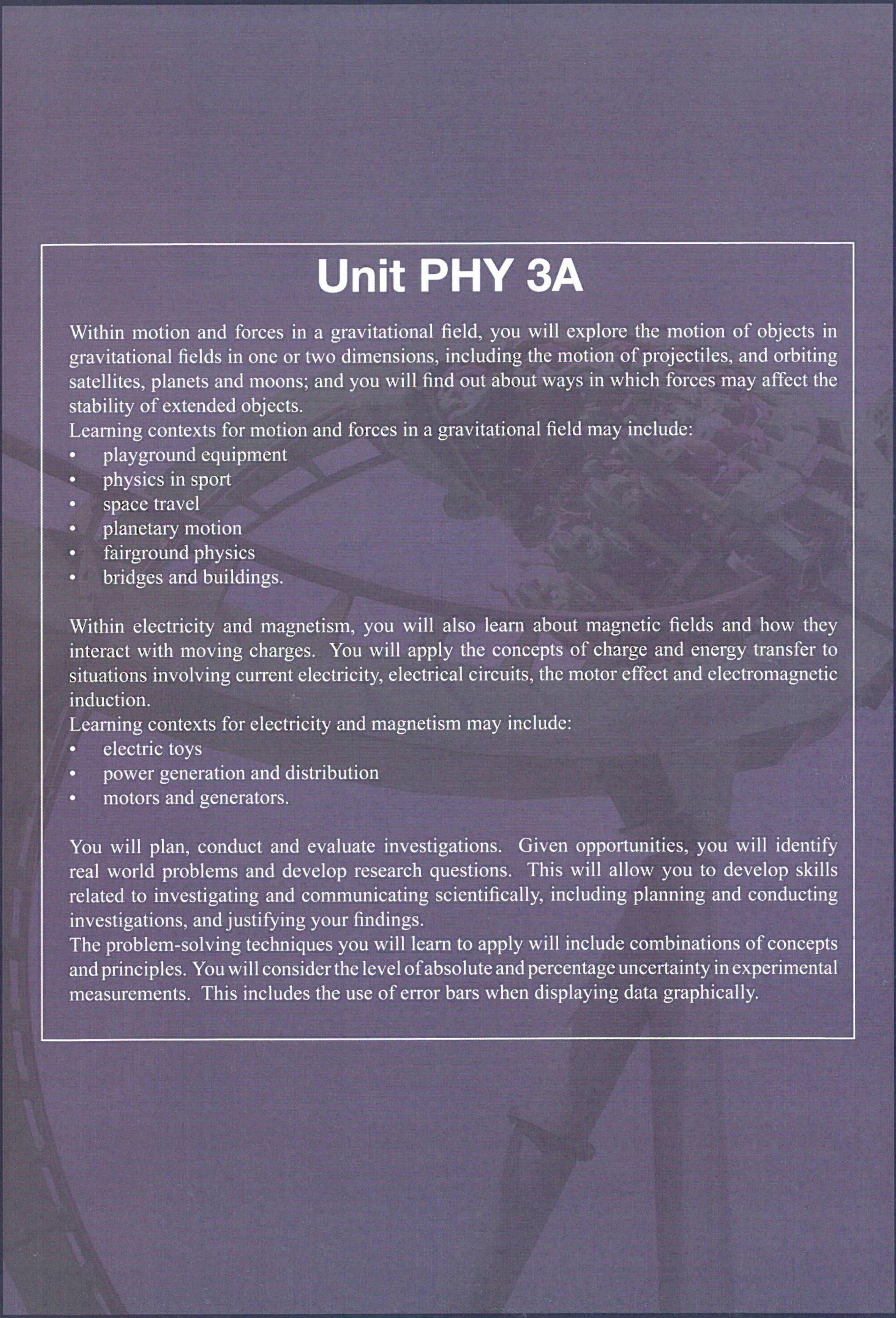
How to learn physics

- One good way is to form a study group of, say, three or four people. Each person in the group should try to help the others learn. (The best way to learn something is to teach it to someone else. While helping others, you will also help yourself.)
- In general: Do not try to memorise facts. Remember, the main emphasis in Physics tests and exams is usually on problem-solving, not recall of facts. Physics problems typically require a range of answer types, including: calculating or approximating numerical results; drawing or interpreting graphs; applying the gradient or area under the curve of a graph; explaining or predicting a phenomenon or experimental result; estimating uncertainties in measurement; and deriving a new formula or relationship from known formulae. You should practice all of these.
- Practice writing out answers in full. This means showing all the steps when you work out a numerical answer, and using complete sentences when explaining or predicting.
- Don't memorise equations. You will be given formulae and data sheets in tests and exams. Instead, know when, where or under what conditions each equation applies. Are the terms in the equation vectors or scalars?
- Learn about and analyse the units used for the quantities in an equation. In Physics, an equation like $s = ut + \frac{1}{2} at^2$ has consistent units. That is, the units of s are the same as the units of ut are the same as the units of at^2. (The term ½ is just a number and has no units). This consistency of units in equations is always true.
- Remember that numerical answers almost always have units. This includes the gradients and areas obtained from graphs.
- Vector answers should include the size (a number), the unit and the direction.
- If you see a quantity such as $\sqrt{\frac{F\ell}{m}}$, where F is force in newtons, ℓ is length in metres and m is mass in kilograms, you should be able to work out the unit for this quantity as a whole (in this case, 'metres per second').
You may be able to do this already – it is a useful skill.



- Think about how the equations apply to your life or things you have seen. Discuss these ideas in your group.
- The main task in Physics is almost always problem solving. Along with getting the correct or appropriate answer, you should always work out why that method works.
- If possible, apply basic principles to the problem - the steps will become clear if you play with it enough. (All physics problems are do-able, even easy, once you know how to do them.)
- Many students like to look at an answer and then work back to try to find what steps lead to it. This can be a useful strategy the first time that you try a new kind of problem, but beware of depending on this approach for all problems - in a test or an exam, you will not have access to the answer!
- If your group gets too social, it might not work too well. You need to focus on the physics. Shortly before a test or exam you will find the group tends to become more serious.



Unit PHY 3A

Within motion and forces in a gravitational field, you will explore the motion of objects in gravitational fields in one or two dimensions, including the motion of projectiles, and orbiting satellites, planets and moons; and you will find out about ways in which forces may affect the stability of extended objects.

Learning contexts for motion and forces in a gravitational field may include:

- playground equipment
- physics in sport
- space travel
- planetary motion
- fairground physics
- bridges and buildings.

Within electricity and magnetism, you will also learn about magnetic fields and how they interact with moving charges. You will apply the concepts of charge and energy transfer to situations involving current electricity, electrical circuits, the motor effect and electromagnetic induction.

Learning contexts for electricity and magnetism may include:

- electric toys
- power generation and distribution
- motors and generators.

You will plan, conduct and evaluate investigations. Given opportunities, you will identify real world problems and develop research questions. This will allow you to develop skills related to investigating and communicating scientifically, including planning and conducting investigations, and justifying your findings.

The problem-solving techniques you will learn to apply will include combinations of concepts and principles. You will consider the level of absolute and percentage uncertainty in experimental measurements. This includes the use of error bars when displaying data graphically.

World records and fun fairs

In weight-lifting, the bench press is performed while the weight-lifter lies on his or her back. The weight-lifter lowers the weight to chest level, then lifts it until the arms are straight and the elbows locked (or nearly so). In 2003, an Irish weight-lifter set a new benchmark for bench presses by lifting an accumulated total of 138 480 kg (that's over 138 tonnes) in one hour.

Roller coaster design also seems to be about pushing the boundaries. The table shows the relationship between maximum speed and the completion date for a number of famous roller coasters in the USA and Japan.

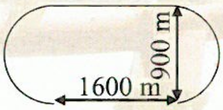
Completion Date	Maximum Speed (km h^{-1})
1996	130
2000	145
2001	170
2003	190
2005	205

Completed in 2005, a roller coaster in California called Kingda Ka offers extreme thrills. The steepest part of the track allows a vertical drop, and the passenger-bearing train exceeds 200 km h^{-1} in sections of the ride – a world record speed. The Kingda Ka also boasts the biggest vertical descent of any roller coaster yet built, with over 127 vertical metres separating the highest and the lowest parts of the track.

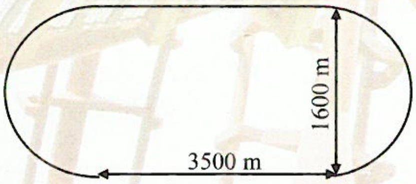
Both players and officials are more interested in the progress of a cricket game than in irrelevant details – any ball that goes over the boundary without bouncing first, earns the batsman six runs. Thus, while a number of cricket batsmen have hit balls that obviously travelled 100 m or more before touching the ground, there is no official longest recorded distance for a 'six'. Wikipedia reports, perhaps unreliably, that Yuvraj Singh of India hit a 'six' that travelled 128 m from the bat before coming to ground. If we assume that the ball was struck one metre above the ground, and that air resistance had no significant effect on the ball's flight, we can calculate that the lowest speed the ball could have had as it left Mr Singh's bat was 35.3 m s^{-1}. In reality, the special conditions required to allow this are most unlikely, and the ball's initial speed was almost certainly significantly higher than calculated.

The unrelated Red Bull pylon races pit individual pilots against the clock. Often, the pilot who can withstand the most 'g' during turns gets the fastest circuit time. Pilots are subjected to 9g or more for very brief periods (two or three seconds) during extremely tight turns. High g has potentially hazardous effects on a pilot. For example, at 3g every part of the pilot seems to weigh three times what it normally weighs, so even the slightest movement requires extraordinary effort. The heart has to work harder to pump blood, that suddenly weighs three times what it normally does, to the head. The result of high g can be loss of consciousness ('blackout') which at low level and high speed can be catastrophic. In general, the higher the g loading, the faster blackout takes hold.

Pylon racing is not for the faint-hearted pilot. Up to eight racers at a time fly their aircraft at very low level around a closed circuit. For "Formula One" racing aircraft this 5.0 km long, with straight legs of 1.6 km length and curved ends 900 m in diameter. The aircraft that completes eight laps in the fastest time wins.



Formula One pylon racing circuit



Unlimited pylon racing circuit

At 400 km h^{-1}, a competitor experiences a continuous centripetal acceleration of almost 3g when swinging around the curved ends (where $g = 9.8$ m s^{-2}). The record speed for "Formula One" class pylon racing, over a 5.0 km course, stands at 423.5 km h^{-1}. "Unlimited" class pylon racing allows the use of larger and much more powerful aircraft, most of which were designed as fighters for World War II, and are over fifty years old. A typical "unlimited" race circuit is 12 km long, and the speed record for this event is an eye-popping 801 km h^{-1}.

World records and fun fairs: Comprehension Questions

Comprehension Questions

1. Which do you think would be an advantage in doing bench presses - long arms or short arms? Explain your answer.

2. a) Estimate the power at which the record-setting bench presser operated when lifting 138 tonnes in one hour. State clearly any assumptions you have to make.

   b) One horsepower is equivalent to 0.746 kW. Express the bench presser's power in horsepower.

3. Construct a graph of completion date vs maximum speed for recently-constructed roller coasters. Use the graph to predict the maximum speed of a roller coaster to be completed in the year 2030. Is this prediction reliable? Explain.

   a) Calculate the speed that a roller coaster train could attain from a standing start if it dropped 127 m vertically.

   b) Compare your answer to (a) with the information given about the Kingda Ka roller coaster. Explain any discrepancies.

4. Some newly-built roller coasters have the steepest part of the journey at an angle greater than 90° to the horizontal. Would this make the train go faster than if it descended at 90°? Explain.

5. a) Consider Mr Singh's cricket ball, which travelled a large horizontal distance while dropping vertically for a very short distance. In general, the ball should leave the bat at a particular angle in order to maximise range for a given initial speed. To a close approximation, this angle is 45°. Verify that, based on the data supplied, the minimum initial speed of the ball must have been about 35.3 m s^{-1}.

   b) Sketch the shape of the ball's trajectory, assuming that air resistance is negligible.

   c) Determine the maximum height above the ground reached by the ball in its journey.

   d) Calculate the initial speed of the ball if it travels 128 m horizontally, but leaves the bat at an angle of 30°.

6. a) Show that, at 400 km h^{-1}, the centripetal acceleration on a Formula One pylon racer is almost 3g.

   b) Calculate how long it takes a Formula One pylon racer to turn through 180° at 400 km h^{-1}. This is the length of time for which the pilot continuously experiences high g.

7. a) Determine the centripetal acceleration on an Unlimited pylon racer completing a circuit at 800 km h^{-1}.

   b) For what time period does the Unlimited pylon racer experience high g?

   c) Why is the track for Unlimited pylon racing longer than the track for Formula One?

Chapter 1: Vectors Explained

Notes

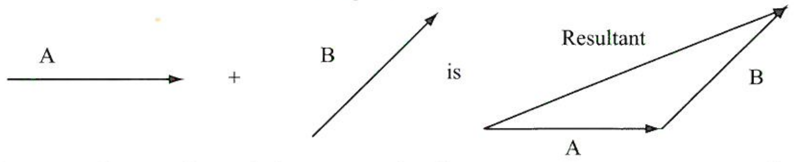
Remember the following important principles

You can represent a vector quantity with an arrow, where the length of the arrow represents the magnitude and the arrowhead represents the **direction**.

You can add or subtract scalar quantities arithmetically but you must **add or subtract vector quantities geometrically.**

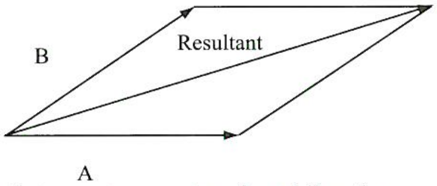
You can add vector quantities by putting the tail of one vector arrow at the arrowhead of the second vector arrow. The sum, or resultant, is a vector that begins at the tail of the first vector you added and ends at the arrowhead of the last vector you added. The diagram shows an example.

Adding Vectors



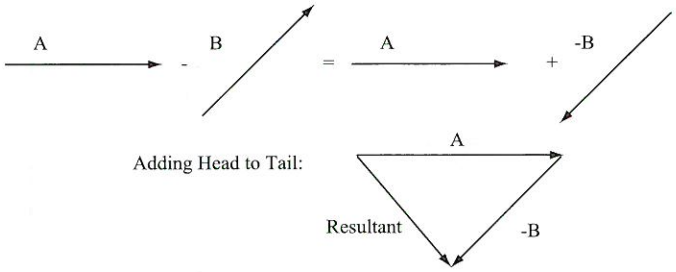
You can add vectors that act through the same point, known as **concurrent** vectors, by completing a parallelogram. The diagonal then gives the resultant, as illustrated.

ConcurrentVectors

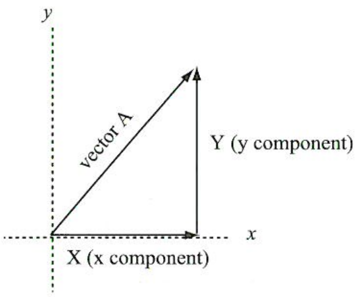


You can find the **difference** between two vectors by adding the negative vector of the vector you are subtracting. A negative vector is one of equal magnitude but opposite direction. You can represent the difference between two vectors A and B as shown below:

Difference BetweenVectors



A vector quantity can have an effect in directions other than that vector's direction. You can express any vector quantity as two vectors at right angles to one another, as long the sum of those two vectors is equal to the original vector. We call such vectors **rectangular components** of the original vector. For example, vector A can have components Y and X. You can convert (resolve) any vector into an infinite number of sets of mutually perpendicular components. Note that a vector has no components perpendicular to itself.



Experiment 1.1: Resolving forces

Background

You can resolve or break down a single force into two forces at right angles to one another. The two resolved forces or components when added together will give the original force.

In this experiment you will measure a force, the tension, and its vertical component, the weight, and the horizontal component, the thrust in the boom.

Notes

Aim

To show that a single force can be resolved into components at right angles to one another.

Apparatus

- Large retort stand with 2 boss heads and clamp
- 2 pieces of 10 mm diameter dowel or metal rod about 50 mm long, one with an eye hook in the end and the other with a short piece of plastic tube partly pushed onto one end
- Dowel - 8 mm diameter, 400 mm long with an eye hook at one end and a nail in the other end. (A level bubble attached to the boom is an easy way to make sure the boom is level)
- String or fishing line about 500 mm long
- Large protractor
- 2 spring balances (10 N)
- a set of slotted masses (e.g. 10 × 50 g)

Pre-lab

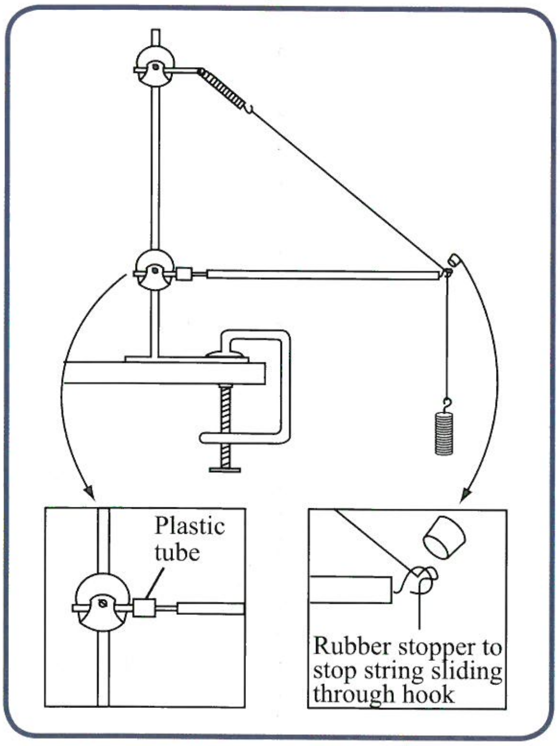
Draw tables similar to Tables 1 and 2 shown below.

	Trial 1	Trial 2	Trial 3
Angle between string and boom			
Tension T (N)			
Weight W (N)			
Thrust P (N)			

Record the weight (W) in newtons in Table 1.

	Trial 1	Trial 2	Trial 3
Vertical component of tension ($T_V = T \sin \theta$)			
Horizontal component of tension ($T_H = T \cos \theta$)			
Difference between T_V and W			
Difference between T_H and P			

Table 2



Set up the equipment as above.

Experiment 1.1: Resolving forces

Notes

Lab notes

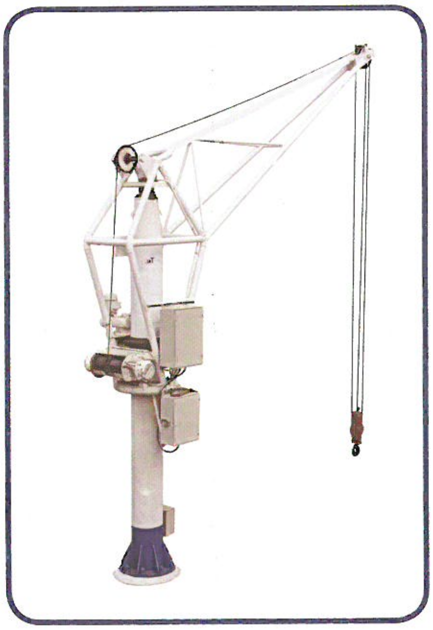
- Adjust the upper balance and string length until the boom is horizontal and the string is at an angle of between 40° and 65° to the boom.
- Measure and record the angle θ between the string and the boom.
- Attach the spring balance to the end of the boom and slowly pull it horizontally until the nail in the boom just moves free inside the plastic tube. Measure and record the horizontal force to achieve this. This is the thrust (P). Measure and record the tension (T) in the string.
- Repeat the experiment using two other values of the angle.

Processing of the results

- For each set of readings, complete the calculations set out in Table 2.
- Represent one of these situations graphically by selecting one set of results and drawing an accurate scale diagram showing all forces acting in this situation.

Post-lab discussion

1. On the basis of your results, write a general conclusion relating a vector to its components.
2. What happens to the tension in the string and the thrust on the boom as the angle is made smaller?
3. The weight of the beam in this experiment was ignored. Is this reasonable? Explain.
4. List the major sources of errors in this experiment.
5. Express the average difference between T_V and W as a percentage of W. Do the same for T_H and P compared to P. Are these errors acceptable?
6. Describe a practical situation you have seen that uses the principles examined in this experiment.



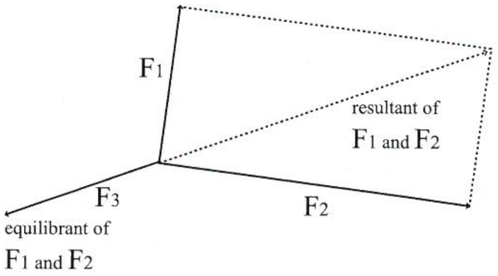
Experiment 1.2: Adding forces

Background

Notes

We define the resultant as the net force experienced by an object when two or more forces act at the same point on the object.

We call the single force that will balance the combined effect of the two or more forces, the equilibrant. Remember, forces are vector quantities so we can add them geometrically and since you will be investigating concurrent forces you may add the vectors by completing a parallelogram as shown below.



Determining the resultant force vector

Aim

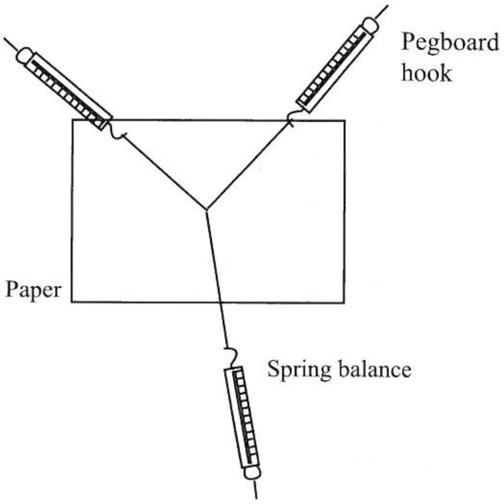
In this experiment you will measure three concurrent forces then compare the resultant of two of the forces with the third force. This third force is the equilibrant.
You will need to find the resultant and equilibrant of two forces acting at an angle to each other, and work out the relationship between them.

Apparatus

- Force table or pegboard approximately 1 m × 1 m
- three pegboard hooks
- three spring balances (10 N or 20 N)
- 1 m of string or fishing line
- protractor
- paper
- rule

Pre-lab

- Place the pegboard on a flat bench
- Connect the three spring balances using the string or fishing line as shown.
- Arrange the three balances so that each balance reads more than half the full scale reading and each reading is different from the others. You will find this easier if you first position two of the balances then adjust the position of the third.
- Arrange a sheet of paper under the strings so that the knot joining the strings is in the middle of the sheet. Carefully mark the point at which the strings meet and the other end of each string.



Experiment 1.2: Adding forces

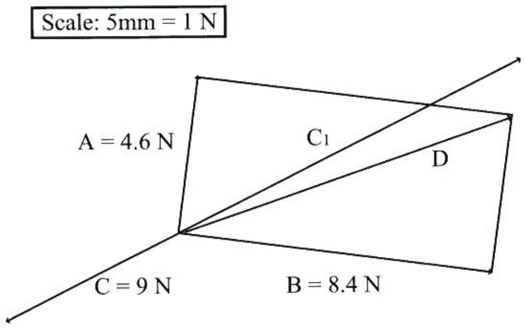
Notes

Lab notes

- Using a pencil and rule, you can now join the points to show the positions of the strings. Label the lines A, B and C in any order and write the balance reading near each string.
- Using a new piece of paper for each set of readings, change the position of the balances so you can measure three additional sets of results.

Processing of the results

- For each of your four sets of results select a suitable scale and draw a vector diagram to represent the forces you measured. Make sure you measure and draw the angles between the forces accurately.
- Add vectors A and B by constructing a parallelogram as shown in the example. Then draw D, the resultant of A and B.
- You can now draw the equilibrant of C and label it C_1. The equilibrant has the same magnitude as C but is in the opposite direction.



Relationship between the resultant and the equilibrant forces

- Complete the table below using your results from each trial.

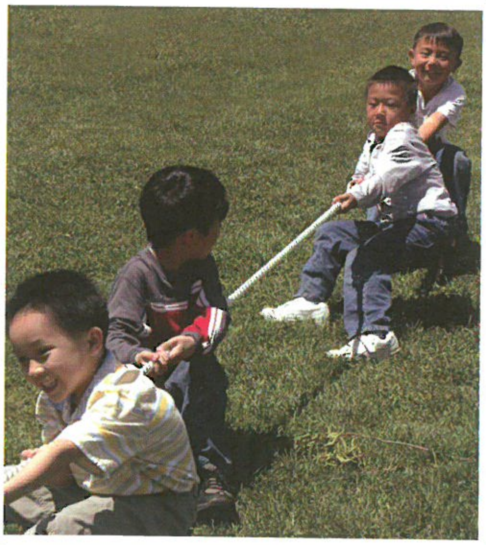
	Trial 1	Trial 2	Trial 3	Trial 4
Magnitude of A (N)				
Magnitude of A (N)				
Magnitude of D = A + B (N)				
Difference in magnitude of C_1 and D (N)				
Angle between D and C_1				

Experiment 1.2: Adding forces

Post-lab discussion

Notes

1. From your results state the relationship between the resultant and equilibrant for forces acting concurrently on a stationary object.
2. Choose one set of results. Add A and C using the same method used above. Compare the sum of these with B. Does the evidence support your conclusions?
3. Under what circumstances would A, B and C be equal in magnitude? Show this in a scale diagram.
4. Explain why differences exist between C_1 and D, and why the angle between C_1 and D is not always zero.
5. List the main sources of error in your experiment. How does each source of error contribute to the variation in your results?
6. From the context you are studying choose two examples where two forces act concurrently.
   a) Describe each example and draw a vector diagram to show the force vectors and the resultant in each case.
   b) For each example indicate whether the resultant force is unbalanced or not.



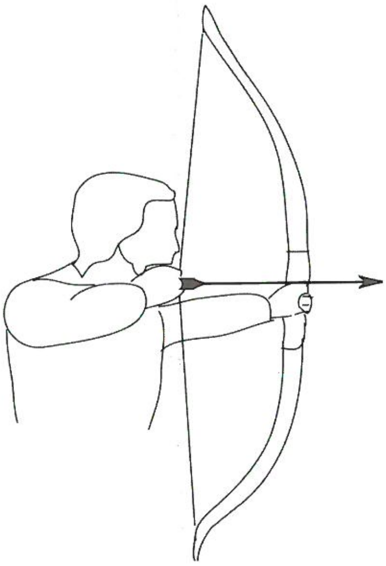
Problem Solving and Calculations

Set 1: Vector addition, subtraction and resolution

Notes

1. Explain why it is essential to describe both magnitude and direction of a quantity such as velocity.

2. A hockey player runs from fullback directly up the field for 15 m in an easterly direction to intercept the ball. He then dribbles the ball for 10 m in a northerly direction before passing the ball to a team-mate 20 m to the west.
   a) Calculate the player's displacement.
   b) Calculate the ball's displacement.



3. An archer stretches a bow so the string makes angles of 45° to the arrow. If the tension in the string is 208 N, what force is exerted on the arrow at the time of release?

4. A swimmer can achieve a speed of 1.5 m s^{-1} in still water. She heads directly across a rip in which the water is moving at a velocity of 3.5 m s^{-1} west. Determine her resultant velocity.

5. A canoeist can paddle a slalom kayak for short bursts at a speed of 2.7 m s^{-1} in still water. He wants to cross a stream in which a 2.0 m s^{-1} current flows.
   a) At what angle to the current must he point his canoe if he wants to land on the other bank directly opposite to where he started? Assume he paddles at top speed throughout his crossing.
   b) Calculate his resultant velocity if he heads directly across the stream at top speed.
   c) The stream is 40 m wide. How far downstream will he land on the opposite bank?

6. A cross country skier uses a compass to determine direction. She leaves a ski village and skis 3.0 km east, then 8.0 km south, then 10.0 km east, then 5.0 km south, then 3.0 km west, then 6.0 km north, and finally 4.0 km west. She wants to return to village by the most direct route.
   a) Draw a diagram to an appropriate scale and work out how far from the village she is.
   b) In what direction should she head to return to the village if the terrain will allow her to travel straight to the village?

7. A netball player is standing still when she catches the ball, that is moving at 5.5 m s^{-1}. Determine the ball's change in velocity.

8. A tennis player serves a ball at 80 km h^{-1} towards his opponent, who returns it directly back to the server at 90 km h^{-1}. Calculate the ball's change in velocity.

9. In a game of squash a player strikes the ball so that hits the side wall at 25 m s^{-1} at an angle of 45° to the wall. It rebounds at 20 m s^{-1} at an angle to the wall of 45° on the opposite side of the normal. Calculate the ball's change in velocity.

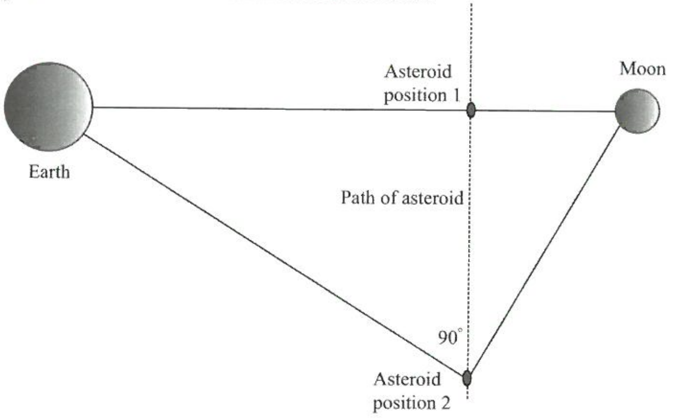
Set 1: Vector addition, subtraction and resolution

Notes

10. Two ice skaters hold one arm each of a third skate and each pulls with a force of 150 N. Calculate the resultant force pulling the third ice skater forward if the angle between his arms is a right angle.

11. A batter hits a cricket ball at right angles to its original direction. The bowler bowled the ball at 30 m s^{-1}. If the ball leaves the bat at 30 m s^{-1}, determine the ball's change in velocity.

12. A small asteroid passes between the Earth and the Moon.



The Earth attracts it with a force of 480 N and the Moon attracts it with a force of 53.2 N when the asteroid is in position 1. The forces of attraction are 359 N and 13.1 N respectively when the asteroid is in position 2. Work out the net force on the asteroid in positions 1 and 2.

13. An archer fires an arrow with a velocity of 45 m s^{-1} at an angle of 18° to the horizontal. What is its velocity the horizontal direction?

14. A marathon runner is running at constant velocity. A spectator looking eastwards notices that the runner is moving northwards at 1.40 m s^{-1}. At the same time another spectator looking northwards notes that the runner is moving eastwards at 1.10 m s^{-1}. Determine the runner's actual velocity.

15. A two person bobsled crew push the sled, one from each side, at an angle of 12° to the track with a force 600 N each.
    a) How much force do they apply to the sled parallel to the track?
    b) What is the force with which each crew member pushes against the other?

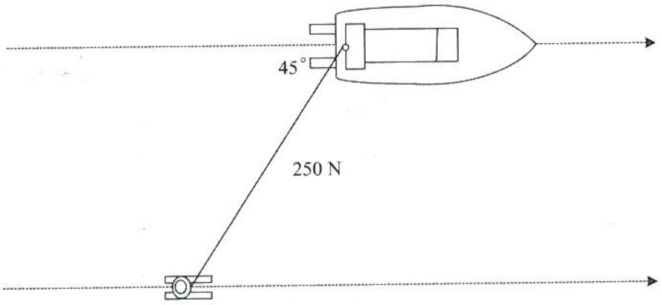
16. A golfer hits a ball with a velocity of 25 m s^{-1} at an angle of 35° to the horizontal. Immediately after she hits the ball, at what rate does it rise and at what rate does it move towards the pin?

17. A roller skater starts down a slope inclined at 25.0° the horizontal. The skater is not significantly affected by frictional forces. Determine the skater's acceleration.

18. Rachael reaches a constant speed of 35 km h^{-1} while sliding down a water slide inclined at an angle of 30.0° to the horizontal. How long does she take to descend a vertical height of 12 m once she reaches this speed?

Problem Solving and Calculations

Set 1: Vector addition, subtraction and resolution



19. A power boat tows a water skier. The skier is situated well to one side of the boat, but is travelling in the same direction as the boat. The tension in the rope is 25 N and the rope makes an angle of 45° to the direction of both boat and skier.
Determine the minimum force the skier must apply to the water to maintain this path.

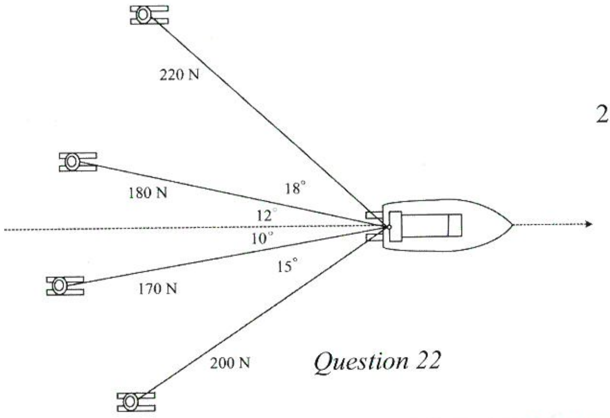
Question 19

Notes

20. During a football game a player kicks the ball eastward at a constant horizontal velocity of 13 m s^{-1} directly toward a team-mate 45 m away. There is a crosswind blowing from the north at 8.5 m s^{-1}.
    a) How much time does the team-mate have to get into position to catch the ball?
    b) How far does the team-mate have to run in a southerly direction to catch the ball?

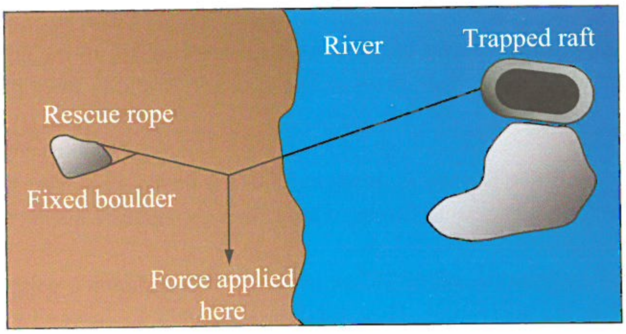
21. A truck driver supported a plank horizontally by its two ends. He then loaded bricks on its centre and found that the weight of 166 kg of bricks was just enough to break the plank. He wanted to use an identical plank as a ramp to load a full fuel drum of total mass 197 kg onto a truck.
    a) Explain why the driver could still use this plank to load the fuel drum.
    b) What is the minimum angle to the horizontal at which he could still use the plank to load the drum?

22. A ski boat is towing four skiers. The diagram below shows the tow ropes' tensions and angles. Calculate the total force the skiers apply to the boat.



Question 22

23. A vector pull is a very simple method rescuers use to increase the force on a rescue rope during river rescues.
Use a diagram with an appropriate scale to show that the force applied to the trapped raft is very much larger than the force applied by the rescuers.



Question 23

Chapter 2: Projectile Motion Explained

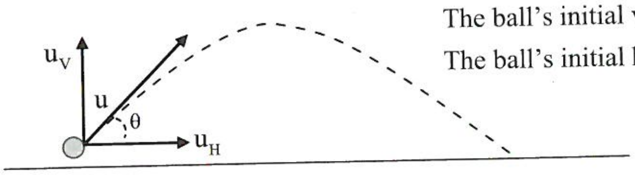
2

Notes

Remember the following important principles

A projectile, such as a cannon ball, a javelin, or a body rolled off the edge of a cliff has a complex motion that carries the projectile in both the vertical and the horizontal directions.

We must separate the projectile's motion into horizontal and vertical components before we can analyse it. Consider a soccer ball kicked with a velocity u (m s^{-1}) at an angle θ to the ground as shown. To work out how far it will travel and how high it rises, we first have to resolve the initial velocity into its horizontal and vertical components.



The ball's initial vertical velocity, $u_v = u \sin \theta$

The ball's initial horizontal velocity, $u_H = u \cos \theta$

Applying the rectilinear equations of motion ($v = u + gt$, $v^2 = u^2 + 2gs$ and $s = ut + \frac{1}{2} gt^2$) to the vertical component of the ball leads to expressions for the maximum height reached, s_v (m) and its time of flight, t (s) assuming that air resistance is negligible.

$$s_v = \frac{(u \sin \theta)^2}{2g}$$

$$t = \frac{2u \sin \theta}{g}$$

Since there are no horizontal forces acting on the ball, its horizontal velocity component remains constant and an expression for its range, s_h (m) can be determined using:

$$s_h = (u \cos \theta)t$$

Note that the gravitational acceleration term g does not appear in the horizontal motion equation. Note also that the time of flight, t is the same whether we consider the ball's horizontal motion component or its vertical component.

If we take account of air resistance, then the actual values for height, time of flight and range will all be less than those previously stated, and the flight path of the projectile will also change, decreasing the horizontal range.

Experiment 2.1: Projectile motion

Notes

Background

Objects such as balls, javelins, shot and people all fall to the ground because they experience an unbalanced force due to gravitational attraction between the object and the Earth. The path they follow results from this force as well as from the object's initial motion.

Aim

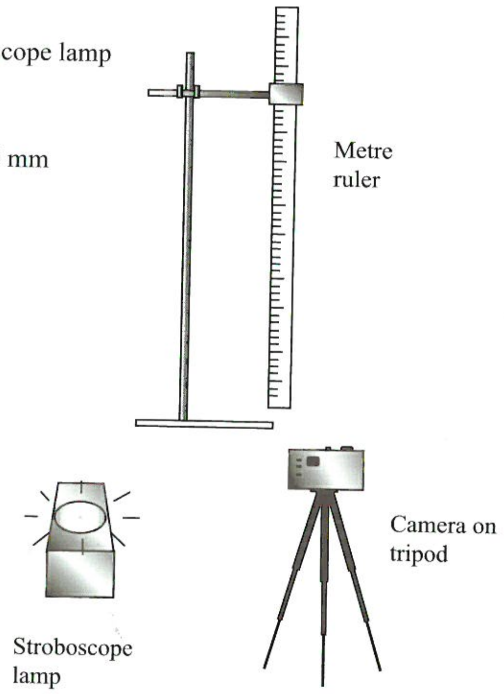
To study the motion of a projectile.

Apparatus

- golf ball
- a video camera or a still camera and a stroboscope lamp
- tripod
- computer and projector
- metre rule with white tape marking every 100 mm
- retort stand and clamp
- dark background (eg. black velveteen)

Procedure Part 1

- Set up the apparatus as shown (*right*). Make sure that you clamp the metre rule in a vertical position.
- Hold the ball at a height so that it is just inside the field of view when looking through the view finder of the camera.



Lab notes

- If you are using a still camera and a stroboscope, use a room that can be completely darkened and set the stroboscope to a flash rate around 10 per second. You may need to use a group member to follow the ball with the stroboscope light for adequate results.
- Turning the camera on its side may allow a longer distance for the ball to fall and still remain within the field of view.
- Side illumination of the ball will improve the clarity of the photograph.
- You will require at least two people to obtain results: one to drop the ball and one to operate the camera.
- Make sure that the person dropping the ball is not between the ball and the camera.
- This should be repeated to obtain at least two independent sets of results.

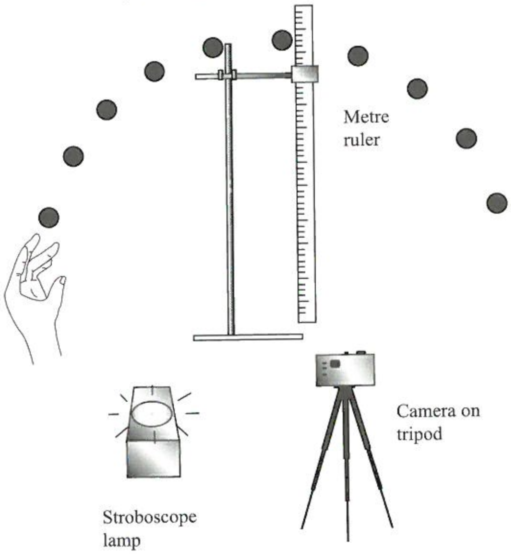
Notes

Procedure Part 2

- Repeat the above but this time, instead of dropping the ball, roll it off the end of a table or stool so that it has a horizontal initial velocity.
- You should try a few practice runs to make sure the ball stays in the field of view of the camera throughout its complete motion. It may be useful to mark boundaries.
- This should be repeated to obtain at least two independent sets of results.

Procedure Part 3

- Repeat the above but this time, throw the ball as shown in the diagram. This should be repeated to obtain at least two independent sets of results.



Lab notes

- Again you should try a few practice runs to make sure the ball stays in the field of view.
- In this part the camera should be placed horizontally so that a wider field of view is obtained. This should be repeated to obtain at least two independent sets of results.

Processing of the results

- Use freeze frame to select a series of images to use for measurements in each part of the experiment. Mark the same point (e.g. the leading edge) on each image of the ball. Make sure the metre rule is clearly visible, so that scale and the vertical direction may be determined.
- If using a still camera and stroboscope, record the flash rate (per second) and scale on each photograph. You will use these to calculate velocities.
- Draw a vector line joining the successive marked points, and on each line draw an arrowhead to indicate the direction the ball was moving. These arrows represent the average velocities of the ball in the intervals between images that is v_1, v_2, v_3
- Resolve each velocity vector into horizontal and vertical components. Measure the length of each component.
- Find the changes in velocity by vector subtraction, that is, $\triangle v_1 = v_2 - v_1$, $\triangle v_2 = v_2 - v_3$ and so on for all images.
- Determine the magnitude of each change in velocity ($\triangle v$).
- Determine the acceleration associated with each change in velocity.

Experiment 2.1: Projectile motion

Notes

Post-lab discussion

1. Refer to your results in Part 1. Make a general statement about the magnitudes of successive vertical velocities.

2. Refer to your results in Parts 2 and 3 to describe the magnitudes of successive:
   - horizontal velocities
   - vertical velocities

3. Refer to your results in part 3. What can you infer about:
   - the vertical velocity at the maximum height?
   - vertical speeds at the same height on either side of the highest point of the trajectory?
   - the upward and downward times of flight past the same level?

4. For each part of this experiment, what is the direction and magnitude of the acceleration? Compare the values for each part. Explain your observations.

5. What would be the value of the acceleration of the ball at the top of its flight in Part 3? Explain.

6. What mathematical curve does the path of the ball follow in Parts 2 and 3?

7. What factors could affect the accuracy of the results in this experiment?

8. You ignored air resistance in this experiment. Was that a reasonable approximation?

9. Would air resistance have a significant effect on the results if you had used a table tennis ball instead of a golf ball? Why, or why not?

10. How would air resistance affect the trajectory of the table tennis ball in Parts 2 and 3? Explain.

Experiment 2.2: Projectile motion and air resistance

Background

Notes

We usually make a number of assumptions before we describe the path of an object projected into the air. These assumptions include that air resistance is negligible, that the acceleration due to gravity is constant, that the Earth's surface is flat and that the Earth does not rotate.

In particular, the shape of the object (strictly speaking, its drag coefficient) and wind or other movement of the air can significantly affect the path of a projectile over relatively short distances.

Repeat the procedures for Experiment 2.1, using first a small, dense projectile such as a ball bearing, and secondly a larger, less dense projectile such as a ping pong ball or a ball made of expanded polystyrene.

Report on the effect that air resistance can have on a projectile. Compare your findings to your answers to questions 8, 9 and 10 at the end of Experiment 2.1.

Problem Solving and Calculations

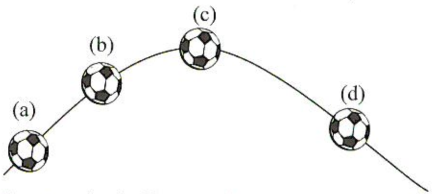
Set 2: Projectile motion and air resistance

Notes

1. If you want to throw a ball as far as is theoretically possible the best angle to throw it is 45° above the horizontal. Explain why this gives the maximum range.

2. A fielder on the boundary of a cricket oval returns the ball to the wicketkeeper. Why does the force of gravity not affect the horizontal velocity of the ball?

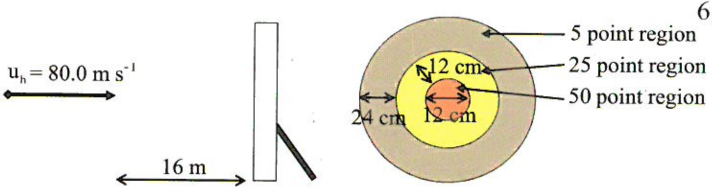
3. The figure below shows the flight path of a soccer ball. It is shown at four positions:
(a) just after it is kicked,
(b) as it rises,
(c) when it is at the top of its path
(d) and as it falls



Show with an arrow the resultant force acting on the ball at each position. If there is no resultant force, write 'no force'. You may ignore the effects of air resistance.

4. A high-board diver jumps horizontally away from the diving tower. Draw a diagram to show the path she will take as she dives into the pool. On the diagram draw arrows to show her vertical, horizontal and resultant velocities at the top, middle and near the bottom of her dive.

5. In a shooting competition the target is 1000 m from the competitors. The shooters set the sights on their rifles so they aim a certain distance above the target. Explain why the bullet still manages to hit the target.



side and front views of target

6. An inexperienced archer in a competition aims his bow and arrow at the centre of a target. He stands 16 m from the target. The bow is capable of firing the arrow at 80.0 m s^{-1}.

Assuming that there is no air resistance, and the archer always fires the arrow at its maximum speed and it leaves his bow horizontally, what score will the archer achieve?

7. A long jumper jumps at an angle of 16.5°. If he launches with a velocity of 7.9 m s^{-1}, how far should he jump?

8. At a fun fair your friend and you decide to try your hand at a 'knock-em-down' game. The target is a stack of empty cans about four metres away at head height. You have four foam rubber balls to use. Your friend tells you to throw the balls as fast as possible. The operator advises you that throwing them more slowly may be better. Explain how each method could successfully knock down the stack of cans.

9. A gymnast dismounts from a beam by leaping into the air doing a somersault and then landing on the floor in a standing position. If she takes off from the beam in a standing position with a velocity that has a vertical component of 4.0 m s^{-1} upwards, how long is it before she lands on the floor? The beam is 1.1 m above the floor.

Problem Solving and Calculations 2

Set 2: Projectile motion and air resistance

Notes

10. A baseball player pitches the ball at an angle of 10° above the horizontal with a speed of 22.5 m s^{-1} towards the batter who is 19.4 m away. If the pitcher throws the ball from a height of 1.50 m from the ground, at what height does the batter hit the ball?

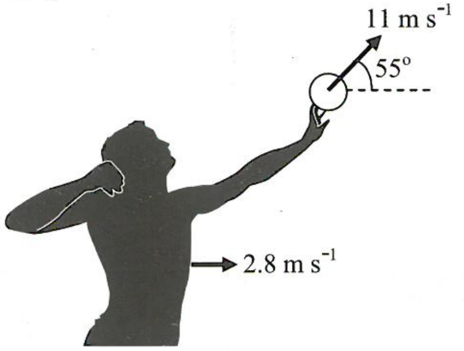
11. Brett kicks a football with an initial velocity of 18 m s^{-1} at 35° to the horizontal.
    a) How much time does Peter have to get to a position where he can catch the ball at the same height off the ground as Brett kicks it?
    b) How far does Peter have to be from Brett to catch the ball in this way?

12. An athlete can throw a javelin with a maximum velocity of 28 m s^{-1}. If she uses angles of projection between 25° and 40° above horizontal, what is the longest throw she can achieve?

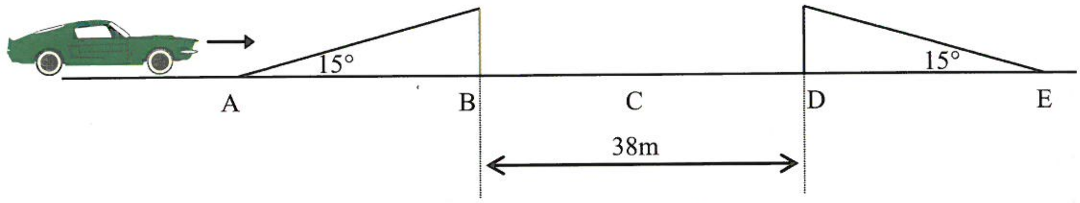
13. A springboard diver leaves the board 3.0 m above the water with a velocity of 2.3 m s^{-1} at an angle of 110° to the board. At what horizontal distance from the end of the board will the diver enter the water?

14. Helicopters are often used to drop water onto small bush fires. A helicopter approaching a bush fire horizontally at a speed of 21 m s^{-1} must release the water no closer than 160 m from the fire and then turn quickly away to avoid flying over the fire. What is the minimum height that this helicopter can fly to ensure that the water reaches the fire?

15. The shot-putter shown in the diagram throws his shot forward with a velocity of 11 m s^{-1} with respect to his hand, in a direction 55° above the horizontal. At the same time, the shot-putter's body is moving forwards horizontally, with a velocity of 2.8 m s^{-1}. At the moment of release, the shot is 2.4 m above the ground.
    a) Calculate the vertical and horizontal velocity of the shot putt at the moment it is released.
    b) Calculate the shot putt's maximum height above the ground.
    c) Calculate the throw (horizontal range) the shot-putter achieves.



16. A stunt woman is attempting to jump her car across a pair of ramps that are 38 m apart. To successfully complete the jump she must drive her car at a minimum constant speed up the ramp.



    a) If she leaves the ramp with an initial speed of 108 km h^{-1}, calculate (in m s^{-1}) the vertical and horizontal components of her velocity.
    b) Will there be a point during the flight of the car where the stunt woman and her car experience zero acceleration? If so where?
    c) What will be the velocity of the car at its highest point? You must justify your answer.
    d) At what point A, B, C, D, or E in her journey will she have the greatest speed? Why?
    e) At what minimum speed must she leave the ramp so as to make it to the other side?

Problem Solving and Calculations

Set 2: Projectile motion and air resistance

Notes

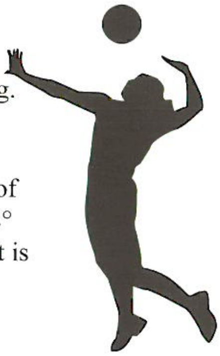
17. A cricket batsman is hitting the bowlers all over the ground. One shot that he makes just clears the fence on one part of the ground.

a) Sketch, using a solid line, the path the ball follows if it just clears the fence. Ignore air resistance.
b) Sketch, using a dotted line, the path the ball follows if it just clears the fence, this time taking air resistance into account. Show the forces acting on the ball at its highest point.
c) Another shot he hits goes straight back over the bowler's head. The fence is 64 m away and 1.4 m high. If he hits the ball with a velocity of 28 m s^{-1} at an angle of 35° to the ground, will he clear the fence? Assume that he strikes the ball at ground level, and ignore air resistance.

18. An archer fires an arrow horizontally towards a target with a velocity of 83.0 m s^{-1}. He fires the arrow from a position 1.35 m above the ground and it hits the bottom of the target, that is 0.450 m above the ground. Determine the distance between the archer and the target.

19. A basketball player shoots successfully at goal from a horizontal distance of 5.3 m to the centre of the goal-ring. She releases the ball at an angle of 48° to the horizontal and 1.2 m below the height of the ring. Calculate the ball's speed as it left her hands.

20. Marc returns a volleyball from near the floor as he stands on the middle of the baseline. He hits the ball with a velocity of 13 m s^{-1} at an angle of 48° above the horizontal directly towards his opponents' base line. The court is 18 m long and the ceiling in the gymnasium is 6.0 m above the floor.
a) Show that the ball does not hit the ceiling.
b) Show that the ball lands in the court if his opponents fail to touch it before it lands.



21. Very fast sprinters are often also very good at long jump. Explain why this might be so.

Chapter 3: Circular motion

3

Notes

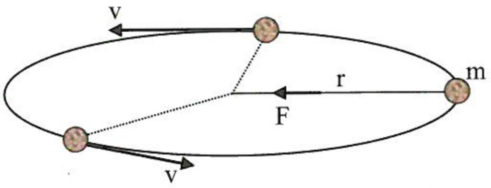
Remember the following important principles

Rectilinear motion describes the path of an object moving in a straight line. We can think of circular motion as the movement of a body in a series of very short, straight lines, that gradually change direction as it progresses.

That is,

is approximately equivalent to

Suppose an object is travelling at constant velocity. If you then apply a force at right angles to its direction of motion, its direction of motion will change. If this force is constant in magnitude and always at right angles to the object's motion, then the path of the object will be a circle. The deviating force points towards the centre of the object's circular path. The object's acceleration is also directed toward the centre of the circle. The object's velocity at any time has a constant magnitude and its direction is tangential to its circular path.



As an example, consider a mass, m being whirled around a horizontal circle on the end of a length of string. Even though it may be travelling with a constant speed, its **velocity** is changing since the direction in which the mass is moving is constantly changing.

The circular path described by the mass has an effective radius, r equal to the length of the string.

The direction of motion of the mass at any point is given by the tangent to the circular path at that point, as shown. Since its velocity is changing, then the mass must be accelerating, which means that there must be a resultant force, F acting on the mass. In this situation, the force is the tension in the string and, as for any object having circular motion, its direction is 'centre-seeking'. Such forces are called centripetal forces.

A centripetal force has a magnitude given by the mathematical relationship: $F_c = \frac{mv^2}{r}$

Where:

F is the centripetal force (in newtons)
m is the mass in kilograms (kg)
v is the speed in metres per second ($m\ s^{-1}$)
r is the radius of the circular path in metres (m)

The acceleration is also directed toward the centre of the path.

Newton's second law tells us that the magnitude of the centripetal acceleration, a_c is $a_c = \frac{v^2}{r}$

Other situations where a centripetal force is evident

Situation	What provides the centripetal force
Earth orbiting the Sun	Gravitational force of attraction between the Earth and the Sun
An object on the Earth's surface	Force of gravity on the object (its weight)
Car rounding a bend on a road	Frictional force between the tyres and the road

Notes

To find the speed of an object moving in a circle use:

$$v = \frac{\text{distance travelled}}{\text{time}} = \frac{2\pi r}{T}$$

Where:

T is the period (time taken to complete one revolution) in seconds (s)

The frequency is the number of revolutions an object completes in one second. It is the reciprocal of the period:

$$f = \frac{1}{T}$$

Where:

f is the frequency, in hertz (Hz)

Non-uniform circular motion

If an object moves in a circle that has a vertical plane then you must take the weight force of the object into account.

Consider someone whirling an object in a vertical circle on the end of a string. The speed of the object is not constant because at the top of the loop the object has gravitational potential energy as well as kinetic energy, while at the bottom of the loop its potential energy is converted into extra kinetic energy.

As it travels around the vertical circle, the object has two forces acting on it: the force exerted by the string tension; and the object's weight force, which always acts downward. The centripetal force is always the resultant of these two forces.

At the top of the circle the resultant centripetal force acts downward, and its magnitude is given by:

$$F_c = \frac{mv^2}{r} = F_1 + mg$$

where Fl is the force supplied at right angles to the motion (e.g. tension in the string) that keeps the object moving in a circular path. In this case, both F1 and mg act in the same direction, so we can treat both as positive.

In the special case where the object travels across the top of the circle at minimum speed, F1 is zero and the centripetal force is supplied entirely by the gravitational force mg.

At the bottom of the circle the resultant centripetal force is directed upward and its magnitude is given by:

$$F_c = \frac{mv^2}{r} = F_2 - mg$$

In this case, F2 and mg acts in opposite directions, so we cannot treat both as positive. Thus if F2 is taken as positive then mg must be negative.

Experiment 3.1: Going around in circles

Background

An unbalanced force must act on an object if that object is to accelerate.

$$a = \frac{F}{m}$$

Acceleration is the rate of change of velocity. Change of velocity can be either change of speed, change of direction, or both. Thus, a driver can make a car accelerate by turning it around a corner just as much as by pushing harder on the accelerator or brake. As it turns it is accelerating. Therefore, a net or unbalanced force is required to make the car go around the corner.

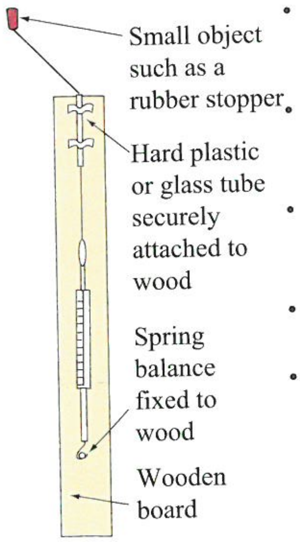
Aim

To study the relationship between some variables for an object moving in a circular path.

Apparatus

- a piece of hollow glass or hard plastic tubing - (150–250 mm)
- large rubber stopper
- fishing line or strong thin cord (1.5 m)
- metre rule
- stop watch
- sticking tape or alligator clip
- spring balance or set of 20 g or 50 g masses

Pre-lab



Apparatus for Experiment 3.1

- Using the equipment shown in the diagram you can investigate the effect on the centripetal force of changes you make to the radius of the circular path, the mass of the object or its speed.
- Note that you can carry out both qualitative (observation-based) and quantitative (measurement-based) investigations using this equipment.
- The glass tubing should be prepared by fire polishing the ends and then wrapping it in cellulose or plastic tape to help prevent it from cutting the line, or cracking and shattering.
- 20 or 50 g masses or large, identical washers and a paper clip can be used instead of a spring balance.
- Be careful. This experiment requires a good deal of space and so should be done outside. It is also advisable to practice whirling the stopper around so that you can control it when you are trying to record your results. Make sure the stopper is securely tied to the fishing line or cord.

Notes

Experiment 3.1: Going around in circles

Notes

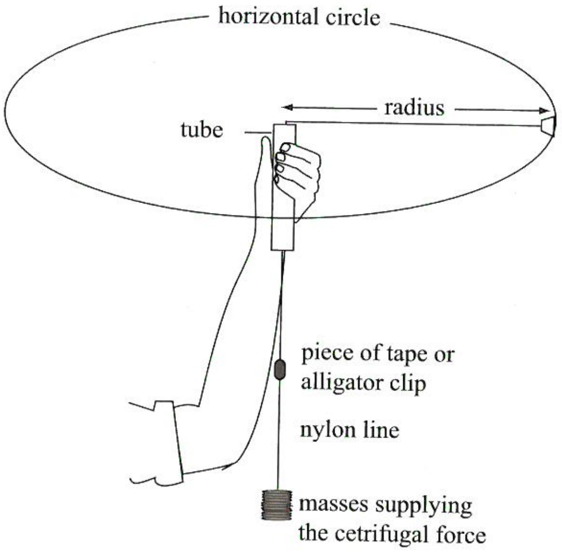
Lab notes

Part A: Variable force with constant radius

- Prepare a data table similar to the one below.

Mass providing centripetal force (kg)	Centripetal force (N)	Time for 20 turns		Average time per turn (s)	Velocity v (m s^{-1})	Velocity^2 v^2 (m^2 s^{-2})
		Trial 1 (s)	Trial 2 (s)			
0.200						

- Measure the mass of the rubber stopper accurately, and record the value.
- If you are using washers and a paper clip instead of slotted masses, measure and record the masses of these as well.
- Use an alligator clip or tape to mark the fishing line below the glass tubing so that you can measure the radius of circle of the revolving rubber stopper. The mark will help you to keep the radius constant.
- Attach a 200 g mass or an appropriate number of washers to the end of the fishing line. *This weight force will provide the centripetal force.*
- Whirl the stopper around so that it is revolving in a horizontal circle of radius 600 mm. You can do this by whirling the stopper with increasing speed until the alligator clip or tape is level with, but not touching, the bottom of the glass tubing.
- Record the time for 20 revolutions in the data table. Repeat to obtain several more results.
- Repeat the experiment with masses of 250 g, 300 g, 400 g and 450 g in the place of the 200 g mass. For each of these, keep the radius of the circular path constant at 600 mm.



Experiment 3.1: Going around in circles

Notes

Part B: Variable radius with constant force

- Prepare a data table similar to the one below.

Radius (m)	Time for 20 turns		Average time per turn (s)	Velocity v (m s^{-1})	Velocity^2 v^2 (m^2 s^{-2})
	Trial 1 (s)	Trial 2 (s)			
0.20					

- Use the same rubber stopper as in Part A and place a mass of 250 g on the end of the fishing line. You will use this throughout this Part.
- Reset the alligator clip or tape so the radius is 200 mm.
- Whirl the stopper at the speed required for it to revolve at a radius of 200 mm. Record the time for 20 revolutions. Repeat to obtain two sets of data.
- By increasing the speed of revolution, measure the time for 20 revolutions for radii of 400 mm, 600 mm, 800 mm, 1000 mm and 1200 mm. Repeat these measurements to obtain two readings for each radius. In each of these keep the 250 g mass on the end of the fishing line. For each trial, you should reset the alligator clip or tape.

Processing of the results

- For each set of results calculate the quantities listed in the tables, using $v = \frac{2\pi r}{T}$
- For the constant radius set of data, plot
  - a) centripetal force *vs* velocity, and
  - b) centripetal force *vs* velocity squared.
- For the constant force set of data, plot
  - a) radius *vs* velocity, and
  - b) radius *vs* velocity squared.

Post-lab discussion

1. Using the mass of the rubber stopper and any line of data from one of your results tables check the equation for centripetal force,

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

2. Determine the slope of the graph of centripetal force *vs* velocity squared. What does this slope represent? Compare it to the value obtained using the mass of the stopper and the radius of revolution.

3. Determine the slope of the graph of radius *vs* velocity squared. What does this slope represent? Compare it to the value obtained using the mass of the stopper and the centripetal force.

Experiment 3.1: Going around in circles

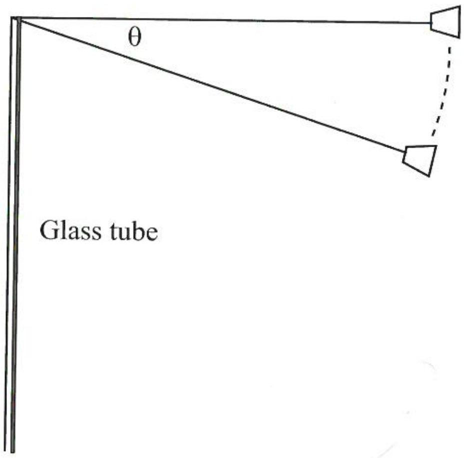
Notes

4. Describe the uncertainties in this experiment. Estimate the percentage uncertainty in the expression:

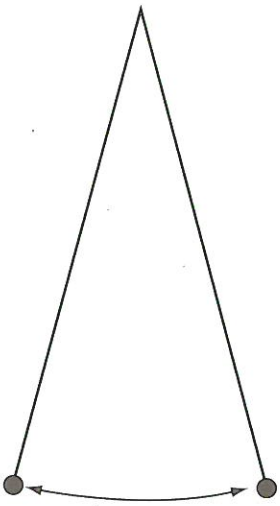
$$\frac{v^2}{r}$$

5. Does the fact that the string holding the stopper is not exactly horizontal affect the relation between F and v? Explain.

6. Determine the relation between F and v in terms of the angle (θ) between the string and the horizontal.



7. The bob of a pendulum swings through a circular arc of constant radius. At what point of the swing does the cord holding the bob exert the greatest centripetal force on the bob? Explain.



Conclusion

State the relationship you have obtained between the variables being investigated in each part of this experiment.

Problem Solving and Calculations 3

Set 3: Circular Motion

Notes

1. An Olympic hammer thrower whirls the hammer, which is a round metal ball on the end of a short steel wire, rapidly in a circle in preparation for the throw. If the athlete wants the hammer to travel due west, at what point should the athlete release the hammer? A diagram may help when you explain your answer.

2. Why does a sprinter running in a 200 m event lean towards the centre of the curve he is rounding?

3. A roller skater coasts around a curve at constant speed on a horizontal surface. What provides the centripetal force?

4. Use a diagram to clearly explain why engineers design banked curves on roads that have high speed limits.

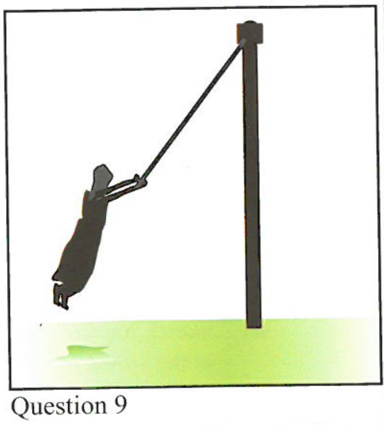
5. An ice skater glides around a curve of radius 15 m at a constant speed of 3.5 m s^{-1}. What is the skater's acceleration?

6. A baseball player swings a 0.585 kg bat in a horizontal arc so that its centre of mass moves in a curved path of radius 1.25 m at a constant speed of 11.5 m s^{-1}. Determine the magnitude of the force with which the player must grip the bat.

7. A playground roundabout takes 15.5 s to make a complete revolution.
   a) Calculate the speed of a child sitting on the roundabout 3.80 m from its centre.
   b) Calculate the centripetal force on the child if her mass is 28.0 kg.

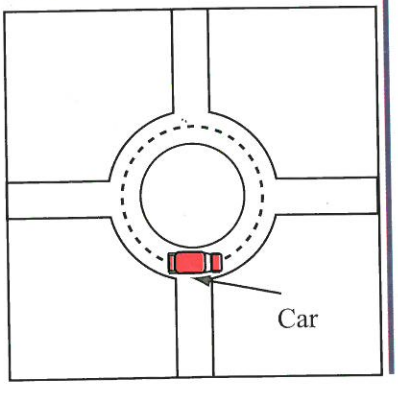
8. A civil engineer has to design a road in which there is a curve with a radius of 300 m. The road will have a maximum speed limit of 110 km h^{-1}. At what angle should the road bank on the curve so that no frictional force is needed by a vehicle, travelling at the speed limit, to move round it?

9. Susanna swings on a 4.00 m long maypole chain with enough speed to swing in a circle of radius 2.50 m. She has a mass of 55.0 kg.
   a) Find the tension in the chain.
   b) Find her period of revolution.



Question 9

10. A 1250 kg car follows a circular path around a roundabout of radius 18.0 m at a constant speed of 24.0 km h^{-1}.
    a) Is the car accelerating? Explain.
    b) Find the average force provided by the friction between the tyres and the road to maintain this circular path.
    c) At what angle would the curved road need to be banked for there to be no need to rely on friction to maintain the circular path?



Question 10

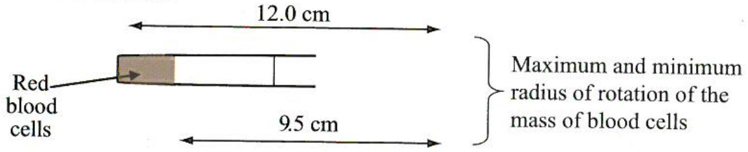
Problem Solving and Calculations

Set 3: Circular Motion

Notes

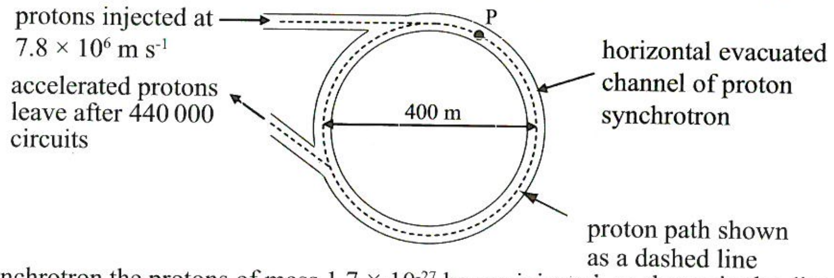
11. The track at a velodrome is banked at an angle of 20°. The radius of the track is 70.0 m. Calculate the minimum speed that a cyclist must maintain in order to stay on the track without relying on friction.

12. Red blood cells are separated from plasma using a centrifuge. Little test-tubes of blood are loaded into the centrifuge and then rotated at high speed. The test tubes swing outwards and the red blood cells move into the ends of the test-tubes. The plasma is poured off, leaving the red blood cells behind.

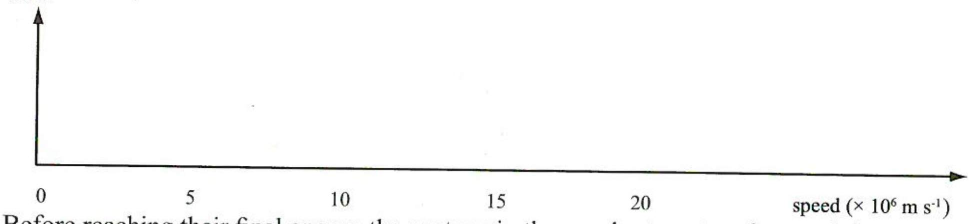


a) If the centrifuge in the diagram is rotating at 3800 revolutions per minute, determine the minimum speed of the red blood cells in the test tubes.
b) Calculate the maximum centripetal acceleration of the red blood cells in the test tubes.
c) A red blood cell has a mass of approximately 98 ng. Red blood cells break if subject to a force greater than 8.2 mN. Determine the maximum rotational frequency of this centrifuge if the cells are not to be damaged.

13. The diagram below shows the schematic diagram (as viewed from above) of a proton synchrotron. This is a device for accelerating protons to high speeds in a horizontal circular path.



In the synchrotron the protons of mass 1.7×10^{-27} kg are injected, as shown in the diagram, at a speed of 7.8×10^6 m s^{-1}. The diameter of the path taken by these protons is 400 m.
a) Show on the diagram the direction of the force required to make a proton move in the circular path when it is at the position marked P.
b) Calculate the force that has to be provided to produce this path for this proton.
c) Sketch, on the grid below, a graph that shows how this force will have to change as the speed of the proton increases over the range indicated on the x-axis. Include an appropriate scale on the force axis.



Before reaching their final energy the protons in the synchrotron travel around the accelerator 440 000 times in 2.5 s.
d) Calculate the total distance travelled by a proton in the 2.0 s time interval.
e) What would happen to the vertical displacement of the proton in this time?
f) Consider your answer to e) above; what must be added to the synchrotron?

Problem Solving and Calculations 3

Set 3: Circular Motion

Notes

14. A string just supports a hanging brick without breaking. Explain why the string breaks if you set the brick swinging.

15. (a) Estimate the minimum speed required to spin a bucket of water at arm's length in a vertical loop without spilling the water.
    (b) Explain why the water does not fall out if the bucket traverses the top of its path at this or greater speed.
    (c) Does the bucket travel at a constant speed throughout its circular path? Explain.

16. A pilot flies her aeroplane in a vertical loop of diameter 1.60 km.
    (a) How fast is the aeroplane travelling at the top of the loop if the pilot feels no force from either the seat or the straps?
    The pilot cuts the engine at the top of the loop.
    (b) Ignoring air resistance, what is the speed of the aeroplane as it emerges from the bottom of the loop?

17. An aeroplane flies in a vertical loop of radius 650 m. At the top of the loop, the pilot experiences a downward reaction force, from her the seat, equal to one fifth of her weight. Calculate the aeroplane's speed at this instant.

18. A model car of mass 2.00 kg moves in a vertical circle of radius 5.00 m. If its speed at the lowest point is 20.0 m s^{-1} and at the highest is 10.0 m s^{-1}, calculate
    (a) the force that the track exerts on the car at the lowest point;
    (b) the force that the track exerts on the car at the highest point.

$F_c = \frac{2\times 20^2}{5} - 9.8\times 2$

$= 20.4$ N up × down

a. $F_c = \frac{2\times 20^2}{5} + 9.8\times 2 = 179.6$ N up

19. You strap into a safety harness and take a roller coaster ride. In one part of the ride, the roller coaster car goes through a vertical loop at a speed of 14.0 m s^{-1}.
    (a) Calculate the radius of the loop of track if you feel "weightless" as you pass through the top of the loop.
    (b) Describe what would happen to you if the car went through the loop faster than 14.0 m s^{-1}. Explain your answer.
    (c) Describe what would happen to you if the car went through the loop slower than 14.0 m s^{-1}. Explain your answer.

20. As a 40.0 kg gymnast swings in a vertical circle on a high bar, her centre of mass moves around 0.90 m from the bar.
    (a) At the highest point her centre of mass is moving at 1.00 m s^{-1}. Sketch a free body diagram for this situation.
    (b) How fast is she moving when her centre of mass is level with the bar? Sketch a free body diagram for this situation.
    (c) How much force must she exert on the bar in order to hang on as she passes through the lowest point of her swing? Sketch a free body diagram for this situation.

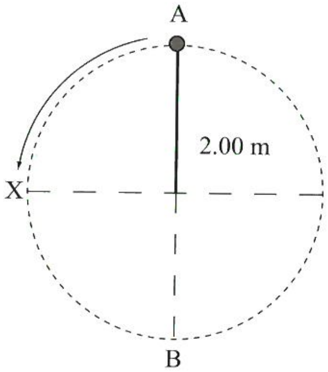
Problem Solving and Calculations

Set 3: Circular Motion

Notes

21. Passengers on a fairground ride revolve at a constant speed in a vertical circle of radius 3.60 m. The ride operator has a choice of two speeds, LOW and HIGH. At the HIGH setting, passengers feel weightless at the top of the circle; at the LOW setting, the passengers revolve at half the HIGH speed.
    (a) Draw free body diagrams showing the forces acting on a passenger at the top and at the bottom, at each speed setting. (That's four diagrams altogether.)
    (b) Calculate the speed at which the ride moves, at the HIGH setting.
    (c) Calculate the reaction forces acting on a passenger of mass 60.0 kg at the top and bottom of the circle, when travelling at the HIGH setting.
    (d) Calculate the reaction forces acting on a passenger of mass 60.0 kg at the top and bottom of the circle, when travelling at the LOW setting.

22. A stone of mass 2.50 kg is whirled in a vertical circle at the end of a 2.00 m length of string.



(a) The stone passes through point X at a speed of 10.4 m s^{-1}. Calculate its speed at points A and B.
(b) Calculate the tension in the string at points A and B.
(c) At which point, A, B or X, is the string most likely to break? Explain your answer.

Investigation 3.2: Centripetal forces in action

Background

There are a number of everyday situations where centripetal forces producing horizontal circular paths are evident – cars turning a corner, athletes running the bend of a race track, high speed trains turning on banked tracks, aircraft banking, etc.

The task

Use diagrams and appropriate mathematics to explain the origin of the centripetal force in three different situations (i.e. do not do an athlete running around a track and a cyclist negotiating a race track, as these are predominantly the same example).

Can I do a car getting airbone on a speed bump?

Cars turning on corners?

~~Helicopter?~~ – Roller Coaster?

Notes

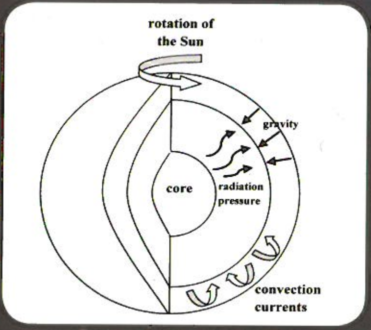
Life cycle of a star

The earliest scientists considered the Earth as not only the centre of our Solar System but the centre of the Universe. Many also believed the Earth to be flat. Comprehensive study of the stars and a more open minded approach quickly replaced these misconceptions with the idea of a heliocentric system.

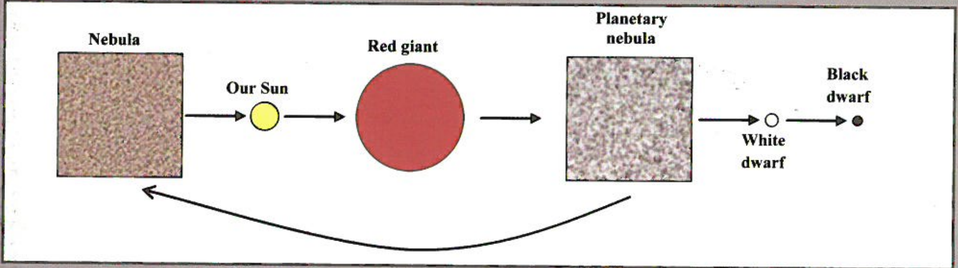
Mass of sun	1.99×10^{30} kg
Radius	6.96×10^{8} m
Distance from its nearest planet	5.79×10^{10} m (average)
Distance from the Earth	1.50×10^{11} m
Typical temperatures	core ~ millions °C, surface ~ thousands °C
Age	~ 5×10^{9} years

Its place amongst the stars

The Sun is actually a very ordinary and average star, currently about one half way through its life. Fortunately for us it is in a stable stage in which the radiation pressure created from within its core balances the gravitational forces as shown here:



The story of the Sun so far, and its expected future.



Who put the lights out?

Since the Sun is only mid way through its life, it will be some time before it dies and the lights go out! The Earth will probably have been engulfed by the red giant stage before this occurs, suffering the fate of all the inner planets. However, since the gravitational pull of the Sun will have decreased by this time due to its loss in mass, it is more likely that the Earth will acquire a wider orbit.

What about the other stars?

Huge stars (between 1.5 to 3 times the mass of our Sun) will follow a similar cycle, forming a red supergiant, then a supernova (the sudden explosive death of a star accompanied by a luminosity equivalent to that of an entire galaxy) and finally a neutron star. The latter stage occurs because the gravitational forces are so immense that the electrons are pushed into the nuclei of the atoms, so that only neutrons remain. Even bigger giant stars (over 3 times the mass of our Sun) follow a similar path but the ultimate stage is to become a black hole.

The Sun is a ball of gas originally formed when a mass of dust and gases (known as nebulae) compressed and contracted.

The fuel that powers the Sun is hydrogen and nuclei of hydrogen are constantly being fused to produce helium and vast amounts of energy, much of which is converted into heat and light. About four billion kilograms of hydrogen is being used up each second and in doing so the central core of the Sun will eventually contract, while its outer layers expand and cool. The result will be a large star with great luminosity but a relatively lower surface temperature – this stage is known as the red giant phase.

Eventually the Sun will expand so much, overcoming the gravitational pull created by its decreasing mass, that it will explode and die, throwing a shell of gaseous matter into space, once again forming a nebula, surrounding the embers of the Sun's core.

The core of the Sun has by this time used up its hydrogen fuel and fusion of helium has formed heavier elements such as carbon. The mass is now concentrated in a much smaller volume, hence a very dense 'white dwarf' results. As it cools further (since its fuel is gone and nuclear fusion reactions can no longer occur), gravitational forces become so huge that the mass of the white dwarf contracts even further, forming a black dwarf in which all the particles of the star are so tightly packed that there is no space between them. The Universe is considered too young at present for any black dwarfs to actually exist.

Life cycle of a star Comprehension Questions

Comprehension Questions

1. a) What does the word heliocentric mean?
   b) Which is the nearest planet to the Sun?
   c) Why is an average distance provided for this planet in Table 1?
   d) Which, if any, of the values quoted in Table 1 will remain constant in the next:
      (i) billion years?
      (ii) five billion years?

   Explain your answers.

2. a) How long would it take light to travel from the Sun's surface to the Earth's surface?
   b) In view of your answer to part a), is it possible to look back in time?
   c) Calculate the gravitational field strength, g, at the surface of the Sun.
   d) Calculate the speed of rotation of a hydrogen nucleus on the Sun's surface.

3. a) Briefly describe how the Sun produces its energy.
   b) What do you think causes the huge radiation pressure/forces generated from within the Sun's core?
   c) What creates the balancing gravitational forces?

4. a) What is the difference between the nebula that formed our solar system and the planetary nebula that occurs following the death of a star?
   b) Why is the planetary nebula that forms when the Sun dies unlikely to repeat the cycle, as indicated in the diagram opposite?

5. Explain the key difference between the red giant stage of a star and its white dwarf phase.

6. a) Why does the gravitational force increase so intensely following the white dwarf stage of a star?
   b) Estimate the original mass of the Sun at its formation.
   c) Estimate the mass of the Sun when it will become a red giant.

7. a) Why does a neutron star contain only neutrons?
   b) Explain why black holes were given this name.
   c) Draw a life cycle diagram, similar to that shown for the Sun in the diagram opposite, for a giant star.

Chapter 4: Gravitation and Satellites Explained

Notes

Remember the following important principles

A force of attraction exists between any two particles that have mass. The force is directly proportional to the mass of each particle and inversely proportional to the square of the distance between them. Spherical bodies such as the Earth are regarded as point masses, in which the centre of the sphere coincides with the centre of mass of the object.

We call this relationship the Law of Universal Gravitation, and express it mathematically as:

$$F_g = G \frac{M_1 M_2}{d^2}$$

where:

F_g is the force of attraction in newtons (N)
M_1 and **M_2** are the masses of the two objects in kilograms (kg)
d is the distance between their centres of mass in metres (m)
G is the Universal Gravitational constant, which has a value of 6.67×10^{-11} N m^2 kg^{-2}

A large object (such as the Earth) creates a gravitational field around itself. You can calculate the gravitational field strength at a point in a gravitational field as follows:

$$g = G \frac{M_1}{d^2}$$

where:

M_1 is the mass of the large object.

This value 'g' is also the gravitational acceleration experienced by an object at this point.

An object on the Earth's surface experiences weight because the Earth's surface provides a reaction force. This reaction force is normally the same size as the gravitational force pulling down on the object. You can calculate the weight of an object of mass M_x at the Earth's surface using the relationships:

$$F_W = G \frac{M_E M_X}{d^2}$$

where:

M_E is the mass in kilograms (kg) of the Earth (object producing the gravitational field)
d is the distance between the centre of mass of the object **M_x**, and the centre of the Earth .

and

$$F_W = gM_X$$

where:

g is the gravitational field strength, in newtons per kilogram (N kg^{-1}) or acceleration due to gravity, in metres per second squared (m s^{-2})
M_x is the mass of the object in the gravitational field

Objects falling freely experience the gravitational force but not the reaction force, so they are said to be weightless.

For a satellite in a stable circular orbit around a star planet, or Moon the centripetal force that causes circular path is the gravitational force of attraction between the star, planet, or Moon, and the satellite. The following relationship states the condition for circular orbit:

$$F = G \frac{M_1 M_s}{r^2} = \frac{M_s v^2}{r}$$

where:

M_s is the mass of the satellite, and **M_1** is the mass of the astronomical body, both in kg
r is the radius of the orbit in metres
v is the tangential velocity of the satellite, in metres per second (m s^{-1})
G is the universal gravitational constant, of magnitude 6.67×10^{-11} N m^2 kg^{-2}.

Experiment 4.1: Measuring the mass of the Earth

4

Notes

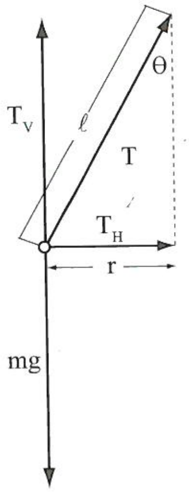
Background

The centripetal force that causes the conical pendulum's bob to go around in a circle is equal to the horizontal component of the tension in the string, and the bob's weight is equal to the vertical component of the tension.

From this you can work out that $g = \frac{v^2}{r \tan\theta}$

Using the value of g in the relationship $g = G\frac{M_E}{r_E^2}$

and knowing the Earth's radius you can calculate the mass of the Earth.



Apparatus

- a small mass of between 200 g and 300 g. The mass of pendulum bob must be large compared to mass of string
- string (strong cotton thread or fishing line)
- metre rule
- sheet of A3 paper
- stop watch

Pre-lab

- Draw a circle on the sheet of paper. Make the radius of the circle about 120–150 mm and mark its centre. Measure accurately and record the radius.
- Tie the mass onto the string and mark the string so that the length of the pendulum is between 250 mm and 350 mm. Measure the length accurately and record it.
- Prepare a data table similar to the one below.

Trial	Time for 20 revolutions (s)	Period (s)	Velocity (m s^{-1})

Lab notes

- Hold the string at the mark and with your hand over the centre of the circle marked on the paper swing the pendulum so that the mass follows the circumference as closely as possible. Measure the time for 20 complete revolutions.
- Repeat the experiment a total of five or six times.

Experiment 4.1: Measuring the mass of the Earth

Notes

Processing of the results

- Complete the data table (use $v = \frac{2\pi r}{T}$) and hence find the average speed.
- Using the length of the pendulum and the radius, calculate the angle that the pendulum makes with the vertical.
- Use the relationship in the background above, the average speed, the radius and the angle θ to calculate the acceleration due to gravity, g.
- Use the radius of the Earth (6.38×10^6 m) to calculate the Earth's mass.

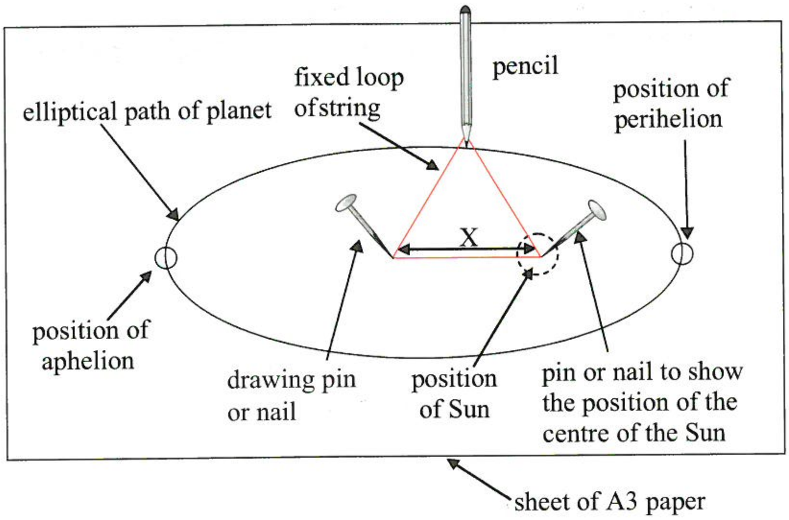
Post-lab discussion

1. Find out the generally accepted value for the Earth's mass.
2. Calculate the percentage difference between your value and the accepted value.
3. Comment on the accuracy of your result.
4. Which part of the experiment was the greatest source of errors? Explain.
5. The most accurate values for the Earth's mass have been obtained from measurements made of artificial satellites orbiting the Earth. What measurements would you need to make? Show how the mass of the Earth can be calculated from these measurements.
6. Suggest reasons why the method discussed in question 5 gives such accurate values.

Experiment 4.2: The elliptical path of planets (short time scale)

Background

This experiment is a method for investigating the elliptical, rather than the circular path of the planets in our Solar System.



Aim

To investigate the elliptical path of planets about the Sun by constructing a two-dimensional scaled drawing.

Apparatus

- the equipment illustrated above right
- a metre rule
- thick cardboard or wooden base
- drawing pins or nails, depending on the base to be used
- a hammer
- ball of string (or thread), ideally string that has very little or no elasticity
- a pencil, scissors, a drawing compass or a template for drawing circles
- sheets of A3 paper

Notes

Pre-lab

Make sure that the paper is firmly attached to the base.

Decide on the planet whose elliptical path you will depict, and research its perihelion and aphelion. As an example, precise instructions have been provided for you to accurately represent Mercury's orbit. Knowing the radii of the Sun and Mercury will be useful.

Perihelion of Mercury is 4.60×10^{10} m	Aphelion of Mercury is 6.98×10^{10} m
Radius of Mercury is 2.44×10^{6} m	Radius of the Sun is 6.96×10^{8} m

Experiment 4.2: The elliptical path of planets (short time scale)

Notes

Set up a table suitable for recording the data from your investigation. An example is shown.

Scale for drawing	

Planet	**Perihelion, P ($\times 10^{10}$ m)**	**Aphelion, A ($\times 10^{10}$ m)**	**P – A ($\times 10^{10}$ m)**	**separation of pins, X (cm)**	**2 x A ($\times 10^{10}$ m)**	**circumference of string loop (cm)**

Lab notes

Draw a 2D scaled drawing of the elliptical path for Mercury

- Calculate the distance between the perihelion and aphelion of Mercury.
- Decide on a suitable scale (eg. 2 cm will represent 1.00×10^{10} m) and calculate the actual separation, **X** that the pins or nails will need to be positioned.
- Place the pins or nails into the base.
- Now double the aphelion distance.
- Use the chosen scale to calculate the circumference the loop of string has to be.
- Place the loop of string around the pins and use a pencil to draw in the path of Mercury, keeping the string tight at all times.
- Remove the pins and draw in the Sun and the position of Mercury at both its perihelion and its aphelion, if possible using the same scale as above.
- Repeat the procedure for other planets, beginning with the Earth.

Scale for drawing	**2cm : 1 × 10^{10} m**

Planet	**Perihelion, P ($\times 10^{10}$ m)**	**Aphelion, A ($\times 10^{10}$ m)**	**P – A ($\times 10^{10}$ m)**	**separation of pins, X (cm)**	**2 x A ($\times 10^{10}$ m)**	**circumference of string loop (cm)**
Mercury	4.60	6.98	2.38	4.76	13.96	27.92

Experiment 4.2: The elliptical path of planets (short time scale)

Notes

Post-lab discussion

1. Does your drawing truly represent the path of Mercury about the Sun? What are some possible sources of error that may have occurred during your procedure? How might you address these sources of error in future investigations?
2. Were you able to accurately represent the Sun and the two positions for the planet Mercury on the diagram, keeping to the scale you had chosen?
3. Find out the *average* radius of Mercury's orbit about the Sun. Explain how this average value could have been determined.

Further Investigations

Draw the paths of the planets on to transparencies, using the same scale for all the planets (this will need careful consideration and quite large transparent sheets). Then, overlay the transparencies to get an idea of how the planets relate within the Solar System.

What are the limitations of such a two-dimensional model?

A three-dimensional model of the Solar System is called an *orrery* – find out more about such models.

Problem Solving and Calculations

Set 4: Gravitation and Satellites

Useful Data
Mass of Earth:
5.98×10^{24} kg
Mass of Moon:
7.34×10^{22} kg
Mass of Sun:
1.99×10^{30} kg

Radius of Earth:
6.37×10^{6} m
g at sea level:
9.80 m s^{-2}

Notes

1. If all objects are attracted to one another by gravity, why are you not attracted towards large buildings?

2. a) When mountaineers climb Mount Everest to a height of about 8 km, does their weight change? Explain your answer.
   b) How does the weight of an underground miner change as he descends into a very deep mine? Explain your answer.
   c) A geophysicist's assistant measures the acceleration due to gravity with a very sensitive accelerometer at various places on the Earth's surface and finds that it is slightly different at each place. What are two possible reasons for this variation?

3. What is the weight of a free falling object? Explain your answer.

4. If air resistance is negligible, all free falling objects near the Earth's surface accelerate at the same rate even though they have different masses. Explain.

5. Black holes form when massive stars at least four times the mass of the Sun collapse into a tiny fraction of their original volume. Why is the gravitational force near a black hole so large that not even light can escape from it, even though its mass is the same as that of the original star?

6. A student measures the acceleration due to gravity at the Earth's surface and finds that it is 10 m s^{-2}. Calculate the mass of the Earth according to the student's result.

7. In an experiment to measure the force of gravity, a physicist suspends two 100 kg lead spheres so that their centres are 622 mm apart. Calculate the force of attraction between the spheres.

8. The gravitational force acting on the space shuttle at sea level is F.
   a) At what height above the Earth's surface would the gravitational force acting on the shuttle be ½F?
   b) The shuttle is in orbit around the Earth at a height of 610 km above the Earth's surface. What is the gravitational acceleration the shuttle experiences?
   c) The Space Shuttle Discovery carried the Hubble Space Telescope to an altitude of 610 km. What orbital speed did the shuttle have to give the telescope to keep it in this orbit?

9. The Earth attracts the Moon with a force of 2.03×10^{20} N. Use this information to calculate how far the Moon is from the Earth.

10. Neptune has a mass 16.6 times that of the Earth and its radius is 3.89 times the Earth's radius. Compare the gravitational field strength at Neptune's surface with that at the Earth's surface.

11. a) The Moon is in an almost circular orbit around the Earth. Why doesn't the gravitational force of the Earth acting on the Moon change the Moon's speed?
    b) Calculate the net force on the Moon due to the Earth and the Sun during a solar eclipse. The radius of the Moon's orbit is 3.80×10^{8} m and the radius of the Earth's orbit is 1.49×10^{11} m.

Problem Solving and Calculations 4

Set 4: Gravitation and Satellites

Notes

12. Which is greater, the period of revolution of a communications satellite at a height in excess of 30 000 km, or that of a satellite that orbits at a height of a few hundred kilometres? Show your reasoning.

13. a) A research satellite in low Earth orbit move across the Earth's surface at several kilometres per second. If engineers fired retro-rockets on board this satellite and slowed it down very quickly, what would happen to the satellite's orbit?
    b) Communications satellites are always located above the same spot on the Earth's surface, that is, their speed across the Earth's surface is zero. Why do they remain in orbit?

14. a) Why do engineers launch rockets carrying satellites in an easterly direction?
    b) Why do engineers try to locate launch facilities as close to the equator as they can?

15. Scientists aboard an orbiting space station want to return some equipment to Earth in a capsule. What must they do with the capsule to achieve this?

16. Technicians want to move a satellite in a stable circular orbit to a lower orbit. Engineers achieve this by reducing the satellite's speed and therefore reducing its kinetic energy. As it moves to a lower orbit why does its speed increase?

17. Astronauts in orbit in a space station float around unless they are strapped into their seats. Why?

18. Calculate the period of a satellite orbiting the Earth at a height of 550 km.

19. The moon Europa orbits Jupiter at a radius of 6.71×10^8 m and an orbital period of 3.07×10^5 s.
    a) Calculate the Europa's orbital speed.
    b) Calculate Jupiter's mass.

20. Scientists have used data from the motions of satellites to determine accurately Earth's mass. A navigation satellite in a circular orbit 2.02×10^4 km above the surface has a period of 12.0 h. From this information, calculate the Earth's mass.

21. What is the height above the Earth's surface of a communications satellite if it always orbits above a particular spot on the equator?

22. Titan is one of Saturn's moons. It completes one orbit every 14.0 Earth days. Our Moon circles the Earth in 27.3 Earth days. The mass of Saturn is equal to 108 Earth masses. Find the ratio of Titan's orbital radius to that of our Moon.

23. The orbit of Mercury is elliptical. Its perihelion (closest approach to the Sun) is $4.60 \text{ x } 10^{10}$ m and its aphelion, or furthest distance from the Sun, is 6.90×10^{10} m.
    a) Calculate the force of attraction between the Sun and Mercury at each position.
    b) What other parameter of Mercury's orbit changes? Calculate this quantity for the maximum and minimum distances from the Sun.
    c) Explain how this can happen without Mercury losing energy and crashing into the Sun.

Investigation 4.3: The elliptical path of planets (long time scale)

Notes

Background

This experiment is a method for investigating the elliptical, rather than the circular path of the Earth about the Sun. However, it will require the whole year to generate meaningful results, during which it will be possible to trace the path of the Sun across the sky.

Aim

To investigate the path of the Earth about the Sun by constructing a two-dimensional drawing.

Apparatus

- a large, flat (outside) surface, that is free of shadows and relatively student free throughout the year
- a pole or large stake
- a set of tent pegs
- a spirit level

Pre-lab

Locate a suitable area in or around your school where the experiment can be set up and left so that it will not be interfered with over the course of the year.

Lab notes

- Begin by hammering the pole or stake into the ground, leaving approximately 0.50 m protruding above the ground.
- Use the spirit level to check that it is absolutely vertical – it will have to be left in this exact position for at least a year.
- Every three days (if possible), mark the position of the tip of the shadow (created by the Sun of the pole), using one of the tent pegs. It is important to do this at the same time on each of your monitoring days, ignoring daylight saving. Noon is ideal.
- When a year is complete, join the pegs with a length of string.

Post-lab discussion

- What figure or shape did the path of the Earth about the Sun take?
- Why is noon an ideal time to make your observations?
- What are some possible sources of error that may have occurred during your procedure or what problems did you encounter?
- How might you address these sources of error in future investigations?

Further Investigations

Investigate the reasons why you obtained the shape you did, explaining why the path of the Earth obtained from this experiment was *not* a simple ellipse.

Chapter 5: Moments and Equilibrium Explained

5

Notes

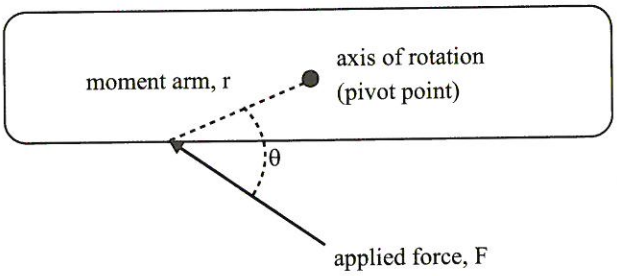
Remember the following important principles

The centre of mass of an object is the point at which all of the mass of the object appears to be concentrated. Depending on the shape of the object, the centre of mass can be within the object, or at some external point, as is the case with a horseshoe.

A moment of a force or torque results when you apply a force to an object in such a way that it is not directed through its centre of mass. As a result, the mass will change its speed of rotation.

The magnitude of this turning effect depends on the magnitude and direction of the force and how far its point of application is from the axis of rotation. An example of this principle is the fact that it is difficult to open a door if you push close to its hinges.

The turning effect of a force is called the moment or torque exerted by that force. The size of a torque depends on: the size of the applied force, the moment arm (the distance between the point of application of the force and the axis about which the object will rotate), and the angle between the line of action of the force and the moment arm.



Mathematically, we can write

$$\boldsymbol{\tau} = \mathbf{r\ F\ sin\ \theta}$$

where:

$\boldsymbol{\tau}$ is the torque, in N m

r is the distance (in m) between the line of action of the force and the axis of rotation

F is the applied force (in N)

$\boldsymbol{\theta}$ is the angle between the line of action of the force, and the moment arm

Note that the formula for torque simplifies to $\boldsymbol{\tau} = \mathrm{r\ F}$ in the special case when the angle between the applied force and the moment arm is 90°.

The units of torque are (metres × newtons) or m N (note the space between m and N, otherwise this would be mN = millinewtons). To avoid confusion this is often written as N m.

Conditions for Equilibrium

If a body is at rest or in a state of uniform straight line motion, then it follows that there are no unbalanced forces acting on it. In this case the vector sum of all forces in any direction acting on the body is equal to zero.

$$\Sigma F = 0$$

Even with this condition satisfied a body can still undergo rotational acceleration in the case where the lines of action of two opposing parallel forces of equal magnitude do not coincide. For rotational equilibrium to exist, the algebraic sum of the moments of the forces about any axis must be zero.

$$\Sigma M = 0$$

This is known as the principle of moments. The expression we use to solve problems where a body is in equilibrium under a system of coplanar forces is:

$$\Sigma(\text{anti-clockwise moments}) = \Sigma(\text{clockwise moments})$$

Experiment 5.1: Parallel forces

Notes

Aim

In this experiment you will be able to test the principle of moments for yourself. In a number of simple equilibrium situations that you set up with the equipment provided you will be able to

- find the values for the clockwise and anticlockwise moments in each case you set up
- verify the principle of moments
- make predictions of where to hang masses on the apparatus in order to balance it
- calculate the mass of the metre rule that you use, by using the method of moments

Apparatus

- one metre rule with holes drilled at the 25 cm, 50 cm and 75 cm mark
- two sets of slotted 50 g masses
- 50 mm long bolt with a diameter of approximately 5 mm
- retort stand, boss head and clamp
- 0–10 N spring balance
- electronic pan balance
- wire or string for suspending masses from the metre rule
- two bulldog clips or similar could also be used to support masses

Pre-lab

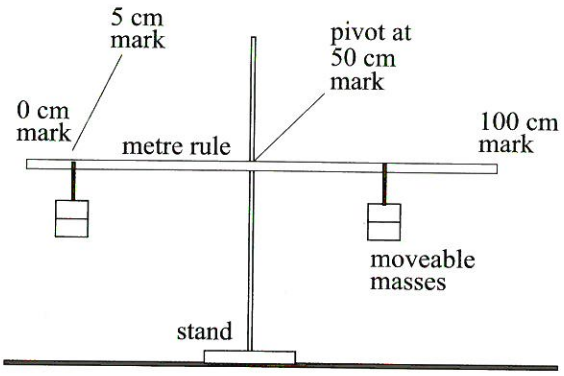
Part A: Balancing a constant moment

- In this part of the experiment you will balance a constant moment produced by a constant weight that is at a fixed distance from the pivot. To do this you will need to use different masses at varying distances from the pivot.
- Set up the equipment as shown by first placing the bolt through the rule, then clamping the bolt with the boss-head. Make sure the rule balances horizontally before you add any weights.
- Adjust the height of the pivot so that when the rule is balanced the weights are a few centimetres above the bench top.

Note: If the metre rule represented is balanced in the horizontal position, the 100 g mass provides an anticlockwise moment about the bolt. The moveable masses provide an equal magnitude moment in a clockwise direction on the other side of the pivot. When the anticlockwise moment cancels the clockwise moment about the bolt, the rule and the masses will be in equilibrium.

Fixed Mass Data	
Mass in grams (g)	100 g
Mass in kilograms (kg)	
Distance from pivot (cm)	45.0 cm
Distance from pivot (m)	
Weight in newtons (N)	
a c moment about pivot (Nm)	

Table 1



Apparatus for Part A

Experiment 5.1: Parallel forces

Lab notes

- Hang a 100 g mass between the 50 cm mark and the 100 cm mark in a position so that the metre rule is balanced in the horizontal position.
- Use the scale on the metre rule to measure the distance from the pivot to the point where you hung the second 100 g mass and record this value in table 2 as shown below, in the column labelled `Distance to weight (cm)'.
- Add successive 50 g masses and repeat steps 2 and 3 for all mass values shown in the first column of table 2.

Notes

Post-lab discussion

Mass used (g)	Mass used (kg)	Weight used (N)	Distance to weight (cm)	Distance to weight (m)	weight × distance (N m)
100					
150					
200					
250					
300					
350					
400					
450					

Table 2

Fill in the remaining blank spaces in table 1 and table 2.

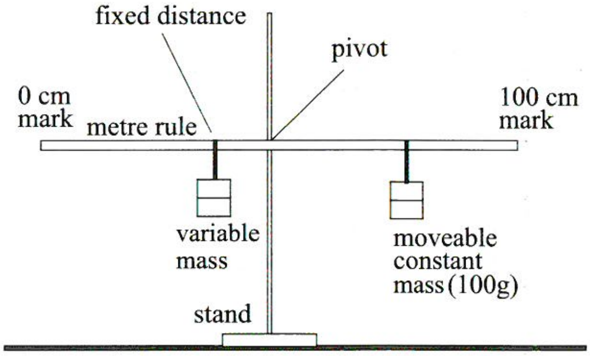
1. Comment on any regularity in the values you obtain in the last column of table 2.
2. Compare the average value in table 2 to the value of the anticlockwise moment in table 1.
3. Write a statement about moments that summarises your findings in this part of the experiment.
4. Why is the mass of the rule ignored in your experiment?
5. Comment on how the length of the lever arm for the clockwise moment changes as you add more weights at a fixed distance to the left of the pivot. Explain your reasoning.

Pre-lab

Part B: Balancing a variable moment

In this part of the experiment you will balance a changing moment produced by a changing weight that is at a fixed distance from the pivot. To do this you will need to shift a constant mass to varying positions from the pivot.

Set up the equipment as in Part A with a 100 g mass at the 40 cm mark on the rule. This will be at the fixed distance of 10 cm from the pivot for this part of the experiment. See the diagram (*right*).



Apparatus for Part B

Experiment 5.1: Parallel forces

Notes

Lab notes

- Position a 100 g mass at the 40 cm mark and balance the rule by hanging a 100 g mass on the other side of the pivot. Record the distance to the pivot of the second mass in table 3.

Values for Constant Measurement	
Mass of movable constant weight (g)	100 g
Weight of movable constant (N)	
Distance from pivot of variable mass (cm)	10.0 cm
Distance from pivot of variable mass (m)	

Table 3

- Add a further 50 g mass to the first one at the 40 cm mark and balance the rule by moving the 100 g constant mass. Record the new balance position.
- Repeat steps 2 and 3 for each of the mass values shown in the first column of table 4.

Mass used at fixed distance (g)	Weight used at fixed distance (N)	Distance to pivot for constant weight (cm)	Distance to pivot for constant weight (m)	Moment for constant weight (N m)	Moment for variable weights (N m)	Difference between ACM and CM (N m)
100						
150						
500						
250						
300						
350						
400						
450						

Table 4

Post-lab discussion

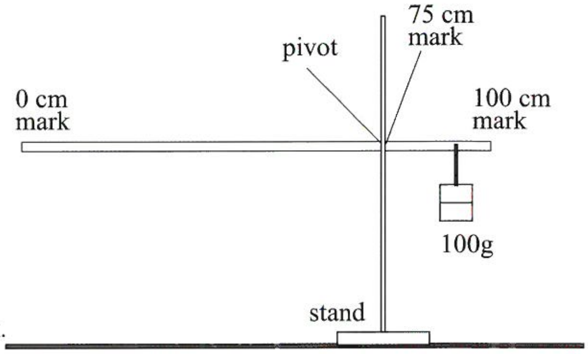
1. Fill in all the remaining blank spaces in table 3 and table 4.
2. Comment on any regularity in the values you obtained in the last column of table 4.
3. Write a statement about moments that summarises your findings in this part of the experiment.
4. Why can you ignore the mass of the rule in your experiment?
5. Comment on how the length of the lever arm for the clockwise moment changes as you add more weights at a fixed distance to the left of the pivot. Explain your reasoning.

Experiment 5.1: Parallel forces

Pre-lab discussion

Part C: Weighing a metre rule

- In this part of the experiment you will calculate the weight of the metre rule by using the principle of moments when the rule is balanced. To do this you will need to change the pivot point of the rule.
- Set up the equipment as shown by placing the bolt through the rule at the 75 cm mark.

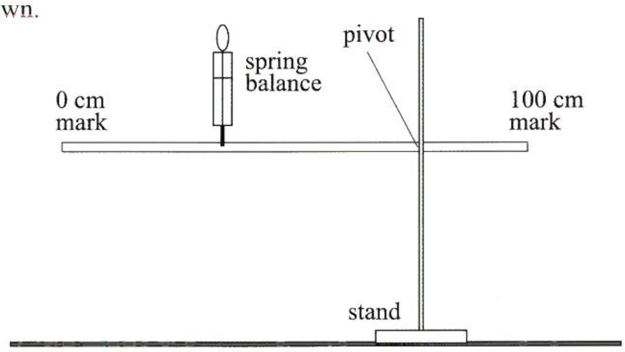


Apparatus for Part C

Notes

Lab notes

- Hang a 100 g mass at a point on the rule so that the rule comes to rest in a horizontal position. Record the distance to the pivot of the 100 g mass.
- Mark on the diagram the position of the ruler's centre of mass and all the forces acting on the rule.
- Use your knowledge of moments to calculate the weight of the rule. Record this value.
- Remove the 100 g mass and use a spring balance to support the rule horizontally from its 30 cm mark as shown.



Using a spring balance

- Mark on the diagram all the forces acting on the rule.
- Use the reading from the spring balance to calculate the weight of the rule. Record this value.
- Dismantle your apparatus and weigh your rule on an electronic balance. Record this value.

Post-lab discussion

1. Compare the two values you obtained for the weight of the rule and comment on any differences.
2. Would the reading on the spring balance change if the rule was not supported horizontally? Explain your answer.
3. If the pivot in "Using a spring balance" was replaced by another spring balance, what reading would it show? Use the measured weight of the rule you found from the electronic balance to calculate your answer.

Experiment 5.2: Forces and torques in equilibrium

Notes

Aim

In this investigation you will verify the conditions you need for a body to be in equilibrium. You will do this by investigating the relationship between

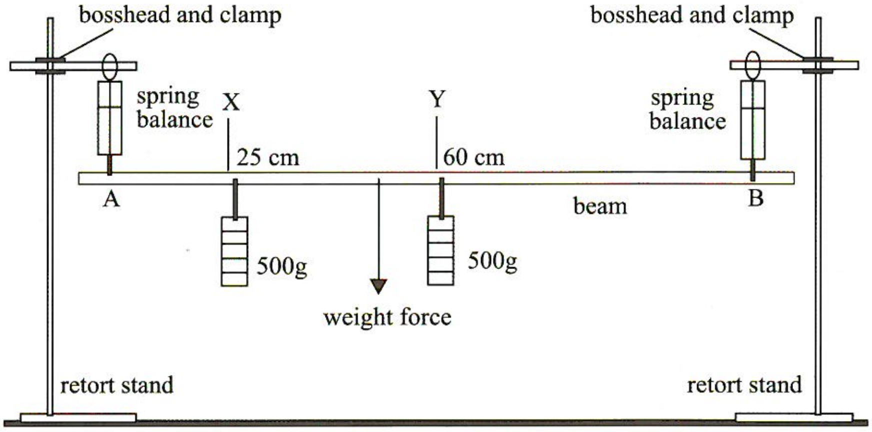
- forces that act on a body that is in equilibrium
- moments that act on a body that is in equilibrium

Apparatus

- one metre rule to act as a beam
- two sets of slotted 50 g masses
- two retort stands with boss heads and clamps
- two 0-10 N spring balances
- wire, string or paper clips for suspending masses from the metre rule and beam from spring balances

Pre-lab

- In this experiment you will use two spring balances to support a beam on which you hang two weights at different points along its length.
- Measure the weight of the beam using one of the spring balances and record your value in the table.



Apparatus for Experiment 5.2

- Set up the equipment as shown with attention to the following points:
  a) Position the retort stands with the longer parts of their bases towards each other.
  b) Position the spring balances on the clamps so that a vertical line through them passes within the area of the base of the stand. The spring balances should be near to and equidistant from each ends of the beam.
  c) The spring balances must hang vertically before you take a reading.
  d) Make sure the beam balances horizontally before you take a reading.

Experiment 5.2: Forces and torques in equilibrium

Lab notes

- Once the beam is in equilibrium record the reading on each spring balance and the position of the weights in the table below. Record the weights in newtons and the positions in metres measured from the spring balance at A.
- Change the positions and sizes of each weight to obtain another two sets of measurements. Use different weight values for the two weights in both trials.
- Complete the column for trial 1 in table 1. The distances should be measured from the position Y.

Note: The spring balances exert upward forces on the beam while the slotted weights and the weight of the beam exert downward forces.

Weight of beam = ___________g				
Measurements taken	Symbol	Trial 1	Trial 2	Trial 3
Upward force at A (N)	F_A			
Upward force at B (N)	F_B			
Distance from A to B (m)	b			
Downward force at X (N)	F_X			
Distance from A to X (m)	x			
Downward weight force of beam (N)	F_W			
Distance of centre of gravity from A (m)	cg			
Downward force at Y (N)	F_Y			
Distance from A to Y (m)	y			
Distance from Y to B (m)	B			
Distance of centre of gravity from Y (m)	CG			
Distance from X to Y (m)	X			
Distance from Y to A (m)	A			

Table 1

Post-lab discussion

1. For *each* trial calculate $F_A + F_B$ and $F_X + F_Y + F_W$ and record your results in table 2. What do you notice about these values in each trial?
2. For *each* trial calculate the sum of the clockwise moments about A and the anticlockwise moment about A and record your results in table 2. What do you notice about these values in each trial?
3. For *trial 1 only*, calculate the clockwise moment about Y and the sum of the anticlockwise moments about Y and record your results in table 2. What do you notice about these values?
4. Write a statement about vertical forces that summarises your findings in this experiment.
5. Write a statement about moments that summarises your findings in this experiment.
6. Write a statement about the position on the beam about which moments can be taken when a system is in equilibrium.
7. Explain why the spring balances have to be attached equidistant from the ends of the uniform beam.
8. What assumption did you make about the centre of mass of the beam in this experiment?
9. Explain why it is important to position the retort stands with the longer ends of their bases towards each other.
10. Explain why the spring balances must be positioned over the bases of the stands.
11. Explain why the spring balances must both be vertical when you take readings from them.

Measurements taken	Symbol	Trial 1	Trial 2	Trial 3
Sum of upward force on beam (N)	$F_A + F_B$			
Sum of downward force on beam (N)	$F_X + F_Y + F_W$			
Sum of clockwise moments about A (N m)	ΣCM_A			
Anticlockwise moment about A (N m)	ΣACM_A			
Clockwise moment about Y	ΣCM_Y			
Sum of anticlockwise moments about Y (N m)	ΣACM_Y			

Table 2

Experiment 5.3: Non-parallel Forces

Aim

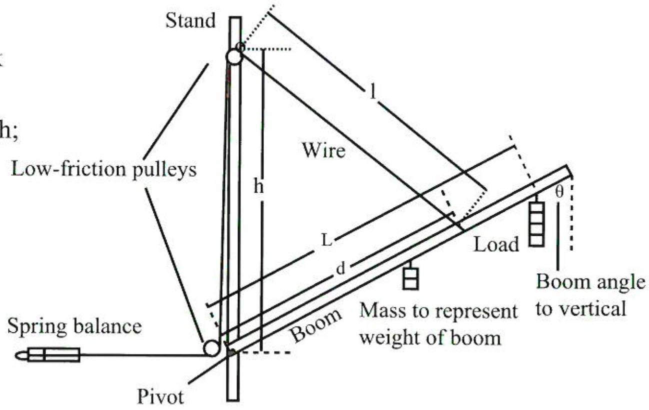
In this investigation, you will use the conditions for equilibrium to study the effect on forces acting at a pivot when a cantilevered object is supported at various angles. You will calculate the reaction at the pivot by resolving the measured values of the tension in a supporting wire when the object is in different positions.

Apparatus

(per group)

- One metre rule with holes drilled at 50 cm, 60 cm and 95 cm mark
- two sets of slotted 50 g masses;
- sturdy retort stand and appropriate clamp for attaching it to a bench;
- bossheads and clamps;
- 0 – 20 N spring balance;
- Wire or string for suspending masses from the metre rule;
- Wire or strong string for supporting boom;
- Pivot for boom;
- 2 low friction pulleys with appropriate mountings;
- Protractor;
- Method for securing spring balance with reading

Note; a 360° protractor attached at the 100 cm end of rule and a plumb line would make the boom angle easier to measure.



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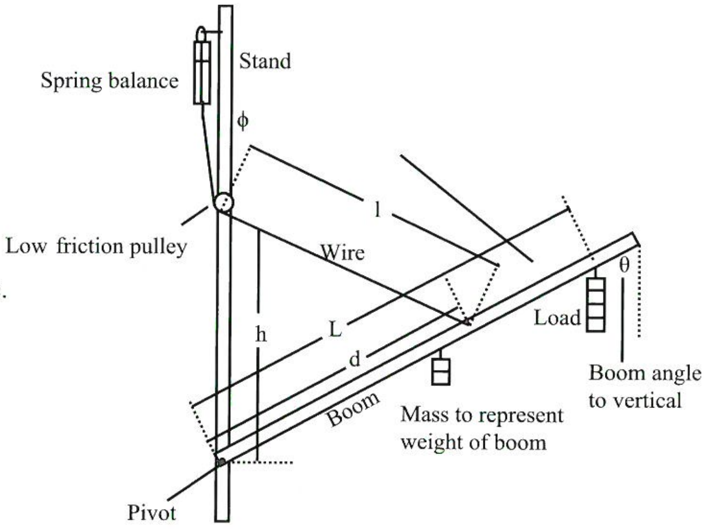


Pre-lab

In this experiment, you will use a metre rule to represent a boom, and a wire to represent a tie as in a crane. Using the equipment as in the figure you will measure the tension in the tie for various angles of the boom. From these and other measurements you will calculate the reaction at the pivot.

- With the help of a partner arrange the quipment as in the figure.
- Attach a 55 g mass to the boom at the 95 cm mark, and a 150 g mass at the 50 cm mark.
- This second mass is to give the boom some weight so that the small weight of the rule can be ignored in your calculations.

Lab notes

- Position the upper pulley so that the wire passes over it at a height of 70 cm above the pivot.
- Attach the wire to the 60 cm mark on the boom and pass it over the pulleys to the spring balance. Use the information below to check that you have used the correct values in your set up.

Boom and other variables						
Length to load, L (cm)	C of mass from pivot, c (cm)	Distance to tie, d (cm)	Mass of boom (kg)	Load (kg)	Height of tie above pivot, h (cm)	Acceleration due to gravity, g (m s^{-2})
95.00	50.00	60.00	0.15	0.50	70.00	9.80

Experiment 5.3: Non-parallel Forces

- Adjust the boom so that it makes an angle of 20° with the vertical and record the tie tension reading T on the spring balance on the results table. Record also the length l of the tie and the angle ϕ the tie makes with the stand.
- Change the angle of the boom and complete the first three columns of the results table *(below)*.

Boom angle to vertical, θ	Tie length, L (cm)	Angle between tie and stand, ϕ	Tension in tie, T (N)	Vertical component, T_v (N)	Horizontal component, $T_h = R_h$ (N)	Vertical reaction, R_v (N)	Reaction of pivot, R (N)	Reaction angle to horizontal γ
20								
40								
60								
80								
90								
100								
120								
140								
160								

Post-lab discussion

1. Draw a diagram showing all forces acting on the boom. Use the following labels in your diagram.
   - T = tension in tie
   - T_h = horizontal component of tension in tie
   - T_v = vertical component of tension in tie
   - W_b = weight of boom
   - W_l = weight of load
   - R = reaction at pivot
   - R_h = horizontal component of reaction at pivot
   - θ = angle of boom to vertical
   - ϕ = angle of tie to vertical
   - γ = angle of reaction to horizontal (above horizontal is positive, and below horizontal is negative)
2. For one angle only of the boom show your working for 3 to 7 below.
3. For one angle of the boom use the tension in the tie and the angle the tie makes with the stand to calculate the vertical component of the tension. You can use $T_v = T \cos \phi$ to find the vertical component.
4. Compare the value you calculated for T_v with the sum of the downward forces due to the mass of the boom and the load.
   Note; you should find that T_v is less than the sum of the weight of the boom and load. The difference in these values is the vertical reaction at the pivot.
5. Find the vertical reaction R_v at the pivot by using the relationship:
   $\Sigma F_{up} = \Sigma F_{down}$. That is $R_v + T_v = W_b + W_l$. What is implied by a negative value for R_v?
6. Find the horizontal reaction R_h at the pivot. You can use the relation $R_h = T_h = T \sin \phi$ to find the horizontal component since the only horizontal force applied to the boom is R_h.
7. Use the values of R_v and R_h that you calculated above to find the reaction R. find also the angle that the reaction force makes with the horizontal. If R_v is negative, then the reaction is angled below the horizontal then you can assign a negative value to γ when recording its value in the table.

Notes

Experiment 5.3: Non-parallel Forces

Notes

8. Enter the values for the remaining boom values in the results table.

9. On the same axis plot R, R_v and R_h against the boom angle on the x-axis. Extrapolate your graphs to boom angles of 0° and 180°.

10. Plot a graph of reaction angle on the y-axis versus boom angle on the x-axis.

11. Based on your measured and calculated results write a general conclusion relating to resolved components and the vector sum of the forces on a system in equilibrium.

12. What happens to the tension in the tie as the boom is raised? Give an explanation for this in terms of moment arm lengths.

13. Select a boom angle and calculate from theory the corresponding reaction. Compare this with the values in your table.

14. List the major sources of error in this experiment. Can you suggest any improvements?

15. From your graphs find the angle of the boom that produces the maximum horizontal reaction. Explain why the maximum will always be at this angle on a boom supported in this way.

16. Why is the horizontal reaction zero at 0° and 180°?

17. From your graph of reaction angle determine the boom angle that produces an horizontal reaction force. How will this angle change if a larger load is placed on the boom? Give an explanation for your answer.

18 At what angle of the boom is the tie longest?
How can this affect the performance of a crane?

19 Suggest a reason why the tension in the tie does not change uniformly with the angle of the boom.

Further Investigations

Use the apparatus to investigate what happens with the point of attachment of the tie is altered on the stand and on the boom.

Problem Solving and Calculations

Set 5: Moments and Equilibrium

Notes

1. What is the difference between m N and mN?

2. Mario, a construction worker, is using a large wrench to tighten bolts joining two steel girders. He holds the wrench at a point that is 750 mm from the bolt and applies an average force perpendicular to the wrench of 160 N. Find the torque he applies to the bolt.

3. Louise uses a torque wrench to tighten the cylinder head bolts on her car. A torque wrench has a dial that allows you to preset the torque you want, then gives you a warning sound when you reach this set torque. Louise sets her wrench to warn her when she exceeds 88 N m. If the handle of the wrench is 400 mm long how much force does she need to apply to the handle before she hears the warning?

4. Explain why buses and trucks usually have much larger diameter steering wheels than normal passenger cars have, while racing cars usually have smaller diameter steering wheels than normal passenger cars have.

5. While hiking through the bush carrying a heavy backpack, Michael finds himself leaning forward as he walks. Why does he do so?

6. While playing in the park with his two children a father sits on the see-saw at a point 1.6 m from pivot point. Amanda tries to balance him by sitting at the opposite end, which is 2.5 m from the pivot.
   a) Amanda has a mass of 24 kg and father's mass is 60 kg. Show that they cannot achieve a balance.
   b) Ben balances the see-saw by sitting 0.50 m front of Amanda. Calculate Ben's mass.

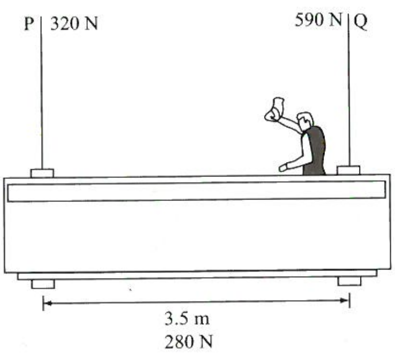
7. When Jackie replaced the standard tyres on her sports car with a set of low profile tyres, the car seemed more powerful and was able to achieve greater acceleration. Explain how this was possible. (Low profile tyres reduce the overall diameter of a wheel.)

8. A plumber carries a long 36 kg pipe on his shoulder finds that he must pull down on the pipe with his outstretched hand 450 mm in front of his shoulder to keep the pipe balanced. He discovered later that the centre of mass of the pipe was actually 120 mm behind him. Calculate:
   a) the downward force that his hand has to exert while he carries the pipe in this way; and
   b) the upward force that his shoulder has to exert while he carries the pipe in this way.

Problem Solving and Calculations

Set 5: Moments and Equilibrium

9. A uniform wooden bench type seat has a mass of 25 kg and a length of 1.9 m. The legs of the bench are 400 mm from each end. A person sits on the end of the bench, their weight acting at a point 100 mm from the end of the bench. What is the maximum mass of a person who can on the bench in this way without causing it to tip up?



10. John works on tall buildings as a window cleaner and stands on a horizontal platform suspended at its ends vertical cables P and Q. The 3.5 m long platform has mass spread uniformly along its length and weighs 280 N. On a particular occasion the tensions in the cables P and Q are 320 N and 590 N respectively.
    a) Determine John's weight.
    b) How far he is standing from the centre of the platform?

Notes

11. The front wheels of Janet's car support 8000 N of its weight, while the rear wheels support the remaining 7000 N. She wanted to find out how far the centre of gravity was from the front wheels, so she measured wheelbase (distance between the front and rear wheels) of her car and found it was 3.20 m. How far was her car's centre of gravity from its front wheels?

12. Ralph is building a bridge. He needs to lift a long, non-uniform tree trunk weighing 48.0 kN into a horizontal position onto two supports, using a crane with a maximum lifting capacity of 30.0 kN. If the crane operates at maximum load when it lifts the first end into position, find:
    a) the lifting force the second operation at the other would need,
    b) the distance to the centre of mass of the log from its heavier end.

13. Engineers design racing cars with a low centre of mass and widely spaced wheels to improve their high speed cornering ability. Explain, using moments, the physics on which they base this design.

Problem Solving and Calculations 5

Set 5: Moments and Equilibrium

14. At the end of a long day of painting his two-storey house Keith finds that he can't quite reach a part of the external wall near a balcony. He decides to improvise and use a heavy plank that is about 4.0 m long and has a mass of 37.5 kg.
    a) How far beyond the edge of the balcony will he be able to stand if he arranges the plank so its centre of mass is 750 mm in from the balcony edge?
    Keith's mass is 73.5 kg.
    b) Describe a simple way Keith could use to increase this distance.

15. A bridge has a weight of 3.15×10^5 N and two piers, 29.7 m apart, support it. The bridge's mass is uniformly distributed along its length. When a truck weighing 5.30×10^4 N is 10.7 m from the far end of the bridge and a car weighing 1.25×10^4 N follows 11.4 m behind it, find the weight supported by each pier.

Notes

16. In a science experiment several students tried to touch their toes while they stood with their backs to the wall. They found that this was not possible if their heels were touching the base of the wall and they kept their legs straight. Explain why none of the students could perform this apparently easy task.

17. By inverting your body to a handstand position your centre of mass moves much closer to the ground.
    A lower centre of mass should give you more stability.
    Why is it therefore more difficult to remain in a handstand position than to stand upright as normal? (with length of arms increases radius

18. Explain why you can not avoid swaying from side to side when you try to walk along a straight line with your arms folded.

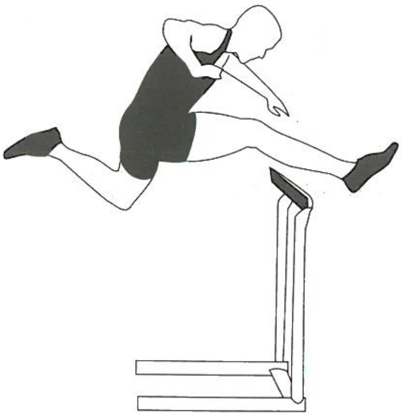
19. Good hurdlers have a distinctive action as they clear each hurdle in a race. You may have noticed that they lean their upper bodies well forward close to horizontal as they stride over each hurdle. Can you suggest why this action improves an athlete's performance in this event?

Taking about point ⊗

$\tau = (19 \times 5.3 \times 10^4) + (7.8 \times 1.25 \times 10^4) + (3.15 \times 10^5 \times 14.85)$

$F = \frac{5.28 \times 10^6}{29.7}$

$=$



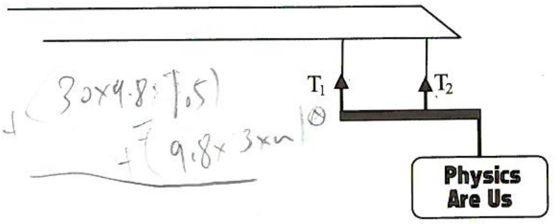
Problem Solving and Calculations

Set 5: Moments and Equilibrium

Notes

260

20. A uniform sign hangs from a beam outside a shop as shown in the diagram below. The beam has a mass of 30 kg, is 3.0 metres long and is suspended from the eaves of the shop by two identical wires, that are under tensions T_1 and T_2 respectively.



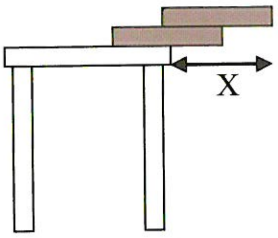
(30×9.8: 1.5)
+(9.8×3×m)

$T_1 = 110.0$ N

$T_2 = 260.0$ N

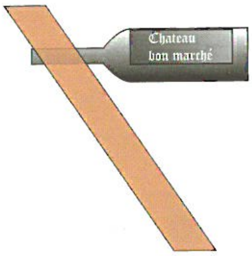
Calculate the mass of the sign and the distance along the beam where the second supporting wire is attached.

21. Two identical wooden planks, each of length 80 cm are positioned so that they hang over the end of a table as shown below.



What is the maximum possible distance, x such that the planks do not topple over?

22. Below is a diagram of a novelty one-bottle wine rack. It consists of a flat piece of wood 80 mm wide, 15 mm thick, and 200 mm long. An angled hole at one end fits the neck of a bottle. The rack, when holding a bottle, is quite stable if you stand it on a flat table as shown. Explain the critical factor in its design. Would one design suit all bottles?



23 A door, 2.40 m high and 0.90 m wide, weighs 206 N. Its centre of mass is located at its geometric centre. Hinges attached 0.30 m from its top and bottom support the door.

a) Assuming that the door's weight is supported entirely by the upper hinge, find the magnitude and direction of the force that the lower hinge exerts on the door.

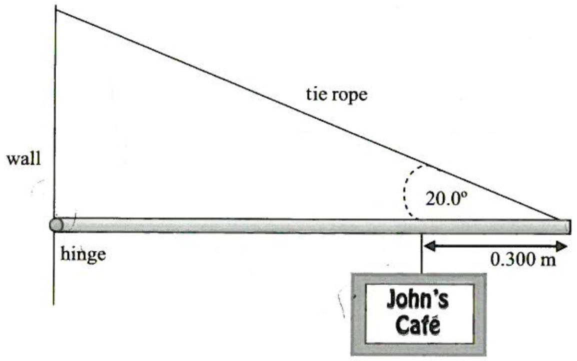
b) If instead each hinge supports half the weight of the door, find the magnitude and direction of the force that each hinge exerts on the door.

Problem Solving and Calculations 5

Set 5: Moments and Equilibrium

Notes

24. A shop sign has mass 45.0 kg and hangs from a uniform 12.0 kg beam as shown. The beam is 1.60 m long.



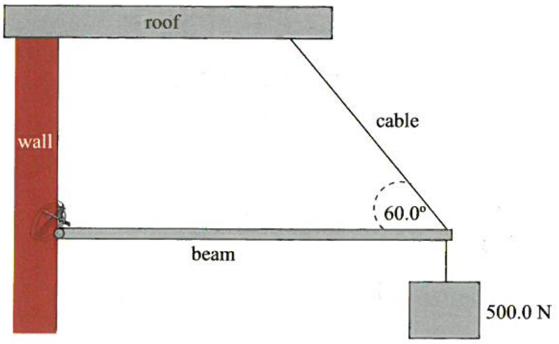
Determine

a) the tension in the tie rope

b) the vertical and horizontal components of the force acting on the beam at the hinge

c) the magnitude and direction of the force acting on the beam at the hinge.

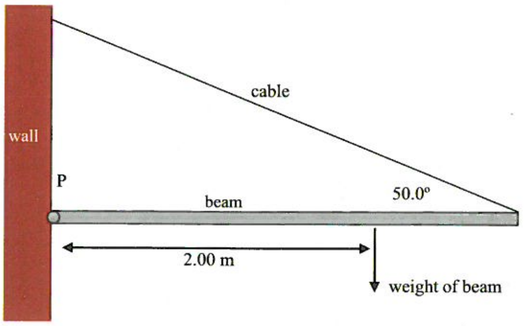
25.



The diagram shows a uniform beam, 1.40 m long and of mass 35.0 kg, that is hinged at the wall. A 500 N mass hangs from the unhinged end. This end is supported by a cable attached to the roof above.

Calculate the tension in this cable, and hence the size and direction of the force that the hinge exerts on the beam.

26. A non-uniform beam of mass 50.0 kg has its centre of mass located 2.00 metres from the pivot point P. The beam is supported by a cable connected 2.40 metres from P as in the diagram below. A man of mass 75.0 kg stands at P, then begins to walk out on the beam.



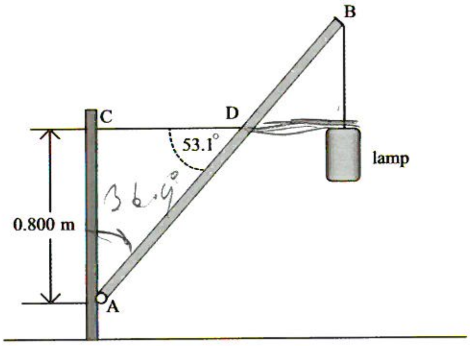
If the breaking strain of the cable is 1.36×10^3 N, how far out can he walk before the rope breaks?

Problem Solving and Calculations

Set 5: Moments and Equilibrium

Notes

27. A lamp hangs from the structure shown in the diagram below.



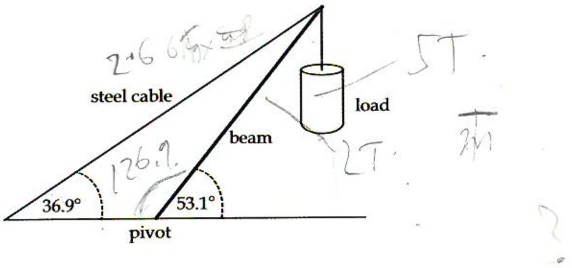
The uniform support AB is 1.70 m long and has mass 5.00 kg; the lamp's mass is 10.0 kg. Find

a) the tension in the light horizontal cable CD,

b) the horizontal and vertical components of the forces that the pivot A exerts on the pole AB, and hence

c) the magnitude and direction of the force exerted by the pivot A on the pole.

28. A simple crane is made from a 2.00 tonne beam that is pivoted at the ground. Its centre of mass is one third of its length from the bottom. The beam is supported by a steel cable, and the crane has a 5.00 tonne load attached, as shown below:

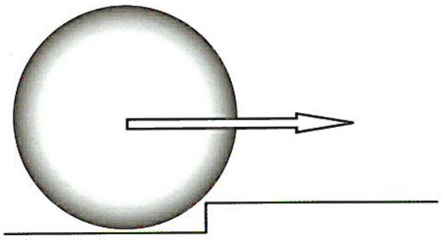


Determine

a) the tension in the steel cable

b) the magnitude of the reaction force exerted on the beam by the ground.

29. In order to roll a metal wheel of radius 50.0 cm up over a kerb 0.200 m high, Max has to pull horizontally at the axle with a force of 240 N.



Calculate

a) the mass of the wheel

b) the size and direction of the minimum force which, applied at the axle, could roll the wheel up over the same kerb.

Investigation 5.4: Cranes

Background

Construction sites often feature cranes such as the one illustrated below. They are used to lift heavy loads into place.

The task

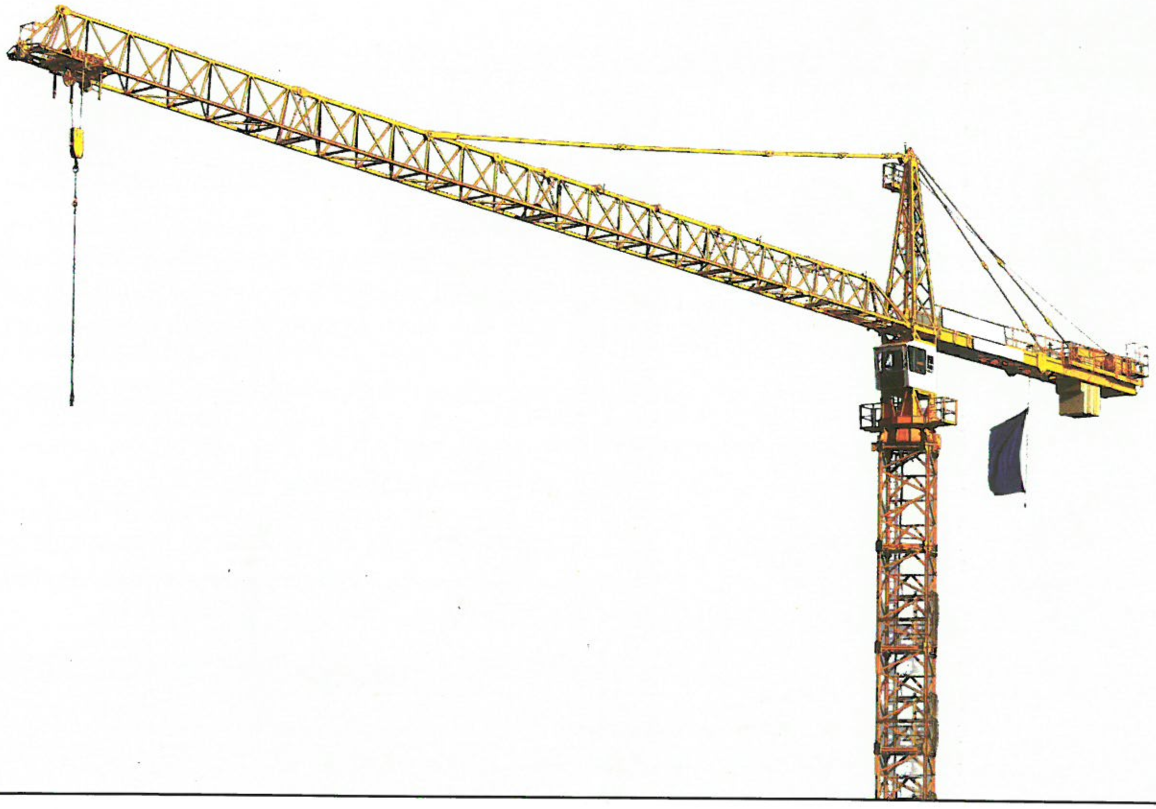
What stops the crane from tipping over when a heavy load is attached to the boom?

What is the purpose of the short boom on the right of the crane, behind the operator's station?

How does the crane operator compensate for the moment created by a load as it moves toward the end of the long boom on the left?

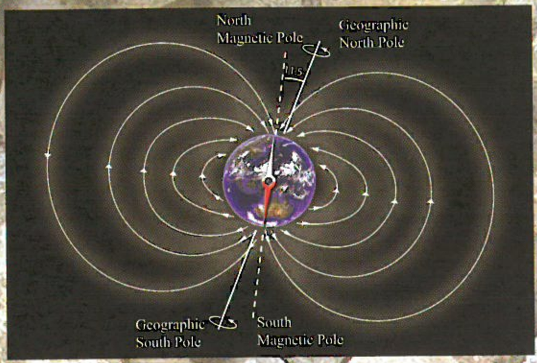
Cranes like this one can be made taller by adding more modules underneath the operator's station. What additional problems must be overcome as the crane gets taller? How are these problems solved?

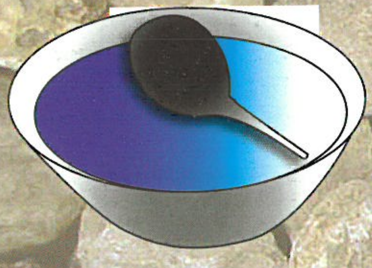
Notes



From lodestones to superconducting magnets

The Earth is surrounded by a magnetic field whose north and south poles are close to, but not in the same places as, the geographical south and north poles respectively. That is, the Earth's field has its south pole close to the geographic north pole. It has not always been thus. There is a lot of evidence that the Earth's magnetic field reverses at irregular intervals. Scientists believe that the Earth's magnetic field depends on currents within its liquid iron core. What actual mechanism creates the field, why the field is almost (but not quite) aligned with the Earth's axis of spin, and why it should reverse itself every few hundred thousand years, remain topics of active research.

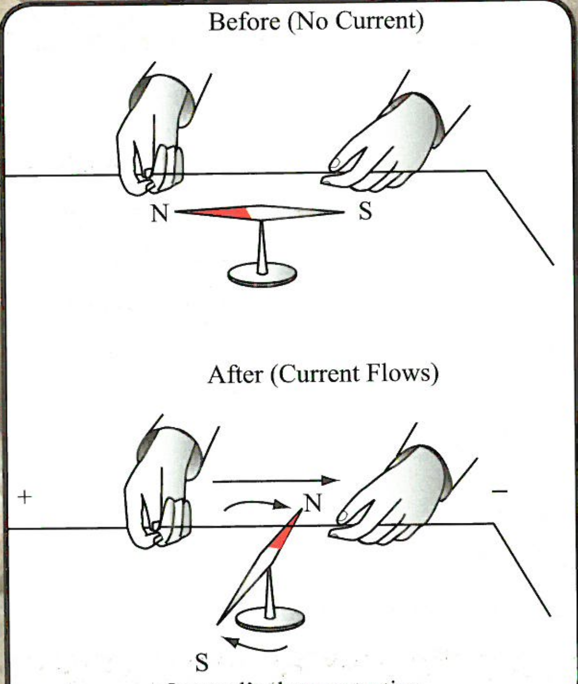




Lodestone used as a compass needle by Chinese navigators hundreds of years ago

Surprisingly few metal elements (including iron, nickel, cobalt and the rare metals gadolinium and dysprosium) can be strongly magnetised. Naturally-occurring magnetic rocks are mostly pieces of a particular iron oxide called magnetite.

These 'lodestones' are permanently magnetised with magnetic fields comparable to those produced by commercial magnets. Throughout history, people have worked out that a lodestone always points in a particular direction (that is, a suspended lodestone aligns itself on a north-south axis). This property has been very useful for navigation. Until quite recently, the process by which lodestones came to be magnetised was a mystery.



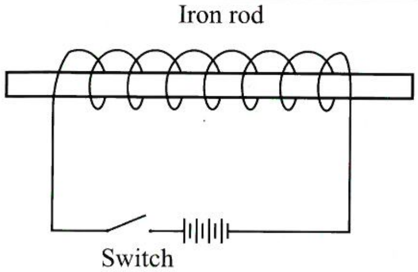
Before (No Current)

After (Current Flows)

Oersted's demonstration

Until the early 1800s, scientists generally accepted that electricity (exemplified by a current in a conducting wire) and magnetism (exemplified by a compass needle) were unrelated. In 1819, Hans Oersted managed to demonstrate that there is a connection after all. Oersted's demonstration was that a compass needle placed above or below a current-carrying wire swung to align itself at right angles to the direction of the current. After this breakthrough, new ideas came quickly. We now know that magnetic fields are created by moving electric charges. In lodestones and magnetic metals, the moving charges are spinning electrons. In electromagnets, the moving charges are the electrons moving through the conducting coils of the device – that is, the electric current.

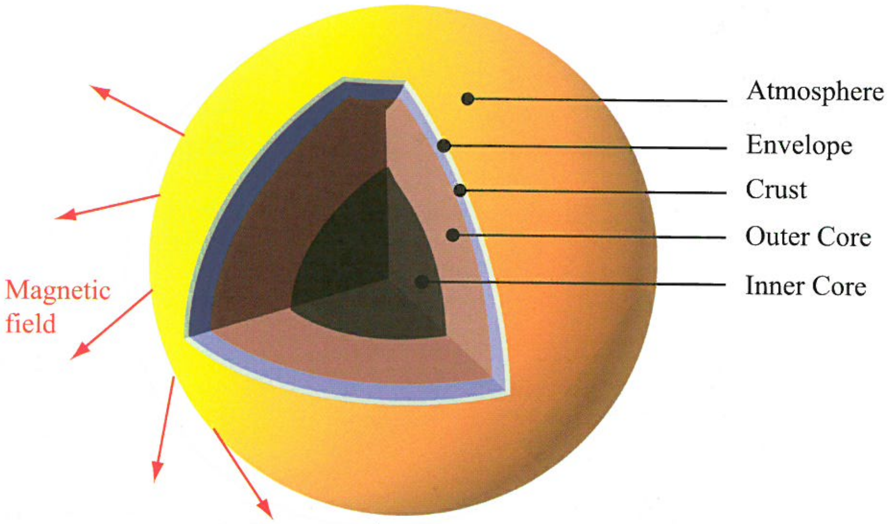
From lodestones to superconducting magnets



Electromagnet schematic

We measure the strength of a magnetic field in units called tesla (T). A field measuring one tesla is a very strong magnetic field. For comparison, the Earth's magnetic field strength is roughly 5×10^{-5} T or tesla. A permanent magnet such as a lodestone or a bar magnet is limited to a field strength of about 0.01 T because it has a limited number of spinning electrons. Electromagnets can create magnetic fields of over 1 T, but are themselves limited by the currents they can carry, and especially the heat produced by those currents. To achieve magnetic fields in the region of 10 T requires an electromagnet cooled by liquid helium at the super-low temperature of 2 K (-271°C). This low temperature allows some materials to become superconductors, with zero resistance to an electric current. At the time of writing, the strongest electromagnets are able to produce fields around 30 T.

Much stronger fields are known to exist in extreme environments, such as the surfaces of some very massive neutron stars. These strange stars are the remains of giant stars that have gone through the supernova stage of their lives. Such 'magnetars' can have magnetic fields with field strengths around 10^{11} T, billions of times stronger than any magnet constructed by humans.



Cross section of a magnetar

From lodestones to superconducting magnets: Comprehension Questions

Comprehension Questions

1. The 'north' end of a compass needle is sometimes called a 'north-seeking pole'. Explain.

2. A magnet, free to swing in the Earth's magnetic field, quickly aligns itself with the field lines. Explain why this alignment happens.

3. Bar magnets have north and south poles but the field around a current-carrying wire has no poles. Explain.

4. Show that the strongest permanent magnets create fields about 200 times as strong as the Earth's magnetic field.

5. How much stronger then the Earth's field is the field produced by the strongest electromagnets?

6. Estimate the force exerted on an electric current of 1 ampere by the magnetic field of:
   a) the Earth
   b) a strong permanent magnet
   c) a strong electromagnet
   d) a magnetar

7. Estimate how much magnetic flux (measured in webers) can be enclosed by a square of side length 10 cm if the magnetic field in question is produced by:
   a) the Earth
   b) a strong permanent magnet
   c) a strong electromagnet
   d) a magnetar

8. Estimate the average voltage that could be induced in a 10 cm square coil of 100 turns that is rotated at 50 times per second in the magnetic field produced by:
   a) the Earth
   b) a strong permanent magnet
   c) a strong electromagnet
   d) a magnetar

9. Why are the voltages estimated in question 8 average rather than peak voltages?

10. Sketch graphs showing the variation of voltage with time for the rotating coils in question 8.

Chapter 6: Magnetic Fields and Forces Explained

6

Notes

Remember the following important principles

A straight, current carrying wire will deflect a nearby compass needle. This shows that an electric current produces a magnetic field around the wire.

If you put the straight, current carrying wire between the poles of a horseshoe magnet the wire experiences a force. The direction of the force is at right angles to the magnetic field. The force is due to the interaction between the magnetic field that the current flowing in the wire produces, and the magnet's magnetic field.

The magnitude of the force on a straight current carrying wire placed perpendicular to a magnetic field is directly proportional to:

1. the current I in the wire,
2. the length ℓ of wire in the magnetic field, and
3. the strength of the magnetic field, B

You can determine the force on a current carrying wire in, and perpendicular to, a magnetic field by:

$$F = I\ell B$$

where:

F is the force in newtons
I is the current in amperes
ℓ is the length in metres of the current-carrying wire in the magnetic field
B is the magnetic flux density, in tesla (T)

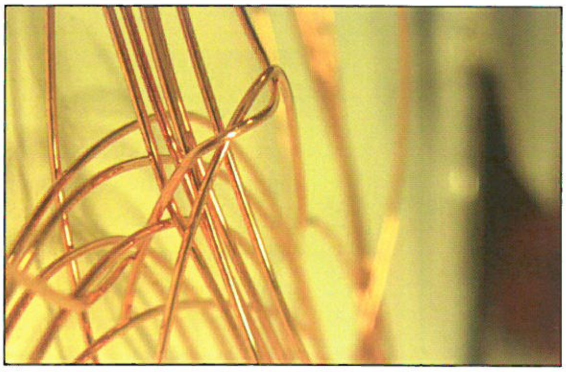
Magnetic Flux

Magnetic flux is the product of the flux density, B, and the area, A, when the flux is at right angles to the area:

$$\phi = BA$$

where:

ϕ is the magnetic flux, in weber (Wb)
B is the magnetic flux in tesla (T) or webers per square metre (Wb m^{-2})
A is the area in m^2



Experiment 6.1: The force-distance relationship for a bar magnet

Notes

Context

Some books state that the relationship between force and distance for poles of magnets are like electrostatic forces. This would mean that there is an inverse square relationship between the force of attraction or repulsion and the distance. In this exercise you will measure the forces and the distances and explore the relationship between the two variables.

Background

An easy way of measuring force is to place one of the magnets on an electronic balance. After zeroing the balance, any additional force (other than the weight of the magnet) will be recorded by the balance. Multiplying the reading on the balance (in kg) by 9.8 gives the force in newtons. Alternatively, you could use some other force-measuring device. For example, if you have access to data logging equipment, you could use the force meters from that equipment rather than an electronic balance.

Apparatus

- magnets
- rulers
- electronic balance or other electronic force meter

Pre-lab

- Use tables like the one shown below to record your results:

Distance between the magnets	Reading on the balance	Force due to the second magnet

- Place one magnet upright on the electronic balance or force meter and zero the reading.

Lab notes

- Place another magnet approximately 1m away from the upper pole of the magnet on the balance and take a reading of force (or “weight”)
- Repeat this for a number of readings as you bring the second magnet closer to the magnet on the balance.

Post-lab discussion

1. Plot a graph of distance between the magnets (on the horizontal axis) and force between the magnets (on the vertical axis).
2. Plot graphs as above but try the inverse square of distance on the horizontal axis.
3. What do your graphs indicate about the relationship between the forces applied by magnets on other magnets and the distances between them?
4. Do your data support or refute the information mentioned in Question 3 from the textbooks?
5. What are the sources of error and uncertainty in this experiment?

Experiment 6.2: Force on a conductor in a magnetic field

Background

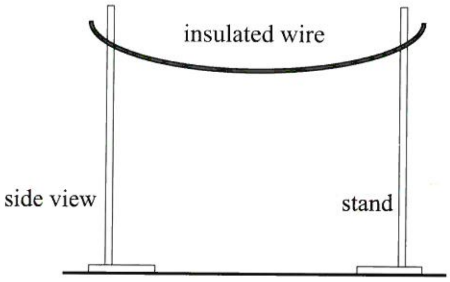
The passage of a current through a conductor creates a magnetic field. When a current-carrying conductor is placed in a magnetic field, the field may exert a force on the conductor. No force is produced when the current flow is parallel to the magnetic field. Maximum force is produced when the current flow is perpendicular to the magnetic field.

Apparatus

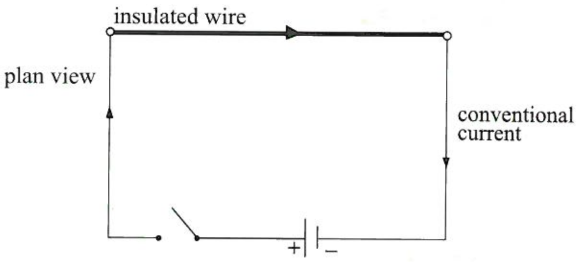
- large 1.5 V cell
- 80 cm flexible (multi strand) PVC insulated copper wire
- key switch
- connecting leads
- horse shoe magnet
- retort stands and clamps

Pre-lab

- Support the insulated copper wire between two retort stands as shown.



- Assemble the circuit shown here.



- Create a table like the one shown below.

Direction of current flow	Direction of magnetic field	Direction of force
left to right	downwards	
left to right	upwards	
right to left	downwards	
right to left	upwards	

- Press the key switch only for short periods.

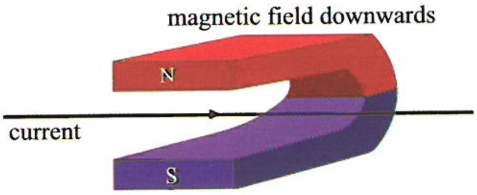
Notes

Experiment 6.2: Force on a conductor in a magnetic field

Notes

Lab notes

Hold the horseshoe magnet so that the PVC wire passes between the poles of the magnet as shown in the diagram.

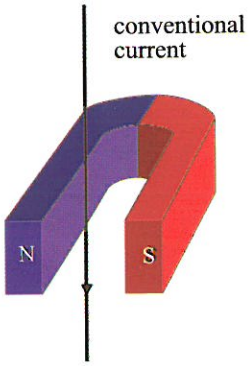


Press the key switch. Remember that conventional current flows from the positive to the negative terminal.

Complete the table from your observations.

Post-lab discussion

1. Explain why you were instructed to hold the switch down only for a short time period.
2. State the direction of current flow in a circuit, with reference to the terminals of the cell.
3. State the direction of the magnetic field between the arms of the horseshoe magnet.
4. Develop a rule that predicts the direction of the force on the wire in terms of the current and magnetic field directions. Explain the physical principles that make the rule work.
5. Predict and explain which way the wire will move in the diagram below.



Experiment 6.3: Efficiency of an electric motor

6

Background

Notes

Electric motors are used to do work. They are commonly used to lift weights, for example on cranes or in lifts. The input to the motor is electrical energy and the output is work. In this activity you will investigate the input power and the output power of a motor.

You will use these measurements to calculate the efficiency of the motor and explore the relationship between efficiency and operating conditions. Explore the relationship between efficiency and one other variable such as the supply voltage, supply current, load lifted, etc.

The work done in lifting a mass is its change in potential energy, $\Delta E_p = m\,g\,\Delta h$ where m is the mass (kg) of the weight being lifted, g is the gravitational field intensity (9.8 N kg^{-1}) and Δh is the height (m) through which the mass is lifted. The useful power developed by a motor is the rate at which it can alter the potential energy of the mass it is lifting.

Hence $P = \dfrac{mg\Delta h}{\Delta t}$ where Δt is the time (s) taken to lift mass m through a height of Δh.

The input power to the motor is V I where V is the potential difference across the motor (V) and I is the current (A).

The efficiency of the motor is the ratio of output power divided by the input power.

Hence efficiency is given by:

$$\text{efficiency} = \frac{\text{output power}}{\text{input power}} = \frac{\left(\dfrac{mg\Delta h}{\Delta t}\right)}{V\,I}$$

Aim

To determine the efficiency of a small electric motor.

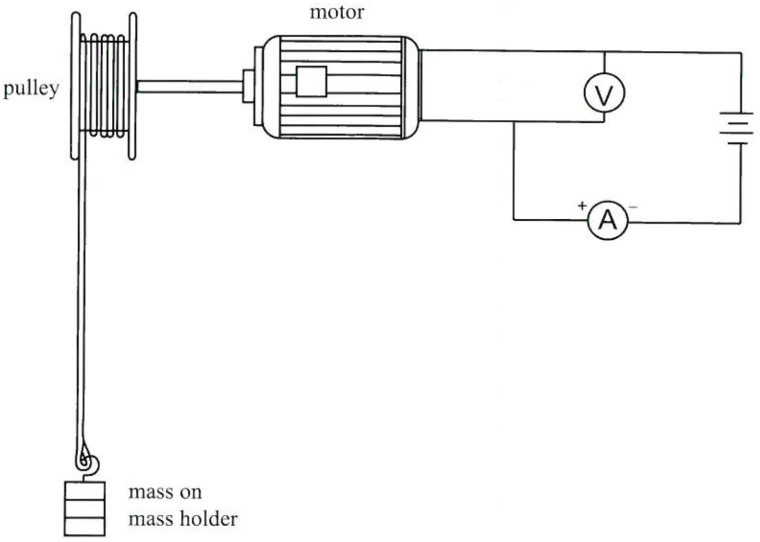
Apparatus

You will need at least the following list. Negotiate with your teacher or technician for other items.

- small electric motor with attached pulley
- DC ammeter (0–1 A) or current sensor
- DC voltmeter (0–5 V) or voltage sensor
- power supply
- cotton or nylon thread
- timer
- masses such as 50g brass slotted masses on a holder

Pre-lab

- Use a set-up similar to the following:



- Keep accurate records of your procedure and measurements. Photographs of your set-up may be useful for your report. Be sure to ***investigate*** rather than simply ***measure***.

Experiment 6.3: Efficiency of an electric motor

Notes

- Measure m, $\triangle h$, $\triangle t$, V, and I for the motor running under various conditions. Use these to plot the efficiency of the motor against another variable that you chose to explore.

Post-lab discussion

1. Summarise your findings.
2. Reflect on your experimental technique. What might you have improved? How?
3. Describe any errors that may have affected the validity of your results.
4. Estimate the uncertainty in your measurement of efficiency.
5. Which of the sources of error and uncertainty had the greatest effect on your results? Explain.

Experiment 6.4: Magnetic field intensity between the poles of a horseshoe magnet

Background

Horseshoe magnets have a nearly uniform magnetic field in the region between their poles. If you try sprinkling iron filings around a horseshoe magnet it will reveal the relative uniformity in that region and that the field is much weaker further from the poles. Horseshoe magnets are used when a relatively uniform permanent field is needed in a small region within a device such as a dynamo.

In this exercise you will measure the force on a current in a magnetic field between the poles of a horseshoe magnet in order to determine the intensity of the magnetic field.

The relationship between the relevant variables is the well known: $F = I \ell B$.

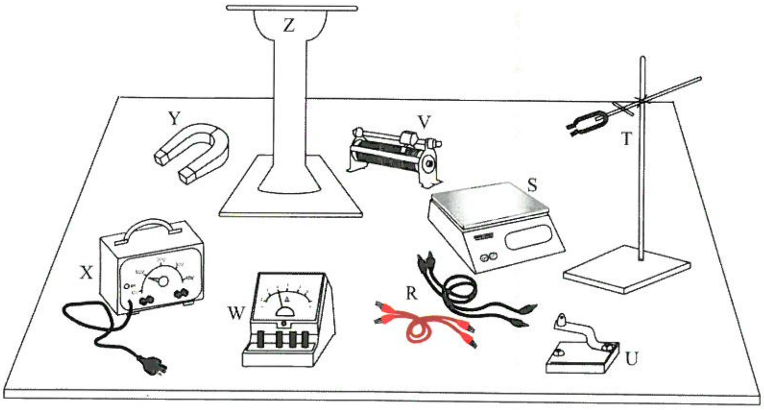
Notes

Aim

You will measure the force on a current carrying wire with an electronic balance and vary the current with a rheostat. A graph of force against current will allow you to determine the magnetic field intensity, B, from the gradient of the line of best fit of the graph.

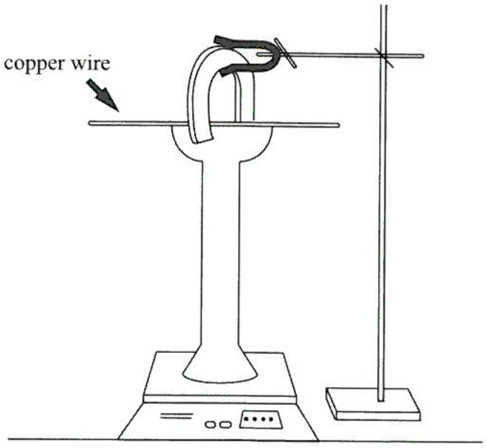
Apparatus

- Z light plastic stand with a piece of copper wire glued to the top edge
- Y horseshoe magnet
- X power supply
- W ammeter
- V rheostat (variable resistor)
- U switch
- T retort stand and clamp
- S top-loading electronic balance
- R leads



Pre-lab

- Place the wire and stand on an electronic balance and place the magnet over the wire as shown.



Experiment 6.4: Magnetic field intensity between the poles of a horseshoe magnet

Notes

Pre-lab

- Place the power supply, ammeter, and rheostat in series with the wire so that a range of known currents can be passed through the wire.
- You will need a table in which to record at least the following:

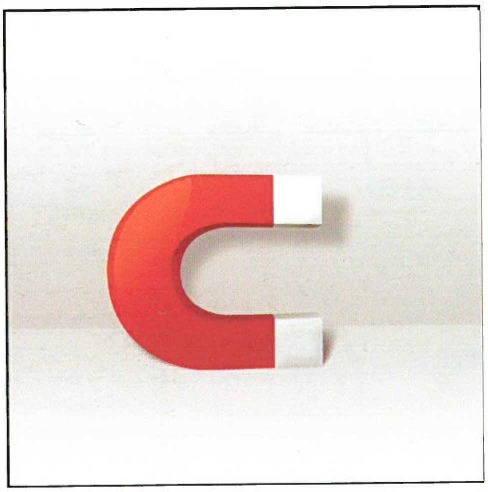
Current (A)	Balance Reading (g)	Force (N)

Lab notes

- Obtain a range of force and current data

Post-lab discussion

1. Create an appropriate graph and draw a line of best fit to the data points.
2. Explain how you used your measurements to produce a straight-line graph.
3. Determine the slope (gradient) of the graph.
4. Estimate the magnetic field intensity of the field between the poles of the magnet.
5. What are the major sources of uncertainty in this experiment?
6. Estimate the percentage uncertainty in your measurement of field intensity.



Problem Solving and Calculations

Set 6: Magnetic Fields and Forces

Notes

1. Draw the magnetic field distribution for each of the following arrangements:
   a) bar magnet.
   b) two parallel (side by side) but separated bar magnets with opposite poles facing each other.
   c) two parallel but separated bar magnets with like poles facing each other.
   d) two bar magnets in line (end to end), separated by 50 mm, with opposite poles facing and with a small iron washer placed midway between them.

2. When plotting the magnetic field around a wire carrying a current, a student first ensured that there were no objects made of iron close to the wire. Explain why she did this.

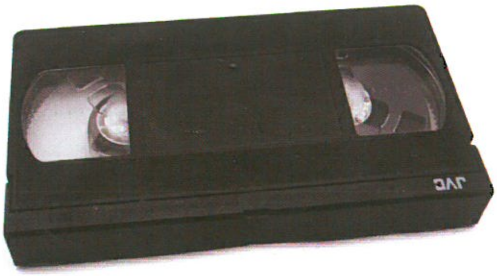
3. A freely suspended current-carrying wire hangs perpendicularly, and parallel to a fixed similar conductor carrying an identical current.
   a) If both currents flow in the same direction, describe movement, if any, of the suspended wire. Support answer with a diagram.
   b) What will happen if the currents flow in the opposite direction?

4. The starter motor in a car contains a solenoid (coil) connected to the car's starter switch. Draw a diagram of a solenoid and show the external magnetic field it produces when driver turns the starter switch on. Show the direction of both the current and magnetic field.

5. In a small household electric motor the rectangular coil of wire has 200 turns. The coil is 100 mm long and 30 mm wide. The coil, when it has a current of 0.20 A flowing through it, is perpendicular to a magnetic field of flux density 0.35 T. Find the torque experienced by the coil.

6. Draw the magnetic field pattern and show the relative strengths for:
   a) current carrying single wire, and
   b) a current carrying circular coil.

7. The instructions on magnetically-recorded media such as videotapes and computer hard drives state that you should not put them next to electrical power cords. What is the reason behind these instructions?

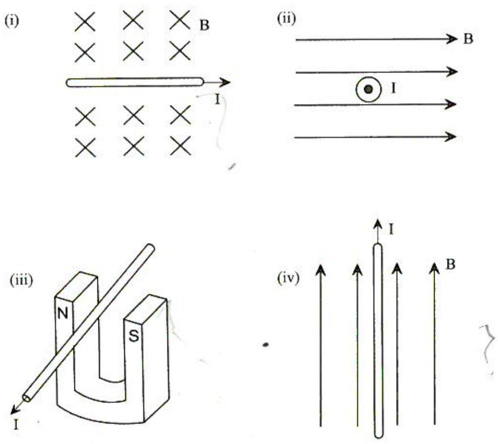


Problem Solving and Calculations

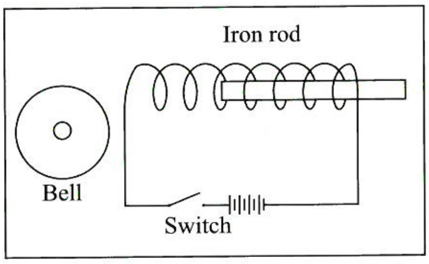
Set 6: Magnetic Fields and Forces

Notes

8. For each of the following, indicate the direction of the force, if any, acting on the current carrying wire.



9. The diagram below represents a circuit for a simple electric door bell. Explain why the bell sounds when you close the switch. Suggest how you can change the arrangement shown in the diagram to make the bell ring louder.



10. An electric motor in a hair dryer draws a current of 10 A when operating at maximum heat and speed. If the side of the armature between the poles of the magnet in the fan motor is 120 mm long, calculate the force acting on the armature when it is perpendicular to the magnetic field of strength 2.0 T.

11. Commercial electric motors may have up to 12 coils or `windings' with each located in a different position around the armature. Such motors produce a much more even torque than motors with fewer coils. Explain, with the aid of a diagram why this is so.

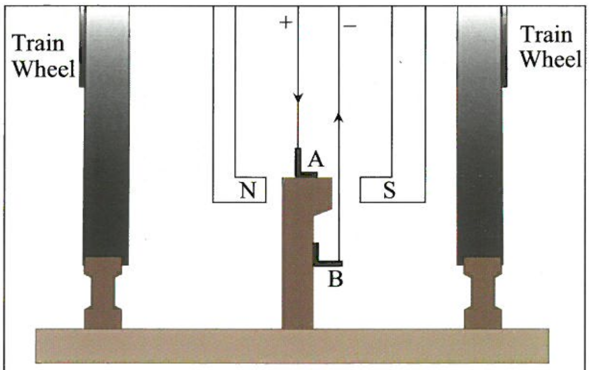
12. A 75 m long DC transmission cable stretches between two light towers in an east-west direction in a location where the horizontal component of the Earth's magnetic field is 2.5×10^{-5} T. Determine the magnitude and direction of the force that the wire experiences when a 40 A current passes through it.

Problem Solving and Calculations 6

Set 6: Magnetic Fields and Forces

Notes

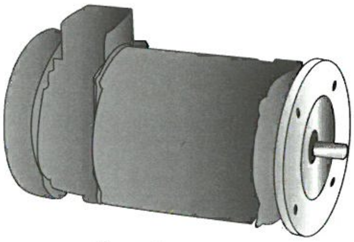
13. The diagram below shows the design of an experimental electric train. It has the two poles of a magnet arranged on each side of a steel third rail in the middle of the track. The train has controls that can vary the direction and strength of current that passes between sliding contacts A and B.
    a) What is the direction of the magnetic force the magnet exerts on the third rail when current flows from A to B?
    b) What is the direction of the magnetic force the rail exerts on the magnet?
    c) In what direction would the train move?
    You may find Newton's Third Law of Motion useful in your explanation.



Experimental train design

Besides braking, the train could use some of its electric motors as generators to stop the train.
   d) What are three essential components of an electric motor?
   e) How does an electric motor differ from an electric generator?
   f) How would the train use its motor to brake?

14. A simple electric motor contains several coils of wire. Draw a diagram of a simple coil and sketch the magnetic field around it that is produced when a current flows through the coil. Show the directions of both the current in the coil and magnetic field produced.



Electric motor

Investigation 6.5: Field intensities around magnets

Notes

Background

A magnetic plotting compass consists of a small magnetised needle pivoted in its centre on a sharp point. They can respond to magnetic fields that are too weak to affect iron filings. Compass needles can usually only rotate in the horizontal plane. Thus a compass needle will align itself only with the horizontal component of the magnetic field in its vicinity.

The end of a plotting compass needle that points due north is commonly called a north pole, but its full name is a north seeking pole.

Magnetic field lines have a direction, given by the direction of the force that the field exerts on the north pole of another magnet placed in that field. Magnetic field lines also indicate field strength. The lines are closer together in regions where the field is stronger. A null point is a spot where two or more magnetic fields cancel each other out.

Aim

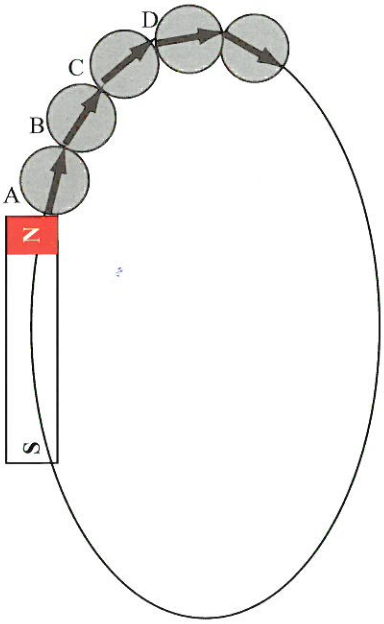
To investigate the magnetic field of a bar magnet and its interaction with the Earth's magnetic field.

Apparatus

- Sheet of white paper (A3)
- Sheet of white paper (fish and chips size wrapping paper)
- bar magnet
- plotting compass

Pre-lab

- Place the plain A3 paper on the bench or desk so that it is clear of any iron or steel objects, including the frame of the bench.
- Place the bar magnet in the middle of the paper and trace around it.
- Place the plotting compass at the corner of the north pole of the magnet. Mark the position of the north and south ends of the compass needle by pencil dots B and A respectively.
- Move the compass until the south end of the needle is over the dot B. Mark the position of the north end with a new dot C. Repeat this process.
- Join the series of dots to give the magnetic field line. Label the line with an arrow to indicate the direction of the field line (it is from north to south)
- Plot several other field lines in the same way.



Investigation 6.5: Field intensities around magnets

Lab notes

Notes

Use the plotting compass to align the edge of the fish and chips wrapping paper north-south. To prevent the paper moving during the experiment, hold the corners in place with small pieces of tape.

Place the bar magnet in the centre of the paper so that its south pole is pointing north. Trace around it to record its position.

Using the procedure described in the Pre-Lab, plot the magnetic field around the bar magnet. You should plot at least 12 lines. If you have access to more plotting compasses, you can work with a partner plotting lines on opposite sides of the magnet.

Post-lab discussion

1. Is the magnetic field symmetrical about the north south axis? Is it symmetrical about the east west axis?
2. Locate the points where the magnetic field of the magnet and the Earth's magnetic field cancel each other out (the null points).
3. Would you expect the same field pattern if the magnet was reversed with its north pole pointing north? Would there be any null points in this case? Test your hypotheses.
4. Describe the evidence that the magnetic field created by the bar magnet varies in strength. Is there any evidence of a relationship between distance from a pole, and the strength of the magnet

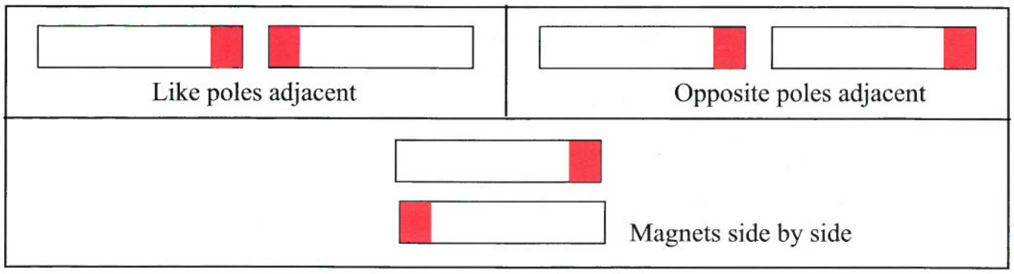
Assessment

Investigating magnetic fields with iron filings

Iron filings can also be used to study the shape of magnetic fields around magnets. Each tiny iron filing becomes a temporarily induced magnet and behaves like a very small compass needle. The filings align themselves and join together in 'chains of filings' in the direction of the field.

The direction of the magnetic field can be determined using a small compass. The direction of the magnetic field is the direction in which the north seeking end of the compass points.

- When you use iron filings to investigate the patterns around some different arrangements of magnets, make sure that you keep the iron filings off the magnets.
- Place the magnet or magnets being investigated underneath the glass or Perspex sheet, and lay the sheet of paper on top of the glass or Perspex.
- Gently shake the iron filings all over the sheet of paper and gently tap the sheet to make the filings link together.
- Sketch the field pattern for each of the following situations.



Investigation 6.6: Designing an electric motor

Notes

Design Brief

Design and operate an electric motor. You must understand and describe the science principles behind its operation. It must be able to drive a light load such as a pulley system or a fan. You might make it drive a small cart.

Details

You will work individually but are expected to collaborate wherever this will aid your learning. You should research various types of electric motor. Make yourself aware of how they produce torque. Find out what is meant by torque.

You may use any materials at all. You must do the construction yourself. There should not be an excessive use of prefabricated parts.
The motor might be just a simple single coil motor or could be a more complicated design using several coils.

Give consideration to using electromagnets rather than permanent magnets. You can borrow permanent magnets from your science teacher.

Assessment

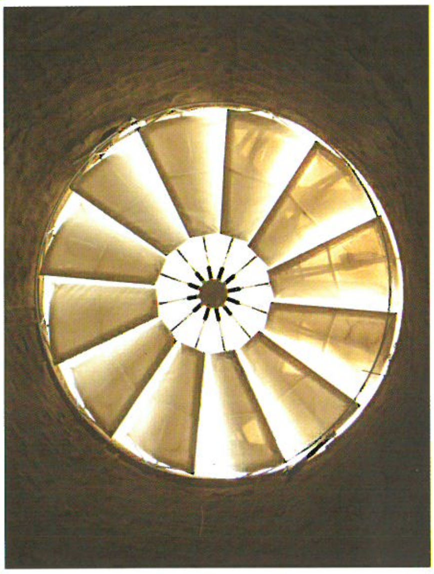
You will be required to be able to ***demonstrate*** and ***explain*** the operation of your motor. The ***explanation*** of the motor and the science principles behind it may be the focus of an oral assessment.

Your motor will be better and you will have learnt more if:

- your motor produces plenty of torque
- your motor can drive a significant load
- your motor always starts by itself without help from you
- your design shows some creativity
- you have chosen a challenge rather than a very simple design
- you motor is robust and shows good workmanship
- you can ***verbally*** demonstrate a good understanding of your motor

Your motor will be inferior and you will have learnt less if:

- you have used too many prefabricated parts
- your motor is just a simple copy of a design you found in a publication
- it does not work
- your motor falls to bits when your teacher picks it up and shakes it gently



Investigation 6.7: Fridge magnets 6

Notes

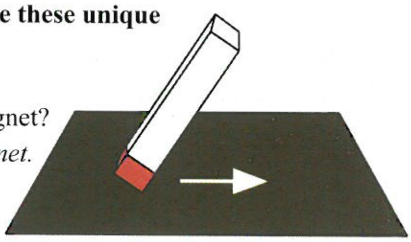
Background

Fridge magnets are ubiquitous, but how do they work? Are fridge magnets all the same? Why is there no magnetic attraction on the outward facing side of the fridge magnet? And what is the "Halbach array"?

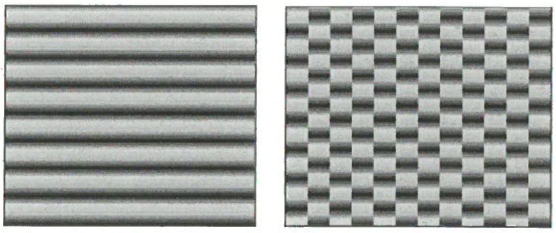
Your target question is:

What are the unique properties of fridge magnets and how are these unique properties produced?

1. What is the arrangement of the magnetic poles on a fridge magnet?
   - *Try dragging the pole of a bar magnet along a fridge magnet.*



2. Are the poles of a fridge magnet arranged in strips or in a checker board pattern?

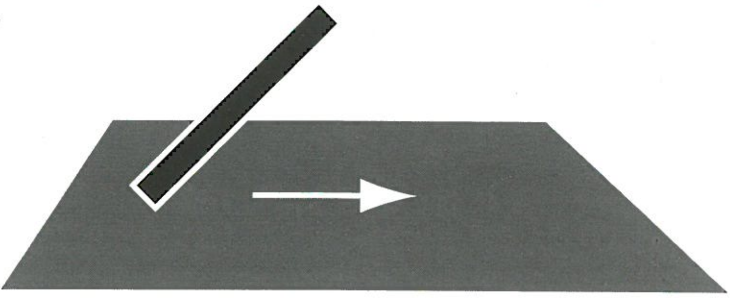


   - *Try dragging the edge of a bar magnet along a fridge magnet in different directions.*

3. Do all fridge magnets have the same pole structure?
   - *Place various fridge magnets face down under a sheet of paper and gently sprinkle the surface with fine iron filings. Record the patterns produced.*

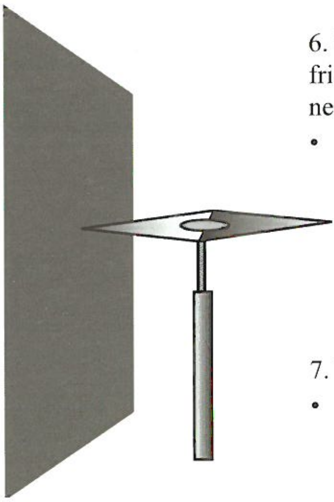
4. How do fridge magnets affect each other?
   - *Cut a small strip from adjacent edges of a fridge magnet drag these strips over the surface of a fridge magnet and observe any effects.*
   - *Drag two identical fridge magnets over each other and feel the magnetic effects.*
   - *Drag two dissimilar fridge magnets over each other. Explain the effects felt.*

5. Can the magnetism of a fridge magnet be detected by a compass needle?
   - *Test the surface of a fridge magnet with a mounted compass needle (not a compass enclosed in a case).*



Investigation 6.7: Fridge magnets

Notes



6. Using all the above tests and procedures map the surface of a fridge magnet and label the poles as indicated by the mounted needle.
   - *You can use a HB or B pencil to map the poles by drawing On the fridge magnet.*

7. What is the magnetic field on the reverse side of a fridge magnet?
   - *Use some of the above tests to study the magnetic field on the reverse side of a fridge magnet.*

Discussion

1. What is the source of the zone structure of the magnetic fields of a fridge magnet? How are the magnetic poles arranged?
2. Explain why there are differences in the magnetic effect on the reverse side of a fridge magnet.
3. What is the magnetic material used to make a fridge magnet?
4. Use this information to explain how the magnetic zones are arranged.
5. Use this information to explain why there are strong magnetic fields on one side but no magnetic fields on the other side of the sheet.

Investigation 6.8: Making an electric motor

There are many simple designs for electric motors that you can make in the laboratory or at home. You can find them in various text books and on the Web.

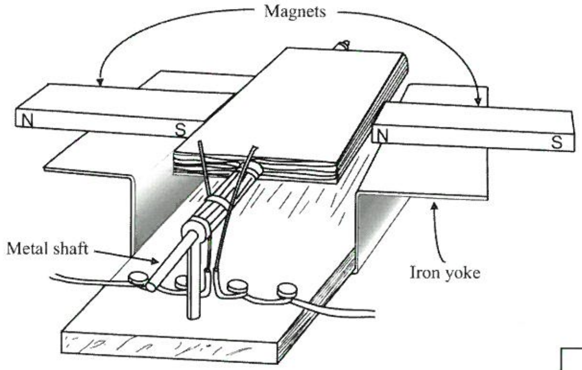
Different members of your group could choose different designs.

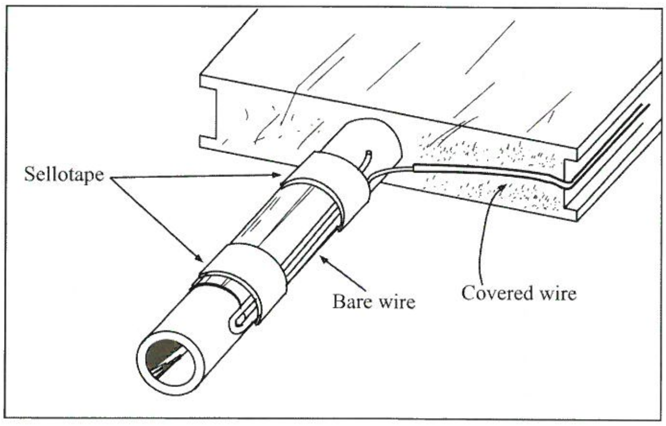
It is quite possible to make a simple electric motor that works with one pair of bar magnets, one metre of 26 gauge single strand insulated copper wire, one or two cells (or a small power supply) and various pieces of wood, tape, etc.

Choose a suitable design for your motor.
Gather the required parts.
Build the motor and make it work.
Try to improve it so it runs on the lowest possible voltage.

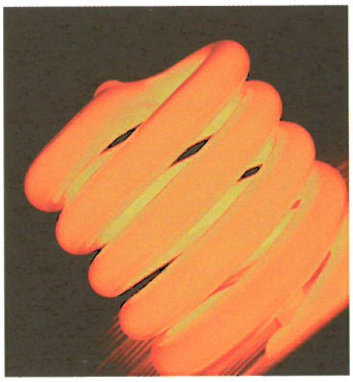
THEN

- Measure the power it uses by measuring the applied **voltage** and the **current** passing through it. The best motor will be the one that requires the least power to keep it running.
- What was Faraday's role in inventing the electric motor?





Chapter 7: Magnetic Induction Explained



Notes

Remember the following important principles

An electric current produces a magnetic field, and in certain circumstances a magnetic field can induce an electric current. This happens whenever the magnetic field changes. We call such a current an induced current.

Electromagnetic induction is the production of an induced electric current in a conductor when there is relative motion between the conductor and the magnetic flux. Two ways of achieving this are:

- moving a magnet through a coil of wire, and
- moving a conductor through a magnetic flux.

This generates a voltage, often called an electromagnetic force (emf), in the conductor. Note that an emf is the greatest potential difference that can be generated by a particular source of electric current, and is not a force at all.

Faraday's Law of Electromagnetic Induction states that the induced emf across a conductor in the form of a coil or solenoid is equal to the rate at which the conductor cuts the magnetic flux. That is,

$$\text{emf} = -N\,\frac{(\phi_2 - \phi_1)}{t}$$

where:

N = number of turns in the coil
$(\phi_2 - \phi_1)$ = change in the magnetic flux, in weber
t = time over which the flux changes, in seconds
emf = induced potential difference, in volts

We often apply this equation in the case of a coil rotating in a magnetic field. Note that in such a case, the formula gives the average emf, if it is calculated over a time period corresponding to ¼ of one complete revolution. This is the time required for the flux cut by the coil to change from a maximum value to zero.

$$\text{emf} = -N\,\frac{(B.A - 0)}{t}$$

where:

N = number of turns in the coil
B.A = (magnetic field strength in tesla) x (cross-sectional area of the coil, in square metres)
t = ¼ of the revolution period, in seconds
emf = average potential difference induced across the coil, in volts

When a conductor of length ℓ moves with a velocity v perpendicularly across a magnetic field B the induced emf across ℓ is:

$$\text{emf} = \ell v B$$

Lenz's Law: An induced emf gives rise to a current whose magnetic field opposes the original change in flux.

Experiment 7.1: Inducing an emf in a solenoid

Background

A solenoid is a tightly wrapped coil of insulated wire. Solenoids are widely used to create magnetic fields similar in shape to those made by bar magnets. A cathode ray oscilloscope (CRO) produces a graph (often called a trace) of voltage (y-axis) vs time (x-axis). The machines used to monitor heart function and so on in hospitals use CROs to display information.

Aim

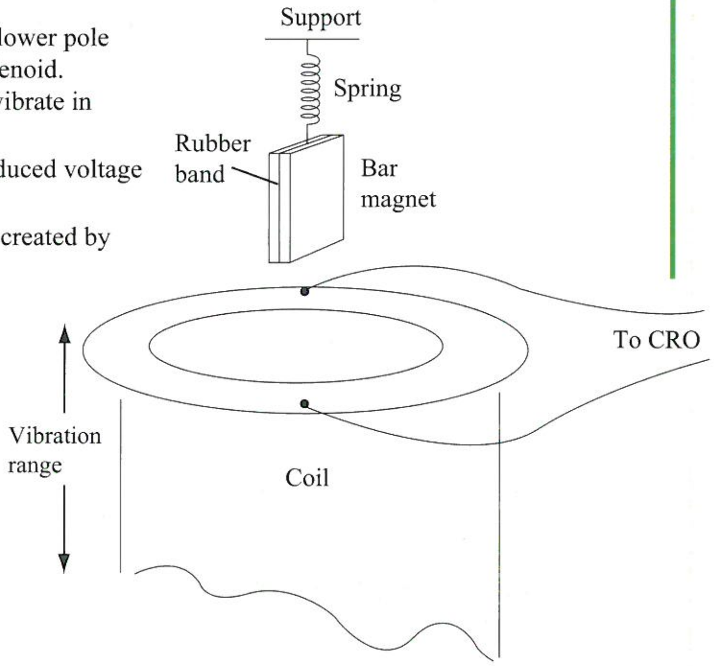
To produce and measure a time-varying emf in a solenoid.

Apparatus

- bar magnet
- rubber band
- a long (loose) spring
- cathode ray oscilloscope
- solenoid (eg the outer of an induction coil, dissectible pair)
- connecting leads
- a tuning fork
- rubber stoppers

Pre-lab

- Set up the apparatus as shown. Pick a spring that gives a period of vibration of about 1 second when the bar magnet is attached.
- Turn off the CRO time base.
  Set the magnet in motion so that the lower pole of the magnet only just enters the solenoid.
  The spot on the CRO screen should vibrate in unison with the magnet.
- Turn on the time base to show the induced voltage versus time relationship.
- Draw a labelled diagram of the trace created by the oscillating magnet.



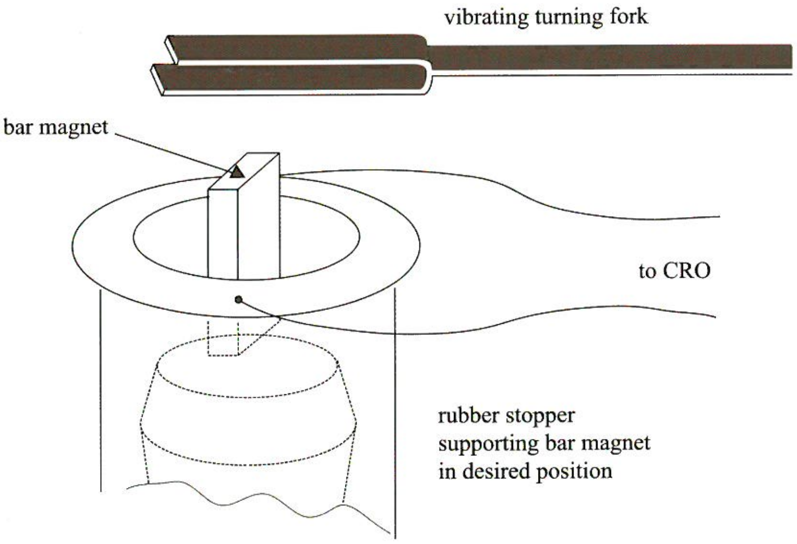
Notes

Experiment 7.1: Inducing an emf in a solenoid

Notes

Lab notes

- Disconnect the magnet from the spring and set up the apparatus as shown. Use stoppers to bring the bar magnet slightly above the top of the coil.



- Draw a labelled diagram of the trace created by the tuning fork.
- Using a suitable time-base and sensitivity determine the frequency of the tuning fork.

Post-lab discussion

1. Explain why the bar magnet attached to the spring induced an emf in the solenoid.
2. In what way does changing the amplitude of the oscillation affect the induced emf?
3. Which of the following changes to the oscillating magnet on a spring could change the frequency of the induced emf? Explain your choice.
   a) using a stronger magnet
   b) using a coil with more turns
   c) using a spring with a different oscillation period

4. Explain how the tuning fork interacted with the magnet to create a varying emf.
5. Sketch how the trace on the CRO would change if you used a tuning fork of a higher frequency.
6. What happened to the amplitude of the trace over time? Explain.

Experiment 7.2: Electricity from a motor

Background

The motors in some trains and buses give a braking effect when the motors are used to generate electricity when the vehicle is decelerating.

The geometry of motors and generators is so similar that a motor can be used as a generator. If you turn a motor (that is, you are an external source of torque) then the coil of the motor will generate emf while it turns in the field of the magnets in the motor.

Apparatus

- voltage sensor for computer or datalogger, or a cathode ray oscilloscope (CRO)
- small electric motor
- electrical leads with alligator clips
- gear system or some other way of rotating the shaft of the motor

Pre-lab

- Create a table to record your results, as follows:

Period of rotation (s)	Frequency of rotation (Hz)	Peak emf generated (V)

- Attach the leads of the motor to the voltage sensor or the CRO.

Lab notes

- Turn the motor at a steady rate.
- Record or sketch the resulting graph of emf vs time.
- Repeat this for other rates of rotation.
- Graph the peak emf generated vs frequency of rotation.

Post-lab discussion

1. Does the motor generate AC or DC when used in this way? Explain.
2. How does the rate of rotation affect the frequency of the output emf?
3. How does the rate of rotation affect the size of the output emf?

Notes

Problem Solving and Calculations

Set 7: Magnetic Induction

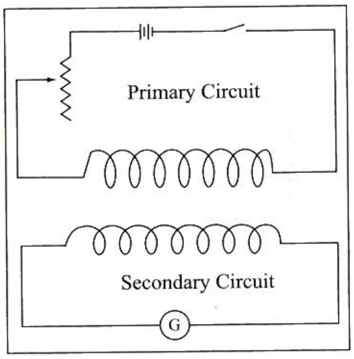
Notes

1. An aircraft flies at 980 km h^{-1} from west to east at an altitude of 10 km. If the vertical component of the Earth's magnetic field is 3.5×10^{-5} T and the aircraft has a wingspan of 60 m, calculate the potential difference it develops between its wing tips.

2. A portable 50 W television set is designed to operate on a 12 V battery, or by using a mains supply of 240 V connected through a transformer.
   a) If the transformer in the set is 90% efficient, what current does the television set draw if it is operating on mains power?
   b) Explain why this television set has vents in the walls of its casing.

3. A physics student inserted the north pole of a bar magnet into a coil that was connected to a galvanometer, and noticed that the galvanometer needle moved to one side. When she withdrew the magnet from the coil she notice the needle moved to the opposite side of the galvanometer. Explain these observations with the help of a diagram.

4. Referring to the diagram at left
   a) explain why, when you close the switch in the primary circuit, you detect a transitory electric current in the secondary circuit;
   b) suggest at least two ways in which you can increase induced voltage in the secondary circuit; and
   c) explain in which direction the current flows in the secondary circuit relative to the primary circuit.



[illegible] vBl

5. A 500 mm long radio aerial is attached to, and insulated from, the roof of a taxi. If the taxi is moving in an easterly direction at 60 km h^{-1} and the horizontal component of Earth's magnetic field is 2.5×10^{-5} T, calculate:
   a) the emf induced in the aerial;
   b) the rate at which the aerial cuts the magnetic flux.
   c) If the taxi turns a corner maintaining the same speed but now travels in a southerly direction, does the induced emf remain the same? Explain.

6. An electrical engineer working on the design of a new electric train said: 'If the opposite of Lenz's law was true, the motors in this train would soon burn out.' Explain why this would happen.

7. A generator coil of 200 turns is 30 mm in diameter. It experiences a uniform flux density change of 0.5 T in 10 s. Calculate the average emf induced in the coil.

8. A student connected the ends of a circular loop of wire with a radius of 0.10 m to a 5.0 Ω resistor. He put the coil near a transformer that, at a particular instant directed a magnetic field of 0.25 T at right angles to the plane of the coil.
   a) Calculate the emf induced in the coil if the magnetic field dropped to zero in 0.20 s.
   b) Draw a diagram of the coil and the resistor and show the direction of the magnetic field passing through the coil as it dropped to zero.
   c) Indicate the direction of the induced current through the resistor.
   d) Calculate the value of the induced current through the resistor.

Problem Solving and Calculations 7

Set 7: Magnetic Induction

9. A train is travelling with a constant velocity of 80 km h^{-1} in an area where the vertical component of the Earth's magnetic field is 36 μT.
   a) What is the size of the emf induced across each 1.0 m long axle?
   b) If the train is travelling in a south westerly direction, describe the force acting on an electron in this axle. – North East ? – [illegible]

10. A student timed the oscillation of a pendulum made of an aluminium plate. She noticed the period of oscillation was much less when she made the pendulum plate swing between the poles of a strong horseshoe magnet. Explain this observation. (Note that if you look at the electric power meter in your home you should see an aluminium disc rotating through the poles of a strong magnet.)

11. A commercial AC generator operates at a frequency of 50 Hz and produces a maximum voltage of 180 V. If the area of the coil is 2.0×10^{-2} m^2 and the armature rotates in a magnetic field of strength 0.20 T, how many turns of wire must the coil have to produce the maximum voltage? Assume the maximum flux through the coil reduces uniformly to zero over one quarter of a rotation.

12. In a laboratory investigation a student moved 20 mm of a length of copper wire perpendicularly across a 0.50 T magnetic field. The ammeter connected to the ends of the wire indicated a current of 10 mA.
    If the total resistance of the circuit was 2.5 Ω, calculate:
    a) the constant velocity with which she moved the wire through the field,
    b) the force she exerted to maintain this constant velocity. F =

13. A simple generator contains a square armature coil of side lengths 200 mm by 200 mm. The coil contains 300 turns of copper wire. It rotates at 60 revolutions per second in a uniform magnetic field
    a) What is the strength of this field if the generator produces an average voltage of 240 V?
    b) At what point in its rotation is the peak voltage produced? At what point is the voltage zero.

when the coil is parallel to the field
min ϕ max EMF

Notes

Investigation 7.3: Electromagnets

Notes

Background

An electromagnet is a coil of wire wound on a soft iron core. Electric bells, door chimes, relays, telephone earpieces and most electric motors all make use of electromagnets.

Apparatus (Pre-lab)

- Four metres of PVC coated wire;
- iron bolt and nut, about 5-6 cm long and 6 mm diameter;
- masking tape.

Pre-lab

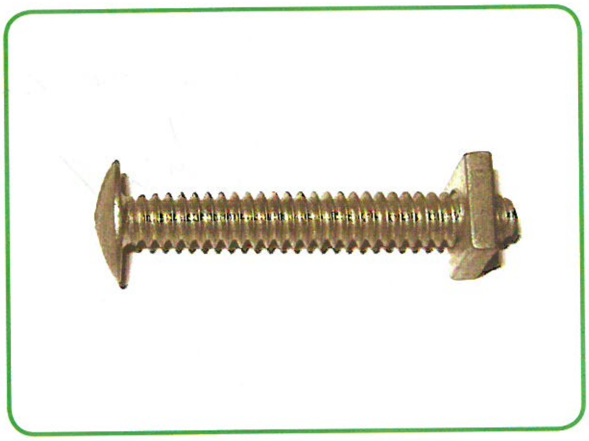
Making an electromagnet

- Start at the head of the bolt. Take the wire and begin to wind it around the bolt. Leave a 10 cm tail at the start. Keep each twist firm and side by side. Always wind in the same direction.
- When you reach the nut, cover the first layer of wire with masking tape, bring the wire back to the bolt head and start the second layer.
- Repeat the process for a third layer of wire.
- Keep repeating till you have 10 cm of wire left. Secure the wire in place by wrapping a firm layer of masking tape around the bolt.

The task: Investigating the strength of the electromagnet

Apparatus (Task)

- electromagnet
- ammeter (0-5 A)
- 12 volt D.C. power pack
- rheostat (0-11 Ω)
- connecting leads
- pins
- ruler

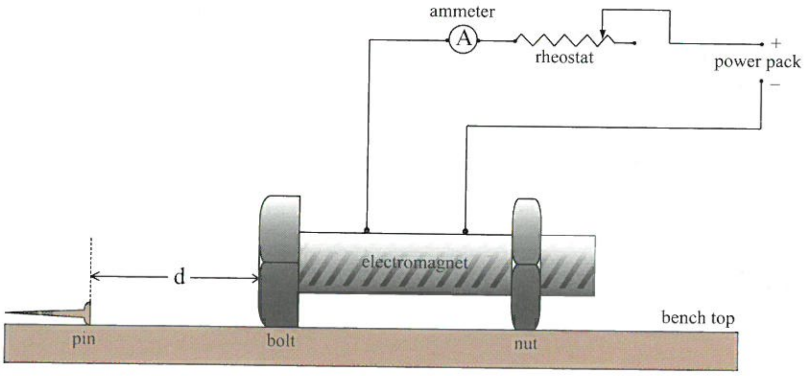


nvestigation 7.3: Electromagnets

Lab notes

Notes

Set up the equipment on a desk or bench as shown. Ensure that you are clear of any iron or steel objects.



Place the pin at various distances (d) from the electromagnet and determine the current (I) needed to just attract the pin to the magnet.

Record your values in a suitable table. You will need sufficient values to plot a graph.

Plot a graph of distance versus current.

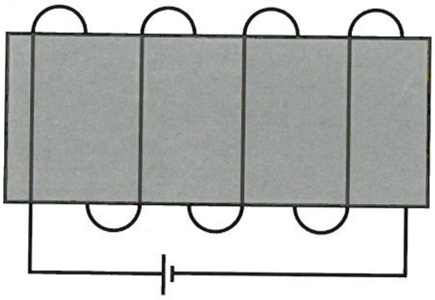
Post-lab discussion

Comment briefly on the shape of the graph you plotted.

How does the 'strength' of the electromagnet depend on the current flowing through it?

Describe briefly some ways of increasing the strength of an electromagnet.

An air-filled solenoid is connected to a battery as shown below. Sketch the magnetic field in and around it.



This experiment assumes that the force needed to move the pin remains constant. Do your results suggest that this is the case?

Chapter 8: Electrical Energy and Power Explained

Notes

Remember the following important principles

Electrical energy can be transformed into mechanical work (e.g. in electric motors) or thermal energy (e.g. in an electric stove or toaster). The following expressions give the rate at which a device transforms electrical energy:

$$\text{Power} = \frac{\text{energy}}{\text{time}} = V.I = \frac{V^2}{R} = I^2R$$

A power transformer functions on AC and changes potential difference from one value to another with a minimal loss of energy. It consists of two coils of wire, known as the primary coil and the secondary coil, wound on the same soft iron core.

An ideal (100% efficient) transformer does not lose any power so that:

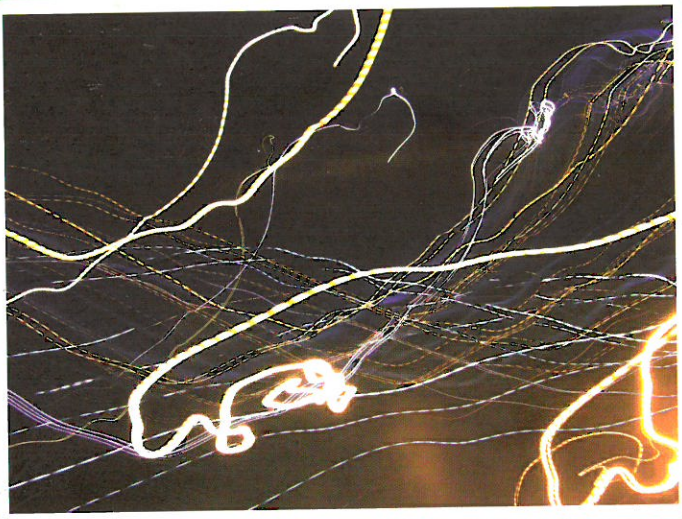
electric power (primary) = electric power (secondary)

i.e. $V_pI_p = V_sI_s$

Note that even the most efficient real transformers may lose up to 1 % of the input power as heat.

The turns ratio of a transformer is $\frac{N_p}{N_s}$

In an ideal transformer, $\frac{N_p}{N_s} = \frac{V_p}{V_s}$



Experiment 8.1: Transformers

8

Background

Notes

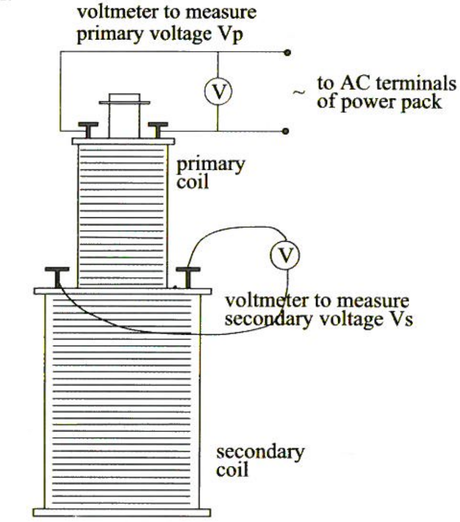
Transformers are extremely useful electrical devices that are able to change AC voltages. In its simplest form a transformer consists of two coils of wire wound on a soft-iron core. An AC voltage applied to one coil induces an AC voltage in the second coil.

Aim

To examine the operation of a simple transformer.

Apparatus

- induction coil (dissectible type with iron core)
- AC voltmeter
- 0-15 V for primary voltages
- AC voltmeter for secondary winding
- AC power pack 0-12 V
- connecting leads



coils and core shown 'exploded'

Pre-lab

- Draw up a table designed to record your results.
- With the power supply OFF connect the smaller coil to the voltmeter and AC terminals of the power pack.
- Connect the second voltmeter to the larger coil (see diagram)
- Insert the smaller coil into the larger coil and the soft-iron core into the smaller coil.
- If your voltmeter has more than one scale always start by using the least sensitive scale, i.e. the scale that can measure the highest voltages.
- Set the power pack to its highest voltage output. Do not touch any exposed terminals.

Lab notes

- Turn on the power. Record the primary voltage V_P and the secondary voltage V_S. Use a more sensitive scale on the voltmeter if it helps.
- Repeat this process for lower voltage outputs. You need at least 6 sets of results.
- Remove the soft-iron core from the primary coil and repeat your measurements.
- For the results *with* the soft-iron core, plot a suitable graph of secondary voltage output vs primary voltage input.
- On the same axes plot the results *without* the soft-iron core.

Post-lab discussion

1. Comment briefly on the shapes of the graphs.
2. What, if any, simple relationship exists between the secondary voltage and the primary voltage?
3. Secondary voltages are usually higher if a soft-iron core is used. Explain why.

Experiment 8.2: Voltage and Turns Ratio for a Transformer

Notes

Background

In a transformer, two coils are wound on a single iron core so that the magnetic flux created by one passes through the other. One coil is connected to the AC supply and is referred to as the primary. The other coil is called the secondary. Whenever a changing magnetic flux passes through a coil, there will be an induced EMF. In a transformer, the changing flux originates from the alternating current in the primary coil. Because this flux also goes through the secondary coil, there will be an induced EMF in both coils.

Apparatus

- U-shaped iron core from a "transformer kit" or a soft iron rod
- PVC-coated or varnished wire
- electrical leads with alligator clips or banana plugs
- AC power supply
- two voltmeters or datalogger voltage sensors

Pre-lab

- Draw up a table for your results as follows:

V_p	V_s	N_p	N_s	$\frac{V_p}{V_s}$	$\frac{N_p}{N_s}$

N_p = number of turns in primary coil;
V_p = voltage across primary coil
Ns = number of turns in secondary coil;
V_s = voltage across secondary coil

- Wind two coils of coated wire onto an iron rod as shown. The rod can be straight or U-shaped. Make sure that the number of turns is different for each coil. The primary coil should have at least 10 turns. Record the number of turns for each coil.

Lab notes

- Connect the primary coil to a 1 V AC power supply. Connect voltmeters or voltage sensors in parallel with both primary and secondary coils. Measure and record the voltage across both primary and secondary coils.
- Increase the voltage to 2 V AC. Measure and record the new voltage across both primary and secondary coils.
- Repeat the process using coils with different numbers of turns, until you have several sets of readings.

Post-lab discussion

1. Taking possible experimental errors into account, what is the relationship between the volts ratio ($\frac{V_p}{V_s}$) and the turns ratio ($\frac{N_p}{N_s}$)?
2. Explain the theoretical basis for the ratio of volts to turns that you found.
3. What should the turns ratio be in a 'step-up' transformer (one that increases output voltage compared with input voltage)?
4. Explain why a transformer will not work on a constant DC supply such as a dry cell.
5. The soft iron core in most transformers is laminated. What does this mean, and why is it done?

Experiment 8.3: Measuring electric energy

Background

Electrical energy can be converted into other forms of energy. A common conversion is the heat produced when an electric current flows through a resistor. Electric kettles, electric hot water systems and bar heaters all depend on this energy conversion.
The energy required to change the temperature of an object is given by:

Energy = (mass of substance)(specific heat of substance)(change in temperature)

Aim

To investigate the relationship between current, potential difference and electrical energy.

Apparatus

- Joule's calorimeter
- access to a balance
- thermometer [0 °C – 100 °C]
- 0–12 V power supply
- ammeter and voltmeter, or multimeter
- switch
- rheostat
- clock or stopwatch
- electrical leads
- water

Pre-lab

- Prepare tables to record the data you will gather (e.g. initial and final temperatures, the masses of water and of the calorimeter, currents, potential differences and times)

Lab notes

- Determine and record the masses of the calorimeter and its accessories, and of the water.
- Set up the equipment.
- Briefly switch on the power supply and use the rheostat to get a steady potential difference across the calorimeter (eg 5 V) and a steady current in the circuit (eg 2 A). Switch off immediately after setting this up.
- Gently stir the water and record the initial temperature to the nearest 0.5 °C.
- Turn the power and the timing device on simultaneously.
- Stir occasionally, and use the rheostat to maintain steady values of current and potential difference. Maintain the current for about 10 minutes, or until the temperature has risen by about 30 °C.
- Just before switching the current off, stir gently again and record the final temperature.

Post-lab discussion

1. Calculate the electrical energy supplied.
2. Calculate the energy absorbed by the calorimeter and the water which resulted in the measured temperature increase.
3. Compare the two energy amounts. Account for any discrepancies.
4. Estimate the uncertainties in the values of energy, and comment on your result.

Notes

Problem Solving and Calculations

Set 8: Electrical Energy and Power

Notes

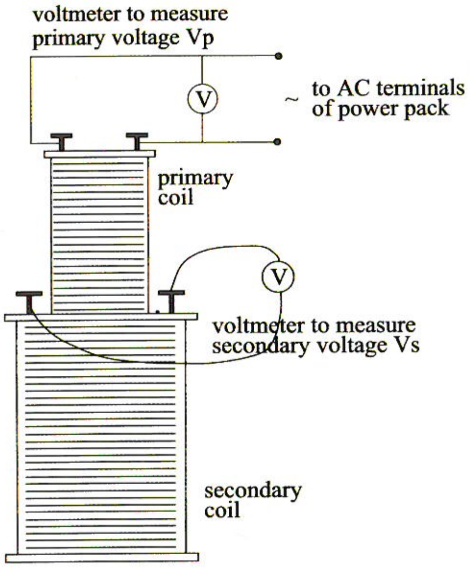
1. A defibrillator is a device medical personnel use to return an irregular heart beat to its normal rhythm. A defibrillator passes a 20 A current at 3000 V through a patient's heart in about 5 ms.
   a) How much electrical power does a defibrillator provide?
   b) How much electrical energy passes through a patient?
   c) What is the resistance of the patient's body in this circuit?

2. A particular communications satellite consumes electrical energy at a rate of 2000 J s^{-1}. The satellite is powered by a solar panel that receives 1373 J of per second from the Sun on each square metre of panel.
   a) If the panel converts solar energy into electrical energy at 10.0% efficiency, what is the area of the panel required to meet the satellites energy needs?
   b) If the panel provides an output voltage of 50. 0 V under optimum load, calculate the load's resistance.

3. An electric train has a motor rated at 1.50 kV, 125 kW.
   a) Calculate the current the motor draws.
   b) Calculate the circuit resistance.

4. While performing a laboratory investigation on the structure of a step-down transformer, a student noticed that the wire in one of the coils was thicker than the wire in the other coil. Does the thicker coil belong to the primary coil or the secondary coil? Explain why this is so.

5. The diagram at right shows a simplified view of a transformer without its metal core plates. It consists of two coils of wire, one inside the other. If the current in the outer coil is flowing in an anticlockwise direction and is increasing, explain how you would determine the direction of the current induced in the inner coil. Lenz's Law may be useful in explaining your answer.



coils and core shown 'exploded'

6. A transformer in a neon sign changes 240 V to 12 kV.
   a) Assuming that the transformer is ideal, compare the magnitude of the current in the secondary coil to the magnitude of the current in the primary coil.
   b) If the primary coil had 200 turns of wire, how many turns should there be in the secondary coil?
   c) If the transformer is actually 98% efficient, how large is the current in the secondary coil compared with the current in the primary coil?

Problem Solving and Calculations 8

Set 8: Electrical Energy and Power

Notes

7. An electric jug has a rating of 240 V, 2.50 kW.
   a) Calculate the jug's resistance.
   b) If the jug is used to heat water over a 2.00 minute period, how much electrical charge will have passed through the jug in that time?

8. A car engine needs 1.00 kW to start it. The starter motor supplies this power. The starter motor is 80% efficient and it runs off a 12.0 V battery.
   a) Calculate the current the starter motor draws from the battery to start the engine.
   b) In what way is the diameter of the copper wire that joins the battery to the starter motor quite different to the other electrical wires in the car? Why is this so?

9. a) For a typical electricity grid system, what is the role of a 'sub-station'?
   b) Suggest some reasons why an electricity company would not use the same sub-station to supply electricity to both an electric train system and to nearby houses.
   c) A power station generator produces a voltage of 18.0 kV, but the voltage in the transmission line that carries the electrical energy to the suburban sub-stations is 330 kV. Why does the electrical utility 'step up' the voltage before it is transmitted?

A substation

10. An electricity generation plant in a small town produces an average of 500 kW of electric power. The 10 km length transmission line from the power plant to the town's sub-station has a total resistance of 0.50 Ω. The voltage is stepped up at the plant from 2.0 kV to 20 kV and then down to 240 V in the town.
    a) If the plant had transmitted electricity at 2.0 kV, what power loss would have occurred in the transmission line when working at the average power output?
    b) Under normal circumstances the plant transmits at 20.0 kV. What power loss would occur in the transmission line at this voltage? ?
    c) Compare your answers to a and b. Give a reason why power is usually transmitted at very high voltages.

11. Electric utilities usually transmit energy at very high voltages. However, engineers have worked out that voltages over 1000 kV are uneconomical, and have an impact on the environment. Why should this be so?

Problem Solving and Calculations

Set 8: Electrical Energy and Power

Notes

12. An electric motor in a goods lift needs a minimum voltage of 405 V to operate. The cable supplying power to the motor comes from a transformer that has an output of 415 V. When the lift is operating, the cable carries a current of 200 A and has a resistance of 4.0×10^{-1} Ω per metre of cable.
    a) Determine the power loss in the cable when the voltage at the electric motor drops to 405 V.
    b) Determine the maximum length of cable that can supply the minimum of 405 V to the motor.
    c) How would you change the this arrangement to allow the motor to work at a larger distance from the transformer? — make the Area Large

13. A portable generator can provide 5.0 kW of electrical power. A petrol engine drives the generator. The generator is 80% efficient.
    a) How much mechanical power must the engine provide?
    b) Explain where you think the power losses occur in the generator.

14. Electric motors, fluorescent lighting systems and arc welding equipment all use some of the electrical energy they consume to create magnetic fields. If you have several such devices operating at your house, what effect would this have:
    a) on the voltage available to other devices on your property?
    b) on the temperature of the supply lines to your property?
    c) on the brightness of electric lights on your property?

15. A 3.0 MW substation provides current at 25 kV to electric trains through overhead wires. The wires are designed to operate in the voltage range 20 to 25 kV. If the resistance of the overhead wires is 1.2 Ω km^{-1}, how far from the substation can the train travel before the supply voltage drops below its operating needs?

Investigation 8.4: Back-emf of an electric motor

Background

A small D.C. electric motor that uses a permanent magnet to produce the magnetic field generates a back-emf when its armature rotates. This back-emf opposes the voltage applied to the motor and reduces the current through the motor. If the motor stops because of a heavy load being applied to it the current will increase because there is no back-emf.

Pre-lab

A researcher applies a fixed voltage of 12 V DC to a small permanent magnet DC electric motor. By varying the load on the motor shaft she was are able to reduce the speed of the motor and measure the current at various speeds. A fixed voltage of 12 V was applied to the motor.
Some of her results are tabulated here:

Current (I) drawn by motor (mA)	550	515	270	140	0
Motor speed (S) revolutions per minute (rpm)	0	200	400	600	800

1. a) Plot a graph of the current drawn (I) versus the motor speed (S).
   b) What does this graph suggest about the relationship between I and S?
   c) Determine the mathematical equation relating I and S.
2. Estimate the resistance of the motor's armature winding. (Hint: There is no back-emf when the motor is stalled.)
3. If the back-emf (V) of the motor is related to the speed S by the formula S = kV determine the value of the constant k.

The Task

Use a small motor and appropriate apparatus to create your own set of results. Be aware that applying too high a voltage, or running a current through a stalled motor, can damage the motor beyond repair.

In what ways were your results similar to, and different from, the ones shown in the pre-lab? Why can running current through a stalled motor cause damage? Explain why a motor produces a back-emf when operating but not when the motor stalls.

Notes

Investigation 8.5: Energy sources and efficiency

Notes

Background Research

Prepare brief notes explaining the following:

- What do we mean by the term 'electricity'?
- Through what materials will electricity flow?
- Distinguish between 'conventional current' and 'electron flow'.
- What is an emf, and how is it measured?
- What are the units used to measure current flow?
- What are the units used to measure the resistance to electricity flow through a conductor?
- What is the unit of electrical power and how is it measured?
- Distinguish between between AC and DC.

The Task

First, make yourself familiar with the various sources of electricity (or sources of electrical energy) by answering the following background questions:

- Identify the various energy transformations by which electrical energy can be produced from other forms of energy, e.g. sound energy to electrical energy.
- Name some of the technological devices that employ each method, e.g. the microphone.
- Name or describe the physical process that each device used e.g. piezo-electric microphone.

Finally, report on your investigation, taking note of the power output available from each source.

Investigation 8.6: Electrical power for transport

Notes

1. The most common type of AC motor used in industry is the 'induction' motor.
   a) Explain how an AC induction motor works.
   b) Three-phase AC induction motors have several advantages over single-phase AC induction motors. What are these advantages?
   c) Explain how a linear induction motor works.
   d) Outline some uses of linear induction motors.

2. Perth's urban trains are powered by DC motors. These same motors can also be used as brakes.
   a) Explain the principles of regenerative braking as used on Perth's trains.
   b) Suggest a reason or reasons why the electrical power generated is dissipated as heat in resistors rather than fed back into the electrical supply.

3. Many electric cars are driven by DC motors that are powered from rechargeable batteries. These batteries must be recharged with 15 V DC, but the domestic power supply is 240 V AC. Outline the main features of an AC/DC converter capable of changing 240 V AC to 15 V DC.

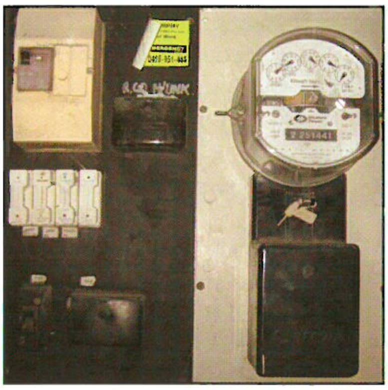
Eddy current brakes can be found on semi-trailers.

a) What are eddy currents?
b) How do eddy current brakes work?
c) Do eddy current brakes have any advantages over other types of braking systems?

Investigation 8.7: Safety and efficiency of electricity in your home

Notes

This investigation requires you to do a survey of the safety and efficiency aspects of the electricity supply in your home.

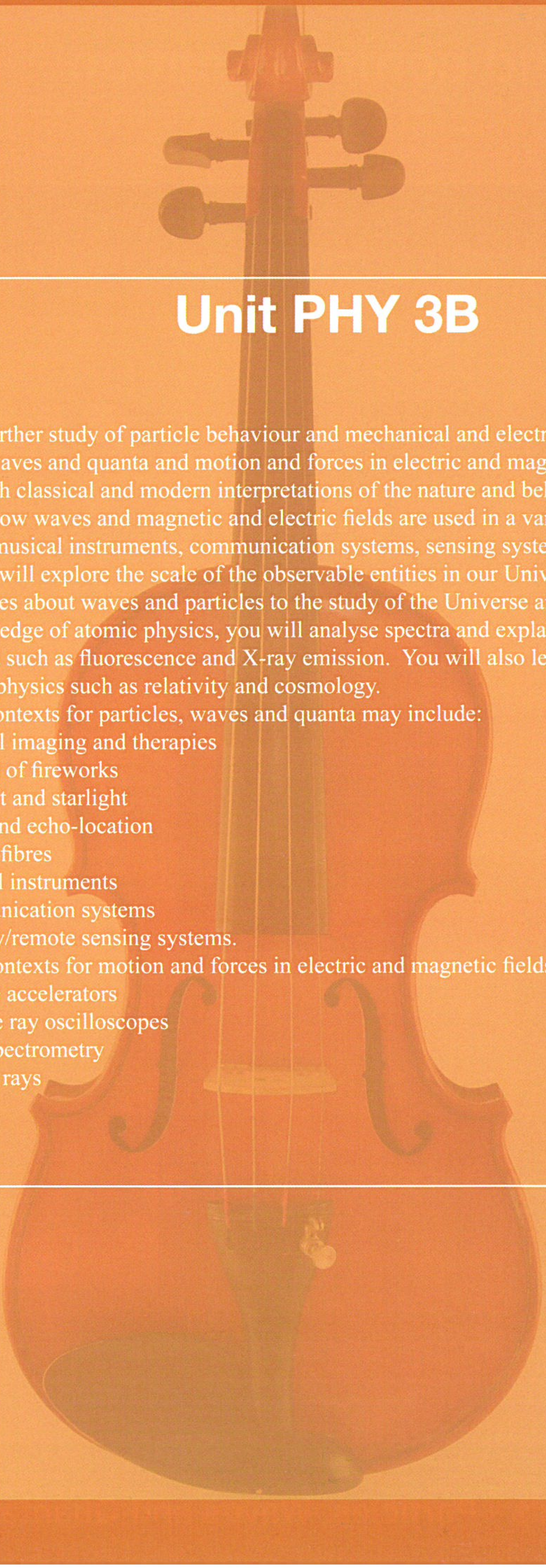


For safety aspects you will need to investigate thefollowing. In each case you will need to research how they work, and then investigate if they are present in your home.
How is electrical energy distributed to homes?

- What types of fuses are used in houses? (melting wire, trip switches, etc.)
- What is an earth wire? What is its purpose? How is it integrated into household wiring?
- What are RCDs and how do they work?
- What are surge protectors and how do they work?
- What are reset buttons for, and how do they work?
- What are the latest regulations/standards for 3 pin plugs and connecting leads?

For efficiency aspects you will need to investigate the following.

- How do you read the electricity meter in the meter box?
- What are the units of electrical energy?
- What is the unit cost of electrical energy?
- How efficient is your home?
- How much electrical energy per hour is used in the daytime when the house is unoccupied?
- Many devices are left in stand-by mode. How much energy is used per hour by these appliances in stand-by mode in your house? (Note: Turn the fridge off during this period of measurement.)
- How much CO_2 is put into the atmosphere by power stations for each unit of electrical energy produced? Note that each kilogram of coal burned produces 3.7 kilograms of CO_2.
- How much CO_2 is put into the atmosphere by power stations during one year of normal operation of your home? Note that each kilogram of coal burned produces 3.7 kilograms of CO_2.



Unit PHY 3B

Through further study of particle behaviour and mechanical and electromagnetic waves in particles, waves and quanta and motion and forces in electric and magnetic fields you will encounter both classical and modern interpretations of the nature and behaviour of waves. You will learn how waves and magnetic and electric fields are used in a variety of technologies, such as in musical instruments, communication systems, sensing systems and particle accelerators. You will explore the scale of the observable entities in our Universe, and relate physical principles about waves and particles to the study of the Universe and its parts. Extending your knowledge of atomic physics, you will analyse spectra and explain a range of physical phenomena such as fluorescence and X-ray emission. You will also learn about some aspects of modern physics such as relativity and cosmology.

Learning contexts for particles, waves and quanta may include:

- medical imaging and therapies
- colours of fireworks
- sunlight and starlight
- sonar and echo-location
- optical fibres
- musical instruments
- communication systems
- security/remote sensing systems.

Learning contexts for motion and forces in electric and magnetic fields may include:

- particle accelerators
- cathode ray oscilloscopes
- mass spectrometry
- cosmic rays

‘Music and communication’

Noise generally has many unrelated frequencies with no recognisable sequences. In general, music involves single frequencies or groups of related frequencies played in recognisable sequences (which we call tunes).

Musical instruments produce sounds through the vibration in regular waveforms of either air columns, strings or membranes. We group musical instruments into groups such as wind, percussion or strings.

The musical note a wind instrument produces depends on the air column’s length and temperature, and whether the air column is open at both ends, or closed at one end. The energy input into most wind instruments involves blowing air across an opening (e.g. the flute); blowing air over a reed to make it vibrate (e.g. the clarinet); or blowing into the instrument (e.g. the trumpet).

The musical note a stringed instrument produces depends on the length, mass per unit length, and tension of the string.

The energy input into a stringed instrument may involve striking the string with a hammer (e.g. the piano); plucking the string (e.g. the harpsichord); or bowing (e.g. the violin).

Mechanical waves such as sound, water waves and earthquake waves may be longitudinal or transverse.

The reason why a wave is longitudinal or transverse is because of the way the energy source vibrates.

While longitudinal waves can travel through either solids or fluids, transverse waves can only travel through matter whose particles are strongly bound together, such as solids.

Waves are important in human communications. We use longitudinal sound waves when we speak and listen.
Many other animals use sound waves to communicate, sometimes over long distances.
Bats, whales, dolphins and birds can communicate by varying the frequency and amplitude of waves.

Waves are important in communications. We use longitudinal sound waves when we speak and listen. Many other animals use sound waves to communicate, sometimes over long distances. Bats, whales, dolphins and birds can communicate by varying the frequency and amplitude of waves.

‘Music and communication’ comprehension questions

Comprehension Questions

. How does a vibrating string produce sound waves that a listener can hear?

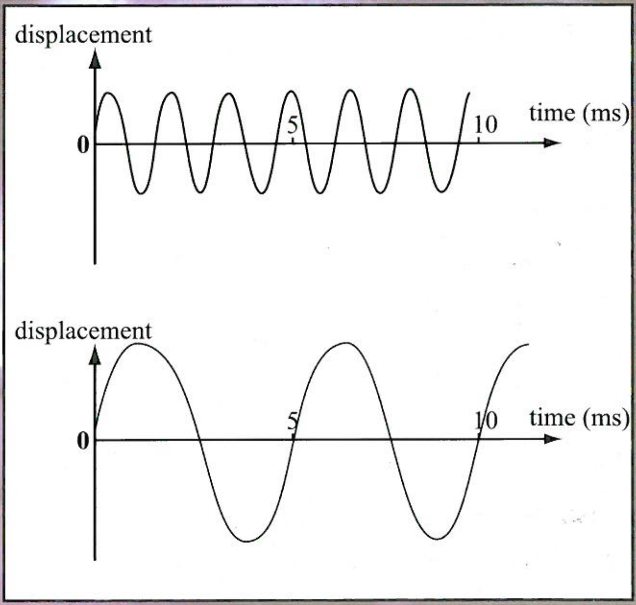
. Explain why a musical instrument requires an energy input before it can produce a sound.

. Stringed instruments can be tuned by adjusting the tension of each string. This changes the speed of the wave that can pass through the string. Explain why this changes the note produced.

. Explain the major differences between longitudinal and transverse waves.

. Earthquakes are waves that travel through rock. Some earthquake waves are longitudinal, others are transverse. One type of earthquake wave cannot pass through the Earth’s liquid outer core. Is this likely to be a longitudinal or a transverse wave? Explain.

. The graphs below represent sounds produced by a musical instrument. Assume the speed of sound was 340 m s^{-1} in each case.



a) Which of the graphs shows the louder sound?
b) Which of the graphs shows the higher-frequency sound? Determine the frequency of this sound.
c) Which of the graphs shows the longer wavelength sound? Determine the wavelength of this sound.

Chapter 9: Waves Explained

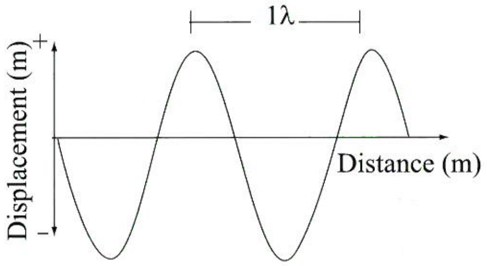
Notes

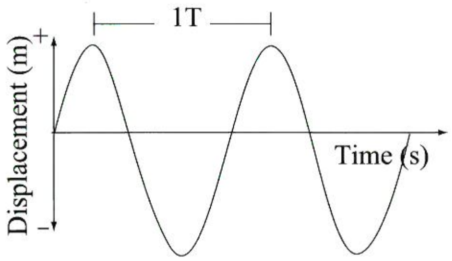
Remember the following important principles

Physicists describe a wave as a disturbance that passes through an elastic medium by means of particles vibrating about their mean position. The wave transfers energy through the medium but does not displace the medium itself. An electromagnetic wave does necessarily need a medium.

You can represent waves by a sine curve on a displacement-distance graph, or, if you study the motion of one point of the wave, on a displacement-time graph.

Graphically, you can show waves as follows:





The properties of waves are related by the following two equations:

$$c = \lambda f$$

and

$$f = \frac{1}{T}$$

where the symbols represent the terms in the following table:

Term	Symbol	Definition	Unit
Phase		Identifies one or more specific points on a harmonic wave train, by reference to the angle in the Sin expression for the wave	
Wavelength	λ	The distance between two adjacent points in a wave which are in phase	
Frequency	f	The number of crests or troughs which pass a point or per unit time, or the number of cycles per second	
Period	T	The time taken for one complete cycle, or the time taken for one complete wave to pass a given point	
Wave speed	c	The speed at which a crest or a trough moves through the medium	
Amplitude	a	The maximum displacement of a particle from its mean position	

Experiment 9.1: Making waves

9

Background

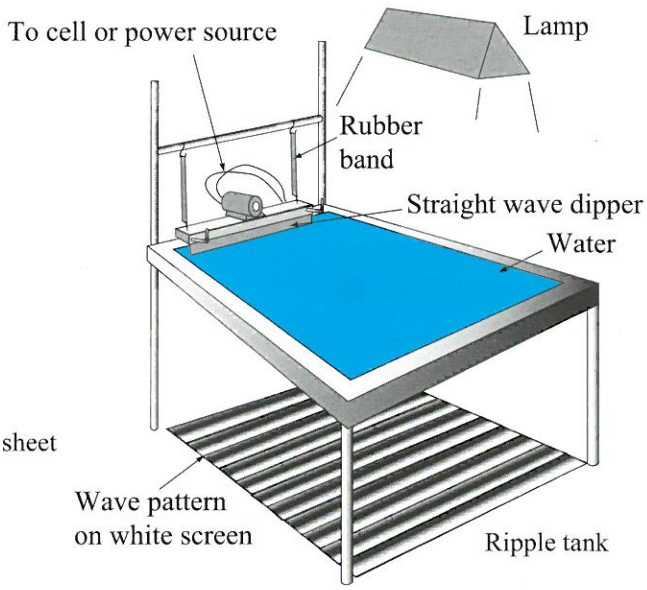
Mechanical waves are affected by various barriers, boundaries, apertures and media. When waves strike barriers they can be reflected. When they pass through apertures or pass edges their direction changes due to diffraction. When they pass from one medium to another, their velocity changes and so may change direction due to refraction. When two different waves collide they interfere. You can observe and study these wave properties using water waves.

Aim

This is a qualitative investigation designed to investigate various wave properties.

Apparatus

- white paper
- stroboscope
- rheostat
- power supply
- leads
- ripple tank kit, including
    - motor
    - vibrator bar
    - dippers
    - reflectors
    - barriers and small Perspex sheet
    - overhead light



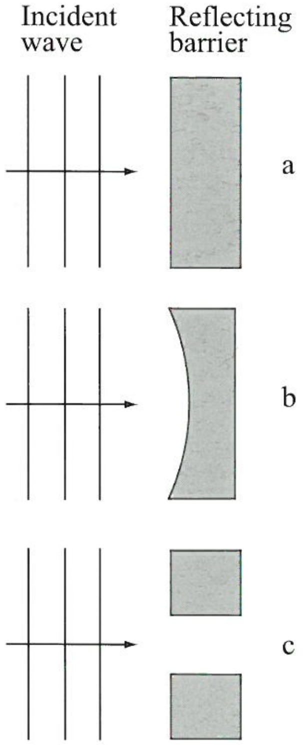
Pre-lab

- Set up the equipment as shown in the diagram.
- Place a lamp 50 cm above the tank.
- Arrange the equipment to show an image of ripple tank on a white backing.
- Add water to 5 mm depth in the tank. Adjust the tank to ensure it is level.

Lab notes

- Adjust the rheostat and observe the relationship between frequency of the vibrator and wavelength. Draw and describe what you observe.
- Place a flat barrier in the tank and observe "head on" reflection. Draw and describe what you observe.
- The diagram at right provides an outline which could be redrawn in your laboratory notebook and completed.

Notes



Experiment 9.1: Making waves

Notes

- Move the barrier so that the waves now strike it at an angle. Again describe and draw what you observe.
- Remove the barrier and replace it with a concave surface. Use the diagram as a guide to describe and draw what you observe.
- Turn the barrier around so that it is now a convex reflector. Describe and draw what you observe.
- Remove the barrier. Place the Perspex sheet into the tank to create a a shallow region. Draw a diagram to show the effect of the shallow water upon waves normal to it.
- Turn the sheet so that the waves are now incident at an acute angle. Draw what you observe.
- Place two barriers in the tank to create a small aperture. Draw what you observe.
- Use the rheostat and increase the wavelength. Again draw what you observe.
- Increase the aperture and repeat the previous two steps. Draw appropriate diagrams to show the observed effects.
- Remove one of the barriers and observe what occurs at the end of the remaining barrier. Describe and draw what you observe.
- Replace the bar with a dipper to create circular waves.
- Repeat all the previous steps using circular waves. Draw your observations.
- Remove the dipper, and replace it with two dippers. Draw what you observe.

Post-lab discussion

1. In which of the above experiments did you observe reflection?
2. In which of the above experiments did you observe refraction?
3. In which of the above experiments did you observe diffraction?
4. In which of the above experiments did you observe interference?
5. What is the general relationship between wavelength and diffraction?
6. How does this relationship explain the fact that sound travels around corners? Which wavelengths of sound would you expect to hear most easily around a corner?
7. Under what conditions would you expect sound waves to interfere?
8. Under what conditions would you expect sound waves to create a stable interference pattern similar to that created in your experiment? Describe what this pattern might sound like to a stationary observer, and to an observer who moves through the pattern.

Experiment 9.2: Measuring the speed of sound

Background

Sound is a form of wave motion. It is a mechanical wave that involves the longitudinal displacement of particles in a medium. The type of medium will affect the speed at which sound will travel. By accurately measuring the difference between the times that two microphones hear the same sound and knowing their distance apart we can determine the speed in air using

$$v = \frac{s}{t}$$

Where: **v** = speed
s = distance between microphones
t = time delay

Aim

To determine the speed of sound in air.

Apparatus

- counter timer
- two microphones
- two or three audio amplifiers (depending upon the ability of the second microphone to pick up the sound)
- electrical leads (two of which are 5 m long)
- tape measure
- thermometer
- a device to make a sharp noise (or you could clap your hands loudly)

Pre-lab

- Draw up a table for recording your measurements.
- Set the mode select switch of the counter timer to M.
- Use two small wires to connect from the Start sockets of the counter time to the Output sockets of one audio amplifier.
- Connect a microphone to the microphone (Mic) sockets of the audio amplifier.
- Hold the microphone in position using a retort stand and clamp.
- Use the long wires to connect from the Stop sockets of the counter timer to the Output sockets of another audio amplifier placed at the other end of the room. If you do not have a powerful amplifier use two in series.
- Connect the second microphone to the mic socket of this audio amplifier.
- Turn the power to the microphones, audio amplifiers and counter-timer to On.

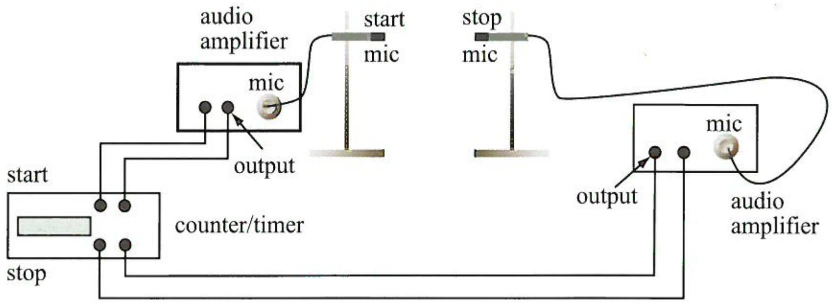
Trial	Time (s)
1	
2	
3	
4	
Average	

Notes

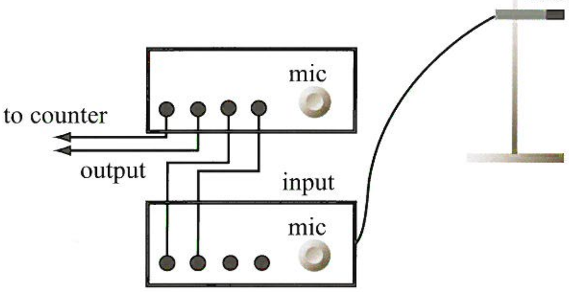
Experiment 9.2: Measuring the speed of sound

Notes

- Quietly reset the counter-timer to show zero on the display.



- Make a sharp sound just above the Start microphone. Trials to obtain the correct sound level may be required.
- Adjust the volume control on both audio amplifiers so that a reading is displayed every time a sharp sound is made.
- If the timer does not stop running, the distant microphone is not picking up the sound. This problem may be corrected by connecting the microphone in series with the second audio-amplifier as shown in the diagram.



Lab notes

- Once the counter timer is working we can take measurements.
- With the counter-timer reset to zero, make a short, sharp sound such as the sound made by clapping two pieces of wood together.
- Record the time shown on the display.
- Reset, and repeat four more times.
- Measure distance between the microphones.
- Measure and record the air temperature.

Post-lab discussion

1. Use your results of distance and time to determine the speed of sound.
2. Look up the average speed of sound at known temperature using a physics reference book.
3. The speed of sound in air increases by 0.61 m s^{-1} per °C increase in temperature. Explain why the speed of sound increases as temperature increases.
4. Determine the speed of sound using the researched values.
5. State the value for the speed of sound in air as determined by you in this experiment and calculate the percentage difference between your value and the accepted value.
6. Give reasons why your answer may not be the same as the theoretical value.
7. What other factors, apart from temperature, affect the speed of sound in air?
8. Compare the speed of sound in air with other gases. Explain the variation.

Problem Solving and Calculations Set 9: Waves

9

Notes

1. The speed of sound varies with temperature according to the equation v = 331 + 0.6T, where v is the speed and T is the temperature in °C. A sound technician finds the speed of sound is 340 m s^{-1} one day and 343 m s^{-1} the following day. If the difference is due to temperature difference only, determine the temperature difference between the two days.

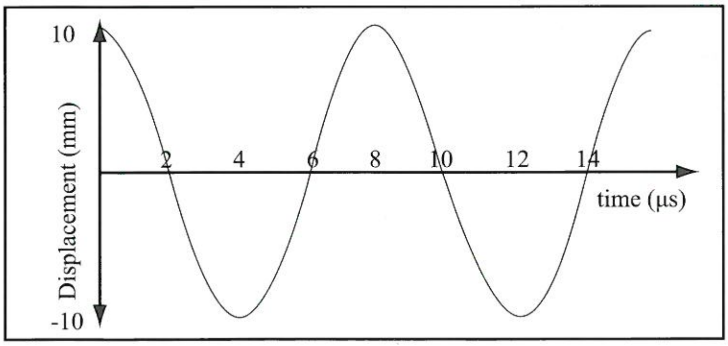
2. A radio announcer reminds listeners that the station he works for is broadcasting at 720 kHz. What is the wavelength of the transmission?

3. A park has a circular fence around it. The top rail of the fence is a metal pipe. A physics teacher sets a group of students the task of finding the radius of the fence by using their knowledge of sound. One member of the group hits the pipe with a hammer giving a sound of 350 Hz; a second student, standing directly opposite on the other side of the park, detects two sounds, 0.30 s apart. If the speed of sound is 330 m s^{-1} in air and 1310 m s^{-1} in this metal pipe, calculate the radius of the fence.

4. If you throw a stone into a still pond, ripples radiate out from where the stone enters the water. A group decides to take some measurements and record the following data to calculate the wavelength, speed and frequency of the ripples. Some five seconds after a stone entered the water, they noted that 42 ripples covered a distance of 2 m from where the stone entered the water. Calculate the:
   a) wavelength,
   b) speed,
   c) frequency,
   of the ripples or waves.

5. While sitting on the beach you notice water waves hitting the shore at the rate of 1 wave every 2 s. Calculate:
   a) the frequency of the waves;
   b) the period of the waves.

6. The graph below shows how a particle vibrates. You can produce such a wave by using a cathode ray oscilloscope (CRO). Determine the:
   a) amplitude of the wave;
   b) period of the wave; and
   c) frequency of the wave.

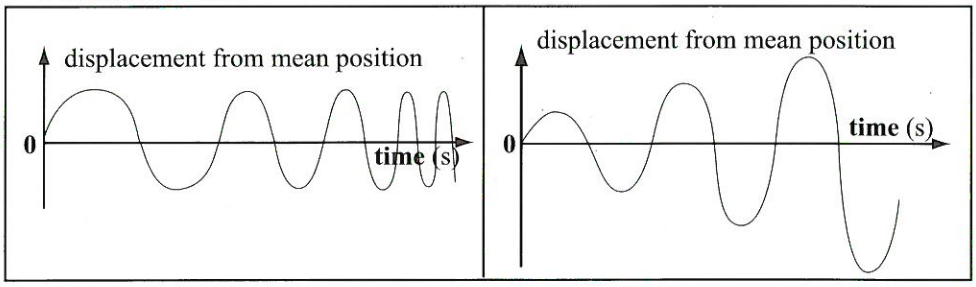


7. In major athletics events having a staggered start, such as the 400 m race at the Olympics, loudspeakers connected to the starter's gun are placed in each lane just behind each competitor. Explain why this is done.

Problem Solving and Calculations
Set 9: Waves

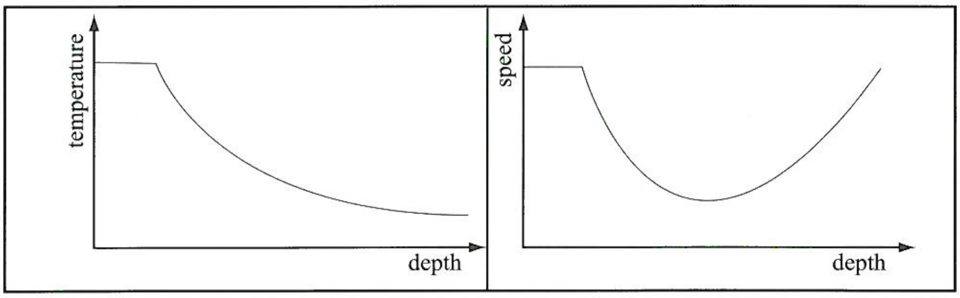
Notes

8. The graphs below represent two separate sounds. Describe the nature of the sound you would hear in case.



9. If the speed of sound in air is 342 m s^{-1}, calculate wavelength of each of the following frequencies:
   a) middle C, 256 Hz, played on the piano,
   b) the upper limit of a stereo system speaker creating a frequency of 20 kHz,
   c) a cat's upper level of hearing, which is 70 kHz,
   d) a pigeon's lower level of hearing, which is 0.1 Hz.

10. The two graphs below show how the temperature and speed of sound change with depth in the ocean. What is the relationship between the depth of the ocean and speed of sound?



11. A group of researchers perform a sensitive experiment. They find that sound travels slightly faster on hot days than on cold days. What is the explanation for this?

12. Why do ships and lighthouses usually use low frequency warning sounds?

13. The timekeeper in a 100 m race stands at the finish and starts a stopwatch when she hears the noise from the starter's gun.
   a) Why will the time she measures for the race be wrong?
   b) Will the time she measures be too long or too short?
   c) Calculate the error in her time measurement.

Graphs for question 14

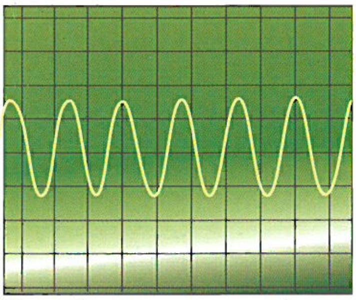


Figure 1

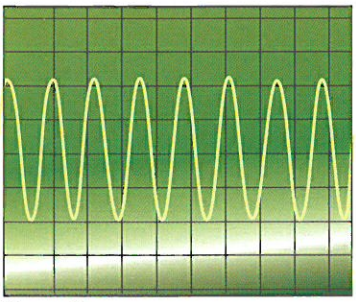


Figure 2

14. Jane whistles into a microphone connected to a cathode ray oscilloscope. Figure 1 (left) shows the trace on the oscilloscope. George then whistles into the same microphone from the same distance. Figure 2 shows his whistle's oscilloscope trace. During the experiment the controls on the cathode ray oscilloscope are unaltered.
   a. Who whistles louder?
   b. Whose note has the greater wavelength?
   c. Whose note has the greater frequency?

Investigation 9.3: Measuring the speed

Background

Notes

Visible light is one form of electromagnetic radiation (emr). Other forms exist that we cannot detect with our eyes, including infra-red, ultraviolet and microwave radiations. All forms of emr travel at the same speed in vacuum, and almost the same speed in air.

Microwave ovens contain a device that emits microwaves of a single frequency. These waves can bounce around inside the oven and create interference patterns or standing waves. The internodal distance in a standing wave is equal to half the wavelength.

Note that many ovens contain a diffuser whose job is to break up the standing waves. This will make the pattern harder to detect.

Aim

To measure the speed of emr using microwaves.

Apparatus

- microwave oven
- two plates, or one plate and a shallow bowl
- bread and butter or margarine, or a large slab of chocolate or other low-melting material
- metre rule

Pre-lab

- Remove the turntable from the microwave oven.
- Cover the turntable spindle (the the rotating parts) using an inverted plate or the shallow bowl.
- Balance the other plate on top of the inverted one.
- Completely cover all the pieces of bread with butter or margarine (not necessary if using chocolate).
- Arrange the buttered bread on the plate so there are no large gaps between them; or place the chocolate slab so that none overhangs the edge of the plate.

Investigation 9.3: Measuring the speed of Light

Notes

Lab notes

- Turn on the oven and observe the butter or chocolate. As soon as it starts to melt, turn the power off and remove it from the oven. This should take only a few seconds.
- The butter or chocolate should begin to melt in bands or rows. Measure and record the distance between the centres of two adjoining rows.
- Check the manufacturer's plate on the back of the oven. Record the frequency of the microwaves in MHz or GHz. If this is not given you will need to do some research.

Post-lab discussion

1. Determine the wavelength of the microwaves produced in the oven.
2. Use the wavelength and the frequency to determine the wave speed.
3. Estimate your uncertainty in measuring the wavelength. Does your measured value agree (within experimental uncertainty) with the accepted value of the speed of emr?
4. Why do microwave ovens have a turntable to rotate the food as it cooks?
5. Other devices that use microwaves include mobile telephones and radar. Is there any hazard in using these devices?

Chapter 10: Wave Behaviour Explained

10

Remember the following important principles

Both air columns and strings have nodes and antinodes.

Notes

Inter-nodal distance = $\frac{\lambda}{2}$

Reflection, refraction and diffraction

Waves can undergo reflection, refraction or diffraction.

Reflection results when the wave bounces off a surface. The laws of reflection determine the wave's direction after reflection. When a sound wave is reflected, you hear an echo if the reflecting surface is sufficiently far away.

Refraction results when waves bend as they pass from one medium to another. The change in direction is caused by a change in the speed of the wave as it enters a new medium.

Diffraction occurs when a wave passes through a narrow opening (aperture). The greatest diffraction results when the width of the opening that the wave passes through is similar to the wavelength of the wave. Diffraction also occurs at the edges of an obstacle. In this case, waves of greater wavelength tend to diffract more noticeably.

Resonance and interference

Interference between waves is common and can cause several different effects. When waves move through the same medium at the same time, constructive and destructive interference may result. This may lead to standing waves or diffraction patterns forming.

Forced vibration occurs when an oscillating energy source forces an object to vibrate in time with the source. This is how loudspeakers work.

Resonance happens when the frequency of forced vibration matches a body's *natural frequency*. The result is a much larger amplitude of vibration than the forced vibration at other frequencies.

Experiment 10.1: Observing wave pulses

Notes

Background

In a transverse wave, the particles of the medium move at right angles to the direction of the wave motion. In a longitudinal wave, the particles of the medium move parallel to the direction of the wave motion.

Aim

To examine both transverse and longitudinal waves moving along a stretched spring.

Apparatus

- Long spring
- slinky spring
- string (3 m)
- mass (approximately 100 g)

Part A: Transverse wave pulses

Pre-lab

- Lay the long spring along the floor. Anchor one end and stretch the spring.

Lab notes

- Give the spring a sideways flick to produce a single transverse pulse.
- Try producing pulses of different shape and amplitude.

Post-lab discussion

1. What happens to the size or amplitude and shape of the pulse as it travels down the spring? Why?
2. Can one pulse catch up with another?
3. If the tension in the spring is increased, what happens to the speed of the pulse?
4. What happens to the pulse when it is reflected from the fixed end?
5. Observe and describe what happens when two pulses are sent along the spring in opposite directions at the same time. Send one pulse down the spring and as it is reflected from the fixed end, send another pulse.
6. By oscillating the spring from side to side at a regular frequency, produce a continuous wave.
7. What happens to the wavelength as the frequency changes?
8. Vary the frequency of the sideways oscillation until the forward and reflected waves combine to form a wave pattern which does not appear to move along the spring. This is called a standing wave. What are the conditions necessary for the production of standing waves?

Experiment 10.1: Observing wave pulses

Notes

Part B: Longitudinal waves

Lab notes

- Try producing pulses of different shape and amplitude.

Post-lab discussion

1. What happens to the size or amplitude and shape of the pulse as it travels down the spring? Why?
2. Can one pulse catch up with another?
3. If the tension in the spring is increased, what happens to the speed of the pulse?
4. What happens to the pulse when it is reflected from the fixed end?
5. Observe and describe what happens when two pulses are sent along the spring in opposite directions at the same time. Send one pulse down the spring and as it is reflected from the fixed end, send another pulse.

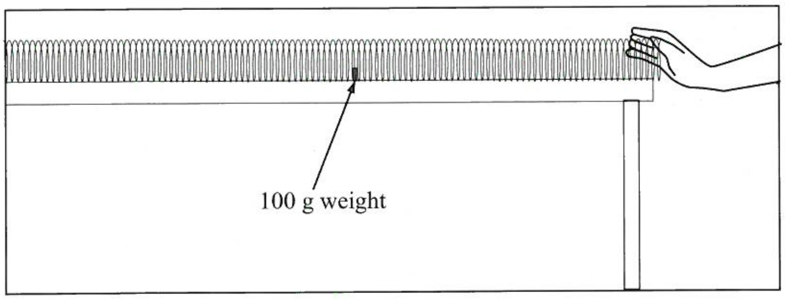
Part C: Waves at a boundary

Lab notes

- Fasten one end of the long spring to a taut piece of string which is about 3 m long. Send a pulse down from the free end and observe the reflection of a transverse pulse at the end which is connected to the string.
- Repeat, with the spring connected to the string by a runner such as a curtain ring.

Post-lab discussion

6. How does the reflection from a fixed and a free end compare?



7. Set up the spring as in Part A and attach a small mass, such as a 100 g piece of lead, to one of the coils of the slinky spring or the long spring. This produces a `discontinuity' in the wave medium by creating one heavy coil surrounded by lighter ones. How is the wave energy reflected and transmitted at the discontinuity?
8. Join the slinky and long springs together. Fix the long spring at the other end and ensure a suitable tension is maintained. Send a transverse wave pulse down the spring. What happens after the pulse reaches the boundary where the two springs join?
9. With the springs still joined, fix the other end of the slinky. Send a pulse down the long spring towards the slinky. What happens after the pulse reaches the boundary?

Experiment 10.2: Resonance in strings

Notes

Background

When a wave pulse travelling along a stretched string reaches the end of the string, the pulse is reflected back along its original path. If the pulse is one of a series of pulses at regular intervals, the incoming pulses will interfere with the reflected pulses. Under certain conditions, this leads to the formation of a standing wave in the string.

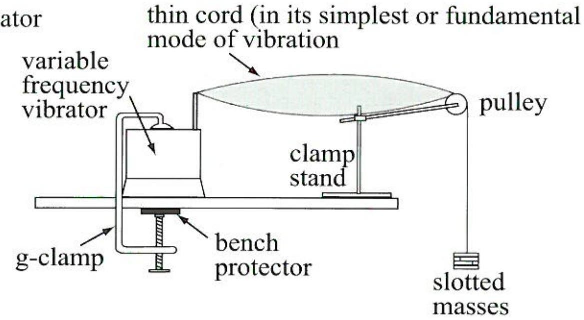
The fixed ends of the string are always displacement nodes, and are separated by one or more displacement antinodes.

Aim

To demonstrate interference and resonance in vibrating stretched strings.

Apparatus

- Variable frequency (wave trough) vibrator
- thin cord
- pulley
- slotted masses
- clamp
- metre rule



Pre-lab

- Draw up a table for recording your measurements.
- Set up the equipment as shown in the diagram here.
- Suspend a small mass from the end of the cord and set the frequency generator to its minimum setting.
- Gradually increase the frequency until a standing wave is produced which has only one antinode. (If you can only produce a wave that has two or more antinodes, reduce the size of the suspended mass.)

Lab notes

- Keeping the tension and the length of the cord constant, gradually increase the frequency until a different standing wave pattern is produced. Observe the pattern. Take any measurements that will allow you to calculate the velocity of the wave in the string.

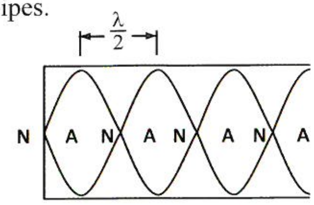
Post-lab discussion

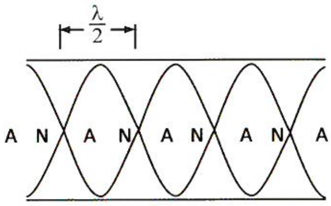
1. Determine the velocity of the wave in the string.
2. If this is a string in a violin, how could it be tuned to produce a note of some desired frequency?

Experiment 10.3: Resonance in air columns

Background

Stationary or standing waves can be produced in pipes in much the same way as that in a stretched string. The diagrams below represent standing waves in both closed and open ended pipes.





N - is a node point of zero displacement of air molecules.
A - is an antinode or point of maximum displacement of air molecules.

The internodal distance (distance between two successive nodes) is half a wavelength. If you know the frequency of the sound then you can work out the velocity of sound in the pipe from:

$$v = f\lambda$$

where **v** = velocity of sound in metres per second
f = frequency of the note in hertz
λ = wavelength of the note in metres.

Note that there are two ways to describe nodes and antinodes in air columns. At a pressure node, the pressure remains constant (but the medium undergoes the most vibration). At a displacement node, the medium undergoes zero vibration (but the pressure varies the most). An open end of an air column is a pressure node or a displacement antinode. A closed end of an air column is a pressure antinode or a displacement node.

This experiment can be attempted in two very different ways. In Part 1 you will use an open pipe together with a microphone, an audio amplifier and a cathode ray oscilloscope to detect the position of successive nodes in the open pipe, and hence determine the wavelength of the sound. Part 2 uses a tuning fork and a closed pipe to detect the position of successive harmonics and again determine the wavelength.

Aim

To measure the speed of sound in air using standing waves.

Apparatus

- audio-frequency oscillator (AFO)
- audio amplifier
- cathode ray oscilloscope (CRO)
- small microphone or crystal earpiece
- metre rule
- large measuring cylinder - (1 L or larger)
- thermometer - (0–100 °C)
- glass or plastic tubing - (large diameter, 0.5–1.0 m long)
- selection of tuning forks

Notes

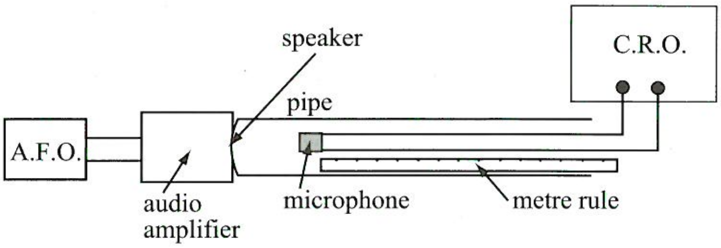
Experiment 10.3: Resonance in air columns

Notes

Part A: Using an Open Pipe

Pre-lab

- Draw up a table for recording your results.
- Set up the equipment as shown in the figure below connecting the microphone to the vertical output of the cathode ray oscilloscope (CRO).
- Set the audio frequency oscillator (AFO) to approximately 3000 Hz.
- Adjust the time-base on the CRO to give a fairly crowded pattern on the screen and set the Y -gain to approximately 0.2 V cm^{-1}.
- Slide the metre rule along the pipe until the microphone is about half way along the tube.
- Adjust the frequency of the AFO to give a maximum amplitude. Do not alter frequency as the system has now been adjusted to give a standing wave in the pipe.



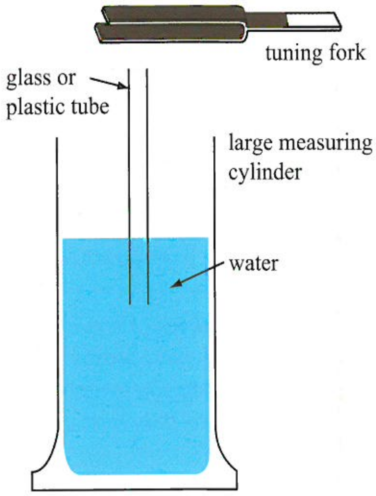
Lab notes

- Slowly slide the rule out of the tube while watching the changes on the CRO. As the microphone approaches a node you will notice the amplitude on the CRO will decrease until it reaches a minimum at the node.
- Measure and record the distance between the nodes. It is important to make these measurements as accurate as possible.
- Record your results in a table.
- Repeat the process for various other nodes in the pipe and average the results for at least five measurements.
- Repeat the whole process for frequencies of 1000 Hz, 2000 Hz, 4000 Hz and 5000 Hz.
- Measure and record the temperature of the air in the room.

Post-lab discussion

1. Calculate the speed of sound for each set of readings.
2. Determine the average of your results.
3. State the average speed of sound as determined above, and the room temperature.
4. Estimate the measurement uncertainties in this experiment. Which measurement introduced the greatest uncertainty? Restate your measured speed of sound, including the uncertainty.

Experiment 10.3: Resonance in air columns



Part B: Using a closed pipe

Pre-lab

- Draw up a table to record your measurements.
- Fill the measuring cylinder to within 10 cm of the top
- Place the glass or plastic tube into the measuring cylinder as shown in the diagram.
- Select a tuning fork and record its frequency.

Lab notes

- Strike the tuning fork and position it near the open end of the tube.
- Slowly raise the tube until resonance is heard. Carefully adjust the length of the tube until the loudest sound is heard.
- Measure the length of the tube above the water level and record this as (1).
- Record results in a suitable table.
- Raise the tube further and listen for the position of resonance corresponding to the next harmonic. It may be necessary to use a telescopic tube.
- Measure the length of the tube above the water and record this as (2)
- Repeat the Pre-lab for tuning forks of different frequencies. Hint: Use higher frequencies as these are easier to work with.
- Record the temperature of the air in the room.

Note: You may hear some harmonics of the tuning fork frequency. Ignore these positions.

Post-lab discussion

1. Calculate the speed of sound for each set of readings.
2. Determine the average of your results.
3. State the average speed of sound as determined above, and the room temperature.
4. Estimate the measurement uncertainties in this experiment. Which measurement introduced the greatest uncertainty? Restate your measured speed of sound, including the uncertainty.
5. Are certain frequencies more suitable for this experiment than others? Explain your answer.
6. What factors affect the speed of sound in the pipe? Describe briefly the effect of each.

Notes

Investigation 10.4: Diffraction and interference

Notes

Background

According the Huygen's principle every point on a wave front may be considered as a new point source of light, but in general, all parts of each new wavelet are cancelled by destructive interference except that moving in the same direction as the original wave front. Thus the whole wave front appears to move as a unit.

If a series of wavefronts strike a barrier having two narrow slit openings, each opening acts as a new source and new wavelets travel out in phase with each other. In certain regions they will reinforce each other producing a large amplitude (loud sound, or bright light). In alternate regions they will interfere producing a small amplitude (soft sound, or darkness).

Diffraction is the reason we can hear sounds from around a corner. Interference occurs when two waves pass through a single medium.

Aim

To produce and study diffraction and interference patterns in sound waves, and light waves.

Part A: Diffraction and interference of sound

Apparatus

- A source of sound of a single frequency, such as a frequency generator,
- an amplifier and
- two speakers wired in series so they are in phase.

Lab notes

- Use a single speaker, and have it produce a single sound frequency such as 300 Hz. While you listen to this sound, have your lab partner place an obstacle such as a piece of foam plastic in between you and the speaker. Observe its effect on the sound you can hear. Record your observations.
- Repeat using a range of frequencies. Is there a relationship between the frequency of a sound and how readily it is diffracted?
- Set up two speakers some distance apart, and connect them in series so they both produce the same sound at the same time. Feed in a single sound frequency such as 300 Hz, and move around in the region in front of the speakers. Record your observations.
- Repeat using a different frequency. Observe how the interference pattern changes if the frequency changes.

Investigation 10.4: Diffraction and interference

Part A: Diffraction and interference of light

Notes

Apparatus

- Diffraction kit
- Laser pointer

Pre-lab

- Darken the laboratory. If the patterns you produce are bright enough, you can photograph them using a digital camera with the flash turned off. If they are not very bright you may have to view the pattern by standing where the screen should be and looking at the slit. **Safety note:** Do *not* allow the light from a laser source to shine directly into your eye. It is safe only if you view a diffuse reflection.
- Hold the single slit between the white light source and the screen. View the diffraction pattern produced by the white light on a screen placed about 1–2 metres from the source and the slit. Sketch or photograph the diffraction pattern you see.
- Repeat using other single slits of different widths and sketch the patterns produced. Sketch or photograph the patterns. Describe the differences between the diffraction patterns that you observe, and relate these to the width of the slit.
- View the white light through the double slits. Sketch or photograph the interference pattern you see.
- Repeat, using other double slits with difference spacings between the slits and sketch the patterns produced. Sketch or photograph the patterns. Describe the differences between the diffraction patterns observed and relate these to the width of the slit. Note any similarities and differences between the diffraction patterns and interference patterns. Describe any coloured fringes observed.
- Place a red filter between the light source and the double slit. View the light source through the double slit and observe what you see.
- Repeat using the blue filter and describe what you see.

Post-lab discussion

1. How does the diffraction pattern change as the slit size is altered?
2. How does the interference pattern change as the spacing between the slits is altered?
3. Suggest an explanation for any colour fringes observed.
4. What do you see if you look at a street light through flywire or sheer curtain? Why does this happen?
5. Describe a photograph or a scene from a film or video which shows or uses the visual effects obtained by diffraction or interference.
6. Describe the similarities and differences between the patterns obtained when white light passes through
7. a) A diffraction grating
   b) A prism

Extension: Diffraction pattern of monochromatic light

Shine the light from a laser pointer through both a single and a double slit onto a screen. Sketch or photograph the diffraction pattern and the interference pattern you see.

Note: Do not look directly into the laser, or point the laser toward anyone else's eyes.

Investigation 10.4: Diffraction and interference

Notes

Apparatus

- microphone
- cathode ray oscilloscope (CRO)
- musical instrument

Lab notes

- Play a note on the instrument and sketch the general shape of the trace on the oscilloscope. Repeat for a range of notes.
- Play a note on the instrument and measure the distance between successive peaks on the CRO trace. Use this to work out the frequency and wavelength of the note being played. Explain how this is done.
- Play a note on the instrument and calibrate the nominal frequency on the C.R.O. Play a second note that is one octave above the original sound and note the variation in frequency. Repeat this for a range of notes. What is the relationship between two notes one octave apart?
- Investigate and report on what happens to the trace when you play a chord on the instrument.

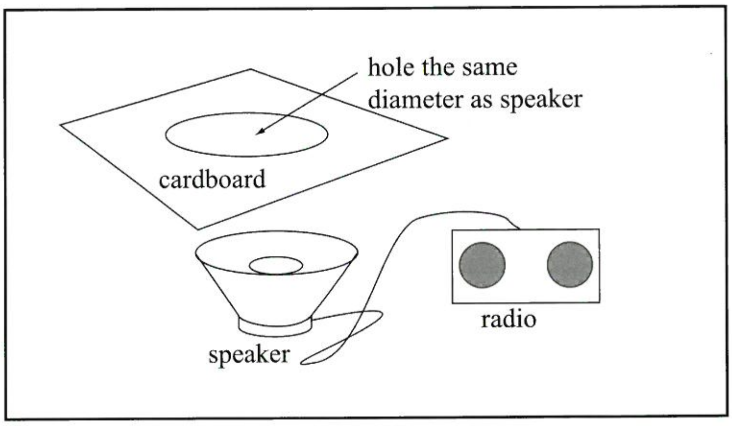
Investigation 10.5: Making sounds – speakers

Apparatus

- small speaker from radio
- piece of cardboard with hole the same diameter as the speaker
- source of music such as radio or CD player

Lab notes

- Plug the speaker into the radio and listen to the sound being produced. Then place the speaker in the hole and note any change in the sound.



Post-lab discussion

What caused the sound to change when the speaker is placed in the hole of the cardboard? Why are speakers encased in boxes?

Notes

Further investigation

Hi-fi speakers often contain more than one speaker in each box.
Find out:

- why there are multiple speakers,
- why they are often of different sizes, and
- whether the size of the box is important in any way.

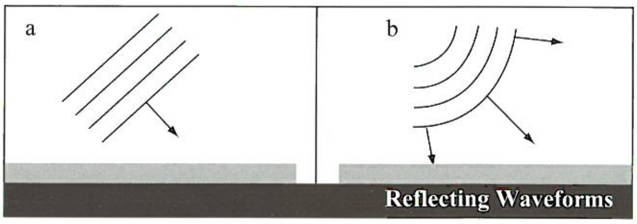
Problem Solving and Calculations

Set 10: Wave Behaviour

Notes

1. You are trying to explain how sound waves behave, to a non-physics student.
   a) Draw a labelled diagram to show him how sound *reflects*.
   b) Draw a labelled diagram to show him how sound *refracts*.
   c) Draw a labelled diagram to show him how sound *diffracts*.

2. Copy the two diagrams below and complete the paths of the wavefronts as they are reflected.



Reflecting Waveforms

3. When a sound wave meets your ear, your ear may absorb, transmit, or reflect some of the wave's energy.
   a) What happens to the wavelength of a reflected wave?
   b) What happens to the frequency of a transmitted wave?
   c) Your ear responds to sound waves of wavelengths between $\lambda = 0.02$ m and $\lambda = 10$ m. If the speed of sound in air is 335 m s^{-1}, calculate the range of frequencies that your ear can detect.

4. Sound researchers have noticed the way completely blind people can walk down busy streets without bumping into things. When researchers block such a blind person's ears, the blind person tends to bump into more objects. Explain why this happens.

5. Animals that rely on ultrasound to navigate can only resolve fine detail when the size of the object is about as large as the wavelength of the sound they use.
   a) About what size object could an animal expect to find if it used pulses with a range of frequencies up to 180 kHz, if the sound is created
      (i) in air?
      (ii) in water?
   b) One of the problems river dolphins have is to resolve, or separate, objects using ultrasonic frequencies. Though they use the same frequencies as bats, it is more difficult for the dolphins to resolve obstacles under water. Explain.
   c) Bats that fly slowly around shrubs and trees have soft calls while those bats that fly high and fast have extremely loud calls that can be detected over large distances. Suggest why there is this difference in their calls.

6. A marine biologist uses an echo-sounder to find schools of fish. The echo-sounder uses ultrasound pulses. An echo-sounder sends a pulse to the sea bottom and it returns to the instrument 0.100 s later. If the speed of sound in water is 1456 m s^{-1}, what is the water depth recorded by that echo-sounder?

Problem Solving and Calculations 10

Set 10: Wave Behaviour

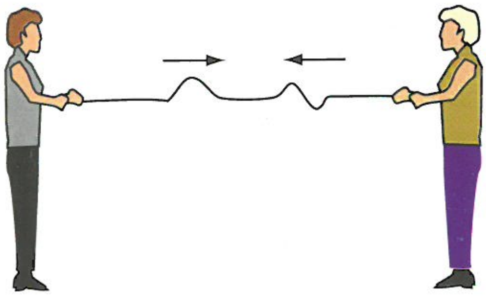
7. Doctors use ultrasound with a frequency of several megahertz to form images of unborn babies. A transmitter sends short pulses of a narrow beam of ultrasound through the body of the mother. As the waves pass from one type of tissue to another they produce echoes.
   a) If the transmitter sends out a pulse every 2 ms how many pulses are sent out in 0.200 s?
   b) If the generator moves through an angle of 40.0° in 0.100 s, what is the angle between pulses?
   c) If the swing by the generator is called a scan, how many scans does it produce each second?

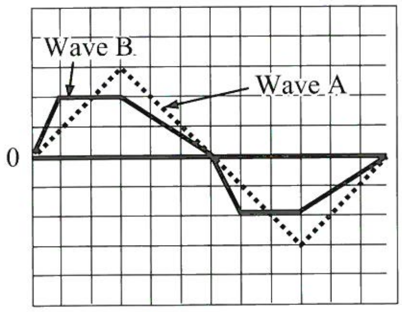
Notes

8. Some whales can communicate over hundreds of kilometres using frequencies as low as 20 Hz. Why is a frequency of 20 Hz more effective for long-range communication than one of 2000 Hz?

9. The lookout on a ship is trained to scan the sea to note any differences in wave patterns. A lookout notices an area of sea ahead where the waves are getting closer together. What could this mean?

10. During an experiment you and your partner hold onto opposite ends of a rope. You each jerk the rope to send a pulse along the rope from each end, as shown in the diagram. Draw a scale diagram to show what the resultant pulse looks like when the two pulses are exactly superimposed.





11. The diagram shows a CRO trace of two superimposed waves. Use the superposition principle to draw a resultant displacement wave.

12. A child's whistle has a distance of 120 mm between the open and closed ends. Determine the lowest frequency note that the child can make on that whistle.

13. A musical ensemble includes a violin, a guitar and a double bass.
    a) The violinist produces a fundamental note of frequency 512 Hz. If the string producing the note is 500 mm long, calculate the speed of the waves along the string.
    b) The guitarist produces different notes by plucking a string with one hand while sliding a finger of the other hand down the string. Describe what happens to the note the guitar produces when the finger slides down the string, and explain why the note changes.
    c) The double bass has strings 1.25 m long. When the musician plucks one of the strings the speed of the waves in the string is 210 m s^{-1}. Determine the frequencies of the first three harmonics (fundamental and first two overtones) of this string.

Problem Solving and Calculations

Set 10: Wave Behaviour

Notes

14. An organ repairer noticed that dust seemed to collect in certain regions inside organ pipes. She suspected that the way the sound waves behaved inside the pipe determined the dust collection points. She drew standing wave diagrams to represent the first three harmonics in an organ pipe:
    a) open at both ends
    b) open at one end only.
    Reproduce her two diagrams.

15. The table shows the musical notes C to C over one octave, and their ratios compared with the first C. Complete the table by filling in the frequencies.

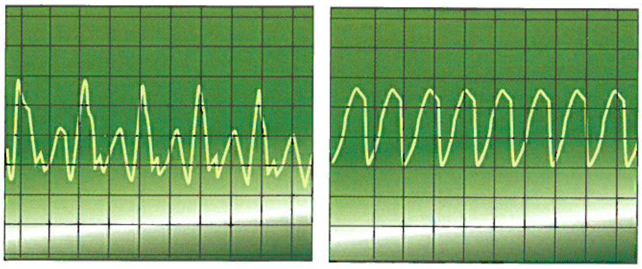
	Musical notes from C to C							
Note	c	d	e	f	g	a	b	c’
Frequency	256							
Ratio	$\frac{1}{1}$	$\frac{9}{8}$	$\frac{10}{8}$	$\frac{4}{3}$	$\frac{12}{8}$	$\frac{5}{3}$	$\frac{15}{8}$	$\frac{2}{1}$

Frequency Table

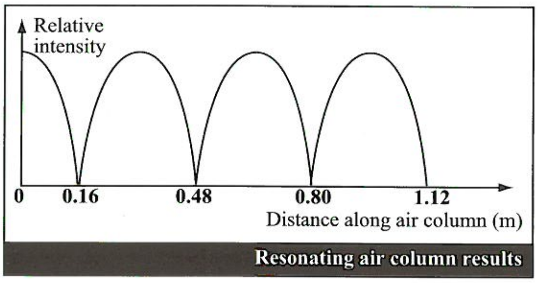
Instrument	*Frequency range (Hz)*
Piano	27-3900
Trombone	80-500
Clarinet	150-1400
Flute	256-2100
Piccolo	512-3600
Voice	*Approximate range (Hz)*
Bass	80-<400
Baritone	100->400
Tenor	170-500
Alto	200-650
Soprano	230-1350

16. On the left is a table of frequency ranges for instruments and voices.
    a) Which instrument has the greatest frequency range?
    b) Which singer can produce the lowest pitched note?
    c) Which instrument can produce the highest pitched note?
    d) Which singer has the most restricted frequency range?

17. During a performance two members of the school orchestra play the same pitch note on their different instruments. A student records the sounds and plays them back through a cathode ray oscilloscope, keeping all controls on the equipment constant.
    Use the diagram to compare the following properties of the two sounds:
    a) loudness;
    b) frequency;
    c) wavelength.



18. During a laboratory session a group of students measure the intensity of sound along a resonating air column. They used a tuning fork with a frequency of 512 Hz to set the air column resonating. They then plotted their results on a graph shown below.
    a) Calculate the wavelength of the sound.
    b) Hence, calculate the speed of sound in air according to their results.
    c) If the air column is 1.12 m long, is it an open or closed pipe? Explain.

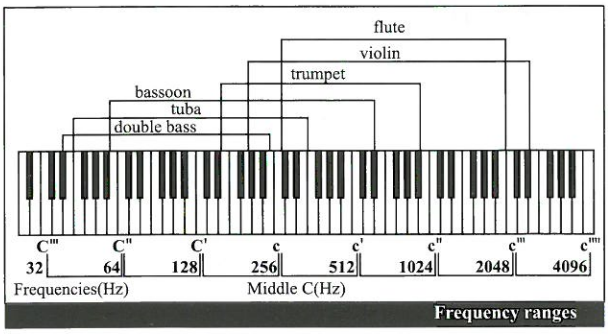


Resonating air column results

Problem Solving and Calculations 10

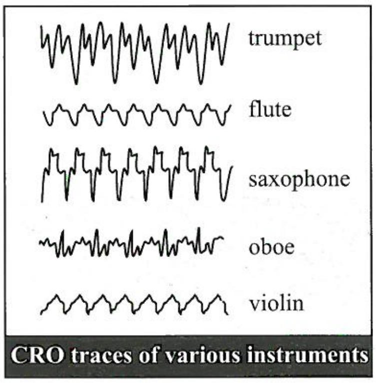
Set 10: Wave Behaviour

19. The diagram shows the frequency ranges of several instruments compared with the notes on a piano.
    a) Which instrument has the largest range of frequencies?
    b) Which instrument has the most restricted range of frequencies?



Frequency ranges

20. A researcher produced cathode ray oscilloscope traces of the sounds made by five different instruments as shown. The CRO settings were not changed during the experiment.
    a) Which instrument produced the *lowest pitched* note?
    b) Is the saxophone more likely to be a bass saxophone or an alto saxophone? Explain your answer.
    c) Why do all the traces have a different shape?
    d) Are the traces more likely to be of *notes or noises*? Explain your answer.



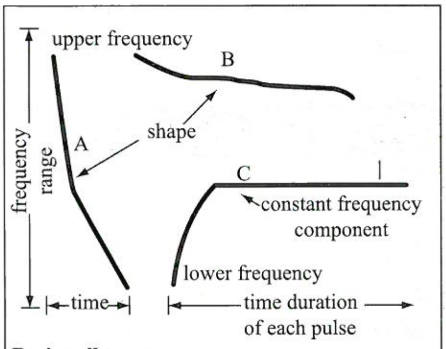
CRO traces of various instruments

21. When you set a tuning fork vibrating you can hear the note better if you hold the stem in contact with a solid surface such as a bench-top. Why?

22. A singer was supposed to be able to smash a wine glass simply by singing a certain note close to the glass. Explain the physical principle that could account for this.

23. Engineers who design tall chimneys, bridges, cables and masts build in devices that reduce resonance and limit the effect of forced vibrations. Why?

24. A bat researcher gathered some data in the field and produced a graph showing the frequency over time of single bat calls from three different species (A, B, and C).
    a) Which call would be from the Sheathtail and Free-tail bats?
    b) Which call would be from bats that use a large range of frequencies in their call?
    c) Which type of bat produces the longest pulse call?



Basic call types:

FM = Frequency Modulated Calls (Common or ordinary bats)

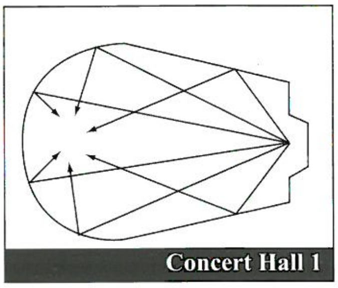
Sh -FM = Shallow Frequency Modulated Calls (Sheath-tail and Free-tail bats)

CF = Constant Frequency (Horseshoe and leaf-nosed bats)

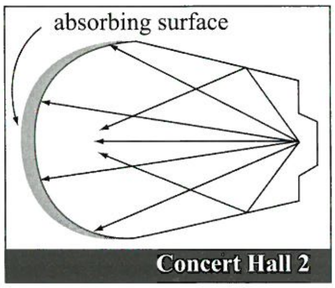
Field information from bat calls

25. When driving an older model car you sometimes notice that at a certain speed, parts of the car's body vibrate excessively causing audible rattles. Why does this happen?

26. When designing concert halls, acoustic engineers avoid 'dead spots' (places where you can hardly hear sounds from the stage that are audible in most other places in the hall).
    a) What could cause 'dead spots'?
    b) The diagrams show how two differently designed concert halls reflect sound. Which is the better design? Explain.



Concert Hall 1



Concert Hall 2

Chapter 11: Photons Explained

Notes

Remember the following important principles

Our current theory about the nature of electromagnetic radiation (emr), including light, states that emr has both wave and particle characteristics. Low energy electromagnetic radiation seems to be most noticeably wavelike and high energy electromagnetic radiation seems to be most noticeably particle-like.

A particle of electromagnetic radiation is called a photon. A photon has a certain amount of energy called a quantum of energy. Each type of photon has its own characteristic frequency, found by using the formula:

$$E = hf$$

where:

E = energy in joules (J)

h = Planck's constant = 6.63×10^{-34} J s

f = frequency in hertz (Hz)

The following formula also applies to electromagnetic radiation whether we are picturing it as either waves or particles.

$$c = \lambda f$$

where:

c = 3.00×10^{8} m s^{-1}

λ = wavelength in metres (m)

f = frequency in hertz (Hz)

Visible light is the very small band of frequencies in the middle of the electromagnetic spectrum to which human eyes are sensitive.

The intensity of a light beam is the energy transfer per square metre per second.

$$I = \frac{E}{A.t} = \frac{P}{A}$$

Where:

I = intensity in watt per square metre (W m^{-2})

E = energy in joules

A = area in square metres

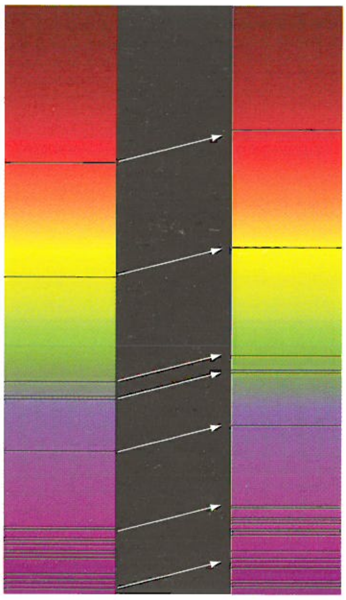
t = time in seconds

P =power in watts

To do the problems in this chapter you may need to refer to information about the electromagnetic spectrum.

Doppler Effect and Redshift

You can hear the Doppler effect whenever a vehicle with a siren approaches you: the sound of the siren rises in pitch as the sound source comes closer, reducing the distance between one wavefront and the next. Redshift is the term used to describe the change in light wavelength (or frequency) from a fast-receding object. The redshifts of galaxies increase as their distances from us increase, leading to the idea of an expanding Universe. The diagram shows the redshift of the light from a distant galaxy.



Experiment 11.1: Observing light sources

Background

The range of photons emitted by a source is called its spectrum. Spectra can be classified as absorption or emission spectra. These can be further classified as line, band or continuous.

Aim

To observe various spectra using a direct-vision spectroscope.

Pre-lab

- Practise using a direct-vision spectroscope until you understand where the slit has to be pointed in order for you to see a useful image.
- Look through the hand held spectroscope at a light source. Adjust the slit and eyepiece to obtain a clear focussed spectrum.

Lab notes

- View the following light sources through the spectroscope, observe and record the spectra produced.
    - A sodium vapour lamp
    - A neon lamp
    - A fluorescent lamp
    - A 100 W globe
    - Bright blue sky

Caution: *Do not look **directly** at the Sun with your eyes or through the spectroscope.*

Post-lab discussion

1. Draw a spectrum of each of the light sources. Label the colours seen.
2. Comment of similarities between the spectrum of the sodium lamp, neon lamp, and the fluorescent light tube.
3. Comment of similarities and differences between the solar spectrum and the globe spectrum.

Notes

Experiment 11.1: Observing light sources

Notes

Part 2: Observation of the Spectra of Heated Compounds

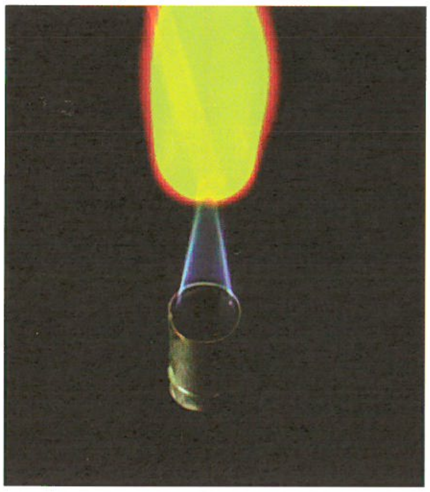
Lab notes

- Adjust the flame of a Bunsen burner until it is very pale blue.
- Using a platinum or nichrome wire, heat a loopful of sodium chloride in the flame until it fuses and vaporises.
- Record your observations.
- Repeat the Pre-lab for calcium chloride, strontium nitrate and barium nitrate. Use a different loop for each salt.

Caution: *these salts are toxic if ingested. Wash your hands after handling them.*

Post-lab discussion

1. Draw a diagram of the spectra as observed through the spectroscope. Label the colours seen.
2. Comment on the similarity of the flame colours of calcium and strontium nitrate. Can you separate the two salts on the basis of their spectral colours?
3. What are the main differences between the spectrum of the sodium lamp and the spectrum of sodium chloride?
4. What is the difference between a continuous emission spectrum and a line emission spectrum? Identify each with reference to your experiment.
5. It is possible to produce a spectrum for each element by using an electric discharge or arc between two electrodes which contain a sample of the element. Using this method how could you determine the elements present in a mixture of substances?
6. Calculate the frequency and wavelength of a photon of light which results from an element in the hydrogen atom moving from one energy level to another with an energy difference of 10.21 eV.
7. How do scientists gain information about the composition of distant stars?



Experiment 11.2: Detecting Infrared radiation

Notes

Background

Most television remote control units work using invisible infrared radiation. Infrared radiation has longer wavelengths than visible light and is affected differently by obstacles in its path.

Aim

To investigate diffraction, absorption and transmission of beams of visible and infrared radiation.

Apparatus

- television set and remote control unit
- electric torch
- hand mirror
- flour or baby powder
- clear glass or plastic container with flat, parallel sides
- water

Pre-lab

- Prepare a table to record your results.
- Find a place that allows a direct line, between 2 to 3 metres, from you to the television set.
- Darken the room.
- With the television off, check that you can see the light from the torch reflecting from the screen.
- Check that the remote control also works from your chosen position.

Lab notes

- Get your lab partner to stand directly in front of the screen, about halfway between you and the television. Operate the remote control "on" button and record the result. Shine the torch beam at the television and record the result.
- Get your lab partner to stand off to one side, about halfway between you and the television, holding the hand mirror. Point the torch at the mirror, and move the mirror around until it shines on the screen. Now point the remote control at the mirror, operate the remote control "on" button and record the result.
- Repeat this using just the lab partner's body (that is, without the mirror).
- Get your lab partner to blow a small amount of flour or baby powder into the air between you and the television. Try to turn on the television through the cloud; then repeat, using the torch. Record your results.
- More than half fill the container with water. Hold the water directly in front of the torch, then the remote control, while pointing at the television. Record your results.
- Get your lab partner to hold one hand between you and the television, at several distances from the remote control unit. Record when the hand obstructs the infrared beam and the visible light beam.

Experiment 11.2: Detecting Infrared radiation

Notes

Post-lab discussion

1. Make general statements about the observed behaviours of infrared and visible beams.
2. Explain your observations in terms of the relative wavelengths of infrared and visible light.
3. Why would television manufacturers use infrared rather than visible light beams in their remote control units?
4. Infrared sensors can locate people in total darkness, but do this best when the air temperature is low. Explain.
5. Infrared sensors can locate the seat (hottest part) of a fire, but have difficulty detecting hot objects in rain, cloud or fog. Explain.

Experiment 11.3: Detecting ultraviolet radiation

Notes

Background

Human eyes are not able to see ultraviolet (UV) light as a colour. We can however see the result when UV light shines on a fluorescent material.

Aim

To use fluorescence to detect ultraviolet light.

Apparatus

- two clear, plastic cups
- waterproof markers
- one litre of tap water
- one litre of tonic water
- black backdrop material (cloth, paper or felt, roughly A4 size)
- access to direct sunlight or to a source of UV radiation ("black light")

Safety note: UV is harmful if it shines directly into your eyes.
If you use a black light source, use a shield to protect your eyes from direct UV emissions.

Pre-lab

- Label the plastic cups "tonic" and "water."
- Nearly fill each cup with tonic water or water as required.
- Place the cups in direct sunlight, or place a UV source above
  the cups, so that sunlight, or UV radiation, strikes the liquid surface in both cups.

Lab notes

- Hold a backdrop behind the cups to increase contrast. Looking through the sides of the cups, observe the surfaces of the liquids.
- Record your observations.

Post-lab discussion

1. Which material is fluorescent? What is your evidence?
2. How do you know that the cup is not fluorescent?
3. Tonic water contains water, sugar and quinine. Suggest how you could determine which one or more of these ingredients causes the fluorescence.
4. Many common substances are fluorescent. If you are using a black light source, test a range of objects and record the results. Do all fluorescent objects glow with the same colour? If so, what colour is it?
5. If you used sunlight, describe how you would test whether the position of the Sun in the sky makes a difference.

Extensions:

- If time permits, you can see how UV light is affected by passage through glass, Perspex, or cellulose acetate (used to make some overhead transparencies).
- How could you test the efficiency of sunscreens of different SPF values?

Problem Solving and Calculations

Set 11: Photons

Notes

1. An Air Traffic Control section at an airport monitors the movement of all aircraft in the area. They use a radar unit that emits microwaves with average photon energies of 2.0×10^{-24} J.
   a) What is the frequency of the microwaves?
   b) What is the wavelength of the microwaves?
   c) How do the energy, frequency and wavelength microwaves compare with those of visible light? Give your answers as higher, lower, longer or shorter.

2. The coloured glass filters on the front of traffic lights allow through bands of frequencies in either the red, orange and yellow, or green sections of the visible spectrum. Given the following average transmitted wavelengths determine the frequencies and energies of the red, orange or amber, and green coloured light.

colour	wavelength (nm)
red	680
orange	580
green	500

3. The average energy of X-ray photons is 1×10^4 eV. The average energy of γ-ray photons is 1×10^7 eV. Compare the frequencies and wavelengths of X-rays and γ-rays.
   That is, find the following ratios: $\dfrac{f_{\text{X-ray}}}{f_{\gamma\text{-ray}}}$ and $\dfrac{\lambda_{\text{X-ray}}}{\lambda_{\gamma\text{-ray}}}$

4. A 1.0 W ruby laser emits monochromatic light of wavelength 694 nm.
   a) What colour is the laser light?
   b) What is the energy per photon?
   c) What is the intensity of the laser beam if its cross-sectional area is 10 mm^2?
   d) The average intensity of sunlight at the Earth's surface is about 1000 W m^{-1}. Compare the intensity of the laser beam with the average intensity of sunlight.

5. How many microwave photons does a 750 W microwave oven produce every second? You may assume that the average energy of the microwave photons is 1.0×10^{-23} J and that the oven is 100% efficient.

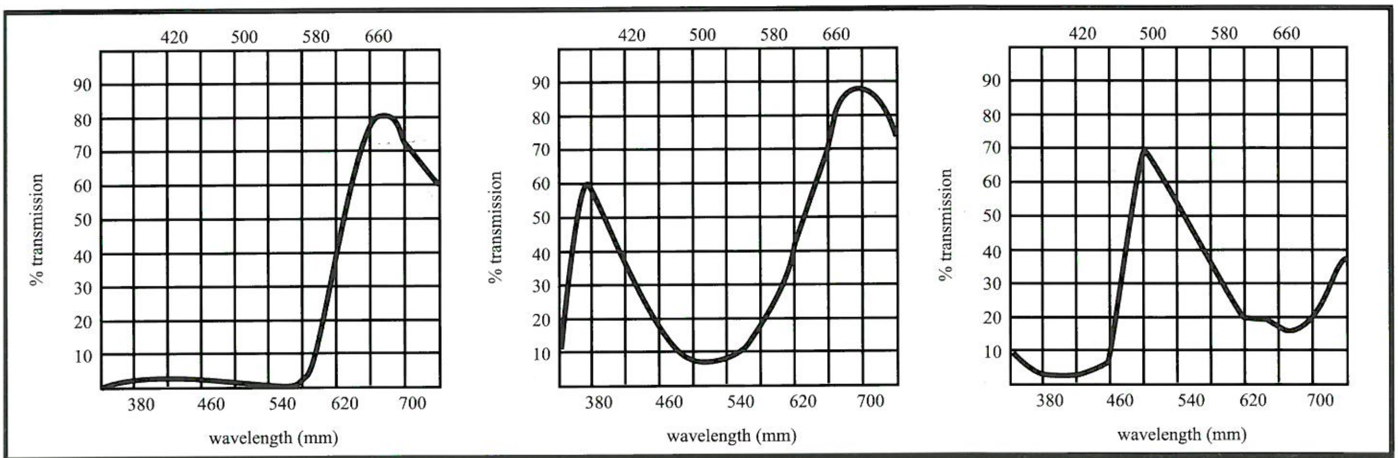
6. The human eye is adapted to seeing the middle colours of the visible spectrum most clearly. The retina can detect yellow light of wavelength $6.\ 0 \times 10^{-7}$ m that has a power of only 1.7×10^{-8} W. Calculate the minimum number of photons per second that a human eye can detect.

Problem Solving and Calculations 11

Set 11: Photons

7. A radio station has a 50 kW transmitter and broadcasts on a frequency of 720 kHz.
   a) What is the wavelength of its waves?
   b) How much radio energy does it send out every day? Assume that it broadcasts continuously.

8. Lighting gels are coloured transparent plastic sheets that lighting technicians fit the front of spotlights to create different colour effects on stage. The colour of the light depends on the amount of light of each wavelength that is transmitted by the gel. The following graphs show the % transmission *vs* wavelength for three different gels. One is a red gel, one is purple and one a green gel. Which graph corresponds with which colour? Briefly explain your reasons for each choice.

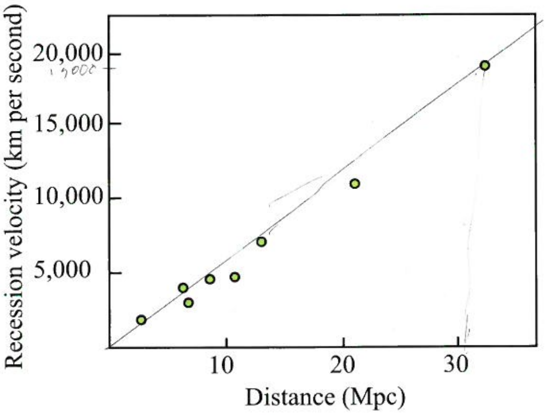


Transmission graphs

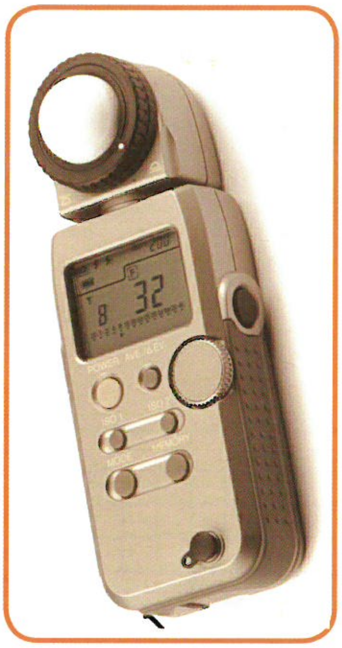
9. Explain what is meant by 'blueshift'. How does blueshift occur in an expanding Universe?

Notes

10. The graph below shows the relationship between recession velocity and distance for a number of galaxies, as derived from redshift data. The gradient of the graph is called the 'Hubble constant'. Use the graph to estimate the value of the Hubble constant with its appropriate units.



Investigation 11.4: Light intensity



Notes

Measuring light intensity

You can use a photographic light meter or a 35 mm camera with in-built exposure meter to compare light intensities.

If you are using a light meter be sure to use the diffusing screen accessory.

If you are using a camera you will obtain more reliable results if you use a diffusing screen in front of the lens. A piece of frosted glass or a piece of greaseproof paper will both work.

The film's exposure is controlled by the shutter speed and the f-stop number which is a measure of the lens aperture size. For a given fixed shutter speed the f-number needed for correct film exposure is an indirect measure of the light intensity. In fact, the light intensity I is directly proportional to the square of the f-number f. For example, if light intensity increased by a factor of 4 then the f-number would have to increase by a factor of 2.

$$I = \text{constant} \times f^2$$

If you are using a photographic light meter, set the film speed to 400 ASA, hold up the meter to the light source and determine the f-number required at a shutter speed of 60 s. By always using the same film speed and shutter speed settings the square of the f-number (f^2) will be your measure of light intensity.

If you are using a camera with an in-built exposure meter, set the film speed to 400 ASA and the shutter speed to $\frac{1}{60}$ s. Point the camera at the light source and determine the f-number needed for correct exposure.

By leaving the film speed and shutter speed settings fixed, the square of the f-number f^2 will be your measure of the light intensity.

Part 1: Comparing light sources

Background

The aim of this activity is to compare the relative intensities of several light sources. Read the section above on Measuring light intensity before you start.

Apparatus

Photographic light meter or a camera with in-built exposure meter
light sources e.g. 12 V globe
various size of incandescent globes and spot lights
metre rule or tape measure
darkish room

Pre-lab

Position the light measuring device a fixed distance from the brightest lamp.
Select a shutter and film speed that gives you an exposure of f/16.

Lab notes

Keeping both the distance and the film speed fixed, determine the f-numbers needed for the other lamps. Record your results in a suitable chart.

Investigation 11.4: Light intensity

Post-lab discussion

Notes

Plot a suitable graph of the square of the f-number (f^2) vs lamp type.
Which lamp gave the highest intensity?
Does the most intense lamp have to be the most efficient? Explain.

Part 2: Variation of light intensity with distance

Background

The further you are from a lamp the less intense is the light. In this activity you are to investigate how the intensity of the light varies with the distance from the light source. Read the section above on Measuring light intensity before you start.

Apparatus

- Photographic light meter or 35 mm camera with in-built exposure meter
- 100 W, 240 V light globe or a compact fluorescent lamp of about 15 W
- metre rules or a tape measure
- darkish room

Pre-lab

- Draw up a table for recording your results.
- Position the light measuring device approximately 1 m from the lamp.
- Select a shutter speed and film speed that gives you an exposure of approximately f/16.

Lab notes

- Vary the distance d between the lamp and device so that the exposure is exactly f/16. Record the distance in your table.
- Determine and record the distance that will give an exposure of f/11.
- Repeat this for the other f-numbers in the table.

Post-lab discussion

1. Plot a suitable graph of the square of the f-number (f^2) *vs* distance d. Comment on the general shape of the graph.
2. Plot a graph f versus $\frac{1}{d^2}$. Comment on the general shape of this graph.
3. Find a simple mathematical relationship between f and d.

Investigation 11.4: Light intensity

Notes

Part 3: Turning up the volts

Background

Increasing the voltage applied to a lamp will usually make it brighter. Devise and conduct an experiment that investigates how the intensity varies with the applied voltage. Read the section above on Measuring light intensity before you start.

Apparatus

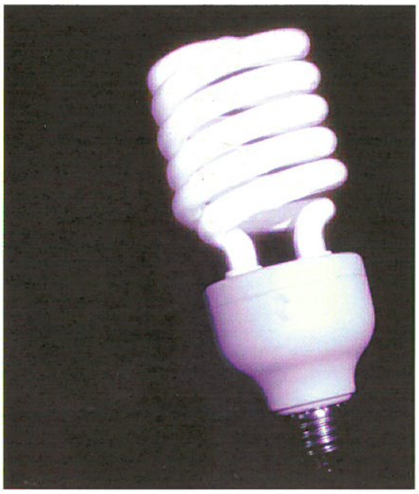
- photographic light meter or camera with in-built exposure meter;
- metre rule;
- 12 V, 36 W globe
- power pack, 0 - 12 V
- rheostat, 0 - 11 Ω
- voltmeter, 0 - 15 V
- connecting leads

Pre-lab

You devise!

Post-lab discussion

Be sure to present your findings in an appropriate way.



Chapter 12: Atoms and X-rays Explained

12

Notes

Remember the following important principles

Photon emission and absorption

Bohr's model or description of the structure of the hydrogen atom explains that the electron can only exist at certain energy levels. This means that it can have only certain energies. Scientists can calculate the energies available to the electron in a hydrogen atom fairly accurately. The picture is much more complicated for atoms with more than one electron and especially so for atoms within molecules and compounds. Even so, many of the energy levels in these more complicated atoms and molecules are known.

A convenient way of illustrating energy levels is to think of them like shelves in a bookcase. Electrons can sit on shelves but not between shelves.

- To move from a lower level to a higher level, an electron must gain an amount of energy equal to the difference between the two levels. This can involve absorption of emr.
- To move from a higher to a level, the electron must emit a photon with an energy equal to the difference between the levels. This involves emission of emr.

In either case, the photon energies correspond to $E_{\text{gained or lost}} = E_{\text{upper level}} - E_{\text{lower level}}$

An atom can gain energy from incident electromagnetic radiation, bombarding electrons, or thermal agitation as happens in a flame. In all cases, the photon energy is given by:

$$E = hf$$

Where:

E = photon energy in joules (J)

f = frequency in hertz (Hz)

h = 6.62×10^{-34} J s

X-rays

The kinetic energy acquired by an electron as it accelerates through an electric potential difference is given by:

$$E_k = \tfrac{1}{2} mv^2 = eV$$

Where:

E_k = kinetic energy of the electron in joules (J)

m = mass of electron in kg

v = velocity of the electron in m s^{-1}

e = charge of the electron (1.6×10^{-19} C)

V = potential difference through which the electron was accelerated in volts (V)

As a high speed electron passes a nucleus and is deflected and decelerated by it, the loss in kinetic energy of the electron is equal to the energy of the X-ray photon produced.

$$\tfrac{1}{2} mu^2 - \tfrac{1}{2} mv^2 = hf$$

Notes

The most energetic photon is produced when the electron is brought to a complete stop:

$$hf_{max} = \quad = \tfrac{1}{2} mu^2 = eV$$

When fast-moving electrons strike a metal target they produce X-rays by two processes:

- the metal decelerates the electrons rapidly, and they lose some or all of their kinetic energy as X-ray photons creating a broad spectrum of photon energies; and
- high energy electrons may knock inner electrons out of the target atoms (ionise the atoms). As electrons in higher energy levels drop down to fill the inner shell vacancy, X-rays of specific (characteristic) wavelengths are produced that correspond to the difference in energy levels.

The atomic nucleus

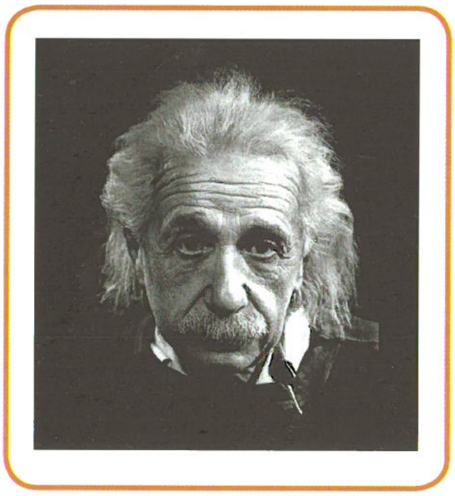
You have learnt that a nucleus typically consists of one or more protons, and a similar or larger number of neutrons. These particles exist at various energy levels within the nucleus and a change to a lower energy state involves the emission of very high energy photons called gamma rays.

The Standard Model of particle physics populates the Universe with more than just electrons, protons and neutrons. In particular, it postulates that relatively heavy subatomic particles (baryons) such as protons and neutrons consist of collections of sub-particles called quarks, bound together so strongly that we have no way of smashing them apart.

Electrons do not consist of quarks. Along with neutrinos, electrons belong to a different group of sub-atomic particles called leptons.

Relativity

One reason that scientists find it difficult to smash baryons into their constituents has to do with Einstein's Special Theory of Relativity. One of Einstein's insights was that the speed of light, *c*, does not vary, no matter what the observer is doing. This means that even when an observer is travelling at almost *c* as measured by reference to a fixed reference point such as your position, both you and the observer would measure the speed of light to be the same value.



While *c* remains the same for both observers, other things that we might expect to stay the same (such as length, mass and time) all change as the speed of the observer changes.

Thus, as we accelerate a particle such as a proton, it becomes more massive as it approaches *c*, making it ever harder to accelerate. A proton has a 'rest mass' of 1.673×10^{-27} kg but at 0.9*c* its 'relativistic mass' is 3.847×10^{-27} kg. At 0.99*c*, a 10% further increase in speed, its mass is 11.876×10^{-27} kg. Increasing the speed by another 1%, to 0.999*c*, increases the relativistic mass to 37.446×10^{-27} kg. In effect, the speed of light is a cosmic speed limit. No particle having a rest mass can travel as fast as, or faster than, *c*.

Experiment 12.1: Line spectra

12

Background

After gaining energy (e.g. from high-temperature atomic collisions, or by absorbing a photon) an atom quickly loses this energy by emitting one or more photons.

Apparatus

- Gas discharge tubes
- an induction coil and DC power pack
- direct vision spectroscopes
- darkened room

Pre-lab

- Mount the gas discharge tube vertically using a retort stand and clamp.
- Connect the high voltage terminals of the induction coil to the discharge tube terminals.
- Connect the primary terminals of the induction coil to the DC terminals of the power pack. Set the power pack to the required voltage and turn on. Be sure to follow the manufacturers' safety rules.

Lab notes

- Examine the light emitted by the tubes through direction vision spectroscopes. Record your observations.
- Choose one tube and estimate the wavelength and frequency of each line in its visible spectrum. This may done by using the wavelength markings on the display in the spectroscope if these are provided. If not, find out the approximate frequency or wavelength range for each colour in the spectrum and estimate the characteristics of the visible lines that way.

Post-lab discussion

1. Sketch the emission spectrum for each tube you observed. Label line colours clearly.
2. Consider the element for which you estimated the wavelengths and frequencies of the lines. Work out the photon energies involved and construct a partial energy level diagram for that element. Show clearly the size and direction of each transition responsible for a spectral line.
3. Why is this a partial energy level diagram?
4. Are any of the lines that you observed the result of transitions to or from ground state? Explain.

Notes

Experiment 12.2: Band spectra

Notes

Background

Gaseous atoms create line spectra by emitting or absorbing light at particular frequencies or wavelengths. Compounds behave differently, by emitting or absorbing many frequencies or wavelengths – in effect, creating bands rather than lines.

Apparatus

- coloured filters
- solutions of coloured salts (copper sulfate, nickel sulfate, cobalt chloride, very dilute potassium permanganate) or vegetable dyes, in parallel-sided glass or plastic containers
- white light source
- direct vision spectroscopes
- darkened room

Pre-lab

- Set up the white light lamp so it shines toward the viewing location.
- Check where the spectroscope has to be placed to obtain a bright, clear spectrum.

Lab notes

- While one group member observes the spectrum from the white light source, another member inserts a filter or sample of coloured liquid between the lamp and the spectroscope. Note changes in the spectrum when the coloured material is introduced, and record your observations. While still observing the spectrum, have the filter or solution sample removed.
- Repeat this for filters or solutions of a range of colours.

Post-lab discussion

1. Did you observe emission or absorption spectra? How can you tell?
2. Choose any two different coloured materials and explain how they caused the spectrum that you observed.
3. Line spectra can be used to identify individual elements by matching the locations and brightness of several lines. Could band spectra be used in a similar way? Explain.

Problem Solving and Calculations 12

Set 12: Atoms and X-rays

Notes

1. a) What is the difference between an atom in the ground-state and an atom in the excited state?
   b) How do atoms become excited?

2. Explain why an iron bar at 200 °C appears grey, at 800 °C appears red, and at 1400 °C appears white.

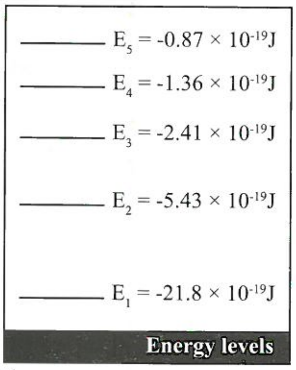
3. Bohr developed a formula for calculating the energies of the energy levels of the hydrogen atom.

$$E_n = -\frac{13.6\ \text{eV}}{n^2}$$

where:

E_n = is the energy of an electron at level n
n =1,2,3, etc

Use this formula to find the values of the first five energy levels of the hydrogen atom, in eV.



Energy levels

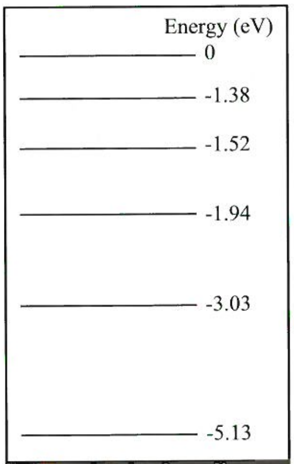
4. An energy level diagram for the hydrogen atom is shown.
   a) For each of the downward transitions listed below, determine:
      the energy of the photon the electron emits,
      the frequency of the photon the electron emits,
      the type of electromagnetic radiation to which the photon belongs
   (i) $E_2 \rightarrow E_1$
   (ii) $E_4 \rightarrow E_2$
   (iii) $E_3 \rightarrow E_2$
   (iv) $E_5 \rightarrow E_3$
   b) A violet line in the visible line emission spectrum of hydrogen gas has a wavelength of 434 nm. Between which two levels must an electron fall to emit this photon?

5. Electrons with energy of 45 keV bombard a metal target in an X-ray tube. The energies of some of the scattered electrons are 15 keV and 5 keV.
   a) Determine the highest energy X-ray that this X-ray tube could produce.
   b) Explain the X-ray's origin.
   c) Find the energy of the X-ray photon produced by each of the two scattered electrons.
   d) Would you classify these X-rays as *hard or soft*? Justify your answer.
   e) The X-ray spectrum the tube produces also shows a significant X-ray peak at 1.0 nm. These X-rays come from electrons dropping into an inner energy level of a target metal atom. Determine the difference between the energies of the two levels.

6. Many minerals that have dull colours in daylight fluoresce under ultraviolet light. Explain how fluorescence occurs, using a simple energy level diagram.

Notes

7. Some cities, such as Adelaide and Perth, use sodium vapour lamps for lighting major streets. Perth also uses sodium vapour lamps for cross-walk lighting. Our eyes are particularly responsive to the bright yellow light of sodium vapour lamps. The line emission spectrum of sodium shows a yellow line and no other colours.
The diagram shows some of the energy levels of the sodium atom. The diagram is not drawn to scale.



Energy levels of a sodium atom

a) What energy will eject an electron from a sodium atom if the electron is in the lowest energy level?
b) The characteristic yellow colour of the sodium lamp is due to the emission of photons of wavelength 589 nm. Between which two levels do electrons fall to emit this colour?
c) The line emission spectrum of a low pressure sodium vapour lamp shows that the yellow line is really two very closely-spaced fine yellow lines of wavelengths 589.0 nm and 589.6 nm. This happens because the upper energy level really consists of two very closely spaced energy levels. Determine the energy difference between these two levels.
d) All other electron transitions within the sodium atom are either in the infrared region or ultraviolet region. Sketch an energy level diagram showing two electron transitions producing infrared radiation and two electron transitions producing ultraviolet radiation.

8. a) Describe with the aid of a diagram, the construction and principle of an X-ray tube.
b) What is the thermionic effect and how is this used in an X-ray tube?
c) Why is the anode usually made to rotate when an X-ray tube is operating?
d) The anode normally consists of a tungsten target embedded in copper. Why are these two materials chosen?
e) Sketch a graph of the intensity of X-rays produced against their frequency.
f) Discuss each of the significant features of the graph and the physical principles that give rise to these features.
g) How would the graph change if:
   (i) A different material was used for the target
   (ii) The current through the heated filament was increased
   (iii) The accelerating potential was increased?
h) Why do X-rays have a maximum frequency for an given accelerating voltage?

Notes

9. X-rays were once used to check the fit of shoes. Why has this practice been discontinued?

10. Varun remembered that his Physics teacher said that in an X-ray machine about 99% of the energy of the incident electrons was converted to heat. When electrons are accelerated through 100 kV, Varun's interpretation was that the maximum energy of the X-ray photon produced was 1% of the 100 keV). Emily however, claims this is not true and that photons of maximum energy 100 keV were produced. Who is right and why?

11. X-rays are created by accelerating electrons from a cathode across a potential difference of 60 000 V. Find:
    a) The energy of each electron
    b) The final speed of each electron
    c) The minimum wavelength of the X-ray photons created by the collision of the electrons with the target.

12. What potential difference is needed to accelerate electrons in order that X-rays of wavelength 10^{-10} m are produced?

13. What is the shortest-wavelength X-rays emitted by electrons striking the face of a 33.5 kV TV picture tube? Why can we not calculate the longest wavelengths?

14. In an X-ray tube, the high voltage between the filament and the target is V. After being accelerated through this voltage, an electron strikes the target where it is decelerated (by positively charged nuclei) and in the process one or more X-ray photons are emitted.
    a) Show that the highest-energy photon will have a wavelength given by:

$$\lambda_0 = \frac{hc}{eV}$$

    b) Determine the shortest wavelength and highest frequency of the X-rays emitted when accelerated electrons strike the face of a 30 kV television tube.

15. The Standard Model postulates the existence of several quark types. Protons and neutrons are made of combinations of three 'up quarks' and 'down quarks'. An up quark has an electric charge of $+\frac{2}{3}$e and a down quark has a charge of $-\frac{1}{3}$e. Predict the quark combination that makes up:
    a) a proton
    b) a neutron

Investigation 12.3: Fluorescence

Notes

Apparatus

- UV 'black light' source
  *(**CAUTION:** do not look directly at the light source when it is turned on)*
- a range of fluorescent materials such as: the minerals fluorite or calcite; soap powder
- quinine sulfate or Fluorescine solution; motor oil; vaseline smeared on paper; zinc sulfide; highlighter pens of various colours

Pre-lab

- A darkened room works best.

Safety note: UV is harmful to the unprotected eye. Make sure that no-one can see the UV lamp directly when it is turned on.

Lab notes

- Compare the colour of the materials when viewed under white light and when viewed under ultra violet light.
- Explain what happens in terms of photons and energy levels.

Post-lab discussion

1. Explain the difference between 'fluorescence' and 'phosphorescence'.
2. Were any of the materials that you observed phosphorescent? How do you know?
3. What makes a UV lamp more potentially harmful to your eyes than a normal bright lamp?
4. Some insects that feed on nectar and pollen from certain flowers have eyes that can detect UV light. Are the flowers on which they feed likely to be fluorescent, or non-fluorescent? Explain.

Investigation 12.4: Sub-atomic particles

Baryons, leptons, mesons – strange names for strange particles.

Select any family of sub-atomic particles, research its discovery, and write a report that highlights the physical nature of the particle family. Remember that this is a physics report and ensure that the physics ideas are given appropriate importance.

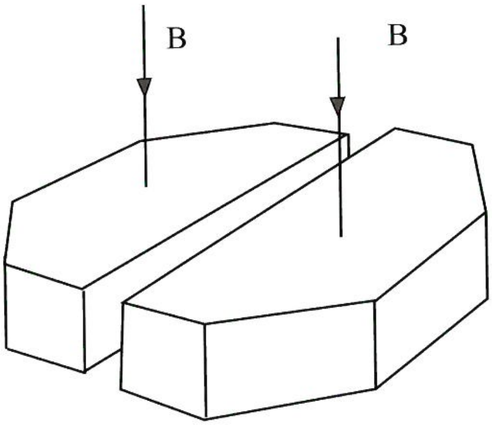
Make sure that you give credit to any sources that you use, for example by indicating direct quotations and by listing the title, author and related details in your reference list.

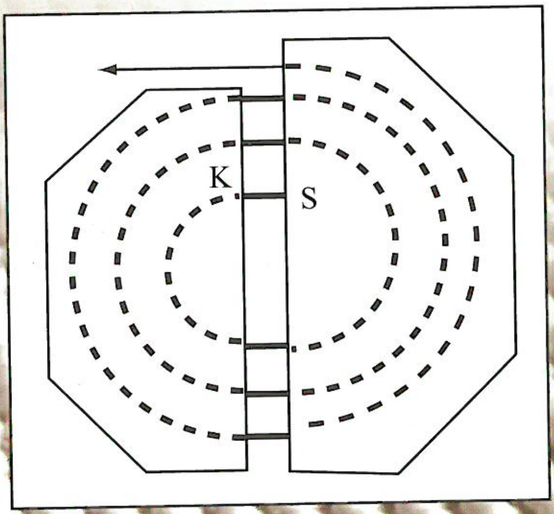
Notes

The Large Hadron Collider

Particle accelerators are machines that feed energy into charged particles. The particles have to be charged because electric and magnetic fields will not accelerate neutral particles. There are many types of particle accelerator, two of which are described here.

A cyclotron is a machine for accelerating ions to very high kinetic energies. It consists of two hollow electrodes (called 'dees') situated in a strong magnetic field B perpendicular to the dees, as shown in the diagram at right.





A source S, situated near the centre and at the edge of one dee, emits ions of mass m and charge q with negligible velocity. These ions are accelerated across the narrow gap between the dees by a potential difference V applied between the dees. The path of the ions is shown in the diagram at left in which you are looking down on the dees along the magnetic field. In fact, the ions make many more circuits than are shown in the diagram.

The maximum particle energy in a cyclotron is limited because the particles increase in mass as they increase in energy (so-called 'relativistic effects') and this makes the accelerating fields get out of step with the orbiting particles. The machine that gives ions the greatest energy increase at the present time is the Large Hadron Collider, LHC, in Switzerland. That's 'large collider', not 'large hadrons'.

In the LHC the ions are sent in a circular path with regular energy boosts along the way. The particles may circulate at about 10 000 revolutions per second for ten hours or more, gaining energy all the way. Then, two particle beams, each of very high energy, are directed by magnetic fields into collision courses, doubling the collision energy. In the LHC, protons can be accelerated to 7 TeV (7×10^{12} eV) so they collide with a combined energy of 14 TeV. At 7 TeV, a proton's velocity is 99.9999991% of c, the speed of light. The result of such collisions can then be compared to predictions from theory. This feedback between theory and experiment leads to improvements in both the theory and the experiments.

Photo: NASA

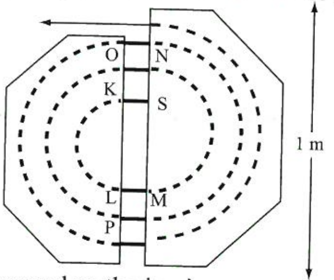
The scale of the LHC is staggering compared to most other accelerators. The first synchrotron ever built had dees about 10 cm in diameter. The LHC is an evacuated tube with a diameter of 8.6 kilometres, with about 1600 immensely powerful superconducting electromagnets that have to be cooled to 1.9 K (-271°C) in order to operate.

The Large Hadron Collider comprehension questions

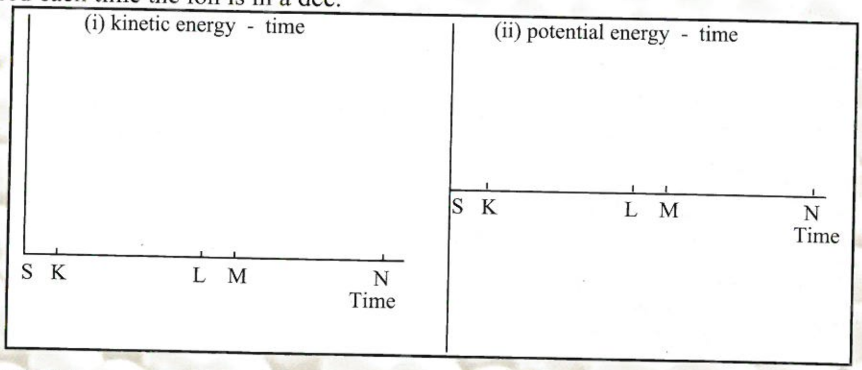
Comprehension Questions

In the questions that follow, give your answers where appropriate in terms of V, B, m and q.
Questions 1 to 9 are about the behaviour of particles in a synchrotron.

1. Determine the speed v of an ion, emitted by the source, after this ion has moved across the gap and is just entering the left hand dee at point K. Assume that the effect of the magnetic field can be neglected for the short path of the ion across the gap.
2. After it enters the left hand dee, the ion is in a region of constant potential (no electric field) and is subject only to the influence of the magnetic field. Determine the radius of curvature of the ion's path as it makes its first passage through the dee (K to L in the diagram at right).

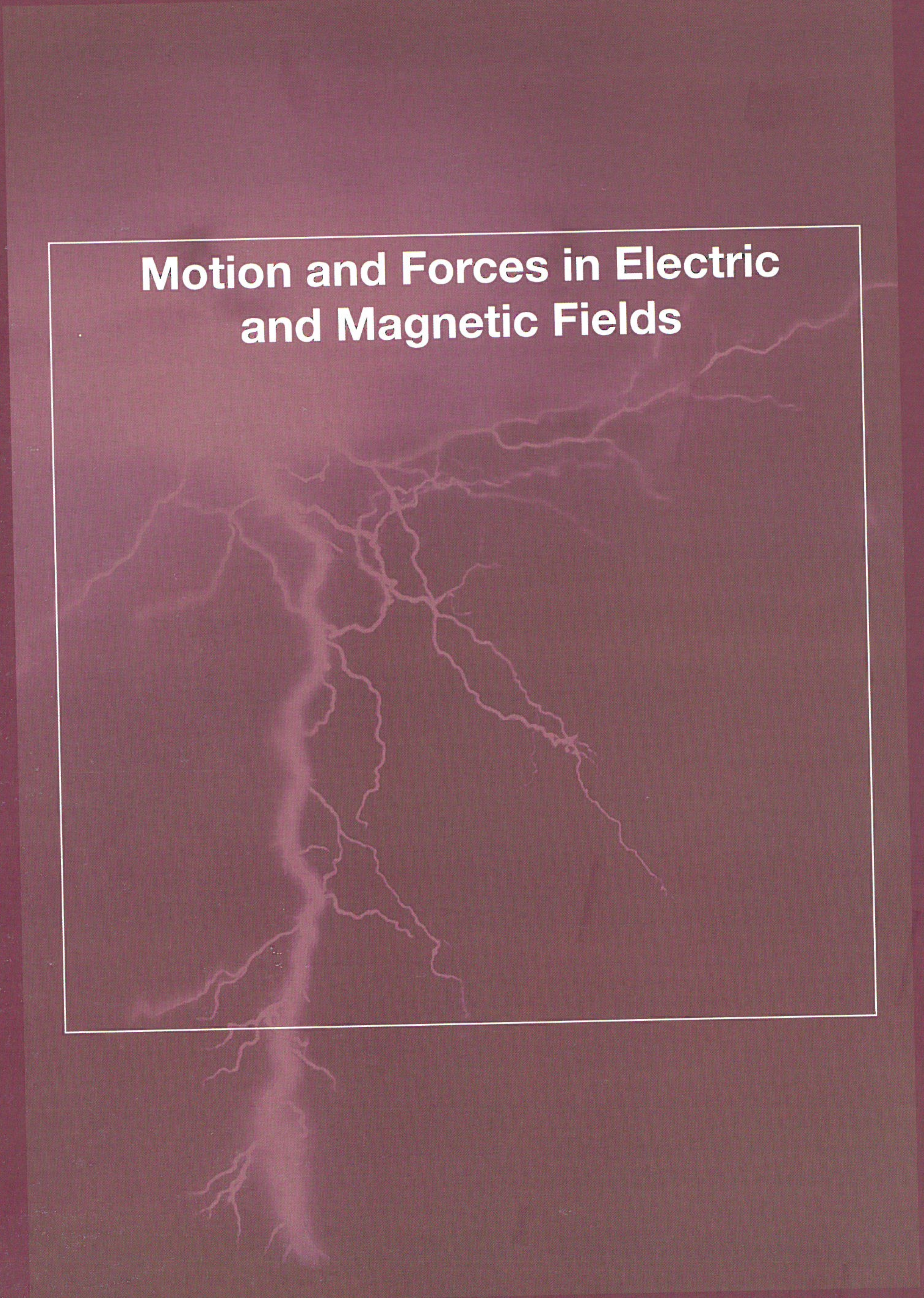


3. While the ion is in the left hand dee, the potential difference V between the dees is reversed so the ion is once again accelerated as it crosses the gap a second time (from L to M). Determine the speed of the ion as it re-enters the right-hand dee at M.
4. By what factor will the radius of curvature of the ion's path M to N in the right hand dee differ from the pervious radius on the path K to L?
5. This sequence of events is repeated many times and the ion follows a path of increasing radius, as shown in the diagram above. What time does the ion spend in the dees while travelling any of the semi-circular paths such as OP?
6. The reversal of the potential difference between the dees is accomplished by a high speed electronic reversing switch. The gap is very narrow so the ion spends negligible time in the gap compared to the time spent in the dees. How frequently must the switch reverse the potential difference?
7. Sketch graphs (see axes below) showing how (i) the kinetic energy and (ii) the potential energy of the ion vary with time. The times at which the ion is at the points S, K, L, M and N are indicated on the axes supplied below. Remember that the potential difference V is reversed each time the ion is in a dee.



8. The radius of the ion's path increases with each successive half circuit. From the diagram you can see that the ion finally emerges from the dees when its path diameter is about equal to the width of the dees. In a particular cyclotron the width of the dees, as shown in the diagram, is 1.0 m, B is 1.0 T, V is 500 volt and the ion being accelerated has charge $q = 1.6 \times 10^{-19}$ C and mass $m = 3.5 \times 10^{-27}$ kg. Estimate how many orbits (complete circuits) this ion will make before it emerges from the dee.
9. For the data supplied, calculate the approximate kinetic energy of the ion (in electron-volts) as it emerges from the cyclotron.
10. Show that the mass of a 7 TeV proton is about 2×10^{-23} kg.
11. Why is this mass greater than the rest mass of a proton?

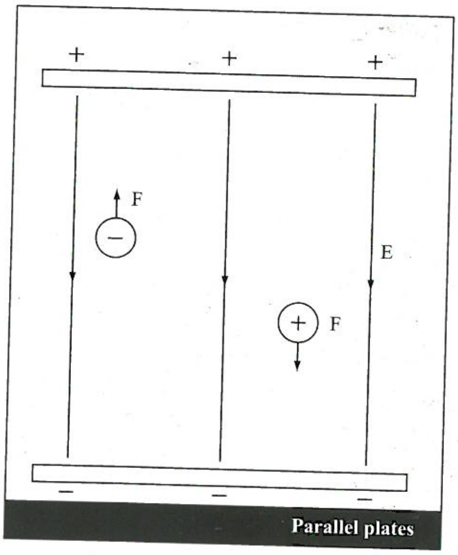
Motion and Forces in Electric and Magnetic Fields



Chapter 13: Charged Particles in Electric Fields Explained

13

Remember the following important principles



Parallel plates

The region around a charge or group of charges that can influence another charge placed in that region is known as an electric field. When a charge is in an electric field it experiences a force. The force is a result of the interaction between the electric field and the charge.

The magnitude of an electric field is the size of the force it causes on a charge placed at a point in the electric field.

The relationship between the electric field strength (E) and the force it causes to act on a charge is:

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

Where:

F is the force acting on a small charge, q

Electric field strength is a vector with the unit newton per coulomb ($N\ C^{-1}$) or volt per metre ($V\ m^{-1}$).

Notes

Two oppositely charged parallel plates that are close together have an electric field between them that is uniform, except near the edges. A charged particle in the uniform electric field between the plates experiences a force and therefore moves.

You can determine the work done by the electric field in moving the charge a distance d parallel to the field by the relationship:

$$W = Fs = Eqd \qquad \text{i. e. } W = Eqd$$

where:

W is the work done (joules, J)
E is the electric field strength ($N\ C^{-1}$)
q is the charge on the particle (coulombs, C)
d is the distance the charged particle moves (metres, m)

also,

$$W = V q$$
$$Eqd = V q$$

where:

V is the potential difference through which the charged particle is moved.

Experiment 13.1: Mapping an electric field

Notes

Background

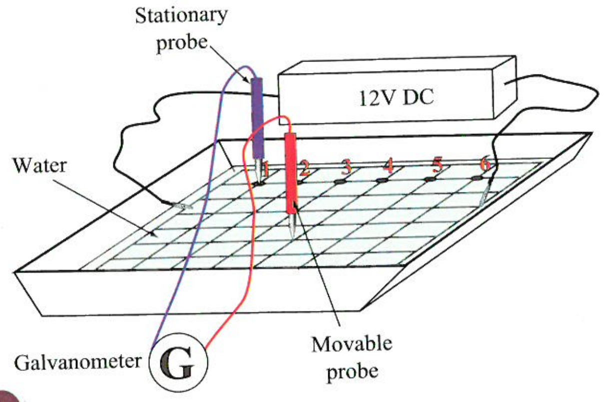
Equipotential lines join points having the same electric potential. Points along an equipotential line are all at the same voltage, so no current flows between them. Electric field lines are always at right angles to equipotential lines.

Pre-lab

- Set up an electric field in a bath of salt water by placing positive and negative electrodes in it.
- Map the equipotential lines by finding curves along which no current flows.
- Map the electric field by drawing lines connecting the electrodes that intersect the equipotential lines at right angles.

Lab notes

- Make sure that your pan contains a plotting sheet. Cover the sheet with a thin layer of water.
- Place the positive and negative electrodes at the ends of your plotting sheet as shown. Your instructor will check the circuit before turning up the voltage.
- Place the stationary probe at the first of six locations as shown. An electric circuit connects this probe through a galvanometer (current meter) to a moveable probe. When current flows through this circuit, the galvanometer will register it; as the current goes to zero, the galvanometer reading will go to zero also. By searching with the moveable probe for points of zero current, and marking them on the plotting sheet, you can map out an equipotential line.
- As you locate each point of zero current in your pan, mark this location on your individual sheet of graph paper.
- Repeat the Pre-lab for each of the stationary probe locations (see diagram below). Note that you should gather enough data to draw at least six equipotential lines.



Post-lab discussion

1. Points along the same equipotential are mapped by finding locations in an electric field between which no current flows. Explain.
2. Why was the experiment carried out in salty, rather than pure, water?

Experiment 13.2: The van de Graaff generator

Background

Notes

A van de Graaff generator is a high voltage, electrostatic generator. The electric charge is carried by a belt and transferred to a large-diameter, hollow metal dome. The sphere stores the charge; every extra electron on the dome increases its electric potential (voltage).

Under ideal conditions, charge may accumulate on the dome until the potential reaches several hundred thousand volts. Such high voltages are possible because the belt that transfers charge to the dome is an insulator, and the air around the dome is also an insulator, trapping the charge.

Dust or humidity increases the air's conductivity. Under these less-than-ideal conditions, the dome cannot reach very high potential because it continually leaks charge into the air.

Aim

To charge a van de Graaff generator and explore some of the effects of very high voltages.

Apparatus

- van de Graaff generator and its accessories
- balloons or a Leyden jar
- spoon with an insulated handle
- Hamilton's mill
- fluorescent tube
- candle
- aluminium foil
- paper strips
- ebonite or plastic rod
- two metal plates
- access to a water tap, scissors and glue

Warning: Although the van de Graaff generator normally produces a very small current when it is discharged, the high voltage spark can still cause harm. In particular:

- Avoid bringing your face anywhere near the dome, as a spark into the eye can cause permanent damage.
- Avoid exposure to the high voltage discharge if you have any type of heart condition or a history of epilepsy.

Pre-lab

- Make sure that the belt and metal dome are clean and dry.
- If necessary, dry the van de Graaff belt and the air around it with an electric heater.

Experiment 13.2: The van de Graaff generator

Notes

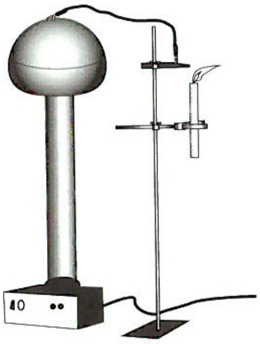
Lab notes

Once the van de Graaff dome is charged, you can remove charges from it by 'spooning'. A copper blade set in an insulated handle is suitable. Touching the charged spoon to an inflated balloon should transfer charge to the balloon. Find out what happens if you bring your finger close to a charged balloon; bring two charged balloons close to one another; or bring a charged balloon close to a volunteer with long, loose hair.

Your school may have one or more Leyden jars. These can be used to store and carry charge more efficiently than a balloon.

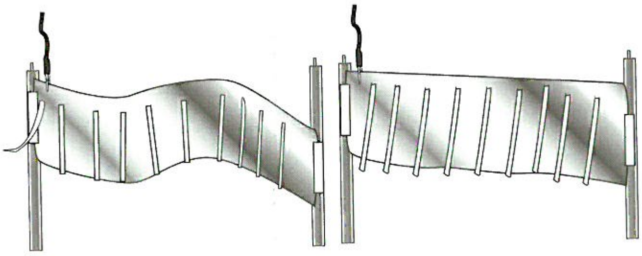
Connect a small metal sphere attached to an insulated handle to the earth terminal of the generator. Bringing the small sphere close to the charged dome of the generator should cause a spark. Find out how the distance between the dome and the sphere affects the way that the generator discharges.

A Hamilton's mill (basically a wire windmill on an insulating stand) can be fitted to the top of the dome and connected to the dome with a wire before charging. Observe what happens when the dome charges up.



Connect a needle or pin to the generator dome before charging, and support it on an insulated stand about 20 mm from a lit candle. Observe what happens when the dome charges up.

Hold the metal contacts at one end of a fluorescent tube onto the generator dome. Observe what happens when the dome charges up.

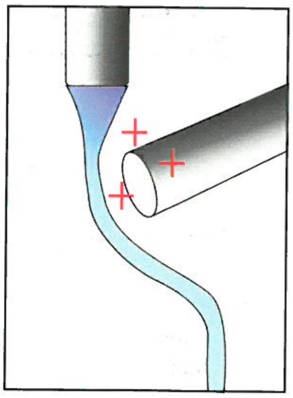


Cut narrow strips of paper and glue them near one edge of a band of aluminium foil. Support the aluminium foil band on two insulated stands as shown, and attach a wire from the dome of the generator to the foil, before charging. Observe what happens to the paper strips when the generator charges up.

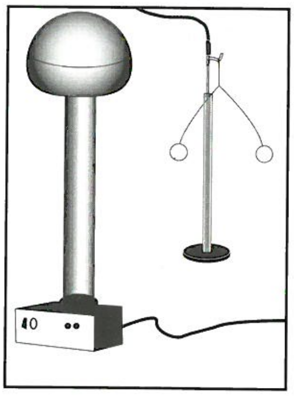
Experiment 13.2: The van de Graaff generator

Notes

Charge an insulating rod (ebonite or plastic) and hold it near the column of water from a slow running water tap. Observe what happens to the water stream as the generator charges up.

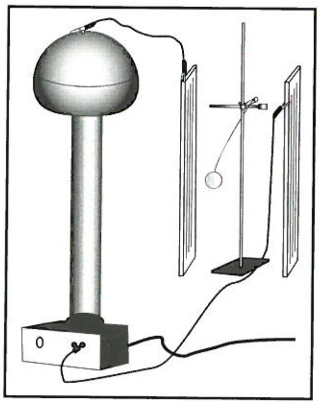


Suspend two pith balls on individual cotton threads from an insulated stand. Connect the ends of the threads to a lead from the dome of the generator, before charging. Observe what happens when the generator charges up.



Suspend a pith ball on a cotton thread from an insulated stand. Place a flat metal plate on one side of the pith ball. Connect the plate to a lead from the generator dome, before charging.
Set up another plate on the other side of the pith ball and connect it to the dome as well.

Make sure the plates are insulated from each other. After the apparatus is set up, start the charging process. Use an insulating (non-conducting) rod to adjust the gap between the plates until the pith ball swings from plate to plate.



Post-lab discussion

1. Explain how you can charge a balloon by contact with a 'spoon' as described above.
2. What causes the light you see when the dome discharges in a 'spark'? What causes the sound?
3. What does the Hamilton's mill apparatus do as the dome charges up? Explain.
4. Explain the effect of the charged needle on the candle flame.
5. Why does the fluorescent tube light up when the generator dome charges up?
6. Consider the paper strips glued to aluminium foil and connected to the generator. Explain the behaviour of the paper strips when the foil is curved, and when it is held straight.
7. Why does a charged rod affect a stream of water?
8. Consider the two suspended pith balls charged by the generator. Explain why they behave as they do.
9. Consider the 'electrostatic pendulum' in which a suspended pith ball is placed between parallel charged plates. Explain what you observe.

Problem Solving and Calculations

Set 13: Charged Particles in Electric Fields

Notes

1. At a point in an electric field, an electron experiences force of 7.2×10^{-13} N. Determine the electric field strength at this point.

2. Two scientists measure the electric field strength in a region. One reports it as 200 N C^{-1} while the other reports it as 200 V m^{-1}. Show that these two units are equivalent.

3. A cathode ray tube (CRT) contains parallel plates that are 30 mm long and have an electric field strength between them of 2.5×10^4 N C^{-1}. An electron travelling at 2.9×10^7 m s^{-1} enters the field at right angles.
   a) Draw a diagram to represent the electric field between the charged plates.
   b) Compare the velocity (including direction of movement) of the electron as it leaves the electric field with its velocity on entering the electric field.
   c) Explain why the electron experiences a change in its velocity.
   d) Explain how a CRT uses the deflection of electrons by such parallel plates.
   The CRT accelerates an electron from rest through a potential of 1.80 kV. Find:
   e) the electron's gain in kinetic energy; and
   f) the electric field strength if the electron travelled 30 mm.

4. The radio frequency component of a radio or television set is totally enclosed in a hollow aluminium box. Explain why the manufacturers do this.

5. Two parallel conducting plates are separated by 3.0 mm and have an electric field between them of 2.2×10^4 N C^{-1}. A charge of +5.0 nC moves against this field from one conducting plate to the other. Find
   a) the work done on the charge, and
   b) the potential difference between the plates.

6. What is the electric field strength between two parallel plates 120 mm apart that have a potential difference of 12 V?

7. An electron is accelerated by a potential difference of 5.00 kV. Determine the electron's gain in kinetic energy
   a) in electron-volts
   b) in joules

8. An alpha particle (helium nucleus) is accelerated by a potential difference of 5.00 kV. Determine the alpha particle's gain in kinetic energy
   a) in electron-volts
   b) in joules

9. The gap between electrodes in a particular spark plug is 2.7×10^{-4} m and they have a potential difference of 1.5×10^4 V between them. Calculate
   a) the electric field strength between the electrodes; and
   b) the energy gained or lost by an electron that moves between the electrodes.

Problem Solving and Calculations 13

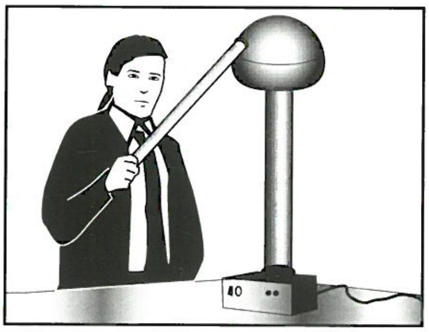
Set 13: Charged Particles in Electric Fields

Notes

10. When the driver got out of a car after stopping it at the side of a dry gravel road, the driver's polyester shirt attracted dust particles.
    a) Explain why the shirt attracted the dust
    b) If the electric field strength is 9.0 N C^{-1} and the shirt has a charge of 4.0 μC, determine the magnitude of the electric force acting on a dust particle
    c) If a dust particle acquired 3.6×10^{-7} J of kinetic energy, how far did it move towards the shirt, and through what potential difference did it move?

11. Many coal fired electric power stations have electrostatic precipitators inside their chimney stacks. Explain:
    a) how an electrostatic precipitator works
    b) why a power company would install one.

12. To demonstrate the magnitude of the electric field produced by a Van de Graaff generator, an investigator used a fluorescent tube. When she held the tube so it pointed towards the generator, it produced light and flickered. When she held the tube at right angles to the generator, it produced no light. Explain why the tube produced light in the one orientation but not in the other.



13. An initially stationary proton is accelerated by a potential difference of 800 V. Determine the proton's final speed.

14. An initially stationary electron is accelerated over a distance of 10.0 cm by an electric field of strength 2.50×10^{4} V m^{-1}.
    a) Draw a labelled diagram showing the direction of the field and the direction of the electron's final velocity;
    b) Determine the electron's change in kinetic energy;
    c) Calculate the magnitude of the electron's final velocity.

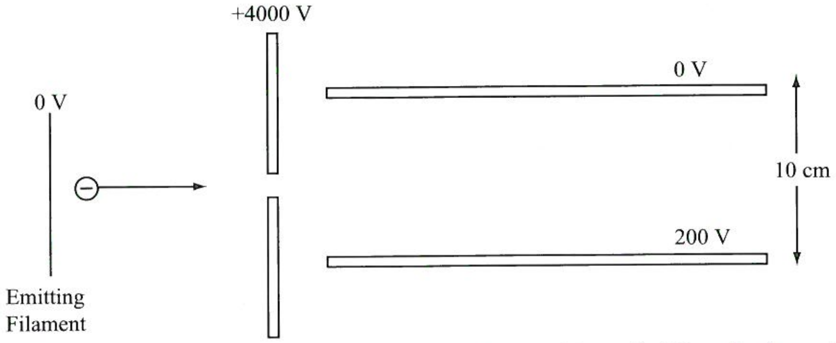
    If the same field had accelerated a proton instead of an electron,
    d) Draw a labelled diagram showing the direction of the field and the direction of the proton's final velocity.
    e) Would the proton have gained more than, the same as, or less than the kinetic energy gained by the electron?
    f) Would the magnitude of the proton's final velocity be greater than, the same as, or less than the final velocity of the electron?

Problem Solving and Calculations

Set 13: Charged Particles in Electric Fields

Notes

15. An electron in a cathode ray tube was accelerated from the emitting filament to a plate, through a potential difference of 4000 V.



a) Assuming the electron started at the filament with negligible velocity, calculate the energy and velocity it attained by the time it reached the plate

b) The electron then passed through a hole in the plate and moved between two long, parallel deflecting plates 10.0 cm apart. If these plates were at a potential difference of 200 V, calculate the electric field strength between them, and hence the deflecting force acting on the electron.

c) Draw a diagram showing the plates, the electric field between them, and the path of the electron assuming that it did not contact either plate during its passage.

16. A plane heated filament emits electrons having negligible kinetic energy. There is a plate parallel to the filament, situated 5.00 cm away in vacuum, that is maintained at +2000 V with respect to the filament.

a) Explain why this would be done in a vacuum.

b) Calculate the acceleration of the electrons.

c) If there is a small hole in the plate and there is no electric field in the region of space on the side of the plate away from the filament, sketch suitably labelled graphs to indicate how the following quantities vary as a function of distance from the filament to a point 2.00 cm beyond the plate:
   (i) acceleration of emitted electrons;
   (ii) velocity of emitted electrons;
   (iii) kinetic energy of emitted electrons.

d) On the same graphs that you drew for (c) above, plot the way that the same three quantities would vary with distance if the hot filament is replaced by a source that emits heavy, singly-charged negative ions. Make sure that your graphs show clearly which lines apply to electrons and which to ions.

Investigation 13.3: Lightning

Notes

1. What is lightning, and what causes it?
2. What causes thunder?
3. Why is there a time lag between the flash and the sound?
4. Are clouds necessary in producing lightning?
5. Can lightning occur in any type of cloud?
6. What is 'ball lightning'?
7. Does lightning occur only in Earth's atmosphere or is there evidence of lightning on other worlds?

Research these questions, and write a report that highlights the physics underlying each. Your report should include relevant mathematical treatments of the information where these are appropriate. Remember that this is a Physics report and ensure that the physics ideas are given appropriate importance. You may wish to review your notes about Experiment 13.2 if you have done it.

Make sure that you give credit to any sources that you use, for example by indicating direct quotations and by listing the title, author and related details in your reference list.

Chapter 14: Charged Particles in Magnetic Fields Explained

Notes

A small charged particle such as an electron or a proton is not affected by a magnetic field unless the particle is moving across the field lines. A moving charged particle creates around itself a small magnetic field. The particle's field interacts with the magnetic field through which the particle is moving, as long as the particle's path crosses field lines. The result is that a force acts on the particle, at right angles to its velocity. As long as the force is at right angles to the velocity, the particle moves in a curved path, for example tracing out a half circle if the field is big enough.

Note that if the particle travels parallel to the field lines, there is no interaction with the field and hence no magnetic force. Such a particle travels through the magnetic field undeflected.

The magnitude of the deflecting force is given by:

$$F = qvB$$

where:

q = particle charge in coulombs (C)
v = particle velocity (m s^{-1})
B = magnetic field strength (T)

You can determine the direction of the force by applying the 'right-hand rule'.

For a charged particle moving in a circular path:

$$F_{magnetic} = F_{circular}$$

$$q\,v\,B = \frac{m\,v^2}{r}$$

$$\therefore r = \frac{m\,v}{q\,B}$$

This formula is useful in calculating the radius of the circular arc travelled by a charged particle in a magnetic field.

Many instruments make use of magnetic fields to control the path and width of a beam of electrons. Examples include cathode ray oscilloscopes or CROs, cathode-ray televisions, and electron microscopes. (Note that LCD and plasma television sets work on a very different principle.)

Two instruments that use the charged particles will move in a circular path in a magnetic field are the mass spectrometer and the cyclotron or synchrotron.

The problems in this set do not take into account relativistic effects.

Experiment 14.1: Electromagnetic stirrer

Background

A current passing through a solution involves charges moving between two electrodes. If these charges also move through a magnetic field, they experience a force that stirs the liquid.

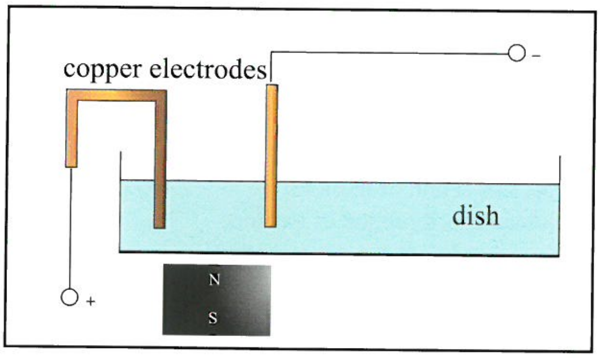
Notes

Apparatus

- Very strong rare-earth disc magnet
- glass petri dish
- saturated solution of $CuSO_4$
- copper electrodes
- 12 V DC power supply

Pre-lab

- Connect the apparatus as shown in the diagram. It helps if you glue the electrodes into place.



Lab notes

- Turn on the current and observe and record the result. Some chalk dust on the surface makes this more obvious.
- Try reversing the field or current directions. Observe and record the result.

Post-lab discussion

1. Using a labelled diagram, explain how the magnetic stirrer actually stirs the liquid.
2. Using a labelled diagram, explain the effect of reversing the current direction.
3. Using a labelled diagram, explain the effect of reversing the magnetic field.

Problem Solving and Calculations

Set 14: Charged Particles in Magnetic Fields

Notes

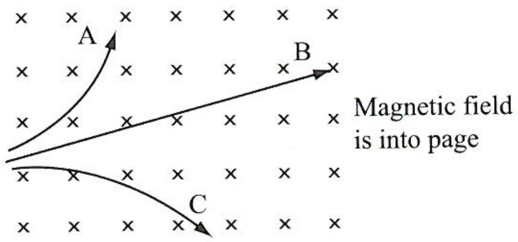
1. a) Explain what we mean by the term *magnetic field*.
   b) Sketch the shape of the magnetic field surrounding the Earth.
   Indicate clearly the geographic and magnetic poles, and show the direction of the field.
   c) A short straight length of steel wire that has been stroked from end to end with a magnet, and a short straight length of copper wire carrying a current, each produce a magnetic field. Describe how these fields *differ*.
   d) How could the copper wire be made to produce a field more like the field produced by the steel wire?

2. Sketch the magnetic field distribution for each of the following arrangements, indicating any null points:
   a) bar magnet,
   b) two bar magnets in line, with opposite poles facing each other and separated by 50 mm,
   c) two bar magnets in line, with similar poles facing each other and separated by 50 mm,
   d) two bar magnets placed parallel to each other, about 50 mm apart, and with opposite poles adjacent,
   e) two bar magnets in line, separated by 80 mm, with opposite poles facing and with a small iron washer placed midway between them.

3. Draw the magnetic field pattern for each of the following:
   a) a single straight current-carrying copper wire, and
   b) a current-carrying circular coil of wire.

4. An electron, travelling at a constant speed, enters a region of uniform magnetic field. Describe the subsequent motion of the electron if the field direction is:
   a) parallel to the electron's direction of motion;
   b) perpendicular to the electron's direction of motion.

5. Particles A, B and C follow the paths shown in the diagram as they pass through a magnetic field. What conclusions can you draw about the charges on particles A, B and C?



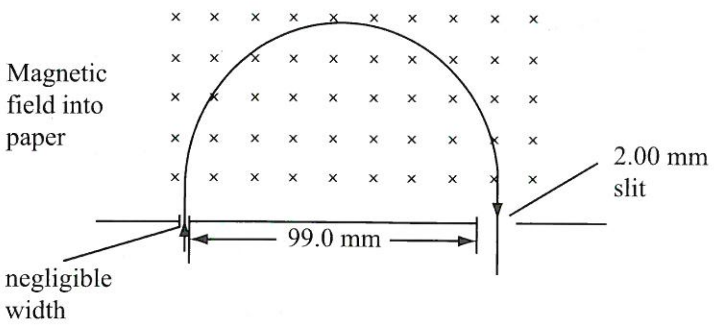
6. A proton of mass m is emitted from the Sun and enters the Earth's magnetic field with a velocity v. Assume that this magnetic field has a magnitude of B, is uniform and at right angles to the direction of travel of the proton.
   a) Using the variables listed above, write an expression for the force F experienced by the proton.
   b) Hence deduce the subsequent path of the proton. Use a labelled diagram and explain clearly why the path has its particular shape.
   c) This path is a repeated one. Derive an expression for the rate at which it is repeated (that is, derive an expression for the frequency).
   d) If you could measure this frequency, what information (if any) would it give you about the speed of the proton and the strength of the Earth's magnetic field?

Problem Solving and Calculations 14

Set 14: Charged Particles in Magnetic Fields

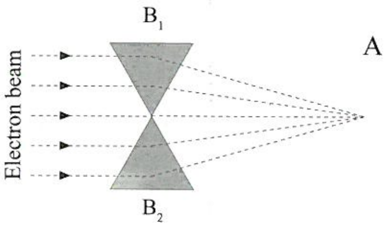
7. A beam of particles, each with a charge of $+1.60 \times 10^{-19}$ C and a velocity of 5.00×10^{6} m s^{-1}, is directed through a narrow aperture into a uniform magnetic field of strength 10.0 T as shown at right.
   The particles move in a semi-circular path and leave the magnetic field through a slit of width 2.00 mm as shown.

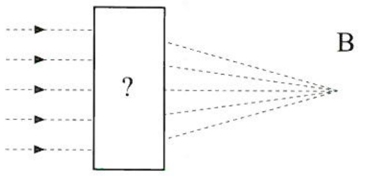
   Find the range of masses of particles in the beam that could pass through this slit.



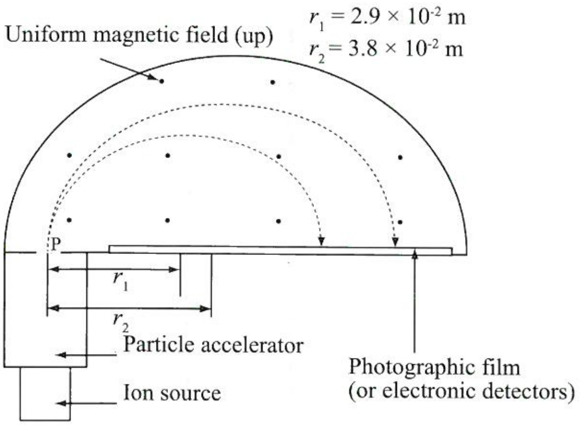
8. A proton moving at 1.00×10^{4} m s^{-1} in a uniform magnetic field of 2.50 μT travels at right angles to the field, and remains in the field.
   a) Determine the radius of the proton's path in this field.
   b) In this field, how long does the proton take to complete one revolution?
   c) Explain how the time for one revolution might change if the magnetic field strengthis increased.
   d) Explain how the time for one revolution might change if the proton's initial velocity is greater.

9. An electron microscope uses a "magnetic lens" to focus a wide beam of electrons to a point, as shown in diagram A. In this case, all the electrons have the same speed.
   a) What would be the directions of magnetic fields B_1 and B_2?
   b) The electron velocity is 1.5×10^{6} m s^{-1} and the magnetic lens has field strength 0.10 T. Calculate the deflecting force.
   c) The triangular shape of the magnetic field deviates the outer electrons more than the inner electrons. Explain.
   d) If the magnetic field was not triangular but had the shape shown in diagram B, how could you achieve different amounts of deviation?





10. A mass spectrometer allows researchers to determine the charge to mass ratio $\frac{q}{m}$ of the various components of a mixture of isotopes or fragments of a molecule.
    a) Derive an expression relating $\frac{q}{m}$ to the radius, velocity and magnetic field strength.
    b) A mixture of helium isotopes produces lines as shown at right. If their velocity on entering at P is 2.20×10^{5} m s^{-1} and the field strength is 0.120 T, find the charge to mass ratio of these isotopes.
    c) Two helium isotopes are ${}^{4}_{2}\mathrm{He}^{2+}$ and ${}^{3}_{2}\mathrm{He}^{2+}$. Could these isotopes produce the lines shown? Explain.
    d) In a similar experiment a sample of oxygen forms +1 ions that enter the mass spectrometer at 4.5×10^{4} m s^{-1}. The magnetic field strength is unchanged. The technician identifies three particles at radii 62.0 mm, 66.4 mm, and 70.1 mm. Identify the three isotopes of oxygen in her sample.



Investigation 14.2: The Earth's magnetic field

Notes

The Earth's magnetic field is usually shown as roughly the same shape as the field around a bar magnet, with the poles of the bar magnet near the Earth's north and south poles. What is the shape of the Earth's magnetic field on a smaller scale – for example, inside your Physics laboratory?

Discuss and plan how you will determine the direction of the Earth's magnetic field at various locations in the laboratory. If you have access to instruments that can measure the strength of a weak magnetic field such as that of the Earth, you should determine both the direction and the strength of the field at a range of locations. You should also plan how you will record and map this information.

Be sure to explain both regularities and anomalies in your mapped field, and relate your findings to the 'bar magnet inside the Earth' model described above.

Chapter 15: Charged Particles in Combined Electric and Magnetic Fields Explained

Notes

Remember the following important principles
A charged particle experiences a force when it is affected by:

- an electric field. The field acts on the particle's charge, whether the particle is moving through the field, or is stationary. The force equation is $F = Eq$.
- a magnetic field that is at an angle to the direction in which the particle is moving. When the field is at right angle to the direction of the particle's velocity, the force equation is $F = vqB$.
- Its mass is affected by a gravitational field. This happens whether the particle is moving through the field, or is stationary. The force equation is $F = mg$.

We can ignore the gravitational force in most problems, because its effect is weak in comparison to the electric and magnetic forces.

An electric and a magnetic field can exist in the same space. Each can deflect a particle passing through. If the electric and magnetic fields are correctly oriented, a charged particle may pass through them undeflected. This only happens at a particular velocity, and an arrangement of "crossed fields" is sometimes called a *velocity filter*.

Experiment 15.1: The Cathode Ray Oscilloscope

Notes

Background

The cathode ray oscilloscope (CRO) is a laboratory measuring device used to measure and display voltage waveforms. A heart monitor is a form of CRO used to monitor the electrical activity of the heart.

The purpose of this activity is to familiarise you with the controls of a CRO so that you can use it to measure voltages and display wave forms.

Apparatus

- Cathode ray oscilloscope
- AC/DC power supply 0 –12 V
- Appropriate leads and coaxial cables
- Lemon
- Copper
- Aluminium and zinc electrodes
- 1.5 V dry cell

Pre-lab

- Not all CROs are the same. Locate the following switches and dials on the CRO you are using.
- *volts/cm switch*: used to obtain trace of convenient height and also for voltage measurement
- input earth
- *Intensity and ON-OFF switch*: turns the instrument on and varies the brightness of the trace on the screen.
- *Focus:* used to control the sharpness of the trace.
- *Time base switch or Time/cm*: The various switch positions give the fastest sweep speed on each range. The control situated in the centre of this switch can be used to vary the sweep speed. Leave this control in the CAL or calibrated position-this is usually fully clockwise.
- *Horizontal position or X-shift*: moves the trace on the screen to the left or to the right.
- *Vertical position or Y-shift*: moves the trace up and down.
- *Sensitivity or volt/cm switch*: adjusts the sensitivity of the instrument.
- *AC-DC switch*
- *Input terminal or socket*
- *Internal-external or Int-Ext switch*: use in the internal position.
- *Triggering or stability control*: use in the auto position.

Lab notes

Before turning on:

- Set horizontal position or X-shift, vertical position or Y-shift and focus to a central position
- Set internal-external to internal
- Set triggering or stability to auto
- Set time base to 10 ms with centre control to cal or calibrated
- Set voltage sensitivity or V/cm to 0.5

Experiment 15.1: The Cathode Ray Oscilloscope

Turning on

- Turn on the power and allow to warm up for a minute or two
- Turn intensity control to maximum (clockwise) till trace appears. If trace does not appear adjust Y-control
- Centre the trace on the screen using the horizontal (X-shift) and vertical (Y-shift) position controls
- Set focus control for a sharp trace

Measuring the battery voltage

- Turn AC-DC switch to DC. Check that the trace is still centred and adjust if necessary
- Connect the 1.5 V dry cell to the input terminals. Record the effect and calculate the cell voltage, using:
  cell voltage = (volts cm^{-1} setting on dial) × (number of cm the trace moved)
- Reverse the battery leads and record the effect.

Measuring the lemon cell voltages

- Insert the aluminium, zinc and copper electrodes into the lemon.
- Measure and record the voltage between the various combinations of electrode pairs: $A\ell$/Zn, $A\ell$/Cu and Zn/Cu.
- Which combination gives the highest voltage?

Displaying waveforms

- With the power pack off, connect the AC terminals of the power pack to the CRO input terminals.
- Set the AC-DC switch on the CRO to AC. Ensure the trace is centred.
- Set the power pack voltage to 2 V and turn on.
- Record the shape of the trace and determine the maximum and minimum voltages of the waveform.
- Measure the period T of the wave using T = time/cm setting x number of cm between adjacent peaks
- Calculate the frequency f of the waveform

Notes

Post-lab discussion

1. Why does the CRO need a minute or two to warm up? Which part of the tube actually "warms-up"?
2. How does the horizontal position (X-shift) control move the trace to the left and right?
3. How does the vertical position (Y-shift) control move the trace up and down?
4. Incandescent lamps work equally well on AC and DC. Given a solar cell and a CRO how could you determine if a lit lamp was operating on AC or DC? The leads to the lamp are, of course, not accessible.

Problem Solving and Calculations
Set 15: Charged Particles in Electric and Magnetic Fields

Notes

1. Moving charges may be deflected by electric or by magnetic fields. Describe the subsequent motion of a proton that enters
   a) a uniform electric field parallel to the field lines
   b) a uniform magnetic field parallel to the field lines
   c) a uniform electric field at right angles to the field lines
   d) a uniform magnetic field at right angles to the field lines

2. An electron is fired vertically downwards between two vertical, parallel, charged metal plates. The West plate has a positive potential with respect to the East plate. To exactly balance the effect of the electric field, what must be the direction of a magnetic field in this region?

3. A region of space contains a magnetic field of intensity 24.5 millitesla. A proton travelling at 4.50×10^6 m s^{-1} enters this field at right angles.
   a) Calculate the strength of an electric field in the same region of space that would allow the proton to pass through undeflected.
   b) Would an electron, travelling at the same speed and also entering the region at right angles to the two fields, pass through undeflected? Explain.

4. A narrow electron beam enters a region at a speed of 6.00×10^6 m s^{-1} and is suddenly influenced by a magnetic field.
   a) Describe and explain the effect on the electrons in the beam if the field is perpendicular to the beam.
   b) Describe and explain the effect on the electrons in the beam if the field is parallel to the beam.
   c) The electron beam leaves the magnetic field and enters a region in which there exists an electric field of strength 1.00×10^3 V m^{-1}. Calculate the path of the electrons in the beam if the field is in the same direction as the beam.

5. An electron, initially at rest, is accelerated through a potential difference of 15.0 kV. It is then allowed to circulate at right angles to a uniform magnetic field of strength 2.35 T.
   a) Calculate the electron's final speed before entering the magnetic field.
   b) Determine the electron's path radius in the magnetic field.
   c) Assuming a completely circular path, calculate the electron's time of rotation.

6. A proton moves in a circular path of radius 50.0 mm at right angles to a uniform magnetic field of strength 1.50 T.
   a) Calculate the velocity required for the proton to maintain a circular orbit while in the field.
   b) Determine the frequency and period of the proton's rotation.
   c) Calculate the potential difference through which the proton was accelerated in order to have this speed.

Problem Solving and Calculations

Set 15: Charged Particles in Electric and Magnetic Fields

15

Notes

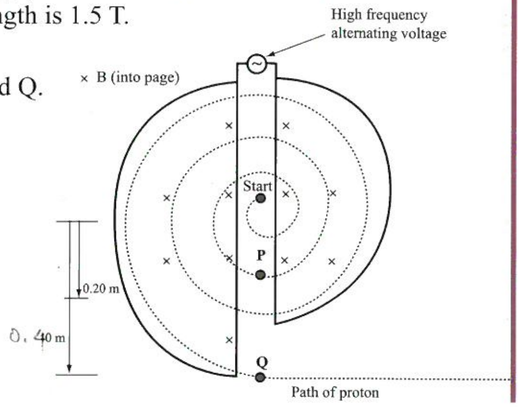
7. An electron beam in a cathode ray oscilloscope can be deflected by either an electric field or a magnetic field.
   a) Compare these two methods with regard to
      (i) the direction of the deflection produced;
      (ii) the effect of the speed of the electrons on this deflecting force;
   b) Show in a diagram how an electric field and a magnetic field can be arranged so that together they produce no resultant force on an electron passing through them.
   c) Such a cancellation of forces can occur for only one particular electron velocity. Calculate the value of this velocity if the electric field has a strength of 1.00×10^4 V m^{-1} and the magnetic field strength is 0.100 tesla.

8. A proton is accelerated from rest through a potential difference of 20.0 kV. The proton then enters, at right angles, a uniform magnetic field of 0.200 T.
   a) Determine the magnitude and direction of the acceleration of the proton in the magnetic field.
   b) Explain why the resulting path of the proton is circular.
   c) What is the strength of the electric field required to be superimposed on the magnetic field in order to allow the proton to proceed in a straight line?

9. An electron travelling at 1.60×10^4 m s^{-1} enters a region where there exists a uniform magnetic field of 3.00×10^{-2} tesla, at right angles to the electron's path.
   a) Calculate the radius of curvature of the electron's path.

   The electron now enters a region where the magnetic force exerted on it is balanced by an electric field.
   b) Calculate the magnitude of the electric field strength required.
   c) Show in a labelled diagram the vectors representing the motion of the electron, the magnetic field and the electric field.
   d) A second electron having a velocity greater than 1.60×10^4 m s^{-1} enters the same region. Using labelled diagrams, show the paths of both electrons through the region, indicating the directions of both the magnetic and the electric fields.

10. A cyclotron accelerates small charged particles in a circular path to very high speeds, then releases the particles to strike a target and make radioisotopes. The cyclotron shown accelerates protons that start at its centre. These travel in circles because of two magnetic fields called dees. An alternating electric field in the gap between the dees accelerates the protons to higher velocities. The magnetic field strength is 1.5 T.
    a) Why does the proton's path radius increase?
    b) Calculate the proton velocities at positions P and Q.



Investigation 15.2: Particle accelerators

Notes

Particle accelerators used in research laboratories include the van de Graaff generator, the cyclotron, the synchrotron, the linear accelerator and the colliding beam accelerator.

A related device, the mass spectrometer, is routinely used in laboratories around the world.

The cathode ray oscilloscope (CRO) is also a widely used laboratory tool in which fields are used to accelerate and direct particles.

The X-ray tube accelerates particles as a part of the X-ray production process.

Select any one of these devices, research its development and application, and write a report that highlights the purpose, use of fields in, and the limitations of the device. Your report should include relevant mathematical treatments of the information. Remember that this is a Physics report and ensure that the physics ideas are given appropriate importance.

Make sure that you give credit to any sources that you use, for example by indicating direct quotations and by listing the title, author and related details in your reference list.

Measurement and Uncertainties

The *maximum* uncertainty of a measurement is usually ± 1 scale division. Thus, on a ruler that measures to 1 mm, a reading of 14.5 cm would be shown as **14.5 ± 0.1 cm**. On a *digital* instrument (stopwatch, balance) this is the best you'll get.

On an *analogue* instrument (ruler, thermometer, measuring cylinder) a skilled user may be able to estimate to less than this. For example, a thermometer having a fairly big spacing between the degree markings might be readable to ± 0.2 degree, if you were good at using it, or to ± 0.5 degree if you are not so skilled.

Other factors such as the reliability of the instrument itself are also important.

Example:

- Use a ruler to measure this page to ± 0.1 cm.
- Now measure it to the best (most accurate) value that you can, and show your result accordingly.
- How can we show which of these measurements has the lesser uncertainty (i.e. is 'more accurate')?

Adding or subtracting uncertainties:

If you *add* two measurements, you also add their uncertainties. Thus,

4.5 ± 0.1 cm + 5.5 ± 0.1 cm = **10.0 ± 0.2 cm**.

(Note that a simple rule about significant figures does not apply here; 2 SF + 2 SF but the answer is to 3 SF. *Significant figures give a general idea of uncertainties* instead of the more thorough treatment of uncertainties shown here.)

If you subtract measurements, you also add the uncertainties. Thus,

5.5 ± 0.1 cm - 4.5 ± 0.1 cm = **1.0 ± 0.2 cm**.

If you *multiply or divide* measurements, you convert to % uncertainty, then add these.

Example:

1. A toy car travelled 6.25 ± 0.05 metres in 22.51 ± 0.01 seconds. The speed is distance divided by time. So, we convert to % uncertainty:

$$\frac{\pm 0.05}{6.25} \times 100 = \pm 0.8\%$$

so we can now write the distance as 6.25 cm ± 0.8% .

The % uncertainty in the time is:

$$\frac{\pm 0.01}{22.51} \times 100 = \pm 0.04\%$$

So we can now write the time as **22.51 s ± 0.04%**.

Then when we calculate the average speed of the car, we can show an estimate of the uncertainty of the speed in the answer.

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{6.25\ \text{m}}{22.51\ \text{s}} = 0.27765\ldots\text{m s}^{-1}$$

$$\text{uncertainty} = 0.8 + 0.04 = \pm 0.84\%$$

$$0.84\% \text{ of } 0.27765 \ldots = 0.002$$

$$\text{thus the speed is } 0.278 \pm 0.002 \text{ m s}^{-1}$$

Note that a significant figure 'rule of thumb' works in this case. But note also that for actual measurements, showing the uncertainty estimate is much better than just blindly following a rule.

Exercise: Use your measurements of this page (above) to calculate its area, and show the result with an estimate of the uncertainty.

Minimising uncertainties by making repeat measurements:

You can reduce the uncertainty in a measurement by making lots of measurements of the same thing, each independent of the others, then finding the mean value and the standard deviation of the distribution. The uncertainty in this case is ± the standard deviation. Another name for standard deviation is 'standard error of the mean'.

For example, a group of students measuring "g" got the following:

Run	1	2	3	4	5	6	7	8	9	10
Value (m s^{-2})	9.36	9.67	9.64	9.41	9.88	10.21	9.55	9.74	9.96	9.92

Calculate the mean and the standard deviation of these values, and hence quote "g" with an estimate of the experimental uncertainty.

Using a spreadsheet to calculate the mean and standard deviation, we get:

Mean = 9.734

St dev = 0.250

We would quote the mean value to be:

9.7 ± 0.2 m s^{-2}, or 9.7 ± 0.3 m s^{-2}; note that either way, the "expected" value of 9.8 m s^{-2} falls within the experimental uncertainty.

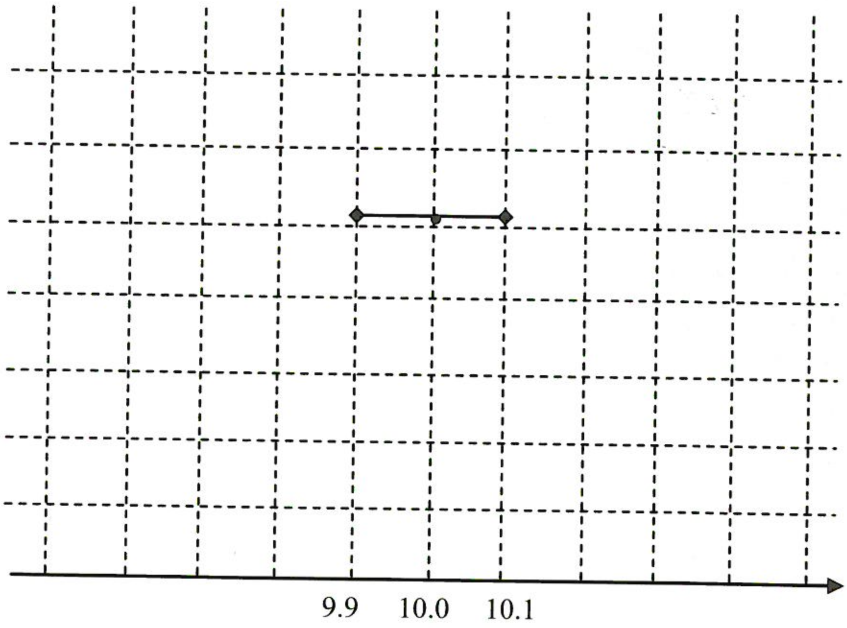
The more values you include, the more likely it is that your mean is close to the expected or actual value.

Why does this reduce the experimental uncertainty? Try using any two or three consecutive values in this table to calculate an average value for "g" and then compare it with the expected value. Note that the standard deviation is a feature of large samples and is not a valid measure for small samples, eg two or three.

Showing uncertainties on a graph:

You can graphically represent uncertainty in a measurement by plotting the value, and then adding 'error bars' that extend along the axis to show the ± values.

For example you would graph a value of 10.0 ± 0.1 m s^{-1} as a dot at 10.0, with a bar extending 0.1 unit in the positive direction (to show that the value could be as high as 10.1) and a bar extending in the negative direction (to show that the value could be as low as 9.9).



When drawing a line of best fit, it is worth keeping in mind that the central dot is not the measurement – anywhere along the bars could be correct. That is what an uncertainty means. A line of best fit should reflect your understanding of the physics of the situation.

Motion & Forces in a Gravitational Field

Set 1	2 a)	18 m N 56° E
	2 b)	22 m N 63° W
	3	294 N
	4	3.8 m s^{-1} at 23° to rip
	5 a)	42°
	5 b)	3.4 m s^{-1} at 53° to the bank
	5 c)	30 m
	6 a)	9.2 km
	6 b)	N 41° W
	7	5.5 m s^{-1} away from the player
	8	47 m s^{-1} toward the opponent
	9	32 m s^{-1} at 51° to the final velocity
	10	212 N in the forward direction
	11	42 m s^{-1} at 45° to both initial and final velocities
	12 a)	Position 1: 427 N toward the Earth
	12 b)	Position 2: 359 N at 2.10° to the line joining the Earth and the asteroid
	13	43 m s^{-1}
	14	1.78 m s^{-1} N 38.2° E
	15 a)	1.17×10^3 N
	15 b)	125 N
	16	14 m s^{-1}, 20 m s^{-1}
	17	4.14 m s^{-2} down the slope
	18	2.5 s
	19	177 N perpendicular to, and toward, the path of the boat
	20 a)	3.5 s
	20 b)	30 m
	21 b)	32.6°
	22	716 N at 2.7° to the left of the boat's path
Set 2	6	5 points
	7	3.48 m
	9	1.04 s
	10	1.16 m
	11 a)	2.1 s
	11 b)	31 m
	12	78.8 m
	13	0.81 m
	14	285 m
	15 a)	vertical = 9.0 m s^{-1} upward; horizontal = 9.1 m s^{-1}
	15 b)	6.5 m
	15 c)	18.9 m
	16 a)	vertical = 29.0 m s^{-1}; horizontal = 7.76 m s^{-1} Is this the other way round?
	16 b)	No
	16 c)	29.0 m s^{-1} to the right
	16 d)	Assuming she hits the ramp with her foot already fully down, then at point A; Ignoring air resistance, the speed at point A should equal the speed at point E
	16 e)	27.3 m s^{-1}
	17 c)	Yes, by 9.2 m
	18	35.6 m
	19	8.10 m s^{-1}
	20 a)	no
	20 b)	yes

Set 3	5	0.82 m s^{-2} toward the centre of the circle
	6	61.9 N
	7 a)	1.54 m s^{-2}
	7 b)	17.5 N
	8	17.6°
	9 a)	691 N
	9 b)	3.55 s
	10 a)	yes
	10 b)	3.09 kN
	10 c)	15.3°
	11	15.8 m s^{-1}
	12 a)	37.8 m s^{-1}
	12 b)	1.90 x 10^{4} m s^{-2}
	12 c)	17.7 kHz
	13 b)	2.59×10^{-16} N
	13 d)	5.53×10^{8} m
	13 e)	it would drop 30.6 m
	16 a)	88.5 m s^{-1}
	b)	198 m s^{-1}
	17	87.4 m s^{-1}
	18 a)	180 N upward (b) 20.4 N downward
	19 a)	20 m
	20 b)	4.32 m s^{-1}
	c)	2.00×10^{3} N
	21 b)	5.94 m s^{-1}
	c)	at top, 0; at bottom, 1176 N upward
	d)	at top, 441 N upward; at bottom, 735 N upward
	22 a)	at A: 8.30 m s^{-1}; at B: 12.1 m s^{-1}
	b)	at A: 61.6 N; at B: 208 N
Set 4	6	6×10^{24} kg
	7	1.72×10^{-6} N
	8 a)	2.64×10^{6} m
	8 b)	8.16 m s^{-2} toward the Earth
	8 c)	7.55×10^{3} m s^{-1}
	9	3.80×10^{8} m
	11 b)	2.38×10^{20} N toward the Sun
	18	5.74×10^{3} s (1.59 hours)
	19 a)	1.37×10^{4} m s^{-1}
	19 b)	1.90×10^{27} kg
	20	5.97×10^{24} kg
	21	3.59×10^{7} m
	22	3.05 × (radius of Moon's orbit around Earth)
	23 a)	2.07×10^{22} N; 9.20×10^{21} N
	23 b)	5.37×10^{4} m s^{-1}; 4.39×10^{4} m s^{-1}
Set 5	2	120 N m
	3	220 N
	6 b)	18 kg
	8 a)	94 N
	8 b)	447 N
	9	46 kg
	10 a)	630 N
	10 b)	0.75 m toward Q
	11	1.5 m from the front wheels
	12 a)	18 kN
	12 b)	0.375 × length of log from the heavier end

14 a)	383 mm from the balcony
15	1.86×10^5 N; 1.95×10^5 N
20	7.76 kg; 2.57 m from the T_1 end.
21	60 cm
23 a)	137 N
b)	lower hinge 172 N toward the door at 36.9° above the horizontal upper hinge 172 N toward the wall at 36.9° above the horizontal
24 a)	1.95×10^3 N
b)	vertical = 109 N upward, horizontal = 1.83×10^3 N out from wall
c)	1.84×10^3 N out from wall at 3.40° above the horizontal
25	tension = 1.09×10^3 N; force at hinge = 551 N out from the wall and 10.1° below the horizontal
26	2.07 m from P
27 a)	156 N
b)	vertical component = 147 N, horizontal component = 156 N
c)	214 N to right and 43.3° below the horizontal
28 a)	2.39×10^5 N
b)	2.97×10^5 N
29 a)	18.4 kg
b)	144 N at 26.9° above the horizontal

Electricity and Magnetism

Set 6	5	0.042 N m
	10	2.4 N
	12	0.075 N downward
Set 7	1	0.57 V
	2 a)	2.3 A
	5 a)	0.21 mV
	5 b)	2.1×10^{-4} Wb s^{-1}
	7	7.1 mV
	8 a)	39 mV
	8 d)	7.9 mA
	9 a)	8.0×10^{-4} V
	11	225 turns
	12 a)	2.5 m s^{-1}
	12 b)	1.0×10^{-4} N
	13 a)	83 mT
Set 8	1 a)	60 kW
	1 b)	300 J
	1 c)	150 Ω
	2 a)	14.6 m^2
	2 b)	1.25 Ω
	3 a)	83 A
	3 b)	18 Ω
	6 a)	0.0200 times
	6 b)	10 000 turns
	6 c)	0.0196 times
	7 a)	23 Ω
	7 b)	1.3×10^3 C
	8 a)	100 A
	10 a)	31.3 kW
	10 b)	0.31 kW
	12 a)	2.00 kW
	12 b)	0.125 m
	13 a)	6.25 kW
	15	35 km

Particles, Waves and Quanta

Set 9	1	5 °C
	2	420 m
	3	82 m
	4 a)	50 mm
	4 b)	0.4 m s^{-1}
	4 c)	8.4 Hz
	5 a)	0.5 Hz
	5 b)	2 s
	6 a)	10 mm
	6 b)	8 ?s
	6 c)	125 kHz
	9 a)	1.3 m
	9 b)	17 mm
	9 c)	4.9 mm
	9 d)	3.4 km
	13 b)	too short
	13 c)	0.29 s
	14 a)	George
	14 b)	Jane
	14 c)	George
Set 10	3 c)	34 Hz to 17 kHz
	5 a)	1.9 mm in air; 8.1 mm in water
	6	72.8 m
	7 a)	100
	7 b)	0.8°
	7 c)	10 scans
	12	708 Hz
	13 a)	512 m s^{-1}
	13 c)	84 Hz, 168 Hz, 262 Hz
	18 a)	0.64 m
	18 b)	328 m s^{-1}
	18 c)	closed
	19 a)	violin
	19 b)	double bass
Set 11	1 a)	3.0 GHz
	1 b)	10cm
	2	red: 4.41×10^{14} Hz; 2.92×10^{-19} J
		orange: 5.17×10^{14} Hz; 3.43×10^{-19} J
		green: 6.00×10^{14} Hz; $3.98 \text{ x } 10^{-19}$ J
	3	0.001:1; 1000:1
	4 a)	red
	4 b)	2.87×10^{-19} J per photon
	4 c)	1.00×10^{5} W m^{-2}
	4 d)	100:1
	5	7.5×10^{25} photons per second
	6	5.1×10^{10} photons per second
	7 a)	420 m
	7 b)	$4.3 \text{ x } 10^{9}$ J
Set 12	3	$E_1 = -13.6$ eV
		$E_2 = -3.4$ eV
		$E_3 = -1.5$ eV
		$E_4 = -0.85$ eV
		$E_5 = -0.54$ eV

	4 a)	(i) 2.4×10^{15} Hz; UV (ii) 6.14×10^{14} Hz; visible (iii) 4.56×10^{14} Hz; visible (iv) 2.32×10^{14} Hz; IR
	4 b)	4.58×10^{-19} J; E_5 to E_2
	5 a)	45 keV
	5 c)	30 keV; 40 keV
	5 e)	2.0×10^{-16} J
	7 a)	5.13 eV
	7 b)	2.11 eV; E_2 to E_1
	7 c)	0.002 eV
	11 a)	60 keV (9.6×10^{-15} J)
	11 b)	1.45×10^{8} m s^{-1}
	11 c)	2.07×10^{-11} m
	12	12.4 kV
	13	3.71×10^{-11} m
	14 b)	4.14×10^{-11} m; 7.24×10^{18} Hz

Motion and Forces in Electric and Magnetic Fields

Set 13	1	4.5×10^{6} N C^{-1}
	3 b)	2.94×10^{7} m s^{-1}, deflected by 8.9°
	3 e)	2.9×10^{-16} J
	3 f)	6.0×10^{4} V m^{-1}
	5 a)	3.3×10^{-7} J
	5 b)	66 V
	6	100 V m^{-1}
	7 a)	5.00 keV
	7 b)	8.00×10^{-16} J
	8 a)	10.0 keV
	8 b)	1.6×10^{-15} J
	9 a)	5.6×10^{7} V m^{-1}
	9 b)	2.4×10^{-15} J
	10 b)	3.6×10^{-5} N
	10 c)	10 mm; 0.090 V
	13	3.91×10^{5} m s^{-1}
	14 b)	2500 eV (4.00×10^{-16} J)
	14 c)	2.96×10^{7} m s^{-1}
	14 e)	same
	14 f)	less
	15 a)	4000 eV; 3.75×10^{7} m s^{-1}
	15 b)	2000 V m^{-1}; 3.20×10^{-16} N
	16 b)	7.02×10^{15} m s^{-2}
Set 14	7	1.58×10^{-26} kg to 1.62×10^{-26} kg
	8 a)	41.8 m
	8 b)	6.28×10^{-3} s
	9 b)	2.4×10^{-14} N
	10 b)	6.3×10^{7} C kg^{-1}; 4.8×10^{7} C kg^{-1}
Set 15	3 a)	1.10×10^{5} V m^{-1}
	3 b)	Yes
	4 c)	They accelerate in a straight line at 1.76×10^{14} m s^{-2}
	5 a)	7.26×10^{7} m s^{-1}
	5 b)	1.76×10^{-4} m
	5 c)	1.52×10^{-11} s

6 a)	7.19×10^{6} m s^{-1}
6 b)	2.29×10^{7} Hz; 4.38×10^{-8} s
6 c)	270 kV
7 c)	1.00×10^{5} m s^{-1}
8 a)	3.75×10^{13} m s^{-2} at right angles to the field
8 c)	3.92×10^{5} N C^{-1}
9 a)	3.04×10^{-6} m
9 b)	480 N C^{-1}
10 b)	2.87×10^{7} m s^{-1}; 5.75×10^{7} m s^{-1}

Formulae & Constants

Motion and Forces in gravitational fields	
Mean velocity	$v_{av} = \frac{s}{t}$ $= \frac{v+u}{2}$
Equations of motion	$a = \frac{v-u}{t}$; $s = ut + \frac{1}{2}at^2$; $v^2 = u^2 + 2as$; $v = u + at$
Force	$F = ma$
Weight force	$F = mg$
Momentum	$p = mv$
Change in momentum (impulse)	$Ft = mv - mu$
Kinetic energy	$E_k = \frac{1}{2}mv^2$
Gravitational potential energy	$E_p = mgh$

Motion and Forces in gravitational fields	
Work done	$W = Fs$ $= \Delta E$
Power	$P = \frac{W}{t}$ $= \frac{\Delta E}{t}$ $= Fv_{av}$
Centripetal acceleration	$a_c = \frac{v^2}{r}$
Centripetal force	$F_c = ma_c$ $= \frac{mv^2}{r}$
Newton's Law of Universal Gravitation	$F = G\frac{m_1 m_2}{r^2}$
Gravitational field strength	$g = G\frac{M}{r^2}$
Moment of a force	$\tau = rF$

Note: the variable "t" refers to the "time taken" sometimes referred to as the "change in time" or Δt

Formulae & Constants

Electricity and magnetism	
Electric current	$I = \frac{q}{t}$
Electric field	$E = \frac{F}{q}$ $= \frac{V}{d}$
Work and energy	$W = Vq$ $= VIt$
Ohm's Law	$V = IR$
Resistances in series	$R_T = R_1 + R_2 + \ldots$
Resistances in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
Power	$P = VI$ $= I^2R$ $= \frac{V^2}{R}$
Magnetic flux	$\Phi = BA$
Electromagnetic induction	$\text{emf} = -N\frac{\Phi_2 - \Phi_1}{t}$, $\text{emf} = \ell vB$
Magnetic force	$F = I\ell B$ $F = qvB$
Ideal transformer turns ratio	$\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Particles and waves	
Energy of photon	$E = hf$
Energy transitions	$E_2 - E_1 = hf$
Wave period	$T = \frac{1}{f}$
Wave equation	$v_{\text{wave}} = f\lambda$
Internodal distance	$d = \frac{1}{2}\lambda$

Motion and Forces in electric and magnetic fields	
Electric field	$E = \frac{F}{q}$ $= \frac{V}{d}$
Magnetic force	$F = qvB$

Formulae & Constants

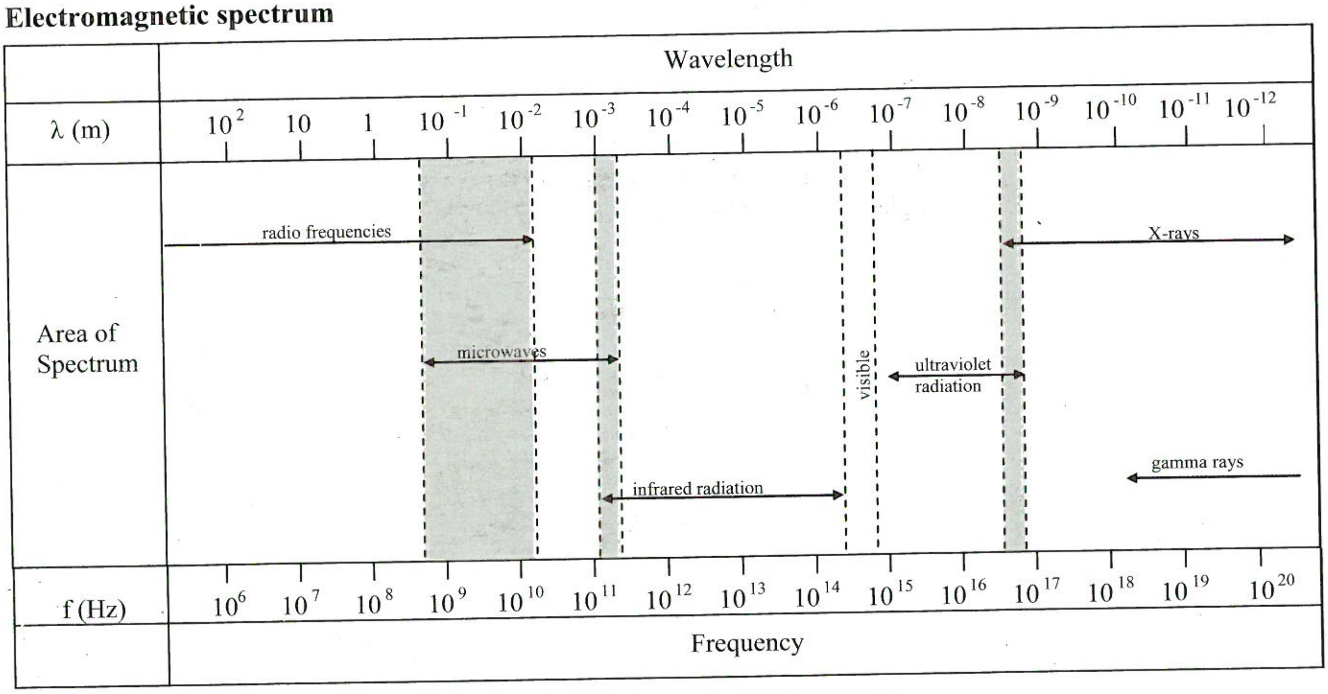
Physical Constants

Speed of light in vacuum or air	c	$= 3.00 \times 10^{8}$ m s^{-1}
Speed of sound in air at 25 °C	v	$= 346$ m s^{-1}
Electron charge	e	$= -1.60 \times 10^{-19}$ C
Mass of electron	m_e	$= 9.11 \times 10^{-31}$ kg
Mass of proton	m_p	$= 1.67 \times 10^{-27}$ kg
Mass of alpha	m_α	$= 6.65 \times 10^{-27}$ kg
Planck's constant	h	$= 6.63 \times 10^{-34}$ J s
Universal gravitational constant	G	$= 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
Electron volt	1 eV	$= 1.60 \times 10^{-19}$ J

Physical Data

Mean acceleration due to gravity on Earth	g	$= 9.80$ m s^{-2}
Mean acceleration due to gravity on the Moon	g_M	$= 1.62$ m s^{-2}
Mean radius of the Earth	R_E	$= 6.37 \times 10^{6}$ m
Mass of the Earth	M_E	$= 5.98 \times 10^{24}$ kg
Mean radius of the Sun	R_S	$= 6.96 \times 10^{8}$ m
Mass of the Sun	M_S	$= 1.99 \times 10^{30}$ kg
Mean radius of the Moon	R_M	$= 1.74 \times 10^{6}$ m
Mass of the Moon	M_M	$= 7.35 \times 10^{22}$ kg
Mean Earth-Moon distance	3.84×10^{8} m	
Mean Earth-Sun distance	1.50×10^{11} m	
Tonne	1 tonne $= 10^{3}$ kg $= 10^{6}$ g	

Electromagnetic spectrum



Note:
1. This graph is not intended to be used for accurate measurement.
2. Shaded areas represent regions of overlap.
3. Gamma rays and X-rays occupy a common region.

Mathematical Expressions

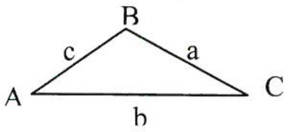
Prefixes of the Metric System

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	µ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p

Mathematical expressions

$$\text{Given } ax^2 + bx + c = 0, \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

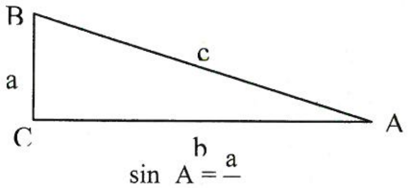
The following expressions apply to the triangle ABC as shown:



$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

$$a = \sqrt{b^2 + c^2 - 2bc\cos A}$$

The following expressions apply to the right-angled triangle ABC as shown:



$$\sin A = \frac{a}{c}$$

$$\cos A = \frac{b}{c}$$

$$\tan A = \frac{a}{b}$$