RQF LEVEL 4



GENMP402

BDC, PWO, LSV, IND, PLT, SWD, MMP, NIT, SPE, CSA, AGR, WOT, WIR, ELT, REN,

Applied Physics

TRAINEE'S MANUAL

October, 2024

MECHANICS AND PROPERTIES OF MATTER

KOICA Korea International Cooperation Agency

TQUM TVET Quality Management Project

2024

AUTHOR'S NOTE PAGE (COPYRIGHT)

The competent development body of this manual is Rwanda TVET Board ©, reproduce with permission.

All rights reserved.

- This work has been produced initially with the Rwanda TVET Board with the support from KOICA through TQUM Project
- This work has copyright, but permission is given to all the Administrative and Academic Staff of the RTB and TVET Schools to make copies by photocopying or other duplicating processes for use at their own workplaces.
- This permission does not extend to making of copies for use outside the immediate environment for which they are made, nor making copies for hire or resale to third parties.
- The views expressed in this version of the work do not necessarily represent the views of RTB. The competent body does not give warranty nor accept any liability
- RTB owns the copyright to the trainee and trainer's manuals. Training providers may reproduce these training manuals in part or in full for training purposes only. Acknowledgment of RTB copyright must be included on any reproductions. Any other use of the manuals must be referred to the RTB.

© Rwanda TVET Board
Copies available from:
- *HQs: Rwanda TVET Board-RTB*
- *Web: www.rtb.gov.rw*
- **KIGALI-RWANDA**

Original published version: October 2024

ACKNOWLEDGEMENTS

The publisher would like to thank the following for their assistance in the elaboration of this training manual:

Rwanda TVET Board (RTB) extends its appreciation to all parties who contributed to the development of the trainer's and trainee's manuals for the TVET Certificate IV in Building Construction, Public works, Land Surveying, Interior Design, Plumbing Technology, Software Development, MMP, Networking and Internet Technologies, Software Programming and Embedded Systems, Computer System and Architecture, Agriculture, Wood Technology, Water and Irrigation, Electrical Technology, Renewable Energy, Electronics and Telecommunication, Automobile Technology, Heavy Machinery, Manufacturing Technology and MNTspecifically for the module "**Applied Physics**".

We extend our gratitude to KOICA Rwanda for its contribution to the development of these training manuals and for its ongoing support of the TVET system in Rwanda.

We extend our gratitude to the TQUM Project for its financial and technical support in the development of these training manuals.

We would also like to acknowledge the valuable contributions of all TVET trainers and industry practitioners in the development of this training manual.

The management of Rwanda TVET Board extends its appreciation to both its staff and the staff of the TQUM Project for their efforts in coordinating these activities.

This training manual was developed:

Under Rwanda TVET Board (RTB) guiding policies and directives

Under Financial and Technical support of

COORDINATION TEAM

RWAMASIRABO Aimable
MARIA Bernadette M. Ramos
MUSABYIMANA Marie Jeanne

Production Team

Authoring and Review

NINKABANDI Theogene

Validation

MUNYURABANGA Alice Allouette Marie

Conception, Adaptation and Editorial works

HATEGEKIMANA Olivier

GANZA Jean Francois Regis

NYINAWUMUNTU Gaudence

Formatting, Graphics, Illustrations, and infographics

MANISHIMWE Marc

Financial and Technical support

KOICA through TQUM Project

TABLE OF CONTENT

Topic 1.1: Interpretation of the concept of force **8**

Topic 1.2: Interpretation of Newton's laws **12**

Topic 1.3: Application of Newton's laws on a free body diagram **14**

Topic 2.1: Explanation of equilibrium conditions **28**

Topic 2.2: Application of Static equilibrium **33**

Topic 2.3: Application of elastic properties **37**

Topic 3.1: Description of Pressure and its variation with depth **50**

Topic 3.3: Analysing Fluid dynamics **62**

UNIT 4: APPLY THERMODYNAMICS ***74***

Topic 4.1: Description of fundamental concepts of thermodynamics **80**

Topic 4.2: Analysing thermodynamic laws **90**

Topic 4.3: Application of thermodynamic laws **94**

Topic 5.1: Description of simple electric circuit **8**

Topic 5.2: Determination of Electric current, resistances and voltages in DC electric circuits **18**

Topic 5.3: Determination of Electric energy, work and power in DC electric circuit **24**

UNIT 6: APPLY OPTICAL INSTRUMENTS ***31***

Topic 6.1: Description of optical instruments **37**

Topic 6.2:Determination of magnification of optical instruments **47**

Topic 6.3: Correction of optical aberrations **52**

LIST OF FIGURES

Figure 1: Free body diagram 16
Figure 2: Tension force 17
Figure 3: Free body diagram on suspended objects 17
Figure 4: Rocket in motion 18
Figure 5: Turning effect 29
Figure 6:Stable neutral and unstable equilibrium 31
Figure 7: Seesaw 33
Figure 8: A slope showing applied forces 35
Figure 9: Horizontal and vertical component 36
Figure 10: Stress vs strain curve 41
Figure 11: Static fluid pressure 52
Figure 12: Water squirts further at greater depths 52
Figure 13: Barometer 54
Figure 14: Atmospheric pressure varies 54
Figure 15: Manometer 55
Figure 16: The Hydraulic pump 55
Figure 17: Buoyant force and weight of the fluid 59
Figure 18: Weight and upthrust force 60
Figure 19: Buoyancy force state 61
Figure 20: Steady flow/ laminar flow 62
Figure 21: Unsteady flow/ Turbulent flow 63
Figure 22: equation of continuity 63
Figure 23: Bernoulli's equation 66
Figure 24: description of a system 81
Figure 25: Linear expansion 87
Figure 26: area expansion 87
Figure 27: Volume expansion 88
Figure 28: Zeroth law 90
Figure 29:Liquid-in-glass thermometer 91
Figure 30: Digital thermometer 91
Figure 31: Infrared thermometer 91
Figure 32: Refrigerators 95
Figure 33: Heat engine 97
Figure 34: Heat pump 98
Figure 35: Power plant 100
Figure 36: simple dc circuit 9
Figure 37Ammeter 9
Figure 38: Voltmeter 9
Figure 39: resistors in series 11
Figure 40: resistors in parallel 11
Figure 41: resistors in mixture 12
Figure 42: Simple electric cell. 13

Figure 43: e.m.f. of a cell....13
Figure 44: Cells network 14
Figure 45: Cells combined in series....14
Figure 46: Each cell is of emf 1.5V. 15
Figure 47: Series arrangement of dry cells in a torch. 15
Figure 48: Cells connected in parallel. 15
Figure 49: Parallel circuit 18
Figure 50: Circuit branch....19
Figure 51: Voltage supply. 19
Figure 52: Voltage drop 20
Figure 53: Loop and junction law....20
Figure 54: electrolysis 27
Figure 55: The Human eye. 38
Figure 56: Visual Angle....39
Figure 57: Eye defect and correction instruments. 40
Figure 58: Magnifying glass....41
Figure 59: A single lens camera 42
Figure 60: Inner parts of single lens camera....43
Figure 61: Projector 45
Figure 62: Compound microscope....45
Figure 63: Image formed by a magnifying glass 48
Figure 64: simple microscope when it is not in normal adjustment 49
Figure 65: An astronomical telescope in normal adjustment 50
Figure 66: Spherical aberration 52
Figure 67: Chromatic aberration....53
Figure 68: Correction of chromatic aberration....54

LIST OF ABBREVIATIONS and ACRONYMS

CBET: Competence Base Education and Training

PPE: Personal Protective Equipment

RQF: Rwanda Qualification Framework

RS: Rwandan Standard

RSB: Rwanda Standards Board

RTB: Rwanda TVET Board

TVET: Technical and Vocational Education and Training

Dc: Direct current

AC: Alternative current

KCL: Kirchhoff's Current Law

KVL: Kirchhoff's Voltage Law KVL

Emf: Electromotive force

VOM: Voltage Ohm Meter

TER: Thermal Energy Reservoirs

COP: Coefficient of performance

kPa: kilopascals

FBD: Free Body Diagram

MPA: Music and performing arts
FAD: Fashion design
FPA: Fine and plastic arts
AGR : Agriculture
FOP: Food processing
ANH: Animal health
FOR: Forestry
LET: Leather technology
FBO: Food and beverages operations

FHO: Front office and housekeeping operations
TOR: Tourism

INTRODUCTION

This trainee's manual encompasses all necessary skills, knowledge and attitudes required to apply dynamic and waves. Students undertaking this module shall be exposed to practical activities that will develop and nurture their competences. The writing process of this training manual embraced competency-based education and training (CBET) philosophy by providing practical opportunities reflecting real life situations.

The trainee's manual is subdivided into units, each unit has got various topics, you will start with a self-assessment exercise to help you rate yourself on the level of skills, knowledge and attitudes about the unit.

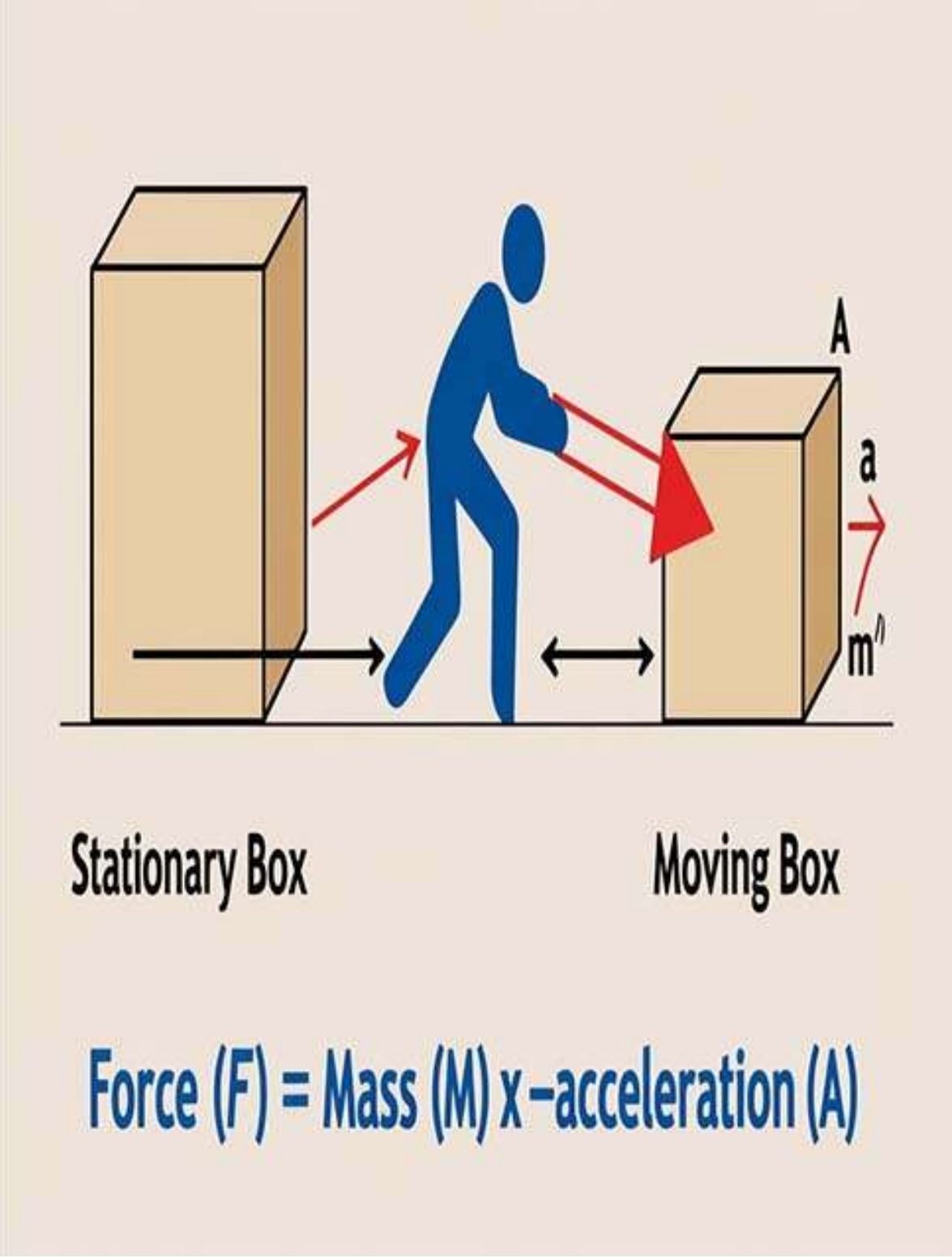
A discovery activity is followed to help you discover what you already know about the unit.

After these activities, you will learn more about the topics by doing different activities by reading the required knowledge, techniques, steps, procedures and other requirements under the key facts section, you may also get assistance from the trainer. The activities in this training manual are prepared such that they give opportunities to students to work individually and in groups.

After going through all activities, you shall undertake progressive assessments known as formative and finally conclude with your self-reflection to identify your strengths, weaknesses and areas for improvement.

Do not forget to read the point to remember the section which provides the overall key points and takeaways of the unit.

Module Units:
Unit 1: Describe laws of motion and their applications **Unit 2:** Apply static equilibrium and elasticity **Unit 3:** Analyze fluid mechanics **Unit 4:** Apply thermodynamics **Unit 5:** Examine effects of electric current flow in DC electric circuit **Unit 6:** Apply optical instruments


A
a
m
Stationary Box
Moving Box
Force (F) = Mass (M) x -acceleration (A)

Unit summary

This unit provides you with the knowledge, skills and attitudes required to describe laws of motion and their applications required to apply mechanics and properties of matter. It covers the interpretation of the concept of force, Interpretation of Newton's laws and Application of Newton's laws on a free body diagram.

Self-Assessment: Unit 1

1. Study the unit illustration above and answer the following questions.

a) What do you see in the illustration?

b) What topics do you think will be covered under this unit based on the illustration?

2. Fill in and complete the self-assessment table below to assess your level of knowledge, skills and attitudes under this unit.

a) There is no right or wrong ways to answer this assessment. It is for your own reference and self-reflection on the knowledge, skills and attitudes acquisition during the learning process.

b) Think about yourself: do you think you have the knowledge, skills or attitudes to do this? How well?

c) Read the statements across the top. Put a check in column that best represents your level of knowledge, skills or attitudes.

3. At the end of this unit, you will assess yourself again.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Define the key concepts of force					
Differentiate types of force					
State Fundamental forces and their characteristics					
Differentiate Internal & external forces					
State Newton's laws of motion					
Differentiate static and kinetic friction force					

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Solve problems related to static and kinetic friction force					
Explain Rocket motion					



Key Competencies:

Knowledge	Skills	Attitudes
1. Define the key concepts of force, friction force	**1.** Having the skill of Solving problems related to force	**1.** Having Precision and patience when solving detailed mathematical problems related to force
2. Identify the types of forces	**2.** Being able to solve problems related to different types of force and illustrating on diagram	**2.** Having Curiosity and Open-Mindedness, Attention to Detail, Logical and Systematic Approach
3. Identify the fundamental forces and their characteristics	**3.** Being skilled in Comparative analysis on fundamental forces and critical thinking	**3.** Having Curiosity and a Desire to Understand, Open-Mindedness and Willingness to Learn and Critical Thinking
4. Recognizing the types of friction force	**4.** Being proficient in Solving problems related to static and kinetic friction force	**4.** Having logical reasoning and attention to detail

Knowledge	Skills	Attitudes
5. Explain the theory for rocket motion	**5.** Being accurate in the Calculation of acceleration of rocket motion	**5.** Having an understanding of how rockets are used in our daily lives

Discovery activity:

Task 1:

Read the below scenario and answer related questions.
Scenario1:
A car is traveling on a flat road. The driver presses the accelerator, and the car begins to speed up. The car's tires are in contact with the road, and the engine produces a forward force that moves the car. However, as the car moves, several forces come into play.

a. What type of force is responsible for propelling the car forward?
b. What type of friction is involved when the car's tires are rolling on the road without slipping?
c. What happens to the frictional force as the car starts to speed up?
d. What is the effect of air resistance (drag) on the car's motion as it accelerates?
e. What force pulls the car downward, and what force balances it?
f. What happens to the net force as the car reaches a constant speed?

Topic 1.1: Interpretation of the concept of force

Activity 1: Problem Solving

Task 2: demonstrate the effects of force on a body

Read the scenario below and then answer related questions.

A book is resting on a table. A person gives the book a push, causing it to slide across the table. After sliding for some distance, the book slows down and eventually stops. While the book is on the table, it is also being pulled downward by Earth's gravity.

What type of force acts between the surface of the book and the table when the book slides? Is it a contact or non-contact force?

a. As the book slows down while sliding, what force is responsible for opposing its motion?
b. While the book is resting or sliding, it is pulled downward by Earth's gravity. What type of force is this? Is it a contact or non-contact force?
c. If the book is not falling through the table, what upward contact force balances the gravitational pull? Refer to the key facts 1.1 a for more clarifications

Key Facts 1.1a: description of force

✓ **Definition of force**

Force is a pull or push upon an object resulting from the object's interaction with another object. Whenever there is an interaction between two objects, there is a force upon each object.[1]

$F = m \times a$

Where F : force in Newton (N)

m : mass of an object in kilogram (kg)

a : acceleration in metre per second square (m/s^2)

[1] https://byjus.com/physics/force-push-and-pull/#:~:text=Force%20is%20an%20important%20concept,has%20both%20magnitude%20and%20direction.

- ✓ **Types of force**

They are two types of force namely contact and non- contact force.

- ✓ **Contact force**

Contact force is a force that is applied by objects in contact with each other.

Example of contact force are Frictional force ; Tension force ; Normal Force ; Air Resistance Force, Applied Force, Spring Force

- ❖ **Non-contact force or Field force**

A non-contact force (Field force) is a force which acts on an object without coming physically in contact with it.

Examples of field forces are Gravitational force, Magnetic force and Electrostatic force.

- ❖ **internal and external forces**
  - ✓ **Internal force**

An internal force is an interaction that exists within a system. Internal force resists the motion.

Examples of internal force:

- Gravitational force
- Magnetic force
- electric force,
- Spring force
  - ✓ **External force**

An external force occurs as a result of interaction between a system and the surroundings. External forces cause motion in an object.

Examples of external forces :

- Applied force
- Normal force
- Tension force

Air resistance

Activity 2: Guided Practice

Task 3: Solve the following problems

1. A planet is pulled toward a star with a gravitational force of 10,000 N. If the planet's mass is 1,000 kg, what is the acceleration due to the star's gravity?
2. A car with a mass of 1,200 kg accelerates at 3 m/s². What is the force acting on it?
3. A 500 kg satellite experiences a gravitational force of 2,500 N from a planet. What is the acceleration due to gravity on the satellite?

Key Facts 1.1b: Fundamental forces and their characteristics

There are four fundamental forces at work in the universe. The four fundamental forces of nature are, in order of strength: **strong nuclear, electromagnetic, weak nuclear, and gravitational.** [2]

- Gravity: Gravity is the attraction between two objects that have mass or energy, whether this is seen in dropping a rock from a bridge, a planet orbiting a star or the moon causing ocean tides.
- The weak force: The weak force, also called the weak nuclear interaction, is responsible for particle decay.
- Electromagnetic force: The Electromagnetic force, also called the Lorentz force, acts between charged particles, like negatively charged electrons and positively charged protons.
- The strong nuclear force : The strong nuclear force, also called the strong nuclear interaction, is the strongest of the four fundamental forces of nature.

The fundamental forces are characterized based on the following four criteria:

- ✓ the types of particles that experience the force,
- ✓ the relative strength of the force,

[2] https://byjus.com/physics/what-are-the-fundamental-forces-in-nature/

- ✓ the range over which the force is effective, and
- ✓ the nature of the particles that mediate the force.

Activity 3: Application

Task 4:

Read carefully the following statements and answer the related questions

1. A driver is driving a car on a smooth road. To move the car forward, the driver presses the accelerator, and when it's time to stop, the driver presses the brake pedal. How is force applied to move the car forward or stop it?
2. A cyclist is riding along a path. To move the bicycle forward, the cyclist pedals, pushing the pedals with their legs. What force is used by a cyclist to move the bicycle?
3. On a construction site, a crane is used to lift heavy steel beams to the top of a building. What force is applied to lift heavy materials like steel beams at a construction site?
4. A carpenter is using a hammer to drive a nail into a piece of wood. The carpenter swings the hammer and hits the nail with force. How is force applied when hammering nails into wood or walls?
5. A soccer player kicks a ball to send it toward the goal. The player uses their foot to apply force to the ball. What type of force is applied when a player kicks a ball?
6. You need to enter a room, so you push on the handle of the door to open it. What force do you apply when opening a door?

Topic 1.2: Interpretation of Newton's laws

Activity 1: Problem Solving

Task 5:

Read the scenario below and then answer related questions.

Scenario

Sarah was driving to work on a busy morning. When she pressed the accelerator, the car started moving, and she felt herself pushed back into the seat. As she made a quick turn, she noticed the car seemed to push against the road to change direction. She started wondering how it all worked. Why the car moved forward when she pressed the pedal, how it turned when she turned the wheel, and why she felt a pull when the car went faster. It was as if the car and the road were working together in a way she had never thought about before.

1. What causes the car to start moving when Sarah presses the accelerator?
2. How does pressing the accelerator affect the car's speed and movement?
3. How do the car and the road work together to make the car move and change direction?
4. What role does friction between the car's tires and the road play in these actions?
5. Key fact 1.2 gives you more clarification about the topic

Key Facts 1.2: Newton's law of motion

Newton has formulated three laws of motion, which are the basic postulates or assumptions on which the whole system of dynamics is based.

✓ **Newton's First Law of Motion**

- It state, "Everyday continues in its state of rest or of uniform motion in straight line, unless acted upon by some external force". This is also known as Law of Inertia.
- Inertia is that property of a matter, by virtue of which a body can not move of itself nor change the motion imparted to it.

✓ **Newton's second Law of Motion**

- It states, "The rate of change of momentum is directly proportional to the impressed force and takes place in the same direction in which the force acts".

$$\sum \vec{F} = \frac{d\vec{P}}{dt} = \frac{md\vec{v}}{dt} = m\vec{a}$$

- The net force in mechanics, the net force is the sum of all the forces acting on an object. For example, if one person pushes on a box forward with 40N and one person pushes the box up with 30N, the net force will be the sum of these vector forces.

✓ **Newton's s third law of motion**

- The force of action and reaction between interacting bodies are equal in magnitude, opposite in direction and have the same line of action



Activity 2: Guided Practice



Task 6:

Referring to the scenario given above (Task5), perform the following tasks: Sarah presses the accelerator, and the car begins to move forward. If the mass of the car is 1,200 kg and the engine applies a forward force of 3,600 N, what is the car's acceleration?

Activity 3: Application

Task 7:

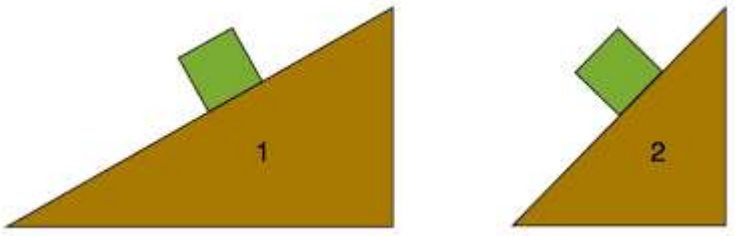
Read carefully the following statements and answer the related questions

1. Sarah places a book on a table and leaves it there. The book does not move unless someone or something pushes it. Why does the book stay at rest on the table?
2. John pushes two objects, one light and one heavy, with the same force. He notices that the light object speeds up faster than the heavy one. Why do lighter objects accelerate faster than heavier ones when the same force is applied?
3. Tom stands against a wall and pushes it with all his strength. He feels a force pushing back on him from the wall. Why do you feel a force pushing back when you push against a wall?

Topic 1.3: Application of Newton's laws on a free body diagram

Activity 1: Problem Solving

Task 8:



Use the figure above to answer the following questions

1. What are the forces acting on a block placed on an inclined slope, and in which directions do they act?
2. If the block is not sliding down the slope, what force is preventing its motion? How does this relate to the coefficient of static friction?
3. As the angle of the slope increases, how does the parallel component of gravitational force change? What happens when the angle reaches a critical value?

Key Facts 1.3a: Motion on a plane

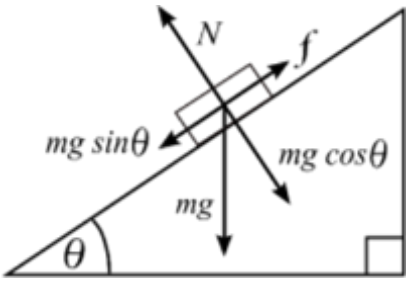
Static friction is friction that occurs between two bodies in contact with one another while they are at rest. It's friction which prevents an object from moving while it is still.

Dynamic or Kinetic friction is friction that opposes the movement of a body which is already in motion.

Differences Between Static and Dynamic Friction

1. The key factor of differentiation between static and kinetic friction is that the static friction acts on a body that is at rest. On the contrary, kinetic friction acts when there is a relative motion of two surfaces.
2. The static friction shows a linear rise up to a maximum value when some external force is applied. While kinetic friction shows invariable nature and remains constant irrespective of the force applied.
3. The magnitude of the coefficient of static friction is comparatively more than that of kinetic friction. Thus, the force of friction that is required to keep the object stable is obviously more than the frictional force which opposes the motion of the object.
4. Static friction is dependent on the magnitude of the force applied while kinetic friction is independent of the magnitude of the force which is applied.
5. Static friction corresponds to the opposition to start a motion whereas kinetic friction is the opposition offered to something which is already in motion.
6. The value of static friction can be zero but the value of kinetic friction can never be zero.

Free Body Diagram (FBD) is simplified representation in a problem of an object (the body), and the force vectors acting on it. This body is free because the diagram will show it without its surroundings; i.e. the body is 'free' of its environment.



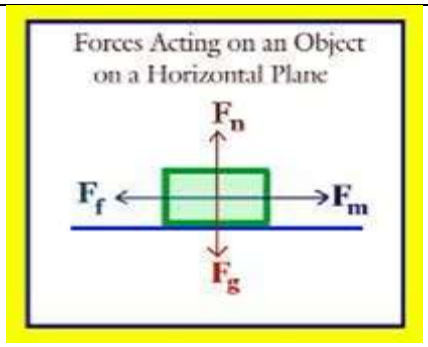


Figure 1: Free body diagram

FBD of inclined plane FBD of Horizontal plane

Activity 2: Guided Practice

Task 9:

Read the scenario below and then answer related questions.

Scenario: The free body diagram

A 15 kg box is placed on a smooth inclined plane that makes an angle of 35° with the horizontal. The box is connected to a 10 kg weight hanging vertically off the edge of the incline by a rope passing over a pulley. Assume the plane is frictionless, and the rope and pulley are ideal (massless and frictionless).

1. What forces are acting on the box on the incline? Include gravity, tension, and the normal force.
2. What forces are acting on the hanging weight?
3. Draw a free-body diagram for the box on the incline. Label the gravitational force (F_g), the normal force (F_N), and the tension force (T).
4. Draw a separate free-body diagram for the hanging weight, showing the gravitational force and the tension force.
5. Refer to the key facts 1.1a for more clarifications

Key Facts 1.3b

Motion of suspended object

Weight of suspended object is the force with which the body is attracted towards the centre of earth. Weight is equal to the product of mass and acceleration due to gravity. $W = mg$

Tension force: Tension force is the force that is transmitted through a string, rope, cable, or any other type of flexible connector when it is pulled tight by forces acting from opposite ends. This force is directed along the length of the connector and pulls equally on the objects at both ends. Essentially, it's the force that keeps the connector taut and prevents it from sagging or breaking under the load.

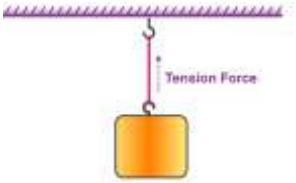


Figure 2: Tension force

Free body diagram on suspended objects

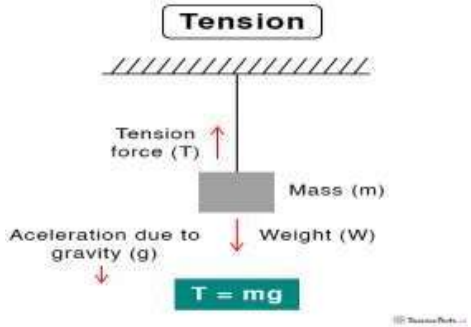


Figure 3: Free body diagram on suspended objects

Rocket motion

Rocket motion is based on Newton's third law, which states that "for every action there is an equal and opposite reaction". Hot gases are exhausted through a nozzle of the rocket and produce the action force. The reaction force acting in the opposite direction is called the thrust force.[3]

- ✓ **Thrust** is the force which moves the rocket through the air, and through space.

[3] https://byjus.com/physics/rocket-propulsion/

Thrust is generated by the propulsion system of the rocket through the application of Newton's third law of motion

- ✓ **Air resistance, which is also known as drag,** is a kind of friction (a force that opposes motion) which occurs between air and another object. It is the force that the object experiences as it passes through the air.
- ✓ **Free body diagram on a rocket**

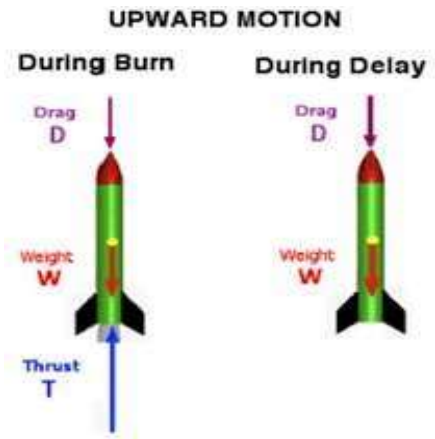


Figure 4: Rocket in motion

Activity 3: Application

Task 10:

Read carefully the following statements and answer related questions

1. Sarah is sitting on a swing in the park. She pushes her feet off the ground and starts moving back and forth. Why does Sarah on the swing move back and forth when she pushes off the ground?
2. Tom accidentally bumps the clock and the pendulum swings more widely than before. After a moment, it returns to its usual motion. What happens to the motion of the pendulum if it is disturbed or displaced?

Formative Assessment of learning unit one

1. Which of the following is example of contact force?

    a. Magnet attract iron nails

    b. Earth moving around the sun

    c. Person pushing a wheelbarrow

    d. Moon orbiting the earth

2. A boy pushes against the wall with 50 Newton of force. The wall does not move. The resultant force is

    i. -50 Newton

    ii. 100 Newton

    iii. 0 Newton

    iv. -75 Newton

3. Which of Newton's laws best explains why motorists should buckle-up?

    a. The first law

    b. The second law

    c. The third law

    d. The law of gravitation

4. A net force F accelerates a mass m with an acceleration a. If the same net force is applied to mass 2m, then the acceleration will be

    a. 4a

    b. 2a

    c. a/2

    d. a/4

5. a. State at least four importance of friction force in real life

    b. A worker exerts a force of 400N on a large cardboard of mass 75.0kg with a coefficient of kinetic friction of 0.520.

    i. Find the magnitude of force of friction.

    ii. Calculate the net force moving the cardboard

6. On take-off, the thrust on a rocket of mass 8000 kg is 200,000 N. Find the acceleration of the rocket.
7. Define friction force and state its SI Unit
8. Differentiate types of force and give an example for each
9. A motorboat of 40kg starting from rest on a lake accelerates in straight line. It travels a distance of 96 m in 8 sec.
   i. Calculate it acceleration.
   ii. By applying Newton's 2 nd law of motion, calculate the force of the motorboat.
10. State newton's laws of motion
11. A force of 25 N just limits the motion of a block of mass 50 kg which is being dragged on the horizontal ground. Calculate the coefficient of static friction force.
12. Which of the following statements correctly describes one of the four fundamental forces of nature?

    a) The electromagnetic force is responsible for the attraction between protons and neutrons in an atomic nucleus.
    b) The strong nuclear force is the weakest force and operates over long distances.
    c) The weak nuclear force is responsible for radioactive decay and operates at very short ranges.
    d) Gravity is the strongest of the four fundamental forces but acts only on large masses.

13. The weight of a person in an elevator at rest is 500 N. Acceleration due to gravity is 10 m/s2. When lift accelerates, the tension force is 750 N.
    a) Find the mass of the person
    b) What is the acceleration of lift?
14. The normal force and static frictional force of an object are 50N and 80N respectively. Find the coefficient of static friction.
15. A book is at rest on tabletop. Draw the forces acting on the book.

Points to Remember

- Force is a pull or push upon an object resulting from the object's interaction with another object.
- The types of forces are contact force and non-contact force.
- Static friction is friction that occurs between two bodies in contact with one another while theyare at rest
- Dynamic or Kinetic friction is friction that opposes the movement of a body which is already in motion.
- Free body diagrams are simplified representations in a problem of anobject (the body), and the force vectors acting on it.

Self-Reflection

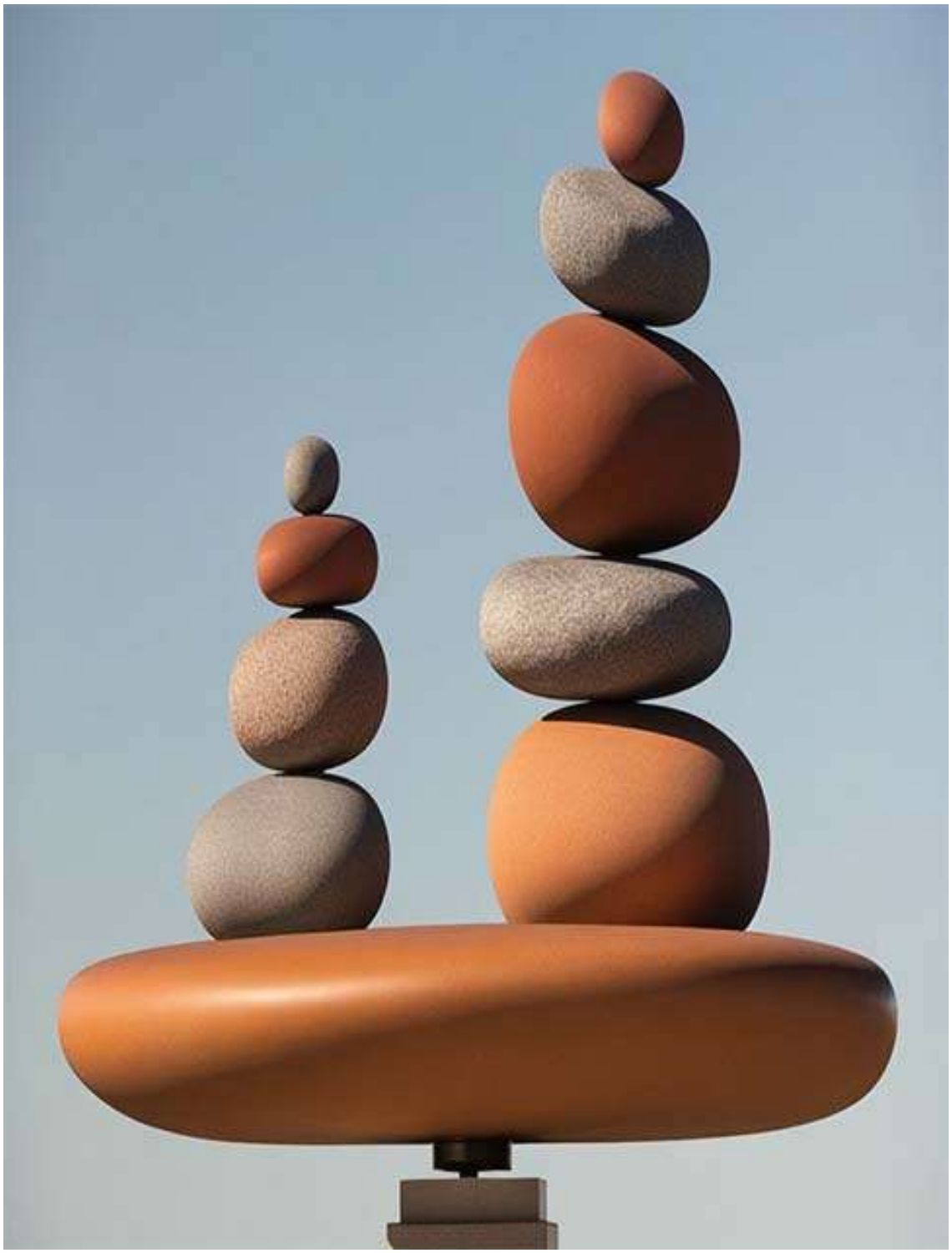
1. Read the statements across the top. Put a check in a column that best represents your level of knowledge, skills and attitudes.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience of doing this.	I have a lot of experience with this.	I am confident in my ability to do this.

2. Fill in the table above and share results with the trainer for further guidance.

Areas of strength	Areas for improvement	Actions to be taken to improve
1. **2.**	**1.** **2.**	**1.** **2.**

3.	**3.**	**3.**



Unit summary

This unit provides you with the knowledge, skills and attitudes required to static equilibrium and elasticity required to apply mechanics and properties of matter. It covers explanation of equilibrium conditions, Application of static equilibrium and Application of elastic properties.

Self-Assessment: Unit 2

1. Study the unit illustration above and answer the following questions.
   a) What do you see in the illustration?
   b) What topics do you think will be covered under this unit based on the illustration?
2. Fill in and complete the self-assessment table below to assess your level of knowledge, skills and attitudes under this unit.

ii. There is no right or wrong ways to answer this assessment. It is for your own reference and self-reflection on the knowledge, skills and attitudes acquisition during the learning process.

iii. Think about yourself: do you think you have the knowledge, skills or attitudes to do this? How well?

iv. Read the statements across the top. Put a check in column that best represents your level of knowledge, skills or attitudes.

3. At the end of this unit, you will assess yourself again.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Key terms moment of force, elasticity, centre of gravity					
Identify conditions of equilibrium					
Describe static equilibrium on horizontal beam					
Identify forces acted on slope					
Describe elastic properties					

Key Competencies:

Knowledge	Skills	Attitudes
1. Key terms moment of force, elasticity, centre of gravity	1. Being able to Solve problems related to moment of force and centre of gravity	1. Having Curiosity, Attention to Detail and critical thinking
2. Identify conditions of equilibrium	2. Being able to solve problems related to conditions of equilibrium	2. Being attentive to detail, critical thinking, and open-minded
3. Describe static equilibrium on horizontal beam	3. Having a strong understanding of conceptual knowledge, analytical thinking, and problem-solving skills	3. Being characterized by critical thinking, collaboration, and responsibility.
4.Identify forces acted on slope	4. Having Conceptual Understanding, Analytical Thinking and Problem-Solving	4. Having Critical Thinking, Logical Reasoning, Patience
5.Describe elastic properties	5. Being able to Solve problems related to elastic properties and Applying Relevant Concepts	5. Being attentive to detail, logical in reasoning, and open-minded

Discovery activity:

Task 11:

Read the scenario below and then answer related questions.

Scenario

One sunny afternoon, Liam and Zoe were playing with a seesaw at the park. Liam, who was older and heavier, sat on one side, and Zoe, being lighter, sat on the other. The seesaw tipped down on Liam's side, leaving Zoe stuck in the air.

Zoe tried to figure out what to do. She scooted farther away from the middle while Liam stayed closer to the center. To their surprise, the seesaw slowly started to level out until they were perfectly balanced and could play together!

1. Why do you think the seesaw became balanced when Zoe moved farther away from the center?
2. What do you think is important to make the seesaw balance?

Topic 2.1: Explanation of equilibrium conditions

Activity 1: Problem Solving

Task 12:

Read the scenario below and then answer related questions.

Consider a uniform meterstick (1 meter long) is placed horizontally on a table. The meterstick has a weight of 1 N, and it is supported at its center, where the fulcrum is located. There are two additional forces acting on the meterstick. A 2 N weight is placed 20 cm from the left end, and a 3 N weight is placed 40 cm from the left end.

Questions:

1. What are the conditions of equilibrium for this system?
2. Is the meterstick in rotational equilibrium? Why or why not?
3. Is the meterstick in translational equilibrium? Explain.

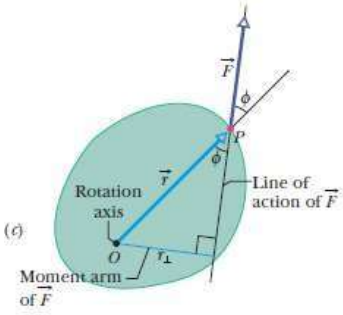
Key Facts 2.1a: Moment of the force

Moment of the force or torque

The Moment of a force is **a measure of its tendency to cause a body to rotate about a specific point or axis.**

Torque is a **measure of the force that can cause an object to rotate about an axis**. Just as force is what causes an object to accelerate in linear kinematics, torque is what causes an object to acquire angular acceleration.

The moment of a force, or the torque, about an axis of rotation is equal to the product of the magnitude of the force and the perpendicular distance of the line of action of the force from the axis of rotation.



Torque $\vec{\tau} = \vec{r}x\vec{F}$

Magnitude of torque: $|\tau| = rxFsin\theta$

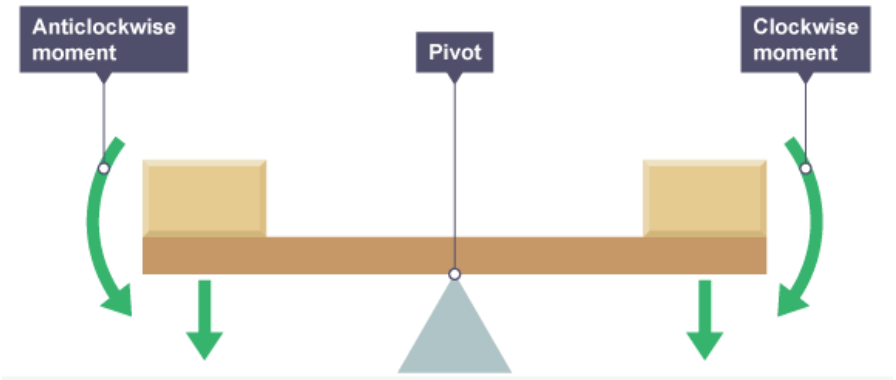


Figure 5: Turning effect

Principle of moment of force

- ✓ The Principle of Moments states that when a body is balanced, the total clockwise moment of a point equals the total anticlockwise moment about the same point. Equation. Moment = force F x perpendicular distance from the pivot r. Moment = Fr.
- ✓ The state in which a system is stable and at rest is called static equilibrium.
- ✓ Rotational equilibrium is state in which net torque is equal to zero.
- ✓ Transitional equilibrium is a state in which the net force is equal to zero.

Example:

1. Find the moment of force about an axis of rotation at distance 40cm from the force of 25N

Answer

Formula : $\boldsymbol{\tau = F \times d}$ $\boldsymbol{then}$ $\boldsymbol{\tau = 25N \times 0.4m}$**=10Nm**

2. Two forces are applied to a doorknob, perpendicular to the door. The first force is twice as large as the second force. The ratio of the torque of the first to the torque of the second is

a. 1/4.

b. 1/2.

c. 2.

d. 4

Answer is c

Necessary conditions for equilibrium of an object

- ✓ The first condition necessary to achieve static equilibrium is the one already mentioned: the net external force on the system must be zero. Expressed as an equation, this is simply, $\sum \boldsymbol{F} = \boldsymbol{0}$ ($\sum \boldsymbol{F_x} = \boldsymbol{0}$ ***and*** $\sum \boldsymbol{F_y} = \boldsymbol{0}$). Note that if net F is zero, then the net external force in any direction is zero.
- ✓ Second condition of static equilibrium must be satisfied to ensure that an object remains in static equilibrium, the net torque acting upon the object must also be zero. $\sum \boldsymbol{\tau} = \boldsymbol{0}$ ($\sum \boldsymbol{\tau_x} = \boldsymbol{0}$ ***and*** $\sum \boldsymbol{\tau_y} = \boldsymbol{0}$)



Activity 2: Guided Practice



Task 13:

Solve the following questions

1. A 40 N force is applied at a distance of 0.6 m from a fulcrum at an angle of 45◦c. What is the moment of force?
2. A 5 m long bar weighs 50 N and a 100 N weight is placed 2 m from the fulcrum. What is the total moment about the fulcrum?

Key Facts 2.1b: Centre of gravity

Center of gravity is the average location of weight of an object.

- ✓ It is also a geometric property of an object.
- ✓ It is also an important concept in determining stability of an object.

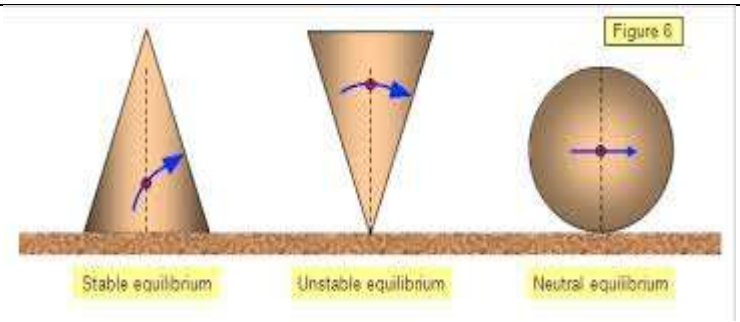


Figure 6:Stable neutral and unstable equilibrium

Determination of center of gravity

✓ The center of gravity of an object is calculated by taking of its moments divided by overall weight of the object.

✓ The moment is the product of weight and its location as measured from set point called the origin.

$$CG = \frac{W_1 d_1 + W_2 d_2 + W_3 d_3 + \cdots}{W}$$

Where $\boldsymbol{W_1}$, $\boldsymbol{W_2}$, and $\boldsymbol{W_3}$ are weight of object 1, 2, 3, respectively, $\boldsymbol{d_1}$, $\boldsymbol{d_2}$, and $\boldsymbol{d_3}$ are distance from origin to object 1, 2, 3 respectively, and $\boldsymbol{W}$ is total weight.

Activity 3: Application

Task 14:

Read carefully the following statements and answer the related questions

1. Consider you're on a small fishing boat. Everyone suddenly moves to one side to take a photo. How do equilibrium principles keep boats and ships stable in water despite uneven loads?
2. Consider a suspension bridge connecting two cities across a river. It is late afternoon, and the bridge is filled with traffic, including trucks, buses, and cars, all concentrated on one side due to a temporary lane closure. How is equilibrium applied in the design of bridges to ensure stability under different loads?

Topic 2.2: Application of Static equilibrium

Activity 1: Problem Solving

Task 15:

Read the following scenario and answer the related questions

Scenario

Consider a uniform beam of length 4 meters and weight 200 N. The beam is resting horizontally on two supports: one at each end. A person of weight 600 N is standing at the midpoint of the beam.

1. What are the two primary conditions for the beam to be in static equilibrium?
2. What forces are acting on the beam? Identify the direction and point of application for each force.
3. What is the condition for **vertical equilibrium** of the beam?
4. What is the condition for the beam to be in **rotational equilibrium**? Explain how this applies to the forces acting on the beam

Key Facts 2.2a: Standing on horizontal beam

A horizontal beam is always horizontal and has a constant cross-section. In addition to common beam parameters, beam has the following properties: Direction. A horizontal beam may be oriented either along the global X-axis or global Y-axis

A seesaw consisting of uniform board of mass M, and length l, supports at rest a father and daughter with masses m_f and m_d respectively as shown in the following figure.

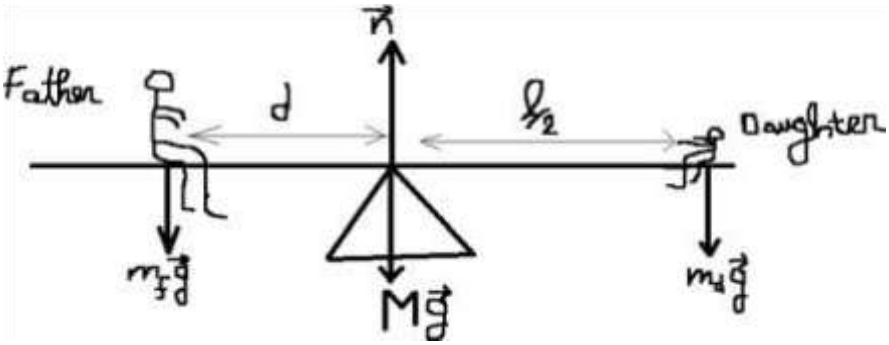


Figure 7: Seesaw

The support (called fulcrum) is under the center of gravity of board, the father is a distance d, from the center and daughter is distance l/2 from the center.

1. Determine the magnitude of the upward force $\vec{n}$ exerted by the support on the board.
2. Determine where the father should sit to balance the system at rest.

Answer:

a) Apply the 1st condition for equilibrium, $\sum F_{ext} = 0$

$$\vec{n} - m_f\ \vec{g} - M\vec{g} - m_d\ \vec{g} = 0$$

$$\vec{n} = m_f\ \vec{g} + M\vec{g} + m_d\ \vec{g}$$

$$\vec{n} = (m_f\ + M + m_d\ )\ \vec{g}$$

b) Apply 2nd condition for equilibrium, $\sum \tau_{ext} = 0$

$$(m_f\ \vec{g})d - (m_d\ \vec{g})\frac{l}{2} = 0$$

$$(m_f\ \vec{g})d = (m_d\ \vec{g})\frac{l}{2}$$

$$d = \left(\frac{m_d\ \vec{g}}{m_f\ \vec{g}}\right)\frac{l}{2}$$

$$d = \left(\frac{m_d}{m_f}\right)\frac{l}{2}$$

Activity 2: Guided Practice

Task 16:

Read carefully the following statement and answer the related question

A seesaw consisting of a uniform board of mass M =10kg and length l=2m supports a father and daughter with masses mf and md, 50 and 20kg respectively as shown in the Figure. The support (called the fulcrum) is under the centre of gravity of the board. The father is a distance d from the centre, and the daughter is at distance l/2 from the centre. (a) Determine the

magnitude of the upward force (reaction) n exerted by the support on the board. (b) Determine where the father should sit to balance the system.

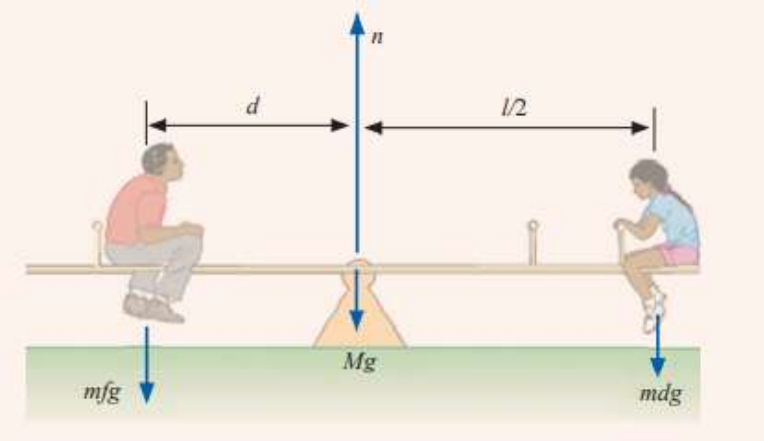


Figure7: A seesaw

Key Facts 2.2b: Standing on a slope

The inclined plane is a problem setting in which a massive object is on a slope, and only subject to motion in the direction down the incline. Although gravity pulls an object straight down, the presence of the slope prevents this.

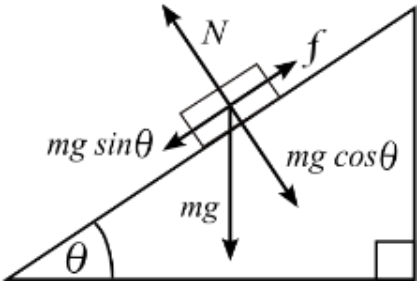


Figure 8: A slope showing applied forces

Horizontal components are f and $mgsin\theta$

Vertical components are: Normal force N and $mgcos\theta$

Determination of horizontal and vertical component

By taking a vector to be analyzed as the hypotenuse, the horizontal and vertical components can be found by completing a right triangle. The bottom edge of the triangle is the horizontal component and the side opposite the angle is the vertical component. The angle that the vector makes the horizontal can be used to calculate the length of the two components.

Examples:

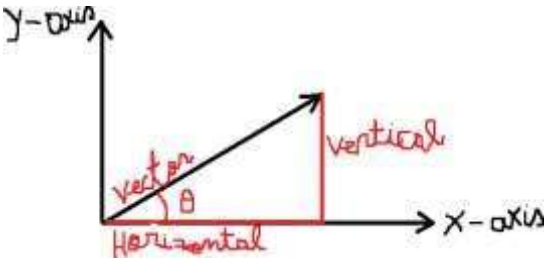


Figure 9: Horizontal and vertical component

1. The force of 120N form an angle Θ with an x-axis as shown in the following

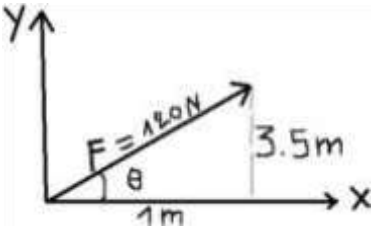


figure:

a. Calculate the angle Θ.
b. Calculate vertical and horizontal components (F_x and F_y)

Answer :

Data : F = 120N, Opposite side of θ =3.5m, adjacent side of θ = 1m

Asked : θ

$$\sin\theta = \frac{opposite\ side\ of\ \theta}{F}$$

$$sin\theta = \frac{3.5m}{F}$$

$$COS\theta = \frac{adjacent\ side\ of\ \theta}{F}$$

$$COS\theta = \frac{1m}{F}$$

$$tan\ \theta = \frac{sin\theta}{cos\theta} = \frac{\frac{3.5m}{F}}{\frac{1m}{F}}$$

$$\tan\theta = \frac{3.5m}{F} \text{X} \frac{1m}{F}$$

$$tan\theta = 3.5$$

$\theta = tan^{-1}$ (3.5)

$\theta = 74^0$

Activity 3: Application

Task 17:

Read carefully the following statements and answer the related questions

1. A person in a wheelchair approaches a building with a steep entrance. To avoid lifting the wheelchair directly upward, a ramp is used. How does the angle of an inclined plane affect the force required to move an object up the ramp?
2. At a warehouse, workers need to load a heavy box onto a truck. Instead of lifting it vertically, they use a ramp. How does the slope of a loading ramp reduce the amount of force needed to lift heavy objects?
3. During heavy rainfall, water flows down the sloped roof of a house. Why are roofs designed with a slope, and how does this help with the flow of water?

Topic 2.3: Application of elastic properties

Activity 1: Problem Solving

Task 18:

Read the scenario below and then answer related questions.

Consider a spring is hanging vertically from a fixed support. A small object weighing 50 N is attached to the free end of the spring, causing it to stretch. Initially, the spring is 20 cm long, but after adding weight, its length increases to 25 cm.

a) What happens to the spring when the object is attached to it?
b) What type of deformation does spring undergo?
c) What is meant by the elastic limit of a spring?
d) What might happen to the spring if the object is too heavy?

Key Facts 2.3a: Deformation of solids in terms of the concepts of stress and strain

Stress and Strain are the two terms in Physics that describe the forces causing the deformation of the objects. Deformation is known as the change of the shape of an object by applications of force.

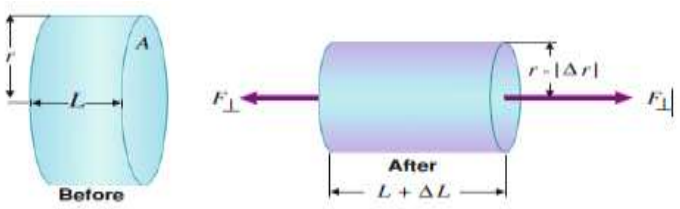


Figure 10: Tensile stress and strain

What is the relation between stress and strain?

The relation between stress and strain is that they are directly proportional to each other up to an elastic limit. ... According to Hooke's law, the strain in a solid is proportional to the applied stress and this should be within the elastic limit of that solid.

Table 1: Stress vs strain

Stress	Strain
Stress is the restoring or deforming force per unit area.	Strain is the change in shape per original shape
Its formula is $\sigma = \frac{F}{A}$	Its formula is $\epsilon = \frac{\Delta L}{L}$
Its unit is N/m^2	It has no unit

Activity 2: Guided Practice

Task 19:

Solve the following questions

1. A string 4 mm in diameter has original length 2 m. The string is pulled by a force of 200 N. If the final length of the spring is 2.02 m, determine: (a) stress (b) strain (c) Young's modulus
2. A metal cube of side 0.20 m is subjected to a shearing force of 4000 N. The top surface is displaced through 0.50 cm with respect to the bottom. Calculate the shear modulus of elasticity of the metal.
3. A metallic cube of side 100 cm is subjected to a uniform force acting normal to the whole surface of the cube. The pressure is 10^6 pascals. If the volume changes by 1.5×10^{-5} m^3, calculate the bulk modulus of the material.

Key Facts 2.3b: Types of deformation and elastic modulus

Three types of deformation and elastic modulus for each.

Young's modulus: is the elastic modulus for tensile stress. It is denoted as Y. Young's modulus is a ratio of tensile stress to tensile strain.

$$Y = \frac{\textbf{Tensile stress}}{\textbf{Tensile strain}} = \frac{\frac{F}{A}}{\frac{\Delta L}{L_0}} = \frac{F}{A} \times \frac{L_0}{\Delta L}$$

Where A is area, ΔL is change in length, F is deforming force, L_0 is initial length.

Bulk modulus: is the elastic modulus for bulk stress, it is denoted by B. It is a ratio of bulk stress to bulk strain.

$$\textbf{Bulk strain} = \frac{\Delta V}{V_0}$$

The bulk strain results from stress which is a force F normal to the surface that pressure on unit surface area A of submerged object. This kind of physical quantity, or pressure(P) is defined as,

$$\textbf{Pressure} = \frac{F}{A}$$

Then, $\boldsymbol{B} = \frac{\boldsymbol{Bulk\ stress}}{\boldsymbol{Bulk\ strain}} = \frac{\Delta \boldsymbol{P}}{\frac{\Delta V}{V_0}} = -\Delta \boldsymbol{P}\frac{\boldsymbol{V_0}}{\Delta V}$

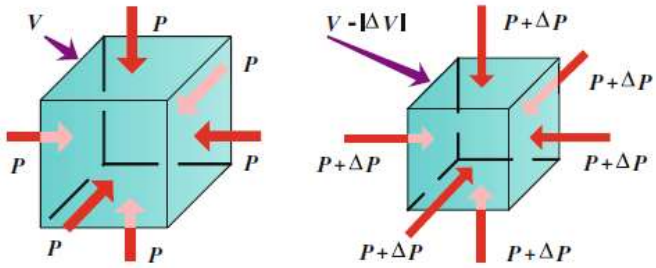


Figure 11: Bulk modulus

Note:

The minus sign (-) in this equation is for consistency, to ensure that B is positive quantity. Note that minus sign (-) is necessary because an increase $\Delta \boldsymbol{P}$ in pressure (positive quantity) always causes a decrease ΔV in volume and decrease in volume is a negative quantity.

The reciprocal of the bulk modulus is called compressibility, K or,

$$\boldsymbol{K} = \frac{\boldsymbol{1}}{\boldsymbol{B}} = -\frac{\frac{\Delta \boldsymbol{V}}{\boldsymbol{V_0}}}{\Delta \boldsymbol{P}} = -\frac{\Delta \boldsymbol{V}}{\Delta \boldsymbol{P}\boldsymbol{V_0}}$$

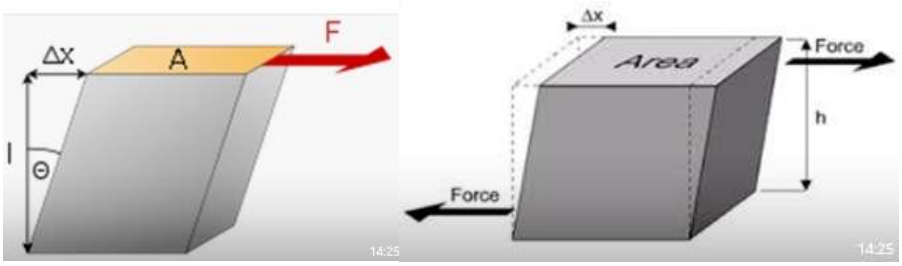
The term compressibility is used in relation to fluids (gas and liquid).

Compressibility is the change in volume of fluid per unit increase in pressure.

Shear modulus: It is a ratio of shear stress to shear strain and is denoted as S.

$$\boldsymbol{Shear\ strain} = \frac{\Delta \boldsymbol{X}}{\boldsymbol{L_0}}$$

$$\boldsymbol{Shear\ stress} = \frac{\boldsymbol{F}}{\boldsymbol{A}}$$



The shear stress is due to the force parallel to the surface F

$$\boldsymbol{S} = \frac{\frac{\boldsymbol{F}}{\boldsymbol{A}}}{\frac{\Delta \boldsymbol{X}}{\boldsymbol{L_0}}} = \frac{\boldsymbol{F}}{\boldsymbol{A}} \times \frac{\boldsymbol{L_0}}{\Delta \boldsymbol{X}}$$

Stress versus strain curve for an elastic solid.

When we study solids and their mechanical properties, information regarding their elastic properties is most important. We can learn about the elastic properties of materials by studying the stress-strain relationships under different leads in these materials. The

Material's stress-strain curve gives its stress-strain relationship. In stress-strain curve, the stress and its corresponding strain values are plotted.

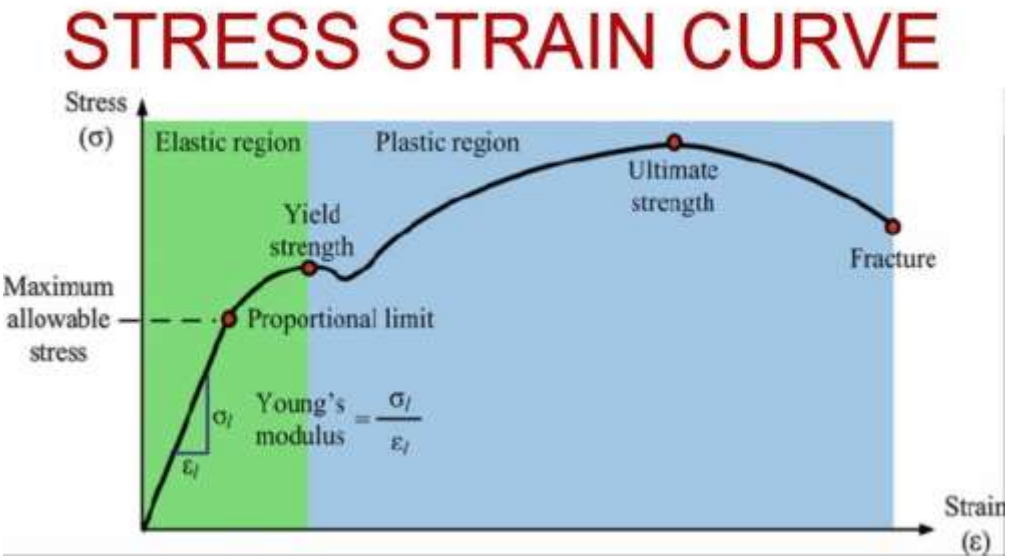


Figure 12: Stress vs strain curve

Activity 3: Application

Task 20:

Read carefully the following statements and answer the related question

1. Consider you have a long steel rod. When you apply a force to stretch it, the rod elongates slightly. After you remove the force, the rod returns to its original length. What property of the steel rod determines how much it stretches under a certain?
2. Consider you are pushing a heavy box across a wooden floor. As you apply force to the box, the box's bottom layer of material (and the floor underneath it) experiences shear deformation, with the materials sliding slightly against each other. What would happen if you were pushing the box on a different surface, like ice, where the shear modulus is much lower?

3. You take a rubber balloon and apply pressure to it. The balloon's volume decreases, but when you stop applying pressure, it returns to its original size. How does the balloon respond to pressure, and what property is responsible for its resistance to volume change?

Formative Assessment for learning outcome two

1. Strain is defined as the ratio of
   i. Change in volume to original length
   ii. Change in length to original volume
   iii. Change in cross-sectional area to original cross-sectional area
   iv. All the above
   v. None of the above
2. In the volumetric strain, the deforming force produces a change in
   i. Length
   ii. Volume
3. Upon the removal of a deforming force, the inability of the body to regain its original shape and size is known as
   i. Plasticity
   ii. Undeformation
   iii. Elasticity
   iv. Hook's constant
   v. All the above
4. A mass of 50 kg is suspended from a steel wire of diameter 1.0 mm and length 11.2 m. How much will the wire stretch? The Young's modulus for steel is $20x10^{10}$ N/m^2
5. A shear force of 400 N is applied to one face of an aluminum cube with sides of 30 cm. What is the resulting relative displacement? (The shear modulus for aluminum is $2.5x10^{10}$ N/m^2)
6. Match each of the term (column A) with its meaning (column B)

Column A	Column B
a) Stress	i) It is a measure of its tendency to cause a body to rotate about a specific point or axis.
b) Rotational equilibrium	ii) The measure of how much an object is stretched or deformed and it occurs when force is applied to an object

c) Strain	iii)It is defined as the state of a system for which the total angular acceleration is zero
d) Moment of force	iv)The force acting on the unit area of a material

7. Define the following terms as used in Physics

a) Elastic deformation

b) Young's modulus

8. How do you know if the object is in static equilibrium?

9. How can you find a centre of gravity of a rectangle lamina?

10. A uniform seesaw of length 4.0 m and mass 10 kg is supported at its center (the pivot). Two children, Aline (mass 30 kg) and Ben (mass 40 kg), sit on the seesaw. Aline sits 1.2 m to the left of the pivot, and Ben sits 1.0 m to the right.

a) Calculate the position d from the pivot where a third child, Carol (mass 20 kg), should sit to balance the seesaw.

b) If Carol is sitting at 1.5 m to the right of the pivot instead, calculate the net torque on the seesaw. State the direction of the rotation.

11. A metal rod with a cross-sectional area of 1×10^{-4} m is subjected to a tensile force of 5000N. If the rod stretches by 2×10^{-3}m under this load, calculate the stress



Points to Remember

- Elasticity is the property by virtue of which a body tends to regain its original shape and size after removal of the deforming force is known as elasticity
- Bodies, which completely regain their original size and shape after the removal of the deforming force, are called elastic bodies.
- Bodies which change the shape and size on the application of force and which do not regain their original condition on removal of the deforming forces are said to be plastic bodies.
- Bodies which do not change their shape and size on application of force are called rigid bodies.

- The stress is defined as the restoring force acting on unit area
- Strain is a measure of the degree of deformation of the object

Self-Reflection

1. Read the statements across the top. Put a check in a column that best represents your level of knowledge, skills and attitudes.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience of doing this.	I have a lot of experience with this.	I am confident in my ability to do this.

2. Fill in the table above and share results with the trainer for further guidance.

Areas of strength	Areas for improvement	Actions to be taken to improve
1. **2.** **3.**	**1.** **2.** **3.**	**1.** **2.** **3.**


Duran
50 ml
Duran
50 ml

Unit summary
This unit provides you with the knowledge, skills and attitudes required to Analyze fluid mechanics required to apply mechanics and properties of matter. It covers the Description of Pressure and its variation with depth, Application of Archimedes' principle and Analyzing Fluid dynamics.

Self-Assessment: Unit 3

1. Study the unit illustration above and answer the following questions.
   a. What do you see in the illustration?
   b. What topics do you think will be covered under this unit based on the illustration?
2. Fill in and complete the self-assessment table below to assess your level of knowledge, skills and attitudes under this unit.
   a) There is no right or wrong ways to answer this assessment.
   b) It is for your own reference and self-reflection on the knowledge, skills and attitudes acquisition during the learning process.
   c) Think about yourself: do you think you have the knowledge, skills or attitudes to do this? How well?
   d) Read the statements across the top. Put a check in column that best represents your level of knowledge, skills or attitudes.
3. At the end of this unit, you will assess yourself again.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Analyzing pressure, velocity, and flow rate distributions in various systems					

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
List the applications of fluid mechanics					
Designing and analyzing hydraulic systems or pipelines					
Interpreting streamline patterns.					
Applying theoretical knowledge to solve real-world fluid mechanics problems					
Staying updated on advancements in fluid mechanics					
Detail-oriented when performing calculations					
Detail-oriented when performing calculations					

Key Competencies:

Knowledge	Skills	Attitudes
1. Key terms definition: fluid, flow rate pressure, buoyancy force, viscosity	**1.** Being able to analyze g pressure, velocity, and flow rate distributions in various systems	**1.** **Having curiosity** curiosity on demonstration
2. State pascal principle	**2.** Being able to design and analyze hydraulic systems or pipelines	**2.** Being able to stay updated on advancements in fluid mechanics
3. State Archimedes principle	**3.** Having the ability to solve fluid mechanics equations	**3.** Having a detail-oriented attitude when performing calculations ensures accuracy and precision in the results
4. State Bernoulli's principle	**4.** Having the ability to interpret streamline patterns	**4.** Having a critical thinking
5. List the applications of fluid mechanics	**5.** Being able to apply theoretical knowledge to solve real-world fluid mechanics problems.	5.Having a systemic thinking

Discovery activity:

Task 21:

Read the following statements and answer the following questions

1. You are designing a water supply system for a residential building. The water flows through a network of pipes from a storage tank to various outlets.
2. A pipeline transports oil from a refinery to a storage facility. You need to ensure the system operates efficiently.

Questions

1. What factors will affect the flow rate of water in the pipes?
2. How can you ensure the water pressure is sufficient at all outlets?
3. What might happen if the pipes are too narrow or too wide?
4. How does the viscosity of oil affect the energy needed to pump it?
5. What factors could lead to pressure losses along the pipeline?
6. How can you determine if the flow is laminar or turbulent in the pipeline?

Topic 3.1: Description of Pressure and its variation with depth

Activity 1: Problem Solving

Task 22:

Read carefully the following scenario and answer the questions that follow.

A submarine is conducting research in the ocean. At a depth of 500 meters, the submarine experiences significant pressure due to the surrounding water. The crew is analyzing how pressure varies with depth and its implications for the submarine's structure.

1. What is pressure, and how is it calculated in a fluid at a certain depth?
2. How does the density of the fluid influence the pressure exerted at depth?
3. Why does pressure increase with depth in a liquid but not in a gas to the same extent?
4. How is the pressure at a depth of 500 meters in seawater different from the pressure at the same depth in freshwater?

5. How does increasing pressure at greater depths impact the materials used to construct the submarine?
6. Why must submarines be designed to withstand both internal and external pressure differences?
7. If the density of seawater changes due to temperature or salinity, how would that affect the pressure at 500 meters?

Key Facts 3.1a: Pressure

Pressure is perpendicular force per unit area. It is a stress at point within confined fluid. The SI unit of pressure is Pascal (Pa) or $\boldsymbol{Nm^{-2}}$.

Pressure in fluid

Fluids are substances that have no fixed shape and yield easily to external pressure. It is a substance that flows. Both gases and liquids are fluids. Fluids play a vital role in many aspects of everyday life. We drink them, breathe them, swim in them. They circulate through our bodies and control our weather. Airplanes fly through them; ships float in them.

Force and pressure

Force is the pull or push action resulting in acceleration of an object.
Pressure is a force acting upon a certain area and acted upon something perpendicular to its surface. $\boldsymbol{P = \frac{F}{A}}$, Where P is pressure, F is force, and A is area.

Difference between force and pressure

Force	**Pressure**
Force is a pull or push action resulting in acceleration of an object.	Pressure is a force acting upon a certain area and acted upon something perpendicular to its Surface
Its SI unit is Newton (N)	Its SI unit is Pascal (Pa)
Instrument used to measure force is called Dynamometer	We use a manometer to measure pressure in liquids and a barometer to measure air pressure.
Force is a vector quantity which means that has direction	Pressure is scalar quantity which means that no direction
Force can be acted upon the face, side, edges or vertices of the objects	Pressure only acts on surface or face of object.
Force changes the speed and direction of an object.	Pressure cannot change the speed and direction of an object

The instrument used to measure the pressure in fluid is called **Manometer**.

Manometer is a U-tube device used to measure pressure.

Variation of pressure with depth

Static fluid pressure

Static fluid, also known as a fluid at rest, refers to a fluid that is not in motion. In this state, the fluid's particles are not moving relative to each other, and there is no shear stresses present within the fluid.

The pressure exerted by a static fluid depends only upon the **depth** of the fluid, the **density** of the fluid, and the **acceleration of gravity**. The pressure in a static fluid arises from the weight of the fluid and is given by the expression:

$\mathbf{P_{staticfluid} = \rho_f gh}$

Where **ρ** is the density of fluid; **g** is acceleration of gravity; and **h** is depth of fluid.

The pressure from the weight of a column of liquid of area A and height h is:

V = hA = volume

Weight = mg

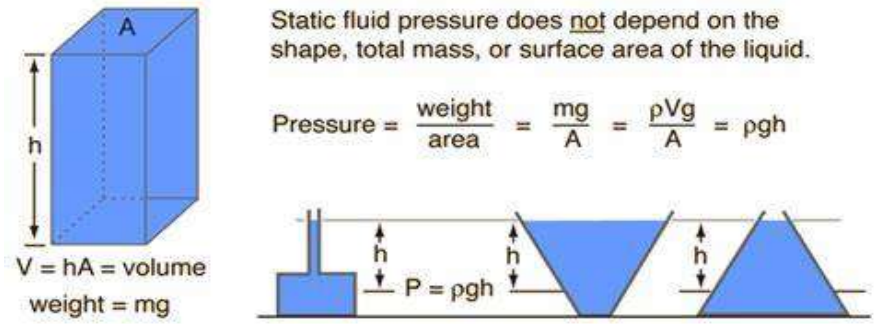


Figure 13: Static fluid pressure

The fluid pressure at a given depth does not depend upon the total mass or total volume of the liquid.

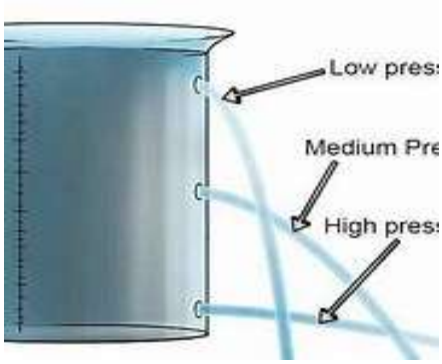


Figure 14: Water squirts further at greater depths

The purpose of the experiment is to demonstrate how **water pressure** increases with depth.



Activity 2: Guided Practice



Task 23:

Solve the following questions

1. A tank of water is filled to a depth 5m. Atmospheric pressure at the surface is 101,325Pa, and the density of water is 1000kg/m^3. Calculate the pressure at the bottom of the tank.
2. A manometer is used to measure the pressure difference between two points in a liquid with a density of 800kg/m^3. The height difference in the manometer columns is 0.4m. Calculate the pressure difference.
3. The dam is 500m wide, and the water is 40.0m deep at the dam.

a. What the average pressure on the dam due to the water?

b. Calculate the force exerted against the dam and compare it with the weight of water in the dam. (weight of water in dam, W = 1.96 × 10^{13}N, density of water, ρ = 10$^3 kg/m^3$)

Key Facts 3.1b: Pressure measurements

Measuring atmospheric pressure

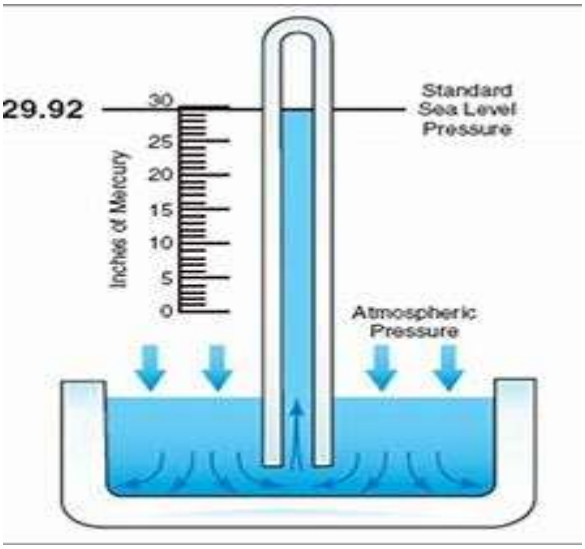


Figure 15: Barometer

The atmospheric pressure is the weight exerted by the overhead mass of air on a unit area of surface. It can be measured with a mercury barometer, consisting of a long glass tube full of mercury inverted over a pool of mercury:

When the tube is inverted over the pool, mercury flows out of the tube, creating a vacuum in the head space, and stabilizes at an equilibrium height, h over the surface of the pool.

The global mean pressure at the surface of the Earth is slightly less than the mean sea-level pressure because of the elevation of land.

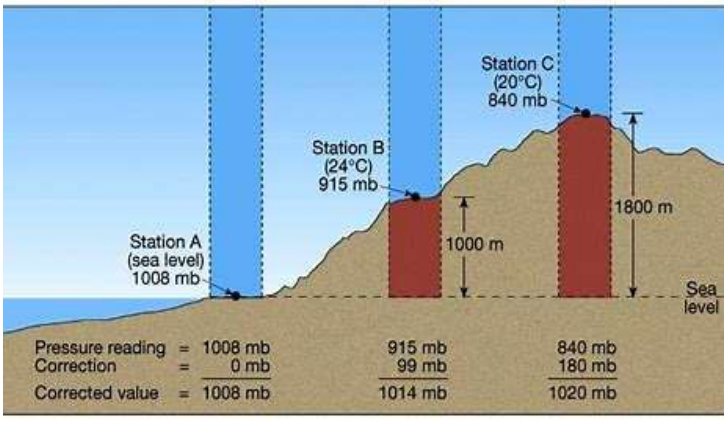


Figure 16: Atmospheric pressure varies

Atmospheric pressure varies with height just as water pressure varies with depth. As a swimmer dives deeper, the water pressure on his/ her increases. As a mountain climber ascends to higher altitudes, the atmospheric pressure on him/her decreases.

Barometric pressure also known as atmospheric pressure describes the weight of the air surrounding the earth.

A simple device for measuring the pressure exerted by a fluid

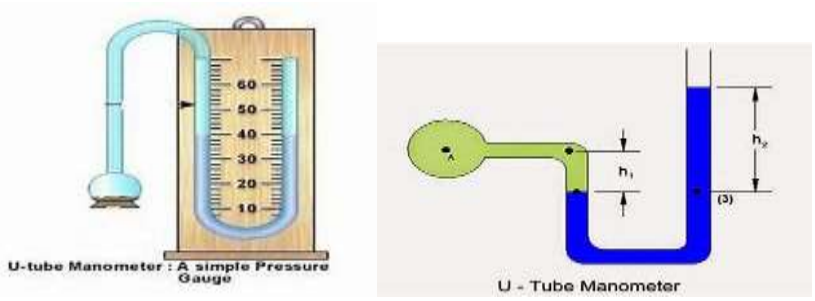


Figure 17: Manometer

A **Manometer** is a device to measure pressures fluid. A common simple **manometer** consists of a U-shaped tube of glass filled with some liquid.

Pascal's principle and its application

In the physical sciences, Pascal's law or Pascal's principle (1647) states that: "pressure applied to an enclosed fluid, is transmitted equally to every part of the fluid."

$\Delta P = \rho . g . \Delta h$

Pascal's Principal calculation

A hydraulic pump is used to lift a car; When a small force F is applied to a small area A of a movable piston it creates a pressure p = F/A. This pressure is transmitted to and acts on a larger movable piston of area A' which is then used to lift a car.

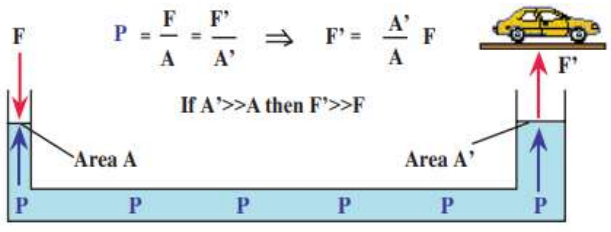


Figure 18: The Hydraulic pump

When a force is applied at one end it is transferred to the other end. From the relation:

$$F = P \times A$$

We see that a small force (thrust) applied at the end with a small area will produce a larger force at the end with the larger area : $F' = P \times A'$

Since pressure equals force per unit area, then it follows that $\frac{F}{A} = \frac{F'}{A'}$

Absolute pressure and gauge pressure

The actual pressure at a given position is called the absolute pressure, and it is measured relative to the absolute vacuum.

Absolute Pressure: Absolute pressure is the total pressure exerted by a fluid, including both atmospheric pressure and any additional pressure created by the fluid itself. It is measured relative to a perfect vacuum, where there is no pressure at all. Absolute pressure is always positive or zero, and it accounts for the pressure of the fluid and the pressure of the atmosphere acting on it. The formula to calculate absolute pressure is:

Absolute Pressure = Gauge Pressure + Atmospheric Pressure[4]

Where:

Gauge Pressure is the pressure measured using a gauge or pressure measuring device.

Atmospheric Pressure is the pressure exerted by the Earth's atmosphere at a given location and altitude. At sea level, standard atmospheric pressure is approximately 101.3 kilopascals (kPa).

For example, if you have a pressure gauge that reads 300 kPa, this is the gauge pressure. To find the absolute pressure at that location, you would add the atmospheric pressure (e.g., 101.3 kPa at sea level) to the gauge pressure:

Absolute Pressure = 300 kPa + 101.3 kPa = 401.3 kPa

So, the absolute pressure at that location is 401.3 kPa.

Gauge Pressure: Gauge pressure, on the other hand, measures the pressure of a fluid relative to the atmospheric pressure at the same location and altitude. Gauge pressure readings do not include the atmospheric pressure, and they can be either positive or negative, depending on whether the fluid pressure is above or below atmospheric pressure. The formula for calculating gauge pressure is:

[4] https://esi-tec.com/news/difference-between-gauge-and-absolute-pressure-measurement/#:~:text=The%20definition%20of%20absolute%20pressure,the%20measurement%20of%20barometric%20pressure.

Gauge Pressure = Absolute Pressure - Atmospheric Pressure

Using the previous example, if the absolute pressure at a location is 401.3 kPa, and the atmospheric pressure is 101.3 kPa, the gauge pressure would be:

Gauge Pressure = 401.3 kPa - 101.3 kPa = 300 kPa

So, the gauge pressure at that location is 300 kPa.

Activity 3: Application

Task 24:

Read carefully the following statements and answer the related questions

1. You are swimming at the bottom of a deep pool. The deeper you go, the harder it becomes to breathe, and you feel more pressure against your body. This pressure is due to the weight of the water above you. The pressure increases the deeper you go because of the weight of the water pushing down on you. Why does water pressure increase the deeper you go in a pool and what is the relationship between the depth of water and the pressure you experience?
2. You are hiking up a mountain, reaching higher altitudes. As you climb, you start to notice that it's harder to breathe, and your ears may pop as you change altitude. This happens because the atmospheric pressure decreases as you ascend. Why does atmospheric pressure decrease as you climb higher in altitude? How does the weight of the air above you affect the atmospheric pressure at different altitudes?

Topic 3.2: Application of Archimedes' principle

Activity 1: Problem Solving

Task 25:

Read the scenario below and answer the question that follows.

A child is playing with a toy boat in a bathtub. The boat is made of plastic and floats on the water's surface. The child places a small metal block inside the boat, and the boat sinks slightly deeper into the water but continues to float.

1. Why does the boat float on the water before the block is added?
2. What happens to the water displaced by the boat when the metal block is placed inside?
3. What factors determine whether an object will float or sink in water?
4. How does the density of the boat compare to the density of water when it is floating?
5. Why does the boat sink deeper into the water when the block is added?
6. What would happen if the block were too heavy for the boat?

Key Facts 3.2a: Buoyant force

Meaning of buoyant force

If you walk in water, you feel water pushing your legs up. If you lift a bucket of water from a tank, the bucket appears to be lighter inside the water and suddenly heavy when it comes out of water.[5]

An object weighs less in water than it does in the air. This loss of weight is due to the upthrust of the water acting upon it and is equal to the weight of the liquid displaced. Buoyancy reduces the apparent weight of objects that have sunk completely to the sea floor. It is generally easier to lift an object up through the water than it is to pull it out of the water.

[5] https://www.britannica.com/science/Archimedes-principle

Buoyancy (also known as the buoyant force) is the force exerted on an object that is wholly or partly immersed in a fluid. The symbol for the magnitude of buoyancy is B or FB Buoyancy is caused by differences in pressure acting on opposite sides of an object immersed in a static fluid.

✓ **Relationship between magnitude of buoyant force and weight of the fluid displaced.**

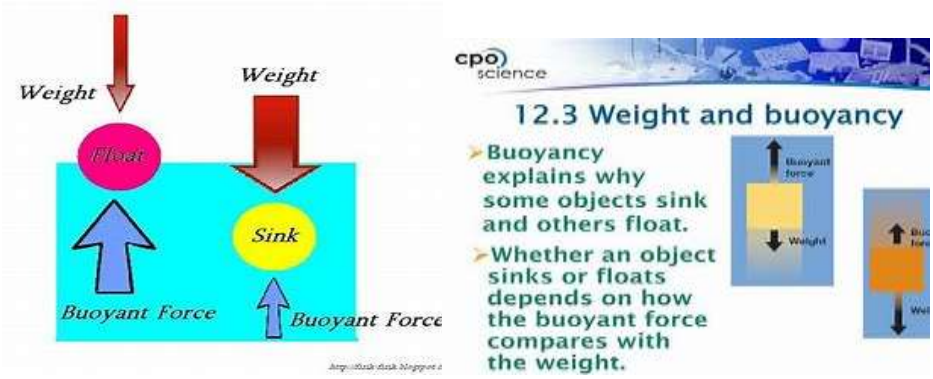


Figure 19: Buoyant force and weight of the fluid

$B = W_f = m_f g = \rho_f g V_{displaced}$, where w_f is the weight of the fluid, mf is the mass of the fluid, ρ_f is the density of fluid and V_{fluid} is the volume of the object.

Thus, among completely submerged objects with equal masses, objects with greater volume have greater buoyancy.

The upward forces against the bottom surface of the object are greater than the downward forces against its top surface. This net force is called the buoyant force. In other words, the "buoyant force" on a submerged body is directed in the opposite direction to gravity and is equal in magnitude.

The net force on the object is thus the sum of the buoyant force and the object's weight:

$F = W + B$

- If the buoyancy of an object exceeds its weight, it tends to rise. $F = B – W$
- An object whose weight exceeds its buoyancy tends to sink. $F = W – B$
- Commonly, the object in question is floating in equilibrium and the sum of the forces on the object is zero, therefore; $F = W – B = 0$

Activity 2: Guided Practice

Task 26:

Solve the following questions

1. A stone has a density of 2.5g/cm3. Will the stone float or sink in water, which has a density of 1.0g/cm3?
2. A wooden block weighs 10N and experiences an upthrust of 12N when placed in water. Determine whether the block floats or sinks.
3. An object has a weight of 15N and experiences an upthrust of 15N when fully submerged in a fluid. Describe the state of the object.

Key Facts 3.2b: Archimedes' principle

The condition for floating is the density of the object, again rho means density, so the density of the object should be smaller than the density of the fluid, in this case, the density of the water. So, if this stone has smaller density than water, it will float, if it has larger density than water, it will sink.

Archimedes' principle states that when an object is totally or partially immersed in a fluid, it experiences an upthrust equal to the weight of the fluid displaced.

Laws of floatation

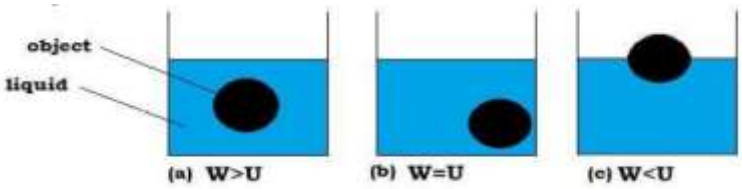


Figure 20: Weight and upthrust force

(a)If the weight of the object, W, is greater than the upthrust, U, i.e. the density of the object is greater than the density of the displaced liquid, the object sinks into the liquid.

(b)If the weight of the object is equal to the upthrust, U, i.e. the density of the object is equal to the density of the displaced liquid, the object remains in equilibrium under the liquid anywhere.

(c)If the weight of the object, W, is less than the upthrust, U, i.e. the density of the object is less than the density of the displaced liquid, the object floats partially in the liquid.

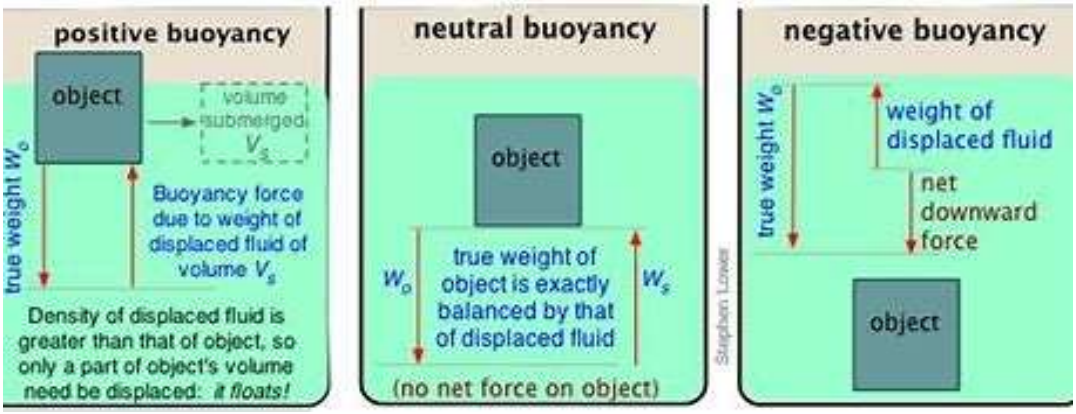


Figure 21: Buoyancy force state

Activity 9: Application

Task 27:

Read the scenario below and answer the related questions

Scenario 1: A stone is dropped into water.

If the weight of the stone is greater than the upthrust, what will happen to the stone? Why?

Scenario 2: A block of wood is placed on water.

If the weight of the wood is less than the upthrust, what will happen to the block?

Scenario 3: A metal cube is placed in a container of mercury.

Mercury is denser than the metal cube. Predict what will happen to the cube and explain why.

Topic 3.3: Analysing Fluid dynamics

Activity 1: Problem Solving

Task 28:

Read carefully the following scenario and answer the questions that follow.

A group of trainees conducts an experiment using two different fluids: honey and water. They pour both fluids down an inclined plane and observe how quickly each fluid flows. They notice that honey flows much more slowly than water, demonstrating that honey has a higher viscosity.

1. What is viscosity, and how does it affect the flow of a fluid?
2. Based on the scenario, which fluid has a higher viscosity: honey or water?
3. How does the viscosity of a fluid impact its behavior when poured on an inclined plane?
4. Can you think of another example where viscosity plays an important role in everyday life?
5. How does temperature affect the viscosity of liquids like honey and water?

Key Facts 3.3a: Viscosity

Viscosity is a measure of fluid's resistance to flow. It is a resistance of fluid (liquid or gas) to change in shape or movement of neighboring portions relative to one another.

- ✓ Steady flow/ laminar flow: The velocity of fluid at each point remains constant in time. The particles move in straight line.



Figure 22: Steady flow/ laminar flow

- ✓ Unsteady flow/ Turbulent flow: Particles unlike straight line in their motion. It is irregularflow of particles.

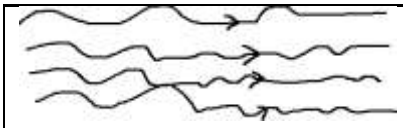


Figure 23: Unsteady flow/ Turbulent flow

- ✓ Incompressible flow: Density of fluid remains constant
- ✓ Irrational flow: The motion of particles is in circular path but the rotation is not about theaxis. There is no turbulence.
- ✓ Turbulence: Instability or disturbance
- ✓ Non-viscous flow: No fluid friction.
- ✓ Equation of continuity for fluids: It states that in the case of steady flow, the amount of fluid flowing past one point must be the same as the amount of fluid flowing past another, or mass flow rate is constant. $\boldsymbol{\rho_1 A_1 V_1 = \rho_2 A_2 V_2}$ Where $\boldsymbol{\rho}$ is density, $\boldsymbol{A}$ is cross sectional area, $\boldsymbol{V}$ is flow velocity of fluid, one and two indicate two different regions.

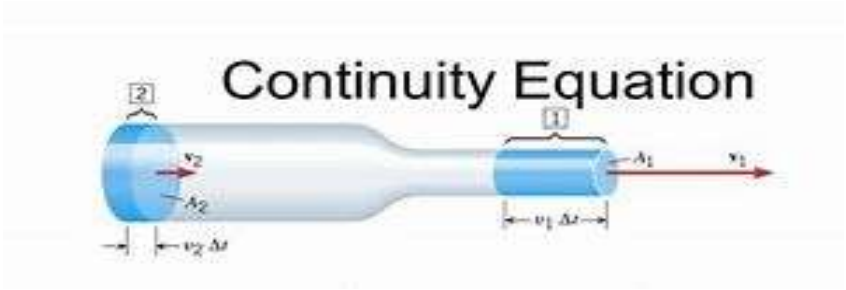


Figure 24: equation of continuity

$\boldsymbol{A_1 V_1 = A_2 V_2}$

Example1:

Suppose water is flowing through the pipe of diameter 1cm with flow velocity of $2\,m/s$. If the pipe widens to a diameter of 3cm, what is the new flow rate?

Solution

$\boldsymbol{\rho_1 A_1 V_1 = \rho_2 A_2 V_2}$

The density of water in this pipe is constant and can be cancelled from both sides of continuity equation.

we get,

$$\boldsymbol{V_2 = \left(\frac{1cm}{3cm}\right)^2 \times 2m/s = 0.22m/s}$$

Example2:

Suppose that a compressible gas is flowing through a pipe. In a region of the pipe with A cross sectional area of $0.02m^2$, it has a flow rate of 4 m/s and density of 2 kg/m^3. What is its density as it flows through another region of the same pipe with cross sectional area of $0.03m^2$ atvelocity 1 m/s?

Solution

We know:

- A_1= 0.02m^2
- v_1= 4m/s
- ρ_1= 2kg/m^3
- A_2 = 0.03m^2
- v_2 = 1m/s

$\rho_1A_1v_1 = \rho_2A_2v_2$

Substitute these values into the equation:

$$2\times0.02\times4 = \rho_2\times0.03\times1$$

$$\boldsymbol{\rho_2 = 5.33kg/m^3}$$

Note that:

The volume flow rate (Q) is given by: $\boldsymbol{Q = AV}$, where $\boldsymbol{Q}$ is volume flow rate, $\boldsymbol{A}$ is cross sectional area, and $\boldsymbol{V}$ is average velocity. The IS unit of volume flow rate is $\boldsymbol{l/s}$ or $\boldsymbol{ml/min}$.

Mass flow rate ($\frac{dm}{dt}$), is given by: $\frac{dm}{dt} = \boldsymbol{\rho AV}$

Example: The pipe with radius of 0.1m is used to drain water cylindrical tank with height of 3m and a diameter of 5m in less than one hour. How fast will the stream of water need to move through the pipe in m/s in order to fill of tank?

Solution

The tank is cylindrical, so its volume can be calculated using the formula:

$$\boldsymbol{V = \pi r^2 h}$$

R = d/2 = 5/2 = 2.5m (radius of the tank)

H = 3m (height of the tank)

$$V = \pi\times(2.5)2\times3 = 58.82m^3$$

Q = V/t = 58.82m3/3600seconds ≈0.01636m3/s

Q = A x v and **A = πr2** = π×(0.1)2 = 0.031416m2

V = Q/A = 0.01636/0.031416≈0.521m/s

Activity 2: Guided Practice

Task 29:

Solve the following questions

1. Water flows through a pipe that narrows from a diameter of 0.1m (point 1) to 0.05m (point 2). The velocity of water at point 1 is 2m/s. Calculate the velocity of water at point 2.
2. A garden hose has a diameter of 0.02m at the nozzle and a flow velocity of 3m/s. Calculate the diameter of the hose at the wider section (point 1) if the velocity there is 1m/s.

Key Facts 3.3b: Bernoulli's principle and its application

Bernoulli's principle formulated by Daniel Bernoulli states that as the speed of a moving fluid increases (liquid or gas), the pressure within the fluid decreases**.**

The total mechanical energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of fluid motion, remains constant

- ✓ Bernoulli's principle formula: Bernoulli's principle formula is a relation between pressure, kinetic energy and gravitational potential energy of fluid in a container.

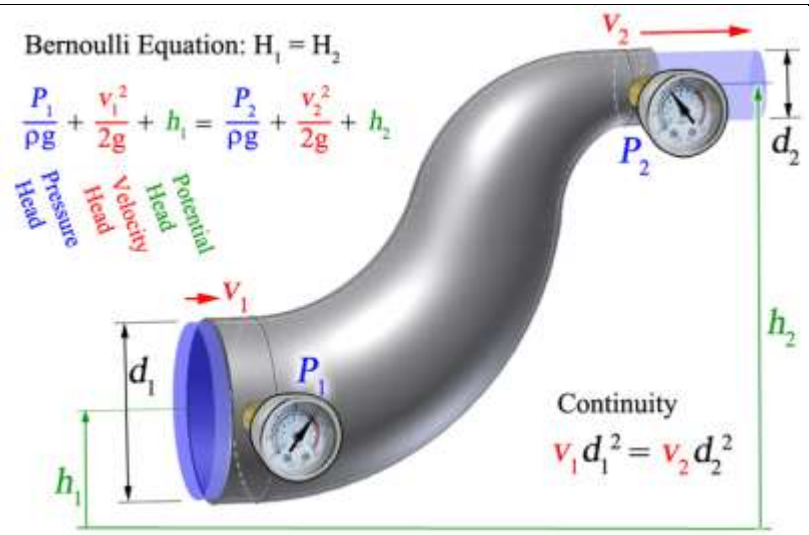


Figure 25: Bernoulli's equation

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

✓ **Application of Bernoulli's principle**

This principle has various applications in different fields. Here are some notable examples:

- **Aeronautics and Aviation:**

Airplane Wings: The shape of an airplane wing is designed to take advantage of Bernoulli's principle. The upper surface of the wing is curved, and the lower surface is relatively flat. As air flows over the curved upper surface, its speed increases, resulting in lower pressure according to Bernoulli's principle. This creates lift, allowing airplanes to fly.

- **Automotive Engineering:**

Carburetors: The principle is applied in carburetors of internal combustion engines. As air flows through the narrowing venturi tube, its speed increases, leading to a decrease in pressure. This drop in pressure helps draw in fuel, creating the air-fuel mixture necessary for combustion.

- **Ball Sports:**

Curveballs in Baseball: Pitchers in baseball can use Bernoulli's principle to create a curveball. By putting a spin on the ball, the airspeed on one side of the ball is higher, creating lower pressure and causing the ball to curve as it moves through the air.

- **Fluid Measurement:**

Pitot Tubes: These are used in aircraft and some fluid flow measurement applications. The principle is applied to measure the velocity of a fluid by comparing the pressure between the stagnation point (where the fluid comes to rest) and another point in the fluid stream.

- **Wind Instruments:**

Wind Instruments: Musical instruments like flutes and recorders operate on Bernoulli's principle. As the musician blows air across a sharp edge, the speed of the air increases, creating lower pressure that causes the air column inside the instrument to vibrate, producing sound.

- **Blood Flow in Arteries:**

Blood Flow: Bernoulli's principle helps explain blood flow in arteries. As blood flows through a narrowing vessel, its speed increases, leading to lower pressure. This principle contributes to efficient blood circulation.[6]

Application of fluid dynamics

Fluid dynamics is a branch of physics that involves the calculation of various fluid properties, such as flow velocity, pressure, density, and temperature, as functions of space and time. It is applied across a vast array of fields, including engineering, meteorology, oceanography, astrophysics, and biology.

Importance of Fluid Dynamics

Fluid dynamics is important because it helps us understand and predict the behaviour of liquids and gases in various situations. It is extremely important for the following reasons:

- ✓ Fluid dynamics help design faster cars and planes by understanding airflow.
- ✓ It makes boats and ships move smoothly through the water.
- ✓ It guides the creation of efficient pipelines for water and oil.
- ✓ It aids in predicting and managing weather, saving lives.
- ✓ It improves heart disease treatment by studying blood flow.
- ✓ It supports creating better-cooling systems for electronics.
- ✓ It enables the development of renewable energy sources like wind turbines.
- ✓ It helps keep our environment clean by designing sewage treatment plants.
- ✓ It assists in understanding how pollutants spread in air and water.

[6] https://www.geeksforgeeks.org/application-of-bernoullis-theorem/

- ✓ Fluid dynamics plays a role in space exploration, studying how fluids behave in zero gravity.
- ✓ It contributes to safer and more effective fire suppression systems.
- ✓ It enhances sports equipment design for better performance.
- ✓ It facilitates the extraction and refining of oil and gas more efficiently.

Streamline flow around a moving airplane wing

Streamline flow provides a useful conceptual framework for understanding the behavior of air around an airplane wing, the actual flow is influenced by a combination of factors, and engineers use advanced tools to analyze and optimize aerodynamic performance.

Newton's third law about the airstream.

Newton's Third Law governs the interaction between an aircraft and the airstream. The deflection of the airstream by the aircraft's wing results in the generation of lift force, and the expulsion of air rearward by the engines results in thrust. This law is fundamental to understanding the forces involved in flight and is a key principle in aerodynamics

Activity 3: Application

Task 30:

Read the following scenario and answer the related questions

You are part of a team designing a new environmentally friendly airplane. Your role is to analyze how air moves around the airplane wings to maximize lift and reduce drag, ensuring the airplane is energy-efficient and safe. You also need to consider how fluid dynamics principles, such as streamline flow and Newton's Third Law, affect the performance of the plane.

1. What is fluid dynamics, and why is it important in understanding the behavior of liquids and gases?
2. How does fluid dynamics help in designing faster cars and planes?
3. Why is streamline flow important for analyzing the behavior of air around airplane wings?

4. If the airflow around an airplane wing is not streamlined, how might this affect the plane's performance?
5. How would fluid dynamics principles change if applied to a spacecraft in zero gravity compared to an airplane on Earth?

Formative Assessment for learning outcome three

1. Match the element in column A with their meaning in column B

✓ COLUMN A		✓ COLUMN B
1. Steady flow		A. The measure of fluid's resistance to flow
2. Fluids		B. Density of fluid remains constant
3. Viscosity		C. A substance that has no fixed shape
4. Incompressible flow		D. The velocity of fluid at each point remains constant in time

2. Pressure is
    a. Proportional to both force and area
    b. Proportional to force and inversely proportional to area.
    c. Inversely proportional to force and proportional to area.
    d. Inversely proportional to both force and area.
3. Which of the following is not a unit of pressure?
    a. Atmosphere
    b. N/m
    c. Pascal
    d. mm of mercury
4. Consider three drinking glasses. All three have the same area base, and all three are filled to the same depth with water. Glass A is cylindrical. Glass B is wider at the top than at the bottom, and so holds more water than A. Glass C is narrower at the top than at the bottom, and so holds less water than A. Which glass has the greatest liquid pressure at the bottom?
    a. Glass A
    b. Glass B
    c. Glass C
    d. All three have equal pressure.

5. 50 cm3 of wood is floating on water, and 50 cm3 of iron is totally submerged. Which has the greater buoyant force on it?
    a. The wood
    b. The iron
    c. Both have the same buoyant force.
    d. cannot be determined without knowing their densities
6. An ideal fluid flows at 12 m/s in a horizontal pipe. If the pipe widens to twice its original radius, what is the flow speed in the wider section?
7. Water flows through a pipe. The diameter of the pipe at point B is larger than at point A. Where is the water pressure greatest?
8. Water flows through a horizontal pipe with a wide section of cross-sectional area $0.5m^2$ and a narrow section of area $0.2m^2$. If the velocity of water in the wide section is 2m/s, calculate the pressure difference between the wide and narrow sections. Assume water density $\rho=1000kg/m^3$.
9. A cube of side 0.5m is submerged completely in water. Calculate the buoyant force acting on the cube. The density of water is $1000kg/m^3$, and $g=9.8m/s^2$.
10. Air flows over an airplane wing. The speed of air on the top of the wing is 80m/s, and on the bottom, it is 60m/s. If the density of air is $1.2kg/m^3$, calculate the pressure difference between the top and bottom surfaces of the wing.
11. Complete the following statements using appropriate terms
    a. Pressure is defined as the force acting normally per …… on the surface of the body.
    b. ……..is a simple device for measuring pressure exerted by a fluid.
    c. The pressure at a point in a liquid depends on…….and ……
12. A100 kg object with a volume of $1m^3$ is submerged 2 meters below water. Density of water $\rho water$ =1000 kg/m^3 and acceleration due to gravity $g=9.81\ m/s^2$
    a) Find the buoyant force acting on the object.
    b) Does this object sink or float in water? Justify your answer.
13. Write down Bernoulli's equation
14. A hydraulic lift is used to lift a car of mass 1200 kg. The input piston has a diameter of

10 cm, and the output piston has a diameter of 50 cm. A force of 300 N is applied to the input piston.

a) Calculate the force exerted by the output piston to lift the car.

b) Explain **Pascal's Principle**



Points to Remember

- Viscosity is a measure of fluid's resistance to flow
- Equation of continuity $\rho 1A1V1 = \rho 2A2V2$
- Bernoulli equation is

$$P + \frac{1}{2}\rho V^2 + \rho gh = constant$$



Self-Reflection

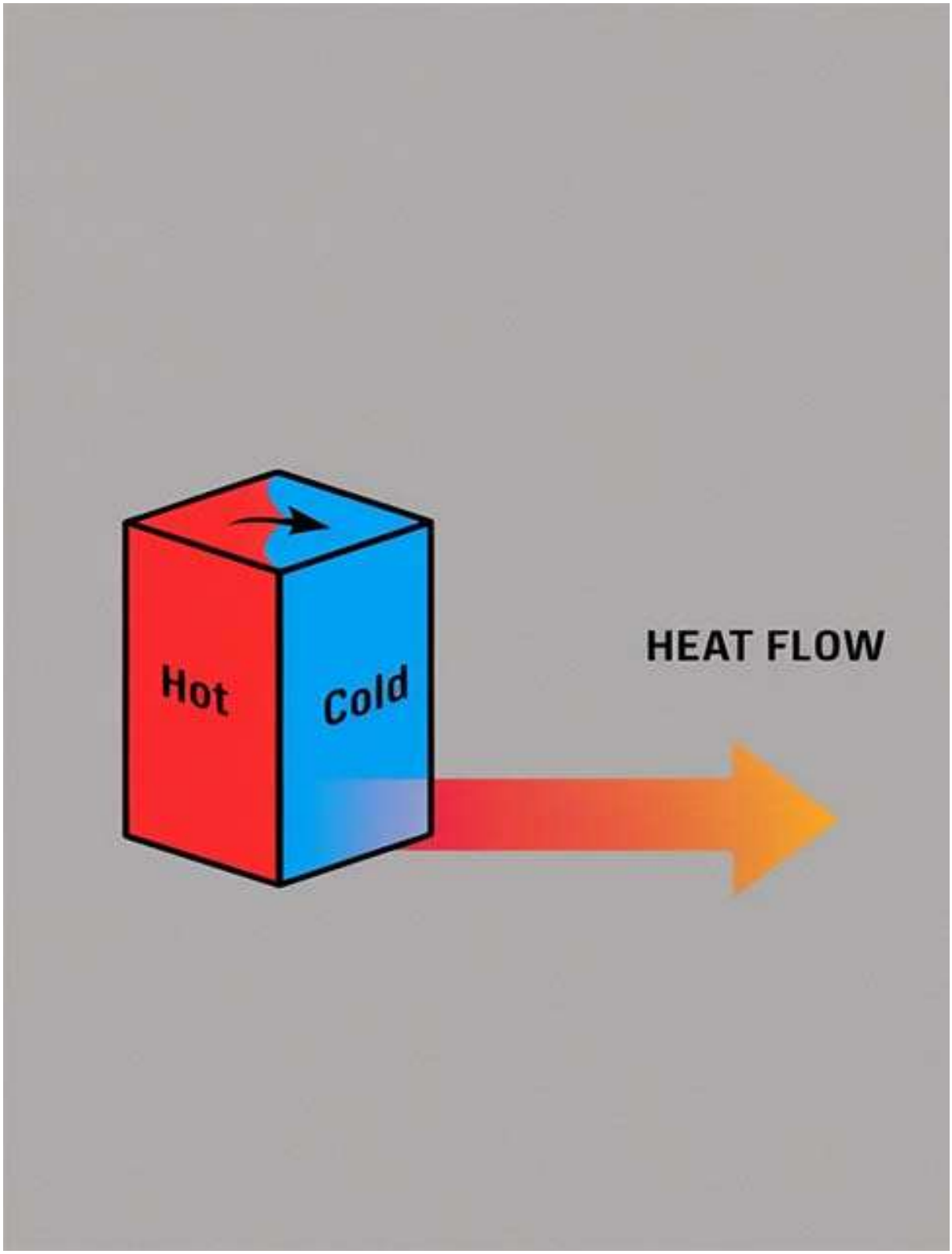
1. Read the statements across the top. Put a check in a column that best represents your level of knowledge, skills and attitudes.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience of doing this.	I have a lot of experience with this.	I am confident in my ability to do this.

2. Fill in the table above and share results with the trainer for further guidance.

Areas of strength	Areas for improvement	Actions to be taken to improve
1.	**1.**	**1.**

2. **3.**	**2.** **3.**	**2.** **3.**


Hot
Cold
HEAT FLOW

Unit summary

This unit provides you with the knowledge, skills and attitudes required to Apply thermodynamics required to apply mechanics and properties of matter. It covers the Description of fundamental concepts of thermodynamics, Analyzing thermodynamic laws and Application of thermodynamic laws.

Self-Assessment: Unit 4

1. Study the unit illustration above and answer the following questions.

a. What do you see in the illustration?

b. What topics do you think will be covered under this unit based on the illustration?

2. Fill in and complete the self-assessment table below to assess your level of knowledge, skills and attitudes under this unit.

   a. There is no right or wrong ways to answer this assessment.

   b. It is for your own reference and self-reflection on the knowledge, skills and attitudes acquisition during the learning process.

   c. Think about yourself: do you think you have the knowledge, skills or attitudes to do this? How well?

   d. Read the statements across the top. Put a check in column that best represents your level of knowledge, skills or attitudes.

3. At the end of this unit, you will assess yourself again

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
State Laws of thermodynamics (Zeroth, First, Second)					
Analyze thermodynamics laws					
Describing temperature conversion					
Identify Thermodynamic Systems					

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Evaluate system efficiency and performance.					
Collaboration and Openness					
Interest in connecting theoretical knowledge					
Identify Applications of Thermodynamic					

Key Competencies:

Knowledge	Skills	Attitudes
1. Define thermodynamics	**1.** Being able to interpret thermodynamic concepts	**1.** Being curious and willing to learn
2. State Laws of thermodynamics (Zeroth, First, Second)	**2.** Being able to analyze thermodynamics laws	**2.** Being interested in connecting theoretical knowledge
3. Describing temperature conversion	**3.** Being able to conduct experiments to measure thermal properties and analyze data	**3.** Having a problem-solving mindset
4. Identify Thermodynamic Systems	**4.** Being able to evaluate system efficiency and performance	**4.** Being ethically responsible.
5. Describe Heat, work, and energy transfer mechanisms	**5.** Being able to solve thermodynamic problems.	**5.** Being precise and attentive to detail
6. Identify Applications of Thermodynamic	**6.** Being able to analyze real-world materials and their thermodynamic properties	**6.** Being collaborative and open

Discovery activity:

Task 1:

Read the following statement and answer the related questions

A rigid, sealed container holds **2 kg of water** at an initial temperature of **20°C**. The container is heated using an external source until the water reaches **100°C**. Assume no heat is lost to the surroundings, and the pressure inside the container remains constant at **1 atm**

1. What type of thermodynamic system is described in this scenario (open, closed, or isolated)? Why?
2. What form of energy transfer occurs between the external heat source and the water?
3. As the water is heated, which thermodynamic properties (e.g., temperature, internal energy, pressure) of the water change?
4. If heating continues beyond **100°C**, what phase change might occur?

Topic 4.1: Description of fundamental concepts of thermodynamics

Activity 1: Problem Solving

Task 32:

You have a bowl of hot soup at **90°C**, placed on a table in a room where the air temperature is **25°C**. Over time, the soup cools down due to heat transfer. The bowl is open, allowing both energy and matter (in the form of steam) to exchange with the surroundings.

1. Based on the description, is the bowl of soup an open, closed, or isolated system? Why?
2. Identify and explain the modes of heat transfer (conduction, convection, and radiation) involved in cooling the soup.
3. What role does the boundary between the soup and the surroundings play in heat transfer?
4. What happens to the internal energy of the soup as it cools?
5. If the soup were placed in a perfectly insulated container, how would the heat exchange process differ from the current setup?
6. Is the soup's temperature an intensive or extensive property? What about its mass?

Key Facts 4.1a: Key terms

System: a set of things working together as parts of a mechanism or an interconnecting network; a complex whole. It is also a regularly interacting or interdependent group of items forming a unified whole.

An open system is a system that exchanges both energy and matter with its surroundings.

Example: An open heating pot is an example of an open system, because heat and water vapor are lost to the air.

A closed system is a system that can exchange only energy with its surroundings but not matter. **Example:** A heating pot with a very tightly fitting lid would be approximated to be a closed system.

An isolated system is a system that cannot exchange either matter or energy with its surroundings. Perfect isolated systems are very rare, but a completely insulated drinks cooler with a lid would ideally represent an isolated system.

Surroundings: Things and conditions around a person or thing.

Boundary: Something that indicates or fixes a limit or extent.

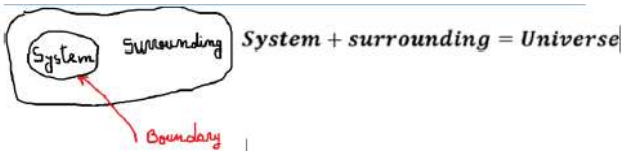


Figure 26: description of a system

Internal energy: It is also known as intrinsic energy. It is defined as the total energy of closed system. It is the sum of potential energy of system and system's kinetic energy.

Extensive properties vary with the amount of the substance and include mass, weight, and volume.

Intensive properties, in contrast, do not depend on the amount of the substance; they include colour, melting point, boiling point, electrical conductivity, and physical state at a given temperature.

Activity 2: Guided Practice

Task 33:

Solve the questions below

1. Convert 42 Fahrenheit to Celsius scale.
2. Convert 302 Kelvin to Fahrenheit scale.
3. A copper rod of length 2 m has its temperature changed from 15 °C to 25 °C. Find the change in length given that its coefficient of linear expansion $\alpha = 1.7 \times 10^{-5}\ K^{-1}$.
4. A round hole of diameter 4.000 cm at 0 °C is cut in a sheet of brass (coefficient of linear expansion is $0.0000017(K)^{-1}$. Find the new diameter of the hole at 40 °C.
5. A metal vessel has a volume of 800.00 cm3 at 0 °C. If its coefficient of linear expansion is 0.000014/K, what is its volume at 60 °C?

Key Facts 4.1b: Heat transfer and quantity of heat

Heat and temperature

Heat: is a form of energy that is transferred between systems or objects with different temperatures. It flows from high temperature system to lower temperature system. When the two objects are kept isolated from the environment in a heat resistant box, the heat lost by the hot object is equal to the heat gained by the cold object and the heat transfer happens still the temperature of both the objects becomes equal. This is called as the principle of heat exchange.

Temperature: A physical quantity express hotness and coldness of the object. It is expressed in several scales including Fahrenheit, Celsius, and kelvin.

Conversion of temperature scales (Celsius, kelvin, and Fahrenheit):

Table 2: Temperature scale conversion

The formula to convert these scales are follows:

Conversion	Formula
Celsius to Fahrenheit	ºF = (ºC× 9/5) + 32
Kelvin to Fahrenheit	$T_F=\frac{9}{5}(K-273)+32$
Fahrenheit to Kelvin	$K=\frac{5}{9}(ºF-32)+273$
Fahrenheit to Celsius	ºC= (ºF– 32)× 5/9
Celsius to Kelvin	K= ºC + 273
Kelvin to Celsius	ºC= k-273

$$\frac{T_C}{100}=\frac{T_F-32}{180}=\frac{T_K-273}{100}$$

Modes of heat transfer

Conduction: Heat or energy is transferred by direct contact, like when any heated object you touch with your hand; the conduction process takes place.

Note: When we heat iron at one side, other side automatically gets heated because the molecules present in it travels to another side and heated that area too. Therefore, conduction is equal to direct contact.

Convection: Process by which heat is transferred by movement of a heated fluid such as air or water. Example: Boiling water: Burner heats water at bottom. Hot water rises and cooler water moves down to replace it.

Thermal radiation: Energy in form of electromagnetic radiation is emitted by heated surface in all direction and travels directly to its point of absorption at the speed of light by a process.

Heat capacity

Heat capacity (H) of a particular sample of a substance is defined as the amount of energy needed to raise the temperature of that sample by 1°C. H = mc (m is mass and c is specific heat capacity)

$$\boldsymbol{H = \frac{Q}{\Delta T}}$$

where Q is amount of heat and $\Delta \boldsymbol{T}$ is temperature change and the SI unit of heat capacity is $joule/kelvin$

Specific heat capacity

Specific heat is the quantity of heat required to raise the temperature of one gram of substance by One-Celsius degree.

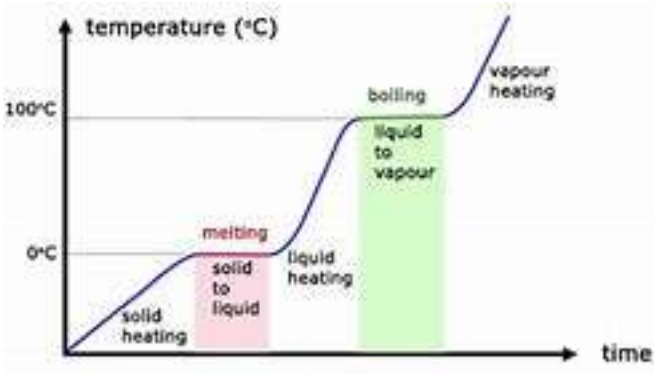
$$\boldsymbol{C_p = \frac{Q}{m\Delta T}}$$

Where $\boldsymbol{C_p}$ is specific heat, $\boldsymbol{Q}$ is heat energy, $\boldsymbol{m}$ is mass, $\Delta \boldsymbol{T}$ is change in temperature

- ✓ The SI unit of specific heat is $\boldsymbol{J/g}$°C or $\boldsymbol{J/kgK}$

Melting

Melting is the change of state from a solid to a liquid. The melting point is usually defined as the **point at which materials changes from a solid to a liquid**. The temperature at which solid changes its state to liquid at atmospheric pressure is called the melting point of that liquid. This is the point at which both liquid and solid phase exists at equilibrium.



Boiling

The action of bringing a liquid to the temperature at which it bubbles and turns to vapour.

Boiling point

The boiling point for any material is the temperature point at which the material transforms into the gas phase in the liquid phase. This happens at **100 degrees centigrade** for water.

HEAT QUANTITIES

Heat lost or gain due temperature change

Heat gains or losses result in **changes in temperature, changes in state or the performance of work**. Heat is a transfer of energy. When gained or lost by an object, there will be corresponding energy changes within that object.

Principle of heat exchange

The essential principle of a heat exchanger is that it **transfers the heat without transferring the fluid that carries the heat**.

Heat transfer is the exchange of thermal energy between physical systems. It moves from one system to another because of temperature difference in the given systems. The direction of heat transfer is always from the region of high temperature to that of lower temperature, and is governed by the Second law of thermodynamics. The region with higher temperature is known as the heat source and the one with lower temperature as the heat sink.

The heat will continue flowing till the two systems are in thermal equilibrium (at equal temperatures).

From the principle of heat exchange,

Heat lost by a hot object = heat gained by a cold object.

The specific heat capacity of water being a standard figure 4200 J/kg °C. We can find either the quantity of heat lost by the hot water or the quantity of heat gained by the cold water using the formula

$Q = mc\Delta\theta$,

where Q is the quantity of heat given out or absorbed, m, the mass of the substance, c, is the specific heat capacity of a substance and $\Delta\theta$, is the temperature change.

Latent heat

The heat required to convert a solid into a liquid or vapour, or a liquid into a vapour, without change of temperature.

Definition of latent heat of fusion

Heat is either absorbed or given out at a constant temperature when a substance is changing its state. When a substance changes from a solid state to a liquid state, heat is absorbed. This heat is called the latent heat of fusion of a substance.

The latent heat of fusion of a substance is defined as the quantity of energy required to change the substance from solid state to the liquid state without change in temperature at a constant pressure.

When the mass of the substance undergoing change is 1 kg, the absorbed heat is called specific latent heat of fusion. The specific latent heat of fusion of a substance is defined as the quantity of heat energy required to change 1 kg of the substance from solid state to the liquid state without change in temperature at a constant pressure.

The latent heat of fusion required in the (Q) is directly proportional to the mass of the substance i.e. $Q \alpha m$

$Q = lm$

Where l is constant called specific latent heat of fusion of the substance.

$\therefore l = Q/m$ SI units of specific latent heat of fusion is Joule per kilogram (J/kg).

Latent heat of vaporization

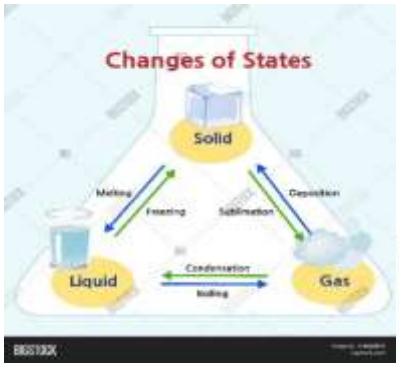
When a liquid changes into vapour, the temperature remains constant till all the liquid has changed its state to vapour. This shows that heat is absorbed to change the state from liquid to vapour state. The heat is called the latent heat of vaporisation of the liquid. The latent heat of vaporisation of a liquid is the amount of heat energy required to change the substance from the liquid state to vapour state at a constant pressure without change in temperature.

When the mass of the substance undergoing change is 1 kg, the heat is called specific latent heat of vaporisation. The specific latent heat of vaporisation of a substance is the quantity of heat energy required to change 1 kg of the substance from the liquid state to the gaseous state at a constant pressure without change in temperature.

The quantity of heat energy required to change a liquid of mass, m, into vapour is given by,

Q = ml where l is called the specific latent heat of vaporization of the liquid

Transition of physical states





Heat of fusion

Heat of fusion is the amount of heat energy required to change the state of matter of a substance from a solid to a liquid.

Its units are usually Joules per gram (J/g) or calories per gram (cal/g).

Heat of vaporization

The Heat of Vaporization is the quantity of heat that needs to be absorbed to vaporize a particular quantity of liquid at a constant temperature.

Heat of sublimation

Sublimation is the process of changing a solid into a gas without passing through the liquid phase. To sublime a substance, a certain energy must be transferred to the substance via heat (q) or work (w)

Thermal expansion:

When heat is added to surface, the molecules gain energy, vibrate, and force other molecules apart. As result, expansion takes place. Inversely, when heat is removed to substance, the molecules loss energy, molecules attract each other, and as result, contraction takes place. Expansion is greater for liquids than for solids and maximum in case of gases. There are three types of expansion: Linear expansion, Areal expansion and Volume expansion.

1. Linear expansion

- ✓ Linear expansion is the change in length due to heat

- ✓ Linear expansion formula is given as:

$$\frac{\Delta L}{L_0} = \alpha_L \Delta T$$

Where L_0 is original length, **L** is expanded length, α_L is length expansion coefficient,

ΔL **is** change in length, ΔT is change in temperature

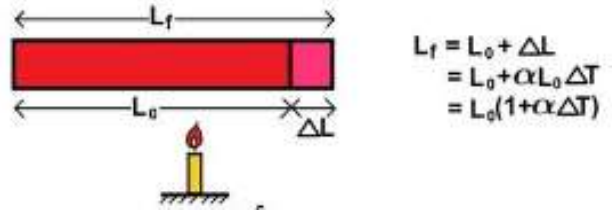


Figure 27: Linear expansion

2. Area expansion

Area expansion is the change in area due to the temperature change
Area expansion formula is given as:

$$\frac{\Delta A}{L A_0} = \alpha_A \Delta T$$

Where A_0 is original area, **A** is expanded area, α_A is area expansion coefficient,

ΔA **is** change in area, ΔT is change in temperature

Note: $\alpha_A = 2\alpha_L$

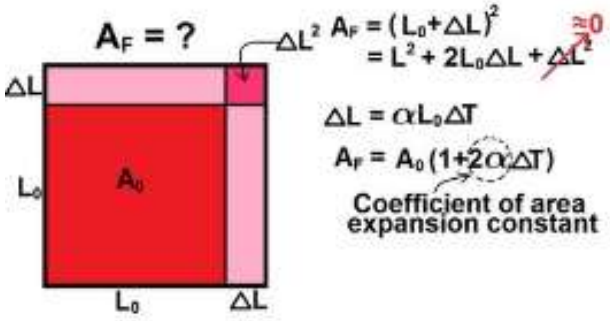


Figure 28: area expansion

3. volume expansion

- ✓ Volume expansion is the change in volume due to temperature
- ✓ Volume expansion formula is given as:

$$\frac{\Delta V}{V_0} = \alpha_V \Delta T$$

Where V_0 is original volume, **V** is expanded volume, α_V is volume expansion coefficient,

ΔV **is** change in volume, ΔT is change in temperature

Note : $\alpha_V = \alpha_L$

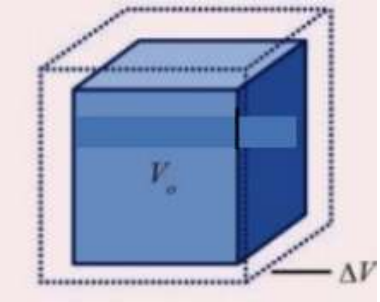


Figure 29: Volume expansion

Example1: a rod of length 5m heated to 40^0 C. if the length increases to 7m after some time, find the expansion coefficient. Room temperature is 30^0C.

Solution: $\Delta l = L_o \alpha \Delta T$

L_0 = 5m

L_f = 7m

T_i = 0^0 C

$$\Delta l = L_f - L_i = 7m - 5m = 2m$$

$$\Delta T = T_f - T_i = 400^0 C - 300^0 C = 100^0 C$$

$$\alpha = \frac{\Delta l}{L_i . \Delta T} \Rightarrow \alpha = \frac{2m}{5m.100^0 C} = 0.004^0 C^{-1}$$

Example 2: a sheet of steel at 20^0C has width and length 20cm, 40cm respectively. If the coefficient of linear expansion for steel is $10^{-5}/^0$C, then what is the change in the area at 60^0C?

Solution: $\Delta A = 2\alpha A_0 \Delta T$, $A_0 = w \cdot l = 0.2m \cdot 0.4m = 0.08m^2$

$$\Delta T = T_f - T_i = 600^0 C - 200^0 C = 400^0 C$$

$$\Delta A = 2\alpha A_0 \Delta T = 0.08 \times 2 \times 10^{-5} C^{-1} \cdot 400^0 C$$

$$\Delta A = 0.00128 \times 10^4 m^2 = 12.8 cm^2$$

Activity 3: Application

Task 34:

Read carefully the following statements and answer the related questions

A blacksmith is tasked with fitting a metal ring tightly onto a metal rod to secure a wagon wheel. At room temperature, the ring fits snugly around the rod, but it needs to be made even tighter for durability. The blacksmith decides to heat the metal ring before placing it over the rod.

1. What happens to the size of the metal ring when it is heated, and why does this occur?
2. Once the ring cools after being placed on the rod, what will happen to its fit? Explain using the concept of thermal expansion.
3. If the rod is also heated alongside the ring, what would be the outcome? How does this affect the snug fit of the ring?

Topic 4.2: Analysing thermodynamic laws

Activity 1: Problem Solving

Task 35:

Read carefully the following scenario and answer the questions that follow.

A rigid, sealed container holds **1 kg of water** at an initial temperature of **20°C**. The container is heated using an external source, supplying **500 kJ** of energy to the system. Since the container is rigid, no work is done by or on the system. Assume no heat is lost to the surroundings.

1. How does the First Law of Thermodynamics apply to this scenario? Write the equation that represents the energy changes in this system.
2. What happens to the internal energy of the water as it is heated?
3. Why is the work done on or by the system zero in this scenario?
4. How is the energy supplied by the heat source used within the system?
5. If some heat were lost to the surroundings during the process, how would this affect the final temperature of the water?
6. Can you think of a real-life example where the First Law of Thermodynamics is applied in a similar manner?

Key Facts 4.2: Thermodynamic laws

Zeroth law and temperature measurement

Zeroth law states that if two systems A and B are in thermal equilibrium with each other, and B is in thermal equilibrium with third system C, then A is also in thermal equilibrium with C. This statement may seem obvious, because all three system have the same temperature, but it is basic to thermodynamics.

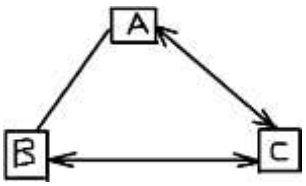


Figure 30: Zeroth law

Temperature measurement

Liquid-in-glass thermometer: It consists of mercury as a liquid filled in glass tube. On the body of glass tube, carbureted marks are provided which facilitates the reading of temperature.



Figure 31:Liquid-in-glass thermometer

Digital thermometer: Use mercury to measure temperature. They show the number. It calculates and give number.



Figure 32: Digital thermometer

Infrared thermometer: Thermometer infers temperature from portion of thermal radiation sometimes called blackbody radiation emitted by object being measured. It does not need contact.



Figure 33: Infrared thermometer

First law of thermodynamics

The first law of thermodynamics states that "the heat energy supplied to a system is equal to the sum of the change in internal energy of the system and the work done by the system".

Heat added = increase in internal energy + external done by the system

$\Delta Q = \Delta U + \Delta W$

Second law of thermodynamics

The second law of thermodynamics talks about the extent and direction of energy transformation. The law states, “Heat flows spontaneously from a hotter object to a colder one, but not in the opposite direction; the reverse cannot happen without the addition of energy”.

$\boldsymbol{Q_H = W + Q_L}$Where $\boldsymbol{Q_H}$ is input heat, W is the work done by the system and $\boldsymbol{Q_L}$is heat exhausted.



Activity 2: Guiceded Practi



Task 36:

Solve the following questions

1. A gas in a system has constant pressure. The surroundings lose 49 J of heat to the system and does 316 J of work onto the system. What is the change in internal energy of the system?
2. In a certain process, 450 J of work is done on the system. If the system gives off 124 J of heat, what is the change in internal energy of the system?
3. In a certain process, 523.6 J of heat is added to a system. The system does work equivalent to 78I.4 J by expanding against the surrounding atmosphere. What is the change in internal energy for the system?
4. A heat pump uses 300 J of work to remove 400 J of heat from the low-temperature reservoir. How much heat is delivered to a higher temperature reservoir?

Activity 3: Application

Task 37:

Read carefully the following statement and answer the related questions

You are in a science lab conducting an experiment that involves heating a metal rod. You are using a **digital thermometer** to monitor the temperature of the rod, which shows the current temperature in Celsius. As the metal heats up, the temperature rises to **120°C**. You notice that the rod starts to glow red at this temperature.

1. What can you infer from the digital thermometer reading and the glowing of the rod?
2. Why might it be important to monitor the temperature closely in this experiment?

Topic 4.3: Application of thermodynamic laws

Activity 1: Problem Solving

Task 38:

Read carefully the following scenario and answer the related questions.

In a hospital's intensive care unit (ICU), maintaining a controlled environment with optimal temperature and humidity is crucial for patient comfort and recovery. The air conditioning system in the ICU operates as a practical application of thermodynamics, particularly the **vapor-compression refrigeration cycle**.

The air conditioning system cools and dehumidifies air in the ICU by cycling a refrigerant through various thermodynamic processes. Key components include a **compressor**, **condenser**, **expansion valve**, and **evaporator**. The system is designed to maintain the room at 22°C, while the outside temperature is 35 °C.

1. What is the First Law of Thermodynamics, and how does it apply to an air conditioning system?
2. Define the term "Coefficient of Performance" (COP) for a refrigeration cycle. Why is it used as a measure of efficiency?
3. Why is the refrigerant compressed to a high pressure before entering the condenser?
4. What happens to the refrigerant as it passes through the evaporator?
5. Explain why heat is rejected in the condenser even though the system is designed for cooling.

Key Facts 4.3: Application of thermodynamic laws

4. Refrigerators

We can think of a refrigerator as a heat engine operating in reverse. A heat engine takes heat from a hot place and gives off heat to a colder place. A refrigerator does the opposite; it takes heat from a cold place (the inside of the refrigerator) and gives it off to a warmer place (usually the air in the room where the refrigerator is located). A heat engine has a net output of mechanical work; the refrigerator requires a net input of mechanical work.

The electric compressor motor forces a gas at high pressure through a heat exchanger (condenser) on the rear outside wall of the refrigerator, where is given off and the gas cools to become liquid. The liquid passes from a high-pressure region, via a valve, to low-pressure tubes on the inside walls of the refrigerator; the liquid evaporates at this lower pressure and thus absorbs heat from the inside of the refrigerator. The fluid returns to the compressor, where the cycle begins again.

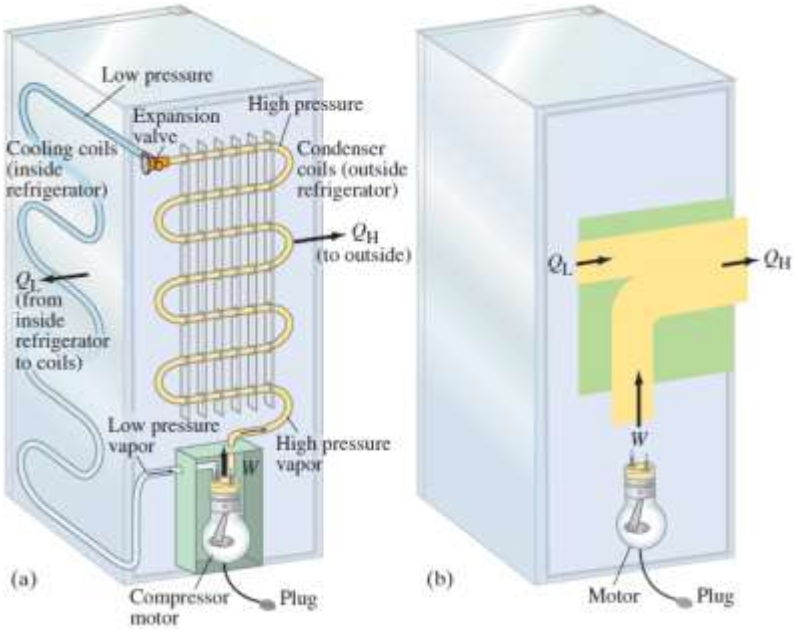


Figure 34: Refrigerators

The coefficient of performance (COP) of a refrigerator is a measure of its efficiency, defined as the heat Q_L removed from the low-temperature area (inside a refrigerator) divided by the work W done to remove the heat $COP = \frac{Desired\ output}{Required\ input} = \frac{Q_L}{W}$

Where:

Q_L is the amount of heat removed from the cold reservoir (inside the refrigerator), typically measured in joules (J) or watts (W).

W is the work input (energy consumed by the compressor), also measured in joules (J) or watts (W).

Example:

If a refrigerator removes 200 J of heat from the inside and requires 50 J of work to do so, the COP would be:

$$COP = \frac{Q_L}{w} = \frac{200\text{J}}{50j} = 4$$

This means that for every unit of work input, the refrigerator removes four units of heat.

5. Heat engines

A heat engine is a device designed to convert heat energy into mechanical work.

A heat reservoir is the system having very large heat capacity i.e. it is a body capable of absorbing or rejecting finite amount of energy without any appreciable change in its' temperature.

Thus, in general it may be considered as a system in which any amount of energy may be dumped or extracted out and there shall be no change in its temperature. Such as atmosphere to which large amount of heat can be rejected without measurable change in its temperature. A large river, sea etc. can also be considered as reservoir, as dumping of heat to it shall not cause appreciable change in temperature.

Heat reservoirs can be of two types depending upon the nature of heat interaction i.e. heat rejection or heat absorption from it.

Heat reservoir which rejects heat from it is called source. While the heat reservoir which absorbs heat is called sink. Sometimes these heat reservoirs may also be called Thermal Energy Reservoirs (TER).

A heat engine is a device used for converting heat into work. Thus, heat engine may be precisely defined as "a device operating in cycle between high temperature source and low temperature sink and producing work".

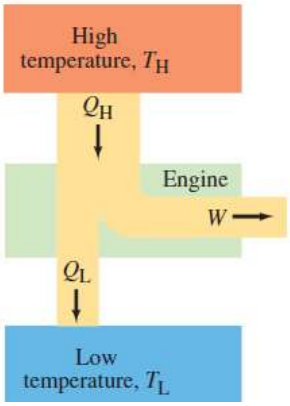


Figure 35: Heat engine

Heat engine receives heat from source, transforms some portion of heat into work and rejects balance heat to sink. All the processes occurring in heat engine constitute cycle.

The efficiency, e, of any heat engine can be defined as the ratio of the work it does, W, to the heat input at the high temperature Q_H

$$e = \frac{W}{Q_H}$$

This is a sensible definition since W is the output (what you get from the engine), whereas Q_H is what you put in and pay for in burned fuel. Since energy is conserved, the heat input Q_H must equal the work done plus the heat that flows out at the low temperatureQ_L.

$Q_H = W + Q_L$.

Thus W= $Q_H - Q_L$ and the efficiency of the machine is

$$e = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$e = 1 - \frac{Q_L}{Q_H}$$

Note: The efficiency of heat engine cannot exceed 1

Example

An automobile engine has an efficiency of 20% and produces an average of 23,000 J of mechanical work per second during operation. (a) How much heat input is required, and (b) how much heat is discharged as waste heat from this engine, per second?

Answer:

a. We know that $e = \frac{W}{Q_H}$, now solve for Q_H

$$Q_H = \frac{W}{e} = \frac{23{,}000\ \text{J}}{0.20} = 1.15 \times 10^5\ \text{J} = 115\ \text{kJ}.$$

The engine requires 115KJ/s = 115kw of heat input.

b. Now use the equation $e = 1 - \frac{Q_L}{Q_H}$ and solve for Q_L

$$\frac{Q_L}{Q_H} = 1 - e$$

so

$$Q_L = (1 - e)Q_H = (0.80)115\ \text{kJ} = 92\ \text{kJ}.$$

6. Heat pump

A heat pump is a device used to warm and sometimes also cool buildings by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle, being the opposite direction in which heat transfer would take place without the application of external power. The heat pump has four main components: evaporator, compressor, condenser and expansion device. In the evaporator heat is extracted from a waste heat source. In the condenser this heat is delivered to the consumer at a higher temperature level. Electric energy is required to drive the compressor, and this energy is added to the heat that is available in the condenser. The efficiency of the heat pump is denoted by its COP (coefficient of performance), defined as the ratio of total heat delivered by the heat pump to the amount of electricity needed to drive the heat pump.

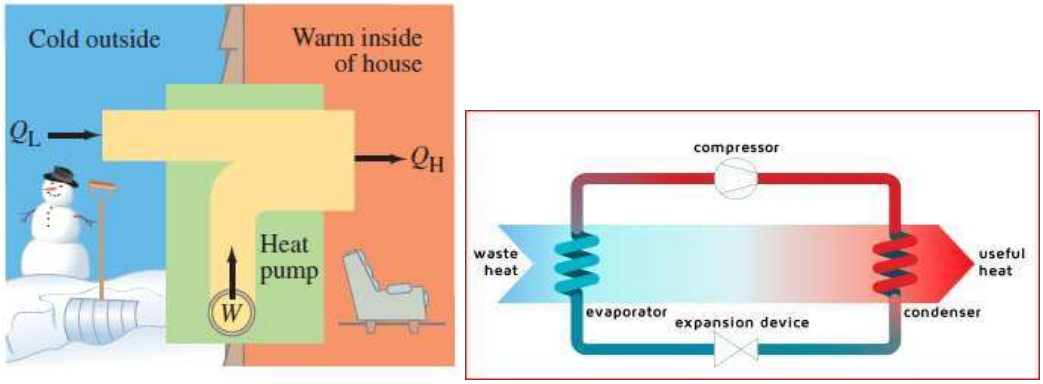


Figure 36: Heat pump

As in a refrigerator, there is an indoor and an outdoor heat exchanger (coils of the refrigerator) and an electric compressor motor. The operating principle is like that for a refrigerator or air conditioner; but the objective of a heat pump is to heat (deliver Q_H), rather than to cool (remove Q_L). Thus, the coefficient of performance(COP) of a heat pump is defined differently than for an air conditioner because it is the heat Q_H delivered to the inside of the house that is important now: $COP = \frac{Desired\ output}{Required\ input} = \frac{Q_H}{W}$

Note: The COP is necessarily greater than 1.[7]

Example:

A heat pump has a coefficient of performance of 3.0 and is rated to do work at 1500 watts. (a) How much heat can it add to a room per second? (b) If the heat pump were turned around to act as an air conditioner in the summer, what would you expect its coefficient of performance to be, assuming all else stays the same?

Answer:

(a) We use equation of COP for heat pump, and, since our device does 1500 J of work per second, it can pour heat into the room at a rate of

$$Q_{\mathrm{H}} = \mathrm{COP} \times W = 3.0 \times 1500\,\mathrm{J} = 4500\,\mathrm{J}$$

(b) If our device is turned around in summer, it can take heat from inside the house, doing 1500 J of work per second to then dump per second to the hot outside. Then

$$Q_{\mathrm{L}} = Q_{\mathrm{H}} - W = 4500\,\mathrm{J} - 1500\,\mathrm{J} = 3000\,\mathrm{J}.$$

The coefficient of performance as an air conditioner would thus be

$$\mathrm{COP} = \frac{Q_{\mathrm{L}}}{W} = \frac{3000\,\mathrm{J}}{1500\,\mathrm{J}} = 2.0.$$

7. Ventilators

A mechanical ventilator works by compressing air or oxygen-enriched gas, increasing its pressure and internal energy to deliver it into the system under controlled conditions. During the process, energy losses such as heat and friction contribute to increased entropy. The ventilator also maintains the gas at a controlled temperature to ensure it is compatible with the target system's thermal needs, preventing discomfort or harm.

8. Power plant

A steam power plant is a heat engine that operates between two thermal energy reservoirs, with steam as the working fluid. In a basic steam power cycle, heat from burning fuel is used to convert water into high temperature, high pressure steam, which is then used to produce work in a turbine before being cooled and pumped back into the boiler for another cycle. However, there is potential for waste heat recovery by directly

[7] https://en.wikipedia.org/wiki/Thermal_energy

pumping low temperature, low pressure steam from the turbine back into the boiler. This would reduce the need for fuel and save on the energy required to drive a larger pump, but it may not be as efficient as a standard steam engine cycle.

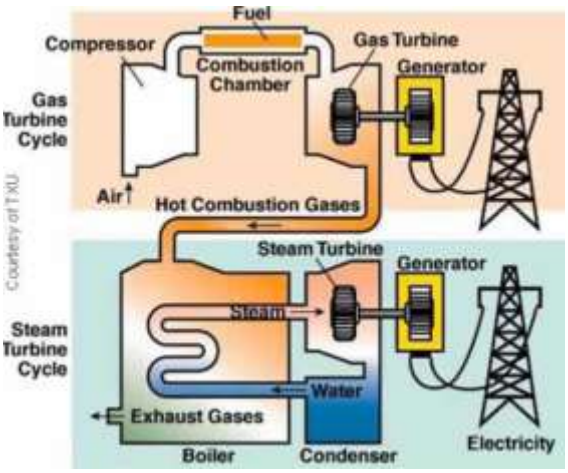


Figure 37: Power plant

The efficiency is given by $e = \frac{W}{Q_H}$ and $Q_H = W + Q_L$.

Example:

A steam power plant produces 50 MW of network while burning fuel to produce 150 MW of heat energy at the high temperature. Determine the cycle thermal efficiency and the heat rejected by the cycle to the surroundings.

Answer:

$$e = \frac{W}{Q_L} = \frac{50MW}{150MW} = 0.333 \; or \; 33.3\%$$

$$Q_L = Q_H - W = 150MW - 50MW$$

Activity 2: Guided Practice

Task 39:

Solve the following questions

1. A heat engine absorbs Q_H=500kJ of heat from a high-temperature reservoir and rejects Q_L=200 kJ to a low-temperature reservoir. Calculate the efficiency (η) of the engine
2. A refrigerator absorbs 300 kJ of heat from the interior of the refrigerator (cold reservoir) and rejects 500 kJ of heat to the surroundings (hot reservoir). Calculate the **Coefficient of Performance (COP)** of the refrigerator

Activity 3: Application

Task 40:

Read carefully the statement below and answer the related questions

1. You have noticed that your refrigerator is running constantly and not cooling efficiently during a heat wave. The manufacturer claims the refrigerator has a Coefficient of Performance (COP) of 3.5 under ideal conditions. What factors might cause the refrigerator's performance to drop in a hot environment, and how can you ensure it operates more efficiently?
2. You are working in an office building where the ventilator system maintains proper airflow. On some days, you feel the air quality isn't as good, especially during high outdoor pollution levels. How does a ventilator system ensure good air quality indoors, and what adjustments might be needed to handle high levels of outdoor pollution?

Formative Assessment

1. Answer true for correct statement and false for incorrect statement
    a. If two systems are in thermal equilibrium with a third system, then they are in thermal equilibrium with each other.
    b. The coefficient of linear expansion for aluminium is $1.8x10^{-6}$ $(C^0)^{-1}$. Its coefficient of volume expansion is $5.4x10^{-6}$ $(C^0)^{-1}$
2. Which temperature scale never gives negative temperatures?
    a. Kelvin
    b. Fahrenheit
    c. Celsius
    d. All of the above
3. The coefficient of performance (COP) of a refrigerator is defined as the ratio of
    a. The heat removed from the inside to the heat expelled to the outside.
    b. The heat expelled to the outside to the heat removed from the inside.
    c. The heat removed from the inside to the work done to remove the heat.
    d. The heat expelled to the outside to the work done to remove the heat.
4. Radiation is the transfer of heat ___

a) In a liquid which involves the movement of the molecules.
b) From one place to another by means of electromagnetic waves.
c) Through a material medium without the bulk movement of the medium.
d) Through a fluid which involves the bulk movement of the fluid itself.

5. The mode of transfer of heat between the boiler and the storage tank of a hot water supply system is

a) Radiation
b) Convention
c) Conduction
d) Evaporation

6. The transfer of heat by the actual movement of molecules of matter takes place

a) only in liquid
b) only in gases
c) in solids and liquid
d) in liquids and gases

7. The laws of thermodynamics dictate the specifics for the movement of _____ and _____ within and across systems.

a) Energy, motion
c) Heat, work
b) Light, heat
d) None of the above

8. The mathematical representation to the first law of thermodynamics is __.

a) W + Q = U
c) Q = U + W
b) U = Q – W
d) none of the above

9. The first law of thermodynamics states that the total energy output is equal to the amount of heat supplied in a system. True or False?

a) True
b) False

10. Which of the following best illustrates the Second Law of Thermodynamics?

a) A cold frying pan heats up faster when placed in the microwave rather than the stove
b) A hot frying pan cools down when it is taken off the kitchen stove.

11. A refrigerator removes heat from the freezing compartment at the rate of 20 kJ and ejects 24 Kj into a room per cycle. What is the coefficient of performance?
12. A refrigerator removes heat from the freezing compartment at the rate of 20 kJ and ejects 24 kJ into a room per cycle. How much work is required in each cycle?
13. State whether each of the following statements is true or false

a) Temperature describes the average kinetic energy of molecules within a material or system and its SI unit is kelvin (K).
b) When an object is heated its temperature always increases.
c) The zeroth law of thermodynamics tells us the concept of temperature

14. Differentiate between conduction and thermal radiation.
15. Differentiate between Specific heat capacity and heat capacity of a substance
16. A round hole of diameter 4.000 m at 0 °C is cut in a sheet of brass (coefficient of linear expansion is $0.0000017(^0C)^{-1}$. Find the new diameter of the hole at 40 °C
17. A metal cube of side 0.20m is subjected to a shearing force of 4000N.the top surface is displaced through 0.50cm with respect to the bottom. Calculate the shear modulus of elasticity of the metal.
18. A cylindrical metal rod of mass 1.2 kg is heated uniformly by an electric heater. The heater supplies energy at a rate of 200 W for 5 minutes. The initial temperature of the rod is 25∘C, and its specific heat capacity is 500 J/kg°C. Calculate the final temperature of the rod after 5 minutes

Points to Remember

- The mass or region outside the system is called the surroundings, and the surface that separates the system and the surroundings is called the boundary
- An extensive property is a property that depends on the amount of matter in a sample. Mass and volume are examples of extensive properties.
- An intensive property is a property of matter that depends only on the type of matter in a sample and not on the amount. Temperature and pressure are examples of intensive properties.
- Heat is transferred by three different methods: conduction, convection, and radiation.
- Heat capacity (*H)* of a particular sample of a substance is defined as the amount of energy needed to raise the temperature of that sample by 1°C
- Specific heat is the quantity of heat required to raise the temperature of one gram of substanceby One-Celsius degree
- Heat engine receives heat from source, transforms some portion of heat into work and rejects balance heat to sink.
- A heat pump is a device used to warm and sometimes also cool buildings by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle.

Self-Reflection

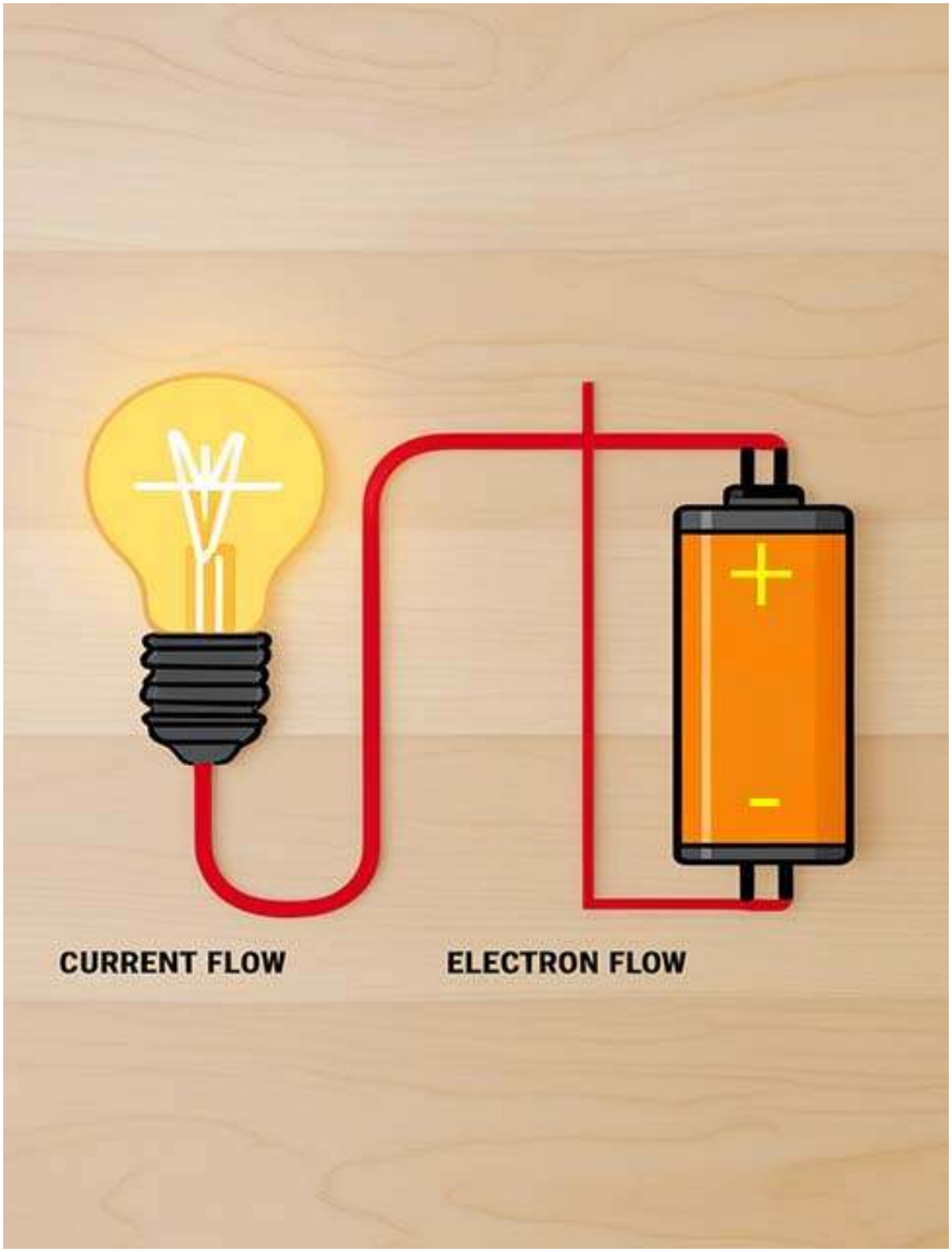
1. Read the statements across the top. Put a check in a column that best represents your level of knowledge, skills and attitudes.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience of doing this.	I have a lot of experience with this.	I am confident in my ability to do this.

2. the table above and share results with the trainer for further guidance

Areas of strength	Areas for improvement	Actions to be taken to improve
1. **2.** **3.**	**1.** **2.** **3.**	**1.** **2.** **3.**

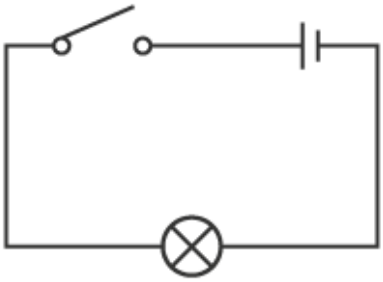
UNIT 5: EXAMINE EFFECTS OF ELECTRIC CURRENT FLOW IN DC ELECTRIC CIRCUIT



Unit summary

This unit provides you with the knowledge, skills and attitudes required to Examine effects of electric current flow in DC electric circuit required to apply mechanics and properties of matter. It covers the Simple electric circuit, Electric current, resistances and voltages in DC electric circuits and Electric energy, work and power in DC electric circuit.

Self-Assessment: Unit 5



Study the above figure and answer the following questions.

What do you see in the figure?

1. What do you think will happen if we connect a battery to a bulb using wires?
2. Why do we need a battery in a circuit?
3. Can a bulb light up without wires? Why or why not?
4. If the bulb doesn't light up, what might have gone wrong?
5. What do you think the switch in a circuit does?
6. At the end of this unit, you will assess yourself again.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Define DC electric circuit, electric current, electric resistance and electric voltage					

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
identifying instruments used in dc electric circuit					
State Ohm's law					
Description of Combination of resistors					
Description of lectric cells					
State Kirchhoff's laws					
Describe energy, power in dc electric circuit					
Identifying effects associated with electric current in a circuit					



Key Competencies:

Knowledge	Skills	Attitudes
1. Define DC electric circuit, electric current, electric resistance and electric voltage	**1.** interpret dc electric circuit with its components	**1.** Having curiosity, Attention to Detail, patience
2. Identifying instruments used in dc electric circuit	**2.** Analyze instruments used in dc electric circuit	**3.** Having attention to detail and curiosity

Knowledge	Skills	Attitudes
3. state Ohm's law	**4.** Analyze ohm's law	**3.** Being interested in connecting theoretical knowledge
4. description of Combination of resistors	**5.** Evaluate Combination of resistors	**4.** Having patience and collaborations
5. Description of Electric cells	**6.** Conduct experiment and graphing electrical cell	**5.** Having attention to detail and curiosity
6. State Kirchhoff's laws	**6.**Analyze Kirchhoff's laws	**6.** Having critical thinking and interest in theoretical
7.Describe energy, power in dc electric circuit	**7.**Solve energy, power in dc electric circuit	**7.** Having precision and Attention to Detail
8.Description of effects associated with electric current in a circuit	**8.** Analyze effects associated with electric current in a circuit	**9.** Having curiosity and critical thinking

Discovery activity:

Task 41:

Read the following scenario and answer the questions follows:

A trainee connects a battery, a resistor, and a bulb in a simple DC circuit. The battery provides a voltage of 9 volts, and the resistor has a resistance of 3 ohms. The trainee notices that the bulb lights up but wonders how the current flows and why the brightness of the bulb depends on the resistor.

a) What does the battery do in this circuit?
b) How does the resistor affect the current flowing through the circuit?
c) If the resistor's value increases, what would happen to the brightness of the bulb?
d) Can you calculate the current in the circuit using the given voltage and resistance?

e) Why do you think the bulb lights up when the circuit is complete?

Topic 5.1: Description of simple electric circuit

Activity 1: Problem Solving

Task 42:

Answer the following questions

1. What is Ohm's Law?
2. Write the formula for Ohm's Law and explain each term in it.
3. A circuit has a voltage of 12V and a resistance of 6Ω. How much current flows through the circuit?
4. What is the unit of resistance, and what does it measure?
5. What instrument is used to measure electric current in a circuit?
6. What instrument is used to measure resistance?
7. In a circuit with three wires meeting at a junction, if 3A flows in one wire and 2A flows out another wire, what is the current in the third wire?
8. What does Kirchhoff's Voltage Law (KVL) state about the voltage in a closed circuit?
9. In a circuit with a 12V battery and two resistors, if one resistor drops 5V, how much voltage is dropped by the other resistor

Key Facts 5.1a: DC electric circuit

DC electric circuit

Simple DC electric circuit is a circuit that contains the three basic components needed for an electric circuit to function. Three basic components are Source of voltage, Conductor and Resistor.
The closed path in which the direct current flows is called the **DC circuit**. The current flows in only one direction and it is mostly used in low voltage applications. The resistor is the main component of the DC circuit.

Elements of DC electric circuit

Elements of a DC circuit are mainly resistive, which contain a DC battery, a switch, ammeter, voltmeter, a load lamp and connecting leads.

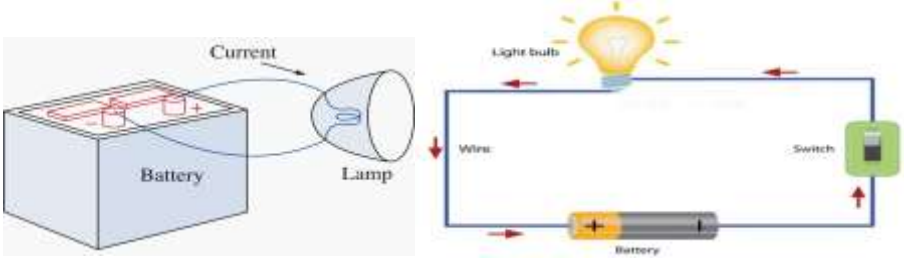


Figure 38: simple dc circuit

Electric current is the movement of electrons or ions through an electrical conductor or space. It is measured in Ampere (A).

Electrical resistance is the electrical quantity that measures how a device or material reducesthe electric current flow through it. It is a ratio between the voltages applied to the current flowing through it.

$\boldsymbol{R = \frac{V}{I}}$ It is measured in Ohms ($\boldsymbol{\Omega}$)

Voltage is the difference in electric potential between two points. It is measured in Volt (V)

Measuring instruments used in DC electric circuit

- ✓ **Ammeter** is a measuring instrument used to measure the current in a circuit. Electric currents are measured in Amperes (A), hence the name.



Figure 39Ammeter

- ✓ **Voltmeter** is a vital instrument used to measure voltage.



Figure 40: Voltmeter

- ✓ **Ohmmeter** is a type of electronic device that is mostly used to measure the electrical resistance of a circuit, and its unit of resistance is an ohm.

- ✓ **Multimeter** is an instrument used to measure DC & AC voltages, DC & AC currents and resistances of several ranges. It is also called Electronic Multimeter or Voltage Ohm Meter (VOM).

Ohm's law

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship: $I = \frac{V}{R}$

Where I is the current through the conductor in units of amperes, V is the voltage measured across the conductor in units of volts, and R is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the R in this relation is constant, independent of the current.

Conductors which obey Ohm's Law have a constant resistance when the voltage is varied across them or the current through them is increased. These conductors are called **ohmic conductors**. A graph of the current vs. the voltage across these conductors will be straight-line. Some examples of ohmic conductors are circuit resistors and nichrome wire.

Non-ohmic conductors are those that do not follow ohm's law which means that their resistance changes with changing current and voltage.

Combination of resistors

1. Series circuits

A series circuit is a circuit in which resistors are arranged in a chain, so the current has only one path to take. The current is the same through each resistor. The total resistance of the circuit is found by simply adding up the resistance values of the individual resistors:

Equivalent resistance of resistors in series: $R = R_1 + R_2 + R_3 + ...$

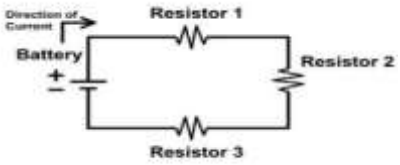


Figure 41: resistors in series

A series circuit is shown in the diagram above. The current flows through each resistor in turn.

2. Parallel circuits

A parallel circuit is a circuit in which the resistors are arranged with their heads connected, and their tails connected. The current in a parallel circuit breaks up, with some flowing along each parallel branch and re-combining when the branches meet again. The voltage across each resistor in parallel is the same.

The total resistance of a set of resistors in parallel is found by adding up the reciprocals of the resistance values, and then taking the reciprocal of the total:

Equivalent resistance of resistors in parallel: $1/R = 1/R_1 + 1/R_2 + 1/R_3 + ...$

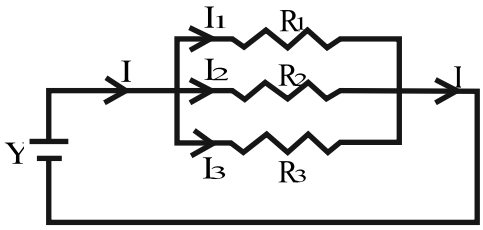


Figure 42: resistors in parallel

A parallel circuit is shown in the diagram above. In this case the current supplied by the battery splits up, and the amount going through each resistor depends on the resistance. If the values of the three resistors are:

$R_1 = 8\Omega$. $R_2 = 8\Omega$ and $R_3 = 4\Omega$

3. Circuits with series and parallel components (In mixture)

If we combined a series circuit with a parallel circuit, we produce a Series Parallel circuit which makes the arrangement of resistors in mixture

R1 and R2 are in parallel and R3 is in series with R1 R2. The double lines between R1and R2 are a symbol for parallel. We need to calculate R1 R2 first before adding R3.

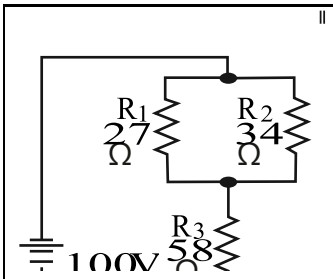


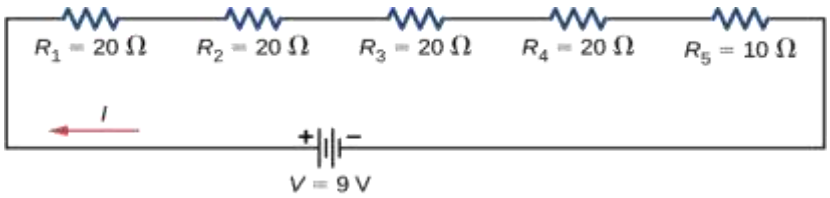
Figure 43: resistors in mixture

Activity 2: Guided Practice

Task 43:

Solve the problems below

1. If a circuit has a voltage of 10V and a current of 2A, what is the resistance of the circuit?
2. A resistor has a resistance of 5Ω, and a current of 2A flows through it. What is the voltage across the resistor?
3. Find the equivalent resistance in the circuit below:



Key Facts 5.1b: Electric cells

Electric cells

An electrical cell is a **device used to generate electricity**, or to make chemical reactions by applying electricity. A battery is one or more cells connected. This cell is also known as electrochemical cells.

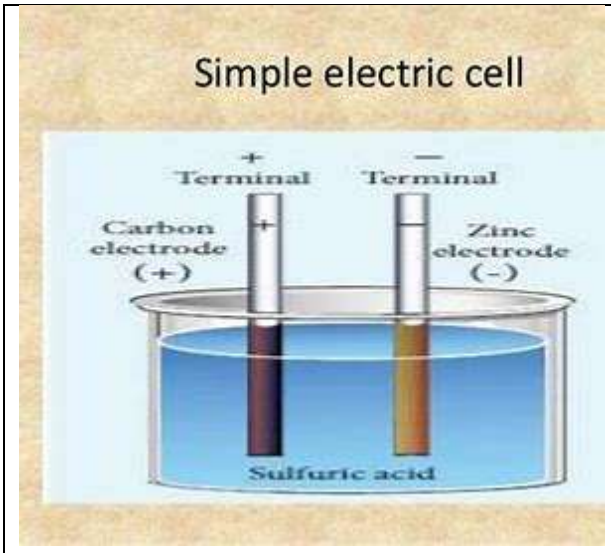


Figure 44: Simple electric cell.

What is the e.m.f. of a cell?

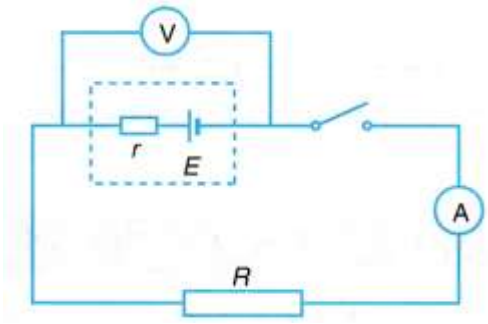


Figure 45: e.m.f. of a cell

Therefore the e.m.f. of a cell can also be defined as the potential difference across the cell in an open circuit. When the switch is closed, the circuit is a closed circuit and the current flows in the circuit. The ammeter gives a reading.

Internal resistance

What is meant by the internal resistance of a cell?

1. In an open circuit when there is no current flow, the potential difference, V across the battery is the electromotive force, E of the battery.
2. In a closed circuit, when there is a current flow in the circuit, the potential difference, V across the cell is smaller than the electromotive force, E of the cell.
3. This drop in potential difference across the cell is caused by the internal resistance of the cell.

4. The **internal resistance** of a source or cell is **the resistance against the moving charge due to the electrolyte** in the cell.
5. Work is done to drive the charge against the internal resistance.
6. This causes a drop in potential difference across the battery as charges flow through it.

Cells network

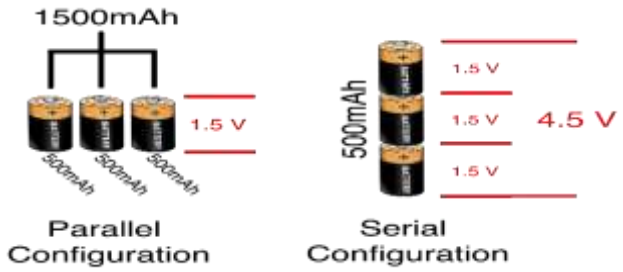


Figure 46: Cells network

Combination in series:

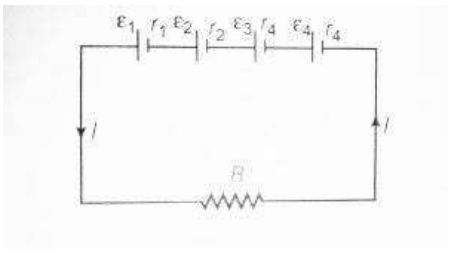


Figure 47: Cells combined in series.

Let us consider cells combined in series of, respectively, emf and internal resistance E1, E2, E3...En and r_1, r_2, r_3 ... r_n,

The p.d at the terminals of the combination is

Vt = V1 + V2 + V3 + ... + Vn = Et – Irt

= E1 – Ir1 + E2 – Ir2 + E3 – Ir3 +.....+En – Irn

= E1 + E2 + E3 + ... + E3 – I (r1 +r2 + r3 + ...rn)

Then Et = E1 + E2 + E3 +.....+En and rt = r1 +r2 + r3 + ...rn

We write Et = Ei and rt

When two or more cells are arranged in series, the total emf is the algebraic sum of their emfs and the total internal resistance is the algebraic sum of their internal resistances For n identical cells of emf E and internal resistance r each, we have:

Et = nE and rt = nr

The intensity of the current produced is:

$$I = \frac{Et}{(R + rt)} = \frac{nE}{(R + nr)}$$

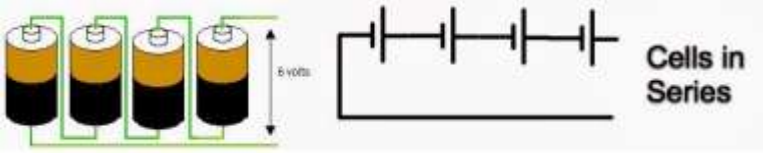


Figure 48: Each cell is of emf 1.5V.

The emf of the combination is 6V, to mean 1.5V+1.5V+1.5V+1.5V

Note: A series arrangement is used to increase the voltage, also the total internal resistance of the circuit, so the energy loss due to internal resistance is greater than for a single cell.



Figure 49: Series arrangement of dry cells in a torch.

The two cells in the figure above act like one cell of emf, which equals to the sum of the two cells.

Combination in parallel

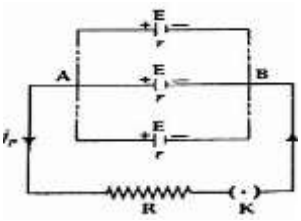
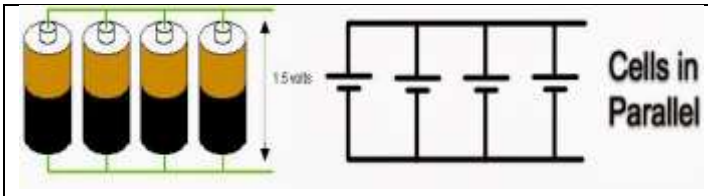


Figure 50: Cells connected in parallel.

Consider a parallel arrangement of n identical cells having (E, r) as characteristics each. The total emf of the arrangement is the emf of one cell and the total internal resistance is found by considering the parallel arrangement of resistors.

Then, we have: Et = E and rt = r/ n



In the figure, each cell having an emf of 1.5 V, the total emf is of 1.5V

The intensity of the current produced is:

$$I = \frac{Et}{(R+rt)} = \frac{E}{(R+\frac{r}{n})} = \frac{E}{\frac{(nR+r)}{n}}$$

finally

$$\boldsymbol{I = \frac{nE}{(nR + r)}}$$

Note: The parallel arrangement is useful normally only if the emfs are the same. A parallel arrangement is not used to increase the voltage, but rather to provide large currents. Each of the cells in parallel must produce only a fraction of the total current, so the energy loss due to internal resistance is less than for a single cell; the batteries will be exhausted less quickly.

Activity 3: Application

Task 44:

Read carefully the following statements and answer the related questions

1. You are designing a basic science project where you use an electric cell to power a small motor. What is an electric cell, and how does it differ from a battery?
2. You want to measure the maximum potential difference your cell can produce before using it in a circuit. What is the e.m.f. of a cell, and how is it measured?
3. You notice that the performance of a remote-controlled car powered by batteries decreases over time. Why is it important to understand the internal resistance of a cell in such applications?
4. You connect four cells, each with an e.m.f. of 1.5V, in series for a science experiment. What will be the total e.m.f. of the combination?

5. Your flashlight uses two cells to produce bright light. Why do torchlights often use series-connected cells?
6. Your smartphone battery drains faster when using multiple apps simultaneously. How does internal resistance affect the efficiency of a smartphone battery in such situations?

Topic 5.2: Determination of Electric current, resistances and voltages in DC electric circuits

Activity 1: Problem Solving

Task 45:

Answer the following questions

1. What is meant by a "complete path" in an electrical circuit?
2. Describe the path taken by current in a circuit with a battery, resistor, and LED connected in series.
3. What happens if the circuit path is not complete?
4. Define a junction in an electrical circuit.
5. What is a branch in an electrical circuit?
6. In a circuit with two junctions, how many branches are typically present?
7. How do you identify a junction in a given circuit diagram?

Key Facts 5.2: Key concepts

Path: The path starts from the positive terminal of the battery, flows through the resistor, then through the LED, and finally returns to the negative terminal of the battery. This constitutes a complete path for the current.

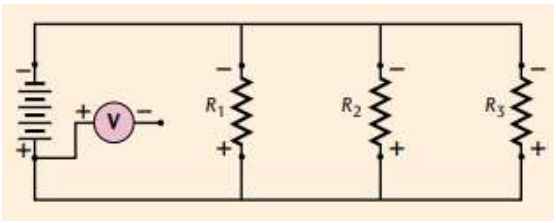


Figure 51: Parallel circuit

A junction is a point where **at least three circuit paths meet**. A branch is a path connecting two junctions.

A junction is a point where at least three circuit paths meet.

A branch is a path connecting two junctions.

In the circuit below, there are two junctions, labeled a and b. There are three branches: these are the three paths from a to b.

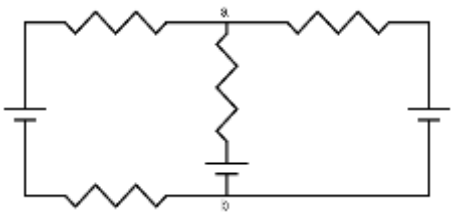


Figure 52: Circuit branch

Voltage supply



Figure 53: Voltage supply.

What is supply voltage?

Supply voltage is the input/source voltage given into a circuit or system to make it work/try to make it work.

Voltage drop is the decrease of electrical potential along the path of a current flowing in an electrical circuit.

Voltage drops in the internal resistance of the source, across conductors, across contacts, and across connectors are undesirable because some of the energy supplied is dissipated.

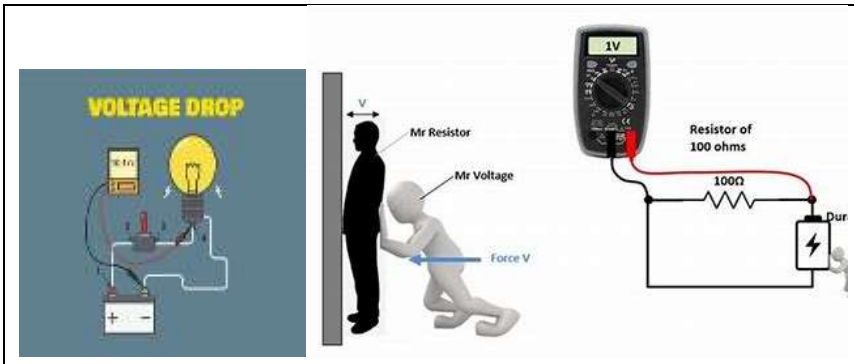


Figure 54: Voltage drop

Voltage gain is the ratio of output **voltage** to input **voltage**

Conservation of charges

This principle states that the total electric charge in an isolated system remains constant over time; it is neither created nor destroyed but can be transferred or redistributed within the system.

Kirchhoff's rules:

Junction rule: The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction: $\Sigma I_{in} = \Sigma I_{out}$

Loop rule: The sum of the potential differences across all elements around any closed-circuit loop must be zero: $\Sigma V_{\text{closed loop}} = IR$

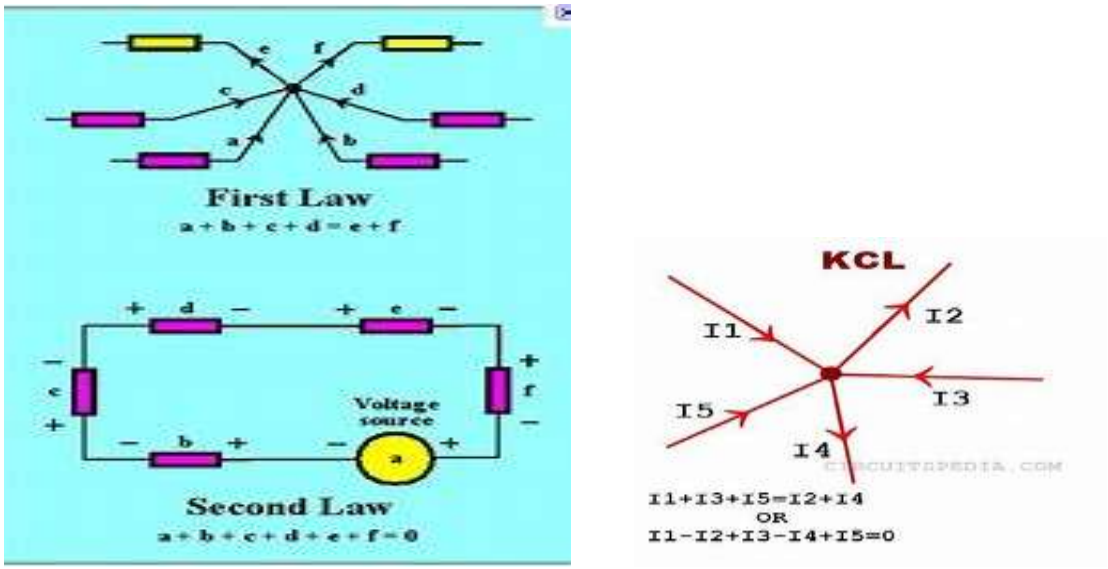
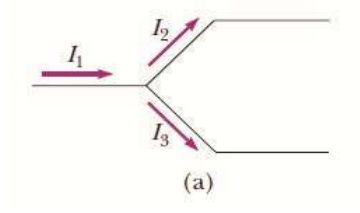
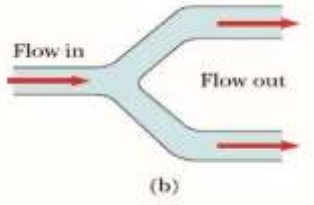


Figure 55: Loop and junction law

	
(a) Kirchhoff's junction rule: Conservation of charge requires that all charges entering a junction must leave that junction; therefore, $I_1 = I_2 + I_3$	*(b) A mechanical analog of the junction rule: the amount of water flowing out of the branches on the right must equal the amount flowing into the single branch on the left.*

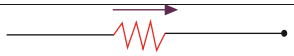
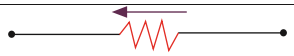
 *a* *b* V = – IR	 *a* *b* V = + IR
E (c) *a* *b* V = + E	*E* (d) *a* *b* V = – E

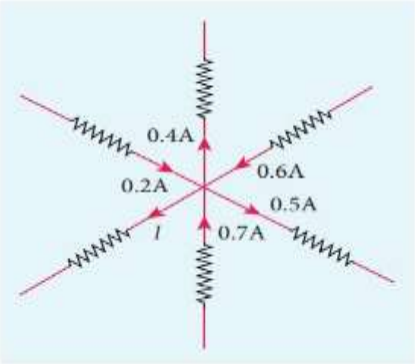
Table 3: Rules for determining the potential differences across a resistor and a battery (the battery is assumed to have no internal resistance). Each circuit element is traversed from left to right.

Activity 2: Guided Practice

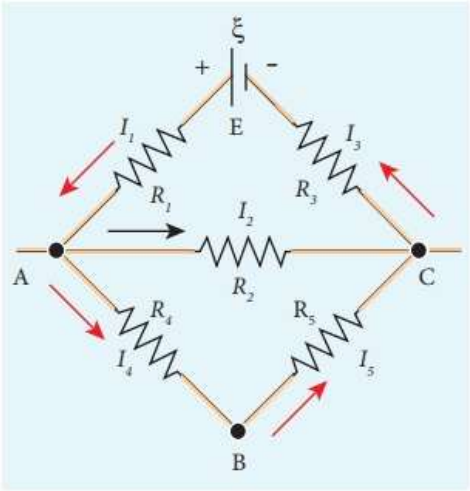
Task 46

Solve the following questions

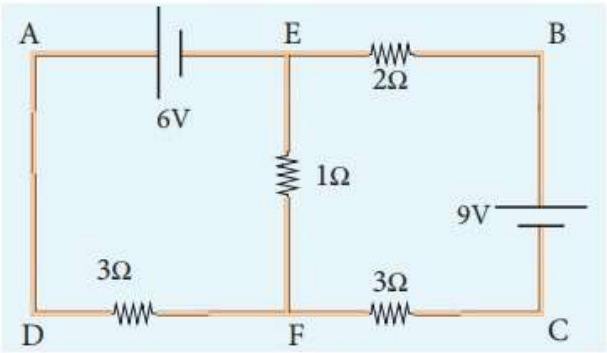
1. From the given circuit find the value of I.



2. The following figure shows a complex network of conductors which can be divided into two closed loops like ACE and ABC. Apply Kirchhoff's voltage rule.



3. Calculate the current that flows in the 1 Ω resistor in the following circuit.



Activity 3: Application

Task 47

Read carefully the following statements and answer the related questions

1. An office has multiple computers, printers, and air conditioners connected to a single distribution panel. The facilities manager wants to ensure no circuit is overloaded. How can Kirchhoff's Current Law assist in calculating the current in each branch and prevent overloading?
2. A technician is troubleshooting a parallel circuit powering LED light. Some lights are dimmer than others. Using Kirchhoff's Current Law, how can they determine if the current through each branch is sufficient and evenly distributed?
3. A car's electrical system includes headlights, air conditioning, and a sound system, all connected to the battery. An issue arises where some components aren't receiving enough voltage. How can Kirchhoff's Voltage Law help diagnose and resolve the voltage drops?
4. In a hybrid electric vehicle, the power is distributed among the battery, generator, and motor. If the vehicle experiences uneven power delivery, how can Kirchhoff's laws help balance the energy flow and optimize performance?

Topic 5.3: Determination of Electric energy, work and power in DC electric circuit

Activity 1: Problem Solving

Task 48:

Answer the following questions

1. What is electrical energy, and how is it related to charge and voltage ?
2. Define electrical work. How is it calculated in terms of charge and voltage ?
3. What is electrical power ? How is it mathematically expressed in terms of voltage and current?
4. State the relationship between electrical power, energy, and time.
5. How is the unit of electrical power (watt) defined?

Key Facts 5.3a: Calculations of energy and power in DC electric circuit

Electrical energy refers to the ability or capacity of an electrical system to perform work.

The unit of energy is **joule(J)**

Electrical energy (E)

The following formula gives the relationship between electrical energy and power

$$E = P \times t$$

$$P = \frac{E}{t}$$

Where E: energy in joule (j)

P: power in watts (w)

T: time in seconds(s)

Electrical work:

Electrical work refers to the transfer of energy that occurs when an electric charge moves through an electric field and performs work on other charges or devices in a circuit. Work is done when a force causes a displacement, and in the case of electrical work, this force is the electric field, and the displacement involves the movement of charges. Potential difference is the work done per unit charge to drive it through the current.

V = $\frac{Work\ done\ (W)}{charge(Q)}$

V = $\frac{W}{Q}$ $or\ W = VQ$……(i)

where, W is the electrical work that is converted into heat energy E.

but current is the rate of flow of charges i.e

current , $I = \frac{charge\ (Q)}{time(t)}$, in symbols, $I = \frac{Q}{t}$

Q = It……(ii)

From equations(i) and (ii), we obtain.

E = V Q = V(It)

The SI unit for electrical energy is **the joule(j)**

Alternative equations for finding electrical energy, E are obtained by replacing V or I in the equation, **E = V(It)** as shown below:

From ohm's law V = IR

Substituting for V in equation E = V(It), we get ,

E = (IR)It

Electrical energy, $E = I^2Rt$

Also, from ohm's law $I = \frac{V}{R}$

Substituting for I in equation E = VIt, we get

$$E = V\left(\frac{V}{R}\right)t$$

Electrical energy, $E = \frac{V^2t}{R}$

Example: A current of 2.0 A is passed through a resistor of 20 Ω for 1.0 hour. Calculate the electrical energy converted into heat energy in the resistor.

Solution

Electrical energy $E = I^2Rt = (2.0)^2 \times 20 \times (1 \times 60 \times 60) = 288\ 000\ J = 2.88 \times 105\ J$

Electrical power: is the rate at which energy is converted to heat energy**.**

Power, $P = \frac{Electrical\ energy\ transformed}{time} = \frac{VIt}{t} = VI$

The SI unit of power **is watts(W)**

So, electrical power is the rate at which work is done or energy is transferred.

In SI units, power is measured in **watts (W),** electric current I, in ampere **(A)**, voltage, V, in volts **(V)**.

Activity 2: Guided Practice

Task 49:

Answer the following questions

1. An 800W toaster is switched on for one minute. What is the energy used?
2. Calculate the energy consumed by a 2-kW appliance operating for 3 hours
3. A resistor of 10 Ω is connected to a 20 V power supply. Calculate the power dissipated by the resistor
4. A charge of 10 C moves through a potential difference of 12 V. Calculate the electrical work done.

Key Facts 5.3b: Effects associated with electric current in a circuit Conservation of charges

✓ **Joule effect**

The Joule effect, also called **Joule's law**, is the thermal manifestation of electrical resistance. [8]

It states that **the heat** generated due to the current that flows along a conductor is proportional to the **electrical resistance**, the **amperage**, and **the time**.

✓ **Chemical effect**

When electric current passes through a conducting solution, it causes chemical reactions. This is called **the chemical effect of electric current.**

chemical effect of electric current may cause:

I. formation of gas bubbies at the electrodes.
II. Deposit of metal on the electrodes.
III. Change in color of the solution.

[8] https://www.sciencedirect.com/topics/chemistry/joule-effect

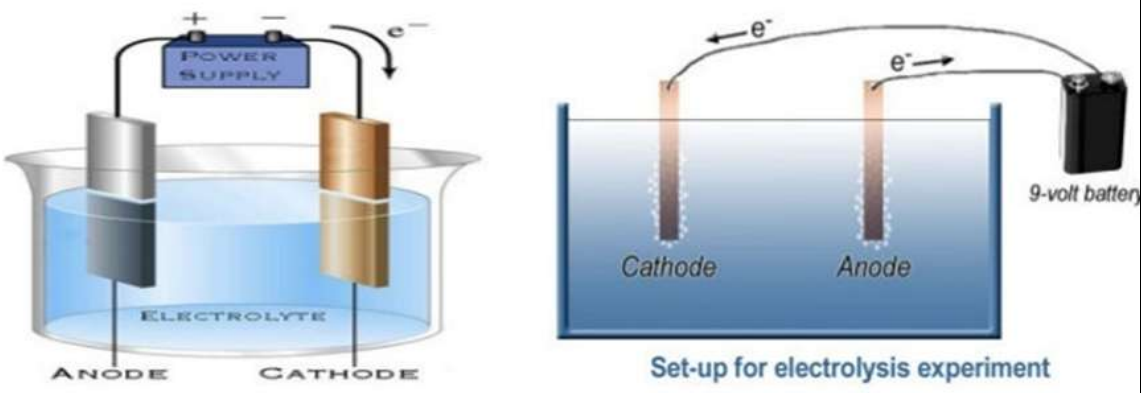


Figure 56: electrolysis

✓ **Magnetic effect:**

When electric current flows through a current carrying conductor, it produces a **magnetic field around it. This can be seen with the help of a magnetic needle which shows deflection. The more the current, the higher the deflection**

Activity 3: Application

Task 50:

Read carefully the following statements and answer the related questions

1. You plug your phone into a charger that provides a voltage of 5 volts and a current of 2 amperes. After 10 minutes, your phone is fully charged. How much electrical work is done during the charging process?
2. You switch on a 100W light bulb in your room and forget to turn it off. It stays on for 5 hours before you realize. How much electrical energy has the bulb consumed?
3. You use an electric kettle with a power rating of 2000W to boil water for tea. It takes 5 minutes to bring the water to a boil. How much energy is consumed during this time?
4. You install a solar panel on your rooftop that produces 250W of power under full sunlight. On a sunny day, the panel receives 8 hours of sunlight. How much energy does the solar panel generate during the day?

Formative Assessment

1. Define electric power and provide the formula for calculating power in a DC electric circuit
2. State Ohm's Law and provide the mathematical expression for it.
3. Define electric work in the context of DC electric circuits.
4. State Kirchhoff's Current Law (KCL) in a DC electric circuit.
5. If a resistor has a resistance of 50 ohms and a current of 2 amperes flows through it, what is the voltage across the resistor?
6. If the resistance in a circuit remains constant and the voltage is doubled, what happens to the current?
7. Consider a circuit with three resistors connected in series. If the voltage across the entire circuit is 12 volts and the resistances are 2 ohms, 3 ohms, and 4 ohms, calculate the total current flowing through the circuit.
8. In a parallel circuit with three resistors, if the voltage across each resistor is 6 volts and the resistances are 5 ohms, 7 ohms, and 10 ohms, calculate the total current.
9. Explain the relationship between electric power, current, and voltage in an electrical circuit.
10. Calculate the electrical energy consumed by a device with a power rating of 50 watts, operating for 3 hours.

Points to Remember

- DC circuit is the closed path in which the direct current flows.
- Elements of a DC circuit are mainly resistive, which contains a DC battery, a switch, ammeter, voltmeter, a load lamp and connecting leads.
- Ohm’s law states that the current through a conductor between two points is direct proportional to the voltage across the two points.
- An electrical cell is a device used to generate electricity, or to make chemical reactions by applying electricity.
- The intensity of the current produced in series is:

$$I = \frac{Et}{(R + rt)} = \frac{nE}{(R + nr)}$$

- The intensity of the current produced in parallel is:

$$\boldsymbol{I = \frac{nE}{(nR + r)}}$$

- **Conservation of charges**

This principle states that the total electric charge in an isolated system remains constant over time; it is neither created nor destroyed but can be transferred or redistributed within the system.

- **Kirchhoff's rules:**

Junction rule: The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction: $\Sigma I_{in} = \Sigma I_{out}$

Loop rule: The sum of the potential differences across all elements around any closed-circuit loop must be zero: $\Sigma V_{\text{closed loop}} = IR$

Self-Reflection

1. Read the statements across the top. Put a check in a column that best represents your level of knowledge, skills and attitudes.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience of doing this.	I have a lot of experience with this.	I am confident in my ability to do this.

2. Fill in the table above and share results with the trainer for further guidance.

Areas of strength	Areas for improvement	Actions to be taken to improve
1.	**1.**	**1.**
2.	**2.**	**2.**
3.	**3.**	**3.**


RAPHIC CAMERA
MICROSCOPE
TELESCOPE



Unit summary

This unit provides you with the knowledge, skills and attitudes required to Apply optical instruments to apply mechanics and properties of matter. It covers the Optical instruments, Magnification of optical instruments and Correction of optical aberrations.

Self-Assessment: Unit 6

1. Study the unit illustration above and answer the following questions.

a) What do you see in the illustration?

b) What topics do you think will be covered under this unit based on the illustration?

2. Fill in and complete the self-assessment table below to assess your level of knowledge, skills and attitudes under this unit.

a) There is no right or wrong ways to answer this assessment. It is for your own reference and self-reflection on the knowledge, skills and attitudes acquisition during the learning process.

b) Think about yourself: do you think you have the knowledge, skills or attitudes to do this? How well?

c) Read the statements across the top. Put a check in column that best represents your level of knowledge, skills or attitudes.

3. At the end of this unit, you will assess yourself again.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Define Geometrical optics					
Identify Single lens optical instruments					
Identify Multi-lens optical instruments					
Describe Magnification of microscope					
Describe Magnification of telescope					

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience doing this.	I have a lot of experience with this.	I am confident in my ability to do this.
Describe Spherical aberration					
Describe Chromatic aberrations					
Describe Astigmatic aberration					

Key Competencies:

Knowledge	Skills	Attitudes
1. Define Geometrical optics	1. interpret geometric optics concept	1. Having curiosity and willingness to learn
2. Identify Single lens optical instruments	2. analyze Single lens optical instruments	2. Having attention to Detail, critical thinking and Open-Mindedness
3. Identify multi- lens optical instruments	3. analyze multi- lens optical instruments	3. Having critical Thinking, Collaboration and Responsibility
4. Describe Magnification of microscope	4. solve problems related to Magnification of microscope	4. Having critical Thinking, Logical Reasoning, Patience
5. Describe Magnification of telescope	5. Solving problems related to Describe Magnification of telescope Applying Relevant Concepts	5. Having attention to Detail, Logical Reasoning and Open-Mindedness
6. Describe Spherical aberration	6.analyze Spherical aberration	6. Being interested in theoretical knowledge, critical thinking
7. Describe Chromatic aberrations	7.analyze Chromatic aberrations	7. Being interested in theoretical knowledge, critical thinking
8. Describe Astigmatic aberration	8.analyze Astigmatic aberration	8. Being interested in theoretical knowledge, critical thinking

Discovery activity:

Task 51:

Read the scenario below and then answer related questions.

Scenario

In a science museum, tiny organisms are being viewed through an instrument that makes them look bigger. A picture of these organisms is taken and then displayed on a big screen for everyone to see. Later, another instrument is used to look at faraway stars, and those images are also shown on the big screen for comparison

1. If you were to take a picture from very far away, what do you think would happen to the clarity of the image?
2. Why do you think we need a different instrument to look at faraway stars?
3. What do you think we would see if we tried to look at the stars without using this instrument?
4. What are the similarities and differences between the images of tiny organisms and the images of stars on the big screen?

Topic 6.1: Description of optical instruments

Activity 1: Problem Solving

Task 52:

Referring to the scenario given above (Task51), perform the following tasks:

1. Which tool is used to take a picture of the tiny organisms to display on the big screen?
2. What do we use to directly observe tiny organisms that are too small to see with our eyes?
3. Which instrument is needed to observe distant stars that are too far away to see clearly?

4. What is used to display the images of the organisms and stars on the big screen for everyone to see?
5. Which part of our body helps us see the images on the big screen directly?

Key Facts 6.1a: Single lens optical instruments

Geometrical optics, or **ray optics**, is to study the geometry of paths of lights and their imagery through optical systems.

We use our eyes to see and view different objects. The eye cannot be used to view clearly these objects at night, and some distant objects or hidden objects. Objects which cannot be viewed by the eye can be focused using other instruments. All the instruments used to aid vision are called Optical instruments.

6.1.1. Single lens optical instruments

Single-lens systems has to either the user to **snap two photos consecutively (with different angles) or use a lesser depth approximation.**

The human eye

The eye is a biological instrument used to see objects at different distances. It uses **a convex lens system** to form **a small, inverted, real image** of an object infront of it.

The structure of the eye:

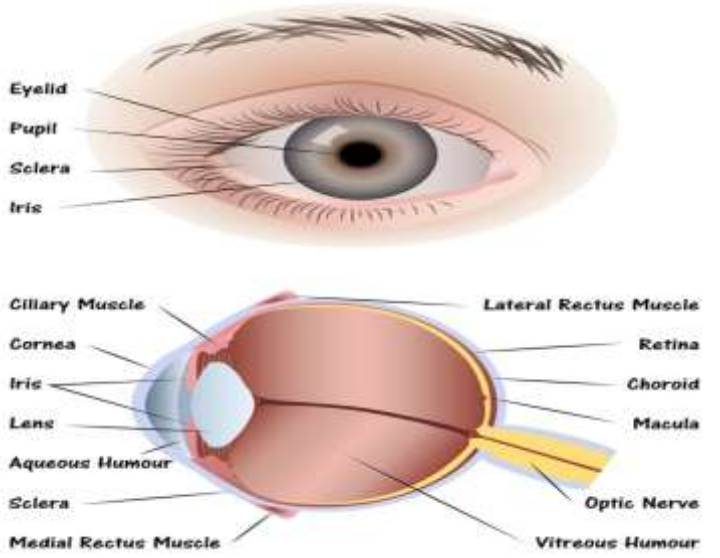


Figure 57: The Human eye.

Functions of the parts of the eye:

The cornea: It is made out of a fairly dense, jelly like material which provides protection for the eye, and seals in the aqueous humour.

The aqueous humour: This is a waterly liquid that helps to keep the cornea in a rounded shape, simila r to that of a lens.

The iris: This controls the amount of light entering the eye. The amount of light that enters the eye is one of the factors determining how focused an image is on the retina. The brighter the light the eye is exposed to, the smaller the iris' opening will be.

The lens: This is used to focus an image on the retina. It controls the bending of light rays by change of its shape, a process called accommodation, which is done by the ciliary muscles.

The ciliary muscles: These control the thickness of the lens during focusing. By contracting or squeezing the lens, they make it thicker and vice versa.

The retina: This is the light sensitive part of the eye and it is where images are formed. It contains millions of tiny cells which are sensitive to light.

The vitreous humour: This is a jerry like substance that helps the eye to keep its round shape. It is very close in optical density to the lens material.

The yellow spot: This is a small area on the retina where the sharpest image, that is, the finest detail can be seen.

The optic nerve: This is the nerve that transmits images received by the retina to the brain for interpretation. The part of the eye where the optic nerve joins the retina is called the blind spot because no images can be observed at this point.

Visual Angle

The height of an object depends on the angle of elevation of its top from the eye. The larger the angle, the taller the objects. This angle is called the **visual angle**. The visual angle is the angle subtended at the eye by an object.

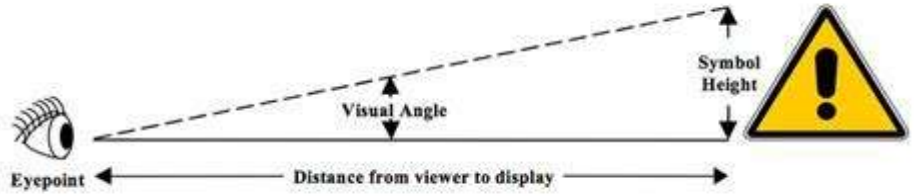


Figure 58: Visual Angle

Let us observe the flame of a candle: its two extremities A and B are seen by an eye at a certain angle. Expressed in radians, this angle has a measure: $\alpha = AB/D$

This angle decreases when the distance D increases and increases when the distance D decreases. It also increases when the length AB increases and decreases when AB decreases. We call it visual angle of the object.

Accommodation of the eye

Accommodation of the eye is the ability of the eye to see near and distant objects.

Near point and far point of the eye:

The distance of 25 cm from the eye is called distance of most distinct vision or least distance for distinct vision. The range of accommodation of the normal eye is thus from 25 cm to infinity.

Defects of vision and their correction

Short-sightedness (myopia)

1) **Short-sightedness** is the defect whereby a person can see near objects clearly but cannot focus distant objects. His far point is nearer than infinity. This is because the eyeball is too long or the lens is too strong so that rays of light from a distance object are focused in front of the retina.
2) **Long-sightedness (hypermetropia)**

This is where a person can see distant objects clearly but cannot focus near objects. This is because either his eyeball is too short, or the eye lens is too weak (thin) so that rays of light from a close object are focused behind the retina.

This eye's near point is further than 25 cm.

3) Presbyopia

When people grow older, their eye lens become stiff and it becomes hard for the ciliary muscles to adjust it. Such people have a defect called Presbyopia. Presbyopia is the stiffening of the eye lens such that it is less capable of being adjusted by the ciliary muscles.

This defect is corrected by wearing bifocals spectacles whose lenses have a top part for looking at distant objects and a bottom part for close ones. These bifocal spectacles have a diverging top part to correct for distant vision and converging lower part for reading.

4) **Astigmatism**

This is the defect that occurs if the curvature of the cornea varies in different directions so that rays in different planes from an object are focused in different positions by the eye and the image is distorted. A person suffering from astigmatism sees one set of lines more sharply than others. This defect is corrected by wearing corrected lenses. These help to bend the incoming rays to correct for irregular refraction.

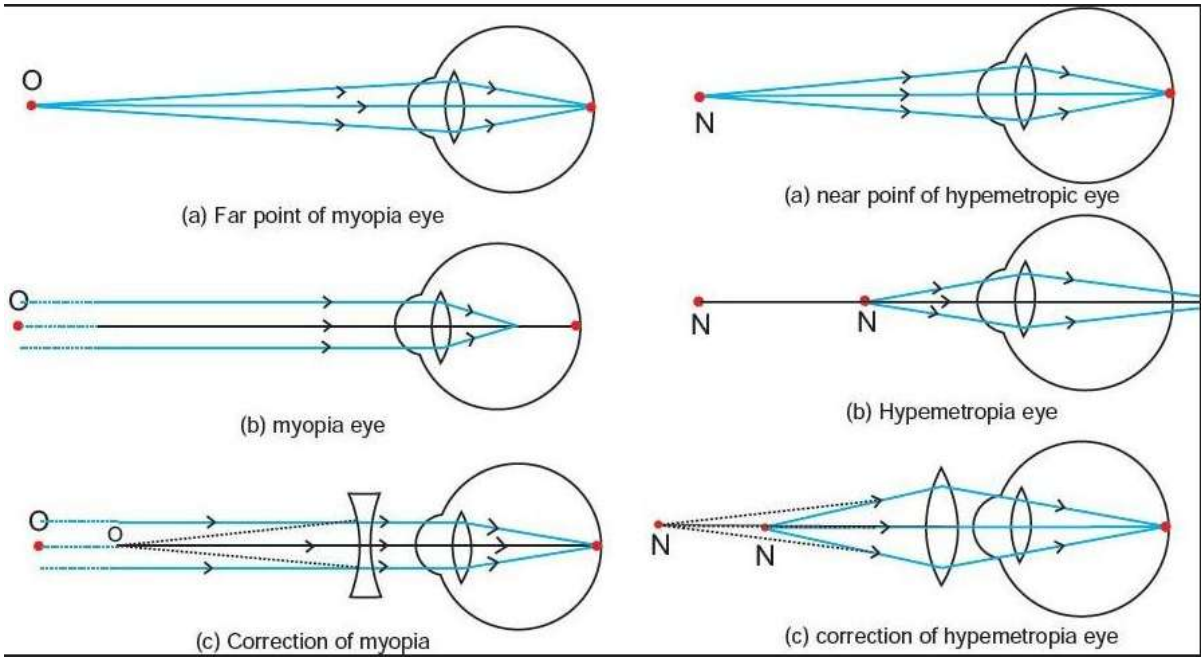


Figure 59: Eye defect and correction instruments.

Formation of an image by the eye

Light enters the eye through the transparent cornea, passes through the lens and is focused on the retina. The retina is sensitive to light and sends messages to the brain for interpretation. Although the image is inverted, the brain interprets it correctly.

Magnifying Glass (Simple Microscope)



Figure 60: Magnifying glass.

A magnifying glass consists of a thin converging lens and it is used to view very small organisms or parts of organisms, which cannot be easily seen by the naked eye.

Magnifying glass is convex lens that is used to produce a magnified image of an object. A magnifying glass forms a virtual, upright, magnified image of an object placed betweenthe lens and its principal focus.

For a given object, the position and size of the image formed by a lens can be found approximately by ray tracing. Algebraically, the relation between image and object distances, d_i and d_o, and the focal length *f*, is given by the thin lens equation: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

The ratio of image height to object height, which equals the **magnification** *m* for a lens, is

$$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

Object height and image heights are positive when measured upright and negative when measured downward.

Magnification is positive for an upright image and negative for an inverted image.

Magnification is dimensionless.

Formation of images by a magnifying glass

The magnification of a magnifying glass depends upon where it is placed between the user's eye and the object being viewed and the total distance between them.

The image is at the least distance of vision since the eyes are not strained and the magnifying glass is said to be in normal adjustment. A microscope is in normal adjustment if the final image is formed at the near point, and it is not in normal adjustment if the final image is at infinity.

Uses of magnifying glass: use the lens to help them read. In everyday life, magnifying glasses can be used to do a variety of things. The most common use for magnifying glasses would be how scientists use them, they use magnifying glasses to study tiny germs.

Single lens camera

A single-lens camera, commonly known as a point-and-shoot camera or a compact camera, is a type of camera that uses a single lens for both focusing and capturing images.

The image is upside down. The pin hole helps you to see the image of the object. This device is called a pinhole camera.

In our daily lives, we take photographs. We use a lens camera to take these photographs.

Notice that the image formed is inverted and coloured if the object is coloured. By placing a lens above the hole, you are making a lens camera from a pin hole camera.

Formation of images by a lens camera

We have already seen that when an object is beyond 2F of a thin converging lens, the image formed is smaller than the object.

A camera consists of a light- tight box with a convex (converging) lens at one end and the film at the other end. It uses the convex lens to form a small, inverted, real image on the film at the back.



Figure 61: A single lens camera

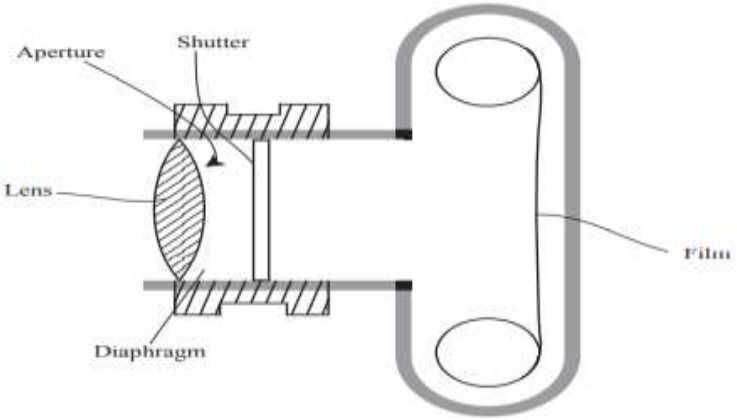


Figure 62: Inner parts of single lens camera

The lens focuses light from the object onto a light sensitive film. It is moved to and fro so that a sharp image is formed on the film. In many cameras, this happens automatically. In cheaper cameras, the lens is fixed and the photographer moves forwards and backwards to focus the object.

The diaphragm is a set of sliding plates between the lens and the film. It controls the aperture (diameter) of a hole through which light passes.

The shutter controls the exposure time of the film. It opens and closes quickly to let a small amount of light into the camera.

The exposure time affects the sharpness of the image. When the exposure time is short, the image is clear (sharp) but when it is long the image becomes blurred.

The film. This is where the image is formed. It is kept in darkness until the shutter is opened. It is coated with light sensitive chemicals which are changed by the different shades and colours in the image. When the film is processed, these changes are fixed, and the developed film is used to print the photograph.

Activity 2: Guided Practice

Task 53:

Solve the following questions

1. A magnifying glass has a focal length of 5 cm. If the image is formed at the position of least distinct vision (25 cm), find the following:

   a) What will the magnification be when the image is formed at 25 cm?
   b) If the image distance is 10 cm, what will the object distance be

   Focal length (f=5 cm)

   Least distinct vision (v=25 cm)

2. A telescope is used to observe distant stars. The objective lens has a focal length of 1.5 meters, and the eyepiece has a focal length of 10 cm. The object (star) is effectively at infinity.

Key Facts 6.1b: multi-lens optical instruments

Multiple lenses are devices like telescopes and microscopes, which use multiple lenses tocreate images.

Telescope

It is an optical instrument using lenses, curved mirrors, or combination of both to observe distant objects. It is also defined as various devices used to observe distant object by emission, absorption, or reflection of electromagnetic radiation.

Projector

It consists of illumination system and projection lens.

Illumination system consists of lamp, concave reflector and the condenser.

Illuminate is either a carbon electric arc or quartz lamp to give small but very high intensitysource of light in order to make image brighter.



Figure 63: Projector

Microscope

In daily life, microscopes are used in hospitals, in biology laboratories, etc.

To give a higher magnifying power, two lenses are needed. This arrangement of lenses makes a compound microscope. It produces a magnified inverted image of an object. A compound microscope is used to view very small organisms that cannot be seen using our naked eyes for example micro-organisms.



Figure 64: Compound microscope

A compound microscope consists of two convex lenses of short focal lengths referred to as the objective and the eye piece. The objective is nearest to the object and the eye piece is nearest to the eye of the observer.

The object to be viewed is placed just outside the focal point (at a distance just greater than the focal length) of the objective lens. This objective lens forms a real, magnified, inverted image at a point inside the principal focus of the eye piece. This image acts as an object for the eye piece and it produces a magnified virtual image. So the viewer, looking through the eye piece sees a magnified virtual image of a picture formed by the objective i.e. of the real image.

Activity 3: Application

Task 54:

Read carefully the following statements and answer the related questions

1. While walking in a park, a child notices a colorful butterfly up close. A moment later, they look at a plane flying high in the sky and are amazed at how quickly their eyes adjust focus. What mechanism in the human eye allows it to focus on objects at different distances, like the butterfly and the plane?
2. In a biology lab, a trainee examines a drop of pond water under a microscope and discovers tiny, moving microorganisms. They adjust the microscope to get a sharper view of the details. What property of a microscope allows it to magnify objects too small to be seen with the naked eye, like microorganisms in pond water?

Topic 6.2:Determination of magnification of optical instruments

Activity 1: Problem Solving

Task 55:

Read carefully the following scenario and answer the questions that follow
Scenario

A trainee is in a science laboratory examining a tiny insect under a microscope, and later, the same trainee uses a telescope to observe distant stars in the night sky. While studying the insect, the trainee uses the microscope to magnify the small creature and observe its details, such as its wings and legs. Later, the trainee points the telescope toward a distant star and marvels at how the stars seem larger and clearer compared to the naked eye view.

1. How does the microscope allow us to see fine details of tiny objects like the insect?
2. Why is it2 important to adjust the focus when using a microscope to examine tiny objects like the insect?
3. How does the telescope magnify distant objects, like stars, and make them appear closer?

Key Facts 6.2a: Magnification of microscope

a) The magnification of a microscope is a measure of how much larger an object appears when viewed through the microscope compared to the naked eye. Microscopes use a combination of Magnifying power of a simple microscope in normal adjustment

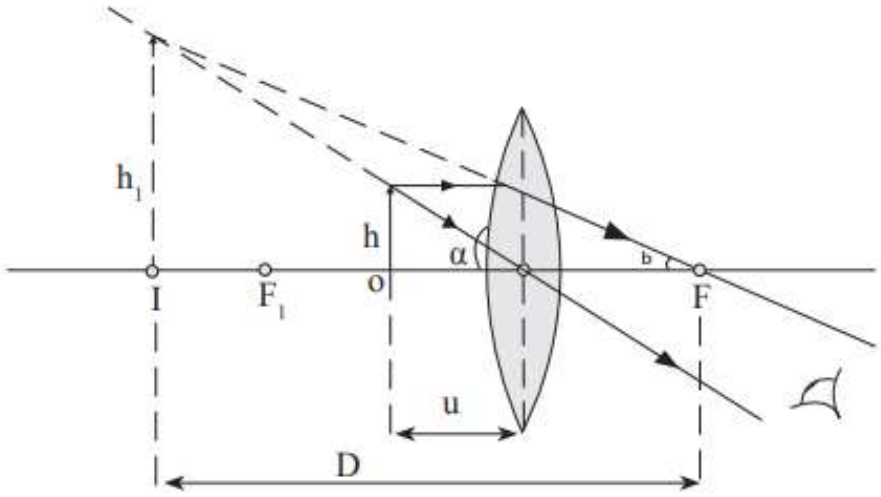


Figure 65: Image formed by a magnifying glass

Consider an object of height h placed at a given distance from the lens. Let β be the angle subtended by the image I to the lens. From the figure, tan β = h_1/D. It implies that β is very small and tan β ≈ β. Thus ***β = h_1/D***

Now suppose that the object is viewed at the near point by an aided eye and that it subtends an angle of α at the eye. Now tan α = h/D. For α small, tan α ≈ α. Thus **α = h/D** (2). It follows that the magnifying power (angular magnification) M is given by

$M = \frac{\frac{h1}{D}}{\frac{h}{D}} = \frac{h1}{h}$ $M = \frac{h1}{h}$ But $\frac{h1}{h}$ = linear magnification produced by a lens or magnifying glass, $M = \left(\frac{v}{f}\right) - 1$ Hence the magnifying power $M = \left(\frac{v}{f}\right) - 1$

Since the image is at the near point (least distance of district vision), the image distance v is equal to – D, (negative for a virtual image). $M = \left(\frac{-D}{f}\right) - 1$. This gives the maximum magnifying power of a simple microscope.

Note that in calculations, the value of the magnifying power is negative. The negative sign can always be neglected since magnification cannot be negative. The object distance can take any value in the range from the focal point to the point where it lies at the near point and if the object is at the focal point, then the object distance is equal to the focal length and the image is at infinity, and the microscope is not in normal adjustment.

b) Magnifying power of a simple microscope when it is not in normal adjustment

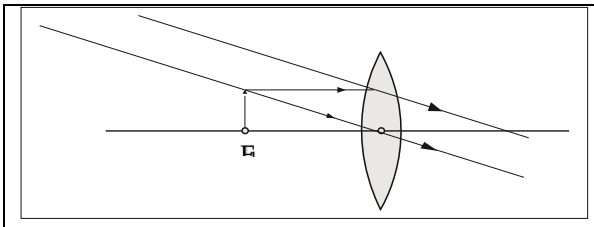


Figure 66: simple microscope when it is not in normal adjustment

Angular magnification, M = β/α, From the figure, tan β = h/f, For α small, tan β ≈ β. Thus, β = h/f, Diagram (not using a microscope). From the figure, tan α = h/D, For α small, tan α ≈ α. Thus, α = h/D, Hence, $M = \frac{D}{f}$. This is the minimum magnifying power of the simple microscope. Note that, in this case, D is positive since it is of a real image from the eye, and from the formula, angular magnification is high for a lens of short local length.

Activity 2: Guided Practice

Task 56:

Solve the following questions

1. A magnifying glass has a focal length of 5 cm. Find the angular magnification and the position of an object if the image is formed at the position of least distinct vision of 25 cm
2. A simple astronomical telescope has an objective lens with a focal length of 100 cm and an eyepiece with a focal length of 5 cm. Calculate the magnification of the telescope when it is adjusted for normal viewing.
3. Using the formula M = D/f, where M is the magnification, D is the least distance for distinct vision (25 cm), and f is the focal length of the microscope (2 cm), calculate the magnification of the microscope.

Key Facts 6.2b: Magnification of telescope

Magnification of telescope

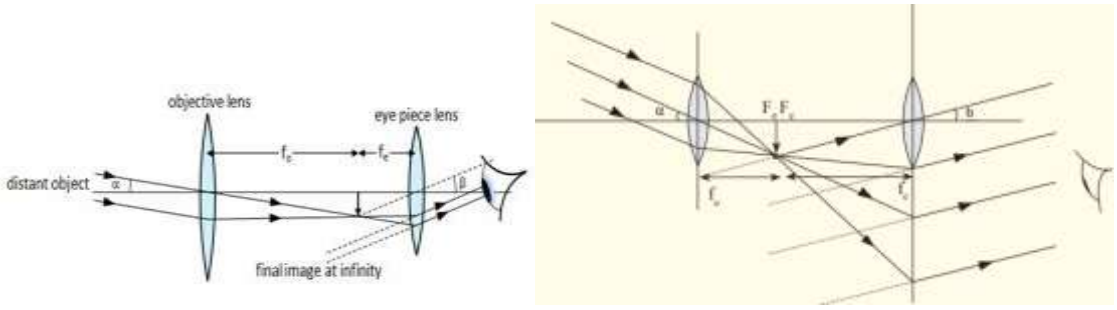


Figure 67: An astronomical telescope in normal adjustment

The rays of light coming from a distant object form a parallel beam of light. This parallel beam is focused by the objective lens and it forms a real, diminished image at its principal focus F_o . The eye piece is adjusted so that this image lies in its focal plane. This image acts as the object for the eye piece and the eye piece produces the image at infinity.

Note that in normal adjustment, the eye is relaxed or unaccommodated when viewing the image. In this case, the eye has minimum strain.

Magnifying power or angular magnification of an astronomical telescope

The magnifying power of a telescope is the ratio of the angle subtended by the image to the eye when the telescope is used to the angle subtended at the unaided eye by the object. Since the telescope length is very small compared with the distance of the object from either lens, the angle subtended at the unaided eye by the object is the same as that subtended at the objective by the object. Angular magnification of an astronomical telescope in normal adjustment

In normal adjustment, the magnifying power (angular magnification) of an astronomical telescope is given by:

$$M = \frac{\text{angle subtended at the eye by the final image at infinity}}{\text{angle subtended at the objective by the object}}$$

Let β = angle subtended by the final image at the eye and α = angle subtended by the object at the objective, hence $M = \frac{\beta}{\alpha}$.

Supposing that the eye is close to the eye piece and h1 is the image of image I1 formed by the objective, then tan α ≈ α and tan β ≈ β, $M = \frac{\frac{h1}{fe}}{\frac{h1}{fo}}$, Therefore, $M = \frac{fo}{fe}$

Note

(i) From the above expression, M is high when eye piece focal length f_e is short and the objective focal length f0 is long. This explains the fact why the objective lens of long focal length and the eye piece lens of short focal length are used during the construction of the astronomical telescope.

(ii) For a telescope in normal adjustment, the separation of the objective and the eye piece is f 0 + f e

Activity 3: Application

Task 57:

Read carefully the following statements and answer the related questions

1. You are standing outside on a clear night, gazing at a distant star through a telescope. The star looks much larger and clearer than it does to the naked eye. Why does the telescope make the star appear so much bigger, and how does it help you see things that are far away in the sky with more detail?
2. In a science class, you look at a tiny insect wing under a microscope. The wing appears huge and you can see intricate details you would never notice with just your eyes. Why does the microscope allow you to see such fine details of the tiny insect

Topic 6.3: Correction of optical aberrations

Activity 1: Problem Solving

Task 58:

Read carefully the following scenario and answer the questions that follows

Scenario

A trainee is using a magnifying glass to look at the fine details of a leaf. However, they hold the magnifying glass too far from the leaf, and the image appears blurry. The teacher steps in to guide them.

1. Why do you think the image is blurry?
2. What happens to the image when the object is too far from the magnifying glass?
3. What would happen if you used a stronger magnifying glass? Would the image be clearer or larger?

Key Facts 6.3: Correction of optical aberrations

- **Spherical abberation**

An optical aberration is a loss of clarity of images formed by the eye, and aberrations can occur in eyeglass lenses or other optical devices (such as binoculars or telescopes) as well. It is normal for all eyes to have some degree of aberration, but correction is rarely required. However, in severe cases causing lower quality vision, you may need special treatment.

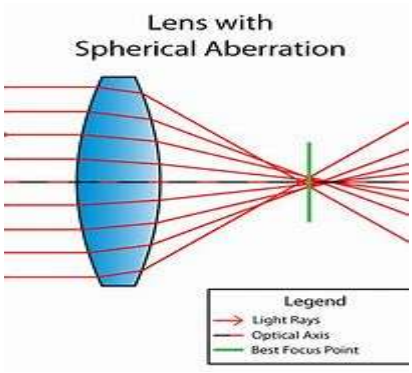


Figure 68: Spherical aberration

Spherical aberration is a specific type of optical aberration. It occurs when light rays passing through the periphery of the cornea and lens come to a focus at a slightly different location

than light rays passing through the center of the cornea and lens. This results in decreased image quality. Spherical aberration can also occur as a result of the following:

Correction of spherical aberation

1. The effect can be corrected for a given object distance by grinding the lens surface to make them spherical.
2. The effect can be reduced by cutting off the marginal rays and placing a stopper in front of a lens. This is called stopping down the lens aperture. This has the disadvantage of making the image lens bright.
3. The effect can be minimized by keeping the angles of incidence at each refracting surface small. This ensures that the deviation of light is shared or divided equally between surfaces. In the plano-convex this is achieved when curved surface receives or emits those rays which are most clearly parallel to the axis.

- **Chromatic aberration**

If a white object is viewed through a converging lens, its image is blurred with coloured edges. This is because as seen above, a lens has a greater focal length for violet light than for red light. This is the case since $\eta_{violet} > \eta_{red}$. The effects resulting from dispersion in which there is failure of lens to focus all colors to the same convergence point is called **chromatic aberration**

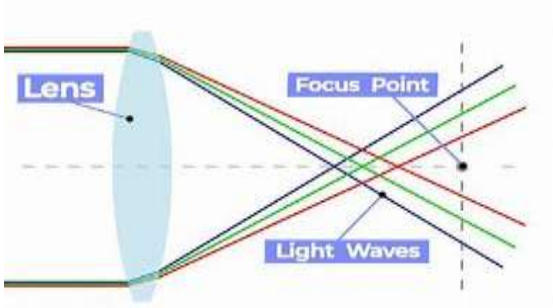


Figure 69: Chromatic aberration

Correction of chromatic aberration

This defect of a lens can be eliminated by a combination of two lens cemented together. This combination is called a chromatic doublet. A chromatic doublet consists of a converging lens of crown glass combined with a diverging lens of flint glass.

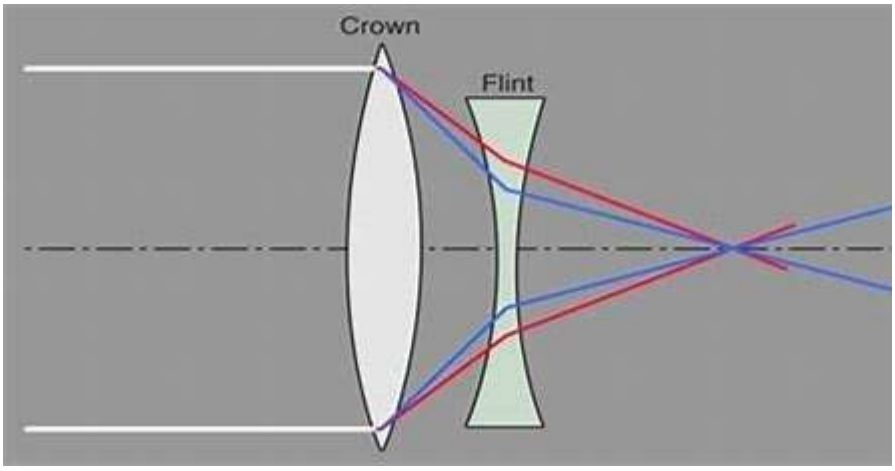


Figure 70: Correction of chromatic aberration

One surface of each lens has the same radius of curvature to allow them to be cemented together using Canada balsam which reduces the loss of light by reflection. The flint glass of diverging lens produces the same refraction as the crown glass of the converging lens but in opposite direction. The result is a converging effect.

- **Astigmatic aberration**

This is the defect that occurs if the curvature of the cornea varies in different directions so that rays in different planes from an object are focused in different positions by the eye and the image is distorted. A person suffering from astigmatism sees one set of lines more sharply than others.

This defect is **corrected** by wearing corrected lenses. These help to bend the incoming rays to correct for irregular refraction.



Activity 2: Guided Practice



Task 59:

1. Why are spherical mirrors or lenses unable to bring all light rays to a single focus?
2. An astronomical telescope has an objective lens of focal length 120cm and an eye piece of focal length 5cm. if the telescope is in normal adjustment, what is,

I. The angular magnification (magnifying power)

II. The separation of the two lenses



Activity 3: Application



Task 60:

Read the following scenario and answer the related questions

A trainee is reading a book using prescription eyeglasses but notices that the text appears slightly distorted, especially near the edges of the lenses. They mention this issue to a friend, who explains that the distortion might be due to aberrations in the lens design.

1. Why do you think the text appears distorted near the edges of your glasses?
2. How can lens manufacturers design glasses to reduce these distortions?
3. Have you ever noticed similar distortions when looking through thick magnifying glasses or curved windows? What causes these effects?
4. If you were designing glasses for someone who reads a lot, what kind of lens design would you recommend to avoid edge distortions?
5. Why do you think high-quality sunglasses or eyeglasses are more expensive? How do they address aberrations?

Formative Assessment

1. Answer question number 1 by True if the statement is correct and False if the statement is not correct
    a. Optical aberrations can occur in eyeglass lenses, binoculars, or telescopes, causing a loss of image clarity.
    b. Spherical aberration occurs when light rays passing through the periphery of the cornea and lens focus at the same location as rays passing through the center, enhancing image quality.
    c. Cutting off marginal rays and using a stopper in front of a lens can reduce the effects of spherical aberration, but it may result in a brighter image.
    d. Keeping the angles of incidence small at each refracting surface can minimize the effects of spherical aberration, ensuring equal deviation of light between surfaces.
    e. Chromatic aberration causes a white object viewed through a converging lens to have a clear image with no coloured edges.
    f. Chromatic aberration can be eliminated by combining two lenses, a converging lens of crown glass, and a diverging lens of flint glass, forming a chromatic doublet.
    g. Astigmatic aberration occurs when the curvature of the cornea is consistent in different directions, leading to focused rays in different positions and a distorted image.
2. What is the function of the cornea in the eye?
3. What role does the iris play in controlling the amount of light entering the eye?
4. Describe the role of the retina in the eye and its sensitivity to light.
5. Explain the function of the optic nerve in the visual system.
6. What is the range of accommodation for the normal eye, and how does it change with age?
7. Explain short-sightedness (myopia) and why it occurs.
8. Describe long-sightedness (hypermetropia) and its causes.
9. What is presbyopia, and how does it relate to the aging of the eye?
10. How is presbyopia corrected, and what type of spectacles are used for this purpose?
11. What is astigmatism, and how does it affect vision?

12. Using the formula M = D/f, where M is the magnification, D is the least distance for distinct vision (25 cm), and f is the focal length of the microscope (2 cm), calculate the magnification of the microscope.
13. The focal length of the objective lens (800 mm), and the focal length of the eyepiece (10 mm), find the magnifying power of the telescope.
14. If the least distance for distinct vision (30 cm), and the focal length of the microscope (3 cm), calculate the magnification of the microscope.



Points to Remember

- The eye is a biological instrument used to see objects at different distances. It uses a convex lens system to form a small, inverted, real image of an object in front of it.
- A magnifying glass consists of a thin converging lens, and it is used to view very small organisms or parts of organisms, which cannot be easily seen by the naked eye.
- A single-lens camera, commonly known as a point-and-shoot camera or a compact camera, is a type of camera that uses a single lens for both focusing and capturing images.
- A compound microscope consists of two convex lenses of short focal lengths referred to as the objective and the eye piece. The objective is nearest to the object and the eye piece is nearest to the eye of the observer.
- **A projector** is an optical device that projects an image (or moving images) onto a surface, commonly a projection screen Telescopes are instruments used to view distant objects such as stars and other heavenly bodies.
- The magnification of a microscope is a measure of how much larger an object appears when viewed through the microscope compared to the naked eye

  $M = \frac{D}{f}$
- The magnifying power of a telescope is the ratio of the angle subtended by the image to the eye when the telescope is used to the angle subtended at the

unaided eye by the object. $\boldsymbol{M = \frac{fo}{fe}}$

- An optical aberration is a loss of clarity of images formed by the eye, and aberrations occur in eyeglass lens or other optical devices.

Self-Reflection

1. Read the statements across the top. Put a check in a column that best represents your level of knowledge, skills and attitudes.

My experience Knowledge, skills and attitudes	I don't have any experience doing this.	I know a little about this.	I have some experience of doing this.	I have a lot of experience with this.	I am confident in my ability to do this.

2. Fill in the table above and share results with the trainer for further guidance.

Areas of strength	Areas for improvement	Actions to be taken to improve
1. **2.** **3.**	**1.** **2.** **3.**	**1.** **2.** **3.**

Summative assessment

Q1. Complete the following statements with appropriate terms: Weight, Frictional force, Force, Mass

a. ……..is a vector quantity that represents the interaction between two objects, resulting in a push or pull that can cause a change in the object's motion or shape.

b. ……is the force exerted on an object due to gravity and is measured in newton.

c. ……is a measure of the amount of matter in object and is typically measured in kilograms.

d. ……is the force that opposes the relative motion or attempted motion of two surfaces in contact.

Q2. What does Newton's second law tell us about the relationship between force, mass, and acceleration, and can it be expressed mathematically?

Q3. Match each of the term (column A) with its meaning (column B)

Column A	Column B
a) Stress	i)The force acting on the unit area of a material
b) Rotational equilibrium	ii) It is defined as the state of a system for which the total angular acceleration is zero The measure of how much an object is stretched or deformed and it occurs when force is applied to an object
c)Strain	iii) The measure of how much an object is stretched or deformed and it occurs when force is applied to an object
d)static friction	iv)Is a friction present between two or more objects that do not moving respect to each other

Q4. State whether the statements below are true or false

a. Static equilibrium occurs when an object is at rest or moving at a constant velocity with no net force acting on it.
b. In static equilibrium, the sum of all the torques acting on the object must be zero to prevent any rotational motion.
c. Static equilibrium allows engineers to predict and control the behavior of objects under various loading conditions.
d. For static equilibrium the sum of all the torques about any point must also be zero ($\Sigma\tau = 0$) and the sum of all forces is not zero.

Q5. An iron rod 4m long and 0.5 m2 in cross section stretches 1mm when a mass of 225kg is hung from its low end. Compute young modulus for the iron.

Q6. State two applications of thermodynamics' law.

Q7. Which principle states that an object immersed in a fluid experiences an upward buoyant force equals to the weight of the fluid it displaces?

a) Archimedes' principle
b) Pascal's principle
c) Bernoulli's principle
d) Newton's third law of motion

Q8. Use true(T) and false(F) to state whether the statement is correct or wrong

a) Ohm's low is used to find the electric circuit's voltage, resistance, or current.
b) One of the limitations of ohm's low is not applicable for unilateral elements like diodes and transistors as they allow the current to flow through in one direction.

Q9. Classify into Kirchhoff's first law and Kirchhoff's second law.

a) The sum of the currents entering any point in a circuit is equal to the sum of the currents leaving that same point.
b) The sum of the e.m.f around any loop in a circuit is equal to the sum of the p.d around the loop.

Q10. Complete the following statement using the terms heat, temperature or energy.

a) …… is a measure of how hot or how cold an object is.

b) Write the general formula relating Celsius and kelvin temperature scale and use it to convert 30°C to kelvin.

Q11. Two identical resistors are first connected in series and then in parallel. Find the ratio of equivalent resistance in two cases.

Q12. A magnifying glass has a focal length of 5 cm.

Find the angular magnification and the position of an object if the image is formed at the position of least distinct vision of 25 cm

Q13. A string 4mm in diameter has original length 2m.the string is pulled by a force of 200N.if the final length of the string is 2.02m, determine

a) Area

b) Stress

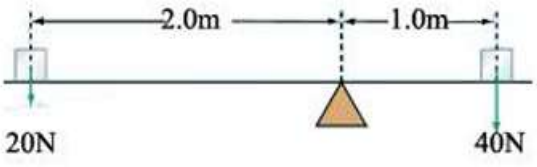
c) Strain

d) Young's modulus

Q14. a) Explain three types of expansion of an object when heat is applied on it

b) A round hole of diameter 4.000 m at 0 °C is cut in a sheet of brass (coefficient of linear expansion is $0.0000017(^0C)^{-1}$. Find the new diameter of the hole at 40 °C

Q15. Observe the figure below and answer related questions.



a) What is static equilibrium?

b) Determine the anticlockwise moment.

c) Determine the clockwise moment.

Q16. A hydraulic lift is used to lift a car of mass 1200 kg. The input piston has a diameter of 10 cm, and the output piston has a diameter of 50 cm. A force of 300 N is applied to the input piston.

a) Calculate the force exerted by the output piston to lift the car.

b) Explain Pascal's Principle and how it applies to the hydraulic lift.

c) Discuss the factors that affect pressure in solid and explain when we observe high pressure and low pressure in practical applications.

REFERENCES

Young, Hugh, D. ; Freedman, Roger, A. (2012), Sears and Zeanmansky's University Physics : With modern physics, 13th edition. New York : Addison Wesley, Pearson

Arthur Beiser (2009) Schaum's Outline of Applied Physics 4th edition. New York : McGraw-Hill Companies, Inc

Giancoli, Douglas C. (2005). Physics Principles with applications 6th edition. Pearson Prentice Hall. New Jersey.

Meriam, James, L.; Kraige, L. G. (2012). Engineering Mechanics7th edition. John Wiley and Sons. Inc

Bansal, Rajeev (2006), Fundamentals of Engineering Electromagnetics. CRC Press

Halpen, Alvin (2009) Schaum's Outline of Beginning Physics II: Waves, electromagnetism, optics and modern Physics. New York: McGraw-Hill Companies, Inc.

Milton, Gussow (2009) Schaum's Outline of basic electricity 2nd Edition. New York: McGraw-Hill Companies, Inc.

Nathan, Ida (2015). Engineering Electromagnetics 3rd Edition. Springer International Publishing Switzerland

Purcell, Edward (2011). Electricity and Magnetism 2nd Edition. Cambridge University Press

Salazar, Félix B.; Rafael Medina F.; Bayón Ana R.; Gascón Francisco L. (2016). Solved Problems in Electromagnetics. Springer-Verlag Berlin Heidelberg

Sameir M.; Ali, Hamed (2017). Electromagnetics for Engineering Trainees. Bentham Science Publishers



October, 2024