Year 12 Physics

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Contents

Chapter 1

Module 5 Advanced Mechanics

1.1 Practical Investigation 5.1

Aim: To confirm the dependence of the range of a projectile (the horizontal distance it travels) on its time of flight and launch velocity by predicting the landing point of a projectile and then testing the prediction.

1.1.1 Variables

Independent	Dependent	Controlled
Height of drop	Initial velocity	Angle of ramp
	Range	Distance of flat surface
		Acceleration due to gravity
		Type and size of ball

1.1.2 Materials

1. Ball
2. Inclined plane
3. Pen
4. Stopwatch
5. Ruler

1.1.3 Method

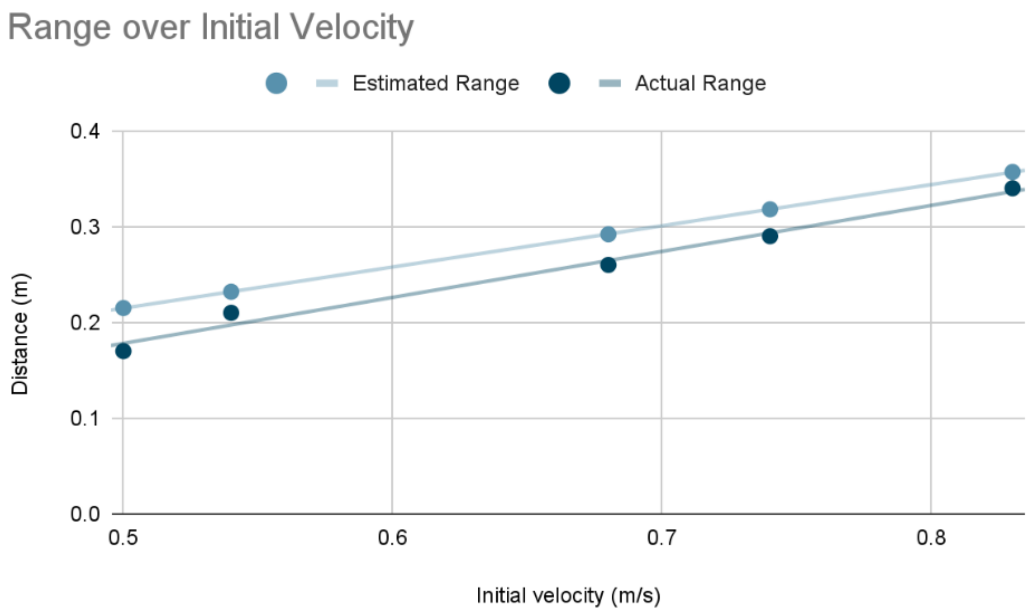
1. Prepare a ramp facing the edge of the table, 50 cm away.
2. Mark 5 cm intervals along ramp
3. Release ball at an interval
4. Record time taken to travel 50cm flat distance and distance from table after drop
5. Repeat steps 3-4 for each interval 3 times.
6. Calculate the initial velocity of the drop using $v = \frac{\Delta s}{\delta t}$

7. Calculate the time of flight using height of table ($height = \frac{1}{2} \times (-9.8)t^2$), hence estimate the horizontal range of the ball ($s_x = ut$)

8. Graph estimated range and actual range over velocity and compare.

1.1.4 Results

Distance released (cm)	Time taken to travel 0.5m (s)			Average time	Initial velocity (m/s)	Estimated range (cm) X = ut	Actual range (cm)
10	1.03	0.96	1.02	1.00	0.5	21.5	17
15	0.92	0.89	0.95	0.92	0.54	23.2	21
20	0.75	0.67	0.79	0.74	0.68	29.2	26
25	0.72	0.65	0.68	0.68	0.74	31.8	29
30	0.54	0.60	0.67	0.60	0.83	35.7	33.5



1.1.5 Data and Analysis

Part A

Distance across tabletop: 0.5m

1. **Is the velocity being calculated the velocity of the ball at the edge of the table? If not, is it a reasonable approximation? Explain your answer.**

   Although the calculated velocity is not completely accurate due to friction forces, it is a reasonable approximation when assuming friction is minimal.

2. **What effect would increasing the horizontal distance have on the reliability of your measurements?**

   Increasing the distance would make the experiment more reliable at the cost of accuracy.

Part B

Height above the ground: 0.90m

1. **Calculate the time it takes for the ball to fall from the table to the floor.**

$$
\begin{aligned}
s &= ut + \frac{1}{2}at^2 \\
0.9 &= (0)t + \frac{1}{2}(-9.8)t^2 \\
t^2 &= \frac{2 \times 0.9}{9.8} \\
t &= \sqrt{\frac{2 \times 0.9}{9.8}} \\
&= 0.43s
\end{aligned}
$$

2. **Calculate the distance the ball will travel in the horizontal direction, ie. the range**

$$
\begin{aligned}
s &= ut + \frac{1}{2}at^2 \\
&= u(0.43) + \frac{1}{2}(0)(0.43)^2 \\
&= 0.43u
\end{aligned}
$$

1.1.6 Discussion

Controlled variables were somewhat maintained to provide validity to the experiment, however numerous sources of error arose. Sources of error included:

- Ramp moving after ball was placed
- Irregular ball movements due to variations in placement and imperfections of ramp
- Inconsistency of measurement of horizontal range
- Timing of ball over flat distance

These errors were mitigated, however could not be avoided. The experiment was repeated three times for each interval to reduce the effect of outliers. More tests per interval could have been conducted to improve the reliability.

1.1.7 Conclusion

1. **State whether your prediction was successful, and describe any difficulties encountered in testing the prediction.**

   The prediction was successful, with a small but consistent variation from the expected value.

2. **In this experiment, the assumption was made that there is negligible effect from air resistance. Would the effect of air resistance be more significant if the ball was released from a height of 30 cm up the ramp or 15 cm? Explain.**

   If released from a higher point, the effect of air resistance would be more significant as there are more air particles applying friction forces to the ball. However, the effect of this resistance would still be minimal.

3. **What is the major source of error in this experiment? What steps were taken to minimise it?**

   The major source of error in this experiment is the human variation when timing with the stopwatch. This was mitigated by using slow motion cameras to more accurately measure the time taken for the ball to travel across the flat surface.

1.2 Practical Investigation 5.2 - The effect of launch angle on range

Aim: To investigate the relationship between the launch angle of a projectile, its motion and the range of the projectile.

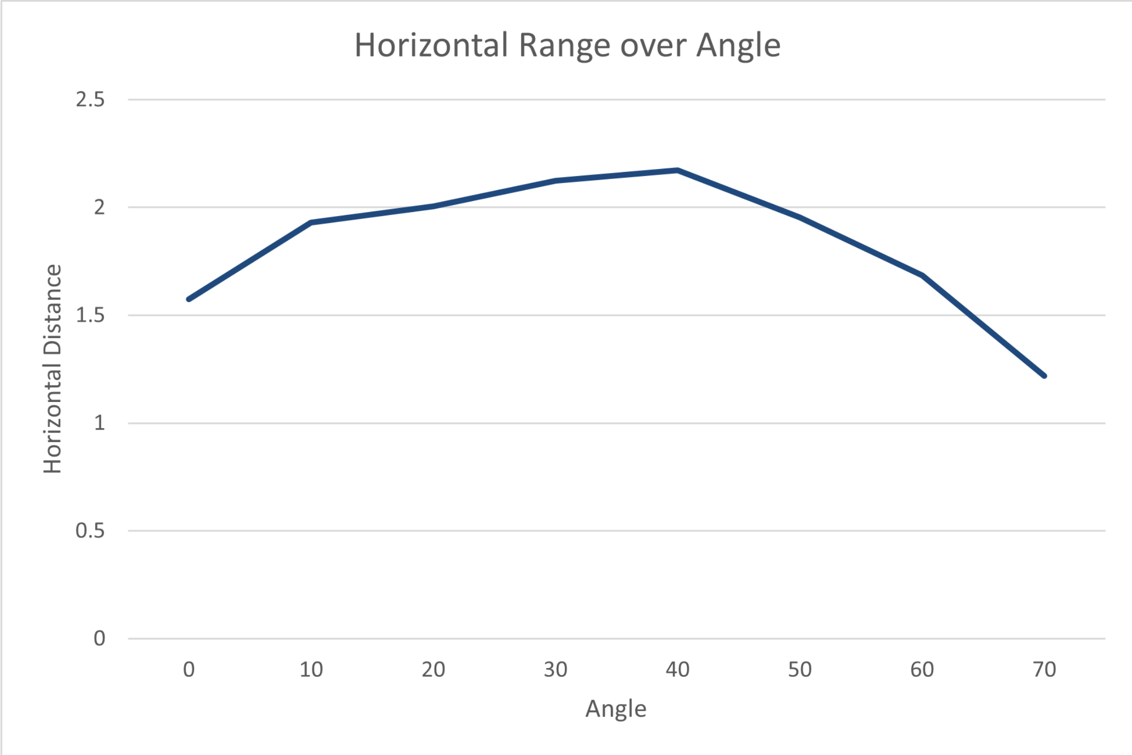
90cm vertical height

1.2.1 Method

1. Set the launcher in the horizontal position with a launch angle of 0°.
2. Load a projectile into the launcher and ensure that the launcher is set to its maximum compression or distance setting.
3. Launch the projectile, and note the point of impact on the paper.
4. Lay a sheet of carbon paper on top of the white paper over the point of impact, carbon side down, so that when a ball lands on it there will be a mark on the paper.
5. Place a sheet of paper where the ball hits. Highlight the point with a pencil or marker when the projectile lands.
6. State recording with the data collection system and launch the projectile
7. Use the angle indicator on the launcher the angle of inclination by 10°each time for data points between 10°and 80°.
8. Measure the horizontal velocity for each angle.

1.2.2 Results

Angle °	Time (s)				Horizontal Range (m)			
	Trial 1	T2	T3	**Avg**	Trial 1	2	3	**Avg**
0	0.46	0.41		**0.44**	1.50	1.65		**1.58**
10	0.46	0.61	0.59	**0.55**	1.94	2.00	1.85	**1.93**
20	0.61	0.65	0.58	**0.61**	2.03	1.98	2.00	**2.00**
30	0.83	0.71	0.83	**0.79**	2.07	2.12	2.19	**2.12**
40	0.79	0.70	0.78	**0.76**	2.22	2.16	2.14	**2.17**
50	0.85	0.83	0.93	**0.87**	1.99	1.85	2.03	**1.96**
60	0.96	0.85	0.88	**0.90**	1.708	1.76	1.59	**1.69**
70	0.85	0.83	0.86	**0.85**	1.14	1.21	1.31	**1.22**



1.2.3 Conclusion

1. **How did the measured horizontal velocities compare to the average horizontal velocities?**

   The measured horizontal velocities were similar to the average horizontal velocities.

2. **For any projectile launched horizontally, what can you state about the horizontal velocity?**

   The horizontal velocity will be constant throughout the time of flight

3. **Which launch angle will yield the maximum range?**

4. **Which launch angle will yield the maximum range?**

   40°

5. **Are there launch angles that yield the same range? What are they and why is that the case?**

   There are some launch angles that yield the same range. This is due to the parabolic shape of the range versus angle graph, meaning that there are two points on either side of the ideal (40°) that provide the same range.

1.3 Circular Motion

1.3.1 Uniform Circular Motion

Occurs when objects travel in a circle at a constant speed, taking the same length of time to make each revolution

The period T is the time taken to travel the full circle

The distance covered during the period depends upon the radius of the circle of travel and is equal to the circle's circumference, ie. $d = 2\pi r$

1.4 Practical Investigation 5.3 - Circular Motion - centripetal force in a horizontal plane

Aim: To investigate the relationship between the centripetal force acting on an object moving in a circle of constant radius and the frequency of revolution. Aim: To investigate the relationship between the centripetal force acting on an object moving in a circle of constant radius and the frequency of revolution.

1.4.1 Method

1. Securely tie one end of the fishing line to the small, soft mass
2. Pass the fishing line down through the thin plastic tube and attach a 50g slotted mass carrier to the end.
3. Attach an alligator clip to the line to act as a marker for a measured radius of around 1 m.
4. Spin the stopper in a horizontal circular path at a speed that pulls the paperclip up to, but not touching the bottom of the tube.
5. Measure time taken for 20 revolutions
6. Add 50g and repeat steps.

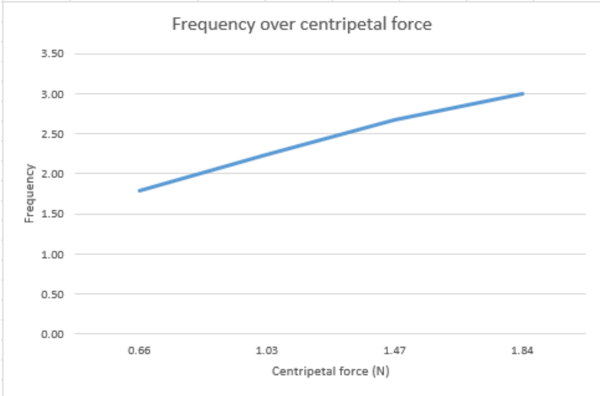
Mass (kg)	Time for 20 revolutions (s)				Period (s)	f=1/T	F_c (N)	F_G (N)	ω $^\circ s^{-1}$
	Trial 1	2	3	Avg					
0.05	10.34	10.78	12.34	11.15	0.558	1.79	0.6601	0.49	11.27
0.1	9.00	8.97	8.85	8.94	0.447	2.24	1.027	0.98	14.06
0.15	7.93	7.22	7.25	7.47	0.373	2.68	1.473	1.47	16.83
0.2	6.56	6.47	7.03	6.69	0.334	2.99	1.837	1.96	18.79

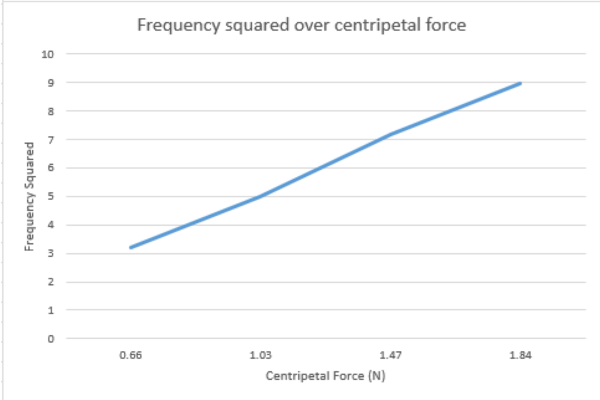
1.4.2 Data and Analysis

Measured radius of revolution: 0.5m

1. **What force is the mass carrier providing in this experiment**

   The mass carrier is exerting a gravitational force on the string





1.4.3 Conclusion

1. **Based on your results, what is the relationship between the centripetal force and the frequency of rotation? Do your results confirm what was expected from theory? Comment on any differences.**

   Based on the results, centripetal force has an square root graph relationship to frequency of rotation. This is expected, as $F_c = \frac{mv^2}{r}$, with velocity being squared.

2. **The radius of revolution will not actually be quite what was measured, nor will the tension in the string be exactly equal to the centripetal force. Why is this so?**

   Due to human inaccuracies, the radius of revolution will vary as the mass moves up and down. It is difficult to maintain a set tension, so this variation is expected. Because of this, the tension will also not be equal to the weight force applied by the mass.

3. **What effect does this have on your results**

   This will shift the results slightly away from the expected value, but each factor somewhat counteracts the other so this is minimised.

1.5 Types of Centripetal Force

Centripetal force is not a fundamental force, rather a label given to the net force that causes an object to move in a circular path. Centripetal force can occur due to: Centripetal force is not a fundamental force, rather a label given to the net force that causes an object to move in a circular path. Centripetal force can occur due to:

- Friction
- Banking (Reaction force at an angle)
- Tension

- Gravity
- Magnetic force
- Electrostatic force

1.5.1 Centripetal Force by Friction

Sideways (lateral) friction between the tyres and the road opposes the inertial outward (tangential) motion, acting inwards towards the centre of the curve.

As this sideways friction makes up the magnitude of the net force, it is the centripetal force that keeps the car moving around the curve.

$$F_{net} = F_f = \mu N$$

$$F_c = \mu N = \mu(-W) = \frac{mv^2}{r}$$

Sample Problem

A 1200 kg car approaches a tight corner on a wet day. If the corner has a radius of curvature of 10 m and the coefficient of friction of the tyres on the wet road is 0.4, what is the maximum speed at which the car can safely turn the corner?

$$m = 1200 \text{ kg},\ r = 10 \text{ m},\ \mu = 0.4,\ F_c = ?$$

$$\begin{aligned} W &= mg = (1200)(9.8) = 11800 \text{ N downwards} \\ R &= -W = -11800 \text{ N upwards} \end{aligned}$$

$$\begin{aligned} F_f &= \mu R \\ &= (0.4)(11800) \\ &= 4720 \text{ N inwards towards the centre of the corner} \end{aligned}$$

The centripetal force must not exceed the frictional force if the car is to corner safely, therefore:

$$\begin{aligned} F_f &\geq F_c \\ F_f &\geq \frac{mv^2}{r} \\ 4720 &\geq \frac{1200 \times v^2}{10} \\ v &\leq \sqrt{\frac{4720 \times 10}{1200}} \\ v &\leq 6.2ms^{-1} \end{aligned}$$

Therefore, the car can turn less than than 6.3 m/s (23 km/h)

1.5.2 Centripetal Force by Reaction Force

If the object undergoing centripetal motion is leaning at an angle, the normal reaction force needs to be dissected into vertical and horizontal components.

The perpendicular component ($R_\perp$) is equal and opposite to the weight force (W)

$$R_\perp = -W = 0$$

F_{net} is the parallel component of the normal reaction force

$$R_\parallel = R\sin\theta$$

1.5.3 Centripetal Force by Banking

The angling of a surface that an object is moving in a circular motion maximises the speed at which the object can move.

$$F_{net} = R\sin\theta + F_f\cos\theta$$

The net force acting horizontally towards the centre of the curve is the sum of the horizontal components of the normal reaction force R_R and the frictional force F_f.

1.5.4 Centripetal Force by Tension

$$\begin{aligned} F_{net} &= F_c \\ &= T + W \end{aligned}$$

Resolving the horizontal component:

$$\begin{aligned} \theta &= \arccos\frac{F_{net}}{T} \\ F_{net} &= T\cos\theta \end{aligned}$$

Resolving the vertical component:

$$\begin{aligned} \theta &= \arcsin\frac{W}{T} \\ W &= T\sin\theta \end{aligned}$$

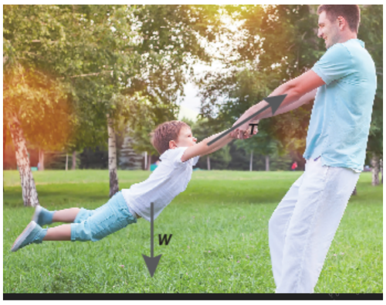
1.5.5 Conical Pendulum

Tension force of the pendulum provides centripetal force

$$F_c = T\sin\theta = \frac{mc^2}{r}$$

The radius can be calculated from the length of the pendulum:

$$r = l\sin\theta$$



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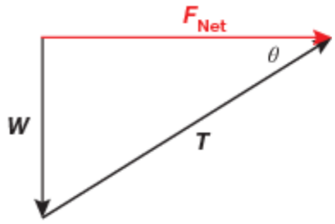


1.6 Practical Investigation 5.4 - Centripetal force in a vertical plane

Aim: To investigate the non-uniform nature of the forces acting in vertical circular motion§

Notes

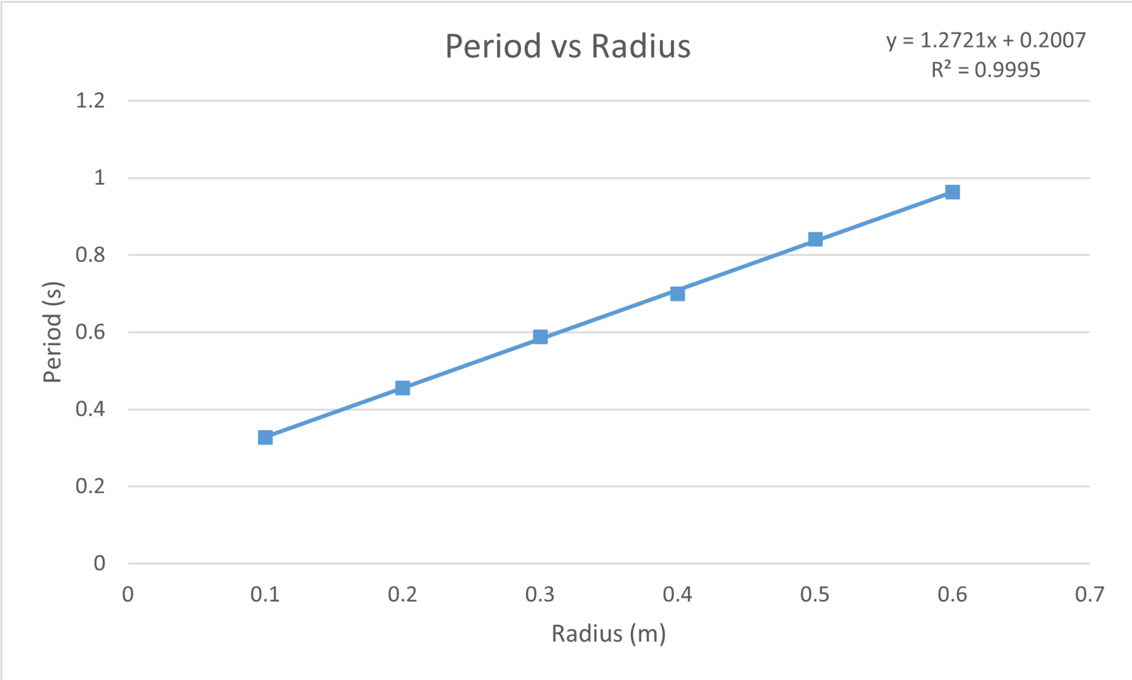
- Mass of weight was 10.4g

1.6.1 Method

1. Tie the string to the mass and measure the length of the string to the centre of the mass. Mark the string in 10 cm segments.
2. Use an alligator clip to mark a point and reduce friction when spinning.
3. Rotate the mass in a vertical circle. Keep rotation as even as possible.
4. Time the period of rotation for 20 revolutions and then find the average period. Repeat 3 times for each radius.

1.6.2 Results

Radius (m)	Time for 20 Revolutions (s)				Period T for one revolution			T_{av}
	Trial 1	Trial 2	Trial 3	**Average**	Trial 1	Trial 2	Trial 3	**Average**
0.1	6.63	6.78	6.25	6.55	0.33	0.34	0.31	0.33
0.2	9.04	9.19	9.06	9.10	0.45	0.46	0.45	0.45
0.3	12.00	11.44	11.82	11.75	0.60	0.57	0.59	0.59
0.4	13.66	14.34	14.00	14.00	0.68	0.72	0.70	0.70
0.5	17.10	16.50	16.91	16.84	0.86	0.83	0.85	0.84
0.6	19.13	19.50	19.18	19.27	0.96	0.98	0.96	0.96



1.6.3 Conclusion

Based on your graph, comment on the relationship between period and radius. Do your results confirm what was expected from theory? Comment on any discrepancies There is a linear relationship between period and radius

1. **Why is a graph of period versus radius being plotted?**

   A graph is being plotted to show the effect of radius on period.

2. **Based on your graph, comment on the relationship between period and radius. Do your results confirm what was expected from theory? Comment on any discrepancies**

   There is a linear relationship between period and radius.

1.7 Angular Velocity

TODO: physics angular velocity

$$\begin{aligned}
K + U &= 0 \\
\frac{1}{2}mv^2 + (-\frac{GMm}{r}) &= 0 \\
v^2 &= \frac{2GM}{r} \\
v &= \sqrt{\frac{2GM}{r}} \\
\text{since } v_{orbital} &= \sqrt{\frac{GM}{r}} \\
v_{escape} &= \sqrt{2}\, v_{orbital} <<<<<<< HEAD
\end{aligned}$$

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Chapter 2

Module 6 Electromagnetism

2.1 Introduction to Electromagnetism

	Gravitational Field	Electric Field	Magnetic Field
Surrounds...	mass	charge	magnet or electric current
Exerts force on	other masses	other charges	other magnets, magnetic materials, or moving electric charges
Direction of a field is determined by...	the direction of the force on a test mass in the field	the direction of the force on a positive test charge in the field	the direction of the force on a test north pole in the field
Field vector	g, units: $\mathrm{N\,kg^{-1}}$, $\mathrm{m\,s^{-2}}$	E, units: $\mathrm{N\,C^{-1}}$ or $\mathrm{V\,m^{-1}}$	B, units:$\mathrm{N\,m\,A^{-1}}$ or T
Uniform field exists...	inside a room on the Earth's surface ie. a small enclosed system on a large mass	between two parallel charged plates	between the poles of a large horseshoe magnet, or inside a coil carrying an electric current

2.1.1 Charged Particles in Uniform Electric Fields

- A uniform electric field occurs between two parallel plates of opposite and equal charges
- The potential difference between the plates, ΔV, is measured as the change in potential over the field, not the value of the potential at a given point.
- It is the **change in potential energy** as a result of **work** being done on the charge

$$V_f - V_i = Fd = -Ed$$

Moving a positive charge **against** the field requires work ($W = Fs$). When a charge is moved in an electric field it experiences a change in potential. The potential difference is defined as **the work done per unit charge**

2.1.2 Acceleration of Charged Particles due to an Electric Field

- Electric field is an electrostatic force, $E = Fq$
- The acceleration experienced by a charge is given by $F = ma$

$$\begin{aligned} F &= ma \\ E &= \frac{F}{q} \\ F &= Eq \\ ma &= Eq \\ a &= \frac{Eq}{m} \end{aligned}$$

2.1.3 Work Done on a Charge

Work is done **by** the field **on the particle** when the charge moves through a potential difference ΔV

$$\begin{aligned} W &= Fd \\ F &= qE \\ W &= qEd \end{aligned}$$

$$\begin{aligned} \because E &= -\frac{\Delta V}{d} \\ -\Delta V &= Ed \\ W &= qEd = -1\Delta V \end{aligned}$$

2.1.4 Acceleration on a Charge

In a uniform field, F is constant, $\therefore a = \text{constant}$

$$\begin{aligned} u_\perp &= u \sin\theta \\ u_\parallel &= u \cos\theta \\ v_\parallel &= u_\parallel + \frac{Eq}{m}t \\ v_\perp &= u_\perp + a_\perp t \\ v_\perp &= u_\perp \end{aligned}$$

2.2 Charged Particles in a Uniform Magnetic Field

Conventional current = direction of a positive charge

$$F = qvB\sin\theta$$

where, B = magnetic field strength, v = velocity of the charge, and q = charge

2.3 Practical Investigation 6.1 - A current-carrying conductor in a uniform magnetic field, force versus current

Aim: To investigate the relationship between force and current for a current carrying conductor in a magnetic field.

2.3.1 Materials

- Current balance
- Connecting wires
- Ammeter
- Rheostat
- Power supply
- Ruler

2.3.2 Variables

Independent	Current
Dependent	Mass required to balance
Control	Temperature, voltage, length inside solenoid, magnetic field strength

2.3.3 Risk Assessment

Hazard	Precaution
Electrocution	Turn off power supply while modifying circuit
Damage to equipment	Keep devices away from solenoid

2.3.4 Method

1. Set up the current balance
2. With no current flowing, level the current balance
3. Position the solenoid around the current balance
4. Connect a power supply and ammeter to the current balance. A second power supply should be connected to the solenoid.
5. Increase the current into the balance and re-level it using masses.
6. Record the mass required to level the balance depending on the current flow

2.3.5 Results

$$\begin{aligned} B &= \frac{\mu_0 N I}{L} \\ &= \frac{\mu_0 \times 700 \times I}{0.15} \end{aligned}$$

$$\begin{aligned} F &= BIl \sin\theta \\ \frac{F}{I} &= Bl = \text{gradient} \\ &= B \times 0.025 \end{aligned}$$

Current	Mass	Force
0.5	0.060	0.00059
1	0.072	0.00071
1.5	0.084	0.00082
2	0.096	0.00094
2.5	0.11	0.0011
3	0.12	0.0012
3.5	0.12	0.0012

2.3.6 Data and Analysis

1. **When investigating the relationship between force and current, what angle should the wire along the end of the current balance make with the magnetic field? Why?**

   The wire at the end of the current balance should be perpendicular to the magnetic field so that the maximum force is generated, ie. $\sin\theta = 1$

2. **Why can the effect of the connection wires along the length of the current balance be ignored?**

   The connection along the length of the current is parallel to the magnetic field and therefore experiences no force. Therefore, it does not affect the result.

3. **Calculate the force corresponding to each measurement of mass and record it in the corresponding column of the results. How is force calculated?**

$$F_B = mg$$

4. **Determine the equation of the relationship between the force and current of the data**

   Force is directly proportional to current. From the graph, $F = 2.48 \times 10^{-4} I$

2.3.7 Conclusion

1. **What is the nature of the relationship between these two variables?**

   Force and current have a linear relationship.

2. **What does this say about how changes in the current will affect the force acting on a wire that is in a magnetic field?**

   Force is directly proportional to current.

3. **What is the significance of the gradient of the graph? How reliable was the value you found**

   The gradient of the graph shows the relationship between force and current. The data was very reliable.

2.4 Practical Investigation 6.2 - Parallel wires, quantitative data analysis

Aim: To quantitatively analyse the way two parallel current-carrying conductors interact.

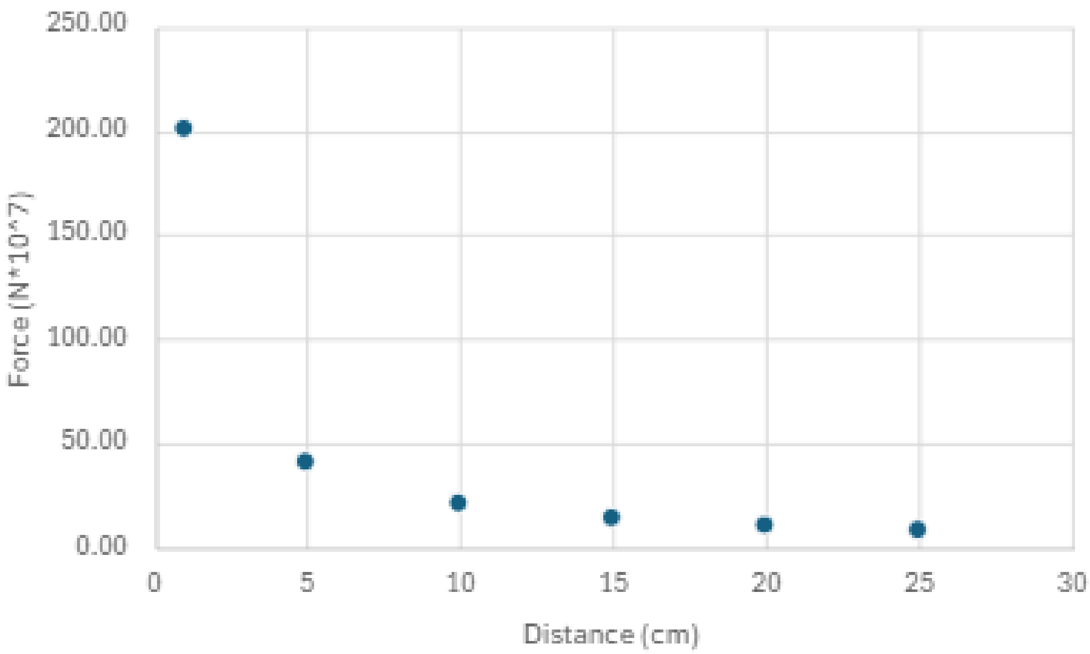


Figure 2.1: Force over Distance graph

2.4.1 Data and Analysis

1. **What will be the ratio of the current in the top wire to that in the bottom wire?** The ratio is one to one.

2. **Will the wires attract or repel? Explain your answer.** Consider the bottom rod. By right hand grip rule, the magnetic field above the rod is into the page. Due to the motor effect, the top wire experiences an upwards force. Similarly, the top wire has a magnetic field into the page that exerts a downward force on the bottom wire. Therefore, the two wires are repelled from each other.

3. **The cables are now brought toward each other and the force per unit length between them is measured. Assuming that the power supply is supplying a constant 10A of current, complete the following table for the variation in distance.**

Distance d (cm)	$\frac{F_B}{l}$ (Nm^{-1})
30	6.67×10^{-7}
25	8.00×10^{-7}
20	1.00×10^{-6}
15	1.33×10^{-6}
10	2.00×10^{-6}
5	4.00×10^{-6}
1	2.00×10^{-5}

4. **At what distance apart would the force due to the magnetic field around each wire be sufficient to balance the mass of the top wire? Assume that the wires are straight and the lower wire is unable to move away.**

$$
\begin{aligned}
m &= 1540 \times 0.001 \\
&= 1.54\text{kg}
\end{aligned}
$$

$$
\begin{aligned}
F_G &= ma \\
&= 1.54 \times 9.8 \\
&= 15.1\text{N}
\end{aligned}
$$

$$
\begin{aligned}
F_B &= \frac{\mu_0 I}{2\pi r} \times l \times I \\
&= \frac{\mu_0 I^2 l}{2\pi r} \\
r &= \frac{\mu_0 I^2 l}{2\pi F_B}
\end{aligned}
$$

$$\text{Let } F_B = F_G$$

$$
\begin{aligned}
r &= \frac{\mu_0 I^2 l}{2\pi F_G} \\
&= 0.133 \times 10^{-6} \text{ m}
\end{aligned}
$$

5. **The cable is designed to support a maximum continuous current of 110A. If the cable were carrying this current, at what distance would the force between the wires balance the mass of the top wire?**

$$
\begin{aligned}
r &= \frac{\mu_0 I^2 l}{2\pi F_G} \\
&= 1.60 \times 10^{-4}
\end{aligned}
$$

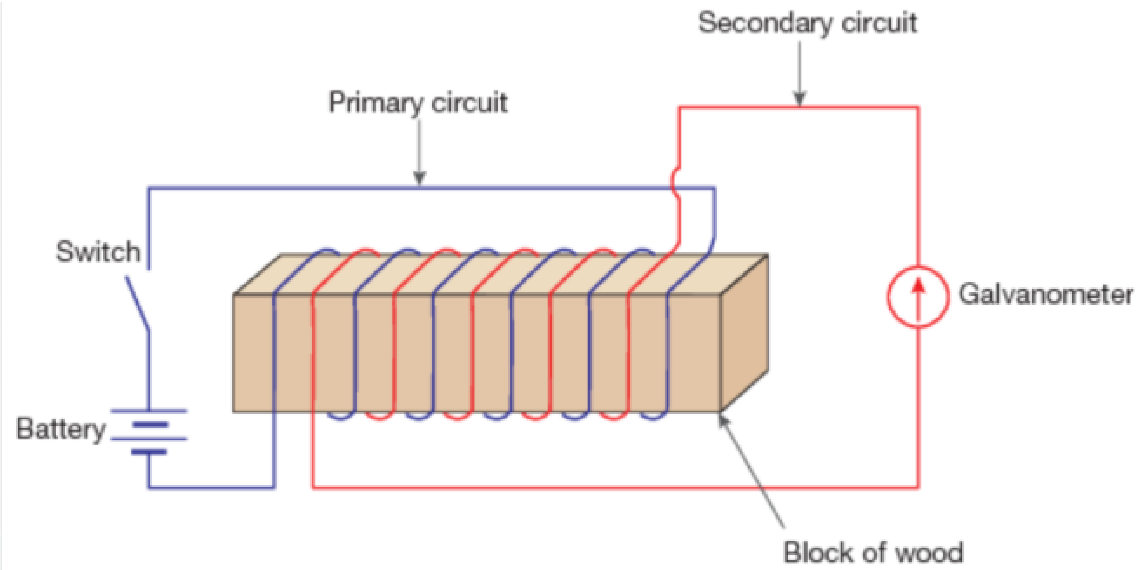
6. **If the force experienced by the top wire is exactly balancing the force due to gravity, would the force experienced by the bottom wire be larger, the same, or small? Explain your answer.**

   The net force of the bottom wire would be greater. The top wire is not fixed in place and still has no acceleration, therefore has a net force of 0. The bottom wire experiences a repulsion force and the force of gravity in the same direction, therefore has a greater net force.

2.5 Electromagnetic Induction

2.5.1 Faraday's Law

- When the primary circuit is closed, a small current is momentarily registered in the secondary circuit
- When the current in the primary coil was turned off, the same observation was made in the secondary coil but in the opposite direction
- When the current in the primary circuit was consistent, no current was detected in the secondary coil



- Both circuits produce a magnetic field with opposite polarities

Faraday's law states that:

The induced emf in a circuit is equal in magnitude to the rate at which the magnetic flux through the circuit is changing with time

$$\epsilon = -n\frac{\Delta\phi}{\Delta t}$$

2.6 Information Retrieval

1. **What is magnetic flux?**

   Flux is the amount of field lines passing through a surface

2. **What is required for electromagnetic induction?**

   - Change in flux
   - Conductor
   - Magnet
   - Relative motion between magnet and conductor

3. **How is relative motion between magnetic field and conductor achieved?**

   - Physically move magnet and coil away from each other
   - Change current in the primary coil
   - Change the magnetic field strength (magnetic flux density)
   - Change the magnetic field direction

4. **How can a change in magnetic flux be created?**

   Same as above

5. **State Lenz's Law**

   Magnetic field produced by the induced current opposes change in flux.

6. **Describe the steps to determine the direction of an induced current.**

   (a) Find the change in flux
   (b) Determine the direction of the magnetic field that needs to be produced to oppose the change in flux
   (c) Determine the direction of the induced emf/current using right hand palm rule
   (d) Describe the effect

7. **State the motor effect**

   A current carrying conductor in an external magnetic field experiences a force

2.7 Back EMF

From electromagnetic induction:

- A conductor experiencing a changing magnetic flux will produce an emf
- In a motor the supply voltage causes the coil to experience motor effect, resulting in torque
- As the coil rotates there is relative motion between the conductor and the magnetic field, ie. the coil experiences a change in magnetic flux
- By Faraday's Law, the changing magnetic flux induces an emf in the coil
- By Lenz's Law, the current produced by this induced emf will produce a magnetic field that opposes the change in magnetic flux
- **Hence**, the induced current will be in the opposite direction to the supply current
- The emf that a motor generates opposes the supply emf is called the **back emf**

$$\epsilon_{incoil} = \epsilon_{supplied} - \epsilon_{back}$$

Effect of back emf:

- The rate of change of flux experienced by the coil increases with the speed of rotation
- $\therefore$ back emf also increases with speed of rotation
- This back emf reduces the net emf across the coil
- Hence, the current is reduced
- Torque due to supply current is reduced
- Torque from induced current (due to back emf) increases until the torques are balanced, $F_{net} = 0$

When the motor is first switched on, before the rotation starts:

- There is no back emf (no relative motion between coil and magnetic field)
- There is a large current flowing through the coil
- Large current produces large torque, spins fast
- As motor spins faster, back emf increases until it is equal to supply emf
- When this occurs, there is no voltage across the coil and therefore no current flowing through the coil
- No current, therefore no net force, therefore constant rate (Newton's first law)

2.8 Example HSC Question

Question 21 (3 marks)

A fan that ventilates an underground mine is run by a very large DC motor. This motor is connected in series with a variable resistor to protect the windings in the coil.

When the motor is starting up, the variable resistor is adjusted to have a large resistance. The resistance is then lowered slowly as the motor increases to its operating speed.

Explain why no resistance is required when the motor is running at high speed, but a substantial resistance is needed when the motor is starting up.

Answer: A variable resistor is required when the motor is starting up because the supplied current will be high and high resistance limits the current. This prevents motor burnout.

When the motor is at operational speed, the coil is rotating relative to a magnetic field and induced emf (back emf) is produced, reducing the current.

2.9 Effects of Back EMF - motor burn out

When a heavier mechanical load is placed on the motor,

- Rotational speed decreases
- Back emf decreases
- Current increases
- Torque and rotational speed increase until new equilibrium is reached

When armature is prevented from moving,

- No back emf due to no $\frac{\Delta\phi}{\Delta t}$
- Large current
- Resistance $\rightarrow$ heat $\rightarrow$ motor burn out

2.10 Eddy Currents

Induced currents do not occur only in coils and wires. They can also occur:

- when there is a magnetic field acting on part of a metal object and there is relative motion between them

2.11 Transformers

- Devices that increase or decrease AC voltage by mutual induction
- Consists of two coils of insulated wire called the **primary and secondary coils**
- The size on the emf depends on the number of turns in the secondary coil: $\varepsilon = -n\frac{\Delta\phi}{\Delta t}1$
- An AC voltage is placed on the primary coil
- If there are less turns in the secondary coil, there is less current

2.11.1 Ideal Transformers

If the transformer is ideal, it is 100% efficient and the energy input at the primary coil is equal to the energy output of the secondary coil.

To prevent eddy currents, the iron core must be split and laminated to form donuts (parallel to the direction of the coils)(idk how to word this)

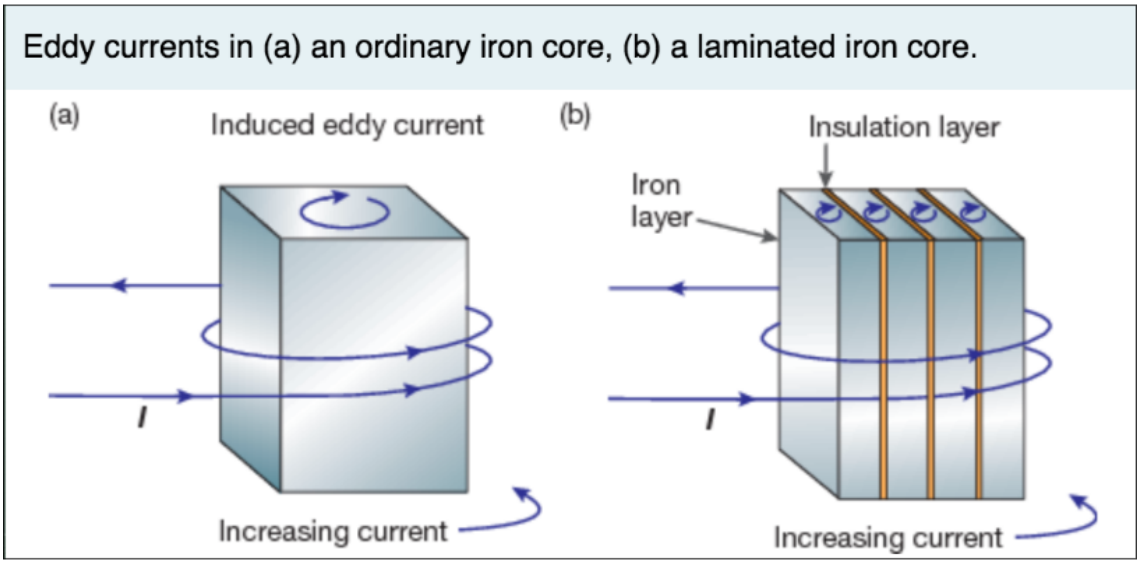
Limitations of the ideal transformer

Resistive heat production; When current passes through wires they heat up, so energy (and power) are lost in the primary and secondary coils. To prevent this:

- Keep resistance low by choosing ideal materials

- Using cooling oil to dissipate heat
- Using fans to dissipate heat

Incomplete flux linkage (or flux leakage); the magnetic field generated by the primary coil does not entirely pass through the secondary coil



2.12 Applications of Transformers

Power Distribution

Resistance is due to:

- Length
- Material
- Temperature
- Thickness

$$P_{in} = IV$$
$$P_{in} = P_{out} + P_{loss}$$
$$P_{loss} = I^2R = \frac{V^2}{R}$$

Since the resistance due to material and distance is constant, P_{loss} can be minimised by decreasing I and increasing V output which is done by a step-up transformer

To minimise line loss:

- Reduce resistance by using thicker wires
- Reduce current (high current $\rightarrow$ higher chance of collision) by stepping up voltage at the power plant

However, step-up transformers are only useful in distributing electricity over long distances. Step-down transformers must be used near the point of use to decrease the voltage.

2.13 Generators

A generator is a device that **transforms mechanical energy into electrical energy**

It is a backwards motor.

2.14 AC Induction Motors

Electrical motor where a rotor produces torque through phased electromagnetic induction from a stator.

Stator: coiled conductors (which act as solenoids, producing magnetic fields) connected to the AC mains power supply

Rotor: squirrel cage - numerous conductor bars attached to end rings

Bars: conduct current

End rings: complete the circuit allowing for current flow

Phase: number of independent circuits (solenoids) pairs within stator, these circuits are connected to a different phase of the mains electrical supply, only one phase can receive voltage at a time (i.e during phase 2 neither phase 1 or 3 can receive voltage in a 3 phase motor). Each phase consists of a pair of solenoids which face each other on opposite ends of the stator. One of these solenoids are connected to their respective phase input (creating a magnetic North pole when given voltage) while the other is neutral (creating a magnetic South pole)

Most common AC induction motors are 3 phase, voltages are out of sync by 120°

2.14.1 How AC induction motors work

1. AC current flows through stator
2. During each phase, current flows through the respective solenoid creating an electromagnet
3. As the stator transitions through phases, a changing magnetic field is created, due to this a current is induced within the rotor (Faraday's law)
4. Consequently, an EMF is induced and force exerted within the rotor, both EMF and force are directed to oppose the change in magnetic flux and motion respectively
5. Hence the motor moves in the same direction as the magnetic field is moving (i.e the magnetic field moves clockwise, therefore the motor moves clockwise)

Example

Let the rotor be the origin of a three phase induction motor (three phase therefore 3 solenoid pairs and 6 solenoids in total)

Phase 1 is a solenoid on a bearing of 330°T to the rotor, phase 2 is on a bearing of 30°T. The magnetic field moves in a clockwise motion, from the perspective of the rotor the field moves right, therefore the relative motion of the rotor is left to the magnetic field, hence force is directed left. Magnetic field is directed downwards towards the rotor.

Using the right hand push rule, thumb points into the page, due to the changing magnetic flux, oppose either force of magnetic field and the current produced is out of the page (Lenz's law). Reapply right hand push rule, thumb out of the page and index finger down, therefore force is exerted towards the right

2.14.2 Slip

The rotor always spins at a slower rate than the stators magnetic field, allowing for relative motion between the two and hence a change in magnetic flux, producing torque from the rotor

Difference in stator and rotor speed = slip