

SCHOOL-BASED ASSESSMENT

LABORATORY MANUAL

PHYSICS

First Edition

4th May 2026

**MALAYSIAN INDEPENDENT CHINESE
SECONDARY SCHOOLS (MICSS)**

Preface

This manual is compiled based on the "Senior Middle Level Physics Curriculum Standards" set by the Physics subject under Unified Curriculum Committee of Malaysian Independent Chinese Secondary School (MICSS) Working Committee, with reference to both national and international secondary physics curricula. Within this framework, experiments are positioned as the core of high school science learning, serving as a bridge between theory and practice. Designed as a tool for school-based assessment by Examination Department, this manual aims to establish a scientific and systematic evaluation system for experimental teaching.

Its key features are as follows:

- (1) Guided by the principle of “using assessment to enhance teaching and learning,” the manual provides a structured evaluation framework covering the entire experimental process – from operation procedures and data collection to analysis and reasoning. It emphasizes not only the accuracy of data but also the cultivation of scientific thinking and inquiry skills.
- (2) The experiments selected align with curriculum standards while reflecting the distinctive characteristics of independent Chinese secondary schools, balancing foundational skills development with opportunities for extended inquiry. Each experiment is designed to holistically assess students’ scientific literacy.

We extend our sincere gratitude to the experts, scholars, and experienced teachers who reviewed this manual and provided valuable feedback on its content and design.

We believe that true science education lies at the intersection of hands-on practice and deep intellectual engagement. May this manual guide students in exploring the scientific world, fostering a rigorous and inquisitive mind, and finding joy in discovery and growth.

We welcome any feedback or corrections regarding shortcomings in this manual.

Dong Zong Examination Department

January 2026

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Exploring the Laws of Free Fall Motion

Hypothesis

Ignoring air resistance, a freely falling object undergoes uniformly accelerated motion. Its instantaneous velocity v is directly proportional to the time t .

Objectives

To investigate the relationship between displacement, velocity, and time in free fall.

Apparatus

Apparatus	Specification	Quantity
Spark timer	6 V - 12 V, 50 Hz	1
Ticker tape	2 m	1
Metal weight	100 g - 50 g	1
Retort stand		1
G-clamp		1
Adhesive tape		1
Clip		1
Cushioning pad		1
Low-voltage AC power supply	According to spark timer	1

Procedure

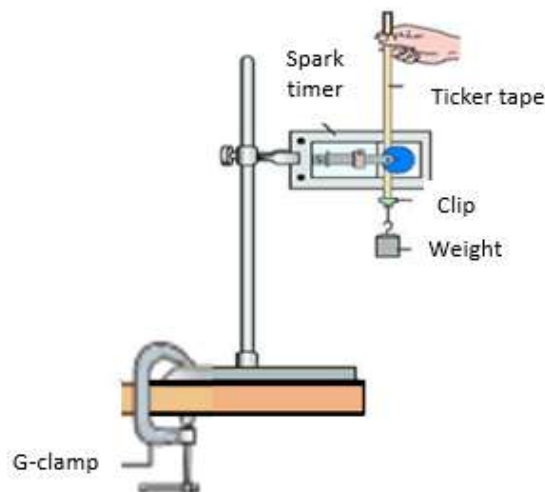


Figure 1

1. Secure the ticker-timer on a stand, approximately 2 meters above the ground, and fasten it to the table using a G-clamp, as shown in Figure 1.
2. Place cushioning material at the intended landing point of the weight to absorb the impact and prevent damage to the ground or the weight itself during the fall.
3. Use a clip to attach one end of the paper tape to the weight (reinforce the connection between the tape and the weight. For example, by wrapping it with multiple layers of adhesive tape), and ensure that the paper tape can be pulled vertically through the ticker-timer.
4. Start the ticker-timer and then release the weight, allowing it to fall while pulling the paper tape and leaving dots on it.
5. At the beginning of the paper tape, select a clear and stable dot as point 0, and then mark points 5, 10, 15, 20, 25, and 30 in sequence.
6. Measure the distance y_n between every five dots and record the results in Table 1.
7. Calculate the time interval Δt for every five dots on the paper tape, and compute the average velocity $v_n = \frac{y_n}{\Delta t}$.
8. Calculate the midpoint time for each group as $t_n = (n - 1/2) \cdot \Delta t$ ($n = 1, 2, \dots$, corresponding to the distance sequence), and use the data from Table 1 to plot the graph of v_n versus t_n .
9. Determine the slope of the best-fit line from the graph of v_n versus t_n .

Results

1. Calculate the time interval Δt for every 5 dots.

2.

Spacing sequence n	Point interval	Displacement y_n (mm)	Midpoint time t_n (s)
1	Points 0-5		
2	Points 5-10		
3	Points 10-15		
4	Points 15-20		
5	Points 20-25		
6	Points 25-30		

Table 1

Instructions:

The displacement y_n is measured and recorded in millimeters (mm), as the millimeter scale can be clearly read on most measuring tools, helping to reduce reading errors and ensure the accuracy of the recorded significant figures. During calculations, the values in mm are then converted to meters (m), balancing measurement precision with computational standards.

Theoretical Explanation:

We can approximate that the average velocity v_n for each segment of the paper tape equals the instantaneous velocity at the midpoint of the corresponding time interval.

3. Attach the graph plotting v_n against t_n to this lab report.

Discussion

1. Please provide one example each of a manipulated variable, a responding variable, and a controlled variable.
2. Given that the gravitational acceleration, g_e near the equator is 9.78 ms^{-2} , calculate the experimental percentage error Δ .
3. Apart from air resistance and the limitations of scale precision, explain other potential sources of error in this experiment and propose one improvement suggestion accordingly.
4. In the experiment, if air resistance cannot be neglected, how would the spacing between dots on the paper tape and the velocity-time graph change? Please explain with reasons.

Newton's Second Law of Motion

Hypothesis

Experiment A: When the mass is constant, the acceleration a , of the trolley is directly proportional to the net force F .

Experiment B: When the pulling force is constant, the acceleration a , of the trolley is inversely proportional to the total mass M .

Objectives

Experiment A: To investigate the relationship between acceleration and force.

Experiment B: To investigate the relationship between acceleration and mass.

Apparatus

Apparatus	Specification	Quantity
Spark timer	6 V — 12 V, 50 Hz	1
Ticker tape		Sufficient
Weights (0.5 kg masses or extra trolley)		3
Runway		1
Trolley		1
Adhesive tape		1
Retort stand		1
Electronic balance		1
Elastic strings	~20 cm unstretched length	4
Low-voltage AC power supply	According to spark timer	1

Procedure

Experiment A

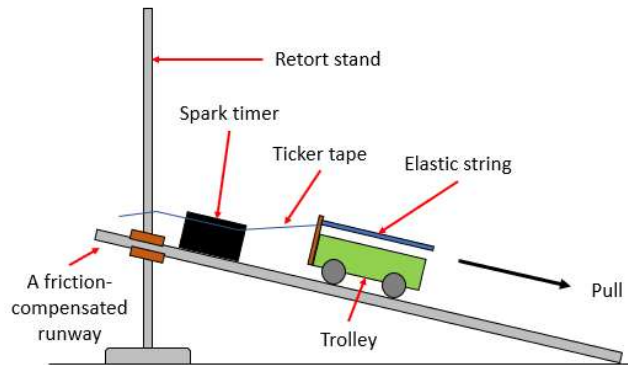
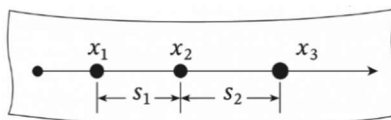


Figure 1

1. Measure the mass of the trolley and record it in Table 1.
2. Assemble the apparatus according to Figure 1, and adjust the runway to a state of friction compensation (the inclination angle should be such that the trolley slides at approximately constant speed when the runway is gently tapped).
3. Start the ticker timer. Use a single elastic cord to pull the trolley along the track. Throughout the experiment, the stretched length of the elastic cord must remain constant. Release the trolley, allowing it to pass the timer under a constant pulling force.
4. After the dots are made, turn off the power, remove the paper tape, and label the tape with its serial number.
5. Repeat steps 3 – 4 using two, three, and four elastic cords to pull the trolley. The elastic cords should be used in parallel, and the stretched length for each trial must be the same as in step 3.
6. From each paper tape, select a clear and stable section of dots after the initial starting phase. Choose three consecutive dots, measure the displacements between adjacent dots (S_1 and S_2), record them in Table 1, and calculate the acceleration a , using the provided formula.



7. Using the data from Table 1, plot a graph of acceleration a , against the number of elastic cords N .

Experiment B

1. Assemble the apparatus according to Figure 1, and adjust the runway to a state of friction compensation.
2. Start the ticker timer. Use two elastic cords to pull the trolley along the track. The stretched length of the elastic cords must remain constant throughout the experiment.
3. After the dots are made, turn off the power, remove the paper tape, and label the tape with its serial number.
4. Gradually add weights to the trolley. For each increase in mass, repeat steps 2-3 to obtain multiple paper tapes. The stretched length of the elastic cords must remain the same as the initial length in all trials.
5. Record the total mass M of the trolley and weights and $\frac{1}{M}$ in Table 2.
6. From each paper tape, select a clear and stable section of dots after the initial starting phase. Choose three consecutive dots, measure the displacements between adjacent dots (S_1 and S_2), record them in Table 2, and calculate the acceleration a , using the provided formula.
7. Using the data from Table 2, plot a graph of acceleration a against $\frac{1}{M}$.

Results

1. Mass of trolley $m =$ _____ kg
2. The time interval between two consecutive dots $\Delta t =$ _____ s .

Number of elastic cords N	Displacement S_1 (m)	Displacement S_2 (m)	$\Delta S = S_2 - S_1$ (m)	Acceleration a (ms ⁻²)
1				
2				
3				
4				

Table 1

3.

Total mass of trolley M (kg)	$\frac{1}{M}$ (kg ⁻¹)	Displacement S_1 (m)	Displacement S_2 (m)	$\Delta S = S_2 - S_1$ (m)	Acceleration a (ms ⁻²)

Table 2

4. Attach the plotted graph papers for a vs. N and a vs. $\frac{1}{M}$ to this lab report.

Discussion

1. Identify one manipulated variable, one responding variable, and one controlled variable in Experiment A.
2. Explain why the stretched length of the elastic cords must be kept the same in every trial for both Experiment A and Experiment B.
3. Based on the relationship graphs plotted from the two experiments above, explain the relationship between an object's mass, acceleration, and the applied force:
 - a) Describe the relationship between the object's acceleration and the applied force as shown by the graph from Experiment A.
 - b) Describe the relationship between the object's acceleration and its mass as shown by the graph from Experiment B.
 - c) By synthesizing the conclusions from both experiments, state the universal relationship between the force applied to an object, its mass, and its acceleration.

4. In Experiment A, if the elastic cords used have weakened tension due to aging, analyse the impact this would have on the experimental results and the corresponding graph. Then, propose one practical method to ensure the reliability of the data obtained.

5. Assuming the frictional force remains constant, if the incline of the runway is adjusted to an angle "less than that required for friction compensation," explain the specific impact this would have on the relationship graphs plotted for Experiment A and Experiment B, respectively.

Ohm's Law Experiment

Hypothesis

When the temperature is kept constant, the current I through a metallic conductor is directly proportional to the potential difference V across it. The ratio $\frac{V}{I}$ is a constant, called the resistance R of the conductor.

Objectives

1. To investigate the relationship between current and voltage in a conductor under constant temperature conditions and determine the conductor's resistance value.
2. Measure the unknown resistance R using the low-resistance method and the high-resistance method, and analyse the systematic error differences in measurement results caused by the internal resistance of the instruments.

Apparatus

Apparatus	Specification	Quantity
Resistor under test	10 Ω or 20 Ω	1
Ammeter	0 ~ 50 mA ~ 500 mA ~ 5 A	1
Voltmeter	0 ~ 5 V ~ 15 V	1
Dry cell	1.5 V, D type	2
Battery holder	For 2 cells or 4 cells	1
Rheostat	60 Ω , 1.5 A	1
Switch	Push-button or SPST	1
Connecting wires	With red and black crocodile clips	8

Procedure

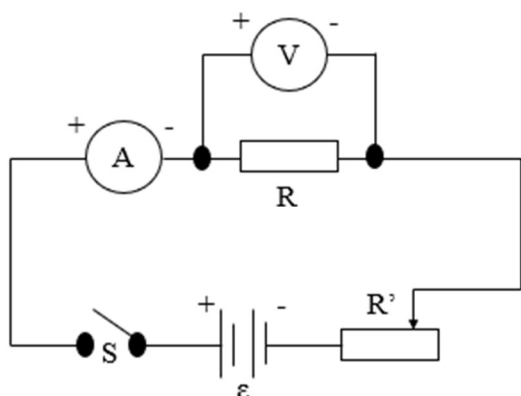


Figure 1

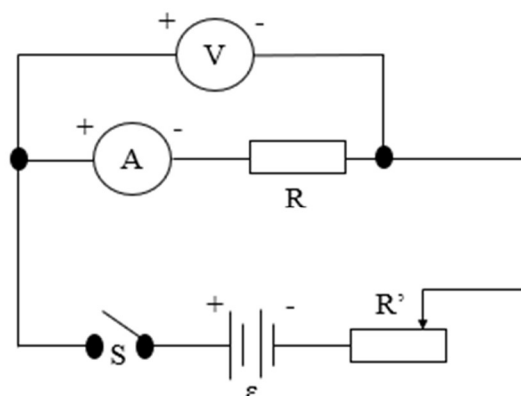


Figure 2

1. Use the low-resistance method by connecting the circuit as shown in Figure 1.
2. Adjust the rheostat R' to maximum resistance. Press the switch S to close the circuit, choose a suitable starting point, and record the readings of both the ammeter and voltmeter in Table 1.
3. Gradually reduce R' so that the voltage across the test resistor increases in steps of 0.2 V. Record corresponding current and voltage values in Table 1.
4. Plot a graph of I against V using the data, and label it as Curve A.
5. Calculate the resistance R for each set of readings and find the average resistance R_{lo} .
6. Repeat the above steps using the high-resistance method (Figure 2). Record data in Table 2 and plot the graph on the same paper as Curve B. Calculate the average resistance R_{hi} .

Results

1. Low-resistance method:

Trial	$V \pm \text{_____} / \text{V}$	$I \pm \text{_____} / \text{mA}$	R / Ω
1			
2			
3			
4			
5			
Average resistance R_{lo}			

Table 1

2. High-resistance method:

Trial	$V \pm \text{_____} / \text{V}$	$I \pm \text{_____} / \text{mA}$	R / Ω
1			
2			
3			
4			
5			
Average resistance R_{hi}			

Table 2

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. Why must the experiment always start from high resistance and gradually decrease, and why must the circuit never be without resistance?
3. If the actual resistance value of the resistor under test R is _____.
Try to calculate the percentage error Δ for each of the two measurement methods.
4. Explain and compare the current and voltage readings obtained by the two measurement methods. Then, identify the sources of error when calculating the resistance using the formula.
5. Given that the voltmeter has a very high (but finite) resistance R_v and the ammeter has a very small (but non-zero) resistance R_a . If you can perform only one experiment (either low-resistance or high-resistance method), propose a principle to decide which method and scale to use to minimize systematic error when measuring an unknown resistor R_x .

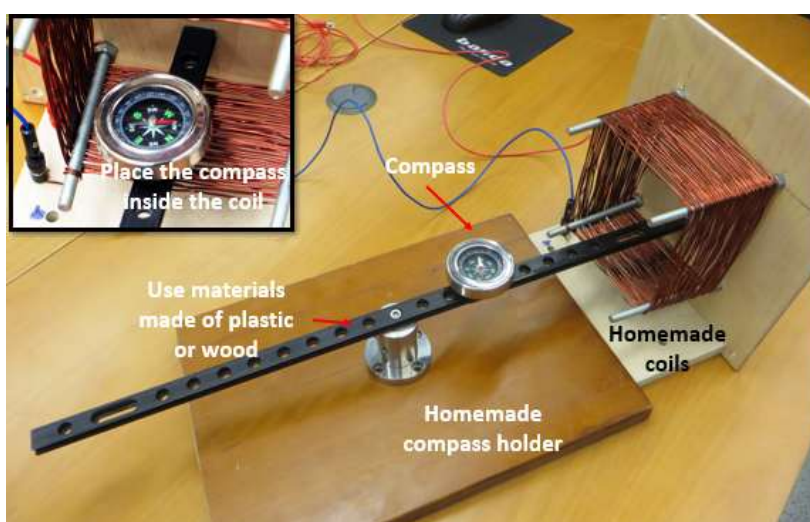
Magnetic Effect of Current and Electromagnetic Induction

Preparation

Since Experiment A requires placing a compass at the center of the coil for observation, if a suitable coil or compass holder cannot be purchased, teachers may guide students to build a simple solenoid (25, 50, or 100 turns) and a compass holder before the experiment, as shown in the diagram.

Suggestion:

During this preparation process, teachers may also observe students' teamwork and scientific attitude, such as whether they cooperate effectively and prepare their apparatus carefully.



Source: <https://physlab.org/class-demo/oersteds-law/>

Hypothesis

Experiment A: A current-carrying conductor produces a magnetic field. Increasing the current or the number of turns in a coil strengthens the magnetic field, which is shown by a larger deflection of a compass needle. Reversing the current direction reverses the deflection.

Experiment B: An induced current appears only when the magnetic flux through a coil change. That is, when a magnet or coil is moved relative to each other, the galvanometer needle deflects; but when both remain stationary, there is no deflection.

Objectives

Experiment A: To investigate the factors affecting the magnetic effect of current.

Experiment B: To observe the phenomenon of electromagnetic induction.

Apparatus

Apparatus	Specification	Quantity
Bar magnet		1
Compass		1
Copper wires	With crocodile clips (red & black)	≥ 4
Dry cells	1.5 V, D type	2
Battery holder	For 2 cells	1
Switch	SPST	1
Bulb with holder		1
Coils	25, 50, 100 turns	1 each
Compass holder		1
Wooden pieces	$\sim 2\text{cm} \times 4\text{cm} \times 0.3\text{cm}$	6
Galvanometer		1

Procedure

Experiment A

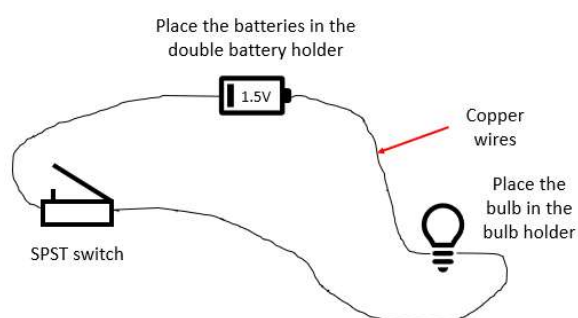


Figure 1

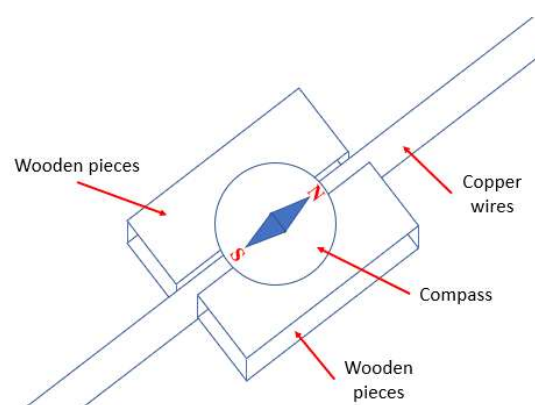


Figure 2

1. Connect the circuit as shown in Figure 1. Press the switch to check if the bulb lights up, then switch off.

2. Place the compass on the table, needle facing upward and pointing north. Use the bar magnet to check it works properly.
3. Place the conductor between two wooden pieces. Put the compass above it (Figure 2).
4. Press the switch, observe compass deflection, and record results in Table 1. Always switch off after recording. This is the initial setup; unless otherwise stated, the following experiments should be compared with this initial setup.
5. Raise the compass using extra wooden blocks. Repeat step 4.
6. Place the conductor directly on top of the compass. Repeat step 4.
7. Reverse current direction by swapping wire connections. Repeat step 4.
8. Connect two dry cells in series. Repeat step 4.
9. Replace the wire with coils of different turns (25, 50, 100). Place compass in the center of each coil. Repeat step 4.

Experiment B

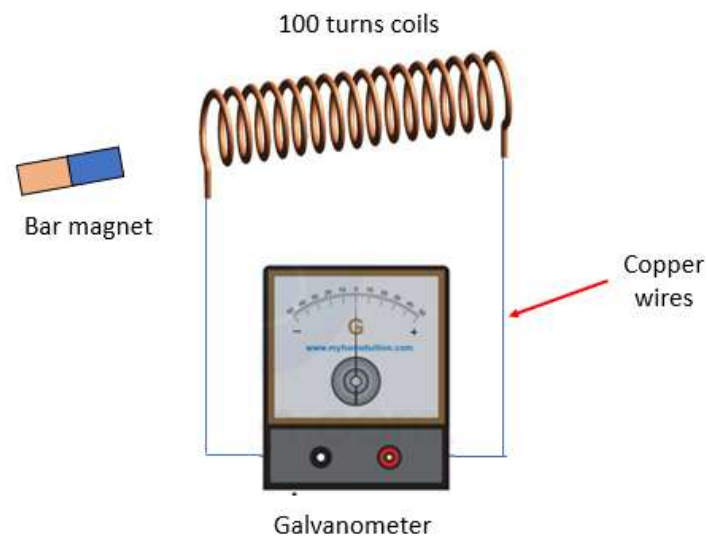


Figure 3

1. Set up as shown in Figure 3.
2. Keep the magnet fixed near the coil and observe the galvanometer. Record in Table 2.
3. Move the magnet into the coil and observe the galvanometer. Record in Table 2.
4. Move the magnet out of the coil and observe the galvanometer. Record in Table 2.
5. Keep the magnet fixed, move the coil closer to and farther from the magnet. Record in Table 2.

Results

1. When the circuit is switched on and off, compare the results with the initial setup, and describe the angle and direction of the needle's deflection. In the final observation, compare only with item (e) and with solenoids of different numbers of turns.

Observation item	Result
a. Wire between wooden pieces, compass above wire (initial setup).	
b. Wire with compass raised on extra wooden pieces, compass above wire.	
c. Wire placed directly above compass.	
d. Reverse current direction.	
e. Two batteries in series.	
f. Coils with 25, 50, 100 turns, compass at coil center.	

Table 1

- Observe the deflection direction of the galvanometer needle and mark your observation with a \checkmark .

Magnet condition	Coil condition	Galvanometer deflection		
		Deflects to the left (-)	Remains at zero (0)	Deflects to the right (+)
Magnet fixed outside coil	Coil fixed			
Magnet moved into coil	Coil fixed			
Magnet moved out of coil	Coil fixed			
Magnet fixed	Coil moved closer			
Magnet fixed	Coil moved away			

Table 2

Discussion

- For Experiment A, item (e) and item (f): state one manipulated, one responding, and one controlled variable.
- From both experiments, explain the difference between magnetic effect of current and electromagnetic induction.
- In Experiment A, why must the circuit be switched off after each observation?
- Using magnetic field strength and current, explain why item (e) gives the observed result.

5. From Q4, suggest two precautions and explain them.

6. Does induced current only occur when either the magnet or coil is moving? Why?

Young's Double-Slit Experiment

Hypothesis

For the same screen distance L and slit separation d , the interference fringes produced by green light are closer together than those of red light.

Objectives

To observe the interference phenomenon from two coherent light sources.

Apparatus

Apparatus	Specification	Quantity
Laser pointer	Emits both red and green beams	2
Retort stand	To hold the laser pointer, double slits, and camera/phone	3
Double-slit slides	Two sets with different slit separations	2
White screen		1
Mobile phone	To record the fringe patterns on the screen	1
Short ruler	15 cm	1

Procedure

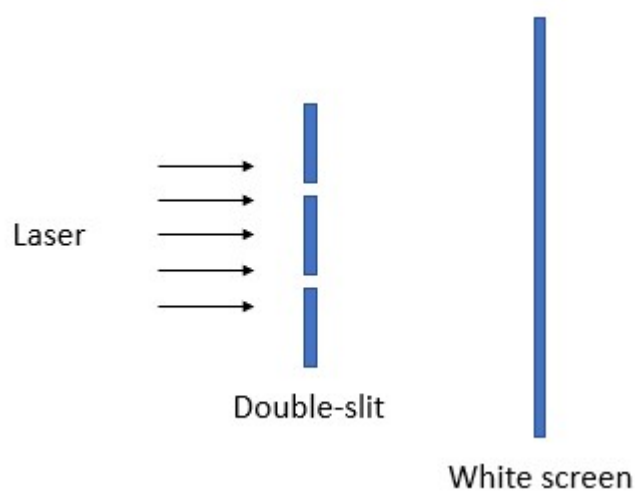


Figure 1

1. Mount the laser on the retort stand and place the white screen far enough so that the laser beam can be projected clearly.
2. Mount the mobile phone on another stand, positioned to capture the interference patterns on the screen.
3. Mount the narrower-spaced double slit on a stand between the laser and screen, close to the laser.
4. Shine a beam of red laser light through the double slit, observe the pattern formed on the screen, move a short ruler into the pattern, capture the interference pattern, and record the data in Table 1.
5. Replace the red light with green light, and repeat step 4.
6. Replace with the wider-spaced double slit and repeat steps 4 - 5.

Results

1. Record the observed patterns and mark one bright fringe and one dark fringe on each image:

Laser color	Narrower slit spacing	Wider slit spacing
Red		
Green		

Table 1

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. Under the same conditions of screen distance and slit separation, which laser produces denser fringes? Explain the relationship with wavelength.
3. The students wish to calculate the wavelength of red or green light using the fringe spacing formula. However, some measurements are missing in this setup. Propose an improved experiment design and justify your method.

Two-Dimensional Kinematics Experiment

Hypothesis

For the same table height H , the greater the horizontal launch speed u_x of a steel ball, the greater the range Δx .

Objectives

To determine the acceleration due to gravity using projectile motion.

Theory

Projectile motion is a basic form of two-dimensional motion. In this experiment, a ball is launched horizontally from a given height. Its range depends on the time of flight and horizontal velocity.

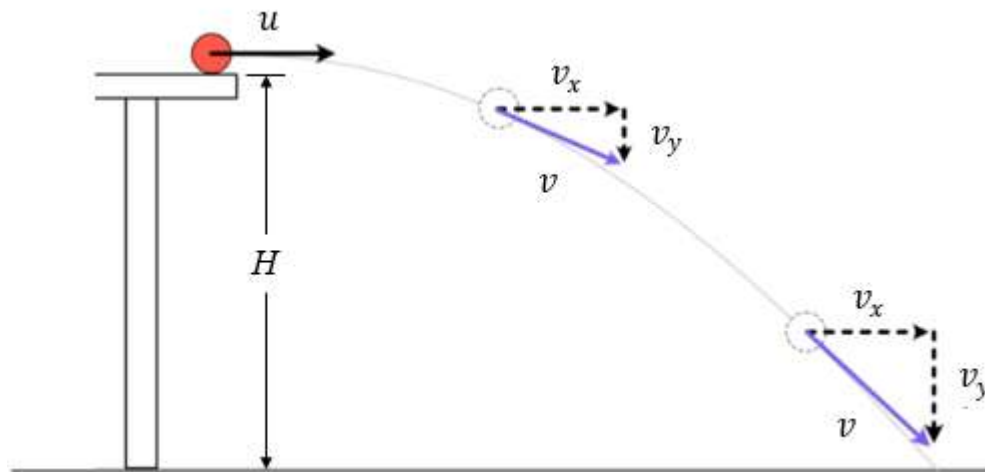


Figure 1

For horizontal motion:

$$s_x = u_x \times t \rightarrow \textcircled{1}$$

For vertical motion:

$$s_y = u_y t + \frac{1}{2} g t^2$$

Since the initial vertical velocity is zero:

$$-H = 0 + \frac{1}{2} (-g) t^2$$

$$t^2 = \frac{2H}{g}$$

$$t = \sqrt{\frac{2H}{g}} \rightarrow \textcircled{2}$$

Substitute ② into ①: The range of a projectile can be expressed as a function of the horizontal velocity and other control variables, such as the height (H) and the acceleration due to gravity (g).

$$\therefore s_x = \left(\sqrt{\frac{2H}{g}}\right) u_x$$

Apparatus

Apparatus	Specification	Quantity
Inclined track		1
Steel ball		1
Carbon paper		1
White paper		1
Meter ruler		1
Stopwatch		1
Adhesive tape		1
Plasticine		Some
Scissors		1
Pendulum bob		1
String		Sufficient

Procedure

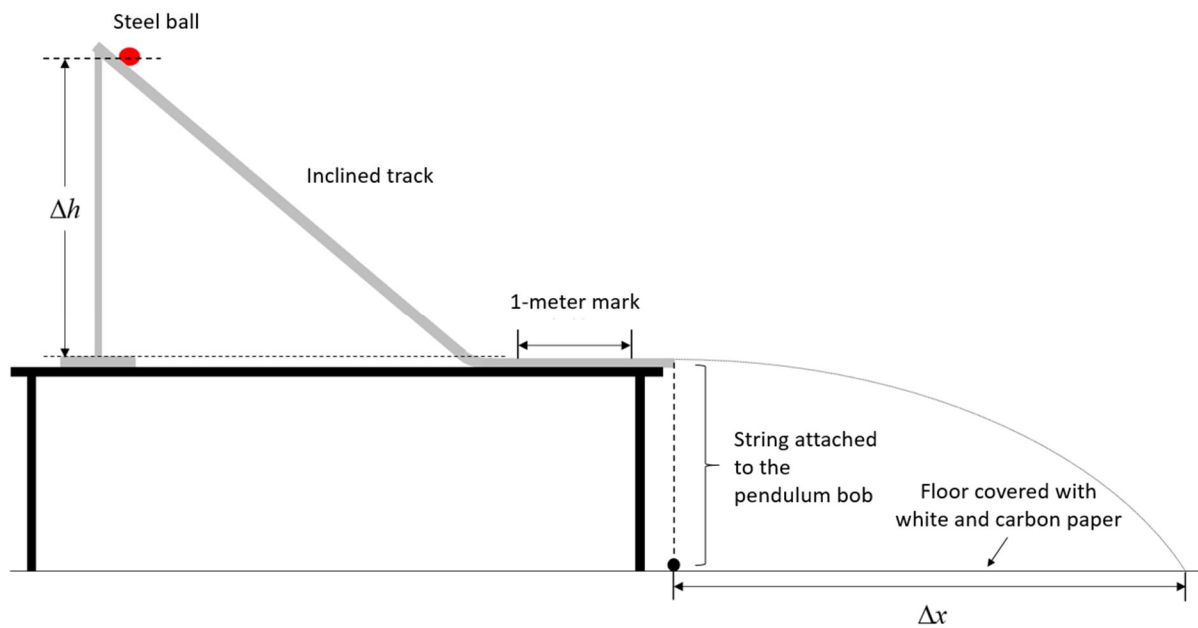


Figure 2

1. Set up the apparatus as shown in Figure 2. Place carbon paper over white paper so the steel ball leaves an impact mark for measuring the horizontal distance. Mark 1 m along the base of the track with tape.
2. Tie a pendulum bob with string to the table edge to serve as the reference point for measuring the range. Record the table height H .
3. Place and release the steel ball at a vertical height of 60 cm (Δh) along the track.
4. Allow the ball to roll down horizontally, measure the travel time for 1 m using a stopwatch, and calculate $u_x = \frac{1}{t}$. Record in Table 1.
5. Measure the horizontal distance Δx from the table edge to the landing point. Record in Table 1.
6. Repeat steps 3–5 for heights 50 cm, 40 cm, 30 cm, and 20 cm.
7. Plot a graph of range Δx against horizontal velocity u_x .
8. From the graph, find the slope m of the best-fit line.

Results

1.

Table height H (m)			
Launch height Δh (m)	Time for 1 m t (s)	Horizontal velocity u_x (ms ⁻¹)	Range Δx (m)
0.6			
0.5			
0.4			
0.3			
0.2			

Table 1

2. Attach the graph of Δx against u_x to this report.

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.

2. Using the theory and slope m of the graph, calculate g .

3. There are various sources of error in this experiment, and certain modifications (such as using a ping-pong ball instead) may further amplify these errors. Please answer the following questions:

a) Identify two possible experimental errors and suggest improvements.

b) If a ping-pong ball is used instead of a steel ball, what happens to the range and measured g ? Explain.

- c) Would using a ping-pong ball affect the accuracy, reliability, and/or validity of the experiment? Explain.

Conservation of Momentum Experiment

Hypothesis

When friction is compensated and external forces in other dimensions are negligible, the total momentum before collision equals the total momentum after collision in all cases.

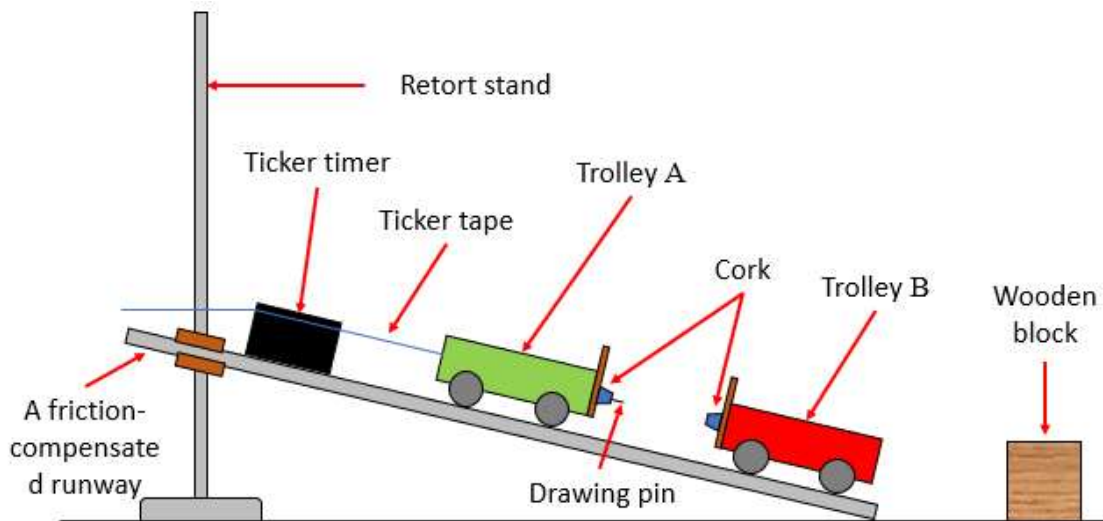
Objectives

To investigate the law of conservation of momentum using trolleys.

Apparatus

Apparatus	Specification	Quantity
Ticker timer	6 V - 12 V, 50 Hz	1
Ticker tape		Sufficient
Runway		1
Trolleys		4
Wooden block		1
Retort stand		1
Adhesive tape		1
Plasticine		Sufficient
Drawing pin		1
Cork		1
Low-voltage AC power supply	According to ticker timer	1

Procedure



1. Set up the apparatus as shown in Figure 1.
2. Adjust the tilt of the runway by raising one end so that friction is compensated.
3. Switch on the ticker timer. Give trolley A a gentle push along the runway so it collides with stationary trolley B.
4. Case (1): Measure and record the initial velocity u of trolley A before collision and the common velocity v of trolleys A and B after collision. Record in Table 1 (velocity unit: cm / 10 ticks).
5. Case (2): One moving trolley collides with two stationary trolleys. Repeat steps 3–4.
6. Case (3): Two moving trolleys collide with one stationary trolley. Repeat steps 3–4.
7. Case (4): Three moving trolleys collide with one stationary trolley. Repeat steps 3–4.

Results

1. Select and attach a ticker tape from one of the situations, and label which situation it represents, as well as the stages before, during, and after the collision.
- 2.

Before collision					After collision		
Trolley mass		Initial velocity (cm / 10 ticks)		Total momentum p_b	Trolley mass	Common velocity (cm / 10 ticks)	Total momentum p_a
m_A	m_B	u_A	u_B	$m_A u_A + m_B u_B$	$m_A + m_B$	v	$(m_A + m_B) v$
1	1		0				
1	2		0				
2	1		0				
3	1		0				

Table 1

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. Explain why trolley B is simply placed on the runway to remain stationary, rather than being fixed or blocked. What is the key condition for trolley B to stay still?
3. Using results in Table 1:
 - a) Based on the conservation of momentum and using the total momentum before collision as the reference, calculate the experimental error for each scenario.
 - b) List at least two possible sources of error or external forces causing total momentum before and after collision to differ, and suggest improvements.

4. Road safety often uses crumple zones in cars to extend collision time and reduce average force on passengers.
 - a) Use conservation of momentum and impulse to explain why increasing collision time reduces force.

 - b) How does this trolley experiment simulate real car crashes? What are its limitations?

 - c) Propose two practical traffic safety suggestions that are suitable for the public (not involving engineering details), and explain how these suggestions are based on the momentum–impulse principle to reduce injuries.

Centripetal Force Experiment

Hypothesis

When the rubber stopper's mass and the rotation radius remain constant, the angular speed ω and the tension T in the nylon string satisfy: $\omega^2 \propto T$.

Objectives

To investigate centripetal force using different suspended masses, and to compare the experimental and theoretical values.

Apparatus

Apparatus	Specification	Quantity
Rubber stopper		1
Glass tube	15 cm	1
Mass set (with hanger)	12×0.02 kg	1
Nylon string	1.5 m	1
Paper marker		1
Stopwatch		1
Meter ruler		1
Adhesive tape		1

Procedure

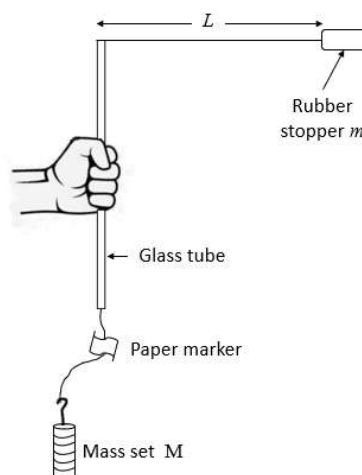


Figure 1

1. Tie one end of the nylon string to the rubber stopper. Pass the other end through the glass tube and paper marker, and tie it to the mass hanger as shown in Figure 1.
2. Adjust the paper marker so it is close to the lower end of the glass tube. Fix it with tape. Set the length of string from the marker to the stopper to $L = 0.8$ m. Start with $M = 0.12$ kg.
3. Hold the glass tube vertically and rotate it, ensuring that the rubber stopper moves in a horizontal circular motion above your head. As the speed of the rubber stopper gradually increases, the nylon string extends (that is, L increases) until the paper marker is just at the lower end of the glass tube, but does not touch the mouth of the tube.
4. Keep angular speed ω steady at this point. Start the stopwatch at the 0th revolution and stop it at the 20th revolution. Record the time t . Repeat for a second trial and calculate the average time t_a .
5. Calculate the tension $T = Mg$ and the $\omega = \frac{2\pi}{t}$.
6. Repeat steps 2–5 for different suspended masses M .
7. Measure the mass of the rubber stopper m_r and record it in Table 1
8. Plot a graph of ω^2 against T .
9. From the graph, obtain the slope m of the best-fit line.

Results

1.

Rubber stopper mass m (kg)						
String length L (m)						
Suspended mass M (kg)	Tension T (N)	Time for 20 revolutions $20t$ (s)			Time for 1 revolution t (s)	Angular speed ω (rad s ⁻¹)
		First	Second	Average		

Table 1

2. Attach the graph of ω^2 against T with slope calculation to this report.

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. Since the string is not perfectly horizontal, prove that:

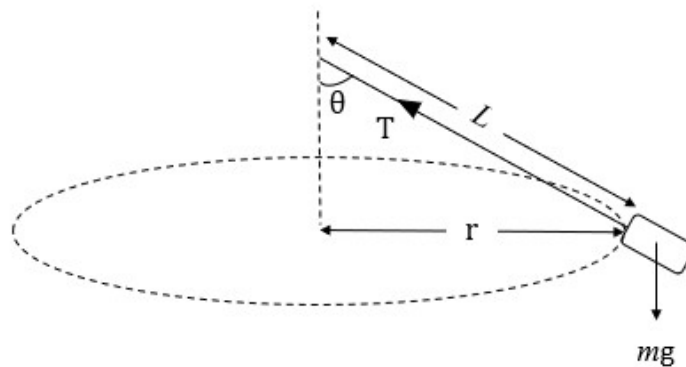


Figure 2

- a) $T = m\omega^2 L$.
 - b) The angle θ is independent of ω .
3. From the graph:
 - a) What is the relationship between ω^2 and T?
 - b) What is the physical meaning of the slope m?
 - c) Calculate the theoretical slope m_t and the percentage error Δ ?

4. Why is it important that the paper marker is just at the bottom of the glass tube but does not touch it, as mentioned in Procedure 3?

5. The experimental slope may differ from the theoretical value. State two main sources of error, classify each as systematic or random, and suggest improvements.

6. Design an experiment to investigate the relationship between ω and L . Explain in terms of steps, variable control, and graph plotting.

Simple Pendulum Period of Experiment

Hypothesis

When the swing angle is less than 10° , the period T of a simple pendulum is proportional to the square root of its length l , and independent of the pendulum bob's mass.

Objectives

To investigate the relationship between the length of a pendulum and its period.

Apparatus

Apparatus	Specification	Quantity
Retort stand		1
Protractor		1
Pendulum bob		1
Stopwatch		1
Meter ruler	100 cm	1
G-clamp		1
Small clamp		2
String	100 cm	1

Procedure

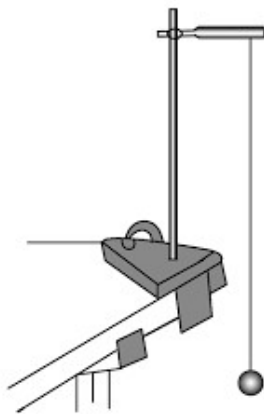


Figure 1

1. Tie one end of the string to the pendulum bob and the other end to the retort stand using a clamp, as shown in Figure 1.
2. Fix the retort stand to the table with a G-clamp.
3. Adjust the pendulum length l to 90 cm. Displace the pendulum slightly (less than 10°) and release.
4. Record the time for 10 complete oscillations as t_1 . Repeat once to get t_2 . Calculate the average t_a .
5. Change the length l to 80 cm, 70 cm, 60 cm, 50 cm and 40 cm. Repeat steps 3–4.
6. Calculate the average period of one oscillation $T = \frac{t_a}{10}$ and T^2 . Record in Table 1.
7. Plot a graph of T^2 against l .
8. From the graph, determine the slope m of the best-fit line.

Results

1.

Pendulum length l (cm)	Time for 10 oscillations t (s)		Average t_a (s)	Period T (s)	T^2 (s^2)
	t_1	t_2			
90.0					
80.0					
70.0					
60.0					
50.0					
40.0					

Table 1

2. Attach the graph of T^2 against l with slope calculation.

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. From pendulum motion, derive the formula: $T^2 = 4\pi^2 \frac{l}{g}$. Using the slope m of the graph, calculate g .
3. Given the standard gravitational acceleration $g_e = 9.81 \text{ ms}^{-2}$, calculate the percentage error.
4. Suggest one possible reason for the error.
5. A swing in an amusement park can be considered a “giant pendulum.” When the swing angle is large, the actual period differs from the theoretical value. Explain the physical reason and suggest how to improve the experiment to reduce this discrepancy.

Experiment on the Oscillation Period of a Spring Oscillator

Hypothesis

When the spring and amplitude remain unchanged, the period T of the spring oscillator is proportional to the square root of the suspended mass m .

Objectives

To investigate the relationship between the period of a spring oscillator and its suspended mass.

Apparatus

Apparatus	Specification	Quantity
Spring	Length 10 cm	1
Retort stand		1
Mass set (with hanger)	50 g - 400 g	1
Nail (marker)		1
Stopwatch		1
Meter ruler		1
Adhesive tape		1

Procedure

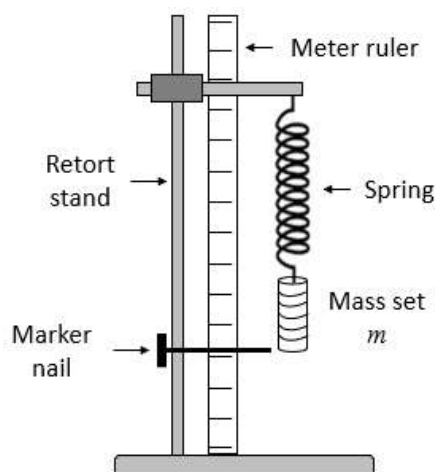


Figure 1

1. Fix the spring securely to the retort stand. Attach a 100 g mass hanger as shown in Figure 1.
2. Pull the hanger vertically downward by about 2-5 cm and release it gently to start oscillation.
3. Start the stopwatch when the hanger passes the marker nail while moving upward.
4. Stop the stopwatch after 10 complete oscillations. Record the total time t_1 . Repeat once more to obtain t_2 . Calculate the average time t_a .
5. Add 50 g mass each time and repeat steps 2-4 until six sets of data are collected. Ensure the displacement before release is the same each time.
6. Calculate the average period of one oscillation: $T = \frac{t_a}{10}$ and T^2 . Record in Table 1.
7. Plot a graph of T^2 against m .
8. From the graph, determine the slope of the best-fit line.

Results

1.

Mass m (g)	Time for 10 oscillations t (s)		Average t_a (s)	Period T (s)	T^2 (s ²)
	t_1	t_2			
100					
150					
200					
250					
300					
350					

Table 1

2. Attach the graph of T^2 against m with slope calculation.

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. Explain the motion pattern of the mass hanger completing one full cycle.
3. From spring oscillation, derive the formula: $T^2 = 4\pi^2 \frac{m}{k}$. Using the slope m of the graph, calculate the spring constant k .
4. State two major sources of error in this experiment, classify them, and suggest improvements.
5. Design an experiment to investigate the relationship between k and amplitude. Describe the steps, variable control, and graph plotting.

Diffraction Grating Experiment

Hypothesis

When a laser beam is perpendicularly incident on the surface of a compact disc (CD), the spacing between the diffraction spots on the screen depends on the track spacing d of the disc. The smaller the track spacing, the larger the diffraction angle, and the more widely spaced the diffraction pattern.

Objectives

To determine the track spacing (track pitch) of CD and DVD discs using diffraction phenomena.

Theory

A compact disc (CD) consists of many concentric reflective tracks. These tracks act like a reflection grating, and the spacing between them is the grating constant d . When light reflects from adjacent tracks, interference occurs. Constructive interference appears as bright diffraction spots on a distant screen when the path difference equals an integer multiple of the wavelength λ .

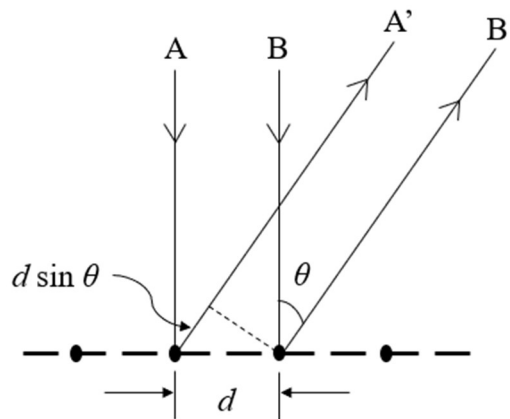


Figure 1

According to the grating equation: $d \sin \theta_m = m\lambda$ where

d : track spacing,

θ_m : diffraction angle,

λ : wavelength of light,

m : order of diffraction.

As shown in Figure 1, when the diffraction angle θ satisfies the condition, bright spots will appear on the distant screen. By measuring the distance L between the grating and the screen, and the distance X between a diffraction spot and the central position, the value of $\sin \theta = \frac{X}{\sqrt{L^2 + X^2}}$ can be calculated.

Apparatus

Apparatus	Specification	Quantity
Laser pointer	Red laser (678.2 nm) and Green laser (532.0 nm)	1
CD disc	e.g., 700 MB, track spacing 1.6 μm (unrecorded disc preferred)	1
DVD disc	e.g., 4.7 GB, track spacing 0.74 μm (unrecorded disc preferred)	1
White screen		1
Measuring tape	3.5 m	1
Cotton string	1.5-2 m	1
Cardboard box	To hold laser and disc	1
Clay or adhesive tape	To secure laser and disc	1

Procedure

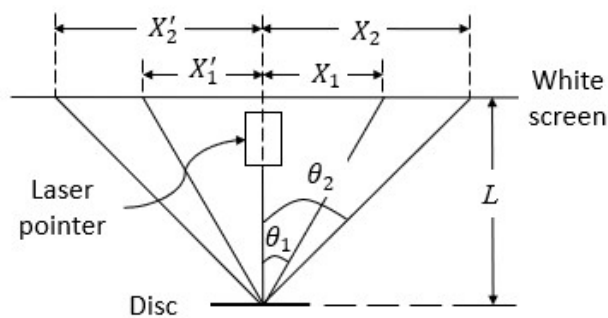


Figure 2

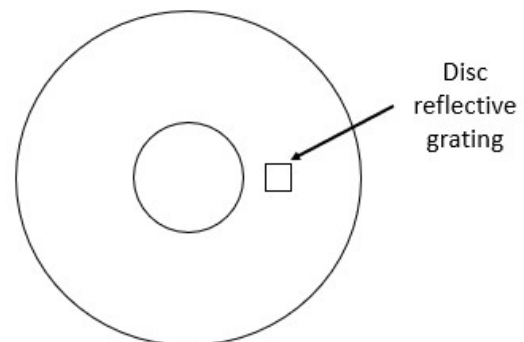


Figure 3

1. Use clay to fix the laser pointer onto a cardboard box so that it faces the white screen perpendicularly. Mount the CD vertically on the box using tape, as shown in Figure 2.
2. Turn on the laser and aim the beam slightly off-centre (left or right) on the CD surface, as shown in Figure 3.
3. Adjust the CD angle until the reflected beam coincides with the incident beam. This ensures normal alignment.
4. Measure the distance X and X' between the central and m -th order diffraction spots on the screen. Record in Table 1.
5. Measure the distance L between the CD and the screen using a string and tape measure. Record in Table 1.
6. Repeat steps 3–5 twice with different values of L .
7. Complete the calculation part in Table 1 to calculate the track spacing d of the CD.
8. Replace the CD with a DVD and repeat steps 1–7.
9. Complete the calculation part in Table 2 to calculate the track spacing d of the DVD.

Results

CD disc:

Laser wavelength / nm							
Actual disc track spacing / m							
Trial	L ± ___ / cm	X ± ___ / cm	X' ± ___ / cm	\bar{X} / cm	m	$\sin\theta =$ $\frac{\bar{X}}{\sqrt{L^2 + \bar{X}^2}}$	$d = \frac{m\lambda}{\sin\theta}$ / nm
1.							
2.							
3.							
						Average d_{avg}	

Table 1

DVD disc:

Laser wavelength / nm							
Actual disc track spacing / m							
Trial	L \pm ___ / cm	X \pm ___ / cm	X' \pm ___ / cm	\bar{X} / cm	m	$\sin\theta =$ $\frac{\bar{X}}{\sqrt{L^2 + \bar{X}^2}}$	$d = \frac{m\lambda}{\sin\theta}$ / nm
1.							
2.							
3.							
						Average d_{avg}	

Table 2

Discussion

1. Calculate the percentage error for both CD and DVD.
2. If the laser is aimed at a point above the CD center, how will the diffraction pattern distribute on the screen? What about aiming at a point to the right of the center? Explain.
3. If the laser is incident normally on the CD, will the total number of bright diffraction spots be even or odd? Why?
4. Compare the diffraction patterns of the DVD and CD. What are the differences, and why?
5. Why are the non-central (non-zero-order) diffraction spots elongated into arcs?

Specific Heat Capacity of a Solid

Hypothesis

Under experimental conditions, assuming the calorimeter is approximately insulated and no significant heat is lost to the surroundings, the heat released by the hot copper ball as it cools from θ_3 to θ_2 equals the heat absorbed by the calorimeter and the water as they warm from θ_1 to θ_2 . Therefore, according to the principle of conservation of energy, the specific heat of the copper ball can be determined using the method of mixtures.

Objectives

To determine the specific heat capacity of a solid (copper) using the method of mixtures.

Theory

In this experiment, a heated copper ball at temperature θ_3 is placed in a calorimeter containing water at initial temperature θ_1 . When thermal equilibrium is reached at temperature θ_2 , the heat released by the copper ball equals the heat absorbed by the water and the calorimeter:

$$\begin{array}{l} \text{The heat released by the small copper} \\ \text{ball as it falls from } \theta_3 \text{ to } \theta_2 \end{array} = \begin{array}{l} \text{The heat absorbed by the calorimeter and} \\ \text{the water inside it as their temperature} \\ \text{rises from } \theta_1 \text{ to } \theta_2 \end{array}$$

Apparatus

Apparatus	Specification	Quantity
Calorimeter	75 mm × 50 mm	1
Thermometer	-10 - 110 °C	2
Electronic balance		1
Copper ball	30 - 40 g	1
Beaker	100 ml, 1000 ml	2
Bunsen burner		1
Water		Sufficient

Fine string		1
Retort stand		1
Glass rod		1
Tripod stand		1
Ceramic fiber wire gauze		1

Procedure

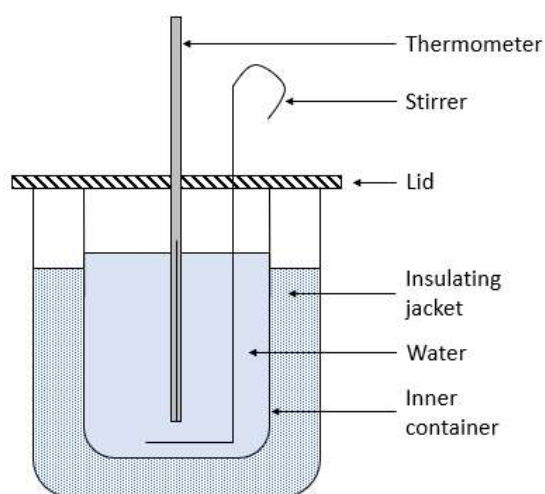


Figure 1

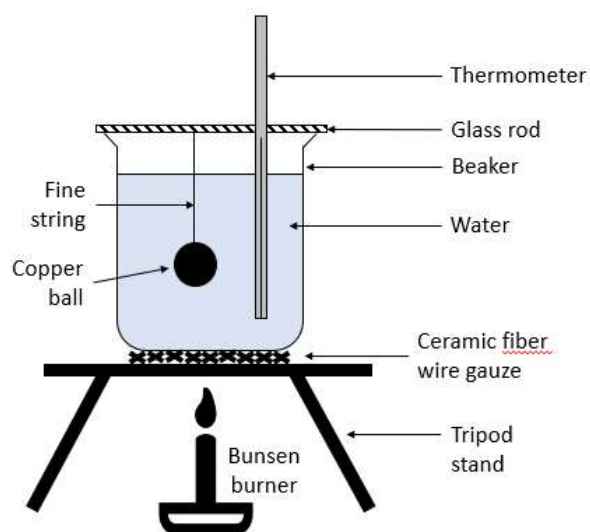


Figure 2

1. Measure the mass of the empty calorimeter (with stirrer) using an electronic balance. Record as m_1 .
2. Measure the mass of the calorimeter with lid, thermometer, stirrer, and insulating jacket. Record as m_2 .
3. Pour room-temperature water into the calorimeter until it is half full. Measure the total mass (calorimeter + lid + thermometer + stirrer + water). Record as m_3 .
4. Measure the mass of the copper ball as m_4 .
5. Stir the water gently for 2 minutes and record its initial temperature as θ_1 .
6. Measure the temperature of boiling water as θ_3 .
7. Tie the small copper ball securely with a fine thread, then immerse it in boiling water for about one minute. Quickly transfer the copper ball into the calorimeter, cover it with the lid, and stir continuously to ensure the water temperature becomes uniform. The

temperature at the moment when it just begins to fall is taken as the highest temperature, θ_2 .

- Repeat steps 3–7 once more using the same copper ball.
- In the blank space under the ‘Results’ section, create Table 1 to record m_1 , m_2 , m_3 , m_4 , θ_1 , θ_2 and θ_3 , including the calculation and recording of the mass of the calorimeter m_c and the mass of the water inside the calorimeter m_w .

Results

Discussion

- Given specific heat of water, $c_w = 4200 \text{ Jkg}^{-1}\text{K}^{-1}$ and specific heat of calorimeter, $c_c = 390 \text{ Jkg}^{-1}\text{K}^{-1}$. Using the data obtained from the experiment, calculate the amount of heat Q_1 absorbed by the calorimeter and the water inside it as their temperature rises from θ_1 to θ_2 .
- In this experiment, from where does the calorimeter and water obtain this heat? Write the corresponding heat expression Q_2 .
- Using the conservation of energy $Q_1 = Q_2$, calculate the specific heat of copper for both trials. Then calculate the average specific heat
- The standard specific heat of copper is $385 \text{ Jkg}^{-1}\text{K}^{-1}$. Calculate the percentage error Δ .

5. Based on the above error results, and referring to the experimental procedures and apparatus, list two most probable sources of error, and explain how each could have caused the obtained results. For each source, suggest a specific improvement that could be implemented in the next experiment.

6. Some cooking pots have hollow or insulated handles. Discuss how specific heat capacity and thermal conductivity influence product design. Relate this to the measurement errors and limitations in this experiment, and describe additional design considerations to ensure safety and comfort.

Latent Heat of Fusion Experiment

Hypothesis

Assuming there is negligible heat exchange with the surroundings and that the ice added is at 0 °C, the heat lost by the calorimeter and the water equals the total heat absorbed by the ice. Therefore, based on measured masses and temperature changes, the calculated latent heat of fusion L should be close to the theoretical value L_0 .

Objective

To determine the latent heat of fusion of ice.

Apparatus

Apparatus	Specification	Quantity
Calorimeter	75 mm × 50 mm	1
Thermometer	-10 - 110 °C	2
Electronic balance		1
Stopwatch		1
Ice cubes	30 - 40 g	1
Beaker	400 ml	1
Water	1000 ml	1
Blotting paper		1

Procedure

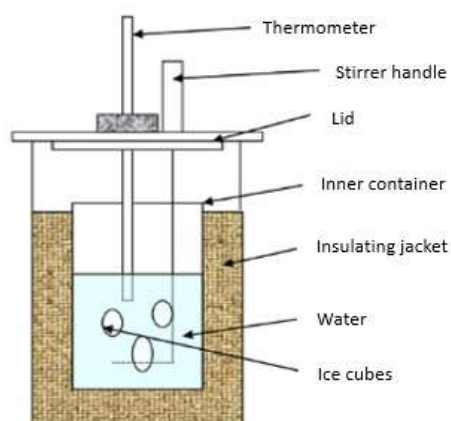


Figure 1

1. Measure the mass of the empty calorimeter with stirrer using an electronic balance. Record as m_1 .
2. Measure the mass of the calorimeter with lid, thermometer, stirrer, and insulation. Record as m_2 .
3. Fill the calorimeter about two-thirds full with room-temperature water. Measure the total mass of the calorimeter + lid + thermometer + stirrer + insulation + water, and record as m_3 .
4. Stir the water evenly for about 1 minute and record its initial temperature as θ_1 .
5. Take several pieces of ice, dry them using blotting paper, and quickly place them into the calorimeter. Immediately cover the lid and stir continuously until the temperature reaches a minimum and then slightly rises. Record this final temperature as θ_2 .
6. Measure the total mass of the calorimeter and the water (including melted ice) again, and record as m_4 .
7. Repeat steps 3 – 6 to obtain another set of data.
8. In the blank space under the 'Results' section, create Table 1 to record m_1 , m_2 , m_3 , m_4 , θ_1 and θ_2 , including the calculation and recording of the mass of the calorimeter m_c and the mass of the water in m_w and mass of ice m_i .

Results

Discussion

1. Given specific heat of water, $c_w = 4200 \text{ Jkg}^{-1}\text{K}^{-1}$ and specific heat of calorimeter, $c_c = 390 \text{ Jkg}^{-1}\text{K}^{-1}$. Using the principle of energy conservation, state the experimental hypothesis and calculate the latent heat of fusion L .
2. The theoretical value of the latent heat of fusion of ice is $L_0 = 3.36 \times 10^5 \text{ Jkg}^{-1}$. Calculate the percentage error.
3. Suggest one way to minimize the experimental error.
4. Explain how each situation affects the measured value of L :
 - a) The water was not stirred before measuring θ_1 .
 - b) The ice was not dried before being added into the calorimeter.
5. This experiment assumes that the added ice is at 0°C and that no additional heat is lost to the surroundings. Design a simple supplementary test that can be carried out in a school laboratory without using complex instruments to check whether the ice temperature is below 0°C . Briefly explain the procedure, how to determine whether the assumption is valid, and whether this method can help reduce certain systematic errors.

Boyle's Law Experiment

Hypothesis

Under constant temperature and fixed gas mass, the volume of a gas is inversely proportional to its pressure.

Objectives

To determine the relationship between the volume and pressure of a fixed mass of gas at constant temperature.

Apparatus

Apparatus	Specification	Quantity
Syringe	100 ml	1
Rubber tube		1
Pressure gauge		1
Retort stand		1

Procedure

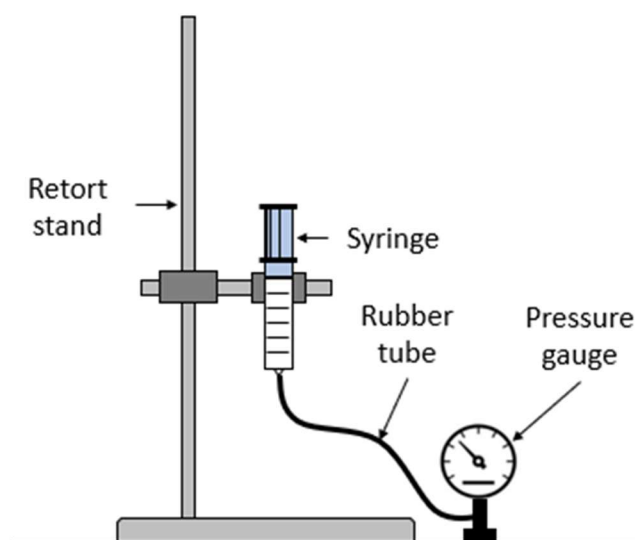


Figure 1

1. Set up the apparatus as shown in Figure 1.
2. Adjust the gas volume in the syringe to 100 ml, then connect the other end of the syringe to the pressure gauge.
3. Record the gas volume and the initial pressure P as shown in Table 1.
4. Slowly push the plunger until the volume becomes 90 ml. Record the corresponding pressure.
5. Repeat Step 4 for volumes of 80 ml, 70 ml, and 60 ml, recording the pressure each time.
6. Complete Table 1, and plot a graph of P against $\frac{1}{V}$.

Results

Volume V (ml)	Pressure P (kPa)	$\frac{1}{V}$ (ml ⁻¹)
100		
90		
80		
70		
60		

Attach the graph of P against $\frac{1}{V}$ to this report.

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. When the gas volume gradually decreases, describe how the pressure reading changes based on your observations.
3. List two possible sources of error. For each, explain the cause and suggest an improvement.

4. On a hot day, a sealed bottle of mineral water brought indoors to an air-conditioned room often appears dented. Explain this phenomenon using the conclusion of this experiment, and discuss what this implies for food packaging design.

Charging and Discharging of a Capacitor

Hypothesis

When a capacitor and a resistor are connected in series with a DC power supply, the charging current of the capacitor decreases exponentially with time. When the power supply is disconnected and the capacitor discharges through the same resistor, the discharging current also decays exponentially with time. If the resistance R or capacitance C increases, the charging and discharging processes become slower.

Objectives

To study the characteristics of a capacitor during charging and discharging, and to determine the time constant of the circuit.

Theory

As shown in Figure 1, when the switch K is pressed, the capacitor begins to charge. According to Kirchhoff's loop rule,

$$\varepsilon - \frac{q}{C} - IR = 0$$

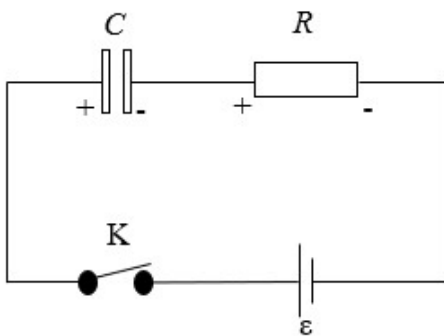


Figure 1

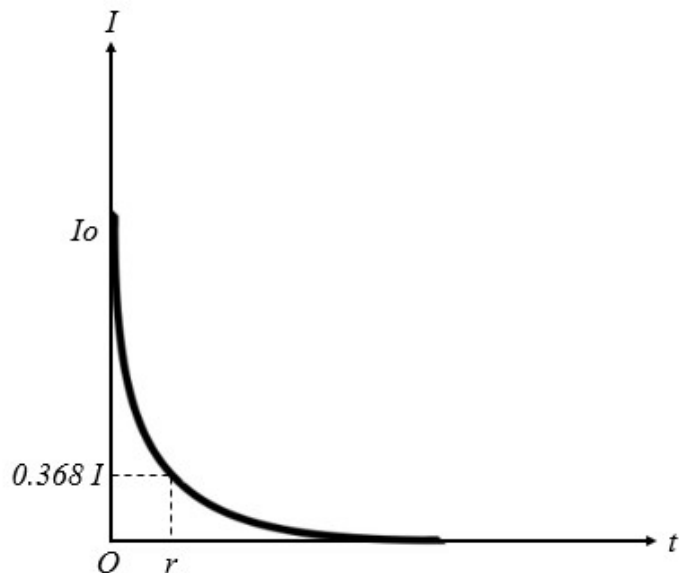


Figure 2

The $\frac{q}{C}$ represents the voltage across the capacitor, and IR is the voltage across the resistor.

$$\varepsilon - \frac{q}{C} - \frac{dq}{dt}R = 0$$

$$\begin{aligned} \frac{dq}{dt}R &= \varepsilon - \frac{q}{C} \\ \frac{dq}{dt} &= \frac{\varepsilon}{R} - \frac{q}{RC} \\ &= -\frac{q-C\varepsilon}{RC} \\ \frac{dq}{q-C\varepsilon} &= -\frac{1}{RC} dt \\ \int_0^q \frac{1}{q-C\varepsilon} d(q-C\varepsilon) &= -\frac{1}{RC} dt \\ [\ln(q-C\varepsilon)]_0^q &= \left[-\frac{1}{RC}\right]_0^t \\ \ln\left(\frac{q-C\varepsilon}{-C\varepsilon}\right) &= -\frac{1}{RC} t \\ \frac{q-C\varepsilon}{-C\varepsilon} &= e^{-\frac{1}{RC}t} \\ q &= C\varepsilon - C\varepsilon e^{-\frac{1}{RC}t} \\ &= C\varepsilon(1 - e^{-\frac{1}{RC}t}) \\ I &= \frac{dq}{dt} \\ &= \frac{Q}{RC} e^{-\frac{1}{RC}t} \\ &= \frac{\varepsilon}{R} e^{-\frac{1}{RC}t} \end{aligned}$$

Here, $Q = C\varepsilon$ is the charge stored in the capacitor when it is fully charged, and the product of R and C is a constant called the time constant τ of the circuit.

From the above derivation, it can be seen that during the charging process of the capacitor, the charge stored on the capacitor increases exponentially with time, while the current decreases exponentially with time, as shown in Figure 2.

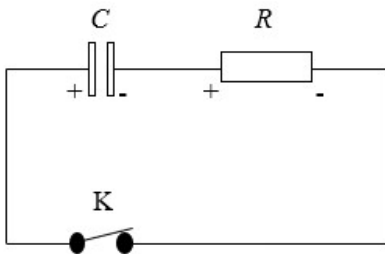


Figure 3

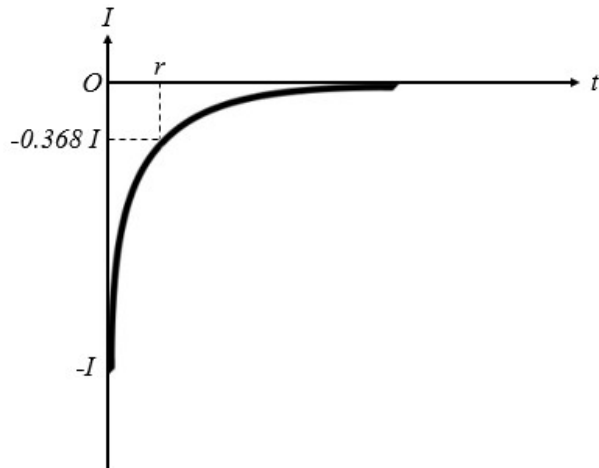


Figure 4

When the charged capacitor C is discharged through the resistor R , as shown in Figure 3, according to Kirchhoff's loop rule,

$$\begin{aligned}
 -\frac{q}{C} - IR &= 0 \\
 IR &= -\frac{q}{C} \\
 \frac{dq}{dt}R &= -\frac{q}{C} \\
 \frac{dq}{q} &= -\frac{1}{RC} \\
 \int_Q^q \frac{1}{q} dq &= \int_0^t -\frac{1}{RC} dt \\
 [\ln q]_Q^q &= \left[-\frac{1}{RC} t\right]_0^t \\
 \ln q - \ln Q &= -\frac{1}{RC} t \\
 \ln \frac{q}{Q} &= -\frac{1}{RC} t \\
 q &= Qe^{-\frac{1}{RC}t} \\
 I = \frac{dq}{dt} & \\
 &= -\frac{\varepsilon}{R} e^{-\frac{1}{RC}t}
 \end{aligned}$$

The time required for the current to decrease from $-I$ to $-0.368I$ is a constant, known as the time constant (τ) of the circuit.

From the above derivation, it can be seen that during the discharging process of the capacitor, the charge stored on the capacitor decreases exponentially with time, and the current also decreases exponentially with time, as shown in Figure 4.

Apparatus

Apparatus	Specification	Quantity
DC power supply	0 ~ 12 V	1
Microammeter	0 ~ 100 μ A	1
Electrolytic capacitor	470 μ F	1
Resistor	20 k Ω	1
Switch (K)	DPDT	1

Stopwatch		1
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Procedure

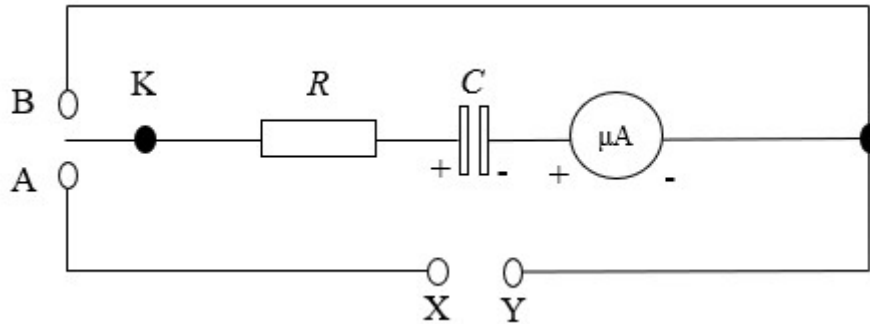


Figure 5

1. Connect the circuit as shown in Figure 5. Connect the DC supply across terminals X and Y (ensure the voltage rating of the supply matches that of the capacitor).
2. Switch K to position A to begin charging. Start timing immediately and record the initial microammeter reading. Then record the current every 5 seconds. Enter the data in Table 1.
3. Using the data in Table 1, plot a graph of charging current I against time t .
4. After the capacitor is fully charged (note: the same capacitor that has just been fully charged in this experiment must be used), switch K to B to discharge the capacitor through the resistor. Start timing immediately and record the initial microammeter reading. Then record the current every 5 seconds until it approaches zero. Enter the data in Table 2.
5. Using the data in Table 2, plot a graph of discharging current I against t on a separate graph paper.

Results

Charging of the capacitor:

Charging time $t \pm$ (s)												
Charging current $I \pm$ (μA)												

Table 1

Discharging of the capacitor:

Discharging time $t \pm$ (s)												
Discharging current $I \pm$ (μA)												

Table 2

Attach both I against t graphs to this report.

(Note: Please ignore the “best-fit line.” The shape of the $I-t$ curve can be referred to in the experimental theory)

Discussion

1. Identify one manipulated variable, one responding variable, and one controlled variable.
2. From the I against t graph of discharging, determine the time constant τ .
3. Using the formula $\tau = RC$, calculate the theoretical value of τ . Compare it with the experimental value and discuss the difference.
4. If the capacitor has leakage or the resistor becomes heated, how will these affect the I against t graph and the measured τ ? Suggest two improvements.
5. In an RC circuit, the time constant determines how quickly charging and discharging occur. Explain how to increase or decrease the charging/discharging speed.

6. Capacitors are commonly used in timing circuits (e.g., camera flash, automatic lighting, voltage stabilizers). Explain, using the relationship $\tau = RC$, how changing R and C can produce different delay times, and discuss the practical importance of this principle in everyday and engineering applications.

Electromotive Force (EMF) and Internal Resistance of a Cell

Hypothesis

When a cell is connected to an external resistor to form a closed circuit, the larger the current, the smaller the terminal voltage. The relationship between current and voltage is linear. The EMF of the cell equals the terminal voltage when no current flows, and the rate at which the voltage decreases with current depends on the internal resistance.

Objectives

To determine the electromotive force ϵ and internal resistance r of a dry cell using the ammeter–voltmeter method, and to analyse the data using both the formula method and the graphical method.

Theory

According to Ohm’s Law for a complete circuit (see Figure 1):

$$\frac{\epsilon}{I} = R + r$$

$$\epsilon = IR + Ir$$

$$\epsilon = V + Ir$$

$$V = \epsilon - Ir$$

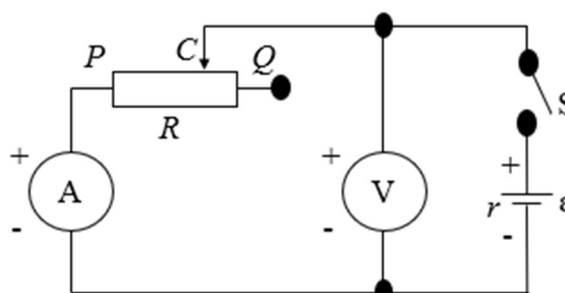


Figure 1

Apparatus

Apparatus	Specification	Quantity
Ammeter	0 ~ 50 mA ~500 mA ~ 5A	1
Voltmeter	0 ~ 5 V ~ 12 V	1
Dry cell	1.5 V, D type	1
Battery holder	4 D type	1
Rheostat (variable resistor)	60 Ω, 1 A	1

Switch (S)	Push-button or SPST	1
Test pen	Standard type	1
Connecting wires	With red and black crocodile clips	8

Procedure

1. Connect the circuit as shown in Figure 1 using a 1.5 V dry cell. ensure that the slider of the rheostat starts at the Q end, not the P end.
2. Close the switch S, and record the readings of the ammeter and voltmeter as I and V in Table 1.
3. Slide the rheostat contact C to reduce resistance gradually. For each position, record the corresponding I and V values in Table 1. Take six sets of readings.
4. Determine the EMF ε and internal resistance r of the dry cell using both the formula method and the graphical method.

Results

Trial	$I \pm$ (mA)	$V \pm$ (V)
1		
2		
3		
4		
5		
6		

Formula method:

Substitute the first and second measured values of V and I into the formula,

$$\left\{ \begin{array}{l} \varepsilon = V_1 + I_1 r \\ \varepsilon = V_2 + I_2 r \end{array} \right.$$

and solve the simultaneous equations to obtain $r = \frac{V_2 - V_1}{I_1 - I_2}$, $\varepsilon = V_1 + I_1 r$

Similarly, use the third and fourth, as well as the fifth and sixth measurement results to calculate the corresponding values of ε and r , and record them in the below table. Then, determine the average electromotive force and internal resistance of the dry cell.

Pair	ε (V)	r (Ω)
1		
2		
3		
Average		

Graphical method:

- Plot a graph of V against I .
- From the V – I graph, determine the slope m of the best-fit line.
- From the graph, obtain:
 Electromotive force $\varepsilon =$ V, Internal resistance $r =$ Ω
- Attach the plotted V – I graph paper to this laboratory report.

Discussion

- Identify one manipulated variable, one responding variable, and one controlled variable.
- When the rheostat slider moves from Q to P, describe how the current and terminal voltage change and explain why. Briefly explain the reason based on your experimental observations.
- The measured EMF is slightly different from the nominal value (1.5 V). State two possible sources of error, explain their causes, and suggest improvements.
- Batteries in mobile phones or vehicles are often labelled, e.g., “3.7 V, 2600 mAh.” Explain why the terminal voltage decreases as current increases, and suggest two design considerations engineers must consider to ensure stable operation of battery-powered devices.

Electromagnetic Induction Experiment

Hypothesis

The magnitude of the induced electromotive force (emf) depends on the rate of change of magnetic field, the number of turns of the coil, and the strength of the magnetic field. The greater or faster the change in magnetic flux, the larger the induced emf.

Objectives

To investigate the factors that affect the magnitude of the induced electromotive force (emf).

Apparatus

Apparatus	Specification	Quantity
Coils	400-turn and 800-turn coils	2
Bar magnets		2
Galvanometer		1
Connecting wires		Several
Rubber bands		Several

Procedure

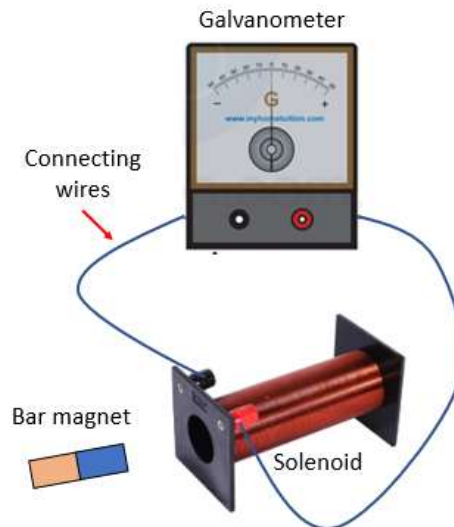


Figure 1

1. Set up the apparatus as shown in Figure 1.
2. Slowly insert a bar magnet into the 400-turn coil, and record the maximum deflection of the galvanometer.
3. Quickly insert the bar magnet into the 400-turn coil, and record the maximum deflection.
4. Slowly insert the bar magnet into the 800-turn coil, and record the maximum deflection.
5. Tie two bar magnets together with like poles facing the same direction using rubber bands.
6. Slowly insert the combined magnets into the 800-turn coil, and record the maximum galvanometer deflection in Table 1.

Results

Number of Magnets	Speed of Motion	Number of Coil Turns	Maximum Deflection of Galvanometer		
			First Trial	Second Trial	Average
1	Slow	400			
1	Fast	400			
1	Slow	800			
2	Slow	800			

Discussion

1. State one manipulated variable, one responding variable, and one controlled variable.
2. When the magnet is pushed into the coil faster, how does the maximum deflection of the galvanometer change? Explain why.
3. State one major source of error in this experiment and propose one improvement.
4. Give one real-life example or technological application that uses the principle of electromagnetic induction, and explain how it relates to the induced emf.

Reference Answers

Exploring the Laws of Free Fall Motion

Discussion	Reference Answer
Q1	Manipulated variable: Number of dots per interval OR Midpoint moments of segmented paper tape
	Responding variable: Distance between intervals OR Distance between segments of the paper tape
	Controlled variable: Frequency of spark timer
Q2	Correct substitution into formula: $\Delta = \frac{g_e - g}{g_e} \times 100$; g is slope m
Q3	Explanation: 1. Air resistance causes error. 2. If the paper tape is not fully straightened when measuring y_n , displacement readings may deviate. Or other reasonable answers.
	Improvement: 1. Use a denser object with larger mass but smaller volume. 2. Lay the paper tape flat and straighten it before measuring to prevent inaccuracies caused by bending. Or other reasonable answers. Note that the suggestions must be based on the explanation of the related errors.
Q4	Dot spacing: still increases but the increase gradually slows, eventually becoming constant.
	Velocity–time graph: curve with decreasing slope, eventually levelling off.
	Acceleration less than g, slope smaller than expected. Cause clearly stated: air resistance.

Newton's Second Law of Motion

Discussion	Reference Answer
Q1	Manipulated variable: Number of elastic strings / forces
	Responding variable: Acceleration of trolley
	Controlled variable: Mass of trolley / Extension of strings / Slope of compensated runway
Q2	Friction compensation means adjusting the inclination of the runway so that the trolley, without any pulling force applied, can move at nearly constant velocity. This adjustment balances the frictional force between the trolley and the runway, so that the measured acceleration is caused only by the tension of the elastic string.
	Verification procedure: 1. Give the trolley a gentle push and observe whether it moves at an approximately constant speed without any pulling force. 2. If the trolley slows down, the slope is too small; if it speeds up, the slope is too large. 3. Adjust the runway inclination and repeat the test until the trolley moves uniformly – this indicates that friction has been compensated.
Q2	Keeping extension constant ensures each string exerts equal force. Different extension changes net force even if number of strings is the same. Affects accuracy and comparability.
Q3a	With constant mass, more strings (greater force) → greater acceleration. $a \propto F$.
Q3b	With constant force, larger mass → smaller acceleration. $a \propto \frac{1}{M}$.
Q3c	By combining the results of Experiment A (acceleration vs. force) and Experiment B (acceleration vs. mass): $F = ma$.
Q4	Impact Analysis: Worn strings → reduced force → lower acceleration than expected, graph flattens.

	<p>Solution:</p> <p>Before each use, measure the tension of every elastic string to ensure that all strings provide approximately the same force.</p> <p>For example, use a spring balance to measure the tension at a specific extension length.</p> <p>If the measured tension is too weak, replace the elastic string or adjust the number of strings used so that the total pulling force matches the intended value.</p>
Q5	<p>Experiment A:</p> <p>Graph shifts downward, slope smaller, negative intercept.</p>
	<p>Experiment B:</p> <p>Acceleration lower, relation no longer ideal inverse, curve bends downward.</p>

Ohm's Law Experiment

Discussion	Reference Answer
Q1	Manipulated variable: Voltage across resistor
	Responding variable: Current through resistor
	Controlled variable: Resistance OR Temperature of test resistor OR Voltmeter internal resistance OR Ammeter of internal resistance
Q2	Without resistance: current increases sharply, short circuit occurs, instruments may be damaged/overheat.
Q3	Correct error formula for both methods. $\Delta_{lo} = \frac{R_{lo}-R}{R} \times 100 \%, \quad \Delta_{hi} = \frac{R_{hi}-R}{R} \times 100 \%$
Q4	Low-resistance method: voltmeter draws current $\rightarrow I$ overestimated $\rightarrow R$ underestimated.
	High-resistance method: ammeter's internal resistance causes voltage drop $\rightarrow V$ overestimated $\rightarrow R$ overestimated
Q5	Principle 1: Measuring instruments should cause minimal disturbance. If $R_x < R_v$, voltmeter's effect negligible \rightarrow use low-resistance method. If $R_a < R_x$, ammeter's effect negligible \rightarrow use high-resistance method.
	Principle 2: T The smallest division of an instrument is fixed, so the measurement range should be chosen so that the pointer reading falls within the upper half of the scale. If the range is too large, the pointer moves only slightly (reading in the lower part of the scale), so each small division represents a large value, making parallax or reading error relatively larger. If the range is too small, excessive current may damage the instrument.

Magnetic Effect of Current & Electromagnetic Induction

Discussion	Reference Answer
Q1	Manipulated variable: Number of turns in coil
	Responding variable: Compass deflection angle
	Controlled variable: Applied voltage
Q2	Magnetic effect: electric current → magnetic field
	Verified by compass deflection
	Electromagnetic induction: changing magnetic field → induced current
	Verified by galvanometer deflection or observed by reading
Q3	Large current overheats or damages battery
Q4	The magnetic field strength (B) is directly proportional to the current (I).
	Ohm's law: $I=V/R$ → Increasing voltage (1.5 V → 3 V) → Resistance constant → Current increases
	Stronger magnetic effect → Larger compass deflection
Q5	Avoid keeping circuit closed too long at 3 V (battery overheats) or Use thicker or shorter wires to reduce heating/resistance or other reasonable answers.
Q6	Yes. Only when magnetic flux changes. Galvanometer deflects or moves accordingly.

Young's Double-Slit Experiment

Discussion	Reference Answer
Q1	Manipulated variable: Colour of laser light OR Distance between the double slits OR other reasonable answers
	Responding variable: Fringe spacing
	Controlled variable: Distance between slits and screen
Q2	Observation: green light produces denser fringes than red light. If the results in Table 1 differ from these observations, use the results in Table 1 as the reference.
	Formula: $\Delta y = \frac{\lambda L}{d}$ Δy fringe spacing λ wavelength L screen distance d distance between the two slits
	Explanation: For the same L and d , fringe spacing depends only on wavelength λ . Shorter wavelength \rightarrow smaller $\Delta y \rightarrow$ denser fringes. Green has shorter wavelength than red.
Q3	Improved design: <ol style="list-style-type: none"> 1. Add a ruler on the screen or capture with camera for scale. 2. Measure slit-to-screen distance L. 3. Measure slit separation d. 4. In the same L and d, record multiple adjacent fringe spacings Δy or higher-order fringes.
	Justification: <ol style="list-style-type: none"> 1. Formula requires L, d and Δy. 2. Current setup only shows patterns, no numerical data. 3. Multiple measurements reduce random errors. 4. Using a ruler/camera improves accuracy and reproducibility.

Two-Dimensional Kinematics Experiment

Discussion	Reference Answer
Q1	Manipulated variable: Launch height of ball
	Responding variable: Range Δx
	Controlled variable: Table height / Ball type / Track angle
Q2	<p>Derivation:</p> <p>From theory, $s_x = \left(\sqrt{\frac{2H}{g}}\right) u_x$</p> <p>Match to straight-line form $\Delta x = m \cdot u_x$</p> <p>Identify slope $m = \sqrt{\frac{2H}{g}}$</p> <p>$\therefore g = \frac{2H}{m^2}$</p>
Q3a	<p>Errors with improvements:</p> <ol style="list-style-type: none"> a. Human error with stopwatch \rightarrow use light gate. b. Launch not perfectly horizontal \rightarrow adjust track. c. Carbon paper shifted \rightarrow secure properly. d. Parallax when measuring \rightarrow align eye with scale.
Q3b	Range decreases.
	Measured g too small
	Reason: small mass + large surface area \rightarrow air resistance significant.
Q3c	<p>Accuracy:</p> <p>Decreases \rightarrow results deviate from true g.</p> <p>Reliability:</p> <p>Decreases \rightarrow greater scatter in data.</p> <p>Validity:</p> <p>Decreases \rightarrow assumption “ignore air resistance” no longer valid.</p>

Conservation of Momentum Experiment

Discussion	Reference Answer
Q1	<p>Manipulated variable: Initial speed of trolley A (push strength/height) or Initial mass configuration</p> <p>Responding variable: Common velocity after collision or Difference in total momentum</p> <p>Controlled variable: Slope of runway (after friction compensation) or Absence of external force</p>
Q2	<p>Runway slope adjusted to friction compensation.</p> <p>Runway nearly horizontal, no external horizontal force.</p> <p>Thus, trolley B naturally stays still until collision.</p>
Q3a	<p>Formula:</p> $\Delta = \frac{p_a - p_b}{p_b} \times 100$
Q3b	<p>Error 1:</p> <p>Friction or air resistance not fully compensated.</p> <p>Improvement 1:</p> <p>Adjust slope until trolley moves uniformly, or use low-friction runway.</p> <p style="text-align: center;">or</p> <p>Error 2:</p> <p>Ticker timer/tape measurement errors (e.g., uneven dots → velocity error).</p> <p>Improvement 2:</p> <p>Repeat trials, average results, or use higher frequency timer/photogate.</p> <p style="text-align: center;">or</p> <p>Error 3:</p> <p>Collision off-centre → rebound or rotation.</p> <p>Improvement 3:</p> <p>Align trolleys carefully or check for rotation after collision.</p>
Q4a	<p>Impulse $I = \Delta p = m \cdot \Delta v = F \cdot \Delta t$</p> <p>Same Δp spread over longer Δt, smaller $F = \frac{\Delta p}{\Delta t}$.</p> <p>Longer collision time reduces force on passengers.</p>

Q4b	<p>Simulated part: Measures momentum before/after collision to test conservation; sticky or elastic collisions show redistribution of momentum.</p> <hr/> <p>Limitation 1: Small, rigid trolleys in 1D cannot simulate car deformation, heat loss, or passenger motion.</p> <p>Limitation 2: Real crashes involve external forces, rotation, braking, and multi-dimensional motion.</p>
Q4c	<p>Suggestion 1: Keep safe following distance → more braking time → lower collision speed → smaller Δp.</p> <p>Suggestion 2: Wear seatbelts/child seats → passengers decelerate with car, increasing collision time and reducing force.</p>

Centripetal Force Experiment

Discussion	Reference Answer
Q1	Manipulated variable: Tension or suspended mass M
	Responding variable: Angular speed
	Controlled variable: String length or Stopper mass or Near-horizontal motion without tube friction
Q2a	Derivation: Write centripetal force equation: $T \sin \theta = m\omega^2 r \rightarrow \textcircled{1}$ State $r = L \sin \theta \rightarrow \textcircled{2}$ Substitute and simplify: $T \sin \theta = m\omega^2 L \sin \theta$ $\therefore T = m\omega^2 L$
Q2b	Derivation: Vertical component: $T \cos \theta = mg$ Derive $\cos \theta = \frac{mg}{T}$ Note $T = Mg$ fixed by suspended mass, independent of ω . Conclude θ depends only on T and mg , not ω .
Q3a	ω^2 and T are linearly related. Line passes through origin.
Q3b	Slope represents mL .
Q3c	Theoretical slope $m_t = mL$ using measured m and effective L from Table 1. Using the error carried forward principle, if $L = 0.8$ m from Procedure 2, then the theoretical value is calculated as $m \times 0.8$ m. Correct substitution into formula: $\Delta = \frac{m_t - m}{m_t} \times 100$; m is slope of best-fit line.
Q4	Ensures effective string length L remains constant.
	Prevents friction/contact at tube mouth that would add tangential resistance and alter tension.
Q5	Example error 1: Random human reaction timing. Improvement 1: Use 40 turns or photogate timing.

	<p style="text-align: center;">or</p> <p>Example error 2: Friction at tube mouth; systematic.</p> <p>Improvement 2: Add low-friction lining and ensure “just not touching.”</p> <p style="text-align: center;">or</p> <p>Example error 3: Unstable ω; random.</p> <p>Improvement 3: Practice for steady rotation and time only in stable region.</p>
Q6	<p>Steps:</p> <ol style="list-style-type: none"> 1. Fix M. 2. Move marker to set different L. 3. Measure ω from 20 turns. <hr/> <p>Variables:</p> <p>Manipulated = L</p> <p>Responding = ω</p> <p>Controlled = $M, m, \text{environment}$</p> <hr/> <p>Graph:</p> <p>From $T = m\omega^2 L \rightarrow \omega^2 = \frac{T}{m} \cdot \frac{1}{L}$.</p> <p>Plot ω^2 against $\frac{1}{L}$ graph.</p> <p>Slope = $\frac{T}{m}$.</p>

Period of a Simple Pendulum

Discussion	Reference Answer
Q1	Manipulated variable: Pendulum length
	Responding variable: Pendulum period
	Controlled variable: Pendulum mass or Swing angle
Q2	State relation: $T^2 = \frac{4\pi^2}{g} l$
	Derive slope: $m = \frac{4\pi^2}{g} \rightarrow g = \frac{4\pi^2}{m}$
Q3	Correct substitution into formula: $\Delta = \frac{g_e - g}{g_e} \times 100$
Q4	Incorrect length measurement (not from clamp to bob centre). <p style="text-align: center;">or</p> Pendulum not swinging in vertical plane. Since the question paper specifies that the swing angle must be less than 10° , this cannot be accepted as an answer.
Q5	At large angles, motion is no longer simple harmonic \rightarrow period longer than theoretical.
	Reason: Approximation $\sin \theta \approx \theta$ invalid at large angles.
	Improvements: Keep angle 10° <p style="text-align: center;">or</p> Use advanced formula for large angles <p style="text-align: center;">or</p> Use sensors (photogate/motion sensor) for more accurate measurement

Period of a Spring Oscillator

Discussion	Reference Answer
Q1	Manipulated variable: Mass suspended from spring
	Responding variable: Oscillation period
	Controlled variable: Type/length of spring or Amplitude
Q2	<p>Define a period: One complete to-and-fro motion returning to the same state.</p> <p>When the mass passes the marker upward, starts the cycle; down–up again to the marker completes one full cycle.</p>
Q3	<p>State relation:</p> $T^2 = \frac{4\pi^2}{k} m$
	Derive slope: $m = \frac{4\pi^2}{k} \rightarrow k = \frac{4\pi^2}{m}$
Q4	<p>Error 1: Human reaction in timing. Improvement 1: Measure more oscillations or use photogate timer.</p> <p style="text-align: center;">or</p> <p>Error 2: Large amplitude affects simple harmonic motion. Improvement 2: Keep amplitude small (≤ 5 cm).</p> <p>Other possible errors: Spring mass not negligible, air resistance, inconsistent release.</p>
Q5	<p>Steps:</p> <ol style="list-style-type: none"> 1. Keep spring and mass constant, vary amplitude e.g., 2 cm, 4 cm, 6 cm. 2. Measure T.
	<p>Variable control:</p> <p>Manipulated = Amplitude Responding = T</p>

	Controlled = Spring, mass, environment.
	Graph: plot T (or T^2) against amplitude. Under small amplitude condition, graph should be approximately horizontal, shows T is independent of amplitude.