FOUNDATIONS OF ENGINEERING PHYSICS

A CONTEXTUAL INTRODUCTION FOR EMERGING ENGINEERS IN AFRICA

Written by Edmore.T. Mushonga, Paul Chawagarira,
Rheneilwe. A. Sekhala,
Brighton.S. Mpofu and Miriam Magavhe

Title: Foundations of Engineering Physics: A Contextual Introduction for Emerging Engineers in Africa

Authors: Eng. Edmore T. Mushonga, Paul Chawagarira, Rheneilwe. A. Sekhala,

Brighton S. Mpofu and Miriam Magavhe

Published by

Chinhoyi University of Technology

CUT LIBRARY PRESS
SHARING KNOWLEDGE

+263 67 2122203-5

omp@cut.ac.zw

Chinhoyi, Zimbabwe

ISBN: 978-1-77932-759-8

Copyedited by: Tatenda Simukai

Cover page design by: Tatenda Simukai

Foundations of Engineering Physics: A Contextual Introduction for Emerging Engineers in Africa

AI Disclosure & Human Oversight

In our commitment to providing a modern and accessible educational resource, the authors utilised Artificial Intelligence (AI) tools to assist in the synthesis and structuring of certain technical presentations. Following the AI-assisted drafting phase, all content underwent rigorous review and verification by human subject matter experts to ensure technical accuracy and academic integrity.

Disclaimer

While every effort has been made to ensure the accuracy of the information contained within this book, the authors and publishers assume no responsibility for errors, omissions, or any liability for damages resulting from the use of the information herein.

Educational Usage

This guide is designed as a supplementary pedagogical tool. It is not intended to be used in isolation and should be utilised in conjunction with other standard first-year engineering physics textbooks and primary academic sources to ensure a comprehensive understanding of the subject matter.

ISBN: 978-1-77932-759-8

DOI: https://doi.org/10.63726/CUTLib.I25

For permissions or inquiries, please contact: CUT Library Press

Email: omp@cut.ac.zw / call. +263 67 2122203-5

Dedication

To the innovators and engineers of tomorrow, may this guide serve as a steady first step in your journey to solving the world’s challenges.

Acknowledgements

We wish to express our sincere gratitude to the **Chinhoyi University of Technology (CUT)** and the **Institute of Materials Science, Processing and Engineering Technology (IMPET)** for providing the institutional support and the opportunity to contribute to the university's engineering curriculum.

We would like to extend our appreciation to the University Library team for their essential support in editing and maintaining the resources necessary for this work.

This book is the result of a collaborative effort, and special recognition is due to the contributing authors—**P. Chawagarira, R. Sekhala, B. Mpofu, and M.P. Magavhe**—whose shared expertise in materials science and engineering physics was fundamental to the development of this text. Finally, we acknowledge the students who will utilise this guide; it is our hope that this work serves as a valuable pillar in your foundational engineering education.

ABOUT THE AUTHOR PAGE

- **Edmore Takunda Mushonga**

Edmore Takunda Mushonga is an emerging academic leader and researcher at Chinhoyi University of Technology, specialising in materials processing, mechatronics, and innovation-driven development. He holds a B.Eng. in Mechatronics Engineering and an M.Phil. in Materials Science and Engineering, and is currently pursuing a DPhil focused on sustainable mineral processing using microwave-assisted techniques.

His work has been published in peer-reviewed journals and presented at international conferences, highlighting advances in critical mineral processing and AI-driven learning. Beyond Zimbabwe, Edmore has served as Head of the School of Engineering and ICT at the National Institute of Technology in Namibia, where he expanded access to education for disadvantaged students.

A member of the Zimbabwe Institute of Engineers and the Engineering Council of Zimbabwe, Edmore blends technical expertise with mentorship and strategic communication. Outside academia, he enjoys gaming, embedded systems design, and consulting as a professional materials engineer.

- **Miriam Patience Magavhe**

Miriam Patience Magavhe is a Lecturer with a background in engineering and materials science. She holds a Master of Philosophy in Materials Science and Engineering from Chinhoyi University of Technology and a Bachelor of Science

(Honours) in Civil Engineering from the University of Zimbabwe. She completed her Advanced Level and Ordinary Level studies at Mufakose 1 High School. Her academic interests include engineering education, materials science, and civil engineering. As an educator, she is passionate about equipping aspiring engineers with a strong understanding of engineering physics and its practical applications within the African context. Through her teaching and scholarly contributions, she is committed to fostering innovation, critical thinking, and excellence in engineering education.

- **Rheneilwe Andries Sekhala**

Rheneilwe Andries Sekhala is a lecturer at Chinhoyi University of Technology, in the Institute of Materials Science, Processing and Engineering Technology. His varied professional expertise includes service as a high school Educator and a clinical Medical Physicist at Parirenyatwa Group of Hospitals.

He holds an MSc in Applied Physics and a BSc (Honours) in Physics, both from the University of Zimbabwe. Currently, he is a DPhil student in Geophysics at the University of Zimbabwe-Pan African Mineral University of Science and Technology. His study focuses on groundwater exploration using IP, ERT, aeromagnetic surveys, and remote sensing. This research uniquely bridges the gap between geophysical subsurface analysis and materials science by examining the physical properties of earth materials and characteristics. With strong expertise in software such as Geosoft Oasis Montaj and QGIS, Mr. Sekhala integrates his academic and technical experience to provide a robust, practice-oriented foundation in engineering physics, with all his work contributing to the objectives of Zimbabwe’s National Development Strategy (NDS2).

- **Brighton Staff Mpofu**

Brighton Staff Mpofu is an accomplished physicist, materials scientist, and educator whose research operates at the vanguard of applied physics, metallurgical engineering, nanotechnology, and renewable energy frameworks. Driven by a commitment to addressing global imperatives in clean energy and sustainable development, his work leverages advanced nanoscale interventions to pioneer scalable solutions. Currently, Mr. Mpofu serves as a Lecturer within the School of Material Science and Engineering at Chinhoyi University of Technology. In this pedagogical role, he instructs undergraduate cohorts across rigorous fundamental and computational disciplines, including Classical Mechanics, Quantum Mechanics, and Computational Materials Science, while actively mentoring the next generation of researchers. His academic foundation is deeply rooted in advanced engineering and technology architectures; he holds a BSc (Honors) in Physics and a Master of Philosophy (MPhil) in Material Science, with a dual specialization in Nanotechnology and Thin Film Technology, both conferred by the University of Zimbabwe.As an active contributor to international scientific discourse, Mr. Mpofu frequently presents his empirical findings across local, regional, and international symposia, with notable presentations in South Africa, Rwanda, and the United States. His peer-reviewed scholarship is widely published in top-tier, high-impact international journals, including Physica Status Solidi (A) and the Journal of the Electrochemical Society. His primary research paradigms focus on the precise modulation of nanoscale surface morphologies, microstructural evolution, nucleation dynamics, and thin-film deposition pathways. Based in Zimbabwe, Mr. Mpofu continues to spearhead localized technological innovations designed to integrate seamlessly into broader, global sustainable energy architectures.

- **Paul Chawagarira**

Paul Chawagarira is an engineer and an academic with strong interests in energy materials, optoelectronic devices, semiconductor physics and nanotechnology. He heads the Institute of Materials Science, Processing and Engineering Technology at the Chinhoyi University of Technology and is actively involved in teaching, research, community engagement and innovation for industrialization. He has authored various peer reviewed articles for a wide variety of readers in industry, research and students of engineering programmes. He is passionate about STEM related programmes and is currently actively involved in Zimbabwe national Science Foundation programme, the Africa Light Source Foundation and the Africa Quantum Consortium. Outside of engineering practice and academia, Paul is a father of four and enjoys recreational activities like fishing, swimming and golf.

Contents Page

Title page i

Publisher page ii

Copyright page...iii

Dedication iv

Acknowledgements… v

About the author page vi

Chapter 1: Measurements and Vectors 1-11

Chapter 2: Kinematics and Forces.. 12-22

Chapter 3: Work and Energy 23-28

Chapter 4: Momentum, Impulse and Collisions..................................... 29-35

Chapter 5: Fluid Mechanics 36-45

Chapter 6: Oscillations..46-52

Chapter 7: Waves 53-59

Chapter 8: Light 60-77

Chapter 9: Electrostatics...78-85

Chapter 10: Electricity and Magnetism 86-93

Chapter 11: Material Science.. 94-106

Examination Question papers...107

Chapter 1: Measurements and Vectors

Chapter Overview

This unit serves as a foundation for understanding two of the most essential tools in engineering physics: **measurements** and **vectors**. In any engineering or scientific investigation, the ability to measure quantities accurately and represent them correctly is the first step toward meaningful analysis. Measurements form the bridge between theory and experiment, while vectors provide a mathematical framework for describing quantities that have both magnitude and direction.

Students will begin by exploring the fundamental principles of measurement. This includes an examination of different types of measurements, common sources of error, and the importance of accuracy, precision, and significant figures in reporting results. The unit will also highlight the use of basic laboratory instruments such as the vernier calliper and micrometre screw gauge, which are essential for obtaining reliable measurements in engineering contexts.

In addition, the unit introduces vectors as a mathematical and physical tool. Vectors are indispensable in describing physical quantities such as displacement, velocity, acceleration, and force. Students will learn how to represent vectors graphically and analytically, resolve them into components, and conduct vector operations including addition, subtraction, and scalar multiplication. The unit will conclude with practical applications of vectors in solving engineering physics problems, providing students with the skills to analyse real-world systems effectively.

Unit Objectives

By the end of this unit, students should be able to:

- **Define and distinguish between scalars and vectors** – identifying the key characteristics of each and recognizing their role in physical descriptions.
- **Describe the types of measurement errors** – including systematic, random, and gross errors, and explain how these affect experimental outcomes.
- **Make accurate measurements** using laboratory instruments such as rulers, vernier callipers, and micrometre screw gauges.
- **Apply the concepts of accuracy, precision, and significant figures** in reporting experimental results.
- **Represent physical quantities using vectors** such as displacement, velocity, and acceleration, both graphically and in component form.
- **Perform vector arithmetic operations** such as addition, subtraction, and scalar multiplication, with confidence.
- **Apply vectors in problem-solving** to analyse physical situations involving force, momentum, work, and energy.

Introduction to Measurements

Measurement is the cornerstone of engineering and physics. Without accurate measurements, it would be impossible to design, manufacture, or test engineering systems. A measurement is the comparison of an unknown quantity with a standard reference.

Fundamental Quantities: These are basic physical quantities that cannot be defined in terms of others, e.g., length (m), mass (kg), time (s), electric current (A), temperature (K).

Derived Quantities: Obtained from fundamental quantities through mathematical relationships, e.g., velocity (m/s), acceleration (m/s^2), force (N).

SI Units: The International System of Units provides standardization, ensuring engineers and scientists across the globe interpret measurements consistently.

Real-life scenario: In precision machining, engineers cutting a shaft to fit into a bearing must ensure tolerances are within micrometres (µm). Even a small error in measurement can lead to excessive friction, vibration, or premature failure of the machinery.

Types of Measurements

Direct Measurement: Obtaining the value of a quantity directly using an instrument (e.g., measuring length with a ruler).

Indirect Measurement: Obtaining the value of a quantity through calculations using other measured values (e.g., measuring density by calculating mass/volume).

Single Measurement: One-time reading.

Repeated Measurements: Multiple readings taken and averaged to reduce random error.

📌 **Example**: Measuring the diameter of a bolt once (single measurement) vs. measuring it ten times and taking the average (repeated measurements) to ensure reliability

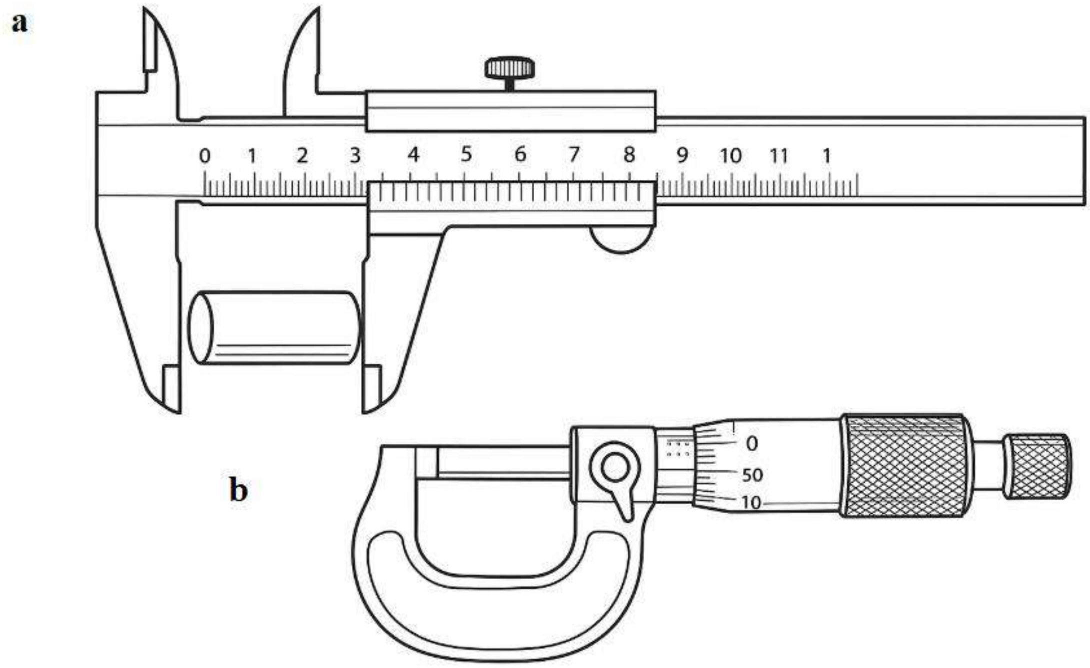


Figure 1.1: Venier callipers (a) and Micrometre screw gauge (b).

Measurement Errors

All measurements are subject to error, which is the difference between the measured value and the true value.

Systematic Errors: Consistent and repeatable errors due to faulty instruments, calibration issues, or observer bias. Examples of systematic errors include zero error, error due to wrong assumption, using wrongly calibrated instrument and error due to color blindness. They can be corrected by adding or subtracting the zero error, repeating the measurements with more than one instrument. Systematic errors usually shift readings in one direction of the true value. They affect the accuracy of the results most.

Random Errors: Unpredictable variations caused by environmental factors (e.g., temperature, vibration). Examples of random errors include parallax error, error due to temperature changes, error due to reaction time and error due to electronic noise. They can be corrected by taking multiple readings and taking the average. They shift reading to either side of the true value.

Gross Errors: Mistakes caused by human oversight, e.g., misreading a scale. Can be minimised by avoiding destruction during observation.

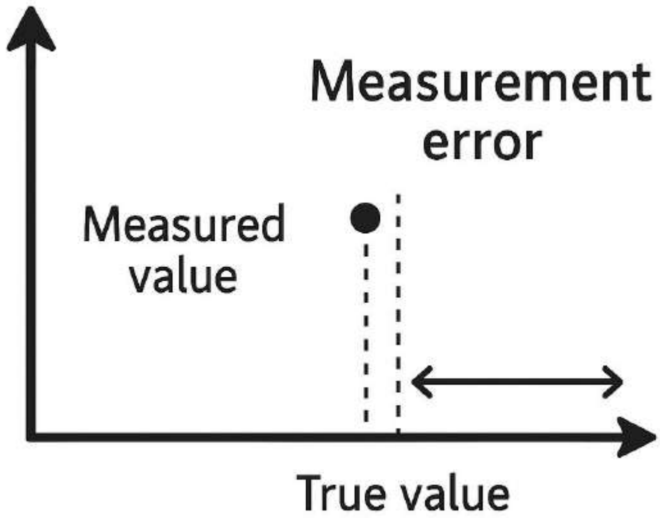


Figure 1.2: Measurement errors.

📌Real-life consequence: In aerospace engineering, a tiny measurement error in the thickness of turbine blades can lead to catastrophic failure due to imbalance at high speeds.

Accuracy and Precision

Accuracy: How close a measured value is to the true value. To determine the accuracy of the readings one has to find the average and then compare it with the true value. The average of accurate readings should be very close to the true value. This means accuracy is measured against the true value.

Precision: How close repeated measurements are to each other, regardless of accuracy. To easily determine the precision of the measurement one has to find the average and then see how far are the readings from the average. This means precision is measured against the mean value.

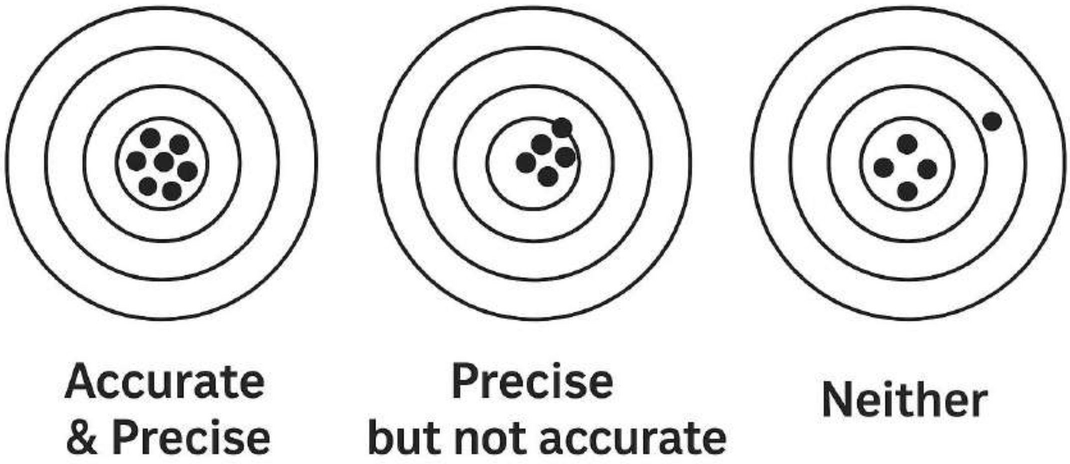


Figure 1.3: Precision and Accuracy

📌 **Example**:

Measuring a rod of true length 10.00 cm.

If your results are 9.99 cm, 10.01 cm, and 10.00 cm → **accurate and precise**.

If your results are 9.50 cm, 9.50 cm, 9.51 cm → **precise but not accurate**.

🔧 **In precision machining**, accuracy ensures parts fit properly, while precision ensures repeatability in mass production. Both are essential for quality assurance.

Significant Figures

Significant figures communicate the reliability of a measurement.

Rules:

Non-zero digits are always significant.

Zeros between non-zero digits are significant.

Leading zeros are not significant.

Trailing zeros are significant only if a decimal point is present.

📌 **Example:**

0.00450 m → 3 significant figures.

123.00 m → 5 significant figures.

🔧 Engineering relevance: Reporting a measurement as 5.000 mm (4 sig. figs) instead of 5 mm (1 sig. fig) makes a huge difference in tolerance-sensitive applications like watchmaking or medical implants.

Vectors

A vector is a physical quantity that has both magnitude and direction.

Scalars: Magnitude only (e.g., mass, temperature).
Vectors**:** Magnitude + direction (e.g., displacement, velocity, force).

📌 Example: A car traveling 60 km/h north has a vector velocity. If we only say, “60 km/h,” we are describing a scalar speed.

🔧 Real-life use: In civil engineering, vectors are used to determine the resultant force on a bridge. Miscalculating force direction can lead to unsafe designs.

Vector Components and Operations

a) Vector Representation

A vector can be represented in component form:

$$\vec{A} = A_X\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$$

A_x, A_y, A_z are components along the x, y, and z axes.

📌 Example: A force of 100 N acts at an angle of 30° above the x-axis.

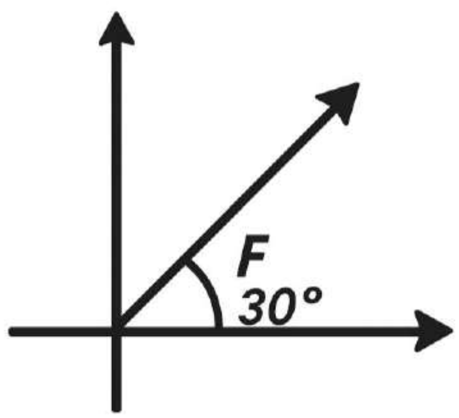


Figure 1.4: A force of 100 N acts at an angle of 30° above the x-axis.

$$F_x = 100cos30° = 86.6N$$

$$F_y = 100sin30° = 50.0N$$

Thus, the force is denoted as $\vec{F} = 86.6\hat{\imath} + 50.0\hat{\jmath}$

b) Vector Addition

If $\hat{A} = 3\hat{\imath} + 4\hat{\jmath}$ and $\hat{B} = -2\hat{\imath} + 6\hat{\jmath}$;

$\hat{A} + \hat{B} = (3 - 2\ )\hat{\imath} + (4 + 6)\hat{\jmath} = 1\hat{\imath} + 10\hat{\jmath}$

c) Dot Product (Scalar Product)

$$\vec{A} \cdot \vec{B} = |\vec{A}||\vec{B}|\, cos\, cos\, \theta$$

Used when calculating work done by a force.

📌 Example: A force of 50 N acts at 60° to the displacement of 10 m.

$$W = \theta\ = (50)(10)(cos\, cos\, 60\ °) = 250\, J$$

d) Cross Product (Vector Product)

$$\vec{A} \times \vec{B} = |\vec{A}||\vec{B}|\, sin\, sin\, \theta$$

Used when calculating torque.

📌 Example: A force of 20 N applied at a distance of 0.3 m from a pivot at 90° gives:

$$\tau = \theta\ = (20)(0.3)(sin\, sin\, 90\ °) = 6\, Nm$$

🔧 Real-life use: Torque calculations are vital in automotive engineering when tightening bolts. Under-tightening leads to failure; over-tightening may strip threads.

Applications of Vectors in Engineering Physics

Displacement: Mapping robot arm movement in manufacturing.

Velocity: Aircraft navigation accounting for wind velocity vector.

Acceleration: Safety design in cars (seatbelts, airbags depend on acceleration forces).

Force: Determining load distribution on building structures.

Momentum: Car crash analysis for safety engineering.

Work & Energy: Efficiency analysis in power plants and machines.

📌 Real-life scenario in machining:
When using a CNC (Computer Numerical Control) milling machine, tool movement is programmed in vector form. The cutter path is determined by vector displacements in x, y, and z directions. Any error in measurement or vector calculation could result in tool crashes, damaged parts, or costly downtime.

Figure 1.5: A person machining a component.

Activity 1.1: Laboratory Practical

Practical Exercise: *Measurements using Vernier Callipers and Micrometre Screw Gauge*

In this laboratory session, students will practice using precision instruments to measure the dimensions of small objects such as wires, rods, or spherical balls. The exercise will reinforce the importance of accuracy, precision, and significant figures in experimental work.

- **Vernier Callipers**: Students will measure internal diameters, external diameters, and depths of objects, learning how to read the vernier scale correctly.

- **Micrometre Screw Gauge**: Students will measure the diameter of thin wires or rods, emphasizing the use of the thimble and sleeve scales for high precision.

Learning Outcome: By completing this activity, you will gain firsthand experience in making reliable measurements, estimating errors, and applying theoretical concepts of measurement in practice.

Exercise:

1. How many significant digits are in:
   a. 23,000
   b. 4000.00
   c. 0.00023040
2. Draw a labelled diagram to show the forces acting on a skydiver falling with a constant velocity.
3. Hooke's law states that the force, F, in a spring extended by a length x is given by $F = -kx$. From Newton's second law $F = ma$, where m is the mass and a is the acceleration. Determine the dimensions of the spring constant k.
4. Two objects are moving at constant velocities: $\vec{V}_A = (2\hat{\imath} - 5\hat{\jmath})m/s$, $\vec{V}_B = (-2\hat{\imath} + 4\hat{\jmath})m/s$.
   a) Which object is moving faster?
   b) Find the angle between objects' trajectories.

5. a) Determine the resultant force on a combination of forces given in figure 1.4 below:

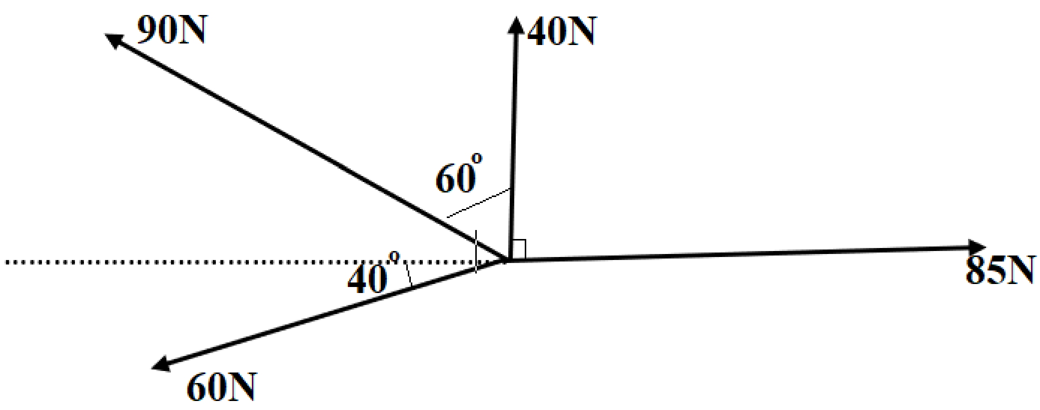


Figure 1.4: The diagram showing four coplanar forces.

b) If the resultant force you have calculated in (a) is used to pull an object of mass 5kg on a frictionless surface, what a

Chapter 2: Kinematics and Forces

Chapter Overview

- Kinematics and Forces are two fundamental topics in physics that deal with the motion and interaction of objects.
- Kinematics describes how objects move, such as their position, velocity, acceleration, and trajectory.
- Forces explain why objects move, such as the effects of gravity, friction, tension, and pressure.
- By applying the principles of kinematics and forces, we can analyse and predict the behaviour of various physical systems, such as projectiles, pendulums, springs, and collisions.

Unit Objectives

By the end of this unit, students should be able to:

- Describe and analyse motion in one and two dimensions, using vectors and scalar quantities.
- Apply Newton's laws of motion to solve problems involving forces.
- Understand the concepts of work, energy, and momentum.
- Apply the concepts of kinematics and forces to engineering problems.

2.1 Introduction

Kinematics and forces are central pillars of physics and engineering.

- **Kinematics** is the study of motion without considering its causes. It describes how objects move in terms of displacement, velocity, and acceleration.
- **Dynamics**, through the concept of forces, explains *why* objects move the way they do. Forces such as gravity, friction, tension, and applied pushes/pulls govern the motion of real-world systems.

Together, kinematics and forces allow engineers to design machines, predict projectile trajectories, analyse vehicle motion, study structures under load, and even understand planetary orbits.

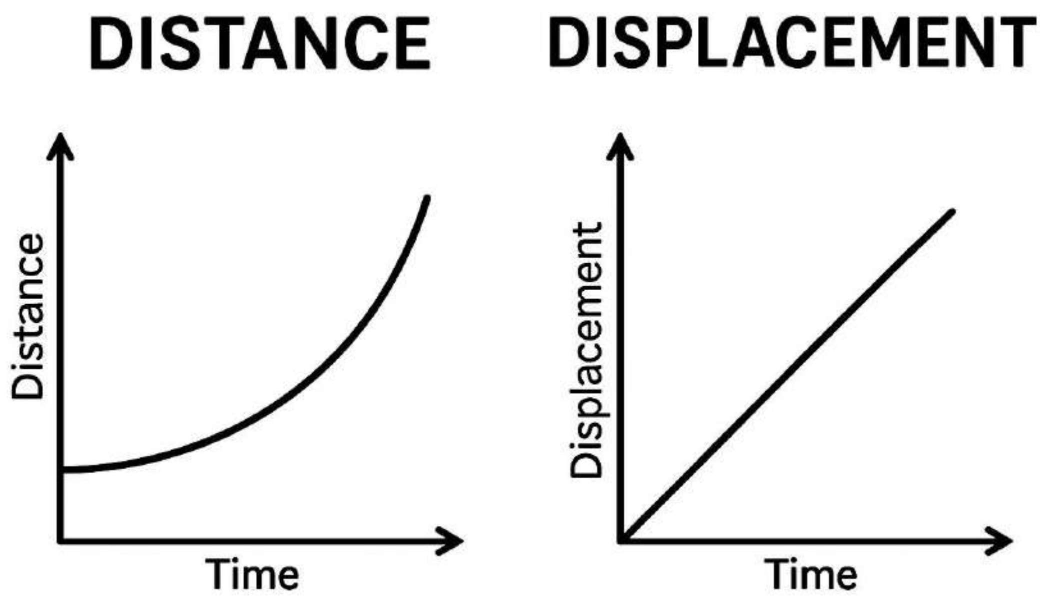
2.2 Kinematics in One Dimension

2.2.1 Displacement and Distance

Distance (d): A scalar quantity that measures the total length of the path travelled, regardless of direction.

Displacement (Δx): A vector quantity defined as the change in position:

$$\Delta x = x_f - x_i$$



The **distance-time graph** always increases with time since distance is a scalar quantity that only measures the total path covered, regardless of direction. The curve indicates that the object is accelerating.
The **displacement-time graph**, on the other hand, can increase, decrease, or stay constant depending on the motion, since displacement is a vector quantity that measures the shortest change in position. The straight line here shows uniform motion in one direction.

2.2.2 Speed and Velocity

Speed (v): The rate of change of distance (scalar).

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

Velocity (v): The rate of change of displacement (vector).

$$v = \frac{\Delta x}{\Delta t}$$

It can be positive or negative, depending on direction.

2.2.3 Acceleration

Defined as the rate of change of velocity:

$$a = \frac{\Delta v}{\Delta t}$$

Positive acceleration: Object speeds up.

Negative acceleration (deceleration): Object slows down.

2.2.4 Equations of Motion in 1D

For constant acceleration, the following equations apply:

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Where.

u = initial velocity

v = final velocity

a = acceleration

s = displacement

t = time

2.2.5 Free Fall Motion

In free fall, only gravity acts (a=g=9.81 ms^2 near Earth).

- Velocity after time t:

$$v = gt$$

- Displacement after time t:

$$s = \frac{1}{2}gt^2$$

Worked Example 2.1

A stone is dropped from rest from a 50 m building. Find:
(a) The time to reach the ground.
(b) The velocity on impact.

Solution:

$$s = \frac{1}{2}gt^2 \Rightarrow 50 = \frac{1}{2}(9.81)t^2$$

$$t = \sqrt{\frac{100}{9.81}} = 3.19s$$

$$v = gt = 9.81(3.19) \approx 31{,}3\,ms^{-1}$$

Answer: Time = $3.19s$, Velocity = $31{,}3\,ms^{-1}$ (downward).

2.3 Kinematics in Two Dimensions

- Many real-world motions occur in a plane, requiring vector decomposition into **x- and y-components**.

2.3.1 Motion in a Plane

Position vector:

$$\vec{r}(t) = x(t)\hat{\imath} + y(t)\hat{\jmath}$$

Velocity vector:

$$\vec{v}(t) = \frac{d\vec{r}}{dt} = v_x\hat{\imath} + v_y\hat{\jmath}$$

Acceleration vector:

$$\vec{a}(t) = \frac{d\vec{v}}{dt} = a_x\hat{\imath} + a_y\hat{\jmath}$$

2.3.2 Projectile Motion

Projectile motion combines uniform horizontal motion and vertical free fall.

Horizontal motion (no acceleration):

$$x = vxt$$

Vertical motion (accelerated by gravity):

$$y = v_y t - \frac{1}{2}gt^2$$

Trajectory equation:

$$y = x\tan\ \theta - \frac{gx^2}{2v_0^2 cos^2\theta}$$

where θ is launch angle, v_0 is initial velocity.

Worked Example 2.2

A football is kicked with speed $20\,ms^{-1}$ at$30°$∘ ab ov e th e ground. F ind:

(a) T ime of fligh t

(b) Max imum h eigh t

(c) H oriz ontal range

Solution:

$$vx = v0\,cos\,cos\,30\ \circ = 20 \times 0.866 = 17.32\,\frac{m}{s}$$

$$vy = v0sin\ 30 \circ = 20 \times 0.5 = 10\,m/s$$

(a) **Time of flight:**

$$T = \frac{2v_y}{g} = \frac{20}{9.81} = 2.04\,s$$

(b) **Max height:**

$$H = \frac{v_y^2}{2g} = \frac{100}{19.62} = 5.1\,m$$

(c) **Range:**

$$R = v_x T = 17.32(2.04) = 35.3\,m$$

✅ The ball travels $35.3\,m$ in $2.04\,s$, reaching $5.1\,m$ high.

2.4 Newton's Laws of Motion

2.4.1 First Law – Inertia

An object continues in uniform motion unless acted upon by a net force.

Engineering Example: A train requires brakes (external force) to stop despite its large inertia.

2.4.2 Second Law – Acceleration

Force is proportional to acceleration:

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

Example: Doubling the mass of a car requires doubling the engine force to achieve the same acceleration.

2.4.3 Third Law – Action-Reaction

For every action, there is an equal and opposite reaction.

Example: A rocket lifts off because the expelled gases push downward, while the rocket experiences an upward thrust.

Worked Example 2.4

A 1200 kg car accelerates from rest to $20\,m/s$ in $10\,s$. Find the net force.

$$a = \frac{v-u}{t} = \frac{20}{10} = 2\,ms^{-2}$$

$$F = ma = 1200(2) = 2400\,N$$

Required net force = 2400 N.

2.5 Work, Energy, and Momentum

2.5.1 Work

Work is the transfer of energy when a force is applied over a displacement.

The general formula is:

$$W = \vec{F} \cdot \vec{d} = Fd\theta$$

where θ is the angle between the force and displacement vectors.

👉 **Key Notes:**

Work is **positive** if the force has a component in the direction of displacement (e.g., pushing a cart forward).

Work is **negative** if the force opposes the motion (e.g., friction).

Work is **zero** if the force is perpendicular to displacement (e.g., centripetal force in circular motion).

Engineering Application:

Calculating the work done by engines, cranes, or pumps to move loads.

2.5.2 Energy

Energy is the capacity to do work. It exists in many forms, but two fundamental mechanical forms are:

2.5.3 Kinetic Energy

$$KE = \frac{1}{2}mv^2$$

Depends on mass and velocity.

Doubling velocity **quadruples** k inetic energy → critical in v eh icle crash analysis.

2.5.4 Potential Energy

Gravitational Potential Energy

$$PE = mgh$$

where h is height above reference point.

Elastic Potential Energy: Stored in springs and elastic bodies:

$$PE_{elastic} = \frac{1}{2}kx^2$$

where k is the spring constant, x is extension/compression.

2.5.5 The Work-Energy Theorem

The net work done on a body is equal to the change in its kinetic energy:

$$Wnet = \Delta KE = KE_f - KE_i$$

👉 This theorem connects **forces** directly to **motion**.

Example: Braking a car converts kinetic energy into heat (via friction).

2.5.6 Momentum

Momentum measures the “quantity of motion” an object has:

$$p = mv$$

Conservation of Momentum

In an isolated system with no external forces:

$$m_1v_1i + m_2v_2i = m_1v_1f + m_2v_2f$$

👉 Critical for analysing **collisions, rocket propulsion, and explosions**.

2.5.7 Impulse and Momentum

Impulse is the product of force and time:

$$J = F\Delta t = \Delta p$$

- Large forces over short times cause big momentum changes (e.g., hammer strikes).
- Safety devices (airbags, cushioned barriers) **increase time of impact** → reduce force ex p erienced.

2.5.8 Connecting Work, Energy, and Momentum

F orce × displacement = Work → Energy

F orce × time = Impulse → Momentum

These two principles are like *two sides of the same coin*. One relates to how forces act over distances, the other to how they act over time.

2.5.9 Engineering Applications

1. **Cranes & Lifting Machines** – Work and potential energy calculations ensure motors are powerful enough.
2. **Automobiles** – KE and momentum determine braking distance, crash safety, and fuel efficiency.
3. **Sports Engineering** – Energy and momentum transfer in kicking a ball, hitting a golf shot, or designing protective gear.
4. **Rocket Propulsion** – Momentum conservation explains thrust: expelling gases at high speed propels the rocket forward.
5. **Industrial Machines** – Flywheels store rotational kinetic energy to smooth out energy supply.

Worked Example 2.4

A 2 kg block is pushed with a force of 10 N over 5 m horizontally. Calculate the work done.

$$W = \theta \ = 10 \times 5 \times \cos \cos 0° \ = 50 J$$

✅ Work = 50 J.

Exercise

1. A 10 kg block is pushed up a smooth incline 5 m long at an angle of $30°$ with a constant force of 60 N.
   a) Calculate the work done by the applied force.
   b) Find the gain in gravitational potential energy of the block.
   c) Explain why the two results differ or agree.
2. A 1200 kg car is moving at 25 m/s.
   a) Calculate its kinetic energy.
   b) If the driver brakes and the car stops in 50 m, find the average retarding force.
3. A spring with constant k=400 N/m is compressed by 0.1 m.
   a) Calculate the elastic potential energy stored.
   b) If the spring launches a 2 kg block horizontally, find the velocity of the block (neglecting friction).
4. A 0.2 kg ball moving at 10 m/s strikes a stationary 0.3 kg ball in a perfectly elastic collision.
   a) Find the velocities of both balls after impact.
   b) Verify conservation of momentum.
   c) Verify conservation of kinetic energy.
5. During a car crash, a passenger of mass 70 kg is brought from 20 m/s to rest.
   a) Calculate the change in momentum.
   b) If this happens in 0.1 s (without an airbag), find the average force.
   c) If an airbag increases the time to 0.5 s, find the new average force.
   d) Discuss the role of airbags using your results.

Chapter 3: Work and Energy

3.1 Introduction to Work and Energy

Work and energy are fundamental concepts in physics and engineering. Work describes the transfer of energy when a force is applied to an object causing displacement, while energy represents the capacity to do work. These two concepts are closely related and underpin many engineering systems, from machines and engines to electrical devices and construction processes.

Understanding work and energy enables engineers to analyse, design, and optimize processes for efficiency and sustainability.

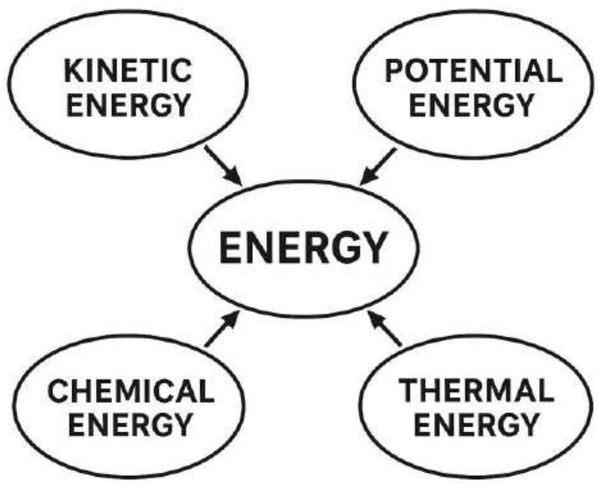


Figure 3.1: Relationship between different forms of energy.

3.2 What is Work?

In physics, work is done when a force is applied to an object and the object is displaced in the direction of the force.

$$W = \vec{F} \cdot \vec{d} = Fd\cos\theta$$

Where:

W = Work done (Joules, J)

F = Magnitude of the force (N)

d = Displacement of the object (m)

θ = Angle between force and displacement

Key Notes:

Work is positive if the force has a component in the direction of displacement.

Work is negative if the force opposes displacement (e.g., friction).

If displacement is zero, no work is done.

Engineering Example:

A crane lifting a 200 kg steel beam vertically by 5 m does positive work against gravity:

$$W = Fd = (200 \times 9.81)(5) = 9810\, J$$

3.3 What is Energy?

Energy is defined as the capacity to do work. It exists in different forms such as kinetic, potential, thermal, chemical, and electrical.

The law of conservation of energy states that energy cannot be created or destroyed, only transformed from one form to another.

Unit of energy: Joule (J)

1 Joule = Work done when a force of 1 N displaces an object by 1 m in the direction of the force.

3.4 The Work-Energy Theorem

The work done on an object is equal to the change in its kinetic energy:

$$W = \Delta KE = KE_f - KE_i$$

Example:

A car of mass 1000 kg accelerates from rest to 20 m/s.

$$W = \frac{1}{2} mv^2 = \frac{1}{2}(1000)(20^2) = 200\,000\,J$$

3.5 Types of Energy

Energy appears in multiple forms:

1. Kinetic Energy (KE): Energy due to motion

$$KE = ½ mv^2$$

2. Potential Energy (PE): Energy stored due to position or configuration

Gravitational PE : $PE = mgh$,

Elastic PE $PE = ½ kx^2$

3. Thermal Energy: Due to particle motion (heat).
4. Electrical Energy: Work done by moving electric charges.
5. Chemical Energy: Stored in bonds, released during reactions.
6. Nuclear Energy: Released from atomic nuclei (fission/fusion).

3.6 Calculating Work and Energy

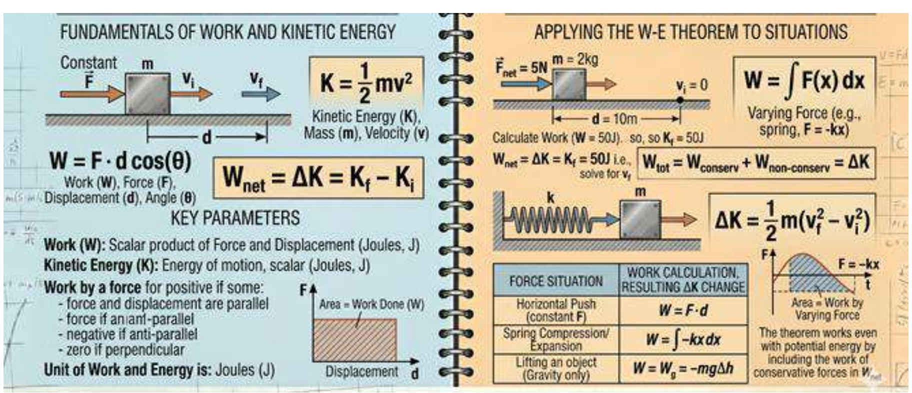


Figure 3.2: Illustration of the work and energy theorem

Work Done by a Constant Force

$$W = Fd\cos\theta$$

Example:

Pushing a cart with 50 N force over 10 m at 30°

$$W = 433\,J$$

Work Done by a Variable Force

$$W = \int_{x_1}^{x_2} F(x)\ dx$$

Example:

Work done by a spring

$$W = \int_0^x kx\ dx = \frac{1}{2}\,kx^2$$

Work Done by Friction2

$W = -f_k\,d,$

Where $f_k = \mu_k N,$ the kinetic friction force

Example:

10 kg block slides 5 m on a surface with μ_k = 0.2

$f_k = \mu_k mg = 0.2 \times 10 \times 9.81 = 19.62N$

$$W = 19.62 \times 5 = -98.1\,JW = mgh$$

3.7 Energy Calculations and Applications

- Engineering Mechanics: Calculating lifting power of cranes.
- Automotive: Work-energy theorem used in braking systems.
- Renewable Energy: Energy conversion efficiency in wind turbines.
- Civil Engineering: Potential energy considerations in dam design.

3.8 Applications of the Work-Energy Theorem

- Design of shock absorbers (dissipation of KE).
- Determining required motor power in conveyor systems.
- Estimating braking distances of vehicles.
- Analysing roller coasters and structural loads.

3.9 Solving Engineering Problems Involving Work and Energy

Example Problem:
A 5 kg block slides down a frictionless incline of 4 m height. Find velocity at the bottom.

$$PE_{top} = KE_{bottom}$$

$$mgh = \frac{1}{2}mv^2$$

$$5 \times 9.81 \times 4 = \frac{1}{2} \times 5v^2$$

$$v = \sqrt{(2gh)}$$

$$v = \sqrt{78.48} = 8.85\,m/s$$

3.10 Summary

- Work is the product of force and displacement in the direction of force.
- Energy is the capacity to do work, existing in many forms.
- The work-energy theorem connects force, motion, and energy.
- Different forces (gravity, friction, variable forces) influence work differently.
- Applications in engineering are vast, from machines to infrastructure.

Exercises

1. A 1000 kg car accelerates from 10 m/s to 25 m/s. Calculate the work done on the car.
2. A spring with k = 500 N/m is compressed by 0.1 m. Find the potential energy stored in the spring.
3. A block of 20 kg is pulled 10 m with a force of 80 N at 30°. Calculate the work done.
4. A 50 kg person climbs a staircase of height 3 m. Find the work done against gravity.
5. Explain how the work-energy theorem is applied in the design of car braking systems.

Chapter 4: Momentum, Impulse, and Collisions

4.1 Momentum

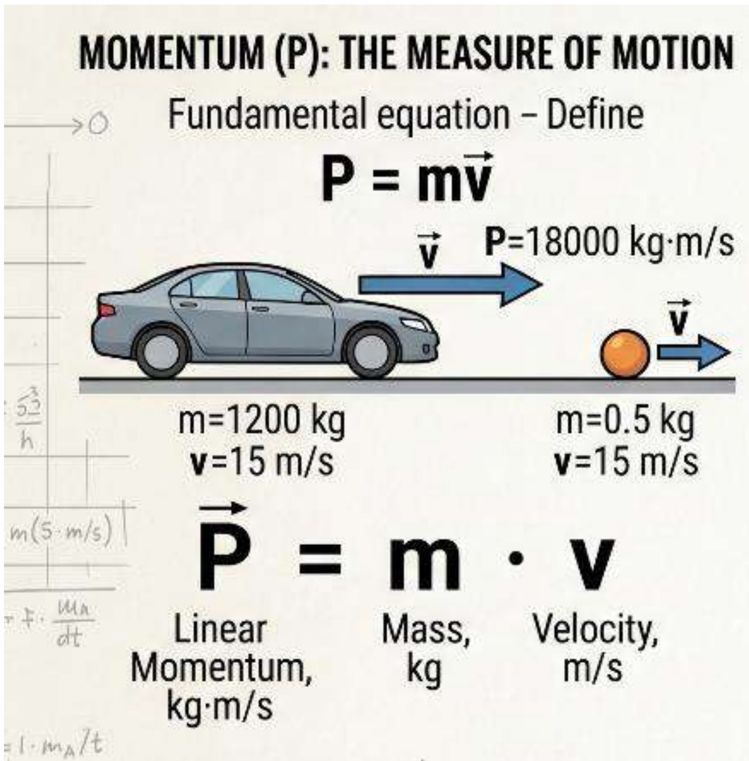


Figure 4.1: Image showing the momentum of a vehicle

Definition of Momentum

Momentum is a fundamental concept in physics that measures the amount of motion an object possesses. It depends on two key factors:

$$p = mv$$

kg·m/s),

m = mass of the object (kg),2

v = velocity of the object (m/s).

Momentum is a vector quantity, meaning it has both magnitude and direction. An object moving east at 10 m/s with momentum of $100\ kg \cdot m/s$ is different from an object moving west with the same magnitude of momentum.

Key Idea: The greater the mass and velocity of an object, the larger its momentum.

Types of Momentum

Linear Momentum

This is momentum that applies to objects moving in a straight line.

Example: A moving truck, a rolling football.

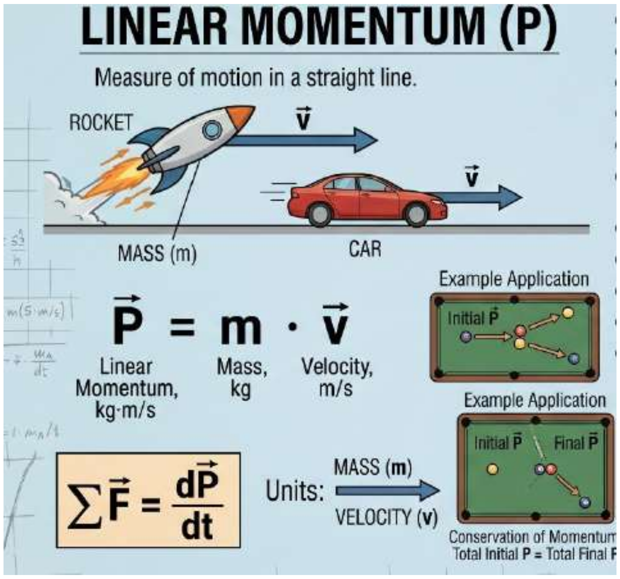


Figure 4.1: Linear momentum

Angular Momentum

Associated with rotating or spinning objects.

Defined as: $L = I\omega$ where I is the moment of inertia and ω is angular velocity.

Example: A spinning wheel, a rotating planet.

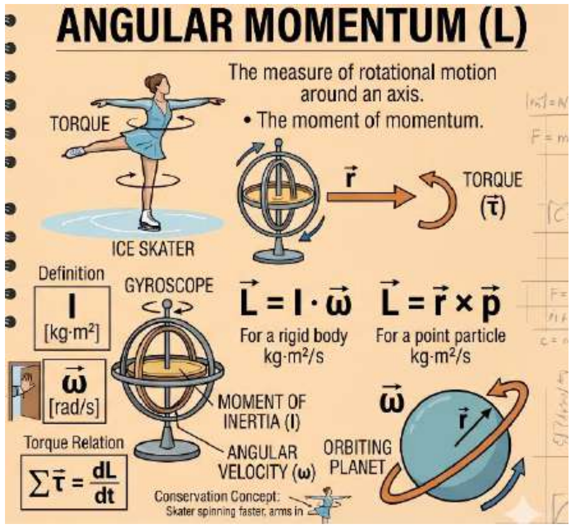


Figure 4.2: Angular momentum illustration

Examples from Everyday Life

- A heavy truck moving slowly can have more momentum than a small car moving fast because of its larger mass.
- In sports, a cricket ball hit with force carries large momentum, making it harder for the fielder to stop.
- In space travel, rockets rely on high-speed exhaust gases to gain momentum in the opposite direction.

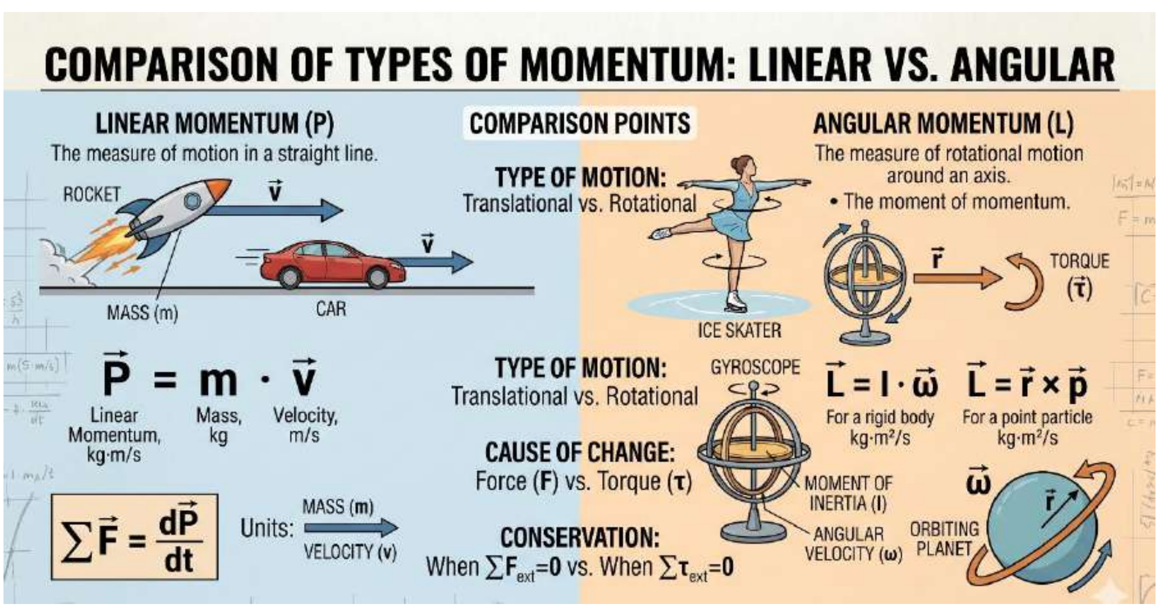


Figure 4.3: Comparison of type of Momentum

Worked Example 1: Comparing Momentum of a Truck and a Bullet

A truck of mass 2000 kg is moving at 15 m/s. A bullet of mass 0.02 kg travels at 600 m/s. Compare their momenta.

Solution:

p_{truck} = mv = 2000 × 15 = 30,000 kg·m/s

p_{bullet} = 0.02 × 600 = 12 kg·m/s

Result: Although the bullet is much faster, the truck's larger mass gives it a far greater momentum.

Worked Example 2: Football Kick

A football of mass 0.5 kg is initially at rest. A player kicks it, and it moves with a velocity of 20 m/s. Calculate the momentum of the football.

Solution:

$$p = mv = 0.5 \times 20 = 10\, kg \cdot m/s$$

Key Points to Remember

Momentum combines both mass and velocity.

It is a vector quantity thus direction matters.

Even small, fast-moving objects can have significant momentum, but usually heavy, fast objects carry the most momentum.

4.2 Impulse

Definition of Impulse

Impulse is the product of force and the time interval over which the force acts. It represents the change in momentum of an object.

$$J = F\Delta t = \Delta p$$

kg·m/s

F = force applied (N),

Δt = time of action (s),

Δp = change in momentum.

Impulse is a vector quantity and always acts in the direction of the force applied.

Units of Impulse

Impulse has the same units as momentum: $kg \cdot m/s$ (or equivalently, Newton-second, N·s).

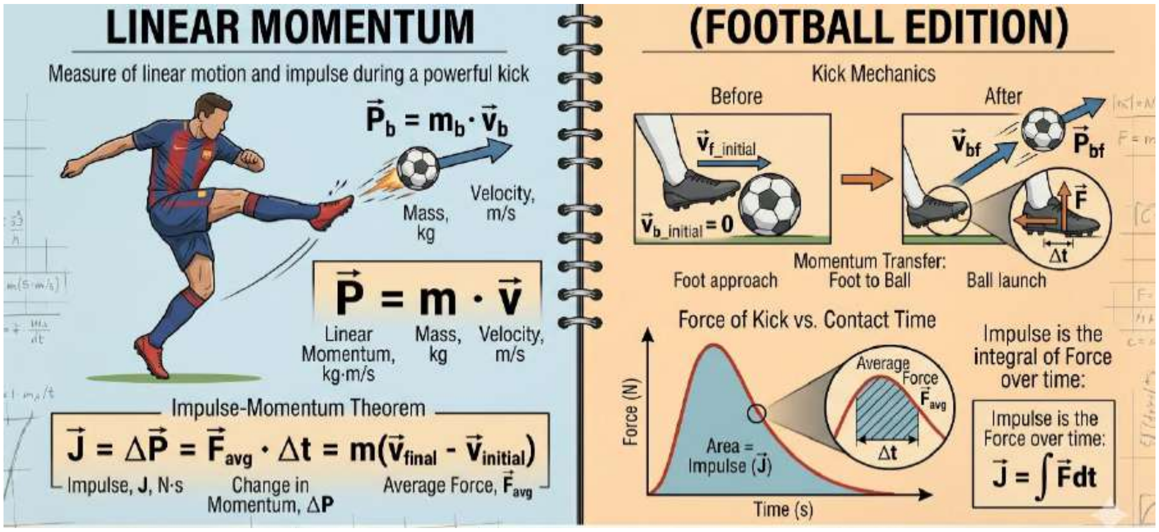


Figure 4.4: Linear Momentum and Impulse

Examples from Everyday Life

Car airbags increase the time of collision, reducing the force on passengers.

A cricket player lowers their hands while catching the ball to reduce the impact force.

Athletes use cushioned shoes to reduce impulse forces on landing.

Worked Example 1: Impulse of a Force

A force of 200 N acts on a 10 kg object for 0.5 s. Calculate the impulse and the change in momentum.

Solution:

$$J = F\Delta t = 200 \times 0.5 = 100\, N \cdot s$$

Result: The impulse is 100 N·s, meaning the object's momentum changes by 100 $kg \cdot m/s$.

Worked Example 2: Catching a Ball

A 0.15 kg ball traveling at 20 m/s is caught and stopped in 0.1 s. Determine the average force exerted on the catcher's hand.

Solution:

$$Initial\ momentum = (0.15 \times 20) = 3\, kg \cdot m/sFinal\ momentum = 0\ (ball\ stopped)\Delta p = 0 - 3 = -3\, kg \cdot m/sImpulse\ J = \Delta p = -3\, N \cdot sF = J/\Delta t = -3\,/\,0.1 = -30\, N$$

Key Points to Remember

- Impulse is the change in momentum caused by a force acting over time.
- Longer interaction time reduces the average force experienced.
- Safety devices (helmets, airbags, cushioned shoes) work by increasing collision time, reducing forces.

Exercises

1. State the Work Kinetic energy theorem both in words and mathematically.
2. An elevator cab of mass *m* = 500 kg is descending with speed v_i = 4.0 m/s when its supporting cable begins to tighten, allowing it to fall with constant deceleration $\vec{a} = \frac{\vec{g}}{5}$ m/s^2. Use the work-kinetic energy theorem to determine the cab's kinetic energy at the end of a 10 m fall.
3. Sphere A of mass 400 g is travelling horizontally with a speed of 6 m s^{-1} when it collides with sphere B of mass 150 g travelling in the opposite direction with a speed of 9 m s^{-1}. Sphere A comes to rest as a result of the collision. Calculate the new velocity of sphere B.

4. A boy with mass 75 kg running at $5\ m/s$ jumps on to a 20 kg trolley travelling in the same direction at $2\ m/s$. Calculate their common velocity.
5. The last part of a roller coaster's track is horizontal. The roller coaster is brought to rest using a constant braking force of 4300. N. It takes 9.00 s to bring the roller coaster to a stop from a speed of 23.0 m/s. Find the mass of the roller coaster.

Chapter 5: Fluid Mechanics (Enriched Draft with Integration)

5.1 Introduction

Fluid mechanics is the study of the behavior of fluids (liquids, gases, and plasmas) and the forces acting on them. Unlike solids, fluids can flow and change shape under the least applied force. Fluid mechanics is a foundational subject in engineering because it explains the behavior of systems involving water, air, oil, and other fluids in motion or at rest.

Applications span across civil engineering (dams, pipelines), mechanical engineering (pumps, turbines), aerospace (aircraft design, rocket propulsion), environmental engineering (water distribution, pollution control), and even biomedical sciences (blood flow in arteries).

Fluid mechanics is broadly divided into:

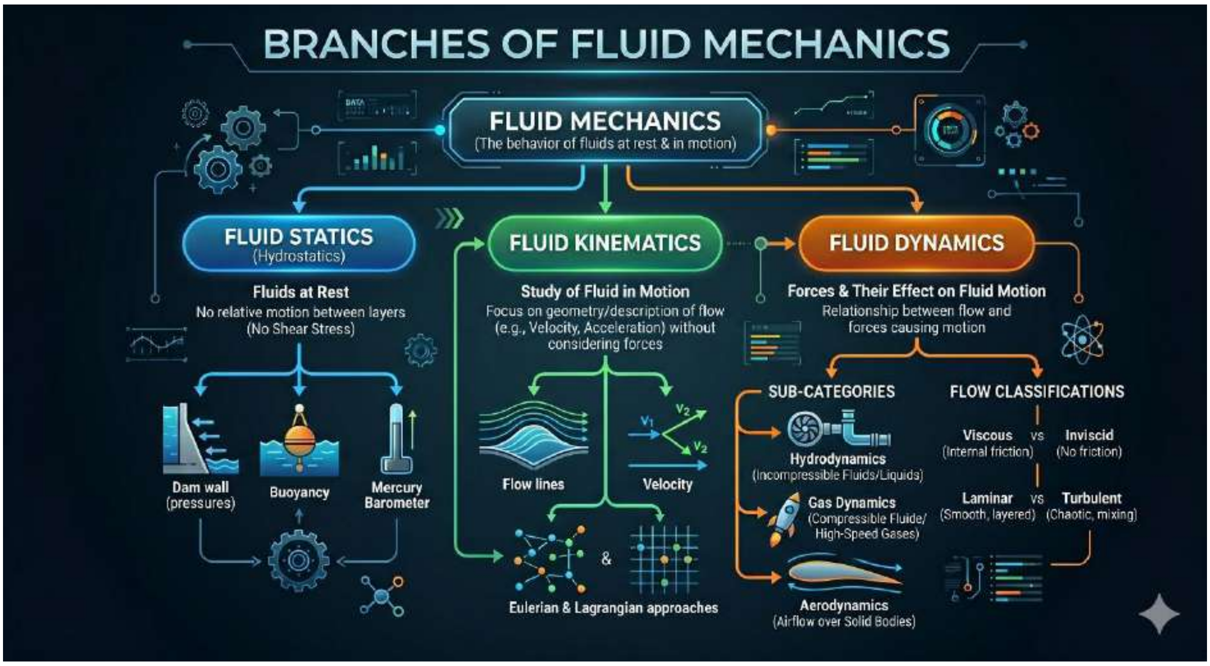


Figure 5.1: Branches of fluid mechanics

- **Fluid statics** – fluids at rest.
- **Fluid kinematics** – fluids in motion without considering forces.
- **Fluid dynamics** – fluids in motion under the influence of forces.

5.2 Properties of Fluids

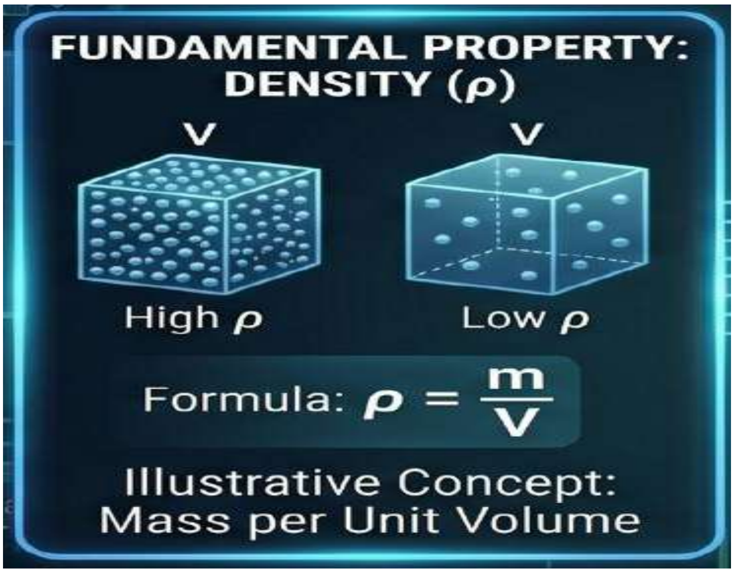


Figure 5.2: illustrative concept for density

1. **Density (ρ)**

$\rho = \frac{m}{V}$

where *m* is mass and *V* is volume.

- SI unit: **kg/m³**
- Water at room temperature: ~1000 kg/m³.
- Air at room temperature: ~1.225 kg/m³.

Application: Density determines buoyancy, fuel consumption in vehicles, and the lift of balloons/airships.

2. **Pressure (P)**

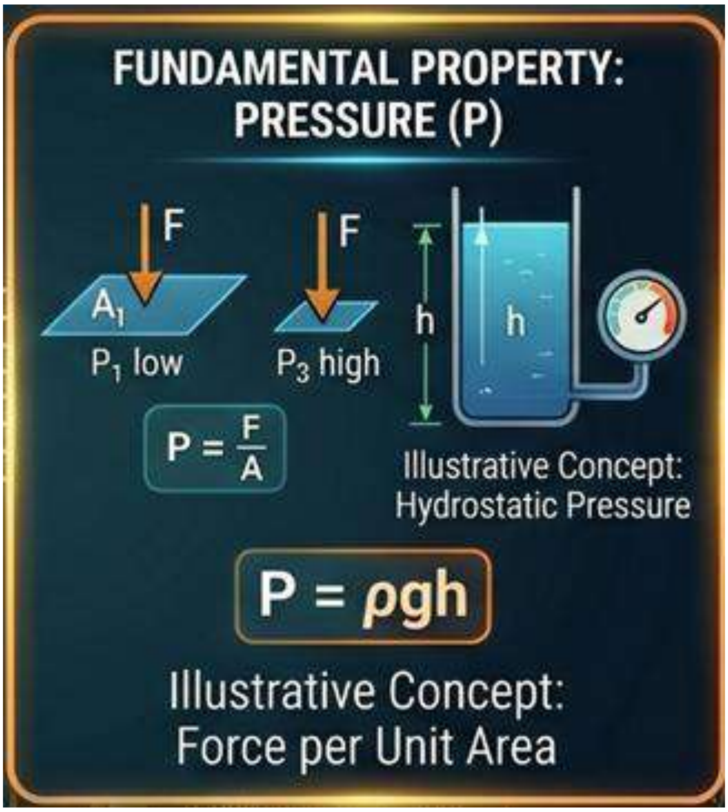


Figure 5.3: Illustrative concept for pressure

$$P = \frac{F}{A}$$

where *F* is the perpendicular force applied on area *A*.

- SI unit: **Pascal (Pa) = N/m²**

Hydrostatic pressure in a fluid column:

$$P = \rho g h$$

where *h* is depth in fluid, *ρ* is fluid density, and *g* is gravitational acceleration.

Example: Calculate the pressure of water at a depth of 5 m below the surface.

P=1000×9.81×5=49,050 Pa≈0.49 atm.

5.3 Fluid Statics

Pascal's Principle

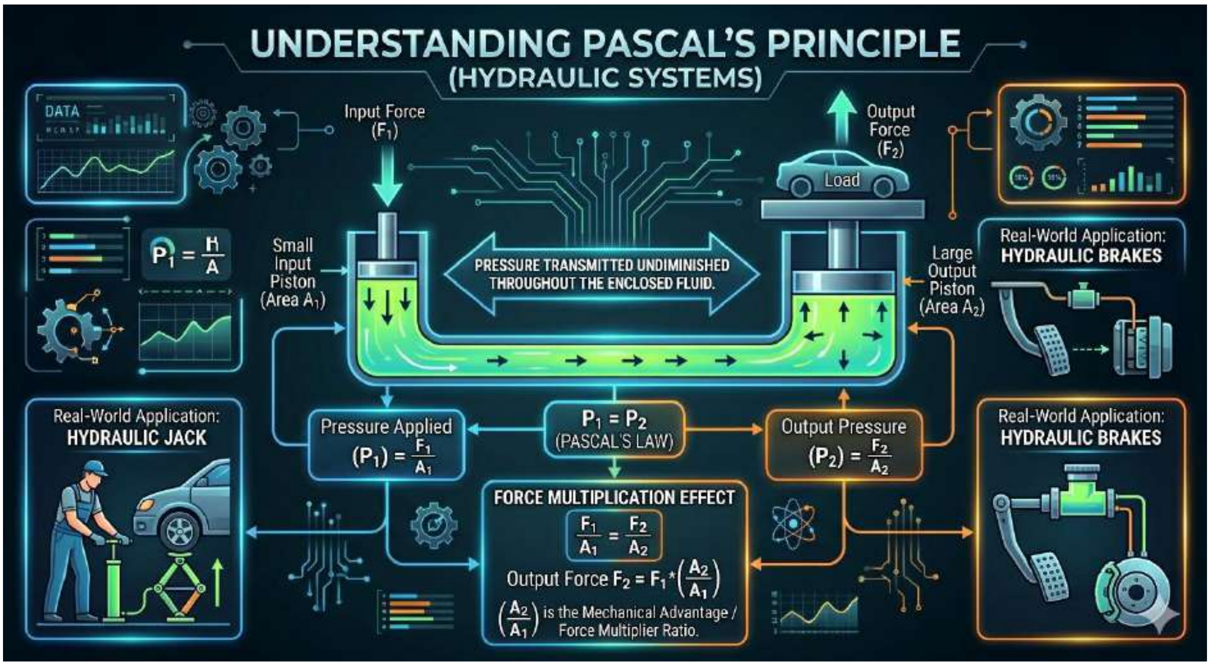


Figure 5.4: Summary Pascal's Principle

A change in pressure applied at any point in an enclosed fluid is transmitted equally in all directions.

Equal Pressure Transmission: The diagram shows that when pressure (P_1) is applied to the small input piston, that pressure is transmitted *undiminished* throughout the fluid to the larger output piston ($P_1 = P_2$).

Force Multiplication: Although the pressure is equal, the output force (F_2) is multiplied because the output piston has a much larger surface area (A_2). This is what allows a small input force to lift a heavy load, like a car.

Application: Hydraulic lifts and brakes in vehicles.

Archimedes’ Principle

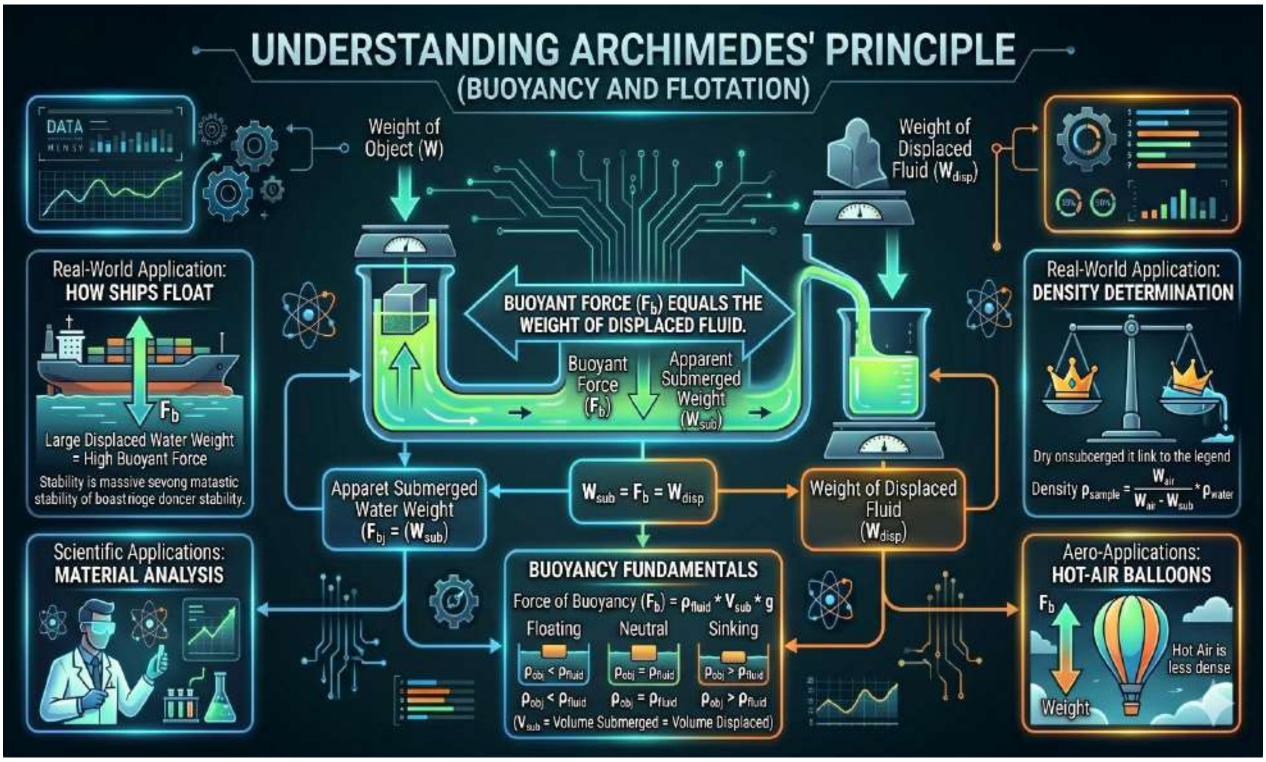


Figure 5.5: Illustration of Archimedes' Principle

A body wholly or partially submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced.

$$F_b = \rho_{fluid} g V_{displaced}$$

Where:

- F_b= buoyant force (N)
- ρ_{fluid} = density of the fluid (kg/m³)
- g = acceleration due to gravity (9.81 m/s²)
- $V_{displaced}$ = volume of fluid displaced (m³)

Key Insights

1. **Floating Objects:** If the buoyant force equals the object’s weight, it floats.
2. **Sinking Objects:** If the buoyant force is less than the object’s weight, it sinks.

3. **Neutral Buoyancy:** When buoyant force equals weight but object is fully submerged (e.g., submarines adjusting ballast).

Worked Example: 1 Floating

A wooden block of mass 1 kg and volume 0.002 m³ is placed in water. Will it float?

- Weight of block:

$W = mg = 1 \times 9.81 = 9.81\,N$

- Maximum buoyant force (if fully submerged):

$$F_b = \rho_{water} gV = 1000 \times 9.81 \times 0.002 = 19.62N$$

Since F_b>W, the block floats, but only part of it remains submerged until F_b=W

Fraction submerged:

$$\frac{V_{sub}}{V} = \frac{W}{F_b} = \frac{9.81}{19.62} = 0.5$$

So, **half of the block's volume is underwater**.

Worked Example 2 – Sinking

A steel ball of volume 0.001 m³ and mass 7.8 kg is placed in water.

- Weight:

$$W = 7.8 \times 9.81 = 76.52\,N$$

Buoyant force (fully submerged):

$$F_b = 1000 \times 9.81 \times 0.001 = 9.81\,N$$

Since $W > F_b$, the steel ball sinks.

Engineering and Real-Life Applications

- **Shipbuilding:** Despite steel being denser than water, ships float because their large hull encloses air, lowering the *average density*.
- **Submarines:** Adjust buoyancy by pumping water in/out of ballast tanks to sink or rise.

- **Hydrometers:** Instruments that float at different levels depending on liquid density (used in alcohol or battery testing).
- **Hot Air Balloons:** Air inside is heated → less dense than surrounding air → buoyant force makes balloon rise.
- **Dams & Reservoirs:** Engineers calculate buoyant forces acting on gates or submerged structures.

Quick Thought Experiment

If you drop a heavy stone in water while in a boat:

- When in the boat, it adds to the boat's total weight → boat sinks deeper → **more water displaced**.
- When thrown overboard, the stone sinks → it displaces only its volume, which is less than the volume displaced by the boat when carrying it.
- So the water level actually **falls** when the stone is thrown out.

5.4 Fluid Dynamics

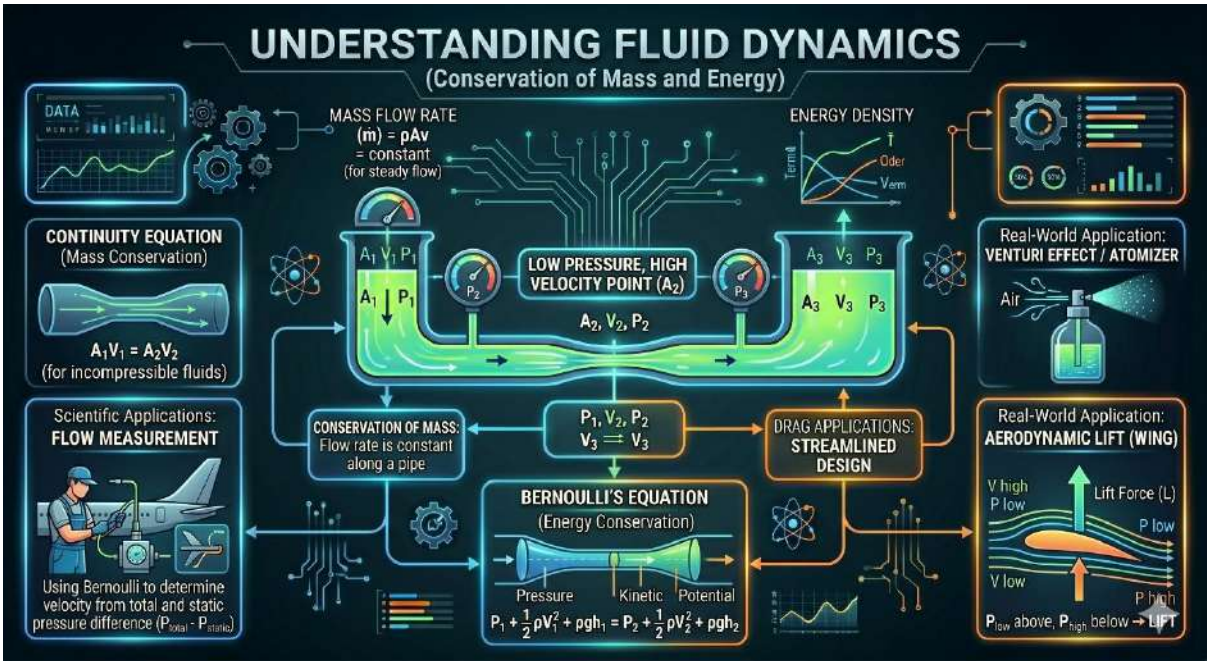


Figure 5.6: Illustration of Fluid Dynamics concept

Equation of Continuity

For an incompressible, non-viscous fluid:

$$A_1 v_1 = A_2 v_2$$

where A = cross-sectional area, v = velocity.

Application: Explains why water speeds up in a narrow hose nozzle.

Bernoulli's Principle

For steady flow of an incompressible, non-viscous fluid:

$$P + \frac{1}{2}\rho v^2 + \rho g h = constant$$

- P: fluid pressure
- ρv^2: dynamic pressure (kinetic energy per volume)
- $\rho g h$: hydrostatic pressure (potential energy per volume)

Energy Conversions in Bernoulli's Principle

Bernoulli's principle can be seen as a statement of the **conservation of mechanical energy in a fluid system**. It shows how energy shifts between three forms:

1. **Pressure Energy** → work done by fluid pressure
2. **Kinetic Energy** → energy due to motion $\frac{1}{2}\rho v^2$
3. **Potential Energy** → gravitational energy $\rho g h$

As a fluid flows:

- If velocity increases (narrow pipe), kinetic energy rises and pressure energy falls.
- If fluid rises in height, potential energy increases while pressure or velocity decreases.

- If pressure is high, it can be converted into velocity or lift.

Examples of Conversion:

- **Aircraft Wing:** Fast-moving air above wing → higher kinetic energy, lower pressure → lift is generated.
- **Venturi Effect (Carburettor/Sprays):** Narrow pipe → velocity increases, pressure drops → suction pulls in fuel or liquid.

5.5 Worked Example

Problem: A water pipe narrows from 0.05 m² to 0.01 m². If the velocity in the wide section is 2 m/s, find the velocity in the narrow section.

Solution:
From continuity equation,

$$A_1 v_1 = A_2 v_2$$

$0.05 \times 2 = 0.01 \times v_2$

$$v^2 = \frac{0.1}{0.01} = 10\, m/s$$

So, the velocity increases fivefold in the narrow section.

5.6 Real-Life Applications of Fluid Mechanics

- **Civil Engineering:** Design of dams, irrigation canals, and storm drains.
- **Mechanical Engineering:** Pumps, turbines, lubrication systems.
- **Aerospace:** Aerofoil lift, jet propulsion.
- **Environmental Engineering:** Pollution dispersion in rivers and atmosphere.
- **Biomedical Engineering:** Blood flow modelling, artificial heart valves.

Exercises

1. Calculate the difference in blood pressure (in atmosphere) between the heart and the foot in a person of height 2.00 m and the height from the heart to the head is 0.40 m and the density of blood is $1.06 \times 10^3 kg/m$.
2. The U-shape in Fig 1 contains two liquids in static equilibrium: water of density $998\ kg/m^3$ and an unknown liquid with unknown density. Find the density of the unknown liquid if h=155 mm and l=135 mm.

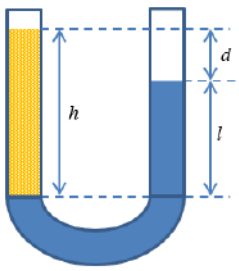


Figure 1

3. Your friend asks you to determine whether the ring that she recently bought is made of pure gold. (The density of gold is $1.93 \times 10^4\ \ kg/m^3$.) Using a thread of negligible mass and volume, you tie the ring to a very accurate spring balance and determine that in air it weighs $6.40 \times\ 10^{-3}\ \ N$. You then fully immerse the ring in a beaker full of water and find that its apparent weight is $6.00\ \times 10^{-3}\ N$. Determine if the ring is made of pure gold.
4. A 60.0-kg woman wearing high-heeled stilettos is invited into a home in which the kitchen has vinyl floor covering. The heel on each shoe is circular and has a radius of 0.5cm. If the woman balances on one heel, calculate the,
   a) pressure does she exert on the floor,
   b) Should the homeowner be concerned,
   c) Explain your answer on b.

Chapter 6: Oscillations

6.1 Introduction

Oscillations are periodic fluctuations around a stable equilibrium point. This unit is critical for engineers because almost every physical system, whether a skyscraper, a vehicle suspension, or an AC circuit, has a natural frequency at which it wants to vibrate. Understanding how to model, damp, or drive these vibrations is fundamental to structural stability and signal processing.

6.2 Types of Oscillations

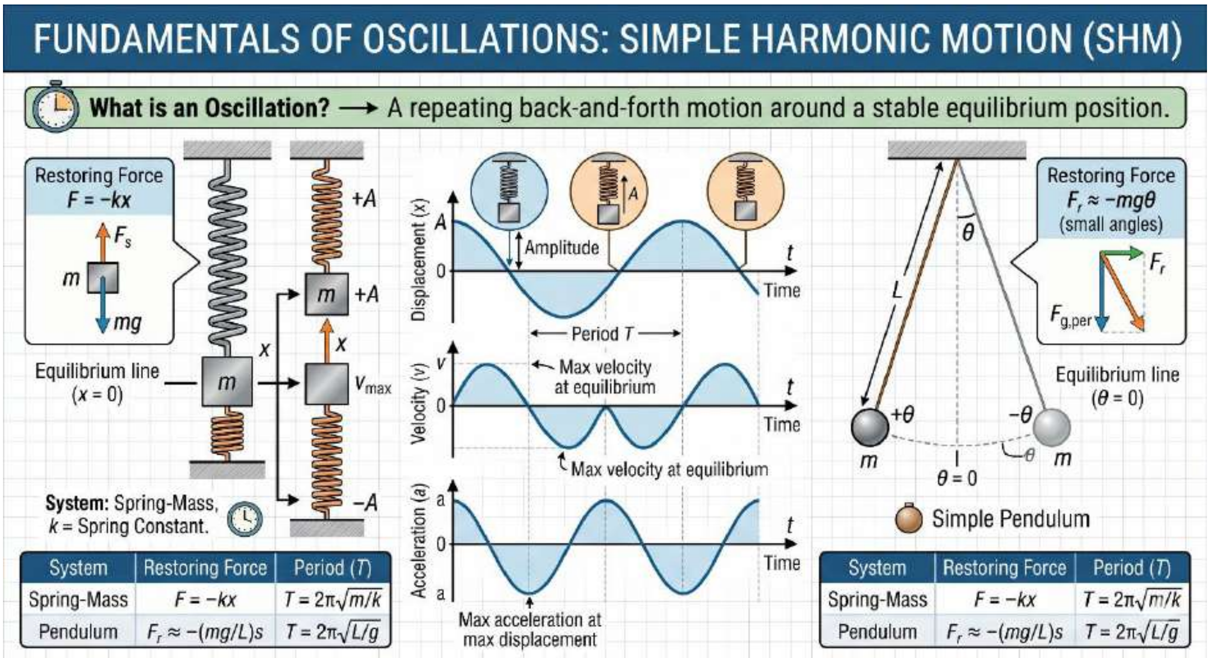


Figure 6.1: Illustration for Oscillations and SHM

Simple Harmonic Motion (SHM)

SHM is the simplest model of oscillation where the system contains no friction (conservative system).

The Condition for SHM: Restoring force is linear and opposite to displacement (Hooke's Law): $F_{restoring} = -kx$

Equation of Motion: Applying Newton's 2nd Law ($F = ma$):

$$m\frac{d^2x}{dt^2} = -kx \implies \frac{d^2x}{dt^2} + \frac{k}{m}x = 0$$

Defining the **natural angular frequency** $\omega_n = \sqrt{\frac{k}{m}}$:

$$\frac{d^2x}{dt^2} + \omega_n^2 x = 0$$

The Solution: The displacement as a function of time is sinusoidal:

$$x(t) = Acos(\omega_n t + \phi)$$

A: Amplitude (determined by initial energy)

ϕ: Phase constant (determined by initial position/velocity)

Energy in SHM

In an ideal SHM system, mechanical energy is conserved and continuously converts between potential and kinetic forms.

- **Potential Energy (U):** Stored in the spring.

$$U(t) = \frac{1}{2}kx^2 = \frac{1}{2}kA^2cos^2(\omega_n t + \phi)$$

Kinetic Energy (K): Possessed by the moving mass.

$$K(t) = \frac{1}{2}kv^2 = \frac{1}{2}m\omega_n^2A^2sin^2(\omega_n t + \phi)$$

Total Energy (E):

$$E = K + U = \frac{1}{2}kA^2 = constant$$

Damped Harmonic Motion

Real systems lose energy to their environment (friction, air resistance, viscosity). This is modelled by a damping force proportional to velocity.

The Damping Force: $F_d = -bv = -b\frac{dx}{dt}$

where b is the damping constant.

Equation of Motion: $m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$

Regimes of Damping: The behavior is determined by comparing the damping term to the restoring force term. We often define the damping parameter $\gamma = \frac{b}{2m}$.

Underdamped ($\omega_n > \gamma$**):** The system oscillates with decaying amplitude. The envelope of decay is exponential:$Ae^{-\gamma t}$.

Critically Damped ($\omega_n = \gamma$ **):** The system returns to equilibrium as fast as possible *without* overshooting or oscillating. **Crucial for engineering applications like vehicle shock absorbers.**

Overdamped ($\omega_n < \gamma$**):** The damping is so strong that the system returns to equilibrium very slowly (sluggishly).

Forced Oscillations and Resonance

Occurs when an external periodic driver acts on the system: $F_{ext}(t) = F_0 cos\,(\omega_{dr}t)$.

Equation of Motion: $m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F_0 cos\,(\omega_{dr}t)$

Steady State Solution:

The system eventually oscillates at the driving frequency (ω_{dr}), not its natural frequency.

Resonance:

When the driving frequency matches the natural frequency ($\omega_{dr} \approx \omega_n$), the amplitude of oscillation peaks dramatically.

- **Q-Factor:** A measure of the "sharpness" of resonance. High Q means low damping and sharp resonance (e.g., a tuning fork). Low Q means high damping and broad resonance.

Applications of Oscillations in Engineering

Mechanical Systems

- **Suspension Systems**: Car shock absorbers are designed to be critically damped so that after a bump, the car returns to a steady level immediately without bouncing.
- **Structural Engineering:** Skyscrapers incorporate "Tuned Mass Dampers" massive pendulums near the top floor to counter oscillations caused by wind or earthquakes.

Electrical Systems (The RLC Circuit)

There is a direct mathematical equivalence between mechanical and electrical oscillations.

Inductor (L): Acts like Mass (m) – resists changes in current (velocity).

Capacitor (C): Acts like a Spring (k) – stores potential energy in an electric field.

Resistor (R): Acts like the Damping constant (b) – dissipates energy as heat.

Application: Radio tuners work by adjusting capacitance to create **Resonance** at a specific broadcast frequency, filtering out all other signals.

Optical and Atomic Systems

- **Quartz Crystals:** Used in watches and computers, these vibrate at a precise resonant frequency due to the piezoelectric effect, acting as the system's "heartbeat" or clock.
- **Molecular Vibrations:** Chemical bonds act like springs. Infrared spectroscopy uses resonance to identify molecules based on their vibrational frequencies.

6.6 Worked Examples

Example 1 – Mass-Spring Oscillator

A 0.5 kg mass is attached to a spring of stiffness 200 N/m. Find the frequency of oscillation.

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{200}{0.5}} = \sqrt{400} = 20\; rads^{-1}$$

$$f = \frac{\omega}{2\pi} = \frac{20}{6.283} \approx 3.18Hz$$

So, the system oscillates about 3 times per second.

Example 2 – Pendulum

A simple pendulum of length L=1.0 m. Find the period of small oscillations.

$$T = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{1}{9.81}} \approx 2.01s$$

So, it swings back and forth every ~2 seconds.

Real-Life Engineering Applications

- **Mechanical Systems:**
  - Car suspensions (damping).

- Clock pendulums (timekeeping).
- Seismographs (earthquake detection).

- **Electrical Systems (AC Circuits):**
  - LC circuits oscillate between electric and magnetic energy.
  - Resonance used in tuning radios and wireless communication.
- **Civil Engineering:**
  - Buildings/bridges designed to avoid resonance with wind or earthquake frequencies.
- **Medical Applications:**
  - Ultrasound imaging uses oscillations of high-frequency sound waves.
  - MIR scanner gives a detailed three-dimensional view of the body.
  - Heart pacemakers rely on periodic electrical oscillations.

Activity: Practical CUMSM 110 No.2

Simple Harmonic Oscillations on a Pendulum

Objective: To verify that the period of a simple pendulum is independent of mass and amplitude (for small angles) and depends only on length (L) and gravity (g).

Key Relationship to Verify: $T = 2\pi\sqrt{\frac{L}{g}}$

Plotting: Plot T^2 vs L. The slope of this graph can be used to experimentally determine the acceleration due to gravity (g).

Exercises

1. At time *t* = 0, the displacement *x*(0) of the block in a linear oscillator like that of Fig. 2 is $-8.50\ cm$. The block's velocity *v*(0) then is $-0.93\ m/s$, and its acceleration *a*(0) is $45.0\ m/s^2$. Determine,

(i) the angular frequency of this system,

(ii) the phase constant and

(iii) the amplitude of this system.

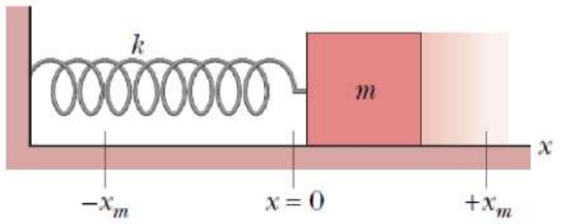


Fig 2.

2. A block weighing 20 N oscillates at one end of a vertical spring for which $k = 100\ N/m$; the other end of the spring is attached to a ceiling. At a certain instant the spring is stretched $0.30\ m$ beyond its relaxed length (the length when no object is attached) and the block has zero velocity.

    a) What is the net force on the block at this instant?
    b) What is the amplitude and,
    c) period of the resulting simple harmonic motion?
    d) What is the maximum kinetic energy of the block as it oscillates?

3. Consider the simplified single-piston engine in Figure 3. Assuming the wheel rotates with constant angular speed, explain why the piston rod oscillates in simple harmonic motion. [4]

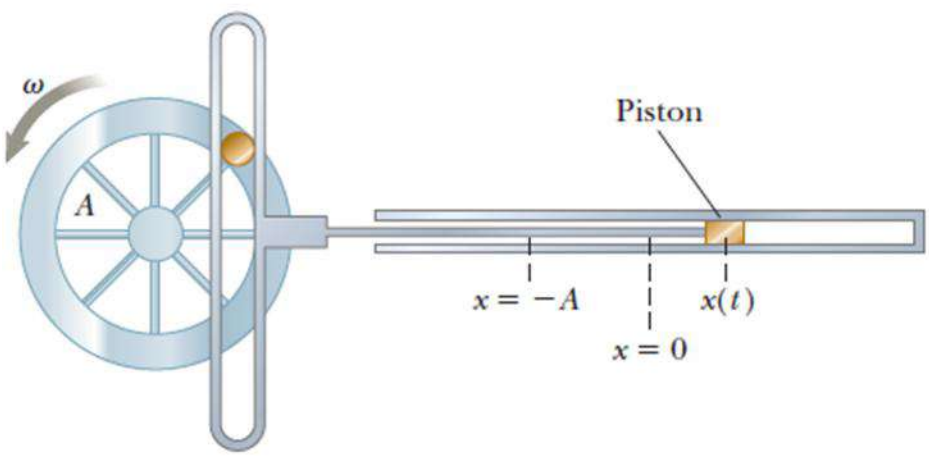


Figure 3

Chapter 7: Waves

7.1 Introduction to Waves

Waves are among the most fundamental phenomena in physics and engineering. They are responsible for the transfer of energy and information over distances, from ripples on a lake to the transmission of radio signals and seismic vibrations. In engineering physics, understanding waves is critical for designing systems in acoustics, optics, telecommunications, and materials testing.

7.2 Nature

Definition: A wave is a disturbance that travels through space and time, usually resulting in a transfer of energy and momentum without the permanent transport of matter.

Energy Transfer: In a mechanical wave, energy is passed from one particle of the medium to the next via elastic forces.

This energy propagates through a medium or, in the case of electromagnetic waves, through empty space.

7.3 Classification of Waves

Waves are classified by their mode of propagation and the medium they require:

7.3.1 Mechanical Waves:

- Require a physical material (medium) containing elements that can deform and restore to their original position (elasticity).
- *Examples:* Sound waves, seismic waves, water waves, waves on a string.

7.3.2 Electromagnetic (EM) Waves:

- Do not require a medium; they are self-sustaining oscillations of electric (E) and magnetic (B) fields.
- *Examples:* Visible light, radio waves, X-rays.

7.3.3 Transverse Waves:

- The displacement of the medium is **perpendicular** to the direction of energy propagation.
- *Example:* Light, or a wave on a string.

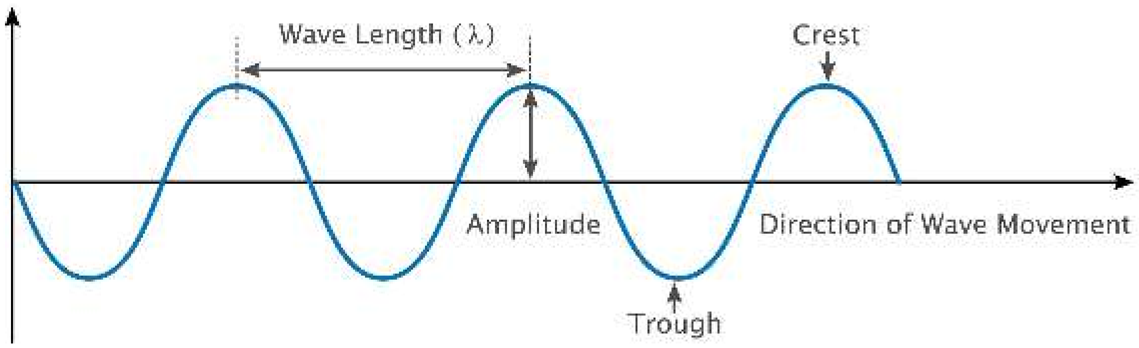


Figure 7.1: Properties of Transverse wave

7.3.4 Longitudinal Waves:

- The displacement of the medium is **parallel** to the direction of energy propagation. These waves consist of **compressions** (high density) and **rarefactions** (low density).
- *Example:* Sound waves in air.

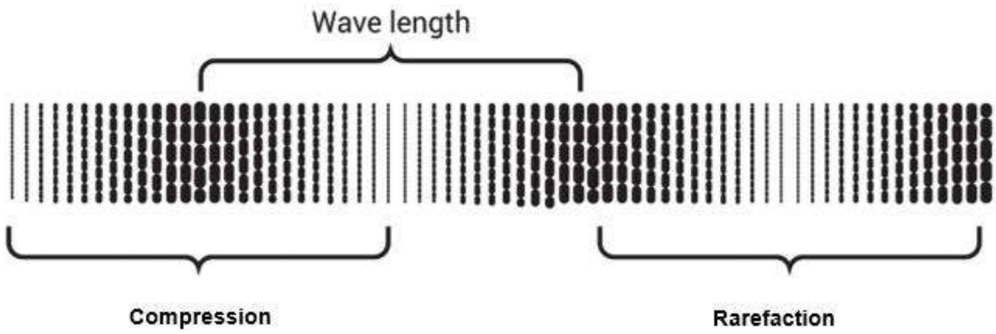


Figure 7.2: Longitudinal wave

7.3.5 Surface Waves:

Particles undergo circular motion (a combination of transverse and longitudinal). Occur at interfaces (e.g., deep ocean waves).

In engineering, both mechanical and electromagnetic waves are used extensively. For example, ultrasonic waves are used in materials testing to detect internal cracks, while radio and microwave waves enable wireless communication.

7.4 Mathematical Description of Waves

7.4.1 The Pulse vs. The Wave Train:

- A **pulse** is a single disturbance.
- A **periodic wave** consists of a continuous series of identical pulses (often sinusoidal).

The general form of a travelling wave can be expressed as: $y(x,t) = A\,sin(kx - \omega t + \varphi)$, where:

- **A** is **amplitude** (the magnitude of maximum displacement from the equilibrium position. It relates to the energy of the wave),
- **k** is the **wave number** (The spatial frequency (radians per meter)), $k = \frac{2\pi}{\lambda}$
- **ω** is **angular frequency** (A measure of rotation rate, used in the wave function), $\omega = 2\pi f = \frac{2\pi}{T}$
- φ is the phase constant (determined by initial conditions).

The wave speed v is related to wavelength λ and frequency f by $v = \frac{\lambda}{T} = f\lambda = \frac{\omega}{k}$. For sound waves, speed depends on the medium's elastic and inertial properties.

In mechanical waves, the speed depends on the properties of the medium. For instance, the speed of sound in air increases with temperature and decreases with humidity.

For a stretched string, the wave speed is given by $v = \sqrt{(T/\mu)}$, where T is the tension and μ is the linear mass density. This principle forms the basis of musical instruments such as guitars, where tuning adjusts T to change pitch.

Example: If a guitar string under 80 N of tension has a mass per unit length of $0.005\ kg/m$, the wave speed is $v = \sqrt{(80 / 0.005)} = 126.5\ m/s$.

7.5 Properties and Interactions of Waves

Waves exhibit several behaviours that are essential for understanding natural phenomena and technological systems:

7.5.1 Reflection & Transmission

When a wave hits a boundary:

- **Reflection:** The wave bounces back.
    - *Rigid Boundary:* The reflected wave is inverted (180° phase shift).
    - *Free Boundary:* The reflected wave is not inverted.
- **Refraction:** The wave enters a new medium, changing speed and wavelength (frequency remains constant).

7.5.2 Diffraction

The bending of waves around obstacles or through apertures.

- Significant diffraction occurs only when the size of the opening/obstacle is comparable to the wavelength (λ).

7.5.3 Interference (The Superposition Principle)

When two waves overlap, the resultant displacement is the algebraic sum of the individual displacements.

1. **Constructive Interference:** Waves meet in phase (crest meets crest). Resultant amplitude is the sum of individual amplitudes.
2. **Destructive Interference:** Waves meet out of phase (crest meets trough). Resultant amplitude is the difference (can be zero).

A vital phenomenon linked to wave motion is the Doppler Effect, the apparent change in frequency when there is relative motion between the source and observer. For instance, an approaching ambulance siren sounds higher in pitch and lower when moving away.

The Doppler Effect describes the apparent shift in frequency due to relative motion between source and observer: $f_o = f\,\frac{(v \pm v_o}{(v \pm v_s)}$.

f_o: Frequency heard by the observer

f: Frequency emitted by source

v: Speed of sound in the medium

v_o: speed of the observer

v_s: speed of the source

7.6 Energy Transport and Intensity

Waves transport energy without carrying matter. The energy transferred depends on both amplitude and frequency. The intensity (I) of a wave is defined as the power transmitted per unit area: I = P/A. For spherical waves, intensity decreases with the square of distance ($I \propto 1/r^2$).

In acoustics, intensity is expressed in decibels (dB), where sound level $\beta = 10 \log_{10}(I/I_0)$, and $I_0 = 10^{-12}$ W/m² is the threshold of hearing.

Applications of intensity include noise control engineering, design of loudspeakers, and vibration isolation systems.

7.7 Engineering Applications of Waves

Wave principles underpin countless modern technologies:

• Acoustics – design of classrooms, theatres, studios, and noise barriers for sound quality and comfort.

• Optics – lenses, lasers, and fibre optics communication systems depend on light wave behavior.

• Medical Imaging – ultrasound scanning and Magnetic Resonance Imaging (MRI) use wave interactions to visualize internal structures.

• Telecommunications – radio, microwave, and optical signals carry information over vast distances.

• Renewable Energy – wave energy converters harness ocean waves for sustainable power generation.

In Zimbabwe, applications include rural telecommunication systems, acoustically optimized classrooms, and seismic surveys for mineral exploration. Wave-based sensing technologies also aid in the structural health monitoring of bridges and dams.

Activity 7.1

Conduct an experiment to measure the speed of sound in air using a resonance tube setup. Record the resonance lengths for several frequencies and calculate the speed using $v = 4fL$. Compare your experimental results with the theoretical speed at the current air temperature. Discuss possible sources of error and how to minimize them.

Exercises

1. The displacement function for a pulse passing through a string is given by $D(x,t) = \frac{5.0}{6.0+(x-5.0t)^2}$ where $\boldsymbol{x}$ and $\boldsymbol{D}$ are in metres and $\boldsymbol{t}$ is in seconds.

    a) Calculate the speed of the pulse, and in which direction it is travelling
    b) Calculate the displacement of a point located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0s}$
    c) Calculate the maximum displacement of a point on the string
    d) Calculate the transverse speed of a point that is located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0s}$
    e) Sketch a displacement versus position (x) graph for $\boldsymbol{t = 0s, 1s, 2s}$, and $\boldsymbol{3s}$ for this waveform

2. A submarine (sub-A) travels through water at a speed of $8.00\ m/s$, emitting a sonar wave at a frequency of $1\,400\ Hz$. The speed of sound in the water is $1\,533\ m/s$. A second submarine (sub-B) is located such that both submarines are traveling directly toward each other. The second submarine is moving at $9.00\ m/s$.

    a) Calculate the frequency that is detected by an observer riding on sub–B as the subs approach each other?

b) The subs barely miss each other and pass. What frequency is detected by an observer riding on sub–B as the subs recede from each other?

Chapter 8: Light

Unit Overview

Light is one of the most fascinating forms of energy in nature and technology. It allows us to see the world, transmits data across continents, and powers many engineering systems.

This chapter explores the dual nature of light, its fundamental laws, and the technologies that harness its behaviour. Understanding light is crucial for engineers working in materials science, telecommunications, photonics, and renewable energy.

8.1 The Nature of Light and Its Electromagnetic Properties

Definition: Light is electromagnetic radiation that is visible to the human eye. In physics, it is treated under the **Wave-Particle Duality** model;

It consists of oscillating electric and magnetic fields that travel through space at the speed of light.

1. **Wave Model:** Light propagates as oscillating electric (E) and magnetic (B) fields perpendicular to each other and the direction of propagation. This model is essential for understanding interference and diffraction.
2. **Particle Model:** Light consists of discrete packets of energy called **photons**. This model explains how light interacts with matter at the atomic level, which is critical in materials science.

Key Constants and Equations:

To solve engineering problems, students must master these relationships;

Speed of Light (c): The universal speed limit in a vacuum.

$$c \approx 3.00 \times 10^8 m/s$$

Photon Energy (E): The energy of a photon is directly proportional to its frequency (f). $E = hf = \frac{hc}{\lambda}$

Where h is Plank's constant ($6.626 \times 10^{-34} J \cdot s$)

Index of Refraction (n): A measure of how much light slows down in a medium. $n = \frac{c}{v}$

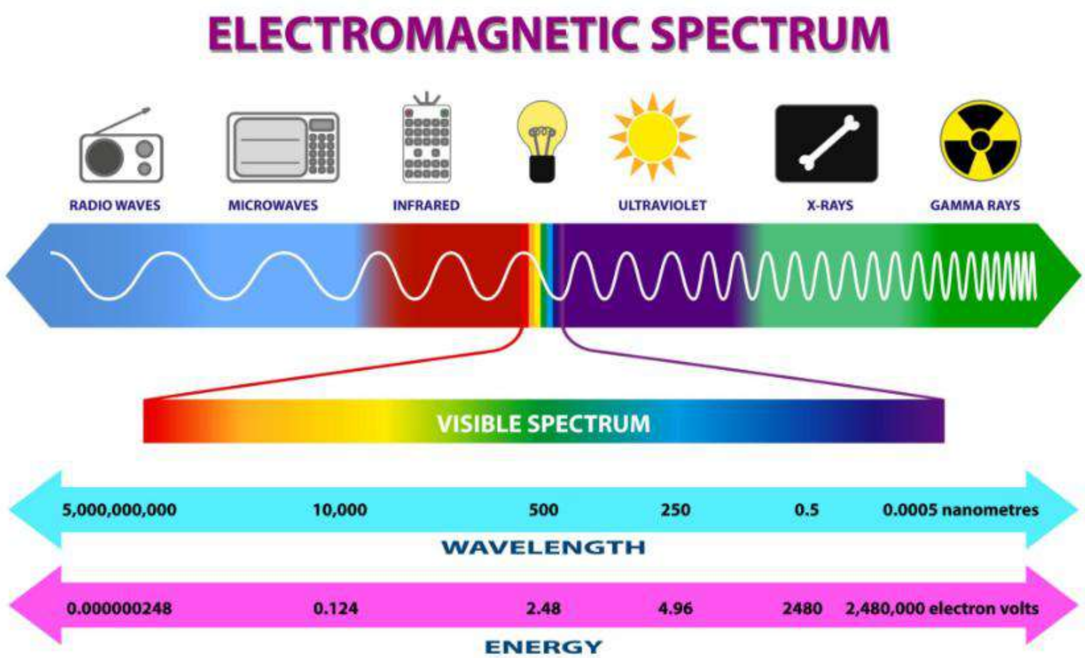


Figure 8.1: Electromagnetic Spectrum

Geometric Optics (Ray Optics)

This branch treats light as rays traveling in straight lines. It is valid when the wavelength of light is much smaller than the obstacles it interacts with ($\lambda \ll D$).

Wave optics explains light behaviour in terms of interference, diffraction, and polarization phenomena that arise from the wave nature of light.

Reflection

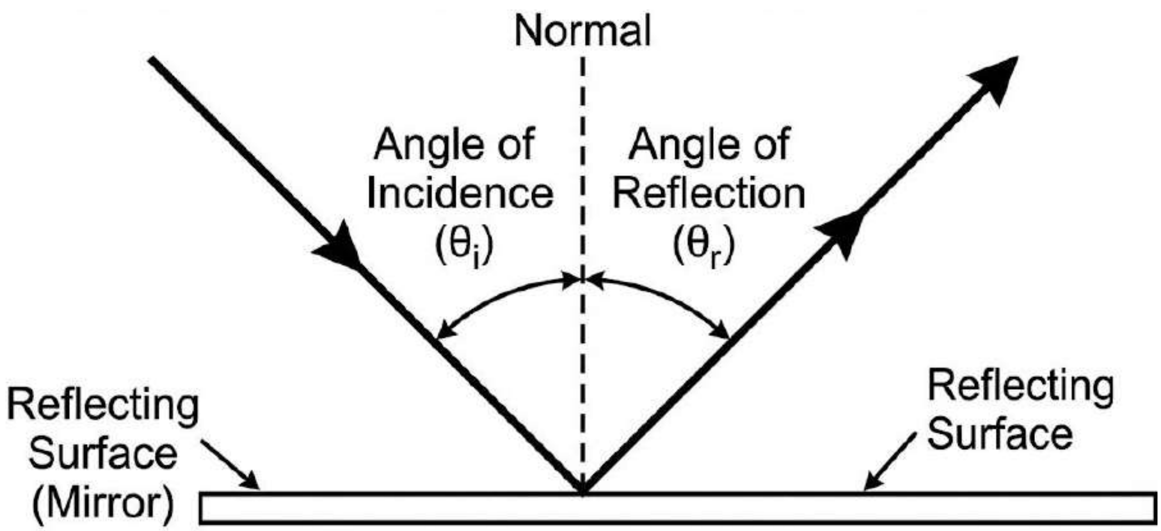


Figure 8.2 image of incident and reflected ray on a surface

Reflection occurs when light bounces off a surface. The angle of incidence equals the angle of reflection. Applications include mirrors, periscopes, and solar concentrators.

Law of Reflection: The angle of incidence equals the angle of reflection ($\theta_i = \theta_r$). Both rays and the normal lie in the same plane.

Specular Reflection

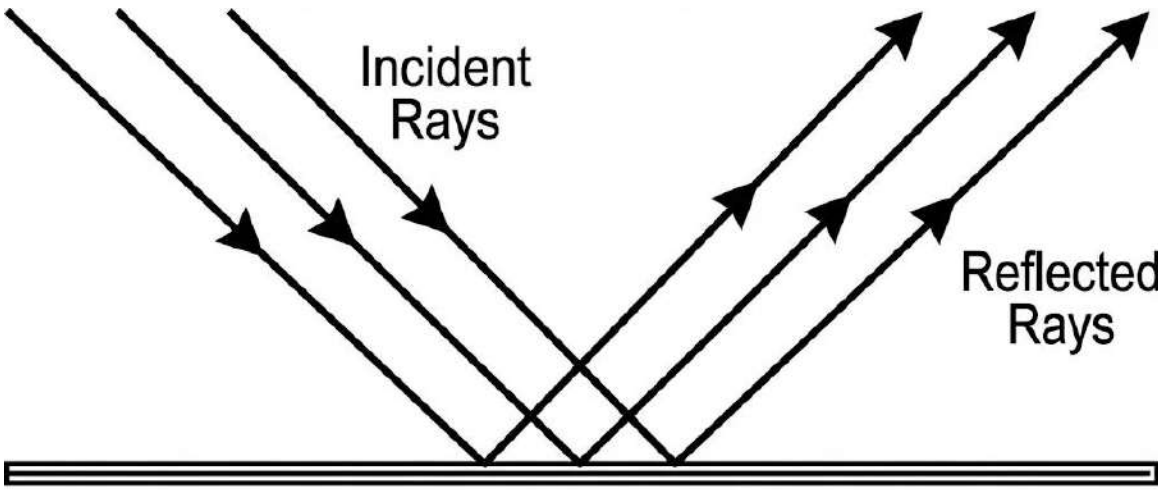


Figure 8.3 Specular reflection

Reflection off a smooth surface (e.g., mirror). This occurs when light reflects from a perfectly smooth surface at a definite, predictable angle. This type of reflection is responsible for the sharp images we see in mirrors and the polished surfaces of engineering materials.

Key Principles:

- **Ray Alignment**: Parallel incident rays remain parallel after reflecting from the surface.
- **Law of Reflection**: For every ray in the beam, the angle of incidence is exactly equal to the angle of reflection.
- **Virtual Image Formation**: Because the rays do not scatter, our brains can trace them back to a point behind the mirror, creating a clear "virtual" image.

Engineering Relevance:

- **Surface Metrology**: Engineers measure the ratio of specular to diffuse reflection to determine the roughness of a material on a microscopic scale.
- **Optoelectronics**: Specular reflection is utilized in the design of high-precision mirrors for laser systems and solar concentrators.
- **Glare Management**: In the design of screens (laptops and phones), engineers often add "anti-glare" coatings to convert annoying specular reflection into diffuse reflection, making the screen easier to read in bright light.

Diffuse Reflection

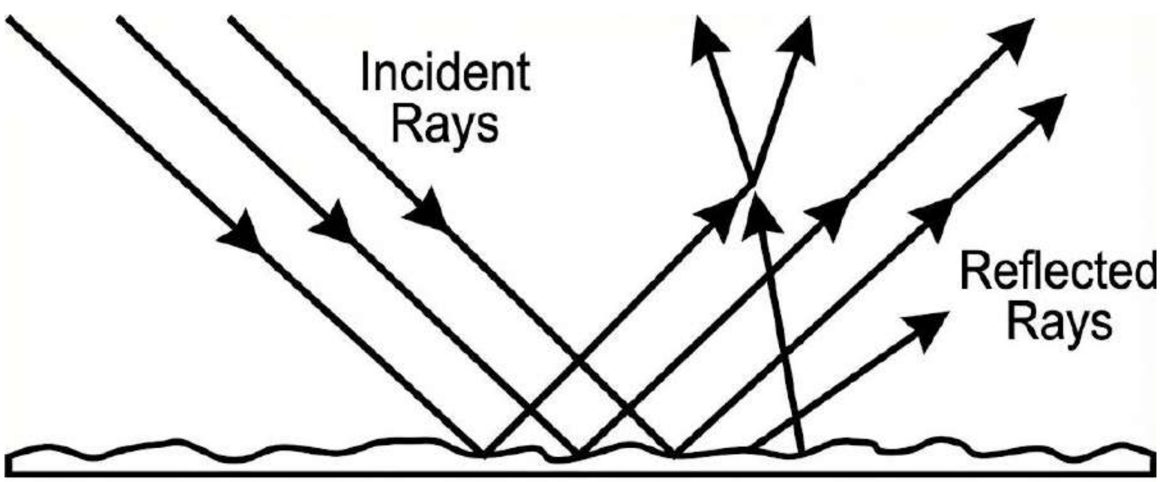


Figure 8.4: Diffuse reflection

Diffuse reflection occurs when light hits a "rough" or irregular surface and scatters in many different directions. While the law of reflection still applies to every individual ray at the microscopic point of contact, the varying orientation of the surface causes the reflected rays to diverge.

Key Principles:

- **Ray Scattering**: Incident parallel rays are reflected at many different angles, preventing the formation of a clear virtual image.
- **Microscopic Roughness**: A surface is considered "rough" for diffuse reflection if its irregularities are larger than the wavelength of the incident light.
- **Visibility**: Diffuse reflection is why we can see non-luminous objects (like paper, wood, or unpolished metal) from any angle.

Engineering Relevance:

- **Material Selection**: Engineers choose matte or "diffuse" finishes for architectural interiors or dashboard materials to prevent blinding glare for occupants and drivers.
- **Safety Engineering**: High-visibility clothing and road signs are designed to maximise diffuse (or retro-reflective) scattering so they are visible to drivers from various perspectives.
- **Optical Inspection**: In quality control, a shift from specular to diffuse reflection on a production line can indicate that a component has not been polished to the required tolerance or that a tool is wearing out.

Refraction, Snell's Law, and Fermat's Principle

Refraction is the bending of light as it passes from one medium to another with a different optical density. The bending of light as it passes from one medium to another due to a change in speed.

Fermat's Principle of Least Time

To understand why light follows a specific path, we look to **Fermat's Principle**, which states:

"The path taken by a ray between two points is the path that can be traversed in the least time."

While light always travels in a straight line within a single uniform medium, it chooses a bent path when crossing into a new medium (like air to water) to minimise the total travel time. To minimize total travel time, light chooses a path that allows it to spend **more distance in the faster medium (air)** and **less distance in the slower medium (water)**. This physical requirement is what causes the light to bend toward the normal, a phenomenon we mathematically describe using Snell's Law.

The degree of bending is given by Snell's Law: $n_1 \cdot sin\theta_1 = n_2 \cdot sin\theta_2$.

If $n_2 > n_1$**(e.g., air to water):** Light bends **towards** the normal.

If $n_2 < n_1$ **((e.g., glass to air):** Light bends **away** from the normal

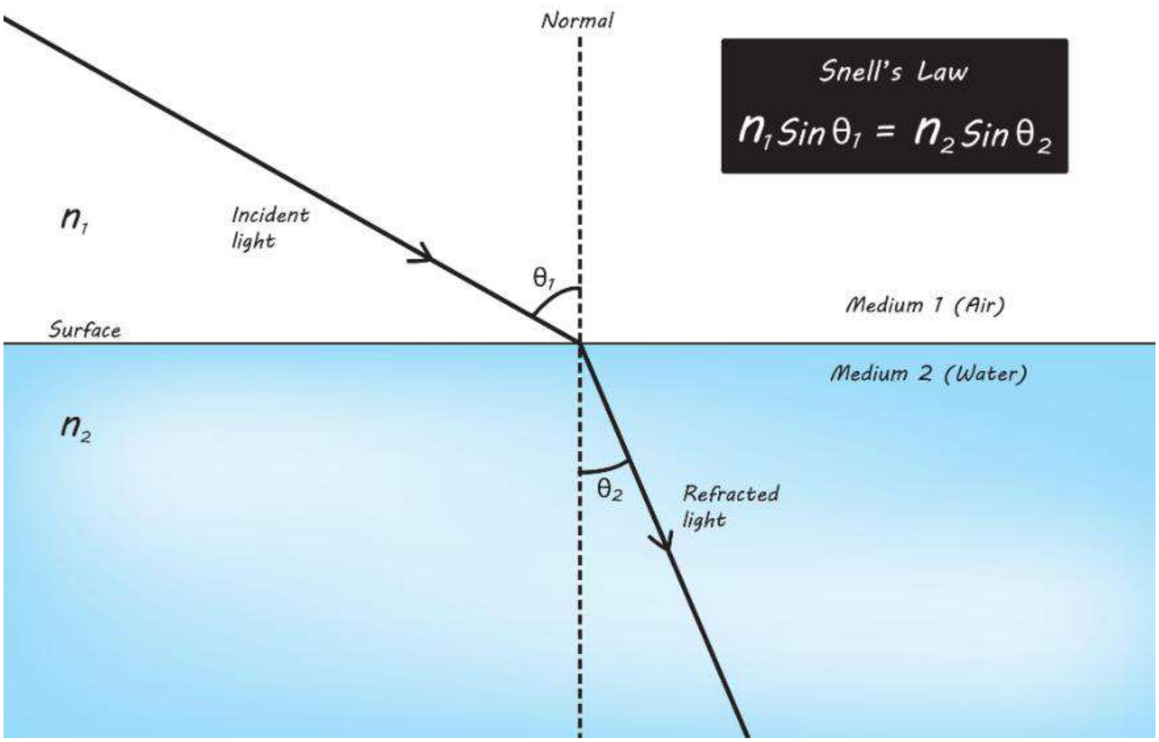


Figure 8.5: Refraction

Total Internal Reflection (TIR)

If light travels from a denser medium to a rarer medium ($n_1 > n_2$) at an angle greater than the **Critical Angle (θ_c)**, no light escapes; all is reflected back.

$$sin\theta_c = \frac{n_2}{n_1}$$

Application: Fiber optics. They form the backbone of modern communication systems, enabling high-speed internet and medical imaging (endoscopy). This is the principle behind high-speed internet. The light signal is "trapped" inside the glass core by reflecting off the cladding.

Example: Snell's Law and Critical Angle

A fiber optic cable has a core with a refractive index of 1.55 and a cladding with a refractive index of 1.45. Calculate the critical angle θ_c for total internal reflection.

Solution:

Formula: $sin\theta_c = \frac{n_2}{n_1}$

Calculation: $sin\theta_c = \frac{1.45}{1.55} \approx 0.935$

$$\theta_c = (0.935) \ \approx 69.3°$$

Conclusion: Any light hitting the boundary at an angle greater than $69.3°$ will be trapped in the core.

Interference

When two or more light waves overlap, they interfere with each other. If the crests of one wave coincide with the crests of another, they produce constructive interference (brighter light). If the crest coincides with the trough, destructive interference occurs (dimmer or no light). Applications include thin-film coatings, anti-reflective lenses, and holography.

Diffraction

Diffraction occurs when light bends around obstacles or passes through narrow openings. This effect becomes significant when the obstacle size is comparable to the wavelength of light. Diffraction is exploited in optical instruments such as spectrometers and diffraction gratings to separate light into its component wavelengths.

Polarisation

Polarisation is the restriction of light vibrations to a single plane. Normally, light vibrates in multiple planes, but through filters or reflection, it can be polarised.

Unpolarised Light: The electric field vibrates in all directions perpendicular to propagation.

Linearly Polarised Light: The electric field vibrates in only one specific direction.

Malus's Law: Describes the intensity I of polarised light passing through an analyser: $I = I_0 cos^2\theta$.

Engineering Importance:

1. **Stress Analysis:** Polarised light helps engineers visualise internal stresses in transparent materials.
2. **Display Technology:** LCD screens use polarisation filters to control light for every pixel.
3. **Glare Reduction:** Polarised filters in sunglasses block horizontally polarized reflections from surfaces like water or roads.

Geometric Optics

Geometric optics describes light in terms of straight-line rays. It explains reflection, refraction, and image formation through mirrors and lenses.

c) Lens Theory

Lenses refract light to form images. Engineers use lenses to manipulate light for imaging and measurement. Convex lenses converge light rays to a focal point, while concave lenses diverge them. The lens formula relates object distance (u), image distance (v), and focal length (f) as $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. This principle is used in cameras, magnifiers, and microscopes.

d) Everyday Technology: Camera Lenses and Optics

Modern smartphone cameras are practical examples of geometric optics. Each camera module contains a miniature lens system that focuses light onto a digital sensor (the image plane). The same physical principles of refraction and focal length apply, just at a compact scale.

• Focal Length (f): The distance between the lens and the image sensor when the subject is in focus. A smaller focal length gives a wider field of view (useful for selfies or landscapes), while a larger focal length provides zoom or magnification.
• Aperture (f-number): The adjustable opening through which light enters. It controls brightness and depth of field a wide aperture (e.g., f/1.8) lets in more light and blurs the background, while a narrow aperture (e.g., f/8) increases sharpness throughout the image.
• Lens Combination: Smartphones often use multiple lenses wide, ultra-wide, and telephoto to simulate optical zoom and create portrait effects by blending images through software.

This example shows how fundamental laws of reflection and refraction are used in optical engineering, leading to clear, high-resolution images on devices we use every day.

8.4 Optical Instruments

Optical instruments use lenses and mirrors to form images and magnify or analyse light. They are fundamental tools in both scientific research and industrial applications.

Thin Lenses

Convex (Converging) Lens: Focuses parallel rays to a focal point.

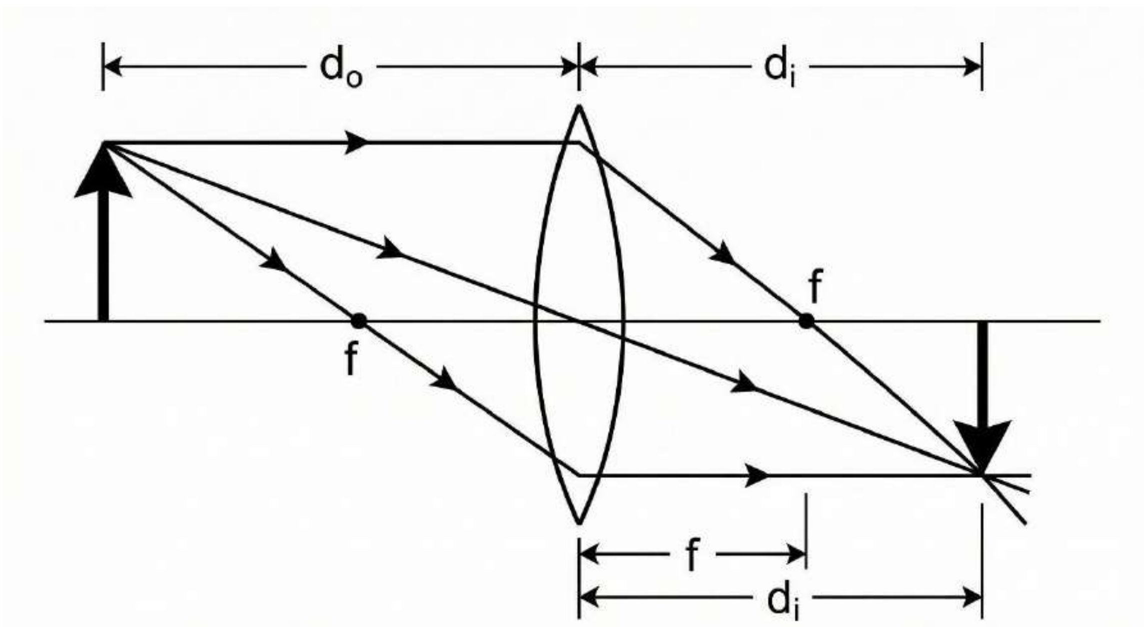


Figure 8.6: Converging Lens forming a real image

This diagram shows a converging lens forming a **real, inverted, and diminished** image. This occurs when the object is placed outside $2f$ (twice the focal length) from the lens.

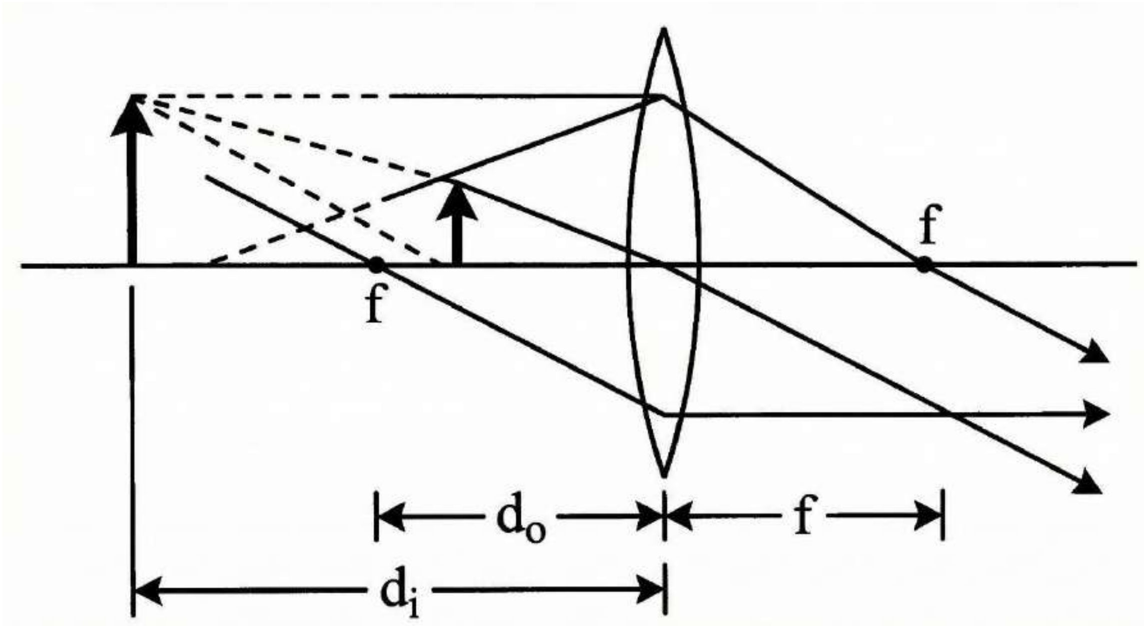


Figure 8.7: Converging lens forming a virtual image

The diagram shows a converging lens forming a **virtual, upright, and magnified** image. This occurs when the object is placed *inside* the focal point f of the lens, which is how a magnifying glass works.

Concave (Diverging) Lens

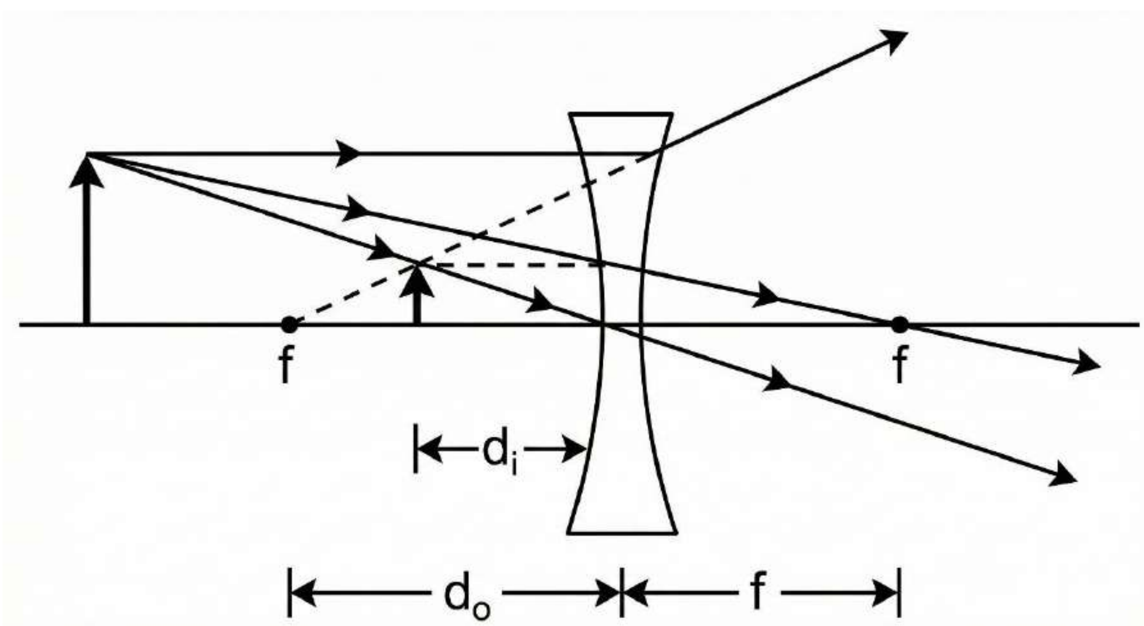


Figure 8.8: Diverging lens showing a virtual image

This diagram shows a diverging lens, which *always* forms a virtual, upright, and diminished image, regardless of where the object is placed. Spreads parallel rays out as if coming from a focal point.

The Thin Lens Equation: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

f: Focal length (positive for convex, negative for concave).

d_o: Object distance.

d_i: Image distance.

Magnification (M): $M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

If M is negative, the image is **inverted**.

Wave Optics (Physical Optics)

This branch treats light strictly as a wave and is necessary to explain phenomena like interference and diffraction.

Interference

The superposition of two coherent light waves (waves with a constant phase difference).

- **Young's Double Slit Experiment:** Demonstrates the wave nature of light.
  - **Constructive Interference (Bright Fringes):** Path difference is an integer number of wavelengths.

$$dsin\theta = m\lambda \quad (m = 0,1,2 \ldots.)$$

Destructive Interference (Dark Fringes): Path difference is a half-integer.

$$dsin\theta = (m + \frac{1}{2})\lambda$$

(d= slit separation, θ = angle to screen)

Application: Anti-reflective coatings on smartphone screens and camera lenses.

Diffraction

The bending of light around obstacles or through slits.

- **Single Slit Diffraction:** Light passing through a slit of width a creates a central bright spot with fading fringes. The condition for **dark minima** is:

$$a sin\theta = m\lambda$$

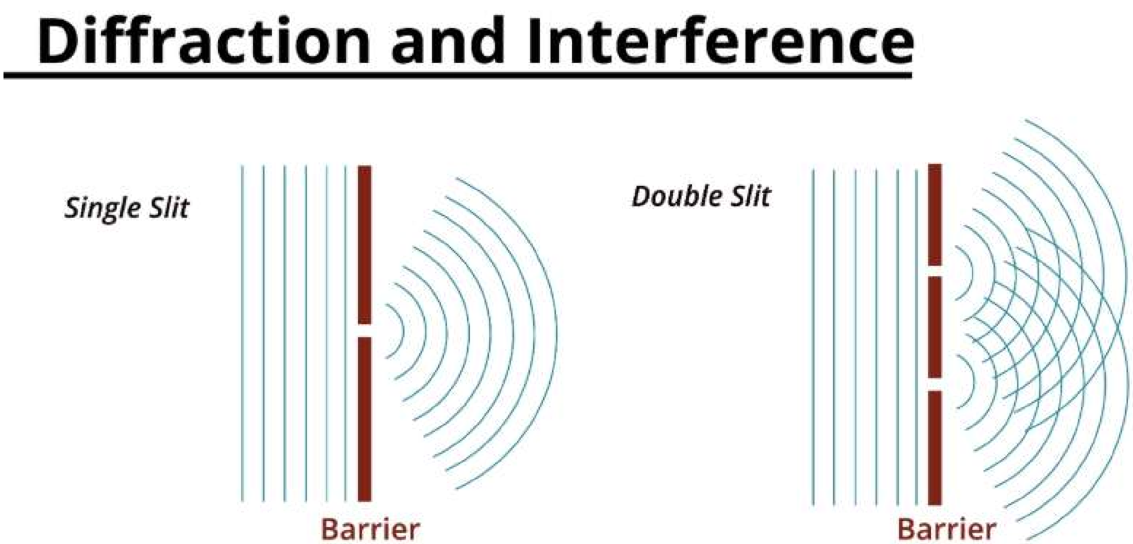


Figure 8.9: Diffraction and Interference

Polarization

Light is a transverse wave. Polarization refers to the orientation of the electric field oscillation.

- **Unpolarized Light:** Electric field vibrates in all directions.
- **Linearly Polarized Light:** Electric field vibrates in one specific direction.
- **Malus's Law:** Describes the intensity (I) of polarized light passing through an analyser.

$$I = I_o cos^2{}_{\theta}$$

Optical Instruments

a) Microscope

Microscopes use combinations of lenses to magnify tiny objects beyond the limits of human vision. They are used in biology, materials science, and nanotechnology to examine microstructures.

b) Telescope

Telescopes collect and magnify light from distant objects. Refracting telescopes use lenses, while reflecting telescopes use mirrors. Applications include astronomy, surveillance, and remote sensing.

c) Spectrometer

A spectrometer splits light into its component wavelengths to analyse materials or light sources. It is used in chemical analysis, quality control, and material characterisation.

8.5 Applications of Light in Engineering

a) Fibre Optics

Optical fibres transmit light signals through total internal reflection.

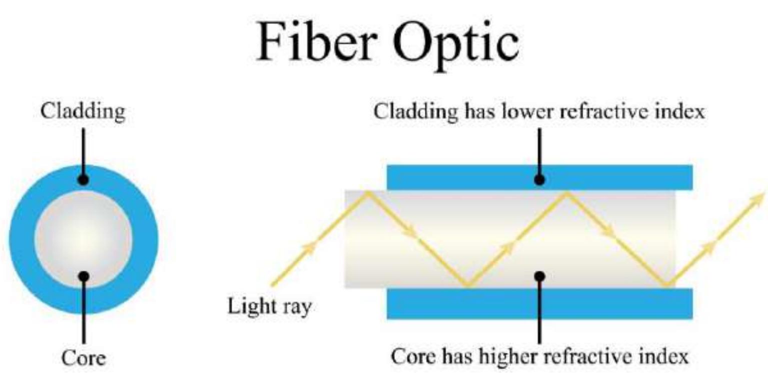


Figure 8.10: A diagram of a fibre optic cable

b) Laser Technology

Lasers produce coherent, monochromatic beams of light. Their precision makes them useful in cutting, welding, barcode scanning, and optical storage devices.

Case Study: Optical Characterisation in Materials Science

The Role of Spectroscopy in Ore Analysis

As an engineering intern, you may deal with the processing of gold ore. Identifying the composition of these materials quickly is vital.

The Technology: Spectrometers utilise the principles of **diffraction** and **refraction** to split light reflected from an ore sample into its component wavelengths. Every element has a "spectral fingerprint" specific wavelength of light it absorbs or emits.

Engineering Impact:

- **Quality Control:** By analysing the light spectrum, engineers can determine the concentration of minerals in a sample without destroying it.
- **Efficiency:** Automated optical sensors can sort "waste" rock from valuable ore on a conveyor belt in milliseconds using high-speed imaging.

Laboratory Practical: Determination of Refractive Index

Aim: To determine the refractive index of a rectangular glass block using Snell's Law and to observe the phenomenon of lateral displacement.

Equipment

- Rectangular glass block
- Ray box / laser pointer
- Protractor, ruler, and drawing pins
- A4 drawing paper

Methodology

1. Place the glass block on the paper and trace its outline.
2. Draw a normal line perpendicular to the surface of the block.
3. Direct a light ray at an angle of incidence θ_1 of $20°$ and mark the entry and exit points.
4. Remove the block and draw the refracted ray inside the glass.
5. Measure the angle of refraction θ_2 using a protractor.
6. Repeat for angles $30°$, $40°$, $50°$, and $60°$

Data Analysis

- Plot a graph of θ_1 (y-axis) against θ_2 (x-axis).

Questions:

1. What does the gradient of the resulting straight line represent?
2. Calculate the speed of light within your specific glass block using $v = \frac{c}{n}$.

Exercise

1. Explain the difference between specular and diffuse reflection in the context of metal polishing.
2. A lens has a focal length of 15 cm. If an object is placed 30cm away,
   i) where is the image formed?
   ii) Is the image inverted?
3. How does the spectral fingerprint of a material help in the mining industry?
4. Explain why fiber optic cables use a cladding layer with a lower refractive index.
5. A concave mirror has a focal length of 20 cm. An object is placed 30 cm away from the mirror. Determine the position, the size and the nature of the image formed by the mirror. Also, draw a ray diagram to show the image formation.

6. An underwater scuba diver sees the Sun at an apparent angle of $45.0°$ above the horizontal. Calculate the actual elevation angle of the Sun above the horizontal.

Chapter 9: Electrostatics

Chapter Overview

Electrostatics is the analysis of electromagnetic phenomena that occur when there are no moving charges (static equilibrium). It forms the foundation for all electromagnetic theory (Maxwell's Equations). For engineers, understanding electrostatics is crucial not just for circuit design, but for analysing stress in dielectric materials, designing sensors and actuators (MEMS), and understanding the fundamental limits of insulation in high-voltage power systems.

9.1 Electric Charge and Its Properties

Fundamental Definition: Charge (q) is an intrinsic property of matter. All matter is made of atoms containing **positively charged protons**, **negatively charged electrons**, and **neutral neutrons**.
When the number of protons and electrons in an object differ, it becomes charged.

- **Like charges** repel each other.
- **Opposite charges** attract each other.

The **SI unit of charge** is the **coulomb (C)**.
An electron carries a charge of -1.6×10^{-19} C, while a proton carries $+1.6 \times 10^{-19}$ C.

Key properties:

- **Quantization of charge:** Electric charge exists in discrete amounts (multiples of 1.6×10^{-19} C).
- **Conservation of charge:** Charge can neither be created nor destroyed; it can only be transferred. In an isolated system, the algebraic sum of charges remains constant.
- **Charging Mechanisms:**
  - **Conduction:** Transfer via physical contact.
  - **Induction:** Redistributing charge without contact (crucial for grounding and shielding).

Example: When you rub a balloon against your hair, electrons move from your hair to the balloon.

Your hair becomes positively charged, while the balloon becomes negatively charged — a classic case of **charge transfer** through friction.

9.2 Coulomb's Law and the Electric Field

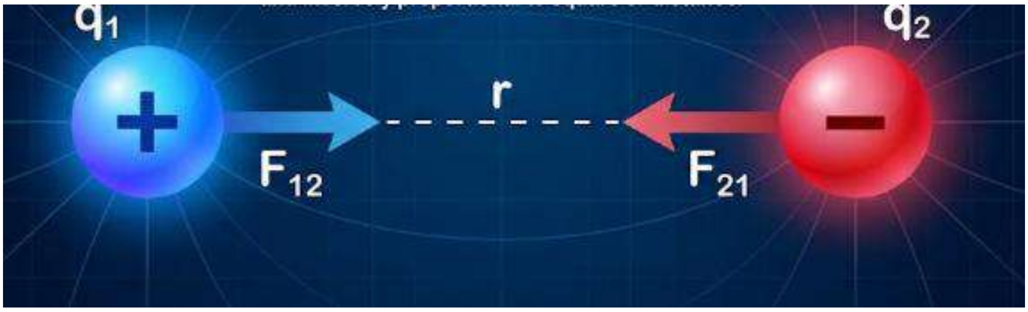


Figure 9.1: Point charges

Coulomb's law quantifies the force between two-point charges:

$F_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}_{12}$ where:

- *F* = electrostatic force (N)
- q_1, q_2 = magnitudes of the charges (C)
- *r* = distance between the charges (m)
- *k* = 8.99 × 10^9 N·m²/C² (Coulomb's constant)

The force acts along the line joining the charges **repulsive** for like charges and **attractive** for opposite ones.

Electric Field (E)

The **electric field** is the region around a charge where another charge experiences a force.

It is defined as the force per unit charge: $\mathrm{E} = \frac{F_o}{q_o}$

- For a continuous distribution, we integrate: $\mathrm{E} = k \int \frac{dq}{r^2} \hat{r}$
- The field is a **vector quantity**.

- **Field lines** originate from positive charges and terminate at negative charges.
- The **density** of the lines represents field strength.

Electric Dipoles: Two equal and opposite charges separated by a distance d. Important for understanding dielectric materials.

- **Dipole Moment (p):** $p = qd$.
- **Torque on a Dipole:** $\tau = p \times E$

Engineering Connection: Electric fields are used to control electron beams in **CRT displays**, charge particles in **photocopiers**, and apply coatings in **electrostatic painting**.

Gauss's Law

Electric Flux (Φ_E): A measure of the number of field lines passing through a surface A.

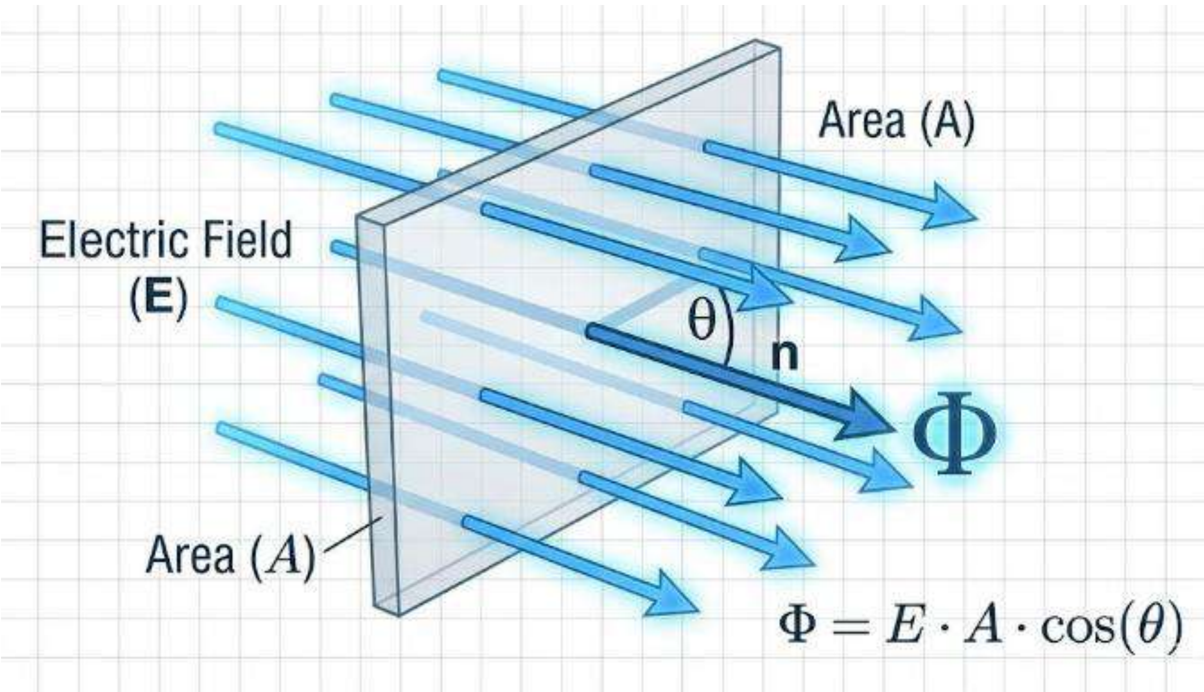


Figure 9.2: electric flux passing through a surface

$$\Phi_E = \int E \cdot dA$$

Gauss's Law Statement: The net flux through any closed surface (Gaussian surface) is proportional to the enclosed charge (Q_{enc}).

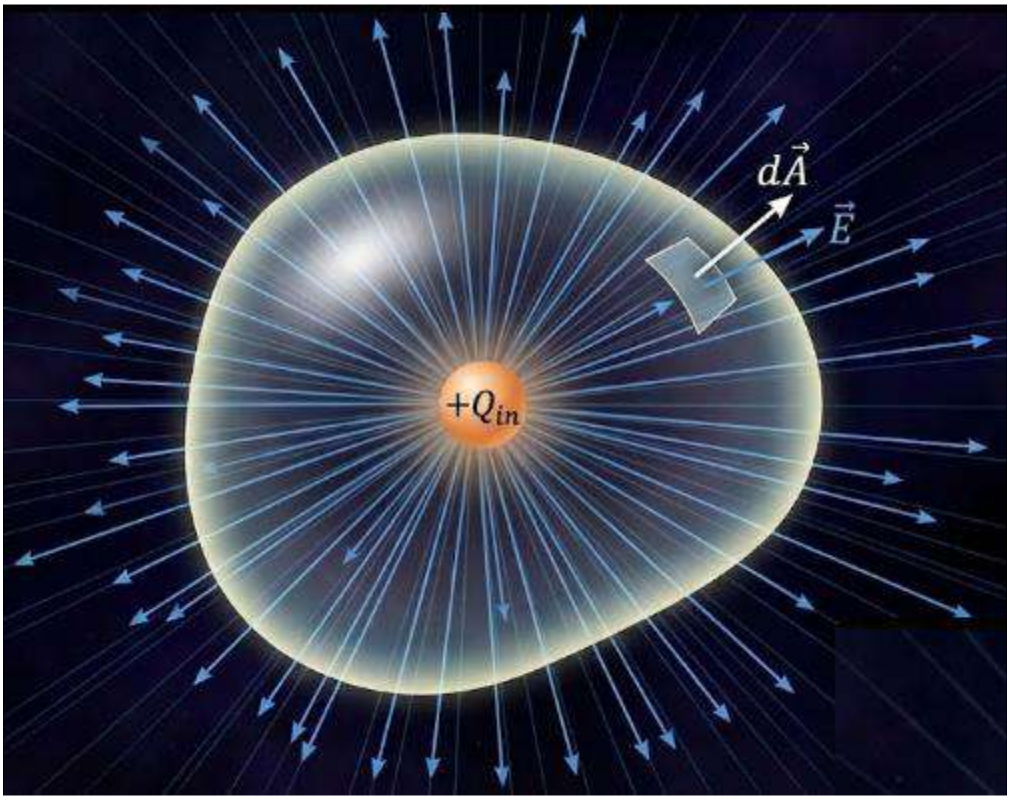


Figure 9.3: Gaussian surface

$$\oint E \cdot dA = \frac{Q_{enc}}{\epsilon_0}$$

Engineering Application: Used to easily calculate fields for symmetric systems (coaxial cables, spherical shells, infinite sheets).

Electric Potential and Energy

Electric Potential (V): The work done per unit charge to bring a test charge from infinity to a point P. $V = -\int_{\infty}^{P} E \cdot ds$

Relationship to Field: E is the negative gradient of V.

$$E = -\nabla V = -\left(\frac{\partial V}{\partial x}\hat{\imath} + \frac{\partial V}{\partial y}\hat{\jmath} + \frac{\partial V}{\partial z}\hat{k}\right)$$

Electric Potential Energy (U): The energy required to assemble a system of charges. $U = k\sum\frac{q_i q_j}{r_{ij}}$

Electron Volt (eV): A common unit in semiconductor engineering $1eV = 1.602 \times 10^{-19}J$

Capacitance and Dielectrics

Capacitance (C): Defined largely by geometry. $C = \frac{Q}{\Delta V}$

Common Geometries:

Parallel Plate: $c = \frac{\epsilon_0 A}{d}$

Energy Storage: The potential energy stored in the electric field of a capacitor:

$$U_E = \frac{1}{2}C(\Delta V)^2 = \frac{Q^2}{2C}$$

Dielectrics:

Insulators placed between plates increase capacitance by a factor κ (dielectric constant).

- **Mechanism:** The external field polarizes the dielectric atoms, creating an internal "reverse" field that reduces the net field, allowing more charge to be stored at the same voltage.
- **Dielectric Strength:** The maximum field a material can withstand before breakdown (arcing) occurs.

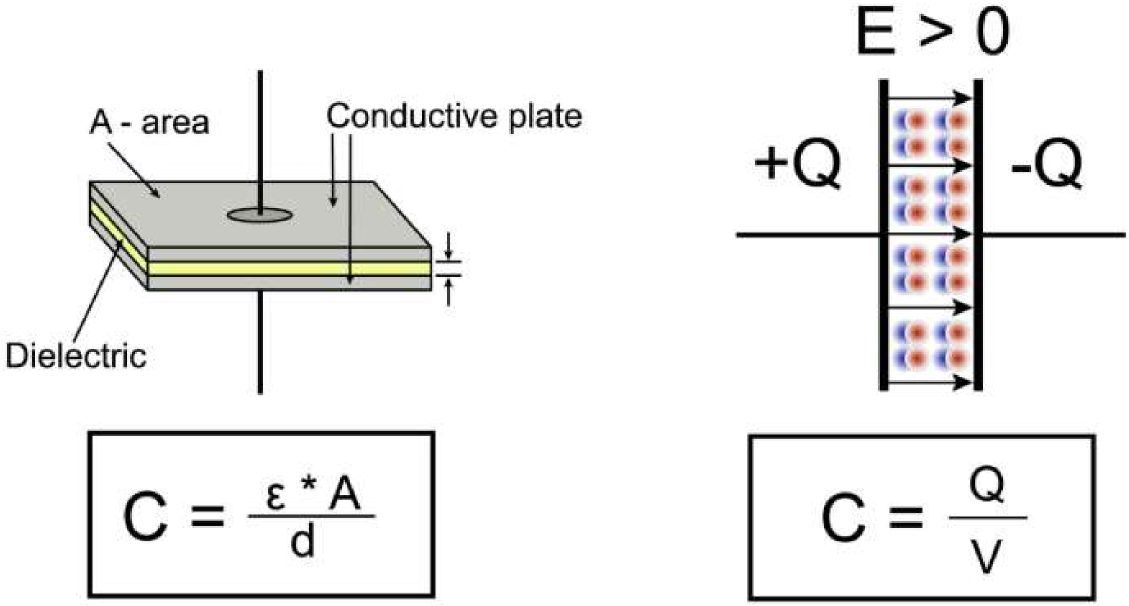


Figure 9.4: Parallel plate capacitor

Conductors in Electrostatic Equilibrium

Understanding conductors is vital for safety and circuit shielding.

1. **Zero Internal Field:** The electric field inside a perfect conductor is zero.
2. **Surface Charge:** All net charge resides on the surface.
3. **Perpendicular Field:** The electric field just outside a charged conductor is perpendicular to the surface.
4. **Sharp Points:** Charge density (σ) is highest at points with the smallest radius of curvature (basis for lightning rods).

Engineering Applications

- **The Cathode Ray Tube (CRT):** Deflection of electron beams using E-fields (legacy displays, oscilloscopes).
- **Electrostatic Precipitators:** Industrial pollution control using corona discharge to ionize smoke particles and attract them to collection plates.

- **Xerography (Photocopiers):** Using a photoconductive drum (selenium) to map an optical image into a static charge distribution.
- **MEMS (Micro-Electro-Mechanical Systems):** Using electrostatic forces to move tiny mirrors (in projectors) or sense acceleration (in airbag sensors).
- **Breakdown Voltage:** Designing insulators for high-voltage transmission lines to prevent "flashover" based on the dielectric strength of air.

Concept Summary

- Electric charge is a fundamental property of matter, existing in positive and negative forms.
- Coulomb's law governs the force between static charges.
- Electric fields describe how forces act in space, while electric potential describes energy changes.
- Capacitors store charge and energy; dielectrics enhance their performance.
- Conductors and semiconductors are essential to modern electronics.
- Electrostatics is the foundation of many technologies — from printers and air purifiers to smartphones and solar cells.

Exercise

1. What is meant by charge quantization?
2. Two charges of +2 μC and –3 μC are separated by 0.5 m. Calculate the force between them.
3. Explain why no work is done moving a charge along an equipotential surface.
4. How does inserting a dielectric affect the capacitance of a capacitor?
5. Give two examples of semiconductor applications that rely on electrostatic control.
6. A $+25.0\ nC$ charge is placed at the origin of a coordinate system, and a $-15.0\ nC$ charge is placed in the xy-plane at the point$(x = 0.200\ m, y = -0.100\ m)$.

a) Determine the magnitude and the direction of the force that the positive charge exerts on the negative charge. Use ijk notation for your result.
b) Determine the magnitude and direction of the force of the negative charge on the positive charge.

7. A capacitor that has two parallel plates of dimensions $15.00cm \times 25.00\ cm$ separated by $3.00\ mm$ of air is connected to a $12.0\ V$ battery. Find
    a) the capacitance
    b) the charge on one plate
    c) the electric field in the capacitor

Chapter 10 - Electricity and Magnetism

Electric Charge and Coulomb's Law

Quantisation & Conservation: Charge is quantised ($q = ne$) and conserved in isolated systems.

Electron charge (e):$-1.602 \times 10^{-19} C$

Proton charge*:* $+1.602 \times 10^{-19} C$

Coulomb's Law (Vector Form): Describes the electrostatic force between two-point charges. unlike charges attract; like charges repel.

$$F_{12} = k \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

Where k (Coulomb constant) ≈ $8.99 \times 10^9 N \cdot m^2 C^{-2}$

Engineering Note: In calculations, we often use the permittivity of free space ϵ_0:

$k = \frac{1}{4\pi\epsilon_0}$ where $\epsilon_0 \approx 8.85 \times 10^{-12} F/m$

Electric Field and Electric Potential

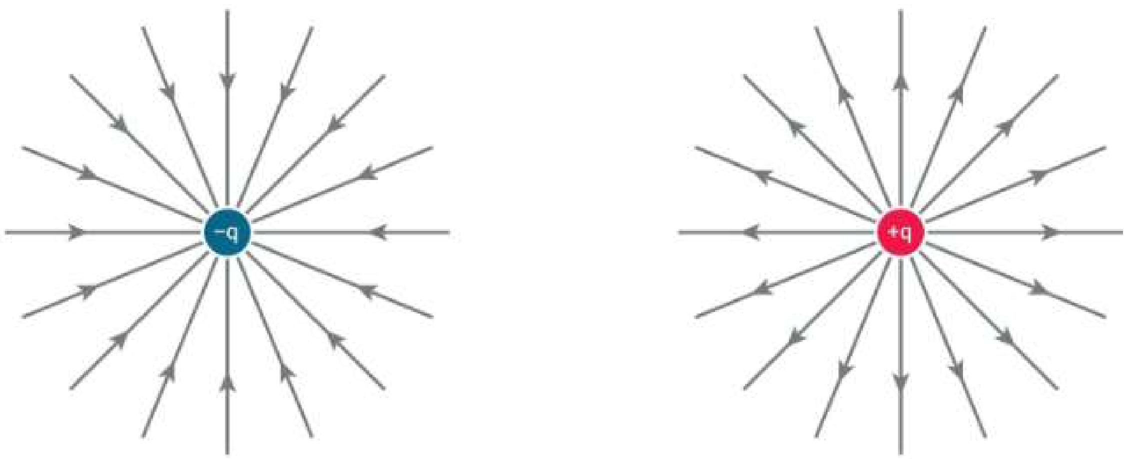


Figure 10.1: Visualization of Electric field lines due to charges

Electric Field (E): A vector field representing the force per unit positive charge at a point in space

$$E = \frac{F}{q_0}$$

Superposition Principle*:* The total E-field due to a distribution of charges is the vector sum of individual E-fields.

Electric Potential (V): A scalar quantity representing the electric potential energy (U) per unit charge. $V = \frac{U}{q_0}$ of $\Delta V = -\int_A^B \quad E \cdot dl$

Unit: Volts (V) or Joules/Coulomb (J/C).

Relation: The electric field points in the direction of the steepest decrease in potential ($E = -\nabla V$).

Equipotential Surfaces: Surfaces where V is constant. Electric field lines are always perpendicular to equipotential surfaces.

Magnetic Field and Magnetic Potential

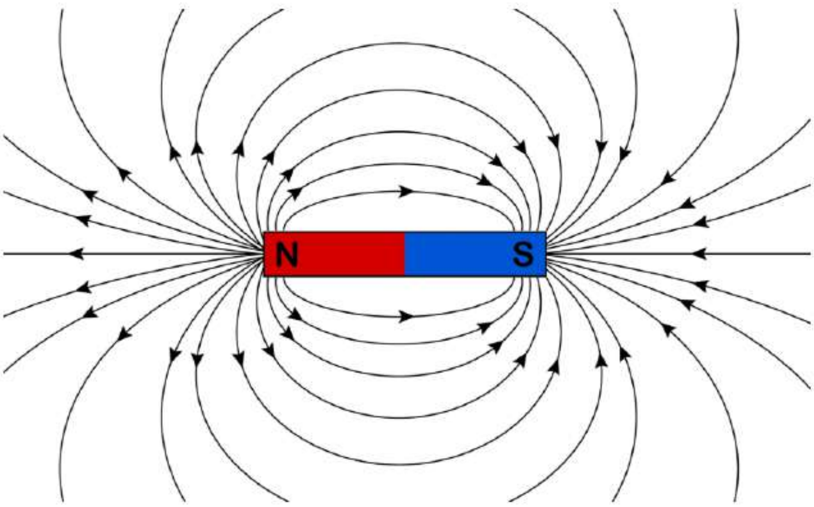


Figure 10.2: Magnetic field around a permanent magnet

Source of Magnetism: Unlike electric fields produced by static charges, Magnetic Fields (B) are produced by moving charges (currents) or intrinsic magnetic moments (spin).

The Biot-Savart Law: Calculates the B field produced by a current element Idl.

$$dB = \frac{\mu_0 I}{4\pi} \frac{dl \times \hat{r}}{r^2}$$

μ_0 (Permeability of free space) $= 4\pi \times 10^{-7} T \cdot m/A$

Direction: Determined by the Right-Hand Rule.

Comparison:

- **Electric:** Sources are monopoles (+ or -). Field lines start/end on charges.
- **Magnetic:** No magnetic monopoles exist. Field lines form closed loops.

Electromagnetic Force (Lorentz Force)

- **The Combined Force:** A charged particle moving with velocity v in the presence of both E and B fields experience the Lorentz force:

$$F = q(e + v \times B)$$

Magnetic Force Specifics:

- Force is maximum when velocity is perpendicular to the B-field ($\theta = 90°$).
- Force is zero if the particle moves parallel to the field lines.
- *Work:* Magnetic force does no work on the particle because F is always perpendicular to v. It changes the direction (centripetal force), not the speed.

Electrical Circuits

Ohm's Law and Resistance

Macroscopic Form: The current through a conductor is proportional to the voltage across it. $V = IR$

Resistivity (ρ): An intrinsic material property. Resistance R is determined by geometry: $R = \rho \frac{L}{A}$

Temperature Dependence: For metals, resistivity increases with temperature: $\rho = \rho_0[1 + \alpha(T - T_0)]$

Kirchhoff's Laws (Circuit Analysis)

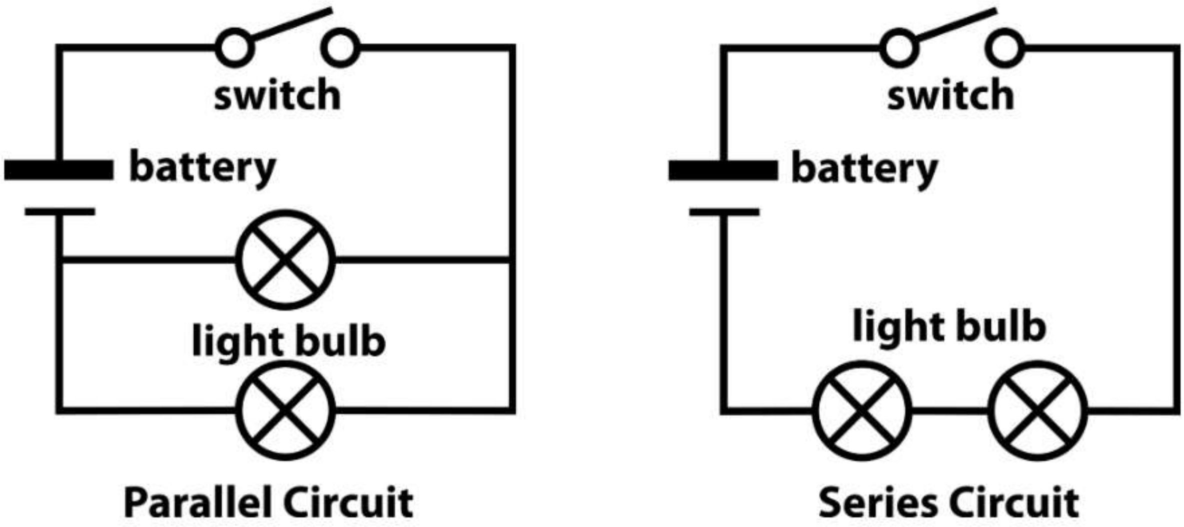


Figure 10.3: circuit types

Kirchhoff's Current Law (KCL): Based on **Conservation of Charge**

$\sum I_{in} = \sum I_{out}$ at any junction(node).

Kirchhoff's Voltage Law (KVL): Based on **Conservation of Energy**

$\sum \Delta V = 0$ around any closed loop

Convention: Voltage drops across a resistor in the direction of current ($-IR$); voltage rises going from negative to positive terminal of a battery ($+E$)

Series and Parallel Configurations

Feature	Series Circuits	Parallel Circuits
Current	Same through all components ($I_{total} = I_1 = I_2$)	Splits across branches ($I_{total} = I_1 + I_2$))
Voltage	Splits across components ($V_{total} = V_1 + V_2$)	Same across all components $V_{total} = V_1 = V_2$)
Equivalent Resistance	$R_{eq} = R_1 + R_2 + \cdots R_n.$	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}$
Failure Mode	One break stops all current (Open Circuit).	One break affects only that branch.

Table 1: Table showing comparison between series and parallel circuits

DC vs. AC Circuits

Direct Current (DC): Unidirectional flow. Source: Batteries, Solar cells.

Alternating Current (AC): Current reverses direction periodically (Sinusoidal). Source: Wall outlets, Generators.

- *Key Metric:* **RMS (Root Mean Square)** values for AC voltage and current are used to calculate equivalent power.
- *AC* allows easy voltage stepping (via transformers) for efficient long-distance transmission

Electromagnetic Induction

Magnetic Flux

- Defined as the amount of magnetic field passing through a surface area A.

$$\Phi_B = \int B \cdot dA = BAcos\theta$$

Unit: Weber (Wb)

Faraday's Law of Induction

A changing magnetic flux induces an electromotive force (EMF, E) in a loop

$$E = -N\frac{d\Phi_B}{dt}$$

This is the operating principle behind **generators**, **transformers**, and **induction cooking**

Lenz's Law

The "Negative" Sign: The direction of the induced current is such that it creates a magnetic field to **oppose the change** in magnetic flux that produced it.

Example: If you push a magnet into a coil, the coil creates a field pushing back. This ensures Conservation of Energy.

Generators and Motors

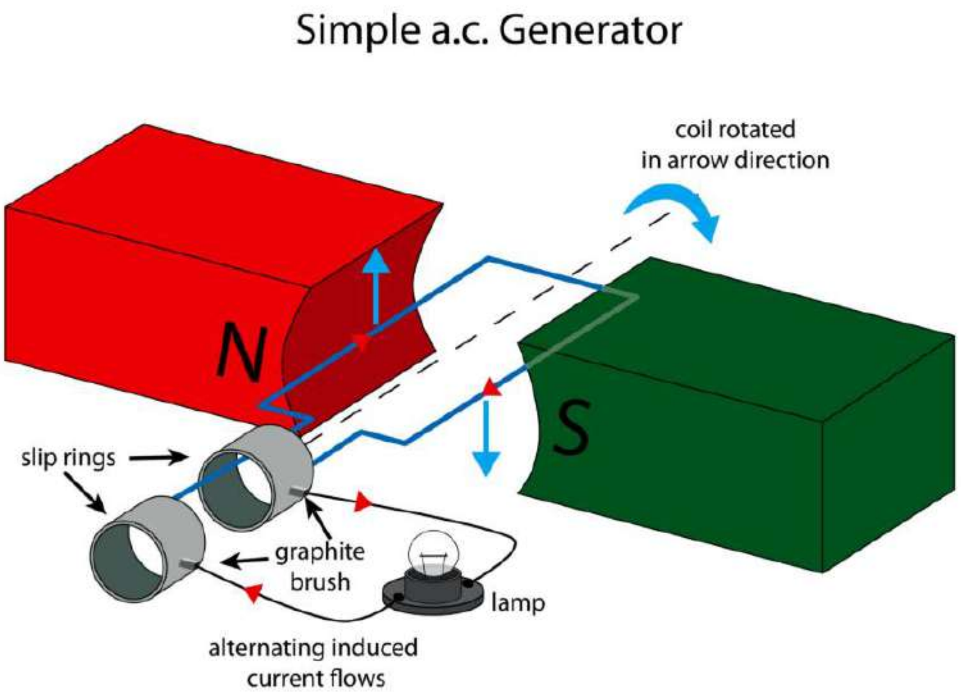


Figure 10.4: Simple AC generator

Generator: Mechanical Energy →Electrical Energy.

- Rotate a coil in a B-field →Change Φ_B → Induce Current.

Motor: Electrical Energy →Mechanical Energy.

- Current in a coil within a B-field →Lorentz Force creates Torque →Rotation

Activities & Practical Applications

1. Laboratory Practical: CUMSM 110 No.3 (Intro to Components & Safety)

- **Focus:** Multimeter usage (Ammeter in series, Voltmeter in parallel).
- **Safety Note:** High current is more dangerous than static high voltage. Always ensure power is off before modifying a circuit.

2. Laboratory Practical: CUMSM 110 No.4 (Series & Parallel)

- **Objective:** Verify R_{eq} formulas experimentally.
- **Troubleshooting:** If readings don't match theory, check for loose connections (added resistance) or blown fuses in the multimeter.

3. Project Prototype (Applicable)

- *Idea:* Build a simple DC motor using a battery, magnet, and copper wire.
- *Idea:* Construct a small solenoid and measure the magnetic field strength vs. current.

Exercises

1. A particle with a charge of $1.1\ nC$ and a mass of $1.2 \times 10^{-9} kg$ moves with velocity $\vec{v} = (1.7 \times 10^4 ms^{-1})\hat{\imath} + (1.8 \times 10^4 ms^{-1})\hat{\jmath}$ as it enters a uniform magnetic field of $\vec{B} = (1.2\ T)\hat{\imath}$.

   a) Calculate the magnetic force acting on the particle as it enters the field.

   b) Describe the path of the particle, and determine its radius.
   c) Calculate the time it takes for the particle to complete one revolution.
   d) Calculate the distance the particle travels along the magnetic field lines as it completes one revolution.

2. Electric eels generate electric pulses along their skin that can be used to stun an enemy when they encounter it. Research has shown that these pulses can be up to $500\ V$ and produce currents of $80\ mA$ (or even larger). A typical pulse lasts for $10\ ms$. Calculate:

   a) The charge released,
   b) the power and,
   c) how much energy are delivered to the unfortunate enemy with a single pulse, assuming a steady current.

3. A straight wire of length 20 cm carries a current of 5 A. The wire is placed in a uniform magnetic field of 0.2 T that is perpendicular to the wire. Find the magnetic force on the wire and the magnetic flux through a rectangular loop of area $0.04\ m^2$ that encloses the wire.
4. A straight wire of length 20 cm carries a current of 5 A. The wire is placed in a uniform magnetic field of 0.2 T that is perpendicular to the wire. Find the magnetic force on the wire and the magnetic flux through a rectangular loop of area $0.04\ m^2$ that encloses the wire.

Chapter 11: Materials Science

This unit introduces the fundamental concepts of materials science, bridging the gap between pure physics (atomic theory, thermodynamics, electricity) and practical engineering applications. It focuses on the central paradigm of materials science: the interrelationship between Processing, Structure, Properties, and Performance.

Students will move beyond macroscopic observations to understand why materials behave the way they do based on their atomic and microscopic arrangements.

1. Overview of Materials Science: Definition, History, and Modern Relevance

Materials Science is not merely a catalogue of substances; it is the study of why materials behave the way they do. The central principle of the field is represented by the **Materials Science Tetrahedron**, which illustrates the four-way interdependence of:

1. **Processing:** How a material is manufactured (e.g., casting, forging, 3D printing).
2. **Structure:** The internal arrangement of components, from the atomic scale to microscopic grains.
3. **Properties:** The material's response to an external stimulus, such as heat, electricity, or a physical load.
4. **Performance:** How effectively the material functions in a specific, real world application

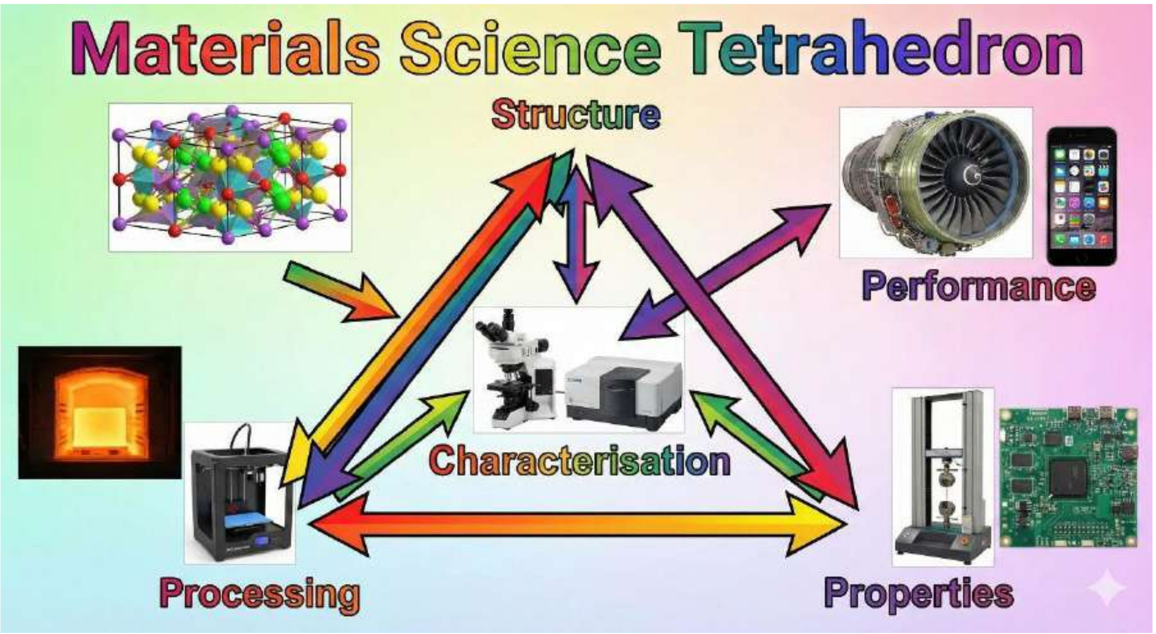


Figure 11.1: Materials Science Tetrahedron (Gemini prompt generated Image)

History

Figure 11.2: Timeline of materials and tools (Gemini prompt generated image)

- Civilisation is often classified by the dominant material used:

- **Stone Age, Bronze Age, Iron Age:** marked human mastery over progressively harder-to-process materials to create superior tools.
- **Modern Era (The "Silicon Age" or "Plastic Age"):** Characterised by the ability to engineer materials from the atom up to suit specific needs, rather than just using what is naturally available.

Modern Relevance in Engineering Physics: Virtually every engineering advance is limited by available materials.

- **Aerospace:** Needs high strength-to-weight ratios and resistance to extreme temperature changes (e.g., carbon fiber composites, superalloys).
- **Electronics:** Driven by semiconductor physics, allowing for miniaturisation (Moore's Law).
- **Energy:** Requires materials for better battery electrodes, efficient solar cells, and high-temperature superconductors for lossless transmission.

1. Classification of Materials

Materials are scientifically grouped based on their chemical makeup and the nature of their atomic bonding.

11.1Metals

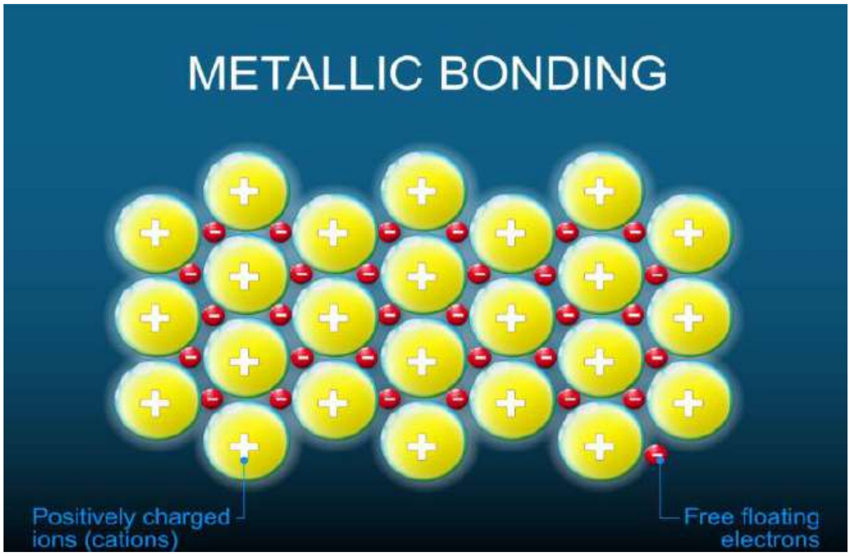


Figure 11.3: Metallic bonding (ttsz/Getty Images)

- **Structure:** Composed of metallic elements (Fe, Al, Cu, Ti) usually arrange in orderly crystalline structures. Atoms are held together by a "sea of delocalized valence electrons", which are free to move throughout the lattice.
- **Key Properties:**
  - High electrical and thermal conductivity (due to free-moving electrons).
  - High strength but usually ductile (capable of being drawn into wires or hammered thin without breaking).
  - Opaque and reflective.

11.1.1 Ceramics

- **Structure:** Compounds between metallic and non-metallic elements (e.g., oxides, nitrides, carbides). Examples: Alumina (Al_2O_3), Silica (SiO_2), Silicon Carbide (SiC). Bonding is usually ionic or strongly covalent.

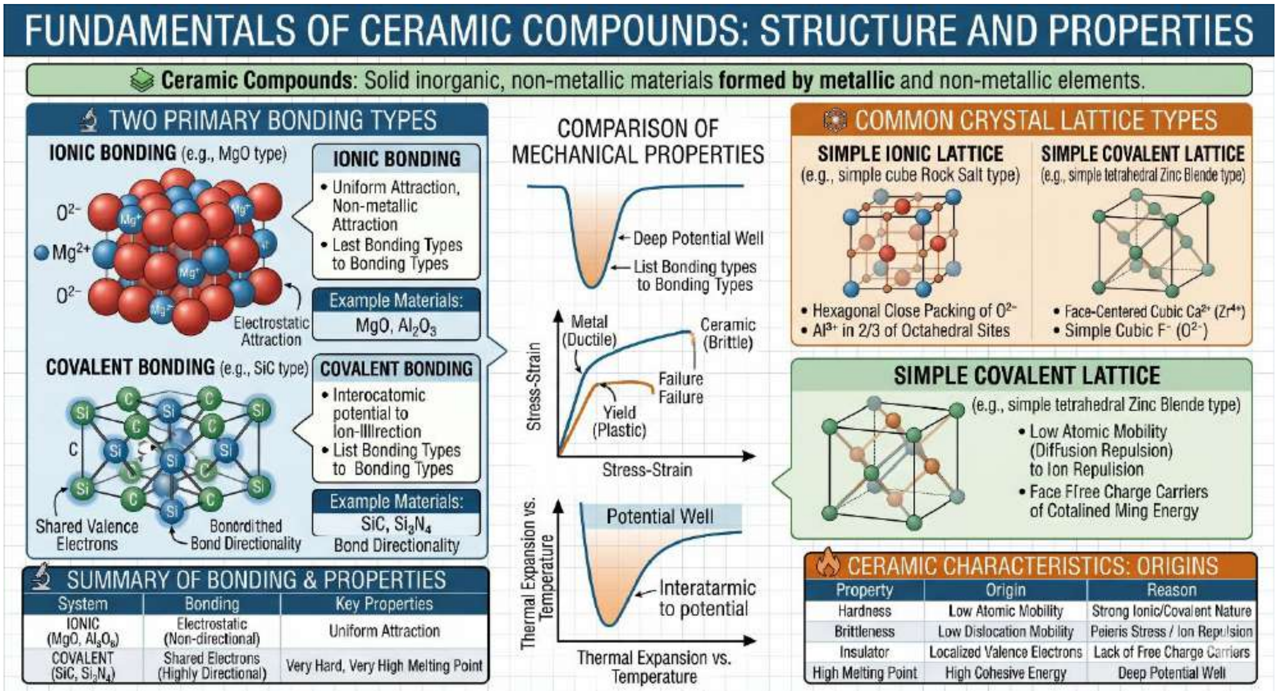


Figure 11.4: ceramic compounds structure and properties

- **Key Properties:**
    - They are extremely hard and resistant to high temperatures but suffer from being **brittle** (they shatter rather than bend under stress).
    - Electrons are tightly bound, making ceramics excellent insulators.
    - High resistance to chemical corrosion.

11.1.2 Polymers

- **Structure:** Made of very long molecular chains (macromolecules) based on carbon, hydrogen, and other non-metals. They are lightweight, flexible, and chemically resistant.
    - *Thermoplastics* (e.g., Polyethylene, PVC): Chains melt when heated and reshape.
    - *Thermosets* (e.g., Epoxies, vulcanized rubber): Permanent network structure; they decompose rather than melt upon reheating.

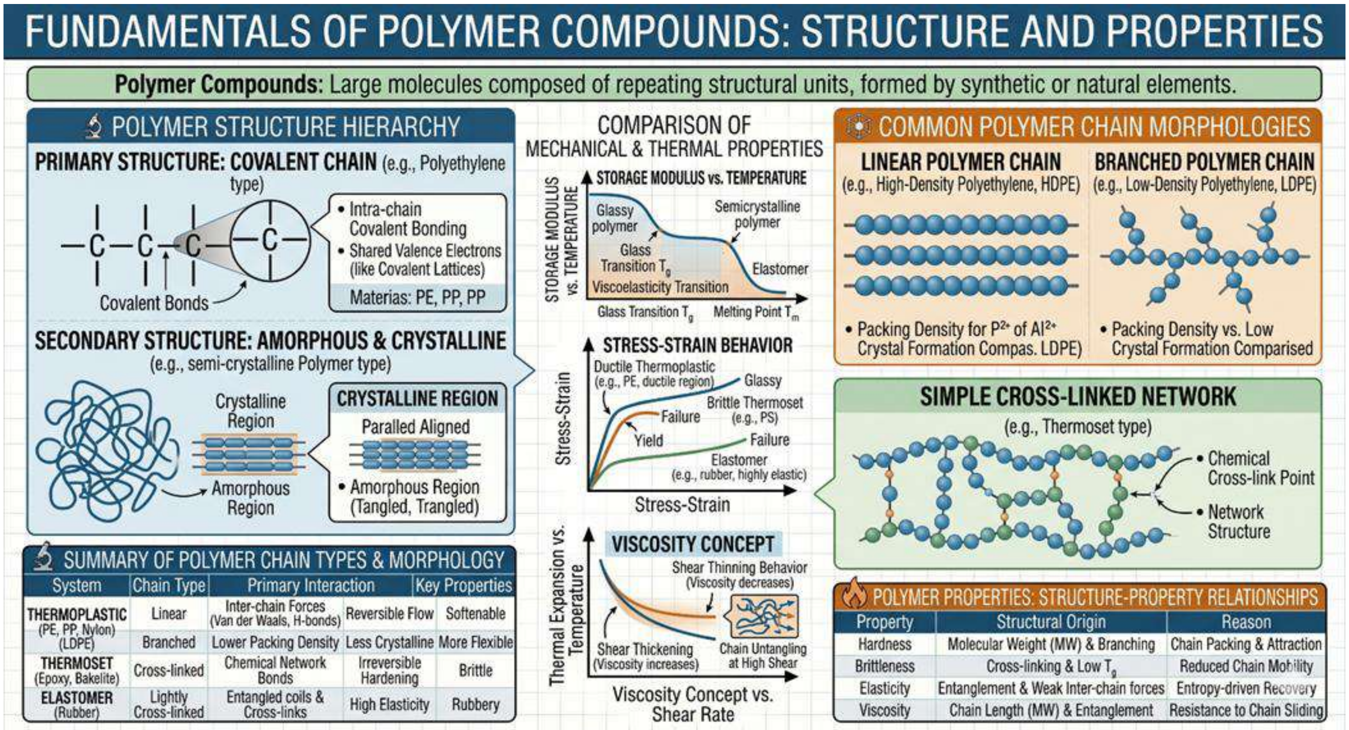


Figure 11.5: Polymer compounds structure and properties

- **Key Properties:**
    - Low density (lightweight).
    - Highly flexible and easily formed into complex shapes.
    - Generally poor conductors of electricity and heat.

11.1.3 Composites

- **Structure:** A multiphase material composed of two or more chemically distinct materials combined to achieve properties better than either individual component. Usually consists of a *matrix* (continuous phase, often polymer or metal) and a *reinforcement* (dispersed phase, like fibers or particles).

- **Examples:**

    - *Fiberglass:* Glass fibers (strong but brittle) embedded in a polymer matrix (tough but weak).

- *Concrete:* Aggregate (sand/gravel) bonded by cement.

11.1.4 Advanced Materials (Semiconductors)

- Crucial for physics and electrical engineering. Their electrical properties are intermediate between conductors and insulators and are highly sensitive to extremely small concentrations of impurity atoms (doping). Example: Silicon, Gallium Arsenide.

11.2 Atomic Structure and Interatomic Bonding

The properties of a material are ultimately determined by the nature of the forces holding its atoms together.

The Physics of Bonding: Atoms bond to achieve the lowest possible energy state. The equilibrium spacing between atoms occurs where the net force between them is zero (balance between attractive and repulsive forces). The depth of this energy potential well relates to the melting point and stiffness (modulus) of the material.

11.3 Primary Bonds (Strong, involving valence electrons):

11.3.1 Ionic Bonds:

- *Mechanism:* Complete transfer of electrons from an electropositive atom (metal) to an electronegative atom (non-metal), creating strong electrostatic attraction between ions (Coulomb force).
- *Characteristics:* Non-directional bond. resulting materials are hard, brittle, and electrically insulating (typical of ceramics).

11.3.2 Covalent Bonds:

- *Mechanism:* Sharing of valence electrons between adjacent atoms to fill outer electron shells.

- *Characteristics:* Highly directional bond. Can be very strong (diamond) or result in long chains (polymers).

11.3.3 Metallic Bonds:

- *Mechanism:* Valence electrons are not bound to any specific atom but form a "sea" or "cloud" that drifts throughout the entire metal structure, holding the positive ions together.
- *Characteristics:* Non-directional. Explains high conductivity and ductility (atoms can slide past one another without breaking the bond),typical of metals.

11.3.4 Secondary Bonds (Weak):

- **Van der Waals / Hydrogen Bonds:** Weak attractions arising from temporary or permanent electric dipoles between molecules.
- *Relevance:* They significantly influence the physical properties of polymers (holding the chains together) and liquids.

11.4 Crystallography: Understanding the Solid State

Solid materials are classified by the regularity of their atomic arrangement.

11.4.1 Crystalline vs. Amorphous:

- **Crystalline Material:** Atoms are situated in a repeating, periodic array over large atomic distances (long-range order). Most metals and many ceramics are crystalline.
- **Amorphous Material (Non-crystalline):** No long-range atomic order. The structure resembles a "frozen liquid." Examples: glass, many plastics.

11.4.2 Crystal Structure Concepts:

- **Lattice:** A 3D grid of points designating atomic positions.

- **Unit Cell:** The smallest repeating unit that describes the crystal structure.
- **Common Metallic Crystal Structures:**
  - *Face-Centred Cubic (FCC):* Atoms at corners and centre of each face. Tends to be highly ductile (e.g., Aluminum, Copper, Gold).
  - *Body-centred Cubic (BCC):* Atoms at corners and one in the dead centre. Often stronger but less ductile at low temps (e.g., Iron below 912°C, Tungsten).

Real Crystals are Imperfect: Real materials contain defects, which profoundly affect properties, especially mechanical strength and electrical resistance.

- **Point Defects:**
  - *Vacancy:* A missing atom in the lattice site.
  - *Interstitial:* An extra atom squeezed into the void space between regular atoms.
  - *Substitutional Impurity:* A different type of atom replacing a host atom (the basis of alloys like brass = copper + zinc).

- **Line Defects (Dislocations):**
  - An extra half-plane of atoms inserted into the crystal lattice.
  - *Importance:* **Dislocations are the primary mechanism responsible for plastic (permanent) deformation in metals.** When stress is applied, dislocations move, allowing planes of atoms to slip past each other. Restricting dislocation movement makes a metal harder and stronger.

- **Interfacial Defects (Grain Boundaries):**
  - Most crystalline solids are *polycrystalline*, meaning they are made of many small crystals (grains) with different orientations. The boundary between them is a "grain boundary." Smaller grains mean more boundaries, which impede dislocation movement, leading to stronger materials.

11.5 Properties of Materials

11.5.1 Mechanical Properties (Response to applied loads)

- **Stress (σ):** Force applied per unit area ($\sigma = \frac{F}{A}$). Units: Pascals (Pa) or MPa.
- **Strain (ε):** The resulting deformation; change in length divided by original length ($\epsilon = \frac{\Delta l}{l_0}$). Unitless.
- **Elastic Deformation:** Reversible deformation. The material returns to its original shape when load is removed.
- Governed by **Hooke's Law**:$\sigma = E \cdot \epsilon$, where E is **Young's Modulus** (a measure of stiffness or resistance to elastic deformation).
- **Plastic Deformation:** Permanent, non-recoverable deformation occurring after a critical stress level (the **Yield Strength**) is exceeded.
- **Ductility:** A measure of how much a material can plastically deform before fracturing.
- **Toughness:** The total amount of energy a material can absorb before fracturing (area under the entire stress-strain curve).
- A material must be both strong and ductile to be tough.

11.5.2 Electrical Properties (Response to electric fields)

- Based on **Band Theory**: Electrons exist in discrete energy levels grouped into "bands."
  - **Valence Band:** Filled with outer shell electrons.
  - **Conduction Band:** Higher energy band where electrons are free to move and conduct electricity.
  - **Energy Gap (Band Gap):** The forbidden energy zone between valence and conduction bands.
- **Conductors (Metals):** Valence and conduction bands overlap. Electrons move easily.
- **Insulators:** Wide band gap. Large energy needed to jump to conduction band.

- **Semiconductors:** Narrow band gap. Thermal energy or doping can bridge the gap.

11.5.3 Thermal Properties (Response to heat)

- **Heat Capacity:** The ability of a material to absorb heat from its surroundings. Physically, this represents the energy required to increase vibrational motion of atoms in the lattice (phonons).
- **Thermal Expansion:** Materials expand upon heating because the interatomic potential energy well is asymmetric; as atoms vibrate more vigorously at higher temperatures, their average separation distance increases.
- **Thermal Conductivity:** The ability to transfer heat. Occurs via lattice vibrations (dominant in ceramics) and free electrons (dominant in metals, which is why good electrical conductors are usually good thermal conductors).

11.5.4 Magnetic Properties

- Originates from electron spin and orbital motion.
- **Ferromagnetism:** Permanent magnetic moments align parallel to each other in regions called *domains* (e.g., Fe, Ni, Co).
- **Paramagnetism & Diamagnetism:** Weak magnetic responses present in all materials, usually overshadowed by ferromagnetism if present.

11.6 Material Selection and Design

Engineering is about optimizing trade-offs.

- **Performance Criteria:** An engineer must define the required properties (e.g., "must withstand 500 MPa of tension at 300°C while conducting electricity").
- **Processing-Structure Link:** How we make it changes what it is.

  - *Example:* Cooling molten steel slowly results in large grains (softer, more ductile). Cooling it instantly (quenching) locks in a different structure and small grains (harder, brittle).
- **Economics:** A titanium alloy might be the perfect performance choice for a car bumper, but steel is used due to cost.
- **Sustainability (Life Cycle Analysis):** Considering the energy burden of mining, refining, toxicity during use, and recyclability at end-of-life.

11.7 Future Frontiers in Materials Science

- **Nanomaterials:** Materials where characteristic dimensions are less than 100 nanometres. At this scale, quantum mechanics dominate, and surface area-to-volume ratios are huge, leading to unique properties (e.g., Carbon Nanotubes, Graphene).
- **Smart Materials:** Materials that sense a change in their environment and respond in a predictable manner (e.g., Shape Memory Alloys that return to an original shape when heated; Piezoelectric ceramics that generate voltage when stressed).
- **Biomaterials:** Materials designed to interface with biological systems to evaluate, treat, augment, or replace any tissue, organ, or function of the body.

Activity 11.1

Field Practical: Visit a local materials processing plant or foundry. Observe the stages of material production, testing, and recycling. Prepare a brief report linking observed processes to material properties discussed in class.

Exercises

1. Good electrical conductors, such as metals, are typically good conductors of heat; electrical insulators, such as wood, are typically poor conductors of heat. Explain why there should be a relationship between electrical conduction and heat conduction in these materials.

2. You are designing a satellite that will orbit the Earth for several years. What kind of materials would you use for the outer shell and why? Consider the factors such as thermal expansion, corrosion, radiation, and weight.
3. Explain what is meant by minority and majority carriers in an p-type material and state whether the numbers of each of these carriers are affected by temperature.
4. Explain how grain structure affects strength in metals.
5. Compare the mechanical properties of a metal and a polymer under tension.

SECTION A *(45 marks)*

Attempt **ALL** questions.

A1. Explain why the Engineering Physics Course is relevant to your area of study.

[3]

A2. Hooke's law states that the force, F, in a spring extended by a length x is given by $F = -kx$. From Newton's second law $F = ma$, where m is the mass and a is the acceleration, calculate the dimensions of the spring constant k. **[3]**

A3. Suppose that the uncertainty in the length $17.386\ 22\ m$ is $0.04\ m$. Round the length to the correct number of significant digits. **[2]**

A4. A female cheetah starts from rest and accelerates uniformly for 5 seconds until she reaches a velocity of $20\ m\ s^{-1}$while chasing a Thompson gazelle. She then runs at a constant velocity for 8 seconds before decelerating as she failed to catch the gazelle. Sketch a velocity-time graph of her motion. **[4]**

A5. A construction worker standing on a beam asks his very strong friend on the ground 9.00 m below to throw his lunch box up to him. The friend wants to throw the box straight up such that it has a velocity of 0.500 m/s up when it reaches the worker on the beam, to give him some leeway as he tries to catch it.

b) What assumption(s) should you make to solve the problem? **[2]**

c) At what speed should the friend throw the lunch box? **[3]**

d) How long will the lunch box be in the air before it is caught by the worker? **[2]**

e) How long does it take for the lunch box to cover the first 4.50 m of its trajectory? **[3]**

f) How high above its initial position will the lunch box be after half the total time of its motion? **[2]**

g) Sketch the distance-time, velocity-time, and acceleration-time graphs for the motion of the lunch box. **[4]**

A6. Two objects are moving at constant velocities: $\vec{V}_A = (2\hat{\imath} - 5\hat{\jmath})m/s$, $\vec{V}_B = (-2\hat{\imath} + 4\hat{\jmath})m/s$.

a) Which object is moving faster? **[3]**

b) Find the angle between objects' trajectories. **[3]**

A7. In Fig 1. a block of mass m_1 = 1.5 kg (**A)** on a plane inclined at $\theta = 30°$ (coefficient of friction = 0.15) is connected by a cord over a frictionless pulley to a second block **B** of mass m_2 = 3.00kg. Ignoring the mass of the pulley, determine

a) the magnitude of the acceleration of each block, **[4]**

b) the direction of the acceleration of the hanging block, and **[1]**

c) the tension in the cord. **[2]**

d) If the blocks are released from rest with the connecting cord taut, use the work kinetic energy theorem to determine the blocks total kinetic energy when block B has moved 30cm. **[4]**

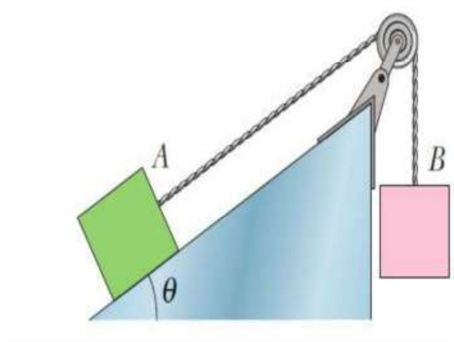


Figure 1

SECTION B *(35 marks)*

Answer question **B1** and **any other three** questions.

B1. (a) Define floating. **[2]**

(b) A cube of edge length $L = 0.600\ m$ and mass $450\ kg$ is suspended by a rope in an open tank of liquid of density $1030\ kg/m^3$, as shown in Fig 2.

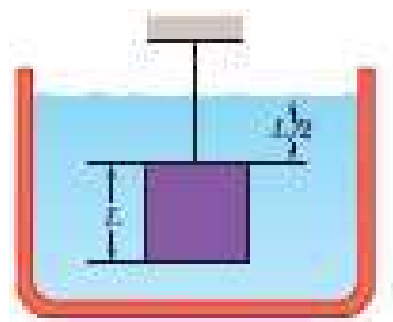


Figure 2

Find,

(i). the magnitude of the total downward force on the top of the cube from the liquid and the atmosphere, assuming atmospheric pressure is 1.00 atm, **[2]**

(ii). The magnitude of the total upward force on the bottom of the cube, **[2]**

(iii). The tension in the rope. **[2]**

(iv). The magnitude of the buoyant force on the cube using Archimedes' principle. **[3]**

B2.

a) Define resonance and describe one scenario where it is applied for the benefit of mankind. **[4]**

b) A block of mass $m = 14.00\ kg$ is released from rest on a frictionless incline of angle $\theta = 30°$, as shown in **Fig 3**. Below the block is a spring with spring constant, $k = 1800 N/m$. The block momentarily stops when it compresses the spring by 7.0 cm. Calculate the speed of the block just before compressing the spring. **[4]**

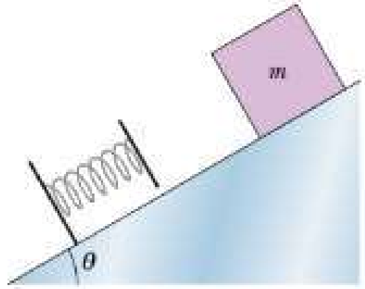


Figure 3

B3. (a). Calculate the difference in blood pressure (in atmosphere) between the heart and the foot in a person of height 2.00 m and the height from the heart to the head is 0.40 m and the density of blood is $1.06 \times 10^3 kg/m$. **[4]**

(b). The U-shape in Fig 4 contains two liquids in static equilibrium: water of density $998\ kg/m^3$ and an unknown liquid with unknown density. Find the density of the unknown liquid if $h = 155\ mm$ and $l = 135\ mm$. **[4]**

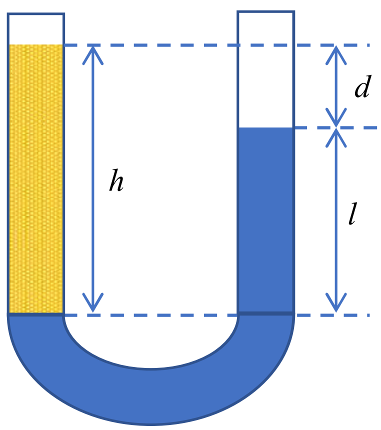


Figure 4

B4. A bat is flying at 7.00 m/s and is emitting cries at a frequency of 82.0 kHz. It is chasing a moth and is detecting the echoes from the moth. Moths fly somewhat erratically. Calculate the frequency detected by the bat when the moth is;

a) Stationary **[2]**

b) flying at 1.00 m/s in the same direction as the bat **[3]**

c) flying at 2.00 m/s toward the bat **[3]**

B5.

a) You went to the farm to do some sightseeing, then the workers ask you to measure the depth of a well. As an engineering student, you decide to show that you can use your intellect to determine the depth of the well to the amusement of the folks there. You drop a stone into the well and hear the splash 2.8 s later. Calculate the depth of the well. **[4]**

b) Consider the simplified single-piston engine in Fig 5. Assuming the wheel rotates with constant angular speed, explain why the piston rod oscillates in simple harmonic motion. **[4]**

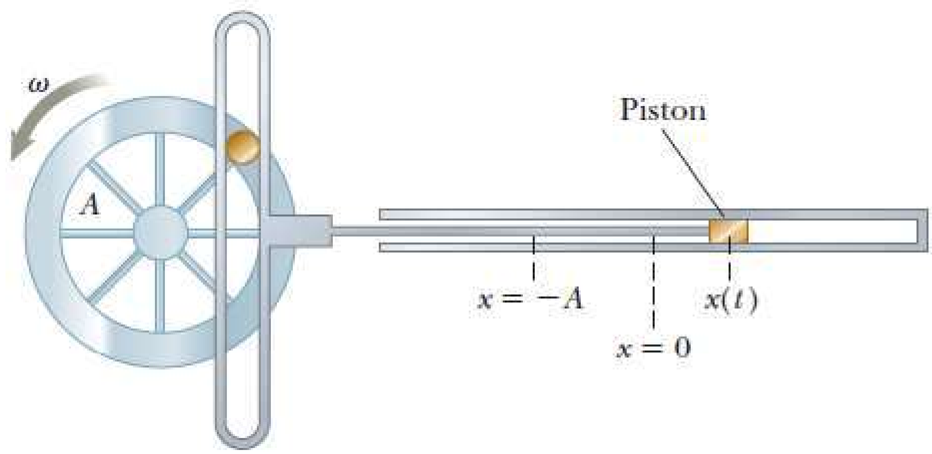


Figure 5

SECTION C *(20 marks)*

Answer question **C1 and any other three** questions.

C1. Draw a diagram showing the effects of both a converging lens on a beam of parallel rays. On the diagram clearly label the principle axis, principle focus, and focal length. **[8]**

C2. Good electrical conductors, such as metals, are typically good conductors of heat; electrical insulators, such as wood, are typically poor conductors of heat. Explain why there should be a relationship between electrical conduction and heat conduction in these materials. **[4]**

C3. An underwater scuba diver sees the Sun at an apparent angle of $45.0°$ above the horizontal. Calculate the actual elevation angle of the Sun above the horizontal. **[4]**

C4. A $+35.0\ nC$ charge is placed at the origin of a coordinate system, and a $-25.0\ nC$ charge is placed in the xy-plane at the point$(x = 0.100\ m, y = -0.0500\ m)$.

a) Determine the magnitude and the direction of the force that the positive charge exerts on the negative charge. Use ijk notation for your result. **[4]**

C5. A Referring to the circuit shown below in Fig 6, determine the number of;

a) nodes; **[1]**

b) elements; **[1]**

c) branches. **[1]**

d) loops **[1]**

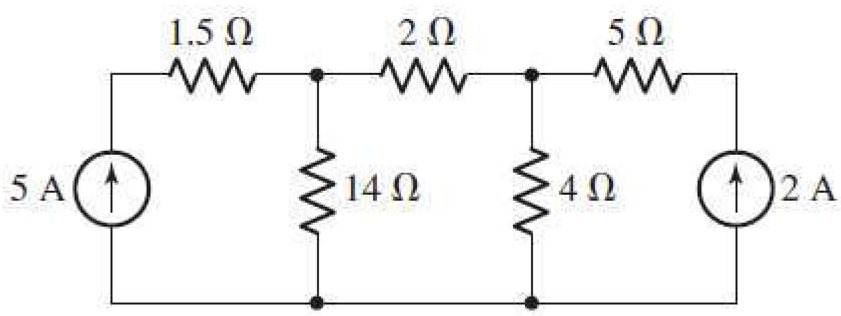


Figure 6

END OF EXAMINATION

SECTION A *(50 marks)*

Attempt **ALL** questions

A1. Explain the importance of dimensional analysis. [1]

A2. Certain stars, whose light and radial velocities undergo periodic vibrations, are thought to be pulsing. It is hypothesized that the period t of pulsation depends upon the star's radius, r, its mass, m, and the gravitational constant, G.

i. Compute the units of force from $F = ma$. [2]

ii. Newton's law of gravitation asserts that the attractive force between two bodies is proportional to the product of their masses divided by the distance between them:

$$F = G\frac{m_1 m_2}{r^2}$$

Compute the units of G from this. [4]

A3. Two vectors $\vec{a}$ and $\vec{b}$ have equal magnitudes of 12.0 m and the angles are $\theta_1 = 30°$ and $\theta_2 = 105°$ as shown in Fig. 1.

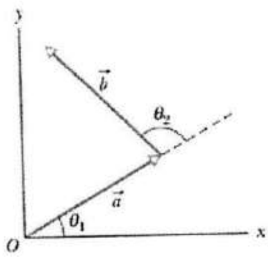


Fig. 1.

Find:

a. the magnitude of $\vec{r}$, and [3]
b. the angle that $\vec{r}$ makes with the positive direction of the x axis. [3]

A4. A certain airplane has a speed of $240.0\ km/h$ and is diving at an angle of $30.0°$ below the horizontal when the pilot releases a radar decoy as shown in Fig. 2.

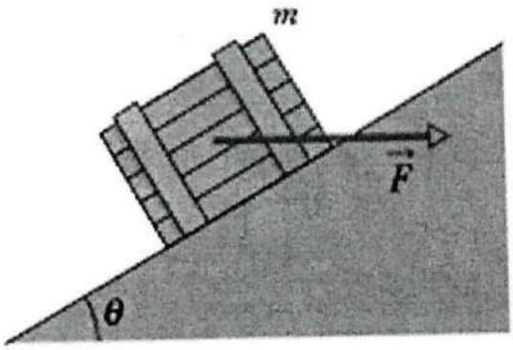


Fig. 4.

If the ramp has a coefficient of friction, $\mu = 0.20$,

i. Calculate the magnitude of the normal force [3]

ii. Calculate the force $\vec{F}$ [2]

A6.

a. Define work. [1]

b. Distinguish between conservative and no-conservative forces. [2]

c. A block of mass $m = 8.00\ kg$ is released from rest on a frictionless incline of angle $\theta = 30.0°$, as shown in Fig 5. Below the block is a spring that can be compressed $2.0\ cm$ by a force of 270 N. The block momentarily stops when it compresses the spring by 5.5 cm.

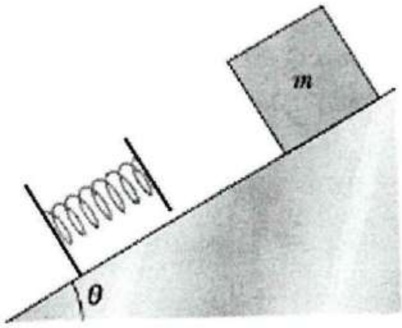


Fig 5.

i. Calculate the distance moved by the block down the incline from its rest position to this stopping point. [3]

ii. Calculate the speed of the block just as it touches the spring. [3]

c. A block of mass $m = 2.5\ kg$ slides head on into a spring of spring constant $k = 320\ N/m$ as shown in Fig. 6. When the block stops, it has compressed the

SECTION B *(30 marks)*

Answer all questions

B1. State
  (i) Archimedes Principle
  (ii) Pascal' s law [2]

B2. Give one important property for ANY four of the five main classes of engineering materials. [4]

B3. Differentiate between composition and atomic structure as applied in Materials science. [4]

B4.

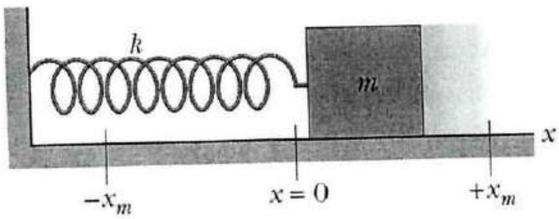


Fig 1. For Question 4.

At time $t = 0$, the displacement $x(0)$ of the block in a linear oscillator like that of Fig. 1 is -8.50 cm. The block's velocity $v(0)$ then is -0.93 m/s, and its acceleration $a(0)$ is 45.0 m/s^2 . Determine,
  (i) the angular frequency of this system, [3]
  (ii) the phase constant and [1]
  (iii) the amplitude of this system. [1]

B5. While moving along a straight road, you first approach, and then pass a stationary car at the side of road. The car's horn is being continuously sounded. The frequency recorder you are carrying reads 638 Hz as you are approaching the car, and records 588 Hz as you recede from the car.
  (i) Describe the Doppler Effect and give one example of its applications. [4]
  (ii) Use the value of 340 m/s for the speed of sound in air in air to calculate your own speed and the frequency the occupant of the car hears. [6]

B6. A rectangular block of low density material weighs 20.0 N. A thin string is attached to the centre of the horizontal bottom of the block and tied to the bottom of a beaker partially filled with water. When 25% of the block's volume is submerged, the tension in the string is 10.0 N.
  i. Calculate the buoyant force acting on the block. [3]
  ii. Oil of density 800 kg/m^3 is steadily added, forming a layer above the water and surrounding the block. Explain why the addition of oil causes the string to break. [2]

SECTION A *(30 marks)*

Attempt **ALL** questions

A1. Explain the importance of dimensional analysis. [1]

A2. Certain stars, whose light and radial velocities undergo periodic vibrations, are thought to be pulsing. It is hypothesized that the period t of pulsation depends upon the star's radius, r, its mass, m, and the gravitational constant, G.

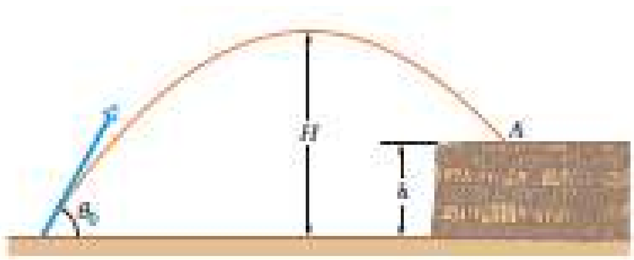
(i) Compute the units of force from $F = ma$. [2]

(ii) Newton's law of gravitation asserts that the attractive force between two bodies is proportional to the product of their masses divided by the distance between them:

$$F = G\frac{m_1 m_2}{r^2}$$

Compute the units of G from this. [3]

A3. A stone is projected at a cliff of height h with an initial speed of 42.0 m/s directed at angle $\theta = 60.0°$ above the horizontal. The stone strikes at A, 5.50 s after launching.



Find

(i) the height h of the cliff [2]
(ii) the speed of the stone just before impact at A, [3]
(iii) the maximum height H reached above the ground. [2]

A4. A constant horizontal force, $\vec{F}_a$ moves a 90 kg crate, 6.2 m up an inclined plane at a constant speed. The coefficient of kinetic friction between the crate and the inclined plane is 0.23. The angle between the inclined plane and the horizontal is θ.

(i) Draw a well labeled free-body diagram to illustrate this information. [3]
(ii) Show by calculation that the magnitude of $\vec{F}_a$ is given by,

$$F_a = \frac{mg(\sin\theta + \mu_k \cos\theta)}{\cos\theta - \mu_k \sin\theta}$$

[5]

(iii) Calculate the work done by $\vec{F_a}$ if $\theta = 30°$ [2]

(iv) Calculate the increase in thermal energy between the crate and the incline. [3]

A5. (a) A block of mass $m = 14.00\ kg$ is released from rest on a frictionless incline of angle $\theta = 30°$, as shown in **Fig 1**. Below the block is a spring with spring constant, $k = 1800N/m$. The block momentarily stops when it compresses the spring by 7.0 cm. Calculate the speed of the block just before compressing the spring. [3]

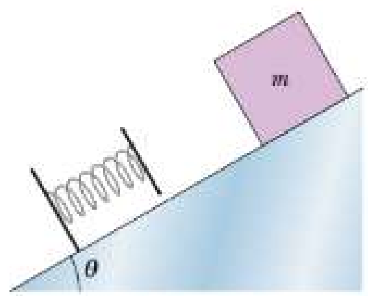


Fig 1.

(b) A $1200\ kg$ car is moving down a 20° inclined hill. At the time the car's speed is 14 m/s, the driver applies brakes. Calculate the magnitude of the kinetic frictional force if the car stops after traveling 100 m along the incline. [3]

(c) What do you understand by the term *elastic collision*. [1]

(d) A body of mass $2.0\ kg$ makes an elastic collision with another body at rest and continues to move in the original direction but with one-fourth of its original speed. Calculate the mass of the other body. [2]

SECTION B *(40 marks)*

Answer all questions

B1. (a). Calculate the difference in blood pressure (in atmosphere) between the heart and the foot in a person of height 2.00 m and the height from the heart to the head is 0.40 m and the density of blood is $1.06 \times 10^3 kg/m$. [2]

(b). The U-shape in Fig 2 contains two liquids in static equilibrium: water of density $998\ kg/m^3$ and an unknown liquid with unknown density. Find the density of the unknown liquid if $h = 155\ mm$ and $l = 135\ mm$. [3]

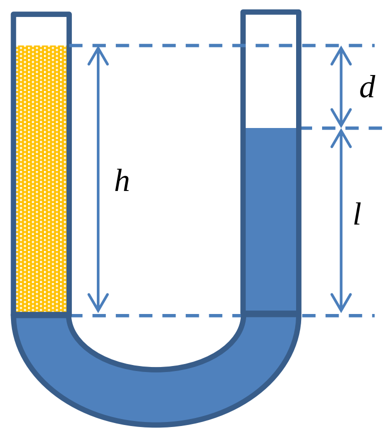


Fig 2

B2. (a) Define floating. [1]

(b) A cube of edge length $L = 0.600\ m$ and mass $450\ kg$ is suspended by a rope in an open tank of liquid of density $1030\ kg/m^3$, as shown in Fig 3.

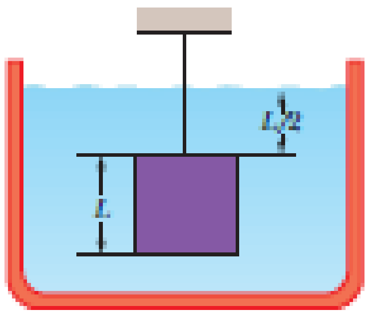


Fig 3

Find,

(i). the magnitude of the total downward force on the top of the cube from the liquid and the atmosphere, assuming atmospheric pressure is 1.00 atm, [2]
(ii). The magnitude of the total upward force on the bottom of the cube, [2]
(iii). The tension in the rope. [2]
(iv). The magnitude of the buoyant force on the cube using Archimedes' principle. [3]

B3. (a) State Pascal's principle. [1]

(b) Hence or otherwise, show that for a hydraulic lever, the output work done, *W* is given by,

$$W = F_o d_o = F_i d_i$$

[3]

(c) A spring of spring constant $3.00 \times 10^4\ N/m$ is between a rigid beam and the output piston of a hydraulic lever. An empty container with negligible mass sits on the input piston. The input piston has area A_i, and the output piston has area $18.0A_i$. Initially the spring is at its rest length. How many kilograms of sand must be (slowly) poured into the container to compress the spring by $5.00\ cm$? [3]

B4. A garden hose with an internal diameter of 1.9 cm is connected to a (stationary) lawn sprinkler that consists merely of a container with 24 holes, each 0.13 cm in diameter. If the water in the hose has a speed of 0.91 m/s, at what speed does it leave the sprinkler holes? [3]

B5.

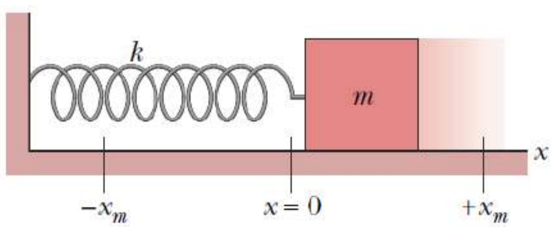


Fig 4.

At time *t* = 0, the displacement *x*(0) of the block in a linear oscillator like that of Fig. 4 is $-8.50\ cm$. The block's velocity *v*(0) then is $-0.93\ m/s$, and its acceleration *a*(0) is $45.0\ m/s^2$. Determine,

(i) the angular frequency of this system, [3]
(ii) the phase constant and [1]
(iii) the amplitude of this system. [1]

B6. The displacement function for a pulse travelling along a string is given by the equation

$$D(x,t) = \frac{4.0}{(x-2t)^2 + 6.0}$$

where *x* is in metres and *t* is in seconds.

a) Determine the speed of the pulse, and the direction in which is it travelling [2]
b) Calculate the displacement of a point located at $x = 4.0\ m$ at $t = 1.0\ s$ [2]
c) Calculate the speed of a point that is located at $x = 5.0\ m$ at t=1.0 s [2]
d) Determine the maximum displacement of a point as the pulse passes through it. [1]

B7. A police siren emits a frequency of 700.0 Hz. When the police car approaches you at a speed of 80.0 km/h, determine the frequency you perceive? (Take the value of the speed of sound in air to be 330ms^{-1}) [3]

SECTION C *(30 marks)*

Answer all questions

C1. Ordinary window glass reflects approximately 4% of incident light and transmits the remaining 96%. Use this information to explain why ordinary window glass works like a mirror for a person inside the house at night but looks transparent during the day. Remember, the light entering the glass encounters two boundaries: an air–glass boundary upon entering the glass pane and a glass–air boundary at the exit. [3]

C2. An observer is positioned so that the far edge of the bottom of an empty glass is just visible (Figure 1 below). When the glass is filled to the top with water, the centre of the bottom of the glass is just visible to the observer. The width of the glass is 6.8 cm.

a) What is the height, h, of the glass? [3]

b) What does the observer see when the glass is filled with oil instead of water? [2]

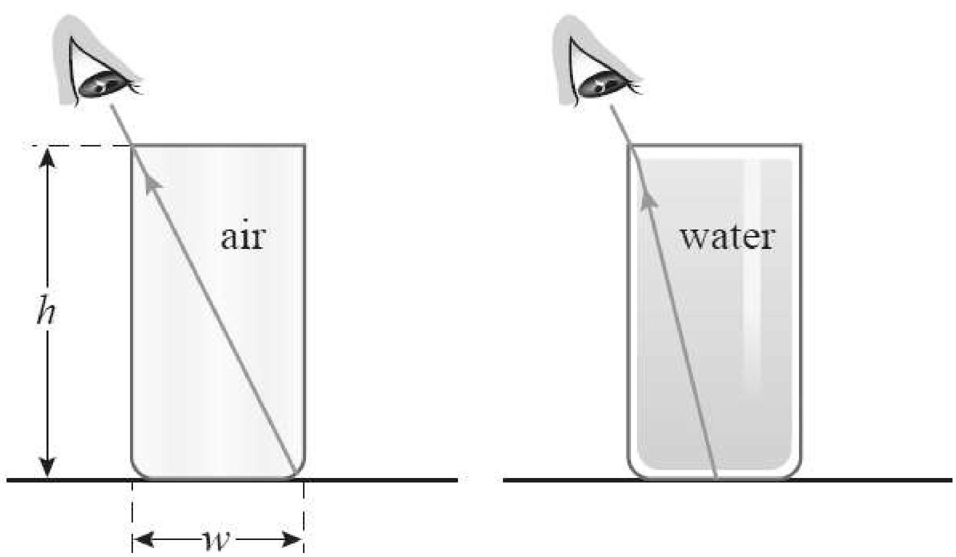


Fig 5.

C3. On a car's side-view mirror you notice a warning: "Objects in mirror are closer than they appear." Explain the physics behind this statement. What kind of mirror is it, and why is it used as a side-view mirror? [3]

C4. A $+30.0\ nC$ charge is placed at the origin of a coordinate system, and a $-50.0\ nC$ charge is placed in the xy-plane at the point$(x = 0.100\ m, y = -0.500\ m)$.

a) Determine the magnitude and the direction of the force that the positive charge exerts on the negative charge. Use ijk notation for your result. [3]

b) Determine the magnitude and direction of the force of the negative charge on the positive charge. [3]

C5. Good electrical conductors, such as metals, are typically good conductors of heat; electrical insulators, such as wood, are typically poor conductors of heat. Explain why there should be a relationship between electrical conduction and heat conduction in these materials. [3]

C6. Determine the resistance of an electric fire which takes a current of 12A from a 240V supply. Find also the power rating of the fire and the energy used in 20 h. [3]

C7. Referring to the circuit shown below (figure 6), determine the number of;

a) nodes; [1]

b) elements; [1]

c) branches. [1]

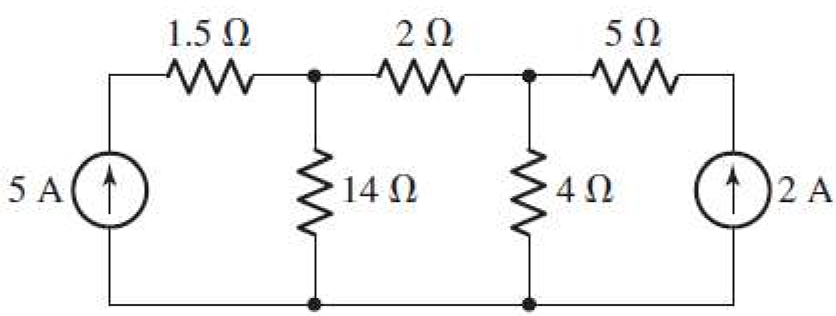


Fig 6.

C8. Use Thevenin's theorem to find the current through the 2 Ω resistor in the circuit shown below. [4]

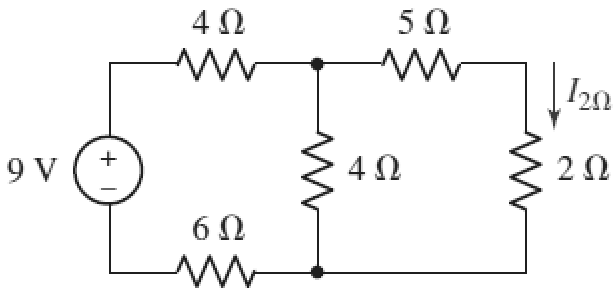


Fig 7.

END OF EXAMINATION

SECTION A *(30 marks)*

Attempt **ALL** questions

A1. Explain the importance of dimensional analysis. **[1]**

A2. How many significant figures are in:

a) 23,000 **[1]**
b) 30000.00 **[1]**
c) 0.0003356 **[1]**

A3. The figure 1 below shows a plot of the position versus time for two objects.

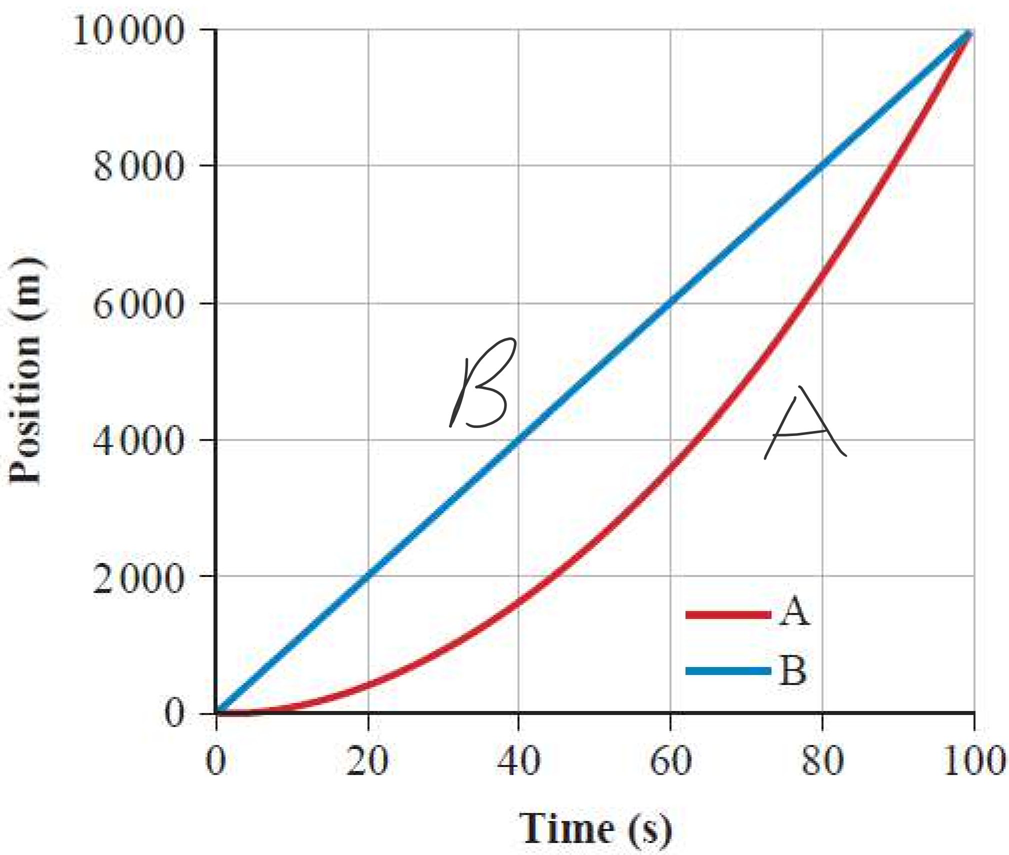


Figure 1

a) Which object has the higher average velocity for the interval shown? **[2]**
b) Which object has the higher speed at $t = 30\ s$? **[2]**
c) Which has the higher speed at $t = 90\ s$? **[2]**

d) Do the objects ever have the same speed? If so, at what time do you estimate this will happen? **[3]**

A4. A block whose mass m is 550 g is fastened to a spring whose spring constant k is $55\ N/m$. The block is pulled a distance $x = 10$ cm from its equilibrium position at $x = 0$ on a frictionless surface and released from rest at $t = 0$.

a) What are the angular frequency, the frequency, and the period of the resulting motion? **[3]**
b) What is the amplitude of the oscillation? **[2]**
c) What is the maximum speed v_m of the oscillating block, and where is the block when it has this speed? **[2]**
d) What is the magnitude a_m of the maximum acceleration of the block? **[2]**

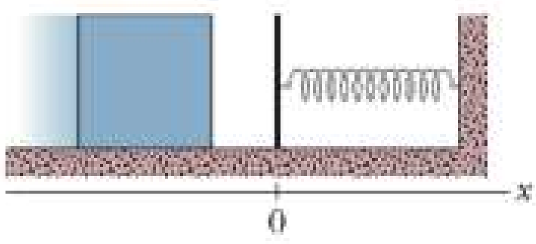


Figure 2

A5. Define work done by a force. **[2]**

A6. An mine elevator carries 11 miners of average mass 60 kg to a height of 70 meters from their shaft level in two minute.

a) Calculate the work done in lifting the passengers **[3]**
b) Calculate the power needed to do that task **[3]**

SECTION B *(45 marks)*

Answer all questions

B1. Calculate the difference in blood pressure (in atmosphere) between the heart and the foot in a person of height 1.80 m and the height from the heart to the head is 0.40 m and the density of blood is $1.06 \times 10^3 kg/m$. **[3]**

B2. A bloc of density 4000kg/m^3 and volume of 0.002m^3 is immersed in water (density 1000kg/m^3). Calculate:

a) The upward force exerted by the fluid on the object **[2]**
b) The weight of the object in air **[2]**
c) Its weight inside the fluid **[3]**

B3. Consider a horizontal pipe with a constriction in its middle section. The diameter of the pipe is 10 cm at both ends and 5 cm at the constriction. The pressure at the left end of the pipe is 200 kPa and the fluid velocity is 2 m/s. Assuming steady, incompressible and inviscid flow, apply Bernoulli's principle to find the pressure and the velocity at the constriction **[4]**

B4. Some wire of cross-sectional area 6mm^2 has a resistance of 250Ω. Determine:

a) the resistance of a wire of the same length and material if the cross-sectional area is $10mm^2$, and **[2]**
b) the cross-sectional area of a wire of the same length and material if the resistance is 50Ω. **[2]**

B5. Light is a form of electromagnetic radiation and can move from one medium to another.

a) State Snell's law of refraction **[2]**
b) Find the critical angle for an air-water boundary. (Assume the index of refraction of water is 1.33.) **[3]**
c) State two applications in which total internal reflection is useful. **[2]**

B6. The displacement function for a pulse passing through a string is given by.

$D(x,t) = \frac{4.0}{8.0+(x-2.0t)^2}$ where $\boldsymbol{x}$ and $\boldsymbol{D}$ are in metres and $\boldsymbol{t}$ is in seconds.

a) Calculate the speed of the pulse, and in which direction is it travelling **[2]**
b) Calculate the displacement of a point located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0s}$ **[2]**
c) Calculate the maximum displacement of a point on the string **[3]**
d) Calculate the transverse speed of a point that is located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0s}$ **[3]**

e) Sketch a displacement versus position (x) graph for $\boldsymbol{t = 0s, 1s, 2s}$, and $\boldsymbol{3s}$ for this waveform. **[2]**

B7. What is the doppler effect. **[2]**

b) how does it affect the frequency of sound or light waves perceived by an observer moving relative to the source? **[3]**

c) Consider a car that is moving towards a stationary observer with a constant speed of 20 m/s. The car emits a sound with a frequency of 500 Hz. What is the frequency of the sound heard by the observer? **[3]**

Assume the speed of sound in air is 340 m/s.

SECTION C *(25 marks)*

Answer all questions

C1. Using sketches were necessary, explain Kirchhoff's current Law. **[2]**

C2. Using sketches were necessary, explain Kirchhoff's Voltage Law **[2]**

C3. Referring to the circuit shown below (Fig. 3), determine the number of.

a) branches **[1]**
b) nodes **[1]**
c) loops **[1]**

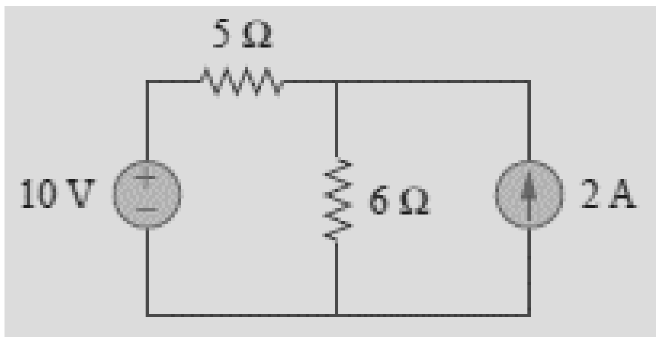


Figure 3

C4. Using the knowledge you have of electrostatic charges, with aid of sketches, describe in detail the process that leads to a lighting discharge. **[4]**

C5. Consider a $2\mu C$ charge located at the origin and a $-4\mu C$ located on the x axis at x=0.002m.

a) Determine the electric force exerted by the $2\mu C$ charge on the $-4\mu C$ charge. **[3]**
b) Determine the electric force exerted by the $-4\mu C$ on the $2\mu C$ charge. **[3]**

C6. Determine the electric field at the point (0.004,0.005) due to a $-6\mu C$ point charge located at the origin. **[4]**

C7. You are designing a satellite that will orbit the Earth for several years. What kind of materials would you use for the outer shell and why? Consider the factors such as thermal expansion, corrosion, radiation, and weight. **[4]**

C8. Explain what is meant by minority and majority carriers in an n-type material and state whether the numbers of each of these carriers are affected by temperature. **[3]**

END OF EXAMINATION

SECTION A *(40 marks)*

Attempt **ALL** questions

A1. Explain the importance of dimensional analysis. **[1]**

A2. Certain stars, whose light and radial velocities undergo periodic vibrations, are thought to be pulsing. It is hypothesized that the period t of pulsation depends upon the star's radius, r, its mass, m, and the gravitational constant, G.

a) Compute the units of force from $F = ma$. **[2]**

b) Newton's law of gravitation asserts that the attractive force between two bodies is proportional to the product of their masses divided by the distance between them:

$$F = G\frac{m_1 m_2}{r^2}$$

Compute the units of G from this. **[4]**

A3. Two vectors $\vec{a}$ and $\vec{b}$ have equal magnitudes of 12.0 m and the angles are $\theta_1 = 30°$ and $\theta_2 = 105°$ as shown in Fig. 1.

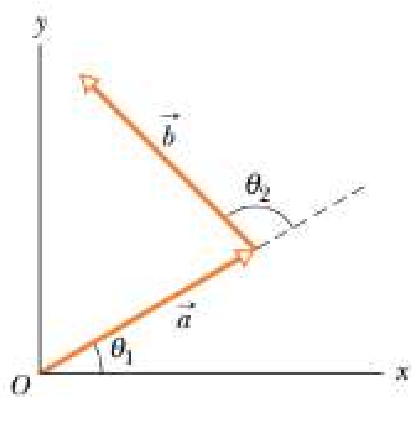


Fig. 1.

Find:

a) the magnitude of $\vec{r}$, and **[3]**

b) the angle that $\vec{r}$ makes with the positive direction of the x axis. **[3]**

A4. A crate of mass $m = 75\ kg$ is pushed at constant speed up a ramp inclined at 30.0° by a horizontal force as shown in Fig. 2.

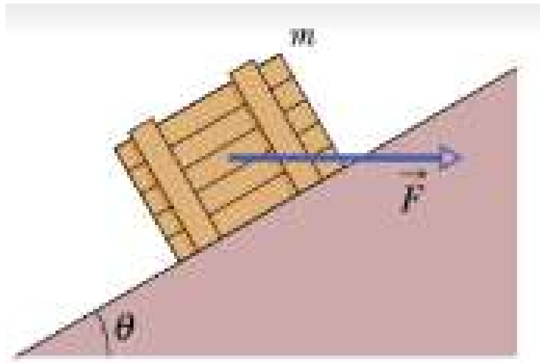


Fig. 2.

If the ramp has a coefficient of friction, $\mu = 0.20$,

a) Calculate the magnitude of the normal force **[3]**

b) Calculate the force $\vec{F}$ **[2]**

A5. Define work. **[2]**

b) Distinguish between conservative and no-conservative forces. **[2]**

c) A block of mass m=5.00 kg is released from rest on a frictionless incline of angle θ=30.0°, as shown in Fig 3. Below the block is a spring that can be compressed 4.0 cm by a force of 300 N. The block momentarily stops when it compresses the spring by 6.5 cm.

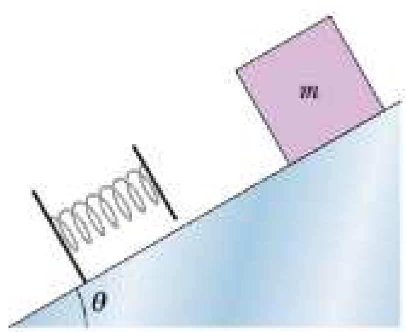


Fig 3.

d) Calculate the distance moved by the block down the incline from its rest position to this stopping point. **[3]**

e) Calculate the speed of the block just as it touches the spring. **[3]**

A6. What do you understand by the term *elastic collision*. **[2]**

b) A body of mass $3.0\ kg$ makes an elastic collision with another body at rest and continues to move in the original direction but with one-fourth of its original speed. Calculate the mass of the other body. **[4]**

A7. A stone is projected at a cliff of height *h* with an initial speed of 12.0 *m/s* directed at angle $\theta = 30.0°$ above the horizontal as shown in Fig 4. The stone strikes at *A*, 7.50 *s* after launching.

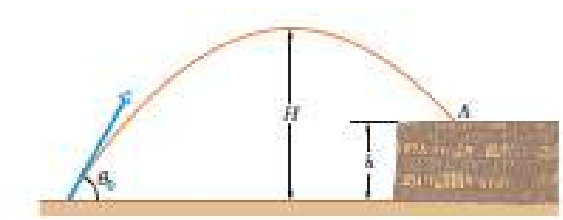


Fig 4.

Find

a) the height *h* of the cliff **[2]**

b) the speed of the stone just before impact at A, **[2]**

c) the maximum height *H* reached above the ground. **[2]**

SECTION B *(35 marks)*

Answer all questions

B1. A hypodermic syringe contains a medicine with the density of water (Fig.5). The barrel of the syringe has a cross-sectional area $A = 2.5 \times 10^{-5} m^2$, and the needle has a cross-sectional area $a = 1.0 \times 10^{-8} m^2$. In the absence of a force on the plunger, the pressure everywhere is $1.00\ atm$. A force $\vec{F}$ of magnitude $2.00\ N$ acts on the plunger, making medicine squirt horizontally from the needle. Determine the speed of the medicine as it leaves the needle's tip. **[4]**

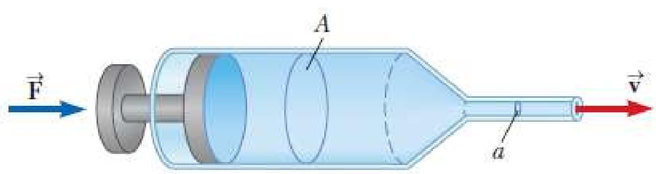


Fig 5.

B2. Give an example of an application of Bernoulli's principle in engineering or everyday life. **[3]**

B3. What is Archimedes' principle and how can it be used to determine the buoyant force on an object submerged in a fluid? **[3]**

B4. A bloc of density $5000 kg/m^3$ and volume of $0.003 m^3$ is immersed in water (density $1000 kg/m^3$). Calculate:

a) The upward force exerted by the fluid on the object **[2]**
b) The weight of the object in air **[2]**
c) Its weight inside the fluid **[2]**

B5. A 55 kg woman wearing high-heeled shoes is invited into a home in which the kitchen has vinyl floor covering. The heel on each shoe is circular and has a radius of 0.500 cm.

a) If the woman balances on one heel, what pressure does she exert on the floor? **[3]**

b) Should the homeowner be concerned? Explain your answer. **[3]**

B6. Light is a form of electromagnetic radiation and can move from one medium to another.

a) State Snell's law of refraction **[2]**

b) Find the critical angle for an air-water boundary. (Assume the index of refraction of water is 1.33.) **[3]**

c) State two applications in which total internal reflection is useful. **[2]**

B7. What is the doppler effect. **[2]**

b) Your phone alarm clock awakens you with a steady and irritating sound of frequency 650 Hz. One morning, on the day of exams, it malfunctions and cannot be turned off. In frustration, you drop the phone out of your three-story hostel window, 12.0 m from the ground. Assume the speed of sound is 343 m/s. As you listen to the falling phone, what frequency do you hear just before you hear it striking the ground? **[4]**

SECTION C *(25 marks)*

Answer all questions

C1. Using sketches were necessary, explain Kirchhoff's current Law. **[2]**

C2. Using sketches were necessary, explain Kirchhoff's Voltage Law **[2]**

C3. Referring to the circuit shown below (Fig. 6), determine the number of.

a) branches **[1]**
b) nodes **[1]**
c) loops **[1]**

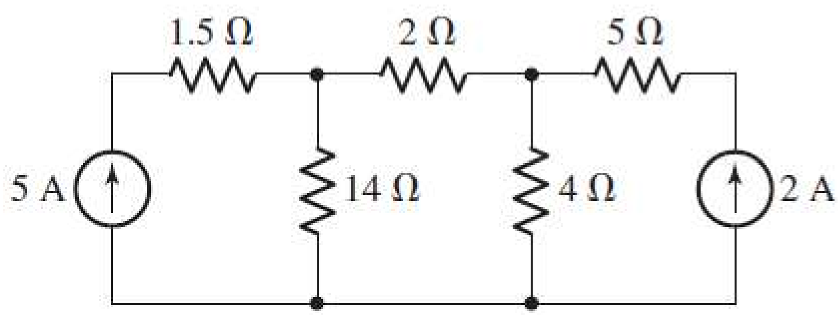


Fig 6.

C4. A capacitor that has two parallel plates of dimensions 15.00cm ×7.50 cm separated by 1.00 mm of air is connected to a 12.0 V battery. Find

a) the capacitance **[2]**
b) the charge on one plate **[2]**
c) the electric field in the capacitor **[2]**

C5. Consider a $4\mu C$ charge located at the origin and a $-6\mu C$ located on the x axis at x=0.002m.

a) Determine the electric force exerted by the $4\mu C$ charge on the $-6\mu C$ charge. **[3]**
b) Determine the electric force exerted by the $-6\mu C$ on the $4\mu C$ charge. **[2]**

C6. Determine the electric field at the point (0.003,0.004) due to a $-5\mu C$ point charge located at the origin. **[4]**

C7. Explain what is meant by minority and majority carriers in an p-type material and state whether the numbers of each of these carriers are affected by temperature. **[3]**

END OF EXAMINATION

SECTION A *(55 marks)*

Attempt **ALL** questions

A1. Explain:

a. the importance of SI units and standards in measurements. **[2]**

b. the importance of dimensional analysis. **[2]**

A2. In fluid mechanics, the *Reynolds number* is a dimensionless number involving fluid velocity v, density ρ, viscosity μ and a characteristic length r. Some of the dimensions of the quantities are given in the table below,

Variable	v	ρ	μ	r
Dimension		ML^{-3}	$ML^{-1}T^{-1}$	

a. Fill in the missing dimensions in the table. **[3]**

b. Hence or otherwise, find this dimensionless number as a product of the variables given in the table above. **[5]**

A3. A certain airplane has a speed of $240.0\ km/h$ and is diving at an angle of $30.0°$ below the horizontal when the pilot releases a radar decoy as shown in Fig. 1.

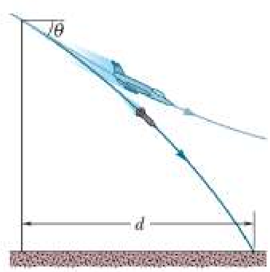


Fig. 1.

The horizontal distance between the release point and the point where the decoy strikes the ground is $d = 700\ m$.

a. How high was the release point? **[3]**

b. What is the speed of the decoy just before it hits the ground? **[3]**

A4. State:

a. Newton's first law. **[1]**

b. Newton's Second law. **[1]**

c. There are two forces on the 1.50 kg box in the overhead view of Fig. 2, but only one is shown.

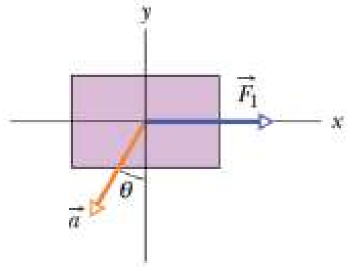


Fig. 2.

For $F_1 = 25.0\ N$, $a = 10.0\ m/s^2$, and $\theta = 25.0°$, find the second force

i. In unit-vector notation and **[2]**

ii. as a magnitude and **[1]**

iii. an angle relative to the positive direction of the x axis. **[2]**

A5. A crate of mass $m = 55\ kg$ is pushed at constant speed up a ramp inclined at 35.0° by a horizontal force as shown in Fig. 3.

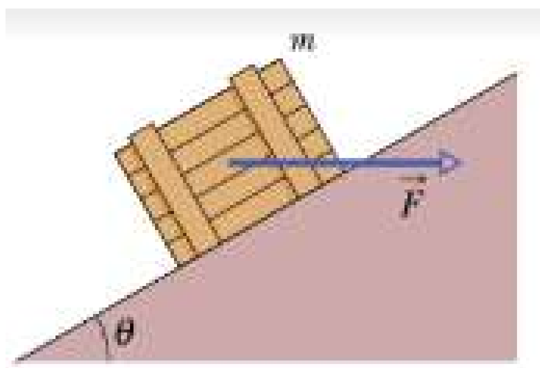


Fig. 3.

If the ramp has a coefficient of friction, $\mu = 0.05$

a. Calculate the magnitude of the normal force **[3]**

b. Calculate the force $\vec{F}$ **[2]**

A6. Define work. **[2]**

a. Distinguish between conservative and no-conservative forces. **[2]**

A7. A block of mass m=4.00 kg is released from rest on a frictionless incline of angle θ=35.0°, as shown in Fig 4. Below the block is a spring that can be compressed 4.0 cm by a force of 300 N. The block momentarily stops when it compresses the spring by 6.5 cm.

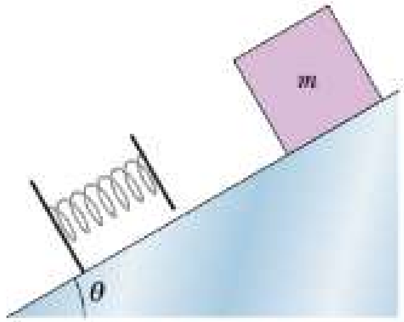


Fig 4.

a. Calculate the distance moved by the block down the incline from its rest position to this stopping point. **[3]**

b. Calculate the speed of the block just as it touches the spring. **[3]**

A8. What do you understand by the term *elastic collision*. **[2]**

b) A body of mass $3.0\ kg$ makes an elastic collision with another body at rest and continues to move in the original direction but with one-fourth of its original speed. Calculate the mass of the other body. **[4]**

A9. A block whose mass m is 750 g is fastened to a spring whose spring constant k is $55\ N/m$ (Fig 5.). The block is pulled a distance $x = 5$ cm from its equilibrium position at $x = 0$ on a frictionless surface and released from rest at $t = 0$.

a. What are the angular frequency, the frequency, and the period of the resulting motion? **[3]**
b. What is the amplitude of the oscillation? **[2]**
c. What is the maximum speed v_m of the oscillating block, and where is the block when it has this speed? **[2]**
d. What is the magnitude a_m of the maximum acceleration of the block? **[2]**

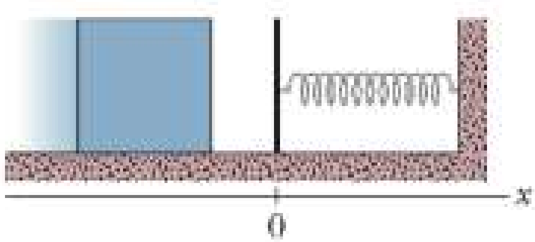


Fig 5.

SECTION B *(30 marks)*

Answer all questions

B1. State

a. Pascal's Law **[2]**

b. Archimedes Principle **[2]**

B2. Give an example of an application of Bernoulli's principle in engineering or everyday life. **[3]**

B3. What is Archimedes' principle and how can it be used to determine the buoyant force on an object submerged in a fluid? **[3]**

B4. A bloc of density $4000 kg/m^3$ and volume of $0.004 m^3$ is immersed in water (density $1000 kg/m^3$). Calculate:

a. The upward force exerted by the fluid on the object **[2]**
b. The weight of the object in air **[2]**
c. Its weight inside the fluid **[2]**

B5. The displacement function for a pulse passing through a string is given by.

$D(x,t) = \frac{2.0}{4.0+(x-2.0t)^2}$ where $\boldsymbol{x}$ and $\boldsymbol{D}$ are in metres and $\boldsymbol{t}$ is in seconds.

a. Calculate the speed of the pulse, and in which direction is it travelling **[2]**
b. Calculate the displacement of a point located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0s}$ **[2]**
c. Calculate the maximum displacement of a point on the string **[3]**
d. Calculate the transverse speed of a point that is located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0s}$ **[3]**
e. Sketch a displacement versus position (x) graph for $\boldsymbol{t = 0s, 1s, 2s}$, and $\boldsymbol{3s}$ for this waveform. **[2]**

B6. What is the doppler effect. **[2]**

SECTION C *(15 marks)*

Answer all questions

C1. Using sketches were necessary, explain Kirchhoff's current Law. **[2]**

C2. Using sketches were necessary, explain Kirchhoff's Voltage Law **[2]**

C3. Referring to the circuit shown below (Fig. 6), determine the number of.

a. branches **[1]**
b. nodes **[1]**
c. loops **[1]**

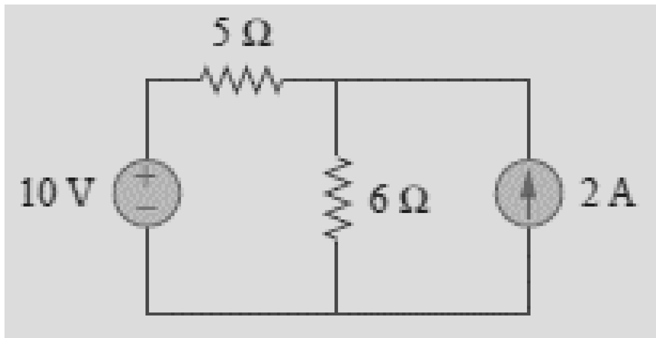


Fig 6.

C4. Using the knowledge you have of electrostatic charges, with aid of sketches, describe in detail the process that leads to a lighting discharge. **[4]**

C5. During an eye exam, you notice that to be able to read a book, you have to hold it 12 cm in front of your eyes. For a healthy eye, this distance should be approximately 25 cm.

a. What vision problem does this indicate? **[2]**
b. What further information do you need to determine the optical power of eyeglasses to correct your vision? **[2]**

END OF EXAMINATION

SECTION A *(35 marks)*

Attempt **ALL** questions.

A1. What are the dimensions of force in terms of mass (M), length (L) and time (T)**[2]**

A2. You measure the length of a rod using a ruler and obtain the value 11.34 cm. The ruler has an uncertainty of ±0.05 cm. Describe how will you report the result of the measurement, taking into account the significant figures and the uncertainty **[3]**

A3. $\boldsymbol{A} = 4i - 3j + 5k$ and $\boldsymbol{B} = -3i + 7j - 5k$, determine the magnitude and direction of their cross-product $\boldsymbol{A} \times \boldsymbol{B}$. **[3]**

A4. A cyclist starts from rest and accelerates uniformly at $3ms^{-2}$ for 10 seconds, then maintains a constant speed for another 15 seconds. Finally, the cyclist decelerates uniformly at $6ms^{-2}$ until it stops. Calculate the total distance travelled by the cyclist? **[3]**

A5. A projectile is launched from the ground at an angle of $45°$ above the horizontal with an initial speed of $25ms^{-1}$. Neglecting air resistance, calculate,

a. the maximum height, **[2]**

b. the time of flight and, **[2]**

c. the horizontal range of the projectile. **[2]**

A6. In figure 1, the pulley has negligible mass, and both it and the inclined plane are frictionless. Block A has a mass of 1.0 kg, block B has a mass of 2.0 kg, and angle θ is 30°. If the blocks are released from rest with the connecting cord taut, calculate their total kinetic energy when block B has fallen 25 cm? **[4]**

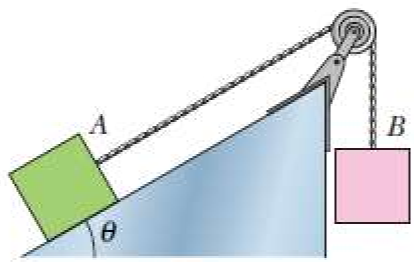


Figure 1

A7. A skydiver of mass 70 kg jumps out of a plane at a height of 3000 m. He opens his parachute at a height of 1000 m. Assume that the air drag force on the skydiver is proportional to the square of his speed, i.e., $F = -kv^2$, where k is a constant. The terminal velocity of the skydiver without the parachute is 60 m/s, and with the parachute is 15 m/s. Calculate,

a. the value of k and, **[2]**

b. the time taken by the skydiver to reach the ground. **[2]**

A8. A roller coaster car of mass 500 kg starts from rest at a height of 50 m. It slides down a track and reaches a height of 20 m at point A. Then it goes through a loop of radius 10 m and reaches point B at the top of the loop. Neglecting friction and air resistance, calculate,

a. the speed of the car at points A and B, and **[3]**

b. the normal force exerted by the track on the car at point B. **[3]**

A9. A boy of mass 55 kg running at 5 m/s jumps on to a 15 kg trolley travelling in the same direction at $2ms^{-1}$. Calculate their common velocity. **[4]**

SECTION B *(40 marks)*

Answer all questions.

B1. Your friend asks you to determine whether the ring that she recently bought is made of pure gold. (The density of gold is $1.93 \times 10^4\ kg/m3$.) Using a thread of negligible mass and volume, you tie the ring to a very accurate spring balance and determine that in air it weighs $6.40 \times\ 10^{-3}\ N$. You then fully immerse the ring in a beaker full of water and find that its apparent weight is $6.00\ \times 10^{-3}\ N$. Determine if the ring is made of pure gold. **[4]**

B2. A 60.0-kg woman wearing high-heeled stilettos is invited into a home in which the kitchen has vinyl floor covering. The heel on each shoe is circular and has a radius of 0.5cm. If the woman balances on one heel, calculate the,

a. pressure does she exert on the floor, **[2]**
b. Should the homeowner be concerned, **[2]**
c. Explain your answer on b. **[2]**

B3. A water pipe having a 2.5 cm inside diameter carries water into the basement of a house at a speed of 0.90 m/s and a pressure of 170 kPa. If the pipe tapers to 1.2 cm and rises to the second floor 7.6 m above the input point, Determine the.

a. speed and **[2]**
b. water pressure on the second floor. **[3]**

B4. A block whose mass m is 680 g is fastened to a spring whose spring constant k is 65 N/m as shown in figure 2 below. The block is pulled a distance $x = 11$ cm from its equilibrium position at $x = 0$ on a frictionless surface and released from rest at $t = 0$.

a. What is the angular frequency, the frequency, and the period of the resulting motion? **[3]**
b. What is the amplitude of the oscillation? **[1]**

c. What is the maximum speed v_m of the oscillating block, and where is the block when it has this speed? **[2]**

d. What is the magnitude a_m of the maximum acceleration of the block? **[2]**

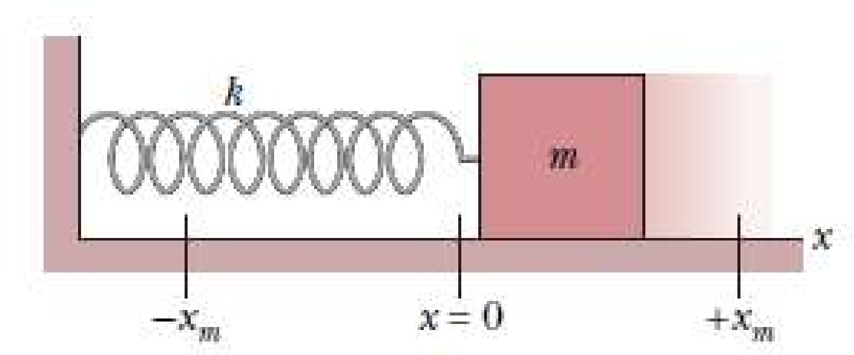


Figure 2

B5. Consider the simplified single-piston engine in figure 3. Assuming the wheel rotates with constant angular speed, explain why the piston rod oscillates in simple harmonic motion. **[4]**

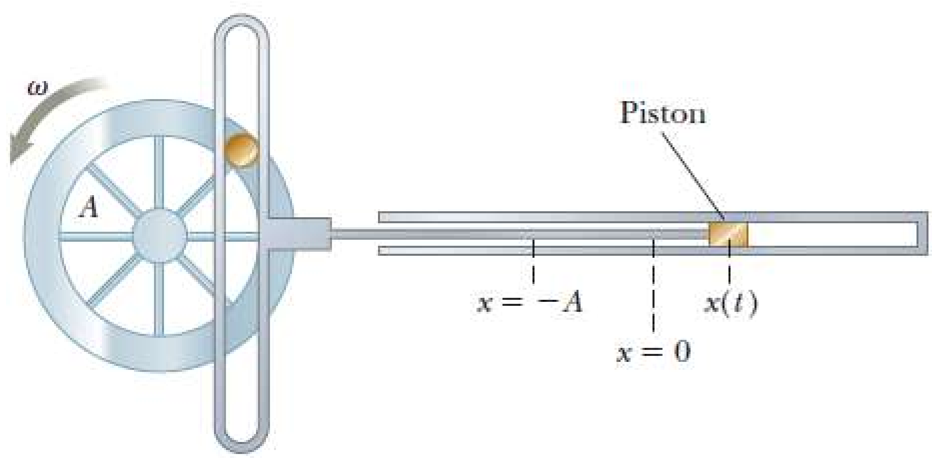


Figure 3

B6. Your phone alarm clock awakens you with a steady and irritating sound of frequency 600 Hz. One morning, on the day of exams, it malfunctions and cannot be turned off. In frustration, you drop the phone out of your three-story hostel window, 15.0 m from the ground. Assume the speed of sound is 343 m/s. As you listen to the falling phone, calculate the frequency you hear just before you hear it striking the ground? **[3]**

B7. The displacement function for a pulse passing through a string is given by $D(x,t) = \frac{5.0}{6.0+(x-5.0t)^2}$ where $\boldsymbol{x}$ and $\boldsymbol{D}$ are in metres and $\boldsymbol{t}$ is in seconds.

a. Calculate the speed of the pulse, and in which direction is it travelling **[2]**

b. Calculate the displacement of a point located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0 s}$ **[2]**

c. Calculate the maximum displacement of a point on the string **[2]**

d. Calculate the transverse speed of a point that is located at $\boldsymbol{x = 2.0\ m}$ at $\boldsymbol{t = 3.0 s}$ **[2]**

e. Sketch a displacement versus position (x) graph for $\boldsymbol{t = 0s, 1s, 2s}$, and $\boldsymbol{3s}$ for this waveform **[2]**

SECTION C *(25 marks)*

Answer all questions.

C1. Three light rays simultaneously emitted by a candle pass through a converging lens, as shown in figure 4 below.

a. Which ray arrives at the screen first? **[2]**

b. Explain your answer to a **[3]**

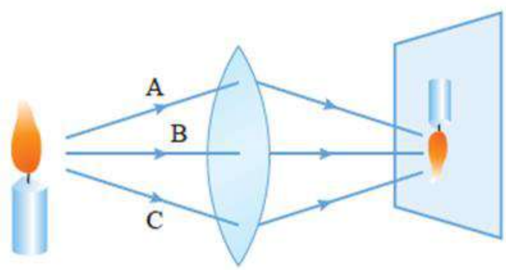


Figure 4

C2. A concave mirror has a focal length of 20 cm. An object is placed 30 cm away from the mirror. Determine the position, the size and the nature of the image formed by the mirror. Also, draw a ray diagram to show the image formation. **[4]**

C3. Referring to the circuit shown in figure 5 below, determine the number of.

a. nodes; **[1]**

b. elements; **[1]**

c. branches. **[1]**

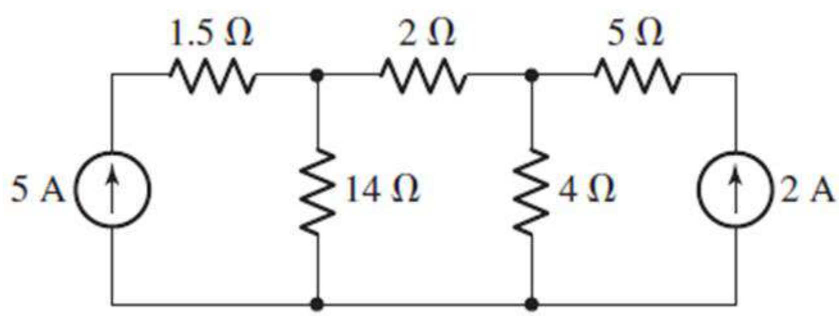


Figure 5

C4. Two-point charges of $+2\ \mu C$ and $-3\ \mu C$ are placed 10 cm apart in vacuum. Find the electric force between them and the electric field at the midpoint of the line joining them. **[3]**

C5. Electric eels generate electric pulses along their skin that can be used to stun an enemy when they encounter it. Research has shown that these pulses can be up to $500\ V$ and produce currents of $80\ mA$ (or even larger). A typical pulse lasts for $10\ ms$. Calculate:

a. The charge released, **[2]**

b. the power and, **[2]**

c. how much energy are delivered to the unfortunate enemy with a single pulse, assuming a steady current. **[2]**

C6. A straight wire of length 20 cm carries a current of 5 A. The wire is placed in a uniform magnetic field of 0.2 T that is perpendicular to the wire. Find the magnetic force on the wire and the magnetic flux through a rectangular loop of area $0.04\ m^2$ that encloses the wire. **[4]**

END OF EXAMINATION

SECTION A *(45 marks)*

Attempt **ALL** questions.

A1. Hooke's law states that the force, F, in a spring extended by a length x is given by $F = -kx$. From Newton's second law $F = ma$, where m is the mass and a is the acceleration, calculate the dimensions of the spring constant k in terms of mass (M), length (L) and time (T) **[3]**

A2. How many significant digits are in:

a) 23,000? **[2]**

b) 4000.00? **[2]**

c) 0.00023040? **[2]**

A3. A train increases its speed steadily from $10\ ms^{-1}$ to $20\ ms^{-1}$ in 2 minutes.

a) Calculate its average speed during this time, in m/s **[3]**

b) Calculate how far does it travel while increasing its speed **[4]**

c) Plot the trains velocity time graph **[3]**

A4. A ball is projected vertically upwards with an initial velocity of $40\ ms^{-1}$. Calculate.

a) Its maximum height and, **[3]**

b) The time taken to return to its starting point. **[3]**

Neglect air resistance and take $\boldsymbol{g = 10\ ms^{-2}}$.

A5. A block of mass 500 g is pulled from rest on a horizontal frictionless bench by a steady force **F** and travels 8 m in 2 s. Find;

a) the acceleration, **[3]**

b) the value of **F**. **[3]**

A6. Draw a labelled diagram to show the forces acting on a skydiver falling with a constant velocity. **[4]**

A7. An elevator carries 11 passengers of average mass 70 kg to a height of 20 meters in one minute.

a) Calculate the work done in lifting the passengers **[3]**

b) Calculate the power needed to do that task **[3]**

A8. Two globes of identical mass and radius are spinning about axes through their centres at the same speed. One of the globes is a solid sphere, and the other has a hollow space at its centre. Which globe is easier to stop? Explain **[4]**

SECTION B *(30 marks)*

Answer any **All** questions.

B1. Calculate the difference in blood pressure (in atmosphere) between the heart. and the foot in a person of height 2.00 *m* and the height from the heart to the head is 0.40 *m* and the density of blood is $1.06 \times 10^3 kg/m$. **[3]**

B2. The U-shape in **Fig 1** contains two liquids in static equilibrium: water of density $998\ kgm^{-3}$ and an unknown liquid with unknown density. Find the density of the unknown liquid if $h = 155\ mm$ and $l = 135\ mm$. **[3]**

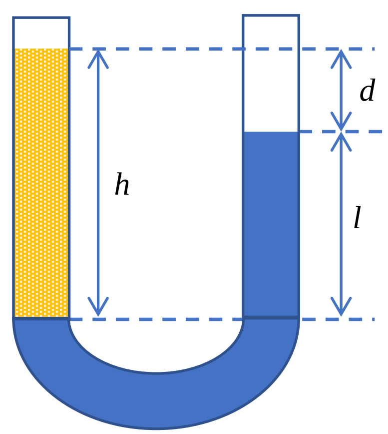


Fig 1

B3. Define floating. **[2]**

B4. A cube of edge length $L = 0.600\ m$ and mass $450\ kg$ is suspended by a rope in an open tank of liquid of density $1030\ kgm^{-3}$, as shown in **Fig 2**.

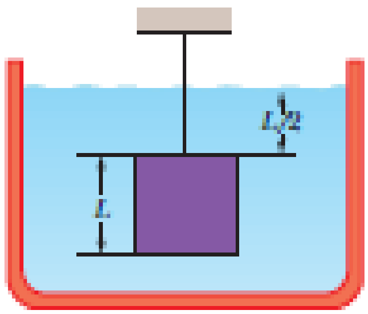


Fig 2

Find,

a) the magnitude of the total downward force on the top of the cube from the liquid and the atmosphere, assuming atmospheric pressure is 1.00 atm, **[2]**

b) The magnitude of the total upward force on the bottom of the cube, **[2]**

c) The tension in the rope. **[2]**

d) The magnitude of the buoyant force on the cube using Archimedes' principle. **[3]**

B5. A garden hose with an internal diameter of 1.9 cm is connected to a (stationary) lawn sprinkler that consists merely of a container with 24 holes, each 0.13 cm in diameter. If the water in the hose has a speed of 0.91 m/s, at what speed does it leave the sprinkler holes? **[3]**

B6. A block of mass $m = 14.00\ kg$ is released from rest on a frictionless incline of angle $\theta = 30°$, as shown in **Fig 3**. Below the block is a spring with spring constant, $k = 1800 N/m$. The block momentarily stops when it compresses the spring by 7.0 cm. Calculate the speed of the block just before compressing the spring. **[3]**

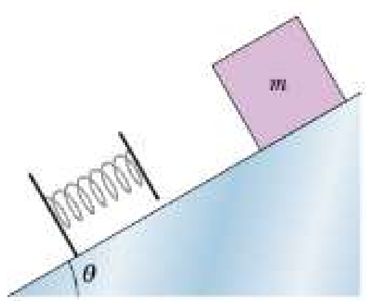


Fig 3

B7. A hypodermic syringe contains a medicine with the density of water (Fig.4). The barrel of the syringe has a cross-sectional area $A = 2.5 \times 10^{-5} m^2$, and the needle has a cross-sectional area $a = 1.0 \times 10^{-8} m^2$. In the absence of a force on the plunger, the pressure everywhere is $1.00\ atm$. A force $\vec{F}$ of magnitude $2.00\ N$ acts on the plunger, making medicine squirt horizontally from the needle. Determine the speed of the medicine as it leaves the needle's tip. **[4]**

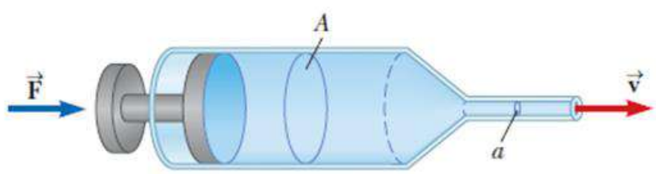


Fig 4

B8. A police siren emits a frequency of 700.0 Hz. When the police car approaches you at a speed of 80.0 km/h, what frequency do you perceive? **[3]**
(Take the value of the speed of sound in air to be 330ms^{-1})

SECTION C *(25 marks)*

Answer any **All** questions.

C1. An observer is positioned so that the far edge of the bottom of an empty glass is just visible (Fig 5 below). When the glass is filled to the top with water, the centre of the bottom of the glass is just visible to the observer. The width of the glass is 4 cm.

(a) Determine the height, h, of the glass? **[5]**

(b) What does the observer see when the glass is filled with oil instead of water? **[2]**

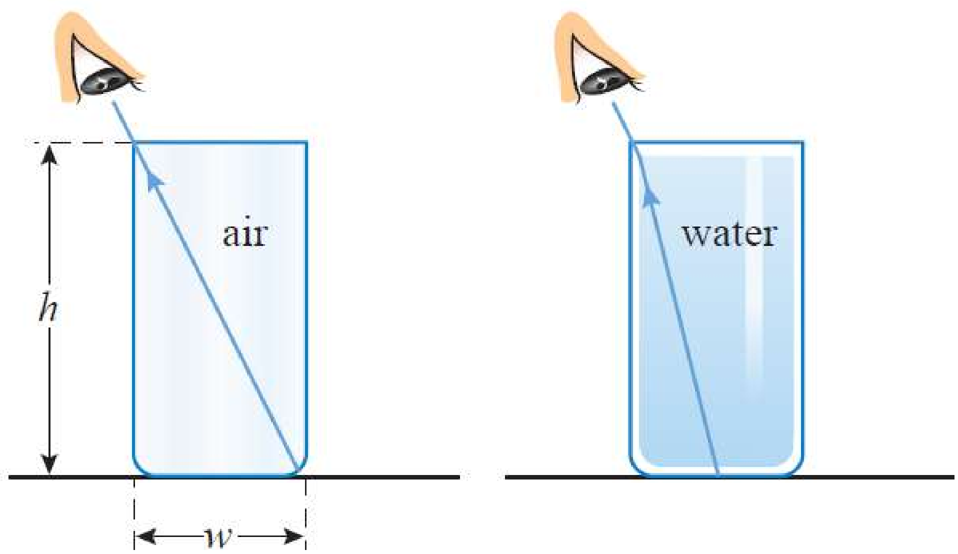


Fig 5

C2. A capacitor that has two parallel plates of dimensions 10.00cm ×7.50 cm separated by 1.50 mm of air is connected to a 24.0 V battery. Find

a) the capacitance **[3]**

b) the charge on one plate **[3]**

c) the electric field in the capacitor **[3]**

C3. Two long, parallel wires are separated by a distance of $4.50\ cm$. The force per unit length that each wire exerts on the other is $8 \times 10^{-5} N$ and the wires repel each other. The current in one wire is $0.750\ A$.

a) Calculate the current in the second wire? **[3]**

b) Are the two currents in the same direction or in opposite directions? **[2]**

C4. A 60W electric light bulb is connected to a 240V supply. Determine:

a) the current flowing in the bulb and **[2]**

b) the resistance of the bulb. **[2]**

END OF EXAMINATION

SECTION A *(40 marks)*

Attempt **ALL** questions.

A1. Show that the expression $v = at$, where v represents speed, a acceleration, and t an instant of time, is dimensionally correct in terms of mass (M), length (L) and time (T). **[3]**

A2. Define the following:

a) Precision **[1]**

b) Accuracy **[1]**

A3. When measuring the length of a room, independent measurements have established that the actual length of a room is $4.50\ m$. Your friends use the same metre stick and measure values from $4.45\ m$ to $4.56\ m$. Another friend uses an ultrasound rangefinder electronic device, reporting values from $4.405\ m$ to $5.014\ m$. Comment on the precision and accuracy of each type of measurement, and on the possibility of systematic errors. **[4]**

A4. One drop of oil falls straight down onto the road from the engine of a moving car every $5\ s$. Figure 1 shows the pattern of the drops left behind on the pavement. Determine the average speed of the car over this section of its motion **[4]**

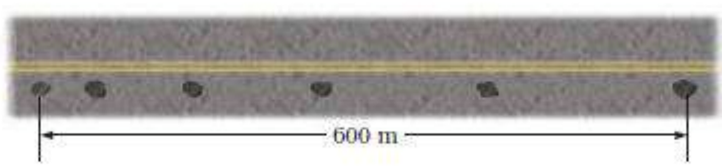


Figure 1

A5. An airplane flying horizontally at a constant speed of $350\ km/h$ over level ground releases a bundle of food supplies. Ignore the effect of the air on the bundle.

a) Determine the bundle's initial.

i. vertical and, **[2]**

ii. horizontal components of velocity **[2]**

b) Determine its horizontal component of velocity just before hitting the ground. **[3]**

c) If the airplane's speed were, instead, $450\ km/h$, would the time of fall be longer, shorter, or the same. **[3]**

A5. You have just had the apples in your orchard harvested into many boxes with a mass of $130.0\ kg$ each. You wish to lift these boxes up to the fourth floor ($12.0\ m$ above ground level) of your packaging facility. Since you are the only person available, you construct a slippery surface that is inclined $30.0°$ above the horizontal, and then fix a pulley at the top corner, as shown in Figure 2. You hang from the rope at the top of the incline and let the force of gravity pull the crates up the ramp. The friction between the crates and the inclined surface is negligible.

a) Determine the minimum mass you should be for this system to work **[3]**

b) If you do not wish to hit the ground with a speed greater than $2.00\ m/s$, determine what your maximum should mass be. **[3]**

c) Calculate how long it will take to lift one crate to the fourth floor if you have the mass calculated in part (b) **[3]**

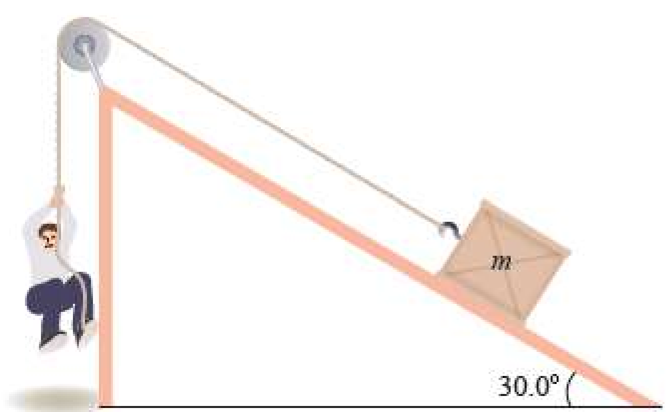


Figure 2

A6. A man cleaning a floor pulls a vacuum cleaner with a force of magnitude $F = 50.0\ N$ at an angle of $30.0°$ with the horizontal (Figure 3). Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced $3.00\ m$ to the right. **[4]**

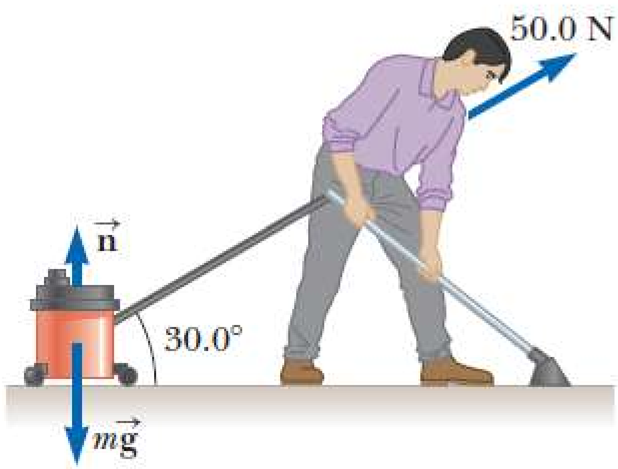


Figure 3

A8. A $10.0g$ bullet is fired into a stationary block of wood having mass $m = 5.00\ kg$. The bullet imbeds into the block. The speed of the bullet-plus-wood combination immediately after the collision is $0.600\ m/s$. Determine the original speed of the bullet.

[4]

SECTION B *(35 marks)*

Answer question **B1** and **any other three** questions.

B1. A $0.250kg$ block resting on a frictionless, horizontal surface is attached to a spring whose force constant is $83.8\ N/m$ as in Figure 4. A horizontal force $\vec{F}$ causes the spring to stretch a distance of $5.46\ cm$ from its equilibrium position.

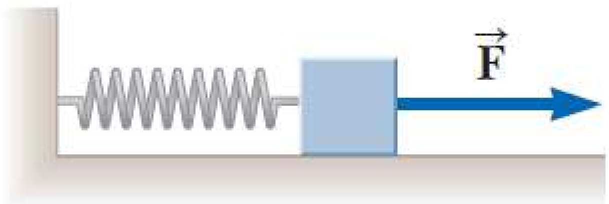


Figure 4

a) Calculate the magnitude of $\vec{F}$ **[3]**

b) Calculate the total energy stored in the system when the spring is stretched. **[4]**

c) Determine the magnitude of the acceleration of the block just after the applied force is removed. **[4]**

d) Determine the speed of the block when it first reaches the equilibrium position. **[3]**

B2. i. Calculate the pressure increase in the fluid in a syringe when a nurse applies a force of $42N$ to the syringe's circular piston, which has a radius of $1.1\ cm$. **[2]**

ii. A $6100\ kg$ rocket is set for vertical firing from the ground. If the exhaust speed is $1200\ m/s$, calculate the quantity of gas that must be ejected each second if the thrust.

a) is to equal the magnitude of the gravitational force on the rocket and **[2]**

b) is to give the rocket an initial upward acceleration of $21\ ms^{-2}$. **[3]**

B3. A glass tube of cross-sectional area $1.0 \times\ 10^{-4}\ m^2$ is partially filled with water. An oil with a density of $800\ kgm^{-3}$ is slowly poured into the tube so that it does not mix with the water and floats on top of it. The height of the oil above the water surface is $8cm$.

a) Calculate the change in pressure at a depth of $10\ cm$ below the water surface. **[3]**

b) Would the pressure at this depth increase or decrease if you added more oil to the tube. **[2]**

c) With aid of diagrams or sketches, explain your answer in b) **[2]**

B4. i. The intake duct in Figure 5 has cross-sectional area of $0.74\ m^2$ and water flow at $0.40\ m/s$. At the outlet, distance $D = 180\ m$ below the intake, the cross-sectional area is smaller than at the intake and the water flows out at $9.5\ m/s$ into equipment. Determine the pressure difference between inlet and outlet. **[3]**

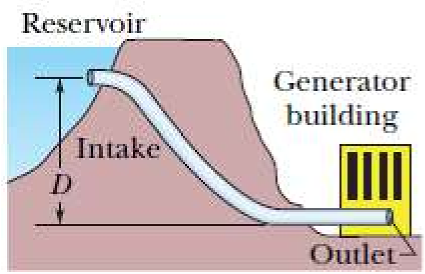


Figure 5

ii. A submarine (sub-A) travels through water at a speed of $8.00\ m/s$, emitting a sonar wave at a frequency of $1\ 400\ Hz$. The speed of sound in the water is $1\ 533\ m/s$. A second submarine (sub-B) is located such that both submarines are traveling directly toward each other. The second submarine is moving at $9.00\ m/s$. Calculate the frequency which is detected by an observer riding on sub–B as the subs approach each other. **[4]**

B5. In an electric shaver, the blade moves back and forth over a distance of $2.0\ mm$ in simple harmonic motion, with frequency $120\ Hz$. Find

a) the amplitude, **[2]**

b) the maximum blade speed, and **[3]**

c) the magnitude of the maximum blade acceleration. **[3]**

B6. The speed of sound in air is $340.0\ m/s$. The angular frequency of a sound wave is $600.0\ rad/s$. Determine the waves.

a) frequency **[3]**

b) period **[2]**

c) wavelength **[2]**

SECTION C *(25 marks)*

Answer question **C1 and any other three** questions.

C1. A capacitor that has two parallel plates of dimensions 10.00cm ×7.50 cm separated by 1.50 mm of air is connected to a 24.0 V battery. Find

a) the capacitance **[2]**

b) the charge on one plate **[2]**

c) the electric field in the capacitor **[3]**

C2. On a car's side-view mirror you notice a warning: "Objects in mirror are closer than they appear."

a) With the aid of sketches and diagrams, explain the physics behind that statement. **[3]**

b) What type of mirror is it, and why is it used as a side-view mirror. **[3]**

C3. A coin is placed at the bottom of an $80.0\ cm$ deep aquarium filled with water. You are looking at the coin from above the aquarium.

a) Explain, using ray diagrams and the necessary calculations, how deep will the coin appear to you. **[6]**

C4. A narrow beam of light is incident on an air–glass boundary at an angle of $30°$.

a) Calculate the angle of deflection (the angle between the incident and refracted beams) of this beam. **[3]**

b) Will the angle of deflection increase or decrease when the angle of incidence increases to $45°$, Justify your answer with calculations and a diagram. **[3]**

C5. A wire made of a manganese alloy has a length of 56 cm and a diameter of 0.40 mm. The resistivity of the alloy is $\rho = 0.45\ \mu\Omega\text{m}$.

a) Find the resistance of the wire. **[3]**

b) Find the current through the wire when the potential difference across it is 3.0 V. **[3]**

END OF EXAMINATION

SECTION A *(50 marks)*

A1. A train increases its speed steadily from $10\ m/s$ to $20\ m/s$ in 2 minutes.

a. Calculate its average speed during this time, in m/s **[3]**

b. Calculate how far does it travel while increasing its speed **[4]**

c. Plot the trains velocity time graph **[3]**

A2. Determine the vector product of these two vectors.

$$\vec{\mathbf{A}} = -2\hat{i} + 3\hat{j} + 4\hat{k}$$

$$\vec{\mathbf{B}} = 3\hat{i} + \hat{j} - 3\hat{k}\ .$$ **[3]**

A3. A stone is projected at a cliff of height *h* with an initial speed of 42.0 *m/s* directed at angle $\theta = 60.0°$ above the horizontal as shown in Fig 1 below. The stone strikes at *A*, 5.50 *s* after launching.

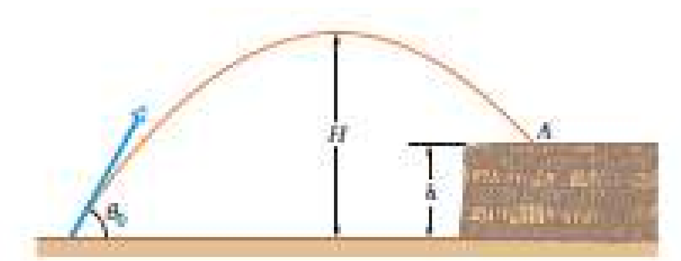


Fig 1

Find

(i) the height h of the cliff **[2]**

(ii) the speed of the stone just before impact at A, **[3]**

(iii) the maximum height H reached above the ground. **[2]**

A4. A crate of mass $m = 55\ kg$ is pushed at constant speed up a ramp inclined at 35.0° by a horizontal force as shown in Fig. 2.

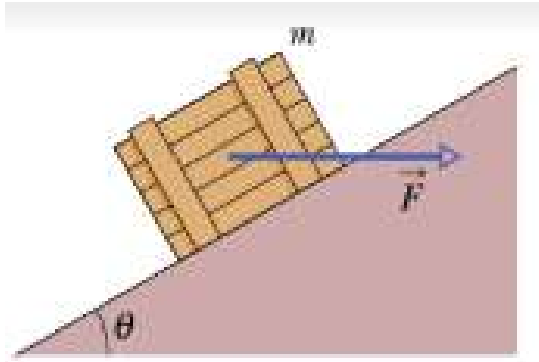


Fig. 2.

If the ramp has a coefficient of friction, $\mu = 0.05$

a. Calculate the magnitude of the normal force **[3]**

b. Calculate the force $\vec{F}$ **[2]**

A5. An elevator carries 7 passengers of average mass 70 kg to a height of 20 meters in one minute.

a. Calculate the work done in lifting the passengers **[5]**

b. Calculate the power needed to do that task **[5]**

A6. Explain what you understand by the term *elastic collision*. **[2]**

b) A body of mass $3.0\ kg$ makes an elastic collision with another body at rest and continues to move in the original direction but with one-fourth of its original speed. Calculate the mass of the other body. **[4]**

A7. A block whose mass m is 750 g is fastened to a spring whose spring constant k is $55\ N/m$ (Fig 3.). The block is pulled a distance $x = 5$ cm from its equilibrium position at $x = 0$ on a frictionless surface and released from rest at $t = 0$.

a. What are the angular frequency, the frequency, and the period of the resulting motion? **[3]**

b. What is the amplitude of the oscillation? **[2]**

c. What is the maximum speed v_m of the oscillating block, and where is the block when it has this speed? **[2]**

d. What is the magnitude a_m of the maximum acceleration of the block? **[2]**

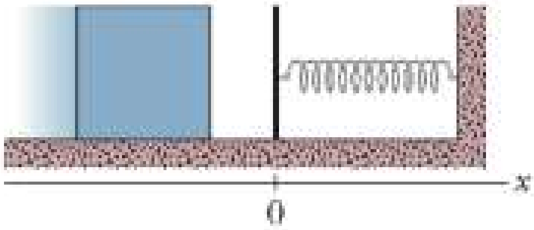


Fig 3.

SECTION B *(30 marks)*

Answer all questions

B1. State

a. Pascal's Law **[2]**

b. Archimedes Principle **[2]**

B2. Give an example of an application of Bernoulli's principle in engineering or everyday life. **[3]**

B3. Explain what you understand on Archimedes' principle and how can it be used to determine the buoyant force on an object submerged in a fluid? **[4]**

B4. A bloc of density $4000 kg/m^3$ and volume of $0.004 m^3$ is immersed in water (density $1000 kg/m^3$). Calculate:

a. The upward force exerted by the fluid on the object **[3]**

b. The weight of the object in air **[3]**

c. Its weight inside the fluid **[3]**

B5. The displacement function for a pulse travelling along a string is given by the equation

$$D(x,t) = \frac{4.0}{(x - 2t)^2 + 6.0}$$

where *x* is in metres and *t* is in seconds.

a. Determine the speed of the pulse, and the direction in which is it travelling **[2]**

b. Calculate the displacement of a point located at $x = 4.0\ m$ at $t = 1.0\ s$ **[3]**

c. Calculate the speed of a point that is located at $x = 5.0\ m$ at t=1.0 s **[3]**

d. Determine the maximum displacement of a point as the pulse passes through it. **[2]**

SECTION C *(20 marks)*

Answer all questions

C1. Using sketches, were necessary, explain Kirchhoff's current Law. **[2]**

C2. Using sketches were necessary, explain Kirchhoff's Voltage Law **[2]**

C3. Referring to the circuit shown below (Fig. 4), determine the number of.

a. branches **[1]**
b. nodes **[1]**
c. loops **[1]**

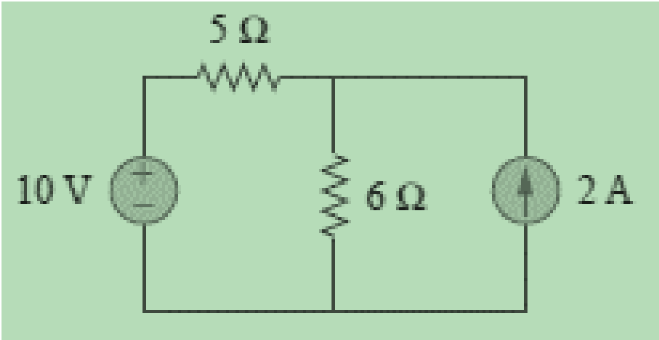


Fig 4.

C4. A $+30.0\ nC$ charge is placed at the origin of a coordinate system, and a $-50.0\ nC$ charge is placed in the xy-plane at the point$(x = 0.100\ m, y = -0.500\ m)$.

a) Determine the magnitude and the direction of the force that the positive charge exerts on the negative charge. Use ijk notation for your result. **[3]**

b) Determine the magnitude and direction of the force of the negative charge on the positive charge. **[3]**

C5. Electric eels generate electric pulses along their skin that can be used to stun an enemy or prey when they come into contact with it. Research has shown that these pulses can be up to 500 V and produce currents of 80 mA (or even larger). A typical pulse lasts for 10 ms. Calculate:

a) The charge released, **[2]**

b) the power and, **[2]**

c) how much energy are delivered to the unfortunate enemy with a single pulse, assuming a steady current. **[3]**

END OF EXAMINATION

SECTION A *(45 marks)*

Attempt **ALL** questions.

A1. Explain why the Engineering Physics Course is relevant to your area of study. **[3]**

A2. Hooke's law states that the force, F, in a spring extended by a length x is given by $F = -kx$. From Newton's second law $F = ma$, where m is the mass and a is the acceleration, calculate the dimensions of the spring constant k. **[3]**

A3. Suppose that the uncertainty in the length $17.386\ 22\ m$ is $0.04\ m$. Round the length to the correct number of significant digits. **[2]**

A4. A female cheetah starts from rest and accelerates uniformly for 5 seconds until she reaches a velocity of $20\ m\ s^{-1}$while chasing a Thompson gazelle. She then runs at a constant velocity for 8 seconds before decelerating as she failed to catch the gazelle. Sketch a velocity-time graph of her motion. **[4]**

A5. A construction worker standing on a beam asks his very strong friend on the ground 9.00 m below to throw his lunch box up to him. The friend wants to throw the box straight up such that it has a velocity of 0.500 m/s up when it reaches the worker on the beam, to give him some leeway as he tries to catch it.

b) What assumption(s) should you make to solve the problem? **[2]**

c) At what speed should the friend throw the lunch box? **[3]**

d) How long will the lunch box be in the air before it is caught by the worker? **[2]**

e) How long does it take for the lunch box to cover the first 4.50 m of its trajectory? **[3]**

f) How high above its initial position will the lunch box be after half the total time of its motion? **[2]**

g) Sketch the distance-time, velocity-time, and acceleration-time graphs for the motion of the lunch box. **[4]**

A6. Two objects are moving at constant velocities:$\vec{V}_A = (2\hat{\imath} - 5\hat{\jmath})m/s$, $\vec{V}_B = (-2\hat{\imath} + 4\hat{\jmath})m/s$.

a) Which object is moving faster? **[3]**

b) Find the angle between objects' trajectories. **[3]**

A7. In Fig 1. a block of mass m_1 = 1.5 kg (**A)** on a plane inclined at $\theta = 30°$ (coefficient of friction = 0.15) is connected by a cord over a frictionless pulley to a second block **B** of mass m_2 = 3.00kg. Ignoring the mass of the pulley, determine

a) the magnitude of the acceleration of each block, **[4]**

b) the direction of the acceleration of the hanging block, and **[1]**

c) the tension in the cord. **[2]**

d) If the blocks are released from rest with the connecting cord taut, use the work kinetic energy theorem to determine the blocks total kinetic energy when block B has moved 30cm. **[4]**

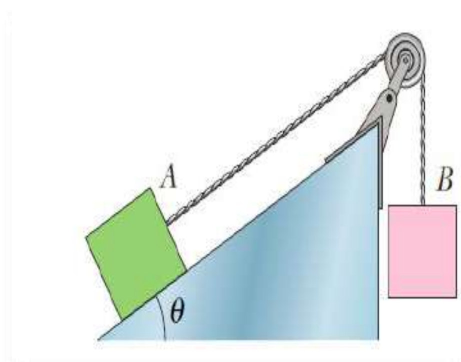


Figure 1

SECTION B *(35 marks)*

Answer question **B1** and **any other three** questions.

B1. (a) Define floating. **[2]**

(b) A cube of edge length $L = 0.600\ m$ and mass $450\ kg$ is suspended by a rope in an open tank of liquid of density $1030\ kg/m^3$, as shown in Fig 2.

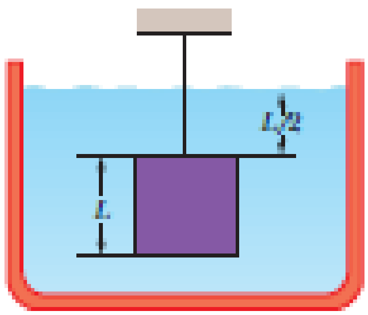


Figure 2

Find,

(i). the magnitude of the total downward force on the top of the cube from the liquid and the atmosphere, assuming atmospheric pressure is 1.00 atm, **[2]**

(ii). The magnitude of the total upward force on the bottom of the cube, **[2]**

(iii). The tension in the rope. **[2]**

(iv). The magnitude of the buoyant force on the cube using Archimedes' principle. **[3]**

B2.

a) Define resonance and describe one scenario where it is applied for the benefit of mankind. **[4]**

b) A block of mass $m = 14.00\ kg$ is released from rest on a frictionless incline of angle $\theta = 30°$, as shown in **Fig 3**. Below the block is a spring with spring constant, $k = 1800 N/m$. The block momentarily stops when it compresses the spring by 7.0 cm. Calculate the speed of the block just before compressing the spring. **[4]**

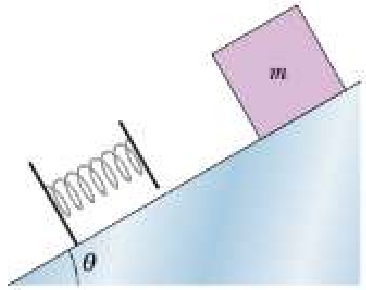


Figure 3

B3. (a). Calculate the difference in blood pressure (in atmosphere) between the heart and the foot in a person of height 2.00 *m* and the height from the heart to the head is 0.40 *m* and the density of blood is $1.06 \times 10^3 kg/m$. **[4]**

(b). The U-shape in Fig 4 contains two liquids in static equilibrium: water of density $998\ kg/m^3$ and an unknown liquid with unknown density. Find the density of the unknown liquid if $h = 155\ mm$ and $l = 135\ mm$. **[4]**

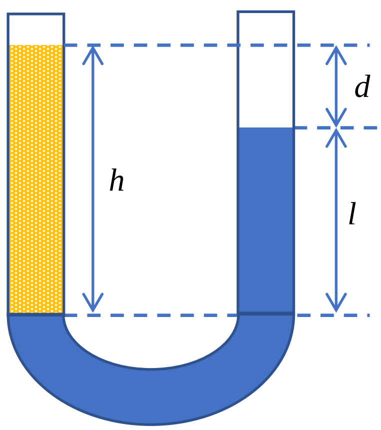


Figure 4

B4. A bat is flying at 7.00 m/s and is emitting cries at a frequency of 82.0 kHz. It is chasing a moth and is detecting the echoes from the moth. Moths fly somewhat erratically. Calculate the frequency detected by the bat when the moth is;

a) Stationary **[2]**

b) flying at 1.00 m/s in the same direction as the bat **[3]**

c) flying at 2.00 m/s toward the bat **[3]**

B5.

a) You went to the farm to do some sightseeing, then the workers ask you to measure the depth of a well. As an engineering student, you decide to show that you can use your intellect to determine the depth of the well to the amusement of the folks there. You drop a stone into the well and hear the splash 2.8 s later. Calculate the depth of the well. **[4]**

b) Consider the simplified single-piston engine in Fig 5. Assuming the wheel rotates with constant angular speed, explain why the piston rod oscillates in simple harmonic motion. **[4]**

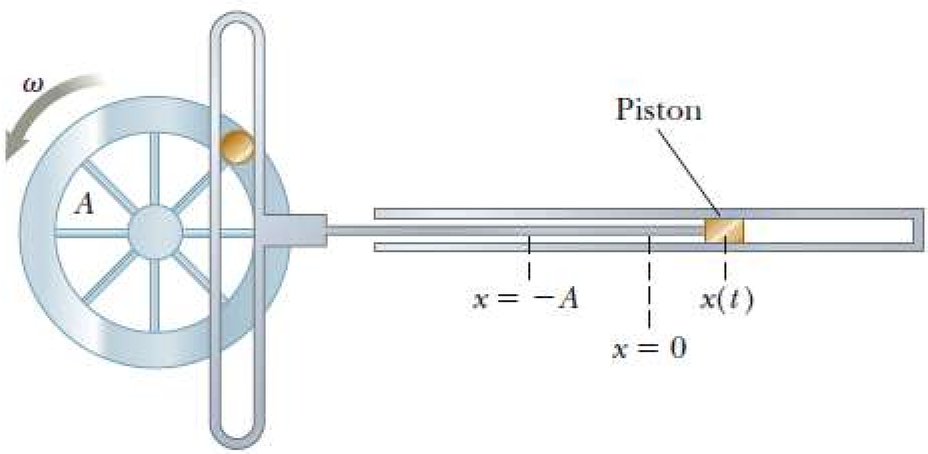


Figure 5

SECTION C *(20 marks)*

Answer question **C1 and any other three** questions.

C1. Draw a diagram showing the effects of both a converging lens on a beam of parallel rays. On the diagram clearly label the principle axis, principle focus, and focal length. **[8]**

C2. Good electrical conductors, such as metals, are typically good conductors of heat; electrical insulators, such as wood, are typically poor conductors of heat. Explain why there should be a relationship between electrical conduction and heat conduction in these materials. **[4]**

C3. An underwater scuba diver sees the Sun at an apparent angle of $45.0°$ above the horizontal. Calculate the actual elevation angle of the Sun above the horizontal. **[4]**

C4. A $+35.0\,nC$ charge is placed at the origin of a coordinate system, and a $-25.0\,nC$ charge is placed in the xy-plane at the point$(x = 0.100\ m, y = -0.0500\ m)$.

a) Determine the magnitude and the direction of the force that the positive charge exerts on the negative charge. Use ijk notation for your result. **[4]**

C5. A Referring to the circuit shown below in Fig 6, determine the number of;

a) nodes; **[1]**

b) elements; **[1]**

c) branches. **[1]**

d) loops **[1]**

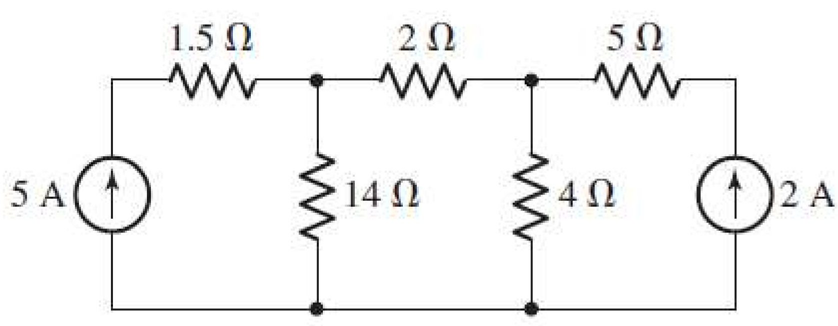


Figure 6

END OF EXAMINATION

SECTION A: NEWTONIAN MECHANICS *(50 marks)*

Attempt **ALL** questions.

A1.

a) Explain the significance of precision and accuracy in experimental measurements. **[2]**

b) A vector $\vec{A}$ has components $Ax = 4.0\,m,\; Ay = 3.0\,m$. Calculate its magnitude and direction. **[4]**

c) Use dimensional analysis to check the correctness of the equation $v = \sqrt{2gh}$ **[3]**

d) Compare the uncertainties in measurements from vernier calipers and micrometer screw gauge. **[4]**

A2. A car accelerates uniformly from rest and covers 100 m in 8 seconds.

(a) Determine the car’s acceleration. **[2]**

(b) Calculate its final speed. **[2]**

(c) Sketch a displacement time graph for the motion of the car. **[2]**

(d) A 10 kg object is acted on by a 50 N force. Calculate its acceleration and comment on the type of force involved. **[4]**

(e) Define terminal velocity and discuss any two factors affecting it. **[4]**

A3.

a) Define work and explain the conditions under which work is said to be zero. **[2]**

b) A spring of constant k = 200 N/m is compressed by 0.1 m. Calculate the potential energy stored. **[2]**

c) A 5 kg block slides 3 m down a 30° incline with negligible friction. Determine:

i) Work done by gravity **[2]**

ii) Final speed if it starts from rest **[3]**

iii) Energy conservation **[4]**

A4.

a) State the law of conservation of linear momentum. **[2]**

b) Two objects (2 kg at 4 m/s and 3 kg at rest) collide inelastically. Determine their common velocity after collision. **[4]**

c) Explain the difference between elastic and inelastic collisions using examples. **[4]**

SECTION B: FLUIDS, OSCILLATIONS, WAVES & MATERIALS SCIENCE

(30 marks)

Answer **any three** questions.

B1.

a) State Bernoulli's principle and describe its application in airplane wing design. **[4]**

b) Water flows in a horizontal pipe from a 6 cm to a 3 cm diameter. If the speed in the larger section is 2 m/s, calculate the speed in the narrow section. **[3]**

c) Explain how hydraulic brakes use Pascal's principle. **[3]**

B2.

a) Define simple harmonic motion and write its general equation. **[3]**

b) A 0.5 kg mass is attached to a spring of $k = 20$ N/m. Find the period of oscillation. **[3]**

c) Discuss two real-life applications of Simple Harmonic Motion (SHM). **[4]**

B3.

a) Define wave speed and write its relation to frequency and wavelength. **[2]**

b) A sound wave has a frequency of 500 Hz and travels at 340 m/s. Find its wavelength. **[2]**

c) Explain the Doppler effect and calculate the frequency heard by a stationary observer when a car moving at 25 m/s emits a horn at 600 Hz. **[6]**

B4.

a) Classify materials into metals, ceramics, and polymers with examples. **[3]**

b) Explain how grain structure affects strength in metals. **[3]**

c) Compare the mechanical properties of a metal and a polymer under tension. **[4]**

SECTION C: LIGHT, ELECTRICITY & MAGNETISM *(20 marks)*

Answer **any two** questions.

C1.

a) State Snell's Law. Light moves from air ($n = 1$) to glass ($n = 1.5$) at 45°. Determine the angle of refraction. **[3]**

b) Explain the working principle of a convex lens with a ray diagram. **[4]**

c) Name two applications of lenses in engineering. **[3]**

C2.

a) Define Coulomb's law and calculate the force between two $1\ \mu C$ charges placed $0.2\ m$ apart. **[3]**

b) Explain how Kirchhoff's current law is applied at a node in a circuit. **[2]**

c) For a $12\ V$ battery connected to a $6\ \Omega$ and $3\ \Omega$ resistor in parallel, find the total current drawn. **[5]**

C3.

a) What is a magnetic field? Describe how to increase the strength of a solenoid's field. **[3]**

b) A coil of 100 turns carries $2\ A$ and has length $0.5\ m$. Calculate the magnetic field inside it. ($\mu_0 = 4\pi \times 10^{-7}\ T \cdot m/A$) **[4]**

c) State one engineering application each of a solenoid and an electromagnet. **[3]**

END OF EXAMINATION

ABOUT THE BOOK

FOUNDATIONS OF ENGINEERING PHYSICS: A CONTEXTUAL INTRODUCTION FOR EMERGING ENGINEERS IN AFRICA PROVIDES A PRACTICAL AND ENGAGING INTRODUCTION TO THE FUNDAMENTAL PRINCIPLES OF PHYSICS THAT UNDERPIN MODERN ENGINEERING. DESIGNED WITH FIRST-YEAR ENGINEERING STUDENTS IN MIND, THE BOOK CONNECTS CORE SCIENTIFIC CONCEPTS TO REAL-WORLD ENGINEERING APPLICATIONS ACROSS CIVIL, MECHANICAL, ELECTRICAL, AEROSPACE, BIOMEDICAL, AND MATERIALS ENGINEERING. RATHER THAN PRESENTING PHYSICS AS ABSTRACT THEORY, IT DEMONSTRATES HOW MEASUREMENTS, MECHANICS, ENERGY, FLUIDS, OSCILLATIONS, AND WAVES ARE APPLIED TO SOLVE AUTHENTIC ENGINEERING CHALLENGES.

EACH CHAPTER COMBINES CLEAR EXPLANATIONS WITH WORKED EXAMPLES, PRACTICAL LABORATORY ACTIVITIES, ENGINEERING CASE STUDIES, AND PROBLEM-SOLVING EXERCISES THAT REINFORCE BOTH CONCEPTUAL UNDERSTANDING AND ANALYTICAL SKILLS. PARTICULAR EMPHASIS IS PLACED ON AFRICAN AND DEVELOPING-WORLD ENGINEERING CONTEXTS, ENABLING STUDENTS TO APPRECIATE THE RELEVANCE OF PHYSICS IN ADDRESSING LOCAL TECHNOLOGICAL AND INDUSTRIAL CHALLENGES.

BY THE END OF THIS TEXT, READERS WILL HAVE DEVELOPED A SOLID FOUNDATION IN ENGINEERING PHYSICS, STRENGTHENED THEIR QUANTITATIVE REASONING AND CRITICAL THINKING SKILLS, AND GAINED THE CONFIDENCE TO APPLY PHYSICAL PRINCIPLES IN ENGINEERING DESIGN, EXPERIMENTATION, AND INNOVATION. THIS GUIDE SERVES AS AN IDEAL BRIDGE BETWEEN INTRODUCTORY PHYSICS AND SUBSEQUENT ENGINEERING STUDIES.

KEY FEATURES:

- CONTEXTUALISED ENGINEERING EXAMPLES RELEVANT TO AFRICAN AND DEVELOPING-WORLD APPLICATIONS.
- CLEARLY DEFINED LEARNING OBJECTIVES AT THE BEGINNING OF EVERY CHAPTER.
- STEP-BY-STEP WORKED EXAMPLES WITH DETAILED SOLUTIONS.
- PRACTICAL LABORATORY ACTIVITIES THAT REINFORCE THEORETICAL CONCEPTS.
- REAL-WORLD ENGINEERING CASE STUDIES LINKING PHYSICS TO PROFESSIONAL PRACTICE.
- COMPREHENSIVE END-OF-CHAPTER EXERCISES FOR SELF-ASSESSMENT AND EXAMINATION PREPARATION.
- INTEGRATION OF MATHEMATICAL ANALYSIS WITH ENGINEERING PROBLEM-SOLVING TECHNIQUES.
- HIGH-QUALITY DIAGRAMS, ILLUSTRATIONS, AND GRAPHICAL EXPLANATIONS.
- EMPHASIS ON ACCURACY, MEASUREMENT TECHNIQUES, AND EXPERIMENTAL SKILLS.
- COVERAGE OF FOUNDATIONAL TOPICS INCLUDING MECHANICS, WORK AND ENERGY, MOMENTUM, FLUIDS, OSCILLATIONS, AND WAVES.
- DESIGNED TO SUPPORT BOTH CLASSROOM INSTRUCTION AND INDEPENDENT LEARNING.

TARGET AUDIENCE:

THIS TEXTBOOK IS IDEAL FOR FIRST-YEAR UNDERGRADUATE STUDENTS IN ENGINEERING, ENGINEERING TECHNOLOGY, APPLIED SCIENCES, AND RELATED STEM PROGRAMMES. IT IS ALSO A VALUABLE RESOURCE FOR ENGINEERING LECTURERS, TUTORS, LABORATORY INSTRUCTORS, AND DIPLOMA STUDENTS SEEKING A CONTEXTUAL, APPLICATION-ORIENTED INTRODUCTION TO ENGINEERING PHYSICS THAT BRIDGES FUNDAMENTAL SCIENTIFIC PRINCIPLES WITH REAL-WORLD ENGINEERING PRACTICE.

ISBN 978-1-77932-759-8
9 781779 327598

CUT LIBRARY PRESS
2026