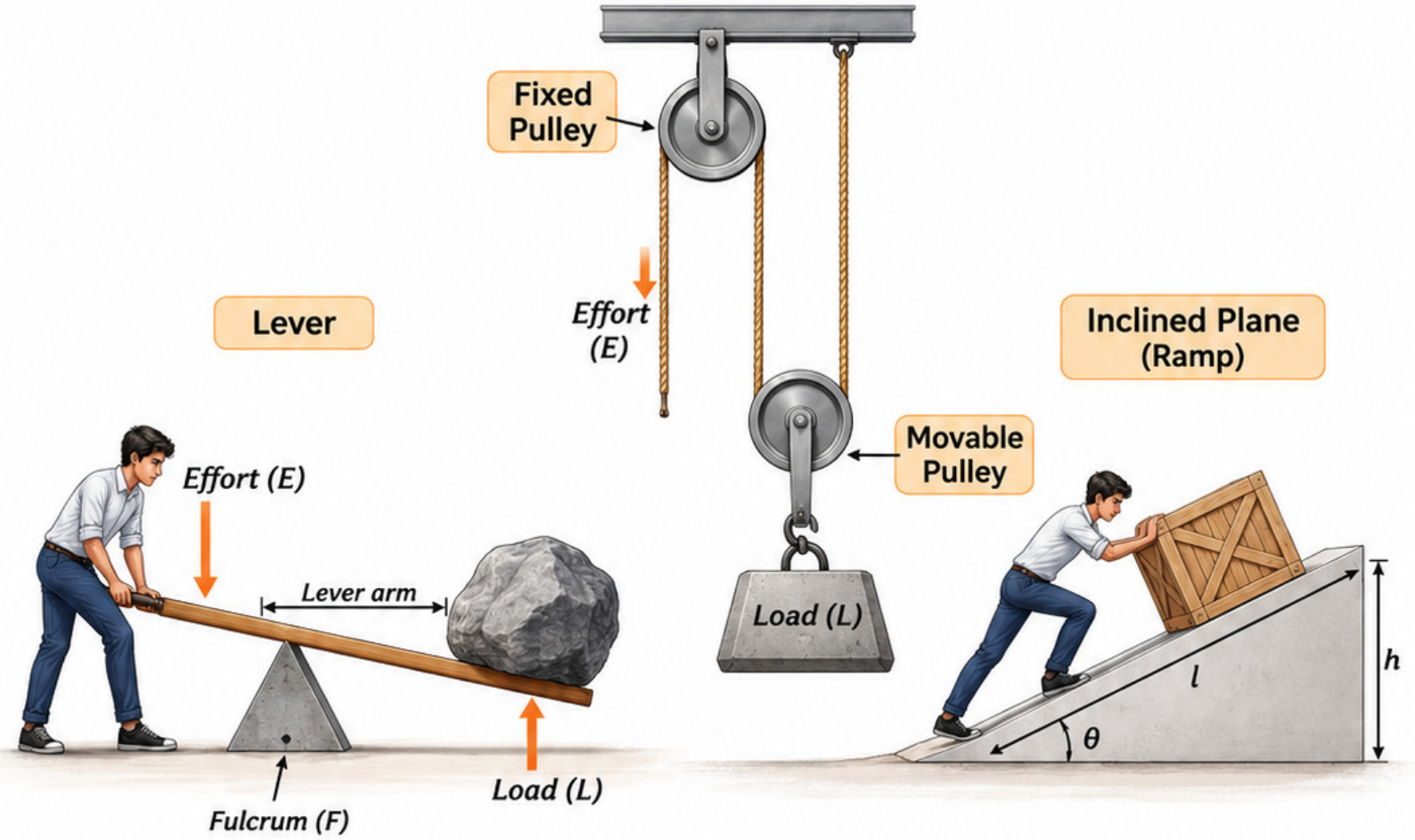
NEXTGEN ACADEMY

SIMPLE MACHINES

Class 9 Science • Complete Study Material

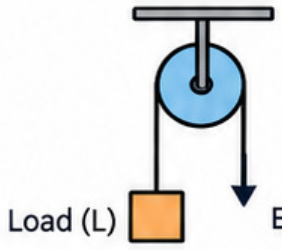


Concepts • Formulae • Solved Examples • Exam Practice

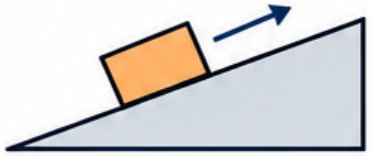
CHAPTER ROADMAP — SIMPLE MACHINES

SIMPLE MACHINES

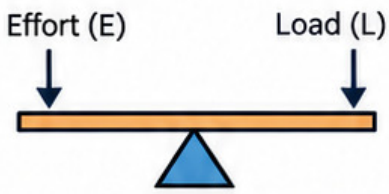
PULLEY



INCLINED PLANE



LEVER



LEARNING GOALS

1. Define **machine**, **load** and **effort**.
2. Calculate **mechanical advantage** (**MA**) of a machine.
3. Compare **fixed** and **movable pulley** (on the basis of MA, effort and use).
4. Derive the expression for **MA** of an **inclined plane**.
5. Apply the **principle of moments** to solve simple problems of a lever (in equilibrium).
6. Classify levers into **three classes** (first, second and third) with examples.

WHY MACHINES?

- Change the **magnitude of force** (make the work easier by reducing the effort).
- Change the **direction** of force.
- Trade **force** for **distance** (reduce the effort by increasing the distance over which it acts).
- **Never create energy** (a machine only makes the work convenient; it does not create energy).

EXAM ROUTE

Concepts → Diagrams → Worked examples → Objective questions → Descriptive answers → Numericals

MACHINE, LOAD, EFFORT & MECHANICAL ADVANTAGE

Key Definitions

Machine

Machine — device that makes a task easier by changing magnitude or direction of applied force.



Load (L)

Load (L) — resisting force the machine overcomes.



Effort (E)

Effort (E) — force applied to overcome the load.



Quick Comparison

Case	MA	Relation (L and E)	Main Effect (Use)
MA > 1	> 1	L > E	**Force multiplier** (smaller effort moves larger load)
MA < 1	< 1	L < E	**Speed or distance multiplier** (load moves farther/faster)
MA = 1	= 1	L = E	**Direction changer** (changes only direction of force)

Mechanical Advantage (MA)

$$MA = \frac{\text{Load}}{\text{Effort}} = \frac{L}{E}$$

MA has **no unit.**

Case 1: MA > 1 — Force Multiplier

- **MA > 1**
- ***L > E***
- Smaller effort moves larger load.



Car jack



Crowbar

Case 2: MA < 1 — Speed or Distance Multiplier

- **MA < 1**
- ***L < E***
- Load moves farther/faster (for a given effort).



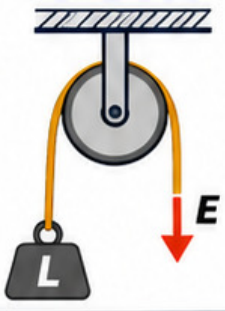
Tweezers



Scissors

Case 3: MA = 1 — Direction Changer

- **MA = 1**
- ***L = E***
- Changes only direction of force (ideal fixed pulley).



Ideal fixed pulley

Golden rule: An ideal machine does not reduce **total work**; less force requires **greater distance.**

WORK PRINCIPLE OF AN IDEAL MACHINE

Work and the Ideal Machine

- **Work input** (input work) is the work done by the effort (input force):

Work input = Effort × effort distance

$$W_{in} = E \times d_E$$

- **Useful work output** (output work) is the work done on the **load**:

Useful work output = Load × load distance

$$W_{out} = L \times d_L$$

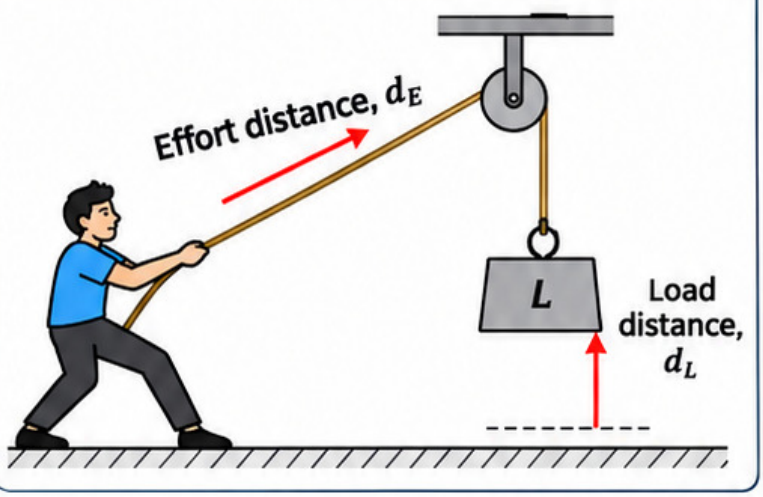
- For an **ideal machine** (no energy loss): input work = output work:

$$E \times d_E = L \times d_L$$

Force–Distance Trade-off

- A machine trades force for distance.
- If the required effort decreases, the effort must act through a proportionally longer distance so that the work input remains equal to the work output ($E \times d_E = L \times d_L$).

Diagram: Lifting a Load with a Rope



Real Machine

- For a real machine (with friction):

Input energy = useful output + energy dissipated by friction as heat and sound.

- The efficiency is always less than 100% for a real machine.

Conservation Reminder

Machines transfer or transform energy; they do not create energy.

Worked Example

A 100 N load rises through 1 m using an ideal machine. The ideal input work is 100 J. If a 25 N effort is used, find the required effort distance.

Solution

Given: $L = 100$ N, $d_L = 1$ m, $E = 25$ N (ideal machine).

(i) Ideal input work:

$$W_{in} = L \times d_L = 100 \text{ N} \times 1 \text{ m} = 100 \text{ J}.$$

(ii) Required effort distance:

From $E \times d_E = L \times d_L$,

$$d_E = \frac{L \times d_L}{E} = \frac{100 \text{ N} \times 1 \text{ m}}{25 \text{ N}}$$

$$= 4 \text{ m}.$$

Therefore, the effort must act through 4 m.

THE PULLEY — BASIC IDEA & FIXED PULLEY

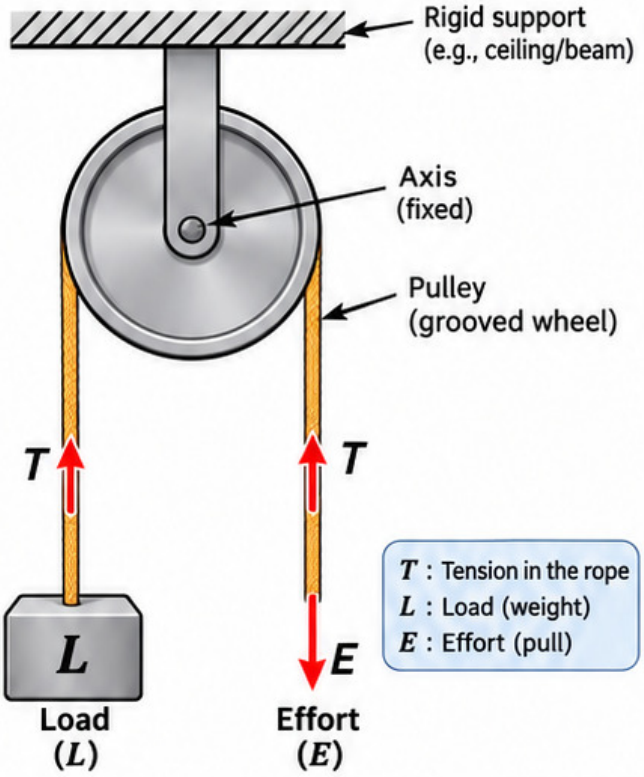
1. What is a Pulley?

- A pulley is a grooved wheel over which a rope, string or cable passes. It guides the rope and helps in lifting or moving a load.
- **Uses:** cranes (lifting heavy materials), elevators (lifting a cabin), flagpoles (hoisting a flag) and wells (drawing water from a well).

2. Fixed Pulley

- A fixed pulley is a pulley whose **axis is attached to a rigid support** (e.g., a beam or ceiling).
- **It does not move with the load,** i.e., the position of the pulley remains fixed while the load moves up or down.

3. Fixed Pulley — Diagram



4. Ideal Fixed Pulley: Working & Results

- In an ideal (frictionless, weightless) fixed pulley, the load is supported by **one segment of the rope** (one supporting rope segment).
- Therefore, the effort equals the load:

$$L = E$$

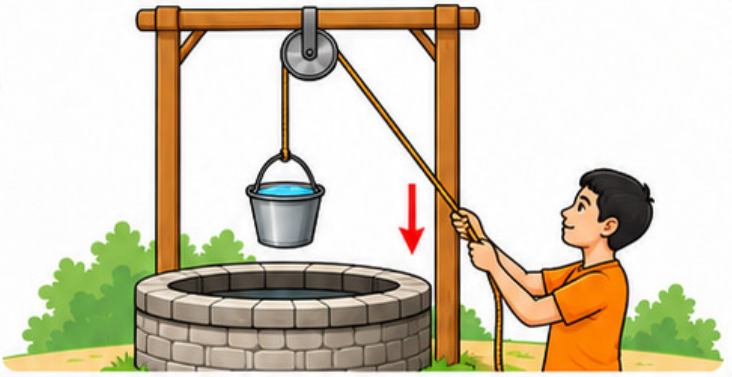
- **Mechanical Advantage (MA):**

$$MA = \frac{L}{E} = 1$$

- Thus, a fixed pulley **does not multiply force** (MA = 1).
- It **changes the direction of force** so that a person can **pull downwards** (which is easier and more convenient) to **raise the load upwards**.

5. Everyday Example

- **Drawing water from a well:** A fixed pulley is mounted on a support above the well. By pulling the rope downwards, the bucket (load) is raised upwards.
- **Another example:** Raising (hoisting) a flag on a flagpole.



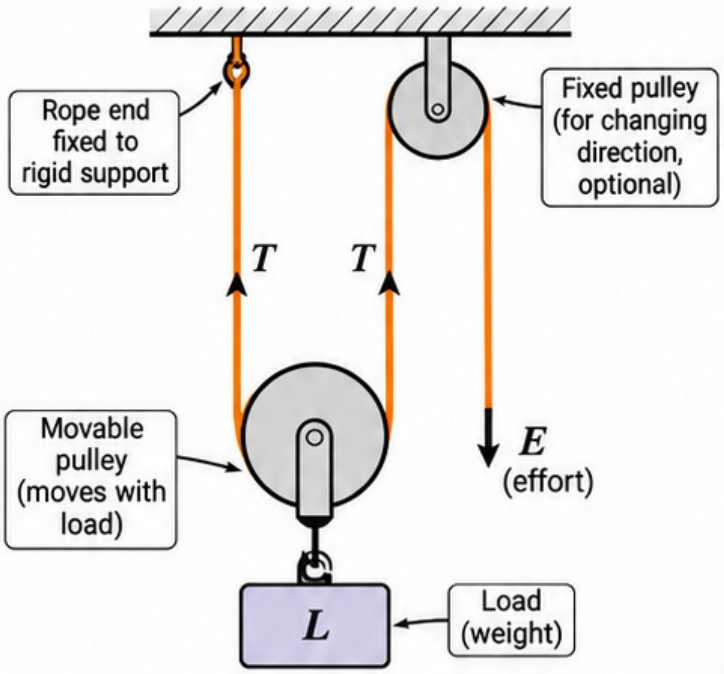
Exam trap: MA = 1 still gives convenience.

MOVABLE PULLEY — FORCE MULTIPLIER

1. What is a Movable Pulley?

Movable pulley: A pulley whose axle (axis) moves with the load.

2. Arrangement and Working



3. Derivation (Ideal Case)

- In an ideal movable pulley (massless pulley, no friction), the load is supported by two segments of the same rope.
- Each segment has the same tension T (equal to the effort E). Both tensions act upwards on the load.
- For equilibrium (or just lifting the load),

$$L = T + T = 2T$$

- **Effort:** $E = T$
- **Mechanical Advantage (MA):**

$$MA = \frac{L}{E} = \frac{2T}{T} = 2$$

Thus, the ideal MA of a movable pulley is 2.

- **Example:** A 50 N effort can ideally lift a 100 N load (because $L = 2E = 2 \times 50$ N = 100 N).

4. Distance Moved and Conservation of Work

- When the free end of the rope is moved by a distance $2d$, the load (with the movable pulley) rises by a distance d, i.e. the **load rises half the distance moved by the free end.**
- Effort distance = 2 × load distance, i.e. $s_E = 2\,s_L$.
- Hence, work done by effort = $E \times s_E = E \times 2\,s_L = (2E)\,s_L = L \times s_L$ = work done on the load.
- Therefore, **work is conserved** (no gain in work; the force gain is obtained at the cost of greater distance).

5. Fixed vs Movable Pulley (Comparison)

Feature	Fixed Pulley	Movable Pulley
Axis (axle)	Fixed to a rigid support (does not move)	Moves with the load
Purpose	Changes the direction of effort (convenience)	Multiplies force (reduces the effort needed to lift a load)
Ideal MA	1	2
Direction	Reverses the direction of effort	Does not reverse the direction by itself (need a fixed pulley if direction change is required)
Distance	Effort distance = Load distance ($s_E = s_L$)	Effort distance = 2 × Load distance ($s_E = 2s_L$); load rises half the effort distance

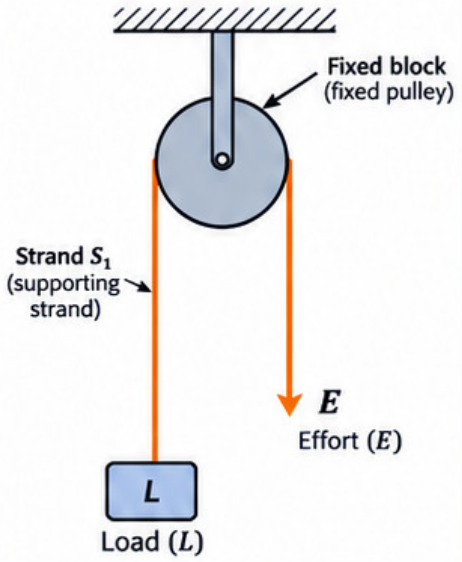
6. More About Pulleys

- **Multiple pulley systems** (a combination of more than one movable pulley) can obtain **higher mechanical advantage** (e.g. MA = 4, 6, ...).
- In **real situations**, the **actual (real)** mechanical advantage is **lower** than the ideal value because of friction in the pulleys and the weight of the pulleys/rope.

PULLEY SYSTEMS — COUNT THE SUPPORTING STRANDS

- A pulley is a simple machine that helps to lift a load using a rope and a grooved wheel.
- The mechanical advantage (MA) of an ideal pulley system equals the number of rope segments (strands) that directly support the movable load or movable block.

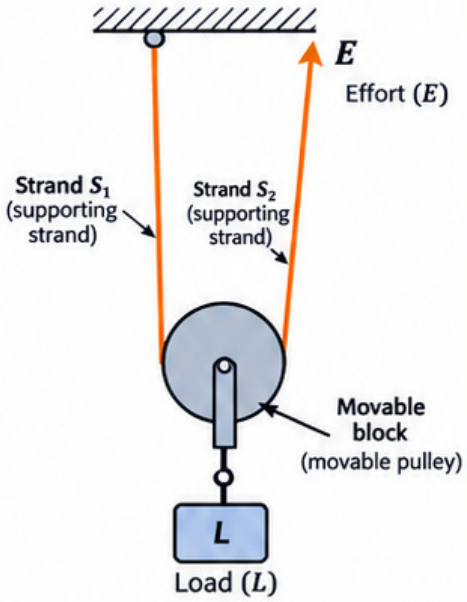
(A) Fixed Pulley (MA = 1)



Mechanical Advantage:
$MA = 1$

- Only one supporting strand (S_1) supports the load.
- A fixed pulley changes only the direction of effort (no gain in force).

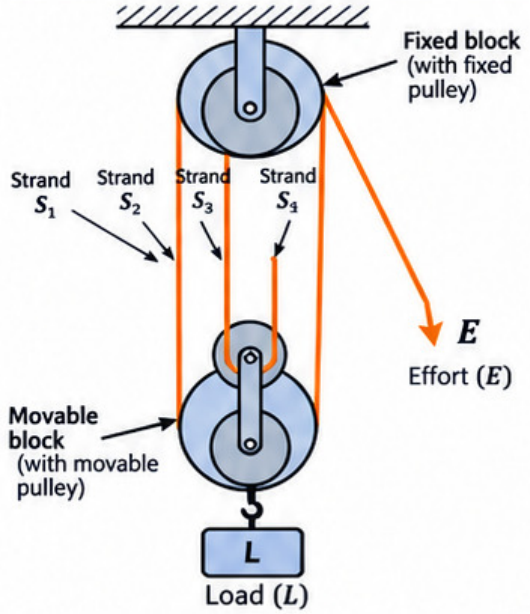
(B) Single Movable Pulley (MA = 2)



Mechanical Advantage:
$MA = 2$

- Two supporting strands (S_1 and S_2) support the movable block (and load).
- Hence, the ideal MA is 2.

(C) Simple Block-and-Tackle (4 Supporting Strands, Ideal MA = 4)



Mechanical Advantage (ideal):
$MA = 4$

- Four supporting strands (S_1, S_2, S_3 and S_4) directly support the movable block (and load).
- Hence, the ideal MA is 4.

RULE

For an ideal pulley system, the mechanical advantage (MA) equals the number of rope segments (strands) directly supporting the movable load/block.

- Do not count the free effort end unless it also supports the moving block.

WORKED EXAMPLE

A load of 600 N is supported by 4 strands in a pulley system.

(i) Find the ideal effort required.

(ii) If the actual effort is 200 N, find the actual MA and state the reason for the difference from the ideal value.

Solution:

(i) For an ideal system, MA = number of supporting strands = 4.

Ideal effort, $E_{ideal} = \frac{L}{MA} = \frac{600\ \text{N}}{4} =$ **150 N.**

(ii) Actual effort, $E_{actual} = 200$ N.

Actual MA, $MA_{actual} = \frac{L}{E_{actual}} = \frac{600}{200} =$ **3.**

- The actual MA (3) is less than the ideal MA (4) due to losses in the system, mainly because of friction in the pulleys and the weight of the pulleys and rope.

USES

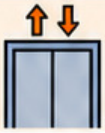
Pulley systems (e.g., block-and-tackle) are widely used where a heavy load has to be lifted with a smaller effort. **Examples:**



Crane
Used at construction sites and workshops to lift and move heavy materials.



Rescue hoist
Used by rescue teams (e.g., on helicopters or in deep wells) to lift people to safety.



Lift mechanism
Used in buildings (elevators) to lift people and goods to different floors easily.

THE INCLINED PLANE

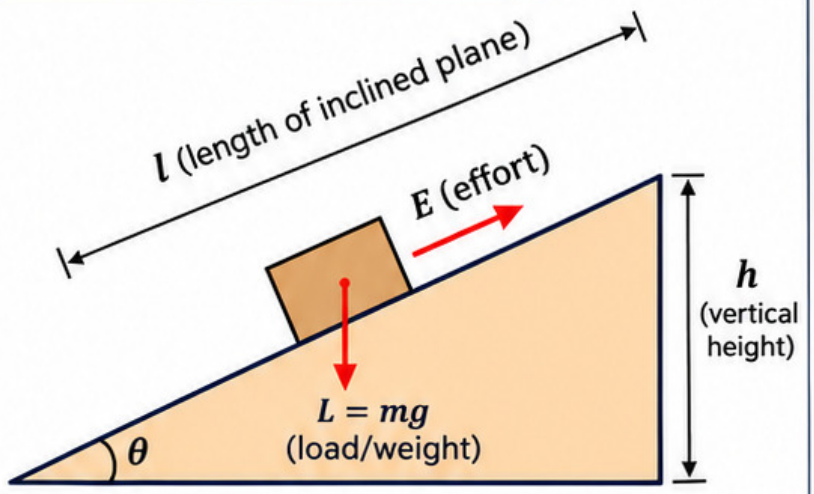
Definition

- An inclined plane is a flat surface that is tilted so that one end is higher than the other.

Examples

- A ramp (e.g., at the entrance of a building).
- A slide (in a playground).
- A winding hill road (which goes up gradually).
- An inclined ladder (placed against a wall).

Diagram: Inclined Plane (Ramp)



How it Works

- An inclined plane raises a load to the same height using a **smaller force** (effort) over a **longer distance** (along the slope).

Ideal (Frictionless) Case: Derivation

- In the ideal case (no friction), the work done by the effort equals the work done in raising the load.

$$E \times l = L \times h$$

- Therefore, the mechanical advantage (MA) is

$$MA = \frac{L}{E} = \frac{l}{h}$$

- Since $l > h$, the ideal mechanical advantage is greater than 1 **(MA > 1)**.

Effect of Length and Angle

- Increasing the length (l) of the inclined plane or reducing its angle (θ) makes the effort required smaller, but the distance over which the effort is applied becomes larger.

Effect of Friction

- In practice, there is friction between the load and the surface, so the **actual effort** required is larger than the ideal effort, and the **actual mechanical advantage** is smaller than the ideal value.

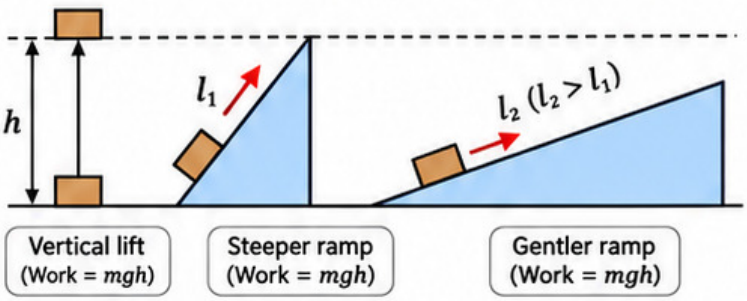
Same Height, Same Ideal Work

- To raise a load of mass m through a vertical height h, the ideal work done is

$$W = mgh.$$

- This ideal work (mgh) is the **same regardless of the path** taken (e.g., vertical lift, a shorter steeper ramp, or a longer gentler ramp), provided the final height is the same.

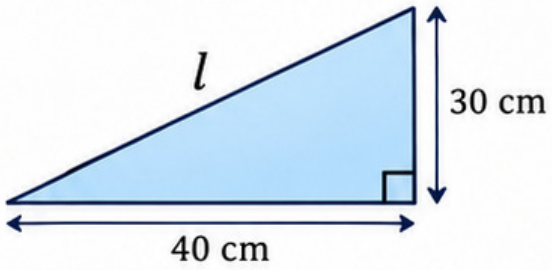
Same Height by Different Paths



INCLINED PLANE — SOLVED EXAMPLES & APPLICATIONS

Example 1

A ramp has a height of 30 cm and a base of 40 cm. Find (i) the sloping length of the ramp and (ii) the ideal mechanical advantage (MA).



Solution:

(i) Using Pythagoras theorem,

$$l = \sqrt{30^2 + 40^2} = \sqrt{900 + 1600} = \sqrt{2500} = 50 \text{ cm}$$

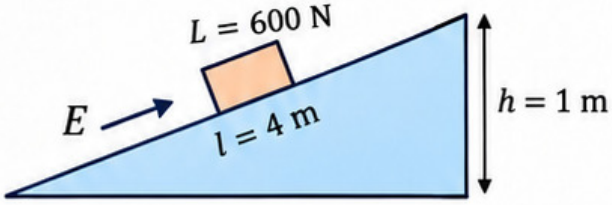
(ii) Ideal mechanical advantage,

$$\text{MA} = \frac{l}{h} = \frac{50}{30} = 1.67$$

Answer:
Sloping length, $l = 50$ cm
Ideal MA = 1.67

Example 2

A load of 600 N is moved up a ramp of length 4 m to a height of 1 m. Find the ideal effort. Also, state the input distance and output rise, and verify the work done.



Solution:

Ideal effort, $E = \frac{Lh}{l} = \frac{600 \times 1}{4} = 150$ N

Input distance (distance moved by effort) $= l = 4$ m

Output rise (vertical height) $= h = 1$ m

Work done by effort (input work): $W_{in} = E \times l = 150 \times 4 = 600$ J

Work done on load (output work): $W_{out} = L \times h = 600 \times 1 = 600$ J

Answer:
Ideal effort, $E = 150$ N
Input distance = 4 m, Output rise = 1 m
Both works = 600 J

Applications of an Inclined Plane

(1) Winding Hill Road



A hilly region often has a winding road. The road is a long, gentle incline, which makes it easier for vehicles to go up.

(2) Loading Ramp



A ramp is used to load heavy goods (e.g., crates) into a truck. By moving the load over a longer distance, a smaller effort is needed.

(3) Inclined Ladder



A ladder is an inclined plane. It allows a person to reach a higher place (e.g., a roof or window) more easily than lifting vertically.

Why does a gentle slope feel easier?

- A gentle slope has a larger sloping length (l) for the same height (h).
- Since ideal MA $= \frac{l}{h}$, a larger l gives a higher MA.
- A higher MA means a smaller effort is needed to move the same load.
- Thus, a gentle (less steep) slope feels easier to climb or push a load on.

Exam Tips

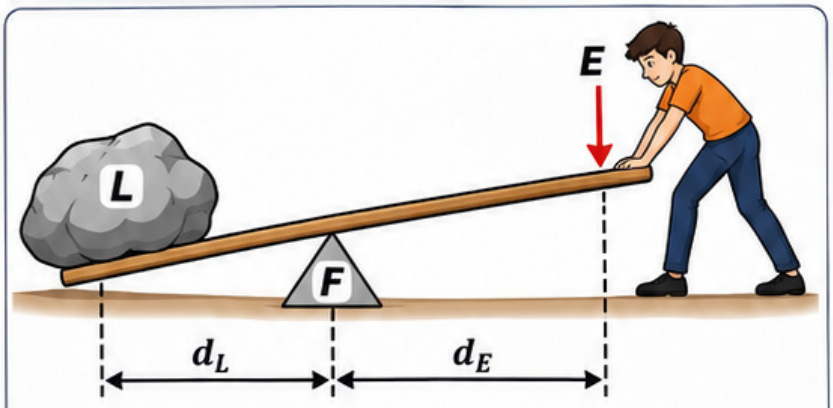
1. Use the same units for all quantities (e.g., cm with cm, m with m, N with N).
2. l is the sloping length of the inclined plane (the actual length of the ramp), not the base.
3. The "ideal case" assumes no friction, so input work equals output work ($E \times l = L \times h$) and MA $= \frac{l}{h}$.

THE LEVER — PARTS, MOMENT & PRINCIPLE

1. What is a Lever?

A **lever** is a rigid bar that turns about a fixed pivot called the **fulcrum.**

2. A Lever and Its Parts



F – fulcrum (fixed pivot)
L – load (the resistance)
E – effort (applied force)
d_L – load arm
d_E – effort arm

3. Definitions of the Parts

- **Fulcrum (F):** The fixed pivot about which the lever turns.
- **Load (L):** The resistance or the weight to be moved (e.g., the rock).
- **Effort (E):** The applied force that makes the lever turn (e.g., the downward push).
- **Load arm (d_L):** The perpendicular distance from the fulcrum to the line of action of the load.
- **Effort arm (d_E):** The perpendicular distance from the fulcrum to the line of action of the effort.

4. Moment (Turning Effect) of a Force

- The moment of a force (or turning effect) about a fulcrum is the product of the force and the perpendicular distance of its line of action from the fulcrum.
- Mathematically,

Moment = Force × perpendicular distance

or $M = F \times d$

5. Balanced Lever and Principle of Moments

- A lever is said to be balanced (in equilibrium) when the clockwise moment equals the anticlockwise moment about the fulcrum.
- This is called the **Principle of Moments.**
- For a balanced lever,

$$E \times d_E = L \times d_L$$

6. Derivation of Mechanical Advantage (MA)

- The mechanical advantage (MA) of a lever is the ratio of the load to the effort.

$$MA = \frac{L}{E}$$

- From the principle of moments, $E \times d_E = L \times d_L$

$$\Rightarrow \frac{L}{E} = \frac{d_E}{d_L}$$

Therefore,

$$MA = \frac{L}{E} = \frac{d_E}{d_L}$$

Key Takeaway

- A **longer effort arm** (larger d_E) or a **shorter load arm** (smaller d_L) **increases** the mechanical advantage (MA) of the lever.

7. Work Tradeoff

- When a lever gives a larger mechanical advantage (MA > 1), the effort has to move through a larger distance than the load.
- The work done (ideally) is the same on both sides:

$$E \times s_E = L \times s_L$$

(s_E = distance moved by effort, s_L = distance moved by load)

- This shows a tradeoff: a smaller effort moves through a larger distance. There is **no free energy**; a lever only makes the work easier by changing the force and distance.

CLASS I LEVER — FULCRUM IN THE MIDDLE

Definition

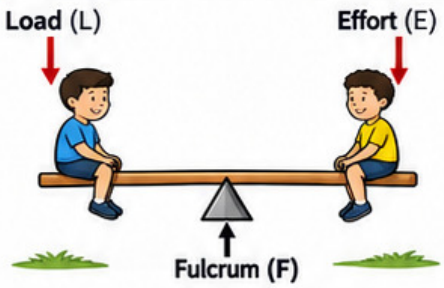
A Class I lever is a lever in which the fulcrum (F) is between the load (L) and the effort (E).

Key Points

- Core order: Load — Fulcrum — Effort (L – F – E), but the lengths of the arms (load arm d_L and effort arm d_E) may vary.
- Mechanical advantage (MA) can be > 1, = 1 or < 1 depending on the arm lengths.
- For a lever: $MA = \frac{L}{E} = \frac{d_E}{d_L}$ and $L \times d_L = E \times d_E$ (principle of moments).

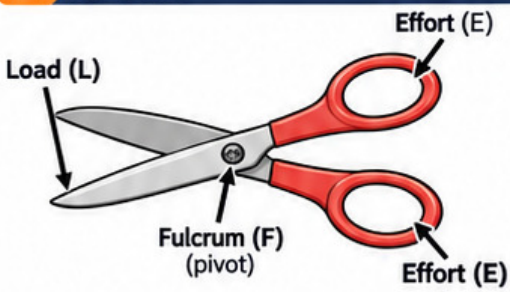
Examples of Class I Levers

1 See-saw / Balance scale



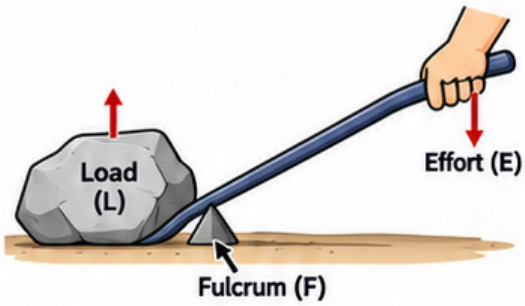
- A see-saw (and a balance scale) is a Class I lever.
- Fulcrum is at the middle, with load and effort on opposite sides.

2 Scissors



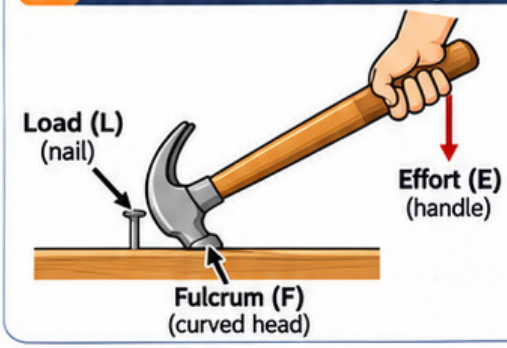
- Scissors are a Class I lever.
- Fulcrum (F): pivot (screw).
- Effort (E): at the handles.
- Load (L): at the blades (material to be cut).

3 Crowbar (lifting a rock)



- A crowbar is a Class I lever.
- Fulcrum (F): the point of support on the ground/rock.
- Load (L): the rock (to be lifted).
- Effort (E): applied at the free end.

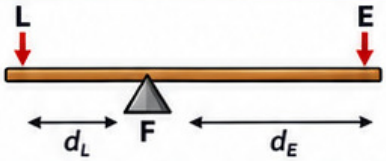
4 Claw hammer (removing a nail)



- A claw hammer is a Class I lever.
- Fulcrum (F): curved head of the hammer (resting on the wood).
- Load (L): the nail (to be pulled out).
- Effort (E): applied at the handle.

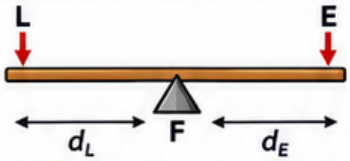
Three Cases (Depending on Arm Lengths)

(i) $d_E > d_L$: Force multiplier



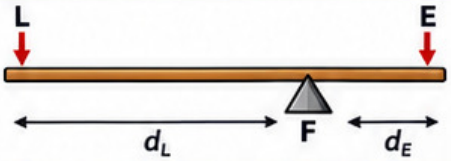
- Effort arm is longer than load arm.
- $MA = \frac{d_E}{d_L} > 1$ (force multiplier).
- A smaller effort can lift a larger load.

(ii) $d_E = d_L$: MA = 1



- Effort arm equals load arm.
- $MA = \frac{d_E}{d_L} = 1$.
- The effort equals the load (no force gain).

(iii) $d_E < d_L$: Speed/Distance multiplier



- Effort arm is shorter than load arm.
- $MA = \frac{d_E}{d_L} < 1$ (speed/distance multiplier).
- A larger effort is needed, but the load moves a greater distance (faster).

Worked Example

A child of 15 kg sits 2 m from the fulcrum of a see-saw. At what distance (x) should a child of 30 kg sit on the other side to balance the see-saw?

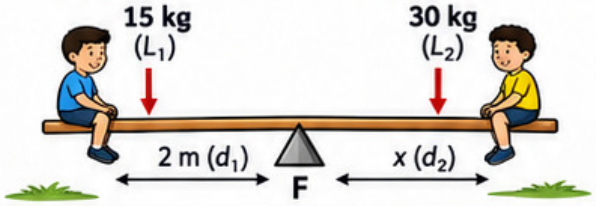
Solution:

For balance, $L_1 \times d_1 = L_2 \times d_2$

Here, $L_1 = 15$ kg, $d_1 = 2$ m; $L_2 = 30$ kg, $d_2 = x$

So, $15 \times 2 = 30 \times x$

$\Rightarrow 30 = 30x \Rightarrow x = 1$ m



Answer: $x = 1$ m

CLASS II LEVER — LOAD IN THE MIDDLE

Definition

A lever in which the load (L) is in between the fulcrum (F) and the effort (E) is called a Class II lever.

Arrangement (Core Order)

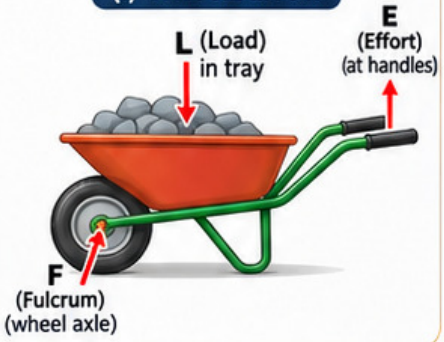
F – L – E

Key Property

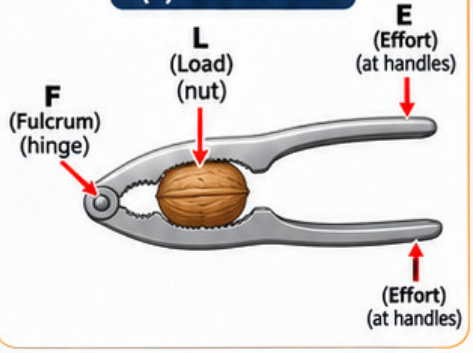
- In a Class II lever, the **effort arm is always longer** than the **load arm.**
- Therefore, the **ideal mechanical advantage (MA) is > 1.**
- Hence, it is a **force multiplier** (it helps to lift or move a larger load with a smaller effort).

Examples of Class II Levers

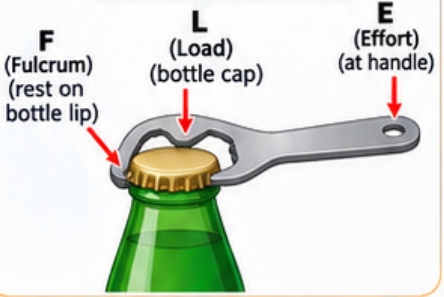
(i) Wheelbarrow



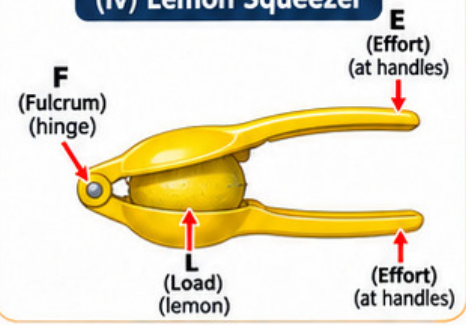
(ii) Nutcracker



(iii) Bottle Opener



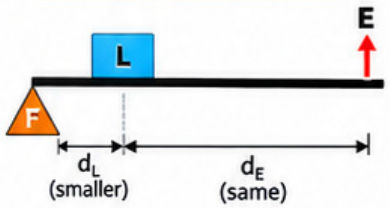
(iv) Lemon Squeezer



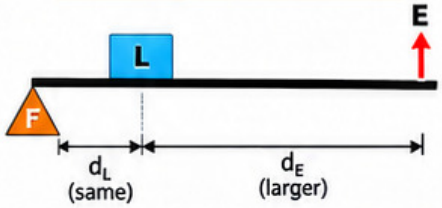
Why Does MA Increase (Become Larger)?

- Moving the **load closer** to the fulcrum **decreases the load arm** (d_L), so the ratio $MA = \frac{d_E}{d_L}$ **increases.**
- Applying the **effort farther away** from the fulcrum **increases the effort arm** (d_E), so the ratio $MA = \frac{d_E}{d_L}$ **increases.**

(a) Load closer to fulcrum ($\downarrow d_L \rightarrow \uparrow$ MA)



(b) Effort farther from fulcrum ($\uparrow d_E \rightarrow \uparrow$ MA)



Worked Example (Numerical)

A Class II lever has an effort arm of 60 cm and a load arm of 20 cm. Find its mechanical advantage and the ideal effort needed to lift a load of 300 N.

Solution:

1. **Mechanical advantage (MA):**

$$MA = \frac{d_E}{d_L} = \frac{60\ \text{cm}}{20\ \text{cm}} = 3$$

2. **Ideal effort (E):**

$$MA = \frac{L}{E} \Rightarrow E = \frac{L}{MA} = \frac{300\ \text{N}}{3} = 100\ \text{N}$$

Answer: MA = 3 and the ideal effort required is 100 N.

Practical Curiosity

A door turns about its hinges.



- The hinges act as the **axis of rotation (turning point)** for the door.
- When we push at the **handle**, which is **far from the hinges**, the **moment (turning effect)** is larger:

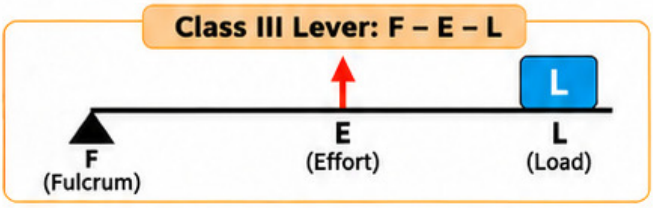
Moment (turning effect) = Force × Perpendicular distance
= F × d

- For the same required turning effect (to open the door), a **larger d** (distance of handle from hinges) means a **smaller force F** is needed.
- Thus, pushing at the handle gives a larger turning effect and needs less force. This is a **turning-effect application of moments**, not a classification of the whole door as a **Class II** lever.

CLASS III LEVER — EFFORT IN THE MIDDLE

1. What is a Class III Lever?

- A lever in which the **effort (E) is applied between the fulcrum (F) and the load (L)** is called a **Class III lever.**
- The order (from one end to the other) is **F – E – L (Core order: F–E–L).**



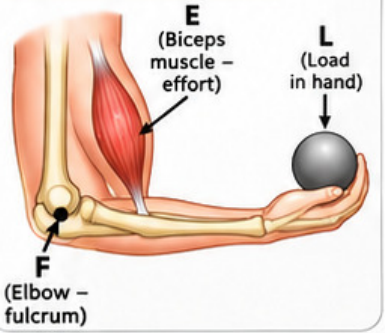
2. Key Facts about Class III Lever

- The **effort arm is always shorter than the load arm,** so the **Mechanical Advantage (MA) is less than 1 (MA < 1).**
- It **does not save force,** but it **multiplies speed (or distance)** and **gives better control** (e.g. precise and convenient movement).

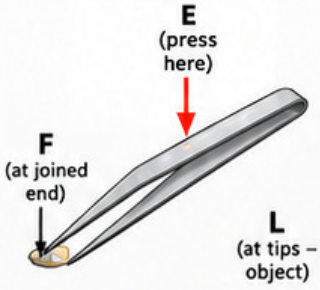
$$MA = \frac{\text{Effort arm}}{\text{Load arm}} < 1 \quad \text{(since effort arm < load arm)}$$

3. Examples of Class III Levers

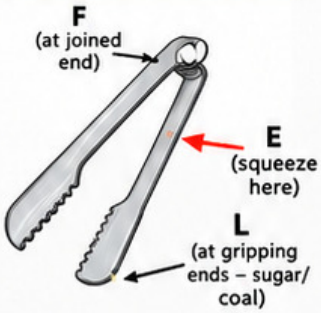
(a) Human forearm



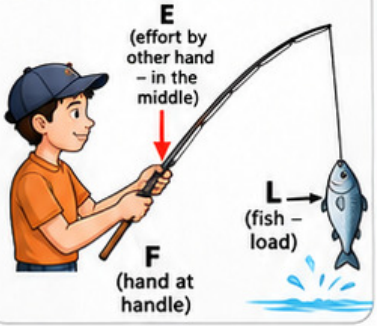
(b) Tweezers



(c) Sugar / Fire tongs



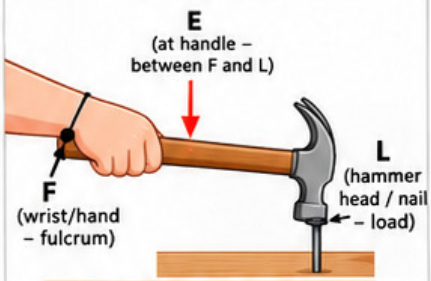
(d) Fishing rod



4. About the Hammer

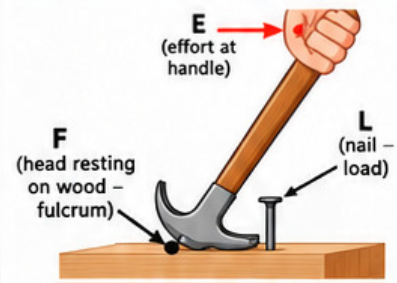
- When a hammer is used to **strike a nail,** the **wrist/hand can form a Class III arrangement,** because the **wrist** acts as the **fulcrum (F),** the **effort (E)** is applied at a point on the handle (between the wrist and the head), and the **load (L)** is at the hammer head (which hits the nail).
- When a **claw hammer is used to remove (pull out) a nail,** it works as a **Class I lever,** because the **fulcrum (F)** is the curved head resting on the surface (wood), the **load (L)** is the nail, and the **effort (E)** is applied at the handle.

Hammer (striking a nail): Class III lever



Order: F – E – L (Class III)

Claw hammer (removing a nail): Class I lever



Order: F – L – E (Class I)

5. Why does the Load Move Farther/Faster?

- In a Class III lever, the **load arm is longer than the effort arm.**
- For the same small movement of the effort point, the end at which the load is applied **moves a larger distance.**
- Hence, the **load moves farther and faster** than the effort point. This gives a benefit of **greater speed (or distance)** of the load and **better control** of the movement (e.g. holding, picking, gripping, precise actions).

Relation between movements

$$\frac{\text{Distance moved by load}}{\text{Distance moved by effort}} = \frac{\text{Load arm}}{\text{Effort arm}} > 1$$

So, the load moves a greater distance (and hence with greater speed) than the effort point.

6. Worked Example

Q. In a Class III lever, the effort arm is 8 cm and the load arm is 32 cm. Find (i) the mechanical advantage, and (ii) the effort required to move a load of 20 N.

Solution:

(i) Mechanical Advantage (MA):

$$MA = \frac{\text{Effort arm}}{\text{Load arm}} = \frac{8\ \text{cm}}{32\ \text{cm}} = 0.25$$

(ii) Effort required:

$$E = \frac{L}{MA} = \frac{20\ \text{N}}{0.25} = 80\ \text{N}$$

PAGE 14

THREE CLASSES OF LEVERS — MASTER COMPARISON

Class of Lever	Middle Component	Order (from fulcrum)	Typical MA	Main Advantage	Examples
Class I	F	L – F – E	MA may >1 = 1 <1	Direction / force / speed depending on the arms.	• Seesaw • Scissors • Crowbar • Balance • Claw hammer (removing nail)
Class II	L	F – L – E	MA > 1	Force multiplier.	• Wheelbarrow • Nutcracker • Bottle opener • Lemon squeezer
Class III	E	F – E – L	MA < 1	Speed / distance / control.	• Forearm • Tweezers • Tongs • Fishing rod

Mnemonic: **1-F, 2-L, 3-E**
(the middle item identifies class).

Classification Practice

■ **Classify the following levers as Class I, Class II or Class III.**

No.	Lever	Answer (Class)
1.	Physical balance	I
2.	Oar	I
3.	Pliers	I
4.	Human arm	III
5.	Fire tongs	III

No.	Lever	Answer (Class)
6.	Sugar tongs	III
7.	Wheelbarrow	II
8.	Nutcracker	II
9.	Scissors	I
10.	Rowing oar	I

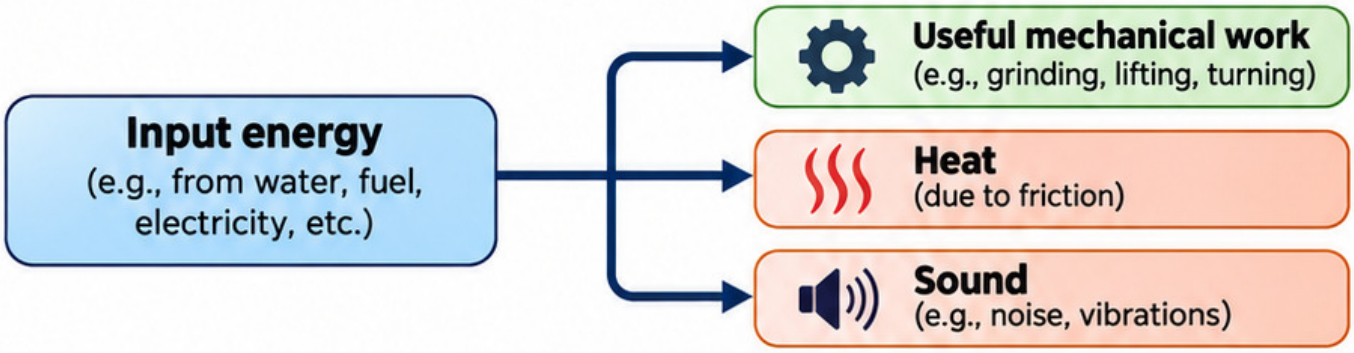
ENERGY CONSERVATION & REAL MACHINES

- Machines obey the **law of conservation of energy.**
- In a real machine, the **input work (input energy)** is equal to the **useful output work** plus the **work against friction.**

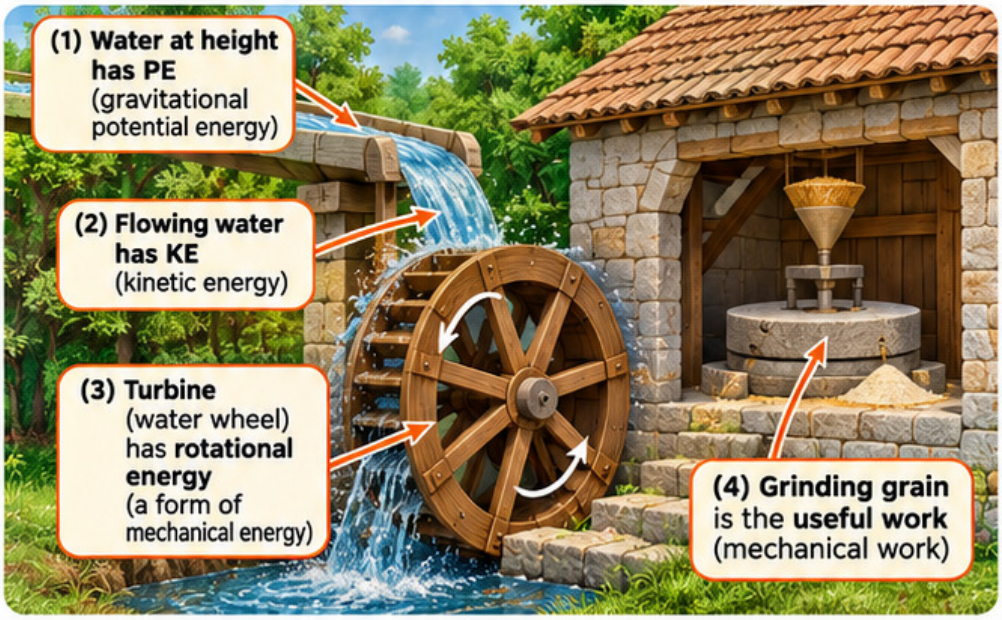
Input work = Useful output work + Work against friction

- Friction **dissipates** (spreads) energy to the surroundings mainly as **heat** and **sound.** Hence, no real machine can run forever without a continuous supply of energy.
- **Perpetual motion is impossible** because energy cannot be created from nothing (it can only be transferred or converted from one form to another).

Flow of Energy in a Real Machine



Example: Watermill



Why a Pendulum/ Machine Slows

- **Air resistance** (drag by air) and **bearing friction** (friction at the axle or in moving parts) continuously transfer mechanical energy from the pendulum/ machine to the surroundings mainly as heat and sound.
- Hence, its mechanical energy keeps decreasing and it gradually slows down and stops, if no energy is supplied.

Key Distinction

- Energy is **conserved for the total system** (e.g., machine + surroundings); it only changes form (e.g., mechanical energy → heat and sound).
- However, the **useful mechanical energy decreases** (because part of the input energy is continuously dissipated by friction).

FORMULA SHEET & EXAM CHECKLIST

A. KEY FORMULAE (SIMPLE MACHINES, WORK, ENERGY & POWER)

1. Mechanical Advantage

$$MA = \frac{L}{E}$$

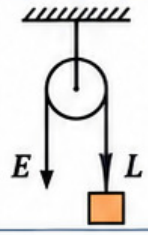
MA : mechanical advantage
L : load (N)
E : effort (N)

2. Ideal Machine

$$E\,d_E = L\,d_L$$

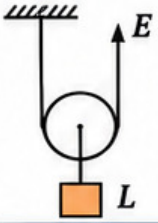
E : effort (N)
d_E : distance moved by effort (m)
L : load (N)
d_L : distance moved by load (m)

3. Fixed Pulley



$MA = 1$

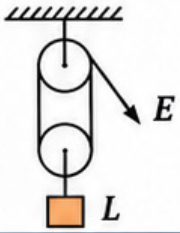
4. Single Movable Pulley



$MA = 2$

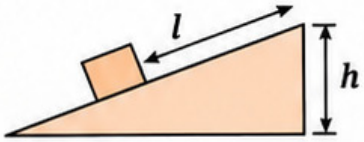
5. Block and Tackle (Pulley System)

MA = number of supporting strands



MA : mechanical advantage (= number of supporting strands)

6. Inclined Plane



$$MA = \frac{l}{h} \qquad E\,l = L\,h$$

l : length of inclined plane (m)
h : vertical height (m)

7. Moment of a Force

$$\text{Moment} = F \times d_\perp$$

F : force (N)
$d_\perp$: perpendicular distance from the pivot (m)

8. Balanced Lever (Principle of Moments)

$$E\,d_E = L\,d_L$$

E : effort (N)
d_E : perpendicular distance of effort (m)
L : load (N)
d_L : perpendicular distance of load (m)

9. Lever – Mechanical Advantage

$$MA = \frac{L}{E} = \frac{d_E}{d_L}$$

MA : mechanical advantage
L : load (N)
E : effort (N)
d_E : effort arm (m)
d_L : load arm (m)

10. Work

$$W = Fs$$

W : work (J)
F : force (N)
s : displacement (m)

11. Gravitational Energy

$$G.E. = m\,g\,h$$

m : mass (kg)
g : 9.8 m s^{-2} (≈ 10 m s^{-2})
h : height (m)

12. Power

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

P : power (W)
W : work (J)
t : time (s)

B. UNIT CHECKLIST

Quantity	SI Unit (Symbol)
Force (F, L, E)	newton (N)
Distance / Length (s, d, l, h)	metre (m)
Work (W)	joule (J)
Power (P)	watt (W)
Mechanical Advantage (MA)	dimensionless (no unit)

C. COMMON MISTAKES (AVOID THESE)

1. Use the perpendicular arm (distance at 90° to the force) for moment and lever calculations.
2. Do not use the base (horizontal length) of a ramp for l (length of inclined plane); use the sloping length.
3. Do not claim that machines reduce the (ideal) work; in an ideal machine, work input equals work output ($E\,d_E = L\,d_L$).
4. Identify the type of lever by the middle component (fulcrum, load or effort), not by its appearance or shape.

D. PROBLEM ROUTINE (STEP-BY-STEP)

1. **Sketch and label:** draw a neat diagram and mark F (force), L (load) and E (effort) with required distances (d_E, d_L, l, h, etc.).
2. **Choose equation:** write the appropriate formula from the formula sheet.
3. **Convert units:** ensure all quantities are in SI units (N, m, J, s, W).
4. **Solve:** substitute values and calculate (showing key steps, if needed).
5. **State unit and reasonableness:** write the unit of the final answer and check if the value is reasonable (e.g., MA > 1 for an ideal machine).

NCERT REASONING — PAUSE, PONDER & APPLY

1 Why are hill roads made to wind (zigzag) instead of going straight up?

Ans. A winding road acts as a longer inclined plane. For the same height h, increasing the length l increases $\frac{l}{h}$, i.e. the mechanical advantage, and reduces the effort: $F = \frac{Wh}{l}$. Hence, less force is needed to take vehicles to the top.



$$MA = \frac{l}{h}$$
$$F = \frac{Wh}{l}$$

2 Why is it easier to climb an inclined ladder than a vertical one?

Ans. The gain in gravitational potential energy is the same in both cases: $\Delta E = mgh$. But with an inclined ladder, the same energy (work) is done over a longer distance l, so the required force is smaller: $F = \frac{mgh}{l}$ (with $l > h$). Hence, climbing an inclined ladder is easier.



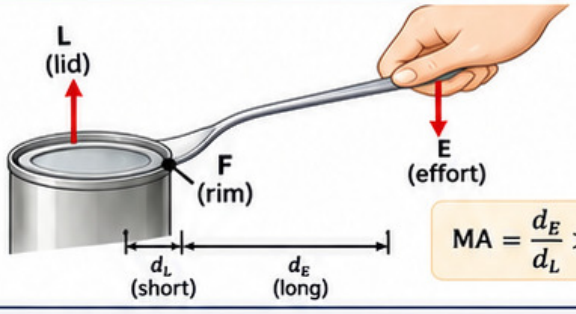
$F_{inclined} = \frac{mgh}{l}$



$F_{vertical} \approx mg$

3 Why can a spoon open a can lid easily?

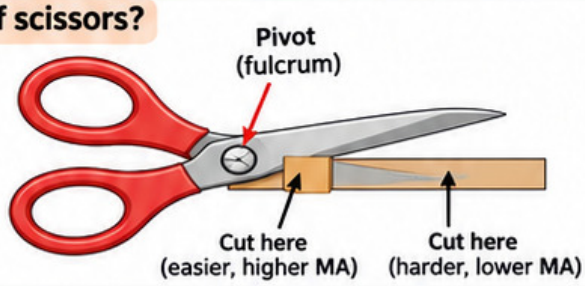
Ans. A spoon works as a **Class I lever**. The rim of the can acts as the fulcrum (F), the upward force at the lid is the load (L), and the effort (E) is applied at the handle. The handle is long (large effort arm) and the load arm is short. Hence, $MA = \frac{effort\ arm}{load\ arm} > 1$, so a small effort can lift the lid easily.



$$MA = \frac{d_E}{d_L} > 1$$

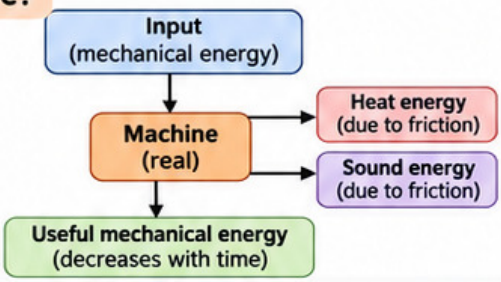
4 Why should a hard object be cut near the pivot of a pair of scissors?

Ans. Scissors are two **Class I levers** with a common pivot. When the object is placed close to the pivot, the load arm becomes shorter. Hence, the mechanical advantage increases, $MA = \frac{effort\ arm}{load\ arm}$, and the cutting force on the object becomes larger, making it easier to cut hard objects.



5 Why do real (and perpetual-motion) machines stop after some time?

Ans. In real machines, friction (and air resistance) always acts and transfers mechanical energy to other forms, mainly heat and sound. The energy is not destroyed (it is conserved), but the useful mechanical energy of the machine keeps decreasing. Hence, the machine slows down and finally stops. A perpetual-motion machine is not possible because it cannot avoid such losses.



APPLICATION QUESTIONS

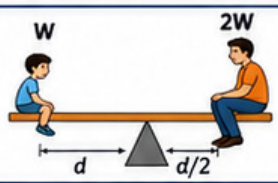
A1 A flag is raised to a height h slowly and then quickly. Is the work done in the two cases the same? If the flag is raised with double the speed, how do the time taken and the power change?

Ans.

- Yes. In both cases, the work done against gravity is the same: $W = mgh$ (independent of speed).
- If the speed is doubled, the time taken is halved ($t' = \frac{t}{2}$) and the power doubles: $P = \frac{W}{t}, \quad P' = \frac{W}{\frac{t}{2}} = 2P.$

A2 An adult is twice as heavy as a child. Where should the adult sit on a seesaw to balance the child?

Ans. Let the child (weight W) sit at a distance d from the fulcrum. The adult has weight $2W$. For balance, $2W \times d_A = W \times d \Rightarrow d_A = \frac{d}{2}$. Hence, the adult should sit at half the distance of the child from the fulcrum.



MULTIPLE-CHOICE QUESTIONS

1. What is the correct relation among mechanical advantage (MA), effort (E) and load (L) of a simple machine?

(A) $MA = L + E$ (B) $MA \times E = L$

(C) $MA = \frac{E}{L}$ (D) $L = \frac{E}{MA}$

2. A load of 10 kg is raised by applying an effort of 200 N. (Take $g = 10\ m\ s^{-2}$.) What is the mechanical advantage (MA) of the machine?

(A) 2 (B) 5

(C) 1 (D) 0.5

3. In a lever, increasing the effort arm (while keeping the load arm the same) results in:

(A) decrease in MA (B) no change in MA

(C) decrease in load (D) increase in MA

4. In a lever having mechanical advantage MA < 1, the effort is applied:

(A) at the fulcrum (B) on the same side of fulcrum as the load

(C) between the fulcrum and the load (D) at the load

5. A class II lever always has:

(A) MA = 1 (B) MA < 1

(C) MA > 1 (D) MA = 0

6. The purpose of an ideal fixed pulley is to:

(A) multiply the effort (B) increase the load

(C) increase the speed (D) provide a convenient direction of effort

7. The mechanical advantage (MA) of an inclined plane of length l and height h is:

(A) $\frac{h}{l}$ (B) $\frac{l}{h}$

(C) $l \times h$ (D) $l + h$

8. A machine cannot:

(A) multiply force

(B) change the direction of force

(C) create energy

(D) make work more convenient

9. The mechanical advantage of a movable pulley (ideal case) is:

(A) 1 (B) 2

(C) 0.5 (D) 3

10. Which of the following is an example of a class I lever?

(A) Seesaw (B) Wheelbarrow

(C) Nutcracker (D) Bottle opener

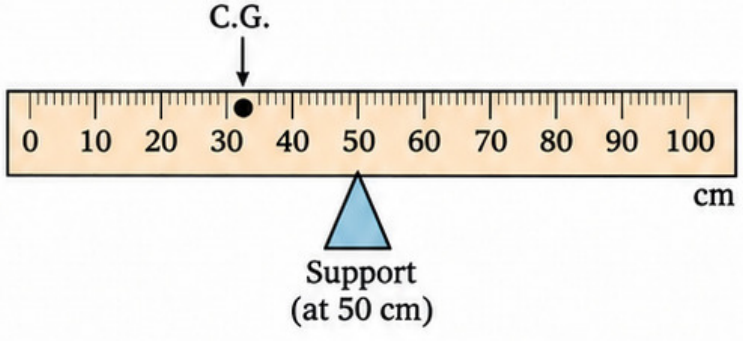
11. A meter scale is supported at its centre (50 cm mark) as shown. If the centre of gravity of the meter scale lies to the left of the support, which side of the scale will fall?

(A) Left side

(B) Right side

(C) It will remain horizontal

(D) It will oscillate without falling



Answer Key: 1. B | 2. D (0.5) | 3. D | 4. C | 5. C | 6. D | 7. B | 8. C | 9. B | 10. A | 11. A

ASSERTION–REASON & CASE-BASED PRACTICE

Directions: For each Assertion (A) and Reason (R), choose the correct option:

- **A** Both A and R are true and R explains A.
- **B** Both A and R are true but R does not explain A.
- **C** A is true, R is false.
- **D** A is false, R is true.

1.

Assertion (A): In a Class I lever, mechanical advantage may be greater than, equal to, or less than 1.

Reason (R): The fulcrum lies between load and effort and its position can vary.

Answer: A

2.

Assertion (A): A nutcracker is a Class III lever.

Reason (R): In a nutcracker, the load is situated between the fulcrum and the effort.

Answer: D

3.

Assertion (A): An inclined plane is a simple machine.

Reason (R): It changes only the direction of effort.

Answer: C

CASE STUDY

A rigid crowbar turns about a fulcrum. At equilibrium,

$$E \times \text{effort arm} = L \times \text{load arm}$$

and

$$MA = \frac{L}{E} = \frac{\text{effort arm}}{\text{load arm}}$$

(a) Identify the class when fulcrum lies between effort and load.

Answer: Class I.

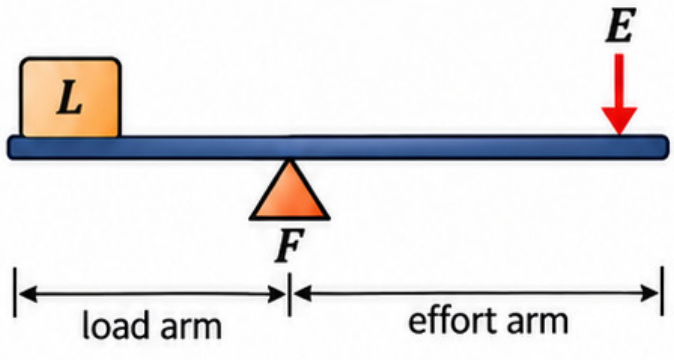
(b) How can MA be increased?

Answer: Move fulcrum nearer load.

(c) A 120 cm crowbar has fulcrum 60 cm from load. Find MA.

Answer: Effort arm = 60 cm, load arm = 60 cm,

$$MA = \frac{60}{60} = 1\,.$$



VERY SHORT ANSWER QUESTIONS — 1 MARK

1 **Define simple machine.**

Ans. A simple machine is a device which makes our work easier by changing the magnitude or direction of the applied force (effort).

2 **Write any two functions of a simple machine.**

Ans. (i) It can multiply the force (increase the effective force).
(ii) It can change the direction of the force (effort).

3 **Define load and effort.**

Ans. **Load (L):** The resistance or the weight to be moved by the machine.
Effort (E): The force applied on the machine to overcome the load.

4 **Define mechanical advantage (MA).**

Ans. Mechanical advantage (MA) of a machine is the ratio of load to effort.

$$MA = \frac{L}{E}$$

where L = load and E = effort.

5 **When does a simple machine act as a force multiplier?**

Ans. When its mechanical advantage is greater than 1, i.e.,

$$MA > 1.$$

6 **When does a simple machine act as a speed multiplier?**

Ans. When its mechanical advantage is less than 1, i.e.,

$$MA < 1.$$

7 **What is a lever? State its principle.**

Ans. A lever is a rigid rod that can turn about a fixed point (fulcrum) to move a load.
Principle: It works on the principle of lever, i.e., in equilibrium, the moments of effort and load about the fulcrum are equal:

$$E \times d_E = L \times d_L$$

8 **What is the mechanical advantage of a fixed pulley? Mention one advantage.**

Ans. For a fixed pulley, $MA = 1$ (i.e., $L = E$).
Advantage: It changes the direction of the effort (e.g., we can pull downward to lift a load upward).

9 **What is the mechanical advantage of a movable pulley?**

Ans. For a single movable pulley, $MA = 2$ (i.e., the effort is half the load, $E = \frac{L}{2}$).

10 **Write the expression for the mechanical advantage of an inclined plane.**

Ans. For an inclined plane,

$$MA = \frac{l}{h}$$

where l = length of the inclined plane and h = its vertical height.

11 **Name the three parts of a lever.**

Ans. The three parts of a lever are:
(i) Fulcrum (F) (ii) Effort (E) (iii) Load (L).

12 **State the condition for a balanced lever.**

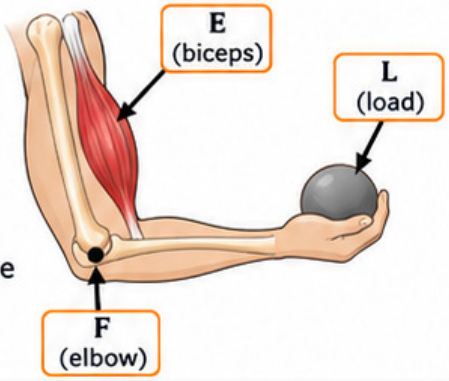
Ans. A lever is balanced (in equilibrium) when the moment of effort equals the moment of load, i.e.,

$$E \times d_E = L \times d_L$$

(Diagram based)

In the given forearm diagram, identify the positions of F, E and L.

Ans. F – at the elbow, E – at the biceps (muscle), L – at the load in the hand.



SHORT & LONG ANSWER PRACTICE

Part A : Short Answer Questions (2 Marks Each)

Q. No.	Question	Model Answer (Key Points)	Marks
1.	How can the mechanical advantage (MA) of a lever be increased?	■ MA of a lever, $M_A = \frac{d_E}{d_L}$. ■ It can be increased by (i) increasing the effort arm (d_E), or (ii) decreasing the load arm (d_L).	2
2.	Why does a Class II lever always have MA > 1 ?	■ In a Class II lever, the load lies between the fulcrum and the effort. ■ Hence, the effort arm is always greater than the load arm ($d_E > d_L$). ■ So, $M_A = \frac{d_E}{d_L} > 1$.	2
3.	Compare a fixed pulley and a movable pulley.	**Point** / **Fixed Pulley** / **Movable Pulley** (i) Support: Axis fixed to a support. / Pulley moves with the load. (ii) Mechanical advantage: $M_A = 1$. / $M_A = 2$ (ideally). (iii) Main use: Changes the direction of effort (no gain in force). / Gives gain in force (less effort needed).	2
4.	Why is a machine with MA < 1 useful?	■ A machine with MA < 1 is useful because it gives a gain in speed or distance (the effort moves a greater distance than the load). ■ It is also useful for better control and convenience (e.g., a pair of tongs, a broom).	2
5.	Explain the trade-off in an inclined plane.	■ An inclined plane reduces the effort needed to raise a load by increasing the distance over which the effort is applied. ■ Its MA is $M_A = \frac{l}{h}$ (l = length of plane, h = vertical height). ■ Trade-off: less effort but a longer distance (more work over a greater distance).	2

Part B : Long Answer Questions (3 – 5 Marks Each)

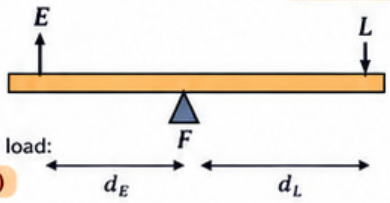
6. Derive the principle of lever and the expression for its MA. [4 Marks]

- Consider a lever with fulcrum F, effort E at distance d_E and load L at distance d_L from F. Let the lever turn through a small angle θ (Fig.).
- Then, effort moves through distance $d_E\theta$ and load through distance $d_L\theta$.
- For an ideal lever (no energy loss), work done by effort = work done on load:

$$E(d_E\theta) = L(d_L\theta) \Rightarrow Ed_E = Ld_L$$ (Principle of lever)

- Hence, the mechanical advantage (MA) of a lever is

$$M_A = \frac{L}{E} = \frac{d_E}{d_L}.$$



(Marking Scheme)
- Diagram with labels – 1 M
- Relation $E(d_E\theta) = L(d_L\theta)$ or $Ed_E = Ld_L$ – 1 M
- Statement of lever principle – 1 M
- Expression for MA ($M_A = \frac{d_E}{d_L}$) – 1 M

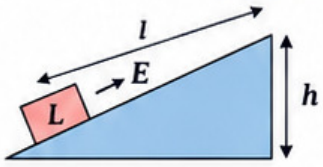
7. Derive the MA of an inclined plane from the work done. [3 Marks]

- Let a load L be raised through a vertical height h by applying an effort E along an inclined plane of length l (Fig.).
- For an ideal inclined plane (no loss), work done by effort = work done on load:

$$E \times l = L \times h.$$

- Hence, the mechanical advantage is

$$M_A = \frac{L}{E} = \frac{l}{h}.$$

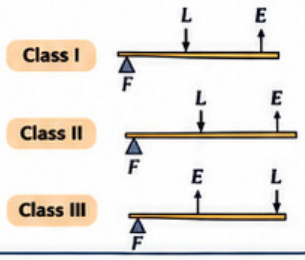


(Marking Scheme)
- Correct work equation ($El = Lh$) – 1 M
- Derivation of MA – 1 M
- Diagram with labels – 1 M

8. Explain the three classes of levers with the order F/L/E and examples. [5 Marks]

- Levers are classified into three classes based on the relative positions of fulcrum (F), load (L) and effort (E).

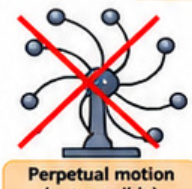
Class	Order (from one end)	Key feature	Example
I	F – L – E (or E – L – F)	Fulcrum between load and effort.	See-saw, scissors, pliers.
II	F – L – E	Load between fulcrum and effort.	Wheelbarrow, nutcracker, bottle opener.
III	F – E – L	Effort between fulcrum and load.	Tweezers, tongs, the human forearm (biceps).



(Marking Scheme)
- Classification criterion – 1 M
- Correct order (F/L/E) for all three – 1½ M
- Key feature (one line each) – 1½ M
- Examples (one or two for each) – 1 M

9. Explain why a perpetual motion machine is impossible. [3 Marks]

- A perpetual motion machine is a hypothetical machine that would keep doing work forever without any external supply of energy.
- It is impossible because, in any real machine, some energy is always lost to the surroundings (mainly as heat due to friction, air resistance, etc.).
- Therefore, the output energy can never be equal to (or greater than) the input energy.
- This is in accordance with the law of conservation of energy and the second law of thermodynamics (no machine can be 100% efficient).



(Marking Scheme)
- Meaning of perpetual motion machine – 1 M
- Reason (unavoidable energy losses, e.g., friction) – 1 M
- Conclusion (violates energy principles / cannot be 100% efficient) – 1 M

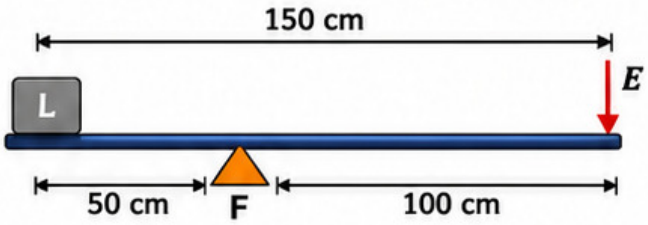
NUMERICAL PRACTICE — LEVERS (SET 1)

Q1 A crowbar is 150 cm long. The fulcrum is 50 cm from the load. Find the load arm, effort arm and the mechanical advantage.

Given:
- Length of crowbar = 150 cm
- Distance of fulcrum from load = 50 cm

Solution:
- Load arm, $L = 50$ cm
- Effort arm, $E = 150 - 50 = 100$ cm
- Mechanical advantage,

$$MA = \frac{E}{L} = \frac{100}{50} = 2$$



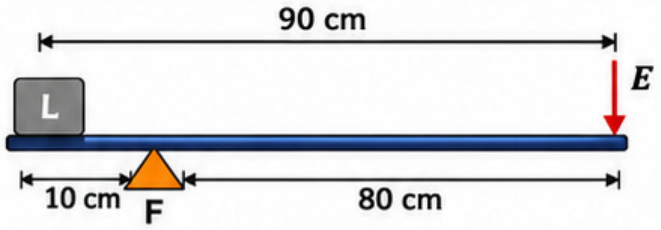
Answer: $L = 50$ cm, $E = 100$ cm, $MA = 2$

Q2 A crowbar is 90 cm long. The fulcrum is 10 cm from the load. Find the effort arm and the mechanical advantage.

Given:
- Length of crowbar = 90 cm
- Distance of fulcrum from load = 10 cm

Solution:
- Effort arm, $E = 90 - 10 = 80$ cm
- Mechanical advantage,

$$MA = \frac{E}{L} = \frac{80}{10} = 8$$



Answer: $E = 80$ cm, $MA = 8$

Q3 A fire tongs has arms 30 cm long. The effort is applied at a point 20 cm from the fulcrum. A load of 2 kgf is held at the tips. Find the mechanical advantage and the effort.

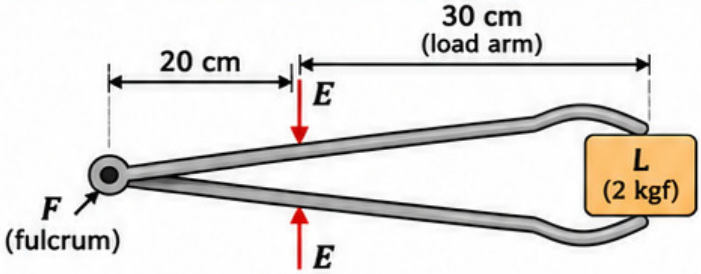
Given:
- Length of each arm (load arm) = 30 cm
- Effort arm = 20 cm
- Load, $L = 2$ kgf

Solution:
- Mechanical advantage,

$$MA = \frac{E}{L} = \frac{20}{30} = \frac{2}{3}$$

- Effort,

$$E = \frac{L}{MA} = \frac{2}{\frac{2}{3}} = 2 \times \frac{3}{2} = 3 \text{ kgf}$$



Answer: $MA = \frac{2}{3}$, Effort = 3 kgf

Q4 A lever has a load of 50 N at A. The fulcrum is 40 cm from A and the effort is applied at B, which is 60 cm beyond A. Find the mechanical advantage and the ideal effort.

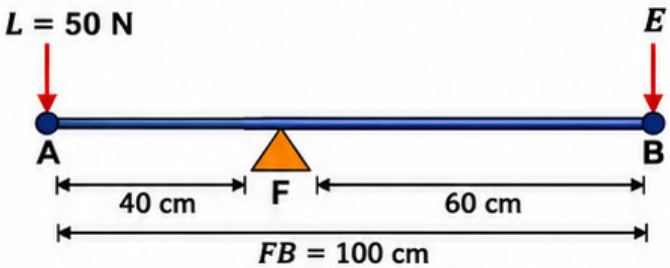
Given:
- Load, $L = 50$ N (at A)
- Distance $FA = 40$ cm
- Distance $AB = 60$ cm

Solution:
- Effort arm, $FB = FA + AB = 40 + 60 = 100$ cm
- Mechanical advantage,

$$MA = \frac{FB}{FA} = \frac{100}{40} = 2.5$$

- Ideal effort,

$$E = \frac{L}{MA} = \frac{50}{2.5} = 20 \text{ N}$$



Answer: $MA = 2.5$, Ideal effort = 20 N

SOLVED NUMERICALS — LEVERS II

1 NUTCRACKER

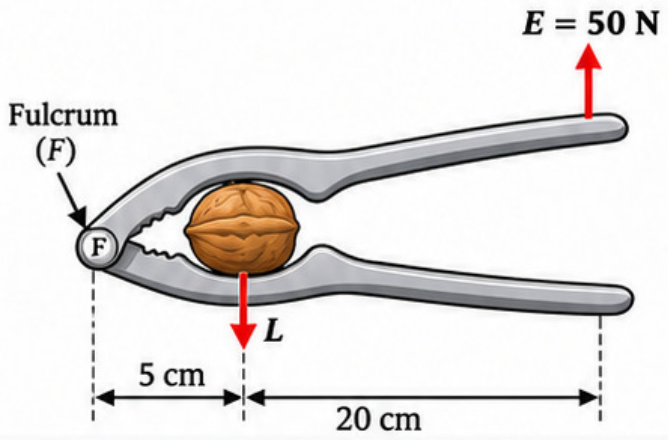
Given: Effort arm = 20 cm, load arm = 5 cm, effort $E = 50$ N.

Solution:

Using $E \times (\text{effort arm}) = L \times (\text{load arm})$,

$$50 \times 20 = L \times 5$$

Therefore, $L = \dfrac{50 \times 20}{5} = \mathbf{200\ N.}$



2 FIRE TONGS

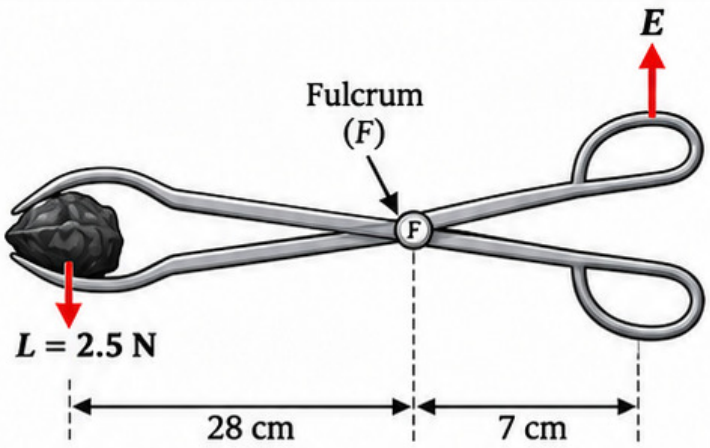
Given: Load arm = 28 cm, effort arm = 7 cm, mass of coal = 250 g = 0.25 kg.

Weight of coal, $L = mg = 0.25 \times 10 = 2.5$ N (taking $g = 10\ \text{m s}^{-2}$).

Solution:

Using $E \times 7 = 2.5 \times 28$,

$$E = \frac{2.5 \times 28}{7} = \mathbf{10\ N.}$$



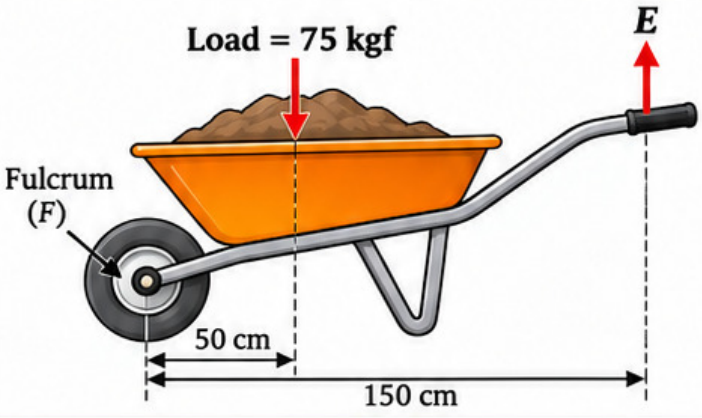
3 WHEELBARROW

Given: Total load = 75 kgf, centre of load is 50 cm from the wheel (fulcrum), handles are 150 cm from the wheel.

Solution:

Using $E \times 150 = 75 \times 50$,

$$E = \frac{75 \times 50}{150} = \mathbf{25\ kgf.}$$



4 UNIFORM METRE SCALE

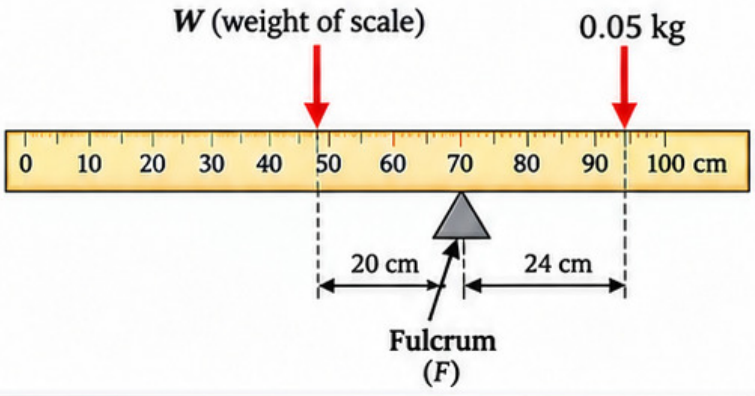
Given: Metre scale (uniform) balanced at 70 cm. A mass of 0.05 kg hangs at 94 cm. Weight of the scale = W, acting at 50 cm.

Solution:

Taking moments about the fulcrum at 70 cm:

$$W \times 20 = 0.05 \times 24,$$

$$W = \frac{0.05 \times 24}{20} = \mathbf{0.06\ kg} = \mathbf{60\ g.}$$



Use perpendicular distance from the fulcrum.

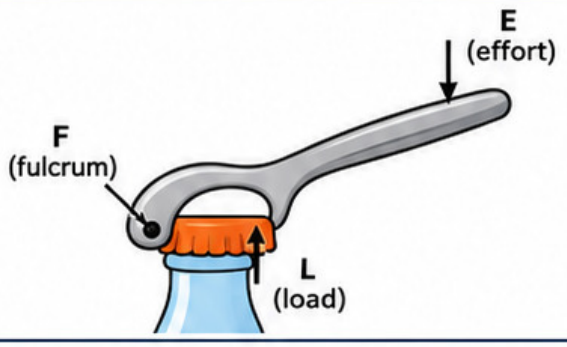
SOLVED NUMERICALS — MIXED APPLICATIONS

1 BOTTLE OPENER

Problem: Identify the class of lever in a bottle opener and state its function.

Solution:

- It is a **Class II lever.**
- The load lies between the fulcrum and the effort (*F* – *L* – E).
- It is a force **multiplier.**

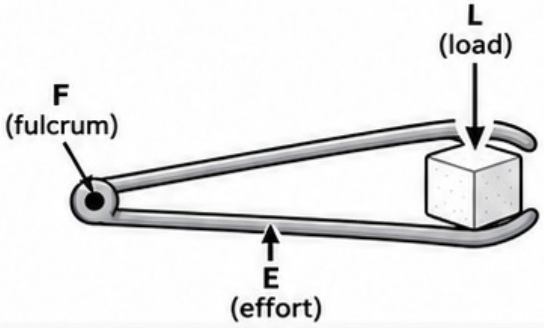


2 SUGAR TONGS

Problem: Identify the class of lever in sugar tongs and state its advantage.

Solution:

- It is a **Class III lever.**
- The effort lies between the *fulcrum* and the load (*F* – E – L).
- It gives **speed/distance advantage.**



3 SHEARS

Problem: In a pair of shears, the cutting force (load) is $L = 10$ kgf, the load arm is 10 cm and the effort arm is 20 cm. Find the effort.

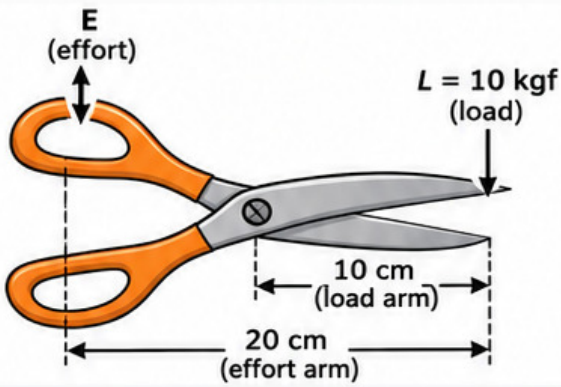
Solution:

Using the principle of moments:

$$E \times 20 = 10 \times 10$$

$$E = \frac{100}{20} = 5 \text{ kgf}$$

$\therefore$ $E = 5$ **kgf.**



4 BALANCED SEE-SAW

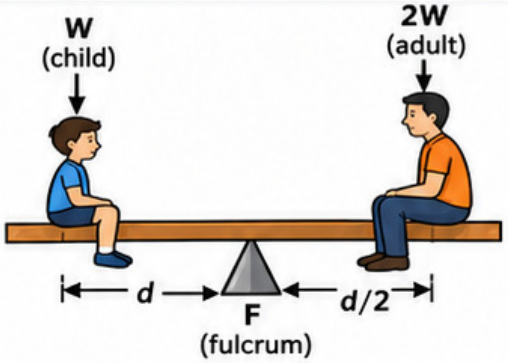
Problem: An adult weighs twice the child. If the child sits at a distance d from the fulcrum, find the distance x of the adult from the fulcrum for balance.

Solution:

Let the child's weight be W, so the adult's weight is $2W$. For balance, moments about the fulcrum are equal:

$$W\,d = 2W \times x$$

$$x = \frac{d}{2}.$$

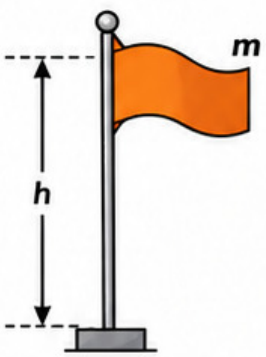


5 FLAG AND POWER

Problem: Find the work done in raising a flag of mass m through height h. State whether it depends on time. Write the expression for power and relate the change in power if the raising speed doubles.

Solution:

- Work done: $W = mgh$.
- It is independent of time.
- Power: $P = \frac{W}{t}$.
- If the raising speed doubles, the time halves ($t' = \frac{t}{2}$), and the power doubles: $P' = \frac{W}{t'} = \frac{W}{t/2} = 2\frac{W}{t} = 2P$.



$$W = mgh$$

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

$$t' = \frac{t}{2}$$

$$P' = 2P$$

EXAM TIP **First identify *F*, *L* and *E*; then compare arm lengths.**

SIMPLE MACHINES — RAPID REVISION TEST

A FILL IN THE BLANKS (5)



1. MA = _____ / Effort.
2. A fixed pulley mainly changes the _____ of force.
3. For an ideal inclined plane, MA = _____ / height.
4. In Class II lever, _____ lies between fulcrum and effort.
5. The SI unit of work is _____.

B TRUE OR FALSE (5)

1. Machines create energy. _____
2. A movable pulley has ideal MA 2. _____
3. Class III levers have MA less than 1. _____
4. Increasing effort arm increases MA. _____
5. Work output of a real machine exceeds work input. _____

C ANSWER IN ONE LINE (5)

1. Define load. _____
2. Define effort. _____
3. State principle of lever. _____
4. Give one example of each lever class. _____
5. Why do real machines stop? _____

D CHALLENGE (3)

1. A ramp is 5 m long and 1 m high—find ideal MA. _____
2. A 300 N load is lifted by 100 N effort—find MA. _____
3. A lever has effort arm 60 cm and load arm 15 cm—find MA. _____

ANSWER KEY

A: load, direction, length, load, joule
B: F, T, T, T, F
D: 5, 3, 4

FINAL CHECKLIST

- ☐ I can label F–L–E.
- ☐ I can classify levers.
- ☐ I can solve MA numericals.