X PHYSICS SHORT NOTES

3. Machines

A) MACHINES, TECHNICAL TERMS & LEVERS.

- **Machines:**
  - **Definition:** A machine is a device by which we can either overcome a large resistive force/load by applying a small force/effort at a convenient point in a desired direction or by which we can obtain a gain in speed.
  - **Function or uses of simple machines:**
    - To lift a heavy load by applying less effort (force multiplier).
    - To change the point of application of effort to a convenient point.
    - To change the direction of effort to a convenient direction.
    - To obtain a gain in speed (a greater movement of load by a smaller movement of effort).
- **Technical terms used:**
  - **Load:** The resistive or opposing force to overcome by a machine is called the load [L].
  - **Effort:** The force applied on the machine to overcome the load is called the effort [E].
  - **Mechanical advantage (M.A.):**
    - **Definition:** The ratio of the load to the effort is called mechanical advantage of a machine.
    - $\text{M.A} = \frac{load\ (L)}{effort\ (E)}$.
    - A machine having M.A. > one, works as a force multiplier.
    - A machine having M.A. < one, works as a speed multiplier.
    - A machine having M.A. = one, works to change the direction of motion as there is no gain in force or speed.
    - Mechanical advantage has no units.
    - **Factors affecting MA:**
      - Load – **Directly Proportional.**
      - Effort – **Inversely Proportional.**
      - Weight of lower block (pulley) – **Direct Proportional.**

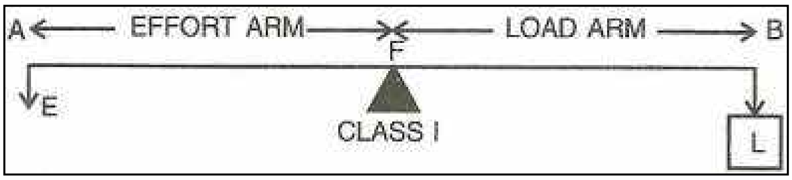
- **Velocity ratio (V.R.):**
  - **Definition:**
    - The velocity ratio of a machine is the ratio of the velocity of effort to the velocity of load. **OR**
    - The velocity ratio of a machine is the ratio of displacement of effort to the displacement of load.
  - V.R. $= \frac{velocity\ of\ effort}{velocity\ of\ load} = \frac{d_E}{d_L}$.
  - A machine having V.R. > one, works as a force multiplier
  - A machine having V.R. < one, works as a speed multiplier.
  - A machine having V.R. = one, works to change the direction of motion.
  - It has no units.
  - **Factors affecting VR:**
    - Load – **Direct Proportional.**
    - Effort – **Inversely Proportional.**
    - Effort arm (lever) – **Direct Proportional.**
    - Load arm (lever) – **Inversely Proportional.**
    - No. of pulley (pulley) – **Direct Proportional.**
- **Work input:**
  - **Definition:** Work input is the work done on a machine by the effort.
  - W_{input} = Work done by the effort.
- **Work output:**
  - **Definition:** Work output is the work done by the machine on the load.
  - W_{output} = Work done on the load.
- **Efficiency (η):**
  - **Definition:**
    - Efficiency of a machine is the ratio of the useful work done **by** a machine **on** the load to the work done **by** the effort **on** the machine. **OR**
    - Efficiency of a machine is the ratio of work output to the work input.
  - $\eta = \frac{work\ output}{work\ input} \times 100\%$.
  - It has no units.
  - **Factors affecting η/ efficiency:**

- MA – **Direct Proportional.**
- VR – **Inversely Proportional.**

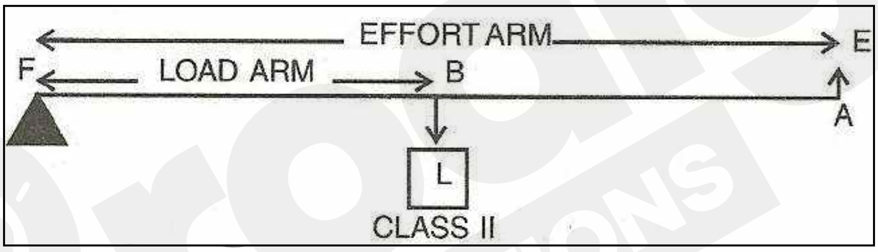
- **<u>Principle of a machine</u>:**
  - Input energy = Work done on the effort point.
    = E × displacement of point of application of effort.
  - Output energy = Work done on the load point.
    = L × displacement of point of application of load.
- **<u>Ideal Machine</u>:** An ideal machine is that in which there is no dissipation of energy in any manner, the work output is equal to the work input, thus its η is 100%.
- **<u>Actual machine / Practical machine</u>:** An actual machine is a machine in which some of the energy is lost in overcoming the force of friction between the moving parts of a machine.
- **<u>Relationship between Efficiency (η), Mechanical advantage (MA) & Velocity Ratio (VR)</u>:**
  - M.A = V.R × η.
  - For an ideal machine, the η = 1 has M.A. = V.R.
  - In all practical machines:
    - $M.A < V.R$ or
    - The output work < input work.
    - Hence the η < 1; since there are energy losses due to friction, etc.
- **<u>Levers</u>:**
  - **<u>Definition</u>:** A lever is a rigid, straight or a bent bar, which is capable of turning about a fixed axis.
  - **<u>Principle</u>:** A lever works on the principle of moments.
  - **<u>Assumption</u>:** The lever is weightless and frictionless.
  - **<u>M.A of lever</u>:**
    - Clockwise moment of load about the fulcrum = Anticlockwise moment of effort about the fulcrum.
    - M.A. $= \frac{Effort\ arm\ FA}{Load\ arm\ FB}$
  - **<u>Law of lever</u>:** The mechanical advantage of a lever is equal to the ratio of the length of its effort arm to the length of its load arm
  - **<u>Note</u>:**
    - If effort arm = load arm, M.A = 1.
    - If effort arm < load arm, M.A < 1.
    - If effort arm > load arm, M.A > 1.
  - **Increase** in M.A. of a lever is brought about by - **increasing** its effort arm or **decreasing** its load arm.

  - **Decrease** in M.A. of a lever is brought about by - **decreasing** its effort arm or **increasing** its load arm.

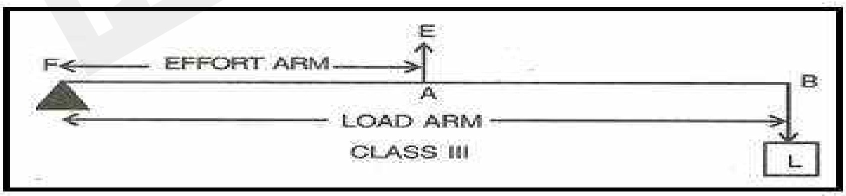
- **Kinds of Levers:** There are 3 kinds of levers:
  - **Class I Lever:**



    - **Definition:** In these types of levers, the fulcrum F is in between the effort E and load L.
    - **Examples:** A seesaw, a spoon used to open the lid of a tin can, the nodding of human head, a pair of scissors, crowbar, handle of water pump, claw hammer, a pair of pliers, the beam of common balance, a spade used for turning the soil, and rowing a boat singly.
    - The mechanical advantage and velocity ratio can be greater than 1 or equal to 1 or less than 1.
  - **Class II Lever:**

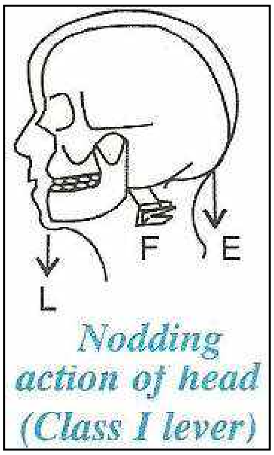


    - **Definition:** In these types of levers, the load L is in between the effort E and the fulcrum F.
    - The M.A and V.R. of Class II Levers are always more than 1.
    - **Examples:** A stapler, a nut cracker, a bottle opener, a paper cutter, a mango cuter, a bar used to lift a load, a wheel barrow, a lemon crusher, raising the weight of the human body on toes.
  - **Class III Lever:**

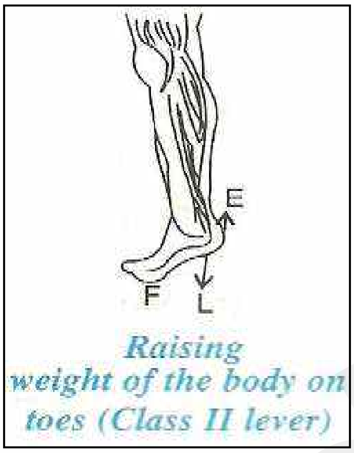


    - **Definition:** In these types of levers, the effort E is in between the fulcrum F and the load L and the effort arm is always smaller than the load arm.
    - The M.A. and V.R. of Class III Levers are always less than 1.
    - **Examples:** Foot treadle, knife, sugar tongs, the forearm used for lifting a load (or action of the bicep muscle) fire tongs, a spade used to lift coal (or soil).

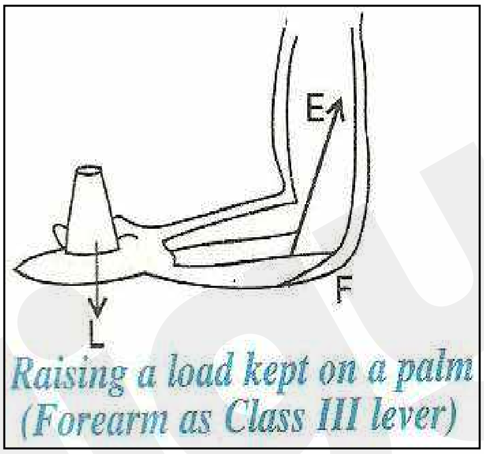
- **<u>Examples of each class of lever as found in the human body</u>:**
    - Class I Lever – The action of nodding of the head.
    - Class II Lever – Raising the weight of the body on toes.
    - Class III Lever – Raising a load by forearm.



Nodding action of head (Class I lever)



Raising weight of the body on toes (Class II lever)



Raising a load kept on a palm (Forearm as Class III lever)

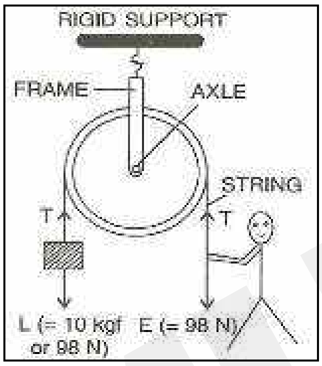
<u>FORMULAE</u>:

1. Mechanical advantage (M.A.) $= \dfrac{Load\ (L)}{Effort\ (E)}$
2. Velocity ratio (V.R.) $= \dfrac{\text{Displacement of the effort}}{\text{Displacement of the load}} = \dfrac{d_E}{d_L}$
3. Work input $= E \times d_E$
4. Work output $= L \times d_L$
5. Efficiency η% $= \dfrac{\text{Work output}}{\text{Work input}} = \dfrac{L}{E} \times \dfrac{d_L}{d_E} = \dfrac{\text{Power output}}{\text{Power input}}$
6. Efficiency η% $= \dfrac{M.A.}{V.R.} \times 100$
7. Load × Load arm = Effort × Effort arm
8. M.A. $= \dfrac{L}{E}$ or $\dfrac{Effort\ arm}{Load\ arm}$

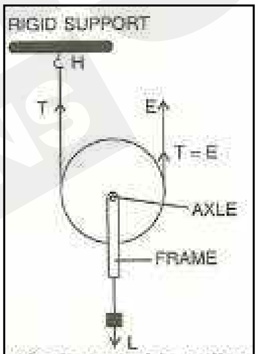
B) PULLEY

- **<u>Pulley</u>:** A wheel with a grooved rim around which a cord passes is a pulley.
- **<u>Block</u>:** A single pulley or a combination of two or more pulleys fixed in a frame is called a block.
- **<u>Tackle</u>:** A string or a rope or a chain that winds around a pulley in different blocks is known as tackle.
- A pulley can be used in two ways:
    - By keeping its axis of rotation fixed in position,
    - Without keeping its axis of rotation fixed i.e., allowing it to move.

- **Single fixed pulley:**
  - **Definition:** A single fixed pulley is a pulley, which has a fixed position of its axis of rotation.
  - The friction between the string and the rim rotates the pulley when the string is pulled.
  - **Technical terms:**
    - Mechanical advantage = $\frac{load\ L}{effort\ E} = \frac{T}{T} = 1.$
    - Velocity ratio = $\frac{d_E}{d_L} = \frac{d}{d} = 1.$
    - $\eta = \frac{MA}{VR}$ = 1 or 100%
    - **Assumption:** The mass of string is negligible and no friction in the pulley bearings.

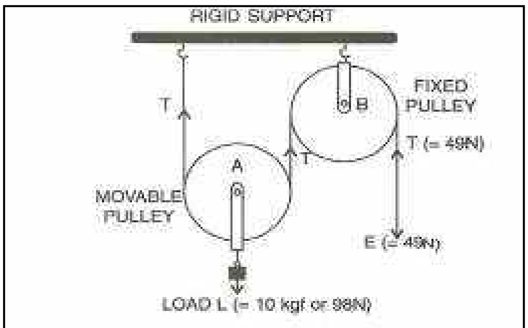


  - No gain in MA or VR, hence it is **neither** a force **nor** a speed multiplier.
  - **Use:** A single fixed pulley is used only to change the direction of the force applied, thus the effort can be applied in a more convenient direction.
- **Single movable pulley:**
  - **Definition:** A pulley, whose axis of rotation is not fixed in a position, is called a movable pulley.
  - **Technical terms:**
    - Mechanical advantage = $\frac{load\ L}{effort\ E} = \frac{2T}{T} = 2.$
    - Velocity ratio = $\frac{d_E}{d_L} = \frac{2d}{d} = 2.$
    - $\eta = \frac{MA}{VR} = \frac{2}{2}$ = 1 or 100%
    - **Assumption:** The mass of string is negligible and no friction in the pulley bearings.



Single movable pulley

  - **Advantage:** The MA greater than 1 hence the single movable pulley acts as a force multiplier.
  - **Disadvantage:** The effort to be applied is in the upward direction which is inconvenient to apply.
- **To change the direction of effort using a movable pulley:** A single movable pulley is used along with the fixed pulley.



Single movable pulley with a fixed pulley

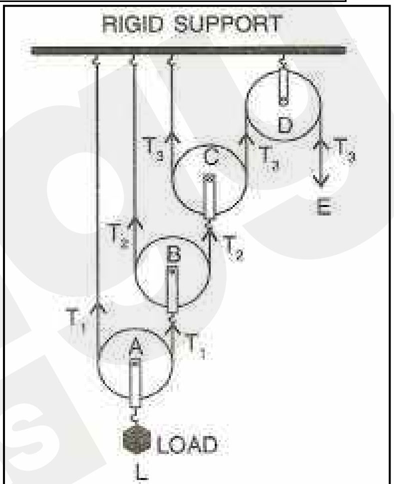
  - It gives gain in MA and
  - It changes the direction of application of force.

➢ **<u>Comparison between single fixed and single movable pulley</u>:**

Single fixed pulley.	Single movable pulley.
1. Its is fixed to a rigid support.	1. It is not fixed to a rigid support.
2. Its M.A. is 1.	2. Its M.A. is 2.
3. Its V.R. is 1.	3. Its V.R. is 2.
4. The weight of pulley does not affect its M.A.	4. The weight of pulley reduces its M.A.
5. It is used to change the direction of application of force.	5. It is used as a force multiplier.
6. The load moves opposite to the direction of the effort.	6. The load moves in the direction of the effort.

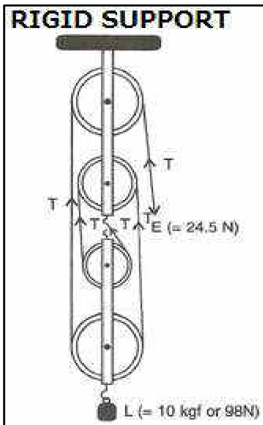
➢ **<u>Combination of pulleys</u>:**

- **<u>Using one fixed pulley and other movable pulleys</u>:**
  - **<u>Technical terms</u>:**
    - M.A. = 2^n
    - V.R. = 2^n; Where n = no. of movable pulleys
    - $\eta = \frac{MA}{VR} = 1$ or 100%
    - **<u>Assumption</u>:** The mass of string is negligible and no friction in the pulley bearings.

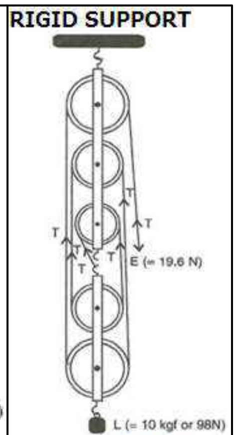


System of one fixed pulley and three movable pulleys

- **<u>Using several pulleys in two blocks (block and tackle system)</u>:**
  - **<u>Technical terms</u>:**
    - M.A = $\frac{Load\ L}{Effort\ E} = \frac{nT}{T} = n.$
    - E = $\frac{L(load)}{n(number\ of\ pulleys)}$.
    - The effort gets multiplied n times.
    - **n** is the total number of pulleys.
    - It therefore acts as a force multiplier.
    - Velocity ratio $= \frac{nd}{d} = n.$
    - The velocity ratio is always equal to the number of strands of tackle (or sections of the string) supporting the load.
    - Efficiency η= $\frac{M.A}{V.R} = \frac{n}{n} = 1\ or\ 100\%.$
    - **<u>Assumption</u>:** The mass of string is negligible and no friction in the pulley bearings.



Block and tackle for 4 pulleys



Block and tackle for 5 pulleys

➢ The pulley system is only a force multiplier.

FORMULAE:

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5. Efficiency η% $= \frac{\text{Work output}}{\text{Work input}} = \frac{L}{E} \times \frac{d_L}{d_E} = \frac{\text{Power output}}{\text{Power input}}$
6. Efficiency η% $= \frac{M.A.}{V.R.} \times 100$
7. M.A. $= \frac{Load\ (L)}{Effort\ (E)}$
8. V.R. $= \frac{\text{Displacement of the effort}}{\text{Displacement of the load}} = \frac{d_E}{d_L}$
9. Resistance due to movable parts or friction of the pulley (X) = E (VR – MA) OR

   $\frac{X}{E}$ = VR – MA
10. VR $= \frac{2R}{R - r}$