

PHYSICS NOTES

FORM 3 SIMPLIFIED VERSION

QUICK REVISION NOTES

*An Updated Well-Organized Detailed Revision Notes for the
Current Form 3 Syllabus.*

SERIES 1

THIS IS A FREE SAMPLE OF THE

ORIGINAL NOTES

CONTACT US FOR FULL VERSION OF THE NOTES

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LINEAR MOTION

Specific objectives

By the end of this topic the learner should be able to:

- a) Define distance, displacement, speed, velocity and acceleration*
- b) Describe experiments to determine velocity and acceleration*
- c) Determine acceleration due to gravity*
- d) Plot and explain motion- time graphs*
- e) Apply the equation of uniformly accelerated motion*
- f) Solve numerical questions.*

Content

- 1. Distance, displacement, speed, velocity, acceleration (experimental treatment required)*
- 2. Acceleration due to gravity*
 - free fall,*
 - Simple pendulum method*
- 3. Motion- time graphs*
 - Displacement-time graphs*
 - Velocity- time graphs*
- 4. Equations of uniformly accelerated motion*
- 5. Problems on uniformly accelerated motion*

Introduction

- ❖ This topic deals with study motion of bodies in a straight line.

Terms Associated with Linear Motion

i. Distance

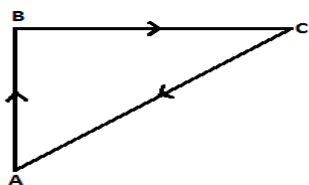
- ❖ Distance is the actual length covered by a moving body. It has no specific direction and it is therefore a **scalar quantity**. The SI unit of distance is **meter (m)**

ii. Displacement, s

- ❖ This is the distance covered by a moving body in a specified direction. Displacement is therefore a **vector quantity**. The SI unit of displacement is **metre (m)**

Illustrating distance and displacement

Consider the diagram below showing motion of a body starting from point A and moving in the direction shown.



- At point B, distance covered is AB while the displacement of the body is AB in the direction **AB**
- At point C, distance covered is AB + BC while the displacement is AC in the direction **AC**
- When back at starting point A, distance covered is AB + BC + CA while the displacement is **zero**.

iii. Speed

This is the rate of change of distance covered by a moving body with time. Speed is a **scalar quantity**.

$$\text{speed} = \frac{\text{distance covered}}{\text{time taken}}$$

For a body moving with a non-uniform speed,

$$\text{average speed} = \frac{\text{total distance covered}}{\text{total time taken}}$$

- ❖ **Instantaneous speed** refers to the rate of change of distance of a moving body at a point (an instant). The SI unit of speed is **the metre per second (ms^{-1})**

iv. Velocity

- ❖ This is the rate of change of displacement with time. It can also be defined as the speed in a specified direction. Velocity is therefore a **vector quantity**.

$$\text{velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

For a body moving with a varying velocity,

$$\text{average velocity} = \frac{\text{total displacement}}{\text{total time taken}}$$

- ❖ The SI unit of velocity is **the metre per second (ms^{-1})**.

v) Acceleration

- ❖ This is the change of velocity per unit time. It is a **vector quantity**.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$\text{Acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$$

$a = \frac{v-u}{t}$, where, **v** is the final velocity, **u** is the initial velocity and **t** is the time taken.

Instantaneous acceleration is the acceleration of a body at a point. **Deceleration or retardation** is the negative acceleration in which a body moves with a decreasing

Solution

$$u = 2.0 \times 10^5 \text{ kmh}^{-1} = 5.55556 \times 10^4 \text{ ms}^{-1}, \quad v = 0 \text{ ms}^{-1}$$

$$a = \frac{v-u}{t}; a = \frac{(0 - 5.55556 \times 10^4) \text{ ms}^{-1}}{2.0 \times 10^{-2} \text{ s}} = -2.77778 \times 10^6 \text{ ms}^{-2}$$

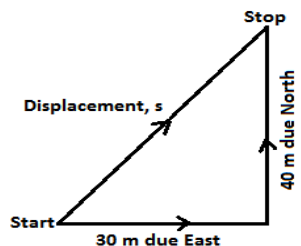
$$\text{Therefore retardation is } -(-2.77778 \times 10^6 \text{ ms}^{-2}) = 2.77778 \times 10^6 \text{ ms}^{-2}$$

velocity with time. The SI unit of acceleration is **metre per square second (ms^{-2})**.

Examples

1. A body moves 30 m due east in 4 seconds, then 40 m due north in 8 seconds. Determine:
- The total distance moved by the body.
 - The displacement of the body.
 - The average speed of the body.
 - The average velocity of the body.

Solution



- Total distance = total length covered
 $30\text{ m} + 40\text{ m} = 70\text{ m}$
- Total displacement is $(\sqrt{30^2 + 40^2})\text{ m}$
 $\sqrt{2500}\text{ m} = 50\text{ m}$ on bearing 36.87°
- Average speed = $\frac{\text{total distance covered}}{\text{total time taken}}$
 $= \frac{70}{12} = 5.833\text{ ms}^{-1}$
- Average velocity = $\frac{\text{total displacement}}{\text{total time taken}}$
 $= \frac{50}{12} = 4.167\text{ ms}^{-1}$ on bearing 36.87°

2. The speed of a body rolling on an inclined plane is 10 ms^{-1} when time is 0 s at time $t = 10\text{ s}$ the speed of the body is found to be 25 ms^{-1} . If the body is moving in the same direction throughout, calculate the average acceleration of the body

Solution

$$a = \frac{v - u}{t}$$

$$a = \frac{(25 - 10)\text{ ms}^{-1}}{(10 - 0)\text{ s}}$$

$$a = \frac{15\text{ ms}^{-1}}{10\text{ s}} = 1.5\text{ ms}^{-2}$$

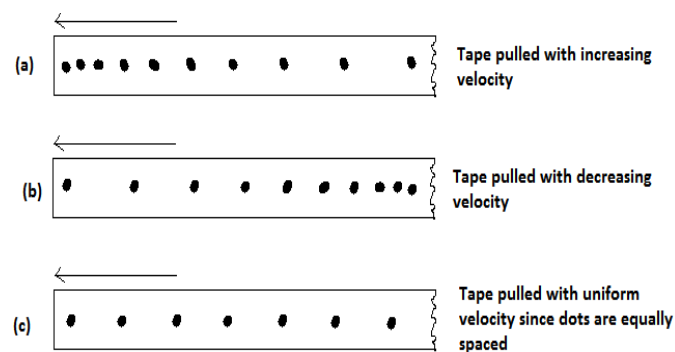
Exercise

- A van on a straight road moves with a speed of 180 kmh^{-1} for 45 minutes, and then climbs an escarpment with a speed of 72 kmh^{-1} for 30 minutes. Calculate:
 - The average speed of the van
 - The average acceleration produced
- A girl runs 40 m due south in 40 seconds and then 20 m due north in 10 seconds. Calculate:
 - her average speed
 - her average velocity
 - her change in velocity for the whole journey
 - The acceleration produced by the girl.

Measuring Speed, Velocity and Acceleration Using Ticker Timer

- A ticker timer has an arm which vibrates regularly due to changing current in the mains supply (alternating current). As the arm vibrates, it makes dots on the paper tape which is moving under the arm. **Successive dots are marked at the same interval of time**
- Most ticker timer operates at a frequency of 50 hertz (50Hz) i.e. 50 cycles per second i.e. they make 50 dots per second. The time interval between two consecutive dots is: $\frac{1}{50} = 0.02\text{ s}$ for a 50Hz ticker timer. This time interval is called **a tick**.

Sample sections of tapes are as shown below. The arrow shows the direction in which the tape is pulled.

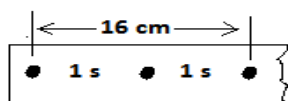


3. A particle moving with a velocity of $2.0 \times 10^5 \text{ kmh}^{-1}$ is brought to rest in $2.0 \times 10^{-2} \text{ s}$. calculate the acceleration of the body, hence the retardation.

Examples

1. A tape is pulled through a ticker timer which makes one dot every second. If it makes three dots and the distance between the first and the third dot is 16cm, find the velocity of the tape.

Solution



$$f = 1 \text{ Hz}$$

$$\text{Time between consecutive dots} = 1 \text{ s},$$

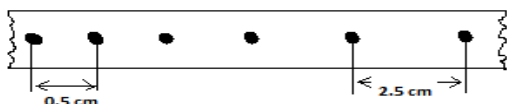
$$\text{total time} = 1 \text{ s} \times 2 = 2 \text{ s}$$

$$\text{Distance between 1st and 3rd dots} =$$

$$16 \text{ cm} = 0.16 \text{ m}$$

$$\text{average velocity} = \frac{\text{total displacement}}{\text{total time taken}} = \frac{0.16 \text{ m}}{2 \text{ s}} = 0.08 \text{ ms}^{-1}$$

3. The tape in the figure below was produced by a ticker timer with a frequency of 100Hz. Find the acceleration of the trolley that was pulling the tape. Solution



Solution

$$\text{time between consecutive dots} = \frac{1}{100} = 0.01 \text{ s}$$

$$\text{initial velocity, } v = \frac{0.005 \text{ m}}{0.01 \text{ s}} = 0.5 \text{ ms}^{-1}$$

$$\text{final velocity} = \frac{0.025 \text{ m}}{0.01 \text{ s}} = 2.5 \text{ ms}^{-1}$$

$$\text{time taken} = 4 \times 0.01 = 0.04 \text{ s}$$

$$\text{acceleration} = \frac{v - u}{t} = \frac{(2.5 - 0.5) \text{ ms}^{-1}}{0.04 \text{ s}} = \frac{200}{0.04} = 50 \text{ ms}^{-2}$$

- I. Calculate the average velocity for the motion
- II. What does the area under the straight line represent?
- III. What is the difference between successive sections of tape?
- IV. Calculate the acceleration of the trolley in ms^{-1}

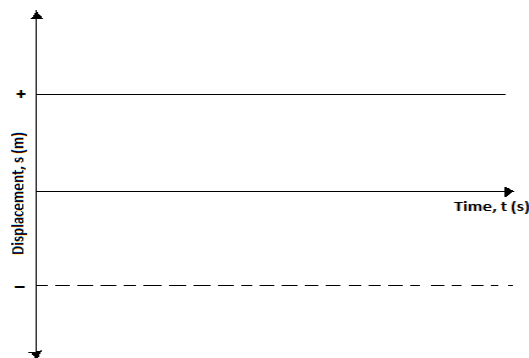
Motion Graphs

- ❖ Graphs can be used to represent variation of distance, speed, velocity or acceleration of a moving body with time. When used this way they are called **motion graphs**

Displacement – Time Graphs

1. Stationary body

- ❖ Displacement does not change with time, since displacement is a vector quantity the position of the body may be negative or positive relative to be observer.

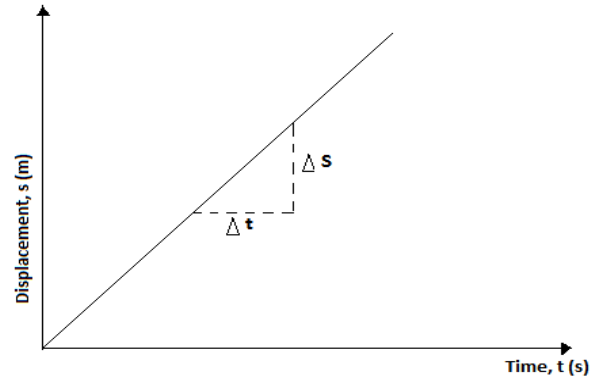
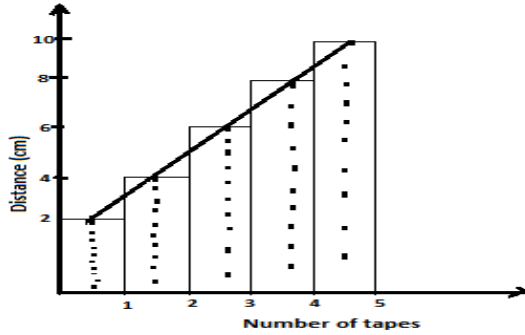


2. A body moving with uniform velocity

- ❖ For a body moving with uniform velocity, displacement changes uniformly over equal time intervals. The graph of displacement against time is a straight line whose slope or gradient represents the velocity of the body which is **constant**.

Exercise

1. The figure below shows a piece of tape pulled through a ticker timer by a trolley down an inclined plane. The frequency of the ticker timer is 50Hz
 - I. What type of electric current is used to operate the ticker timer?
 - II. Calculate the average velocity for the trolley between A and B
2. The figure below shows a tape chart from the paper tape obtained (frequency of ticker timer 50 Hz)

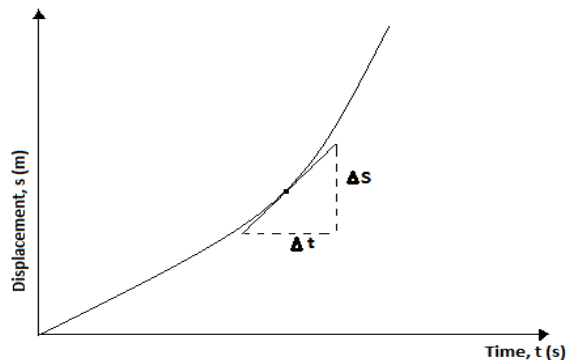


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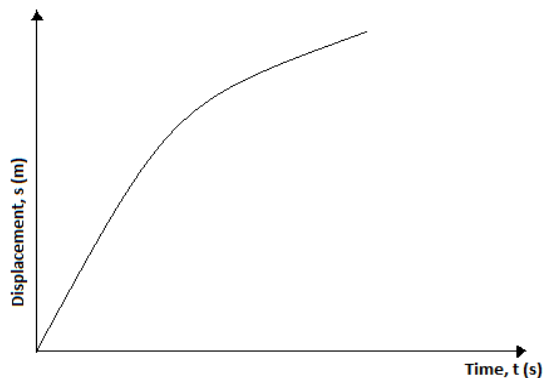
3. A body moving with variable velocity

- ❖ a. For a body moving with a **velocity increasing uniformly with time**, the displacement-time graph is a curve of increasing slope since the distance the body covers increases for equal time intervals. The slope of the graph at any given point gives instantaneous velocity of the body i.e.

$$\text{instantaneous velocity} = \frac{\Delta s}{\Delta t}$$



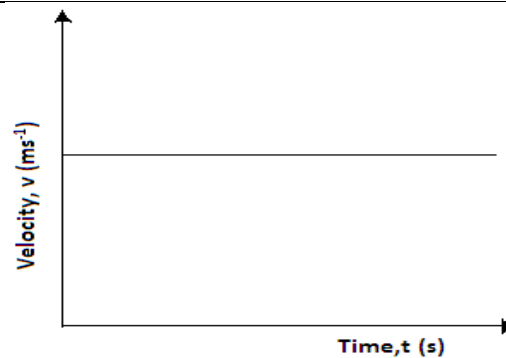
- ❖ b. For a body moving with a **velocity decreasing uniformly with time**, the displacement-time graph is curve of decreasing slope since the distance the body covers decreases for equal time intervals as shown below.



Velocity – Time Graphs

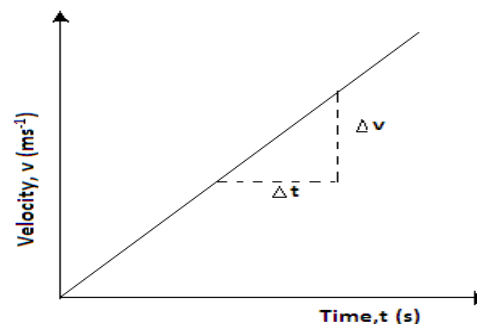
1. Body moving with uniform velocity

- ❖ The slope/gradient of the graph is zero and therefore acceleration of the body moving with uniform velocity is zero.



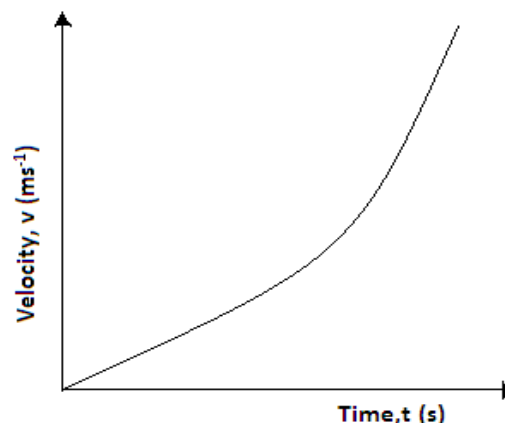
2. A body moving with its velocity changing uniformly

- ❖ The gradient of this graph is a straight line; meaning that velocity changes uniformly over equal time intervals. This gradient graph gives **constant acceleration** i.e. $\text{acceleration} = \frac{\Delta v}{\Delta t}$

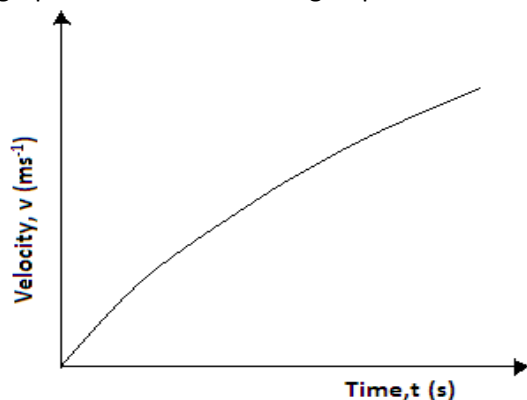


3. A body moving with its velocity changing non-uniformly

- ❖ a) For a body moving with an **increasing acceleration**, meaning that its velocity is increasing at an increasing rate, the velocity-time graph is curve of increasing slope as shown alongside. The **slope of the graph at any point gives the instantaneous acceleration** of the body at that point.

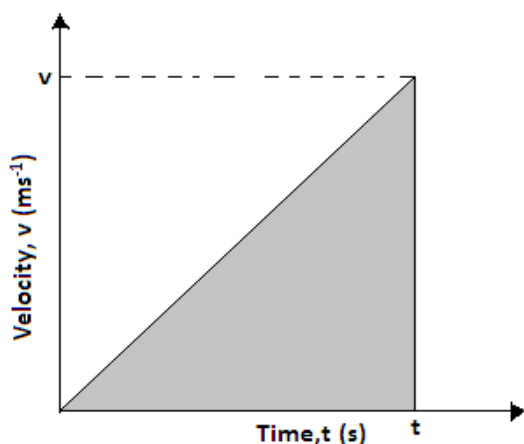


- ❖ b. For a body moving with a **decreasing acceleration**, meaning that its velocity is increasing at a decreasing rate, the velocity-time graph is curve of decreasing slope as shown below.



Area under velocity – time graph

- ❖ Consider a body starting from rest moving with constant acceleration for time, t . The velocity-time graph for the body is as shown alongside.



distance travelled

$$= \text{average velocity} \times \text{time}$$

$$= \left(\frac{0 + v}{2} \right) \times t = \frac{1}{2} vt$$

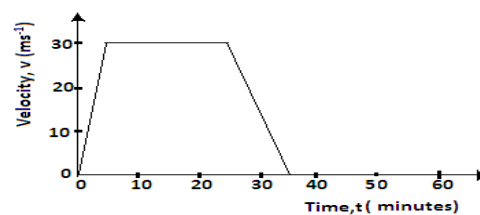
- ❖ Therefore, **area A under the velocity – time graph represents the distance covered by the body** after time t seconds.

Examples

Solution

- *ab-* the velocity of the car increases uniformly from rest (i.e. it accelerates uniformly)
- *bc-* the velocity of the car decreases uniformly to rest (i.e. it decelerates uniformly)
- *cd-* velocity of the car increases uniformly but in opposite direction (accelerates uniformly in opposite direction)
- *de-* velocity of the car decreases uniformly but still in same opposite direction (decelerates uniformly in opposite direction)

2, A car starting from rest accelerates uniformly for 5 minutes to reach 30 ms^{-1} . It continues at this speed for the next 20 minutes and then decelerates uniformly to come to stop in 10 minutes. On the axes provided, sketch the graph of velocity against time for the motion of the car and hence, find the total distance covered by the car. Solution



Total distance = total area under the graph

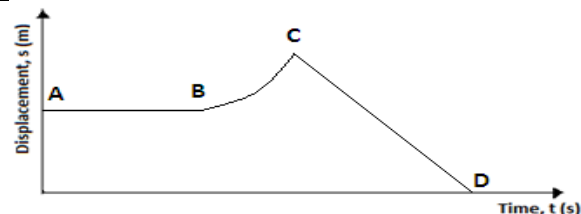
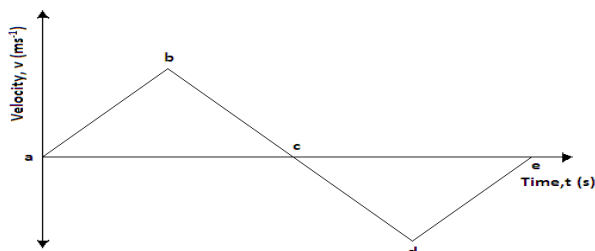
$$\begin{aligned} \text{Total distance} &= \frac{1}{2} (35 + 20) 60 \\ &\quad \times 30 \text{ (i.e. area of a trapezium)} \end{aligned}$$

$$\text{Total distance} = 49500 \text{ m}$$

Exercise

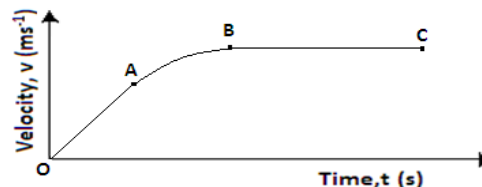
- 1. The figure below shows the displacement time graph of motion of a particle.**

1. Interpret the graph below representing motion of a car from point a to e.

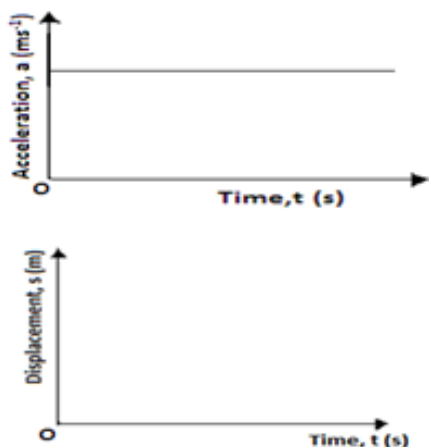


State the nature of the motion between: (i) A and B (ii) B and C (iii) C and D

2. The figure below shows a velocity time graph for the motion of a certain body. Describe the motion of the body in the region: (i) OA (ii) AB (iii) BC.



3. The figure below shows the acceleration time graph for a certain motion. On the axes provided, sketch the displacement-time graph for the same motion.



Therefore, for a body moving with uniform acceleration, any of these three equations may be used.

$$1. v = u + at$$

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

$$3. v^2 = u^2 + 2as$$

Examples

1. A car starts from rest with uniform acceleration of 5ms^{-2} . How long does it take to cover a distance of 400m?

Solution

$$a = 5\text{ms}^{-2}$$

$$S = 400\text{m}$$

$$t = ?$$

$$U = 0\text{ms}^{-1}$$

Best equation for use is; $s = ut + \frac{1}{2}at^2$

Equations of Uniformly Accelerated Motion

- ❖ Consider a body moving in a straight line with uniform acceleration a , so that its velocity

increases from an initial value u to a final value v in time t and it is displaced by s ;

Derivation of the 1st equation

$$\text{acceleration, } a = \frac{\text{change in velocity}}{\text{time taken}} = \frac{\Delta v}{\Delta t}$$

$$a = \frac{v - u}{t}$$

$$at = v - u$$

$$v = u + at$$

Derivation of 2nd equation

displacement, $s = \text{average velocity} \times \text{time}$

$$s = \left(\frac{u + v}{2}\right) \times t$$

but from equation 1, $v = u + at$

$$s = \left(\frac{u + u + at}{2}\right) t$$

$$\frac{1}{2}(2ut + at^2)$$

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

Derivation of 3rd equation

displacement = average velocity $\times$ time

$$s = \left(\frac{u + v}{2}\right) \times t$$

but from equation 1, $v = u + at$

$$t = \frac{v - u}{a}$$

$$400 = 0 \times t + \frac{1}{2} \times 5 \times t^2$$

$$400 = \frac{5}{2}t^2$$

$$t = \sqrt{\frac{400 \times 2}{5}} = 12.65 \text{ seconds.}$$

2. A body is uniformly accelerated from rest to a final velocity of 100 ms^{-1} in 10 seconds. Calculate the distance covered.

Solution

$$u = 0$$

$$v = 100 \text{ ms}^{-1}$$

$$t = 10 \text{ s}$$

$$s = ?$$

$$\text{right equation is } v^2 = u^2 + 2as$$

$$100^2 = 0^2 + 2as$$

$$\text{But } a = \frac{v - u}{t}$$

$$\frac{100 - 0}{10} = 10 \text{ ms}^{-2}$$

$$s = \frac{10000 \text{ m}^2 \text{ s}^{-2}}{2 \times 10} = 500 \text{ m}$$

3. A body whose initial velocity is 30 ms^{-1} moves with a constant retardation of 3 ms^{-2} . Calculate the time taken for the body to come to rest.

Solution

$$u = 30 \text{ ms}^{-1}$$

$$a = -3 \text{ ms}^{-2}$$

$$t = ?$$

$$v = 0 \text{ ms}^{-1}$$

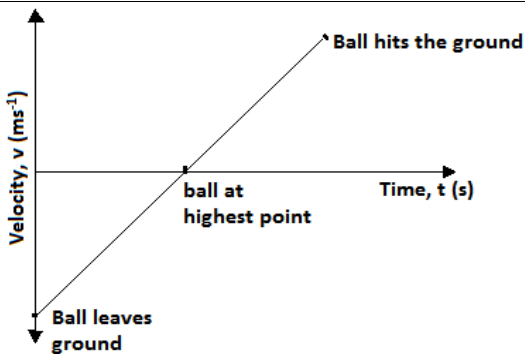
$$\text{Right equation is } v = u + at$$

$$0 = 30 - 3t$$

$$-30 = -3t$$

$$t = 10 \text{ s}$$

$s = \left(\frac{v+u}{2}\right) \times \left(\frac{v-u}{a}\right)$ $s = \frac{v^2 - uv + uv - u^2}{2a}$ $2as = v^2 - u^2$ $v^2 = u^2 + 2as$	4. A body moving with a uniform acceleration of 10ms^{-2} covers a distance of 320m. If its initial velocity was 60ms^{-1}, calculate its final velocity. $a = 10\text{ms}^{-2}$ $s = 320\text{m}$ $u = 60\text{ms}^{-1}$ $v = ?$
Right equation is $v^2 = u^2 + 2as$ $v^2 = 60^2 + 2 \times 10 \times 320$ $v = \sqrt{3600 + 6400}$ $= \sqrt{10000}$ $= 100 \text{ms}^{-1}$	(b) Right equation is $v^2 = u^2 + 2gs$ $20^2 = 0^2 + 2 \times 10 \times s$ $s = \frac{400}{20} = 20\text{m}$
<u>Motion under Gravity</u> Acceleration (In Free Fall) and Deceleration (In Vertical Projection) Due To Gravity ❖ When a body is projected vertically upwards, it decelerates uniformly (negative acceleration) due gravitational pull. When this body falls from maximum height, it accelerates uniformly downwards and this is called free fall. ❖ Consider a ball thrown vertically upwards from the ground. The graph below shows how the velocity of the ball changes with time from when it leaves the ground until it hits the ground again. Air resistance is assumed to be negligible. Downward velocity is taken to be positive. The gradient of this graph is a constant whose value is gravitational acceleration, g.	2. A bullet shot vertically upwards rises to a maximum height 1000m. Determine: a) The initial velocity of the bullet b) The time of flight of the bullet <u>Solution</u> (a) At maximum velocity, velocity is zero $v = 0 \text{ms}^{-1}$ $u = ? \text{ms}^{-1}$ $g = -10\text{ms}^{-1}$ because the bullet decelerates upwards $s = 1000\text{m}$ Using the equation $v^2 = u^2 + 2gs$ $0 = u^2 + 2 \times (-10) \times 1000$ $0 = u^2 - 20000$ $u = \sqrt{20000} = 141.42 \text{ms}^{-1}$ (b) Total time the bullet is in air using the expression $s = ut + \frac{1}{2}gt^2$,



❖ Equations of uniformly accelerated bodies also apply in motion under gravity.

1. $v = u + gt$

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

3. $v^2 = u^2 + 2gs$

displacement is 0 m

$$0 = 141.42 \times t + \frac{1}{2}(-10)t^2$$

$$141.42 = 5t$$

$$t = \frac{141.42}{5} = 28.28 \text{ s}$$

Exercise

1. A stone is released from a cliff of 180m high calculate
 - a) The time it takes to hit the ground
 - b) The velocity with which it hits the water (take $g = 10\text{ms}^{-1}$)
2. A body is projected vertically upward with an initial velocity u . it returns to the same point of projection after 8s. Plot:
 - a) The speed time graph
 - b) The velocity time graph for the body
3. A body is thrown vertically upwards with an initial velocity of u . show that:
 - I. Time taken to reach maximum height is $t = \frac{u}{g}$
 - II. Time flight (time taken for the body(projectile) to fall back to point of projection) is $t = \frac{2u}{g}$
 - III. Maximum height reached is $H_{\max} = \frac{u^2}{2g}$
 - IV. Velocity of return is equal in magnitude to velocity of projection
4. A stone is projected vertically upward with a velocity of 30ms^{-1} from the ground. Calculate:
 - I. The time it takes to reach maximum height.
 - II. The time of flight.
 - III. The maximum height reached.
 - IV. The velocity with which it lands the ground.

Examples

1. A stone is released vertically downwards from a high cliff. Determine
 - a) its velocity after two seconds
 - b) How far it has travelled after two seconds.

Solution

(a) $u = 0$

$t = 2\text{seconds}$

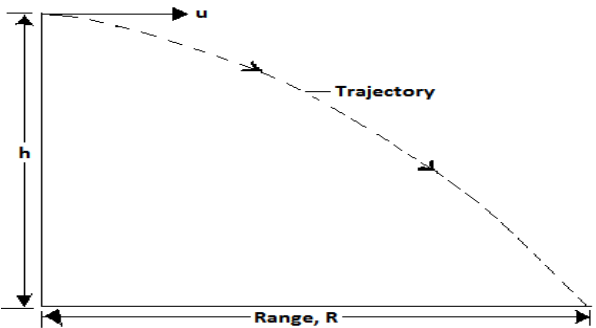
$g = 10\text{ms}^{-1}$

Right expression is

$v = u + gt$

$v = 0 + 10 \times 2$

$v = 20\text{ms}^{-1}$

Horizontal projection	Example
Some examples of horizontal projection include: 1. A jet from a water pipe held horizontally 2. A bullet from a gun held horizontally 3. A tennis ball when it rolls from the tennis table. 4. A stone thrown horizontally. 5. An arrow released horizontally from bow. ❖ Consider a body projected horizontally with an initial horizontal velocity <i>u</i>. The body maintains that initial horizontal velocity but since it also experiences free fall due to gravity, it describes a curved path as shown below.  ❖ The path followed the body projected horizontally (projectile) is called <i>trajectory</i>. The maximum horizontal distance covered by the body projected horizontally is called the <i>range</i>. The <i>vertical acceleration is due to gravity</i> while the <i>horizontal acceleration is zero since the body maintains its initial horizontal velocity throughout the motion.</i> ❖ <i>The displacement of the projectile at any given time t is given by $s = ut + \frac{1}{2}at^2$</i>	<u>1. An arrow is shot horizontally from the top of the building and it lands 200 m from the foot of the building after 10s. Assuming that the air resistance is negligible, calculate:</u> a. <i>The initial velocity of the arrow.</i> b. <i>the height of the building</i> <u>Solution</u> a. <i>initial horizontal velocity, $u = ?$</i> $R = 200\text{m}$ $t = 10\text{s}$ From the expression $R = ut$; $200\text{m} = u \times 10$ $u = \frac{200}{10} = 20\text{ms}^{-1}$ b. <i>from the expression; $h = \frac{1}{2}gt^2$</i> $h = \frac{1}{2} \times 10 \times 10^2$ $= 5 \times 100 = 500\text{m}$
<i>Horizontal displacement, R</i> ❖ Since horizontal acceleration, <i>a</i>, is zero, <i>$R = ut$</i> <i>The vertical displacement, h</i> ❖ Initial velocity for vertical displacement is zero. This means that vertical displacement is; $s = 0 \times + \frac{1}{2}gt^2$ $s = \frac{1}{2}gt^2$ $h = \frac{1}{2}gt^2$	<u>Exercise</u> 1. <i>A ball is thrown from the top of a cliff 20m high with a horizontal velocity of 10ms^{-1}, calculate:</i> a. <i>The time taken by the ball to strike the ground</i> b. <i>The distance from the foot of the cliff to where the ball lands.</i> c. <i>The vertical velocity at the time it strikes the ground.</i> 2. <i>A stone is thrown horizontally from the building that is 45m, high above a horizontal ground. It hits the ground at a point which is 60m from the foot of the building. Calculate the initial velocity of the stone.</i> 3. <i>A ball is thrown from the top of a cliff 20m high with a horizontal velocity of 10ms^{-1}, calculate:</i> I. <i>The time taken by the ball to strike the ground</i> II. <i>The distance from the foot of the cliff to where the ball lands.</i> III. <i>The vertical velocity at the time it strikes the ground.</i> 4. <i>A stone is thrown horizontally for the building that is 45m, high above a horizontal ground. It hits the</i>

Note: The time for horizontal displacement is equal to time for vertical displacement at any given point.

ground at a point which is 60m from the foot of the building. Calculate the initial velocity of the building.

NB: REMEMBER THE SIMPLE PENDULUM

EXPERIMENT.

A pendulum is a small heavy body suspended by a light inextensible string.

Revision Exercise

1. A body moving at an initial velocity u (ms^{-1}) accelerates at a (ms^{-2}) for t seconds and attains a final velocity v (ms^{-1}). Represent this motion on the velocity against time axes shown below.

2. The data in the table below represents the motion over a period of 7 seconds

Time in s	0	1	2	3	4	5	6	7
D in m	0	20	40	60	80	95	105	110

- Plot on graph paper a graph of displacement (y-axis) against time.
- Describe the motion of the vehicle for the first 4 seconds.
- Determine the velocities at 4.5s and 6.5 s. Hence or otherwise determine the average acceleration of the vehicle over this time interval.

3. A ball-bearing X is dropped vertically downwards, from the edge of a table and it

- State the direction in which the parcel moved immediately it was released.
- Calculate the time taken by the parcel to reach the ground from the maximum height.
- Calculate the velocity of the parcel when it strikes the ground.
- Calculate the maximum height above the ground the parcel reached.
- What was the height of the helicopter at the instant the parcel was dropped.

5. A stone is thrown horizontally from a building that is 50 m high above a horizontal ground. The stone hits the ground at a point, which is 65m from the foot of the building. Calculate the initial of the stone.

6. The figure represents dots made by a ticker-timer. The dots were made at a frequency of 50 dots per second. (Diagram not drawn to scale)

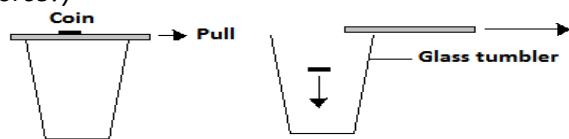


- What is time interval between two consecutive dots?

takes 0.5s to hit the floor below. Another bearing Y leaves the edge of the table horizontally with a velocity of 5m/s. find: - The time taken for bearing Y to reach the floor. - The horizontal distance traveled by Y before hitting the floor. - The height of the table-top above the floor level. 4. A helicopter, which was ascending vertically at a steady velocity of 20m/s, released a parcel that took 20second to reach the ground.	- The first dot from the left was made at time $t = 0$. Copy the diagram and indicate using arrows pointing downwards the dots made at $t = 0.1s, 0.2s, 0.3s$. - Determine the average velocities of the tape over time intervals -0.02s to 0.02s, 0.08s to 0.12s, 0.18s to 0.22s and 0.28s to 0.32s - Draw a suitable graph and from it determine the acceleration of the tape.
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<u>Specific Objectives</u>	<u>Content</u>
By the end of this topic, the learner should be able to: - State Newton's laws of motion - Describe simple experiments to illustrate inertia - State the law of conservation of linear momentum - Define elastic collision, inelastic collision and impulse - Derive the equation $F=ma$ - Describe the application of frictional force - Define viscosity - Explain terminal velocity - Solve numerical problems involving Newton's laws and the law of conservation of linear momentum.	- Newton's laws of motion (experimental treatment of inertia required) - Conservation of linear momentum: elastic collision, inelastic collisions, recoil velocity, impulse (oblique collisions not required) $F=ma$ - Frictional force - Advantages and disadvantages - Viscosity - Terminal velocity (qualitative treatment) - Problem on Newton's law of conservation of linear momentum (exclude problems on elastic collisions)
Introduction ❖ Effects of force on motion of a body are based on Newton's three laws motion. In this topic, these laws are looked into. Newton's First Law (The Law of Inertia) ❖ It states that "a body remains in its state of rest or of uniform motion in a straight line unless acted upon by an external force". This law is also called the law of inertia Definition of Inertia ❖ Is the tendency of a body to remain in its state of rest if it was at rest or in its state of motion if it was in motion. Examples of Inertia (i.e. Examples of Newton's First Law in Practice) When a card supporting a coin on a glass tumbler is suddenly flicked, it is observed that the card flies off but the coin falls in the tumbler. This is because the coin tends to maintain its state of rest (it falls in glass	- The bottom wooden block can easily be pulled out of the stack without disturbing others placed on it. The other blocks remain in a pile undisturbed except that their position is lowered because of downward pull of the gravitational force. - When a moving train or a car stops suddenly, passengers are thrown forward. The passenger in a moving vehicle is also in a state of motion. Hence, when the vehicle stops suddenly, the upper part of his body continues to move. This is why it is necessary to wear seat belt. - A cyclist on a level ground continues to move for some time without pedaling. Definition of Force as per Newton's First Law of Motion ❖ Force is defined as that which produces motion in body at rest or which alters its existing state of motion.

because another force acts on it. Which is that other force?)



Momentum

- ❖ Momentum of a body is defined as **the product of its mass and velocity**. For a body of mass m in kg and velocity v in ms^{-1} ,

$$\text{momentum} = \text{mass}(\text{kg}) \times \text{velocity}(\text{ms}^{-1})$$

$$P = mv$$

- ❖ **SI unit** of momentum is **the kilogram metre per second (kgms^{-1})**. Momentum is **a vector quantity** since it has both magnitude and direction. The direction of momentum is same as that of the velocity of the body.

Examples

1. What is the momentum of a racing car of mass 500kg driven at 270km/h?

Solution

$$v = 270 \text{ kmh}^{-1} = 75 \text{ ms}^{-1}; \quad m = 500 \text{ kg}$$

$$\text{momentum} = \text{mass}(\text{kg}) \times \text{velocity}(\text{ms}^{-1})$$

$$\begin{aligned} \text{momentum} &= 500 \text{ kg} \times 75 \text{ ms}^{-1} \\ &= 37500 \text{ kgms}^{-1} \end{aligned}$$

$$\Delta p = mv - mu$$

$$\text{Rate of change of momentum} = \frac{\text{change in momentum}}{\text{time}};$$

$$\frac{\Delta p}{t} = \frac{mv - mu}{t}$$

$$\text{From Newton's second law, } F \propto \frac{mv - mu}{t}$$

$$F \propto m \left(\frac{v - u}{t} \right); \quad \text{but } \frac{v - u}{t} = a$$

$$\text{therefore, } F \propto ma$$

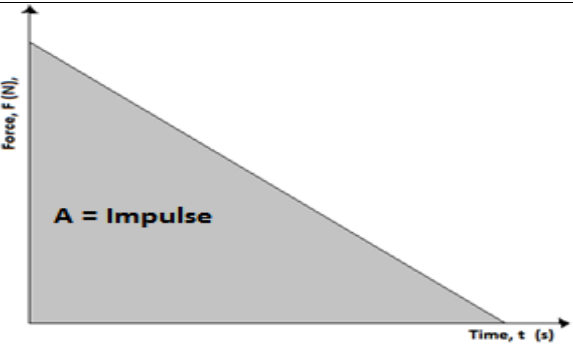
$$\text{so, } F = kma. \text{ where } k \text{ is a constant of proportionality.}$$

$$\text{When } F = 1\text{N}, \quad a = 1\text{ms}^{-2}, \\ m = 1\text{kg}, \text{ then } k = 1$$

$$\text{hence, } F = ma,$$

This is an expression for Newton's second law

2. Find the momentum of : a. An object of a mass 100g moving at 20ms⁻¹ <u>Solution</u> $\begin{aligned}\text{momentum} &= \text{mass}(\text{kg}) \times \text{velocity}(\text{ms}^{-1}) \\ &= 0.100 \text{ kg} \times 20 \text{ ms}^{-1} \\ &= 2 \text{ kgms}^{-1}\end{aligned}$ b. An object of mass 2.0kg which falls from rest for 10s (Momentum after 10s). <u>Solution</u> $u = 0 \text{ ms}^{-1}, \quad t = 10 \text{ s}, \quad g = 10 \text{ ms}^{-2},$ $v = ?$ using the expression $v = u + gt$, $v = 0 + 10 \times 10$ $= 100 \text{ ms}^{-1}$ $\text{mom} = 0.1 \times 100 = 100 \text{ kgms}^{-1}$	Definition of a newton as per Newton's 2nd law of motion ❖ A newton is the force which produces an acceleration of 1ms⁻² when it acts on a body of mass 1kg.
	Examples
1. What is the momentum of a racing car of mass 500kg driven at 270km/h? 2. An apple of mass 100g falls a distance of 2.5m to the ground from a branch of a tree. a) Calculate the speed at which it hits the ground and the time taken for it to fall.(Ignore air resistance). b) Calculate the momentum of the apple just before hitting the ground	1. What force is needed to stop a 500kg car moving at 180kmh⁻¹ in 12.5m? <u>Solution</u> $m = 500 \text{ kg}, \quad v = 0 \text{ ms}^{-1},$ $u = 180 \text{ kmh}^{-1} = 50 \text{ ms}^{-1}, \quad s = 12.5 \text{ m}, \quad F = ?$ From the equation, $v^2 = u^2 + 2as$, $a = \frac{v^2 - u^2}{2s}$ $a = \frac{0^2 - 50^2}{2 \times 12.5},$ $a = -100 \text{ ms}^{-2}$ From Newton's 2nd law, $F = ma$, $F = 500 \times -100$ $F = -50\,000 \text{ N}.$ what does the negative mean?
<u>Relationship between Force, Mass and Acceleration</u> Consider a force F acting on a body of mass m for a time t. if its velocity changes from u to v, then; change in momentum $= \text{final momentum}$ $- \text{initial momentum}$	2. An external force applied to a ball of mass 160g increases its velocity from 2.5cms⁻¹ to 275cms⁻¹ in 10 seconds. Calculate the force applied. <u>Solution</u> $m = 160 \text{ g} = 0.160 \text{ kg},$ $u = 2.5 \text{ cms}^{-1} = 0.025 \text{ ms}^{-1},$ $v = 275 \text{ cms}^{-1} = 2.75 \text{ ms}^{-1}, \quad F = ? \text{ N}$ $F = ma, \quad F = m \left(\frac{v - u}{t} \right)$ $F = 0.160 \left(\frac{2.75 - 0.025}{10} \right) = 0.0436 \text{ N}$
<u>Newton's Second Law of Motion</u> ❖ It states that "the rate of change of momentum of a body is directly proportional to the resultant external force producing the change and takes place in the direction of the force".	

Resultant force acting $\propto$ rate of change of momentum	
<u>Exercise</u> - What is the mass of an object which is accelerated at 5 ms^{-1} by a force of 200 N? - A gun fires a bullet of mass 10.0g horizontal at 50 ms^{-1} at a fixed target of soft wood. The bullet penetrates 50 cm into a target. Calculate - Time taken by the bullet to come to rest in the wood - The average retarding force exerted by the wood on the bullet. - A trolley of mass 1.5kg is pulled along by an elastic cord given an acceleration of 2 ms^{-2}. Find the frictional force acting on the trolley if the tension in the cord is 5N. - State Newton's second law of motion. Hence, show that $F = ma$. - Define the newton (unit of force) - A car of mass 1500kg is brought to rest from a velocity of 25 ms^{-1} by a constant force of 3000N. Determine the change in momentum produced by the force and the time that it takes to come to rest. - A hammer of mass 800 g produces a force of 400 N when it strikes the head of a nail. Describe how it is possible for the hammer to drives the nail into a piece of wood, yet a weight of 400 N resting on the head of the nail would not - A resultant force F acts on a body of mass m causing an acceleration a_1 on the body. When the same force acts on a body of mass $2m$, it causes an acceleration a_2. Express a_2 in terms of a_1.	 ❖ Note: Impulse occurs when bodies collide and the impulsive force is the one which causes destruction during collision. The time for which this impulsive force acts determines the extent of damage caused. If time of impact is long, damage is less than when time of impact is short. The following are some examples of designs made to prolong time of impact and therefore reduce damage by impulsive force. - Eggs are packed in spongy crates - Smart phones are put in soft holders - vehicles are fitted with safety airbags - some vehicles have collapsible bumpers and steering - High jumpers usually land on soft ground etc
Impulse ❖ Impulse is defined as the product of force acting on a body and the time in which the force acts. Impulsive force refers to the force which acts on a body for a very short time during a collision. ❖ If a force F acts on a body of mass m for time, t, then the impulse of the force is given by: Impulse = force $\times$ time Impulse = Ft (SI unit of impulse is the newton second (Ns)) But from Newton's second law of motion, $F = \frac{mv - mu}{t}$ $Ft = mv - mu$, but $Ft = \text{impulse}$ and $mv - mu$ is the change in momentum of the body ❖ This implies that the impulse of force acting on a body during some time interval is equal to the change in momentum produced in that body in that time. ❖ The area under the plot of force F against time (t) represents impulse or change in momentum during a collision.	<u>Examples</u> - Determine the change in momentum produced when a force of 4000 N acts on a body which is at rest for 0.003 minutes <u>Solution</u> $F = 4000 \text{ N}$, time, $t = 0.003 \text{ minutes} = 0.18 \text{ s}$ Impulse = change in momentum = Ft change in momentum = 4000×0.18 = 720 kgms^{-1} or 720 Ns - A car of mass 400 kg starts from rest on a horizontal track. Find the speed 4 s after starting if the tractive force by the engine is 500 N. <u>Solution</u> Impulse = change in momentum, $Ft = m(v - u)$ $500 \times 4 = 400(v - 0)$ $v = \frac{500 \times 4}{400} = 5 \text{ ms}^{-1}$

Exercise

1. An apple of mass 100g falls a distance of 2.5m to the ground from a branch of a tree.

i. Calculate the speed at which it hits the ground and the time taken for it to fall. (Ignore air resistance).

C. Lift moving downwards with acceleration

❖ The downward acceleration is negative and this is why the one feels lighter when lift is accelerating downwards. Therefore reading on the machine (apparent weight of the body in lift) is:

$$P' = mg - ma$$

Notes:

i. If the lift moves with constant velocity, the machine will read weight of the body since acceleration will be zero.

ii. If $a = g$ (free fall) the body will experience weightlessness since the reaction from the lift on the body will be zero.

Exercise

1. A lady of mass 80 kg stands on weighing machine in a lift. Determine the reading on the weighing machine when the lift moves:

- downwards at a constant velocity of 2.0 ms^{-1}
- downwards with an acceleration of 3 ms^{-2}
- upwards with an acceleration of 3 ms^{-2}

2. A man of mass 80 kg stands on a lift which is accelerating upwards at 0.5 ms^{-2} . if $g = 10 \text{ N/kg}$ determine the reaction on the man by the floor of the lift.

The Law of Conservation of Linear Momentum

❖ This law states that, “for a system of colliding bodies, their total linear momentum is a constant, provided no external forces are acting”.

❖ If a body A of mass m_A initially moving with a velocity of u_A collides linearly with a body B of mass m_B initially moving with a velocity u_B and their velocities after collision are v_A and v_B respectively, then:
Total linear momentum before impact

= Total linear momentum after collision

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

ii. Assuming the apple takes 100 milliseconds to come to rest Calculate the average force experienced by the apple.

2. The table below shows the values of the resultant force, F , and the time t for a bullet traveling inside the gun barrel after the trigger is pulled.

Force, F (N)	360	340	300	240	170	110
Time, t (millisecond s)	3	4	8	12	17	22

i. Plot a graph of Force, F , against time t .

ii. Determine from the graph:

a) The time required for the bullet to travel the length of the barrel assuming that the force becomes zero just at the end of the barrel.

b) The impulse of the force.

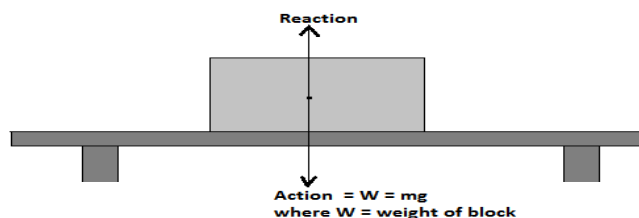
c) Given that the bullet emerges from the muzzle of the gun with a velocity of 200 m/s, calculate the mass of the bullet.

3. A body of mass 5 kg is ejected vertically from the ground when a force of 600N acts on it for 0.1s. Calculate the velocity with which the body leaves the ground.

4. A high jumper usually lands on a thick soft mattress. Explain how the mattress helps in reducing the force of impact.

Newton's Third Law of Motion

It states that “for every action, there is an equal but opposite reaction force”. This means that if a body P exerts a force on another body Q, Q exerts an equal and opposite force on P. It is clear that it is due to action (force exerted by foot on ground) and reaction (force exerted by earth on foot) that we are able to walk forward.

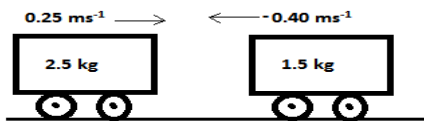


Weight in a lift

a. Lift at rest ❖ Lift machine reads the weight of the body in lift since action and reaction are equal and opposite i.e. $R = mg$. b. Lift moving upwards with acceleration a The resultant upward force F produces the acceleration ($F = ma$) resultant upward force $F =$ total upward force $P -$ downward force (weight) W $F = P - W \Rightarrow P = F + w \text{ and } \therefore$ $P = mg + ma$ ❖ This is what the lift machine will read (the reaction of the lift on the body).	Note: velocity is a vector quantity and must be treated appropriately in calculations Types of Collisions I. Elastic Collision ❖ This is a collision in which both kinetic energy and momentum are conserved. If the bodies A and B above collide elastically; $m_A u_A + m_B u_B = m_A v_A + m_B v_B$ $\frac{1}{2} m_A u_A^2 + \frac{1}{2} m_B u_B^2 = \frac{1}{2} m_A v_A^2 + \frac{1}{2} m_B v_B^2$ ❖ Note: In this collision, bodies separate and move in same or different directions after collision.
II. Inelastic Collision ❖ This is a collision in which momentum is conserved but kinetic energy is not. In this collision, colliding bodies fuse and move together in one direction with a common velocity. ❖ If the collision of bodies A and B above collide inelastically, then; $m_A u_A + m_B u_B = m_A v_A + m_B v_B$ $\frac{1}{2} m_A u_A^2 + \frac{1}{2} m_B u_B^2 \neq \frac{1}{2} m_A v_A^2 + \frac{1}{2} m_B v_B^2$ ❖ Note: the total kinetic energy after the impact is always less than the total kinetic energy before the impact and the loss is due to: - Energy used in deformation of bodies - Energy transformed to heat, sound and even light Examples 1. Two trolleys of masses 2 kg and 1.5 kg are traveling towards each other at 0.25m/s and 0.40 m/s respectively. The trolleys combine on collision. I. Calculate the velocity of the combined trolleys.	I. $m_b u_b + m_w u_w = (m_b + m_w) v$ $0.020 \times 50 + 1.980 \times 0 = (0.020 + 1.980) v$ $v = \frac{1}{2} = 0.5 \text{ ms}^{-1}$ II. at maximum height, all K.E is converted to P.E $\frac{1}{2} m v^2 = m g h, \text{ m cancels out}$ $\frac{1}{2} \times 0.5^2 = 10 \times h$ $h = \frac{0.125}{10} = 0.0125 \text{ m}$ Exercise 1. A lorry of mass 3000 kg travelling at a constant velocity of 72 kmh^{-1} collides with a stationary car of mass 600 kg. The impact takes 1.5 seconds before the two move together at a constant velocity for 15 seconds. Calculate: - The common velocity - The distance moved after the impact - The impulsive force - The change in kinetic energy 2. A bullet of mass 15 g is shot from a gun 15 kg with a muzzle velocity of 200 ms^{-1}. If the bullet is 20 cm long, calculate: - the acceleration of the bullet - the recoil velocity of the gun 3. Explain how: - Rocket propulsion takes place - Garden sprinkler works

II. In what direction do the trolleys move after collision?

Solution



Total linear momentum before impact
= Total linear momentum after collision

$$m_A u_A + m_B u_B = (m_A + m_B) v$$

$$\Rightarrow 2.5 \times 0.25 + 1.5 \times (-0.40)$$

$$= (2.5 + 1.5) v$$

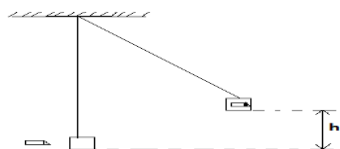
$$v = \frac{0.25}{4.0} = 0.0625 \text{ ms}^{-1}$$

III. They move in the direction to which trolley of mass 2.5 kg was moving to before collision

2. A bullet of mass 20 g travelling horizontally at a speed of 50 ms^{-1} embeds itself in a block of wood of mass 1980 g suspended from a light inextensible string. Find:

- I. The velocity of the bullet and block immediately after collision
- II. The height through which the block rises

Solution



Frictional Force

❖ Frictional force refers to the force that opposes or tends to oppose relative motion between two surfaces in contact. Frictional force acts in the direction opposite to that of the pulling force.

Types of Frictional Force

I. Static/ Limiting Frictional Force

❖ This is the force required to just start the body sliding. The force is directly proportional to the reaction force on the body by the surface. $F_S = \mu_s R$,

where μ_s is the coefficient of static or limiting frictional force

II. Kinetic/ Sliding Frictional Force

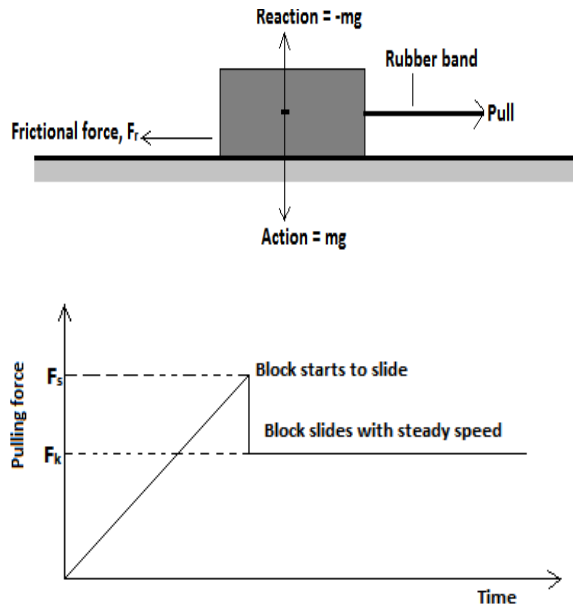
❖ This is the force required to keep the body sliding or moving at a constant speed. It opposes motion between two surfaces that are in relative motion. Sliding friction is directly proportional reaction force.

$$F_K = \mu_k R,$$

where μ_k is the coefficient of kinetic or sliding frictional force

Exercise

Note: Consider a block of wood being pulled using a rubber band on a horizontal surface as shown below.



- ❖ The rubber band stretches for some time before the block starts moving (stretch is due to limiting frictional). The stretching increases to a point when the block starts sliding steadily (sliding frictional force limits motion at this point). $\mu_s > \mu_k$
- ❖ **Frictional force is useful/ advantageous** in walking, moving vehicles, braking, writing, lighting a match stick etc.
- ❖ **Frictional force can be disadvantageous** as it causes wear and tear in moving parts of machine and leads to generation of unnecessary noise.

Example

1. A bullet of mass 10g traveling horizontally with a velocity of 300m/s strikes a block of wood of mass 290g which rests on rough horizontal floor. After impact they move together and come to rest after traveling a distance of 15m.
 - I. Calculate the common velocity of the bullet and the block.
 - II. Calculate the acceleration of the bullet and the block.
 - III. Calculate the coefficient of sliding friction between the block and the floor.
2. Under a driving force of 4000N, a car of mass 1250 kg has an acceleration of 2.5 m/s². Find the frictional force acting on the car.
3. A bullet of mass 22g travelling with a horizontal velocity of 300ms⁻¹ strikes a block of wood of mass 378g which rests on a rough horizontal surface. After the impact, the bullet and the block move together and come to rest when the block has travelled a distance of 5m. Calculate the coefficient of sliding friction between the block and the floor.
4. A block of a metal A having a mass of 40kg requires a horizontal force of 100N drag it with uniform velocity a long horizontal surface.
 - I. Calculate the coefficient of friction
 - II. Determine the force required to drag a similar block having a mass of 30kg along the same horizontal surface, calculate.
- III. If the two blocks A and B are connected with a two bar and a force of 200N is applied to pull the two long the same surface, calculate.
 - a) The tension in the tow bar
 - b) The acceleration
- IV. If the tow bar is removed and the 40kg blocks of metal moves around a smooth path of radius 10m at a constant speed of 24ms⁻¹ calculate the centripetal force.
- V. At the end of the circular path, the 40kg mass drops vertically in a trench 10m high and falls freely determine the time it takes to land at the bottom of the trench.

Factors Affecting Frictional Force between Two Surfaces in Contact

A smooth wooden block is placed on a smooth wooden table. A force of 14N should be exerted on the 4kg wooden block to keep the block moving with a constant velocity.

a) What is the coefficient of kinetic friction, μ_k

Solution

$$F_K = \mu_k R, \quad F_K = \mu_k mg$$

$$14 = \mu_k \times 4 \times 10$$

$$\mu_k = \frac{14}{40} = 0.35$$

b) If a 20N brick is placed on the block, what force will be required to keep the block and brick moving with required constant speed?

Solution

coefficient of kinetic friction, μ_k remains constant

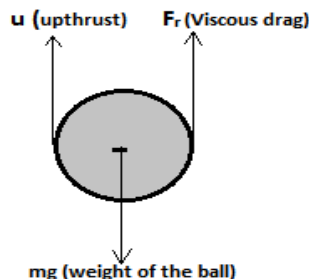
$$\mu_k R \Rightarrow F_K = 0.35 \times (40 + 20) = 20 \text{ N}$$

c) Use of ball bearing - This is applied on rotating axles. The bearing allows the movement of the surface over the other.

d) Air cushioning - This is done by blowing air into the space between surfaces. This prevents surfaces from coming into contact since air is matter and occupies space.

Viscosity

- ❖ This is the force that opposes relative motion between layers of the fluid.
- ❖ Consider a small ball bearing introduced gently into glycerine in a long cylindrical jar. The forces acting on the ball are as shown below.



- ❖ The resultant downward force ($mg - (u + F_r)$) accelerates the ball downwards.
- ❖ The viscous drag increases with velocity until the sum of upward forces equal the downward forces,

$$u + F_r = mg$$
- ❖ At this point the resultant force is zero and the ball attains a constant velocity called **terminal velocity**.

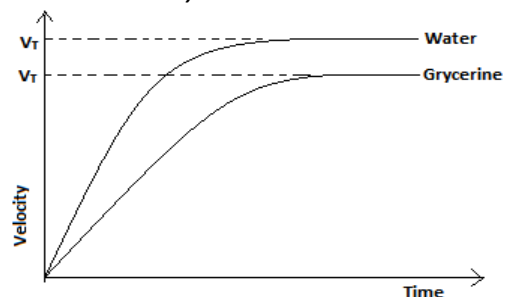
- I. **Normal reaction**— frictional force is directly proportional to normal reaction.
- II. **Nature of the surfaces**- the more rough a surface is, the larger the frictional force.

Methods of minimizing friction

- a) **Using rollers**- The rollers are laid down on the surface and the object pushed over them
- b) **Lubrication** -Application of oil or grease to the moving parts

Factors Affecting Viscosity In Fluids

- I. **Density** - The higher the density of the fluid, the greater the viscous drag and therefore the lower the terminal velocity.



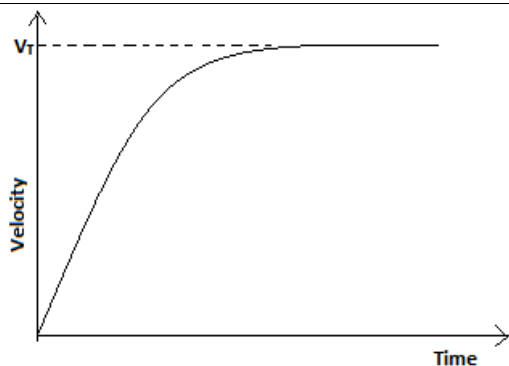
- II. **Temperature** - In liquids, viscous drag decreases (terminal velocity increases) with temperature, while in gases viscous drag increases (terminal velocity decreases) with temperature.

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Exercise



❖ **Terminal velocity** is defined as the constant velocity attained by a body falling in a fluid when the sum of upward forces is equal to the weight of the body. Graphically:

1. The diagram shows a tall measuring cylinder containing a viscous liquid. A very small steel ball is released from rest at the surface of the liquid as shown. Sketch the velocity- time graph for the motion of the ball from the time it is released to the time just before it reaches the bottom of the cylinder.



2. Two small spherical identical stones A and B are released from the same height above the ground. B falls through air while A falls through water. Sketch the graphs of velocity against time (t) for each stone. Label the graph appropriately.

Chapter Three

ENERGY, WORK, POWER AND MACHINESSpecific objectives

By the end of this topic, the learner should be able to:

- Describe energy transformations
- State the law of conservation of energy
- Define work, energy, power and state their SI units
- Define mechanical advantage, velocity ratio and efficiency of machines
- Solve numerical problems involving work, energy, power and machines.

Content

- Forms of energy and energy transformations
- Sources of energy
 - Renewable
 - Non-renewable
- Law conservation of energy
- Work, energy and power (work done by resolved force not required)
- Kinetic and potential energy
- Simple machines
- Problems on work, energy, power and machines

Energy

- Energy is the capacity to do work. The SI unit of energy is the **joule (J)** after **the physicist James Prescott Joule** who was also a brewer.

Sources of Energy

- They are classified into renewable and nonrenewable sources.

i. Renewable sources

- These are sources whose supply can be renewed again and again for use. Examples are; *water, solar, wind, geothermal etc.*

ii. Non-renewable sources

- These are sources of energy whose supply cannot be renewed again and again for use. Examples are; *fossils, firewood, nuclear source etc.*

Forms of Energy

- The various forms of energy include:
 - Mechanical (potential and kinetic)
 - Chemical – stored in batteries and foods
 - Electrical
 - Light
 - Nuclear
 - Wave

- Note:** **potential energy** is the energy possessed by a body due to its relative position or state while **kinetic energy** is the one possessed by a body due to its motion.

Conservation and Transformation of Energy**The Law of Conservation of Energy**

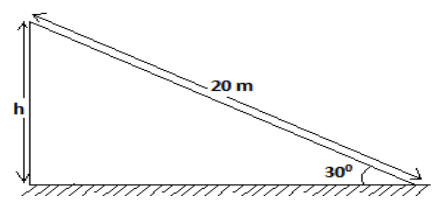
- This law states that **“Energy can neither be created nor destroyed but can only be transformed from one form to another.”**

Energy Transformation

- Any device that facilitates the transformation of energy from one form to another is called **a transducer**. The following are some examples:

Initial form of energy	Final form of energy	Transducer
Solar	Heat	Solar panel
Electrical	Kinetic	Motor
Kinetic	Electrical	Dynamo
Solar	Electrical	Solar cell
Heat	Electrical	Thermocouple
electrical	Sound	Loudspeaker
chemical	Electrical	Battery

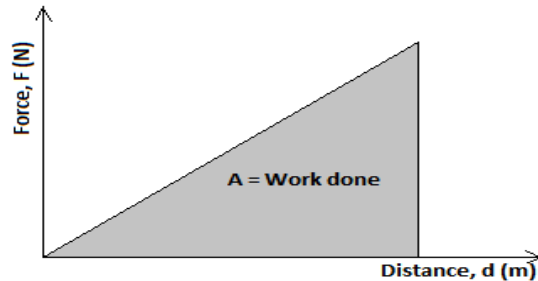
- Note:** Energy transformations are represented by **charts**.

Examples	Examples
Describe the energy transformation that takes place in each of the following: a) A car battery is used to light a bulb <pre> graph LR A[Chemical] --> B[Electrical] B --> C[Heat] B --> D[Light] </pre> b) Coal is used to generate electricity <pre> graph LR A[Chemical] --> B["Kinetic Energy of rotating turbines"] B --> C[Electrical Energy] </pre> c) A pendulum bob swing to and fro <pre> graph LR A[P.E] --> B[K.E] B --> C[P.E] C --> D[K.E] D --> E[P.E] </pre> d) Water at the top of a waterfall falls and its temperature rises on reaching the bottom <pre> graph LR A[P.E] --> B[K.E] B --> C[Heat] </pre>	1. Calculate the amount of work done by: a) A machine lifting a load of mass 50 kg through a vertical distance of 2.4m <u>Solution</u> work done, $W = \text{force}, F \times \text{distance}$ work done = $mg \times \text{distance}$ = $(50 \times 10)N \times 2.4 m = 1200 J$ b) A laborer who carries a load of mass 42kg to a height of 4.0m <u>Solution</u> work done, $W = \text{force}, F \times \text{distance}$ work done = $mg \times \text{distance}$ = $(42 \times 10)N \times 4.0 m = 1680 J$
Work and Energy - Work is defined as the product of force and distance moved in the direction of application of the force. work done, $W = \text{force}, F \times \text{distance moved in the direction of the applied force}, d$ $W = F \times d$ - Work is therefore said to be done when an applied force makes the point of application of the force move in the direction of the force. No work is done when a person pushes a wall until he sweats or carrying a bag of cement on his head for hours while standing. - The SI unit of work is the joule (J). 1 joule (J) = 1 newton metre (Nm)	2. A man of mass 70 kg walks up a track inclined at an angle of 30° to the horizontal. If he walks 20 m, how much work does he do? <u>Solution</u>  work done, $W = \text{force}, F \times \text{distance}$ work done = $mg \times \text{distance}, h$ = $(70 \times 10)N \times (20 \sin 30)m = 7000 J$ Exercise

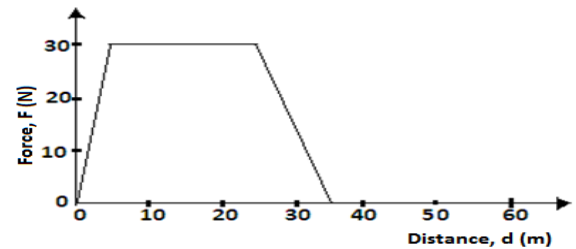
N/B: Joule is the work done when the point of application of a force of 1 newton moves through 1 metre in the direction of the force.

Notes:

- I. Work done is equivalent to energy converted while doing work.
- II. The area under force-distance graph represents work done by the force or energy converted.



1. A girl of mass 40 kg walks up a flight 10 steps. If each step is 40 cm high, calculate the work done by the girl.
2. A body is acted upon by a varying force F over a distance of 35 m as shown in the figure below.

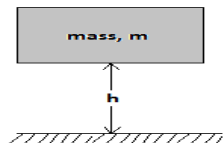


Calculate the total work done by force

3. Sometimes work is not done even if there is an applied force. Describe some situations when this can happen.

Gravitational Potential Energy

- This is the energy possessed by a body due to its height above some surface. Consider a block of mass m raised through the height h the ground. At that height the block has gravitational potential energy.



Potential energy, P.E gained
= work done in raising the block P.E

$$= \text{weight of the block} \times \text{height}$$

$$P.E = mgh$$

Elastic Potential Energy

- This is the energy stored in a stretched or compressed spring. The energy is equal to work done in stretching or compressing the spring.

work done

$$= \text{Force} \times \text{distance moved in direction of force}$$

$$\text{work done} = \text{Average Force}$$

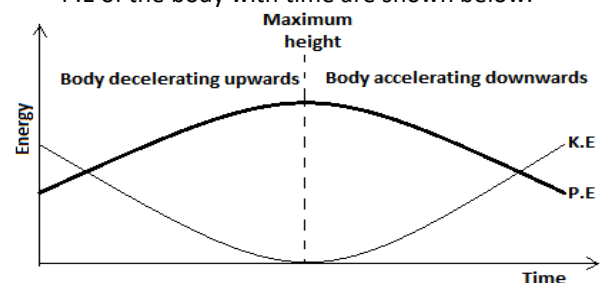
$$\times \text{change in length of spring}$$

$$(\text{compression or extension}) \text{ work done}$$

$$= \frac{0 + F}{2} \times e;$$

Variation of K.E and P.E for A Body Projected Upwards

- Consider a body of mass m projected vertically upwards. Gravitational force is the only force acting on it, assuming negligible air resistance. As it rises kinetic energy decreases since the velocity decreases (the body decelerates upwards). At the same time, the potential energy of the body increases and becomes maximum at the highest point, where K.E is zero. As the body falls from the highest point, P.E decreases while K.E increases. The curves for variation of K.E and P.E of the body with time are shown below.



- Therefore, at any given points; **total energy, $E = P.E + K.E = \text{Constant}$.**

$$\text{work done} = \frac{F}{2} \times e,$$

but $F = ke$, where k is the spring constant $\therefore$

$$\text{work done} = \left(\frac{1}{2}ke\right)e,$$

$$\text{work done} = \frac{1}{2}ke^2$$

Kinetic Energy, K.E

- Consider a body of mass m being acted upon by a steady force F . the body accelerates uniformly from rest to final velocity v in time t seconds. If it covers a distance s ;

work done in accelerating the body
= the K.E gained by the body
= Force, $F \times$ distance, s

Method 1

$$K.E = F \times s ;$$

$$K.E = ma \times (\text{average velocity} \times \text{time})$$

$$K.E = m \left(\frac{v-u}{t}\right) \times \left(\frac{u+v}{2} \times t\right)$$

$$K.E = m \left(\frac{v-0}{t}\right) \times \left(\frac{0+v}{2} \times t\right) = \frac{mv}{t} \times \frac{vt}{2}$$

$$K.E = \frac{1}{2}mv^2$$

Method2

$$K.E = F \times s ; K.E = ma \times \left(ut + \frac{1}{2}at^2\right)$$

$$K.E = m \left(\frac{v-u}{t}\right) \times \left(0 \times t + \frac{1}{2}\left(\frac{v-u}{t}\right)t^2\right)$$

$$K.E = m \left(\frac{v-0}{t}\right) \times \left(0 \times t + \frac{1}{2}\left(\frac{v-0}{t}\right)t^2\right) = \frac{mv}{t} \times \frac{vt}{2}$$

$$K.E = \frac{1}{2}mv^2$$

- A stone of mass 5 kg moves through a horizontal distance 10 m from rest. If the force acting on the stone is 8 N, calculate:

- the work done by the force
- the kinetic energy gained by the stone
- the velocity of the stone

Examples

A stone of mass 2.5 kg is released from a height of 5.0 m above the ground:

- Calculate the velocity of the stone just before it strikes the ground.
- At what velocity will the stone hit the ground if a constant air resistance force of 1.0 N acts on it as it falls?

Solution

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

$$2.5 \times 10 \times 5.0 = \frac{1}{2} \times 2.5 \times v^2$$

$$v = \sqrt{\frac{100}{1}} = 10 \text{ ms}^{-1}$$

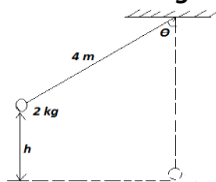
$$b) \text{Resultant force} \times h = \frac{1}{2}mv^2 ;$$

$$(mg - \text{resistance})h = \frac{1}{2}mv^2$$

$$(2.5 \times 10 - 1.0) \times 5 = \frac{1}{2} \times 2.5 \times v^2$$

$$v = \sqrt{\frac{240}{2.5}} = 9.798 \text{ ms}^{-1}$$

2. Calculate the amount of energy needed by a catapult to throw a stone of mass 500g with a velocity of 10ms^{-1}
3. A tennis ball is dropped from a height of 1.8m. it rebounds to a height of 1.25m.
 - a) Describe the energy changes which take place
 - b) With what velocity does the ball hit the ground?
 - c) With what velocity does the ball leave the ground?
4. A ball rolls on a table in a straight line. A part from the transitional kinetic energy, state the other form of kinetic energy possessed by the ball.
5. A body has 16 Joules of kinetic energy. What would be its kinetic energy if its velocity was double?
6. A force of 8N stretches a spring by 10cm. How much work is done in stretching this spring by 13cm?
7. A simple pendulum is released from rest and it swings towards its lowest position. If the speed at the lowest position is 1.0m/s , calculate the vertical height of the bob when it is released.
8. A metal ball suspended vertically with a wire is displaced through an angle θ as shown in the diagram below. The ball is released from A and swing back to B.



Given that the maximum velocity at the lowest point B is 2.5ms^{-1} . Find the height h from which the ball is released

9. A 30g bullet strikes a tree trunk of diameter 40cm at 200ms^{-1} and leaves it from the opposite side at 100ms^{-1} . Find:
 - I. The kinetic energy of the bullet just before it strikes the tree.
 - II. The kinetic energy of the bullet just before it leaves from the tree.
 - III. The average force acting on the bullet as it passes through the tree.
10. The initial velocity of a body of mass 20kg is 4ms^{-1} . How long would a constant force of 5.0N act on the body in order to double its kinetic energy?
11. A compressed spring with a load attached to one end and fixed at the other and is released as shown below.



Sketch on the same axis the variation of potential energy, kinetic energy and total energy with time

12. The figure below shows how the potential energy (P.E) of a ball thrown vertically upwards varies with height

Power

- Power is defined **as the rate of doing work (i.e. work done per unit time)**. Since work done is equivalent to energy used, and energy cannot be destroyed or created but converted from one form to another,
- Power can also be defined as **the rate of energy conversion OR the rate of transfer of energy.**

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} \text{ or } \text{Power} = \frac{\text{energy converted}}{\text{time taken}}$$

- The SI unit of power is **the watt**; named after the physicist **James Watt**. **1 watt(W) = 1joule per second (Js^{-1})**

Relationship between power and velocity

$$\text{Power} = \frac{\text{work done}}{\text{time taken}};$$

$$\text{Power} = \frac{\text{Force} \times \text{displacement of point of application of force}}{\text{time taken}}$$

$$\text{Power} = \text{Force} \times \frac{\text{displacement}}{\text{time taken}}$$

$$\text{Power} = \text{Force} \times \text{velocity}$$

Examples

1. An electric motor raises a 50 kg mass at a constant velocity. Calculate the power of the motor if it takes 30 seconds to raise the mass through a height of 15 m

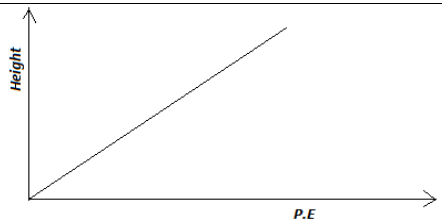
Solution

$$\text{Power} = \text{Force} \times \text{velocity}; \text{ Power} = mg \times \frac{\text{displacement}}{\text{time taken}}$$

$$\text{power} = 50 \text{ N} \times \frac{15 \text{ m}}{30 \text{ s}} = 25 \text{ W}$$

- 2.A soldier climbs to the top of the watch tower in 15 minutes. If the work done by the soldier against gravity is 60 kJ, what is his average power in climbing?

Solution

 On the same axes plot a graph of the kinetic energy of the ball	$\text{Power} = \frac{\text{work done}}{\text{time taken}}$ $\text{power} = \frac{60 \times 1000}{15 \times 60} = 66.67 \text{ W}$ Exercise - A crane lifts a load of 200 kg through a vertical distance of 3.0m in 6 seconds. Determine the; - Work done - Power developed by the crane - A load of 100N is raised 20m in 50s. Calculate; - The gain in potential energy - The power developed - Water falls through a height of 60m at a rate of flow of 10×10^5 litres per minute. Assuming that there are no energy losses, calculate the amount of power generated at the base of the water fall. (the mass of 1 liter of water is 1 kg) - If 50 litres of water is pumped through a height of 15m in 30 seconds, what is its power rating of the pump is 80% efficient? (the mass of 1 liter of water is 1 kg) - A small wind pump develops an average power of 50N. It raises water from a borehole to a point 12N above the water level. Determine the mass of water delivered in one hour.
Simple Machines - A machine is a device that makes work easier OR Is any device by means of which a force applied at one point of it can be used to overcome a force at some other point of it. Terms Associated with Machines Effort, E - This is the force applied to the machine. The SI unit of effort is the newton (N). Load, L - This is the force exerted by the machine. The SI unit of load is the newton (N). Mechanical advantage, M.A - This is the ratio of the load to the effort. It has no units since it is a ratio of two forces.	N/B Efficiency, just like M.A of a machine depends on friction between moving parts of a machine and weight of the parts that have to be lifted. These reasons explain why the efficiency of a machine is always less than 100%. Examples - A certain machine uses an effort of 400N to raise a load of 600N. If the efficiency of the machine is 75%, determine its velocity ration. <u>Solution</u> $M.A = \frac{\text{load}}{\text{effort}}$ $M.A = \frac{600}{400} = 1.5$ $\eta = \frac{M.A}{V.R} \times 100\% \Rightarrow 75 = \frac{1.5}{V.R} \times 100\%$ $V.R = \frac{1.5}{75} \times 100\% = 2$

$$M.A = \frac{\text{load}}{\text{effort}}$$

- For most machines, M.A is greater than one since load is greater than effort. In a few machines M.A. is less than one (i.e effort is greater than load) e.g. a bicycle.

Factors Affecting M.A of a Machine

- Friction between moving parts of the machine-The greater the friction, the less the mechanical advantage
- Parts of the machine that have to be lifted – The heavier the weight, the less the mechanical advantage.

4. Velocity Ratio, V.R

- It is the ratio of the distance moved by the effort D_E to the distance moved by the load D_L in the same time.

$$\text{Velocity ratio, } V.R = \frac{\text{distance moved by the effort, } D_E}{\text{distance moved by the load, } D_L}$$

$$V.R = \frac{D_E}{D_L}$$

- Note:** If two machines A and B with velocity ratios $V.R_A$ and $V.R_B$ respectively are combined, the resultant velocity ratio V.R will be given by:

$$V.R = V.R_A \times V.R_B$$

5. Efficiency, η

- It is the ratio of the useful work done by the machine (work output) to the total work put into the machine (work input) expressed as a percentage.

$$\eta = \frac{\text{work done by the machine (work output)}}{\text{total work into the machine (work input)}} \times 100\%$$

Relationship between Mechanical Advantage, Velocity Ratio and Efficiency

$$\eta = \frac{\text{work done on load (work output)}}{\text{work done by effort (work input)}} \times 100\%$$

$$\eta = \frac{L \times D_L}{E \times D_E} \times 100\%$$

$$\eta = \frac{L}{E} \times \frac{D_L}{D_E} \times 100\%$$

$$\text{but } \frac{L}{E} = M.A \text{ and } \frac{D_L}{D_E} = \frac{1}{V.R}$$

$$\eta = M.A \times \frac{1}{V.R} \times 100\%$$

$$\eta = \frac{M.A}{V.R} \times 100\%$$

- A crane lifts a load of 200 kg through a vertical distance of 3.0m in 6 seconds. Determine the;

- Work done
- Power developed by the crane
- Efficiency of the crane given that it is operated by an electric motor rated 1.25 kW.

Solution

$$I. \text{ work done} = mgh$$

$$\text{work done} = 200 \times 10 \times 3.0 = 6000 \text{ J}$$

$$II. \text{ Power} = \frac{\text{work done}}{\text{time taken}}$$

$$\text{Power} = \frac{6000}{6} = 1000 \text{ W or } 1 \text{ kW}$$

$$III. \eta = \frac{\text{power output}}{\text{power input}} \times 100\%$$

$$\eta = \frac{1000}{1250} \times 100\% = 80\%$$

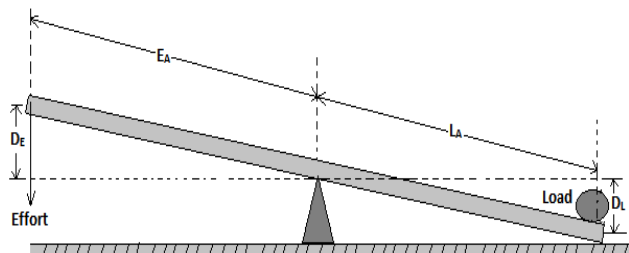
Exercise

- When an electric pump whose efficiency is 70% raises water to a height of 15m, water is delivered at the rate of 350 litres per minute.
 - What is the power rating of the pump?
 - What is the energy lost by the pump per second?
- An electric pump can raise water from a lower-level reservoir to the high level reservoir to the high level reservoir at the rate of 3.0×10^5 kg per hour. The vertical height of the water is raised 360m. If the rate of energy loss in form of heat is 200 kW, determine the efficiency of the pump.
- Define the efficiency of a machine and give a reason why it can never be 100%
- A pump uses 1g of a mixture of petrol and alcohol in the ratio 4:1 by mass to raise 1000 kg of water from a well 200m deep.
 - How much energy is given by 1g of mixture?
 - If the pump is 40% efficient, what mass of this mixture is needed to raise the water?
(1g of alcohol = 7000J, of petrol = 48000J)
- In a machine, this load moves 2m when the effort moves 8m, if an effort of 20N is used to raise a load of 60N, what is the efficiency of the machine?

Types of Simple Machines

1. Levers

- A lever is a simple machine whose operation relies on the **principle of moments**. It consists of the **effort arm**, **load arm** and **pivot** *fulcrum*. **The effort arm** E_A is the perpendicular distance of the line of action of the effort from the pivot. **The load arm**, L_A is the perpendicular distance of the line of action of the load from pivot.
- Consider the figure of simple levers shown below



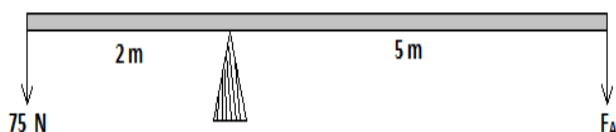
$$V.R \text{ of lever} = \frac{\text{distance moved by the effort, } D_E}{\text{distance moved by load, } D_L}$$

$$\text{Using concept of similar triangles; } \frac{D_E}{D_L} = \frac{E_A}{L_A}$$

$$\text{Therefore, for the lever, } V.R = \frac{\text{effort arm, } E_A}{\text{load arm, } L_A}$$

Example

The figure below shows a lever

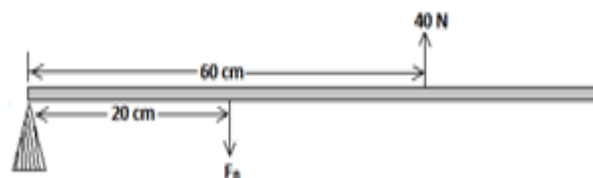


- Determine the force F_A
- Determine the *M.A* and *V.R*
- Calculate efficiency

Exercise

The figure below shows a lever

- Determine the force F_A in each case
- Determine the *M.A* and *V.R* in each case
- Calculate efficiency in each case

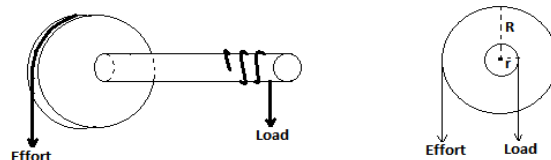


Classes of Levers

- Levers with pivot between load and effort e.g. pliers, hammer etc.
- Levers with the load between pivot and effort e.g. wheel barrow, bottle openers etc.
- Levers with the effort between the load and the pivot e.g. sweeping brooms, a fishing rod and hammer arm.

2. Wheel and axle

- Consists of **large wheel of radius R** attached to **axle of radius r** , the effort is applied on the wheel while the load is attached to the axle. An example of the wheel and axle is the **winch** used to draw water from well



- In one complete revolution the wheel moves through a distance $2\pi R$ while the load moves through $2\pi r$.

$$V.R \text{ of wheel and axle} = \frac{2\pi R}{2\pi r} = \frac{R}{r}, \quad V.R = \frac{\text{Radius of wheel}}{\text{Radius of axle}}$$

Solution

a) clockwise moment = anticlockwise moment

$$F_A \times 5 = 75 \times 2$$

$$\Rightarrow F_A = \frac{150}{5} = 30 \text{ N}$$

b) $M.A = \frac{\text{load}}{\text{effort}} ;$

$$M.A = \frac{75}{30} = 2.5$$

$$V.R = \frac{\text{effort arm, } E_A}{\text{load arm, } L_A} ;$$

$$V.R = \frac{5}{2} = 2.5$$

c) $\eta = \frac{M.A}{V.R} \times 100\% ;$

$$\eta = \frac{2.5}{2.5} \times 100\% = 100\%$$

Example

A wheel and axle is used to raise a load of 300N by a force of 50N applied to the rim of the wheel. If the radii of the wheel and axle are 85cm and 10cm respectively, calculate the M.A, V.R and efficiency.

Solution

$$M.A = \frac{\text{load}}{\text{effort}} ;$$

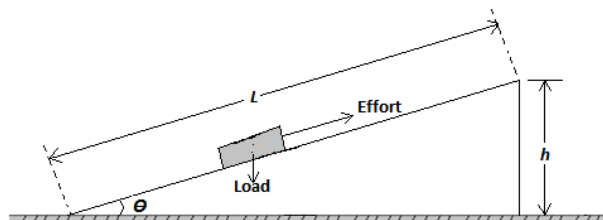
$$M.A = \frac{300}{50} = 6$$

$$V.R = \frac{\text{Radius of wheel}}{\text{Radius of axle}} ; \quad V.R = \frac{0.85 \text{ m}}{0.10 \text{ m}} = 8.5$$

$$\eta = \frac{M.A}{V.R} \times 100\% ; \quad \eta = \frac{6}{8.5} \times 100\% = 70.59 \%$$

3. The Inclined Plane

- Consider the plane below inclined at an angle θ to the horizontal.



$$V.R \text{ of the inclined plane} = \frac{\text{effort distance}}{\text{load distance}} = \frac{L}{h}$$

$$\text{but } \sin \theta = \frac{h}{L} \Rightarrow h = L \sin \theta$$

$$V.R \text{ of the inclined plane} = \frac{L}{L \sin \theta} ; \quad V.R = \frac{1}{\sin \theta}$$

$$V.R \text{ of screw} = \frac{\text{circumference of the screw head}}{\text{pitch}} \\ = \frac{2\pi R}{\text{pitch}}$$

Where R is the radius of the screw head. A screw combined with a lever is used as a jack for lifting heavy loads such as cars.

Example

The figure below shows a car-jack with a lever arm of 40 cm and a pitch of 0.5 cm. If the efficiency is 60 %, what effort would be required to lift a load of 300 kg.

Example

A man uses the inclined plane to lift 100kg load through a vertical height of 8.0m. The inclined plane makes an angle of 40° with the vertical. If the efficiency of the inclined plane is 85%, calculate

- I. The effort needed to move the load up the inclined plane at a constant velocity.
- II. The work done against friction in raising the load through the height of 8.0m

Solution

$$I. \eta = \frac{M.A}{V.R} \times 100\%; \quad 85 = \frac{M.A}{1/\sin 50} \times 100\%;$$

$$M.A = \frac{85 \times 1/\sin 50}{100} = 1.110$$

$$M.A = \frac{\text{load (mg)}}{\text{effort}}; \quad 1.110 = \frac{1000}{\text{effort}};$$

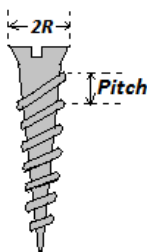
$$\text{effort} = \frac{1000}{1.110} = 900.9 \text{ N}$$

- II. 15 % of work input is used to overcome friction

i.e. 15 % of (effort $\times$ distance moved by effort)

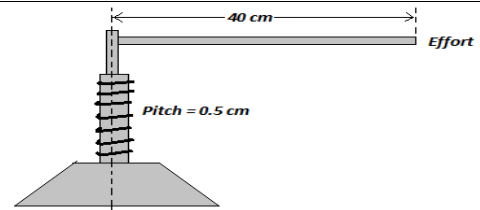
$$\frac{15}{100} \times \left(900.9 \times \frac{8}{\sin 50} \right) = 1411.26 \text{ joules}$$

4. The Screw



- The distance between two successive threads of a screw is called the **pitch of the screw**.
- In one complete revolution, the screw moves forward or backward through a distance equal to one pitch.

Exercise



Solution

$$\eta = \frac{M.A}{V.R} \times 100\% \Rightarrow \eta = \frac{M.A}{2\pi R / \text{pitch}} \times 100\%$$

$$60 = \frac{M.A}{2\pi \times 0.4 / 0.005} \times 100\%$$

$$\Rightarrow M.A = \frac{60 \times (2\pi \times 0.4) / 0.005}{100} = 301.63$$

$$M.A = \frac{\text{Load (mg)}}{\text{Effort}} \Rightarrow 301.63 = \frac{300 \times 10}{\text{Effort}}$$

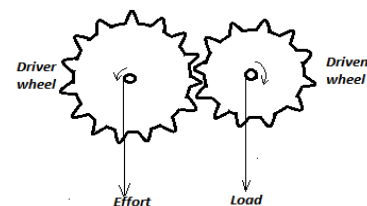
$$\text{Effort} = \frac{300 \times 10}{301.63} = 9.46 \text{ N}$$

Exercise

A car weighing 200kg is lifted with a jack of 15mm pitch. If the handle is 32cm from the screw, find the applied force.

5. Gears

- A gear is a wheel which can rotate about its centre and has equally spaced teeth or cogs around it. Two or more gears are arranged to make a machine which can be used to transmit motion from one wheel to another.



- If the driver wheel has P teeth and the driven wheel has Q teeth, then, when the driver wheel makes one revolution, the driven wheel makes $\frac{P}{Q}$ revolution

$$V.R = \frac{\text{revolutions made by the driver wheel}}{\text{revolution made by the driven wheel}}; \quad \frac{1}{P/Q} = \frac{Q}{P}$$

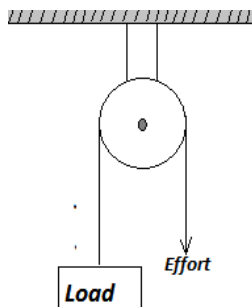
$$V.R \text{ of a gear system} = \frac{\text{number of teeth in driven wheel}}{\text{number of teeth in the driver wheel}}$$

A certain gear has 30 teeth and drives another with 75 teeth. How many revolutions will the driver gear when the driving gear makes 100 revolutions?

6. Pulleys

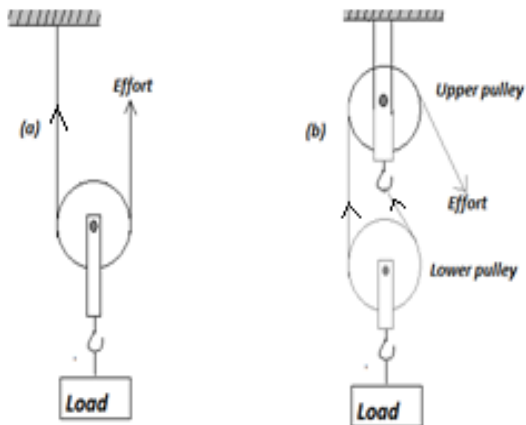
- A pulley is a wheel with a groove for accommodating a string or rope. **V.R for a pulley system is the number of ropes supporting load.** There are three common pulley systems.

A) Single Fixed Pulley



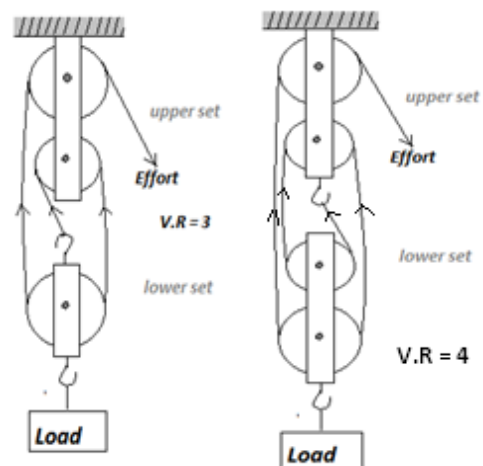
The **velocity ratio** of single fixed pulley is **1**.

B) Single Movable Pulley



The **upper pulley** in (b) makes it possible for effort to be applied downward. The **velocity ratio** of each of the pulleys (a) and (b) is **2** since two ropes are supporting the load.

C) Block and tackle



NB For a block and tackle with an odd number of pulleys it is convenient to have more pulleys fixed than movable.

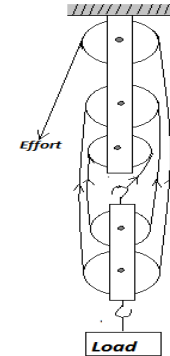
This system consists of two or more sets of pulley blocks. Below are examples.

Example

A block and tackle system is used to lift a mass of 400 kg. If this machine has a velocity ratio of 5 and an efficiency of 75 %

- a) *Sketch a possible arrangement of the pulleys showing how the rope is wound*

• **Solution**



- b) *Calculate the effort applied.*

• **Solution**

$$\eta = \frac{M.A}{V.R} \times 100\% \Rightarrow 75 = \frac{M.A}{5} \times 100\%$$

$$M.A = \frac{75 \times 5}{100} = 3.75$$

$$M.A = \frac{Load}{Effort}; 3.75 = \frac{400 \times 10}{Effort}$$

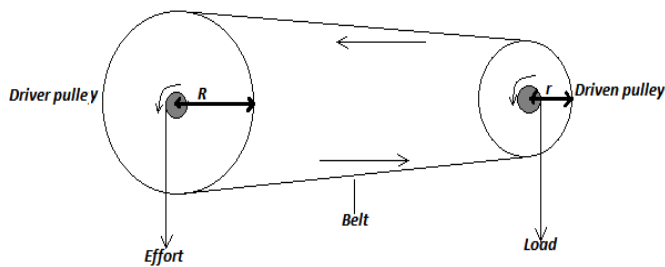
$$\Rightarrow Effort = \frac{4000}{3.75} = 1066.7 \text{ N}$$

Exercise

1. *An effort of 125N is used to lift a load of 500N through a height of 2.5m using a pulley system. If the distance moved by the effort is 15m, calculate*
 - a) *The work done on the load*
 - b) *The work done by the effort*
 - c) *The efficiency of the pulley system.*
2. *Draw a block and tackle pulley system of V.R 6 to show how the pulley can be used to raise a load L by applying an effort E*

Example

7. Pulley Belts



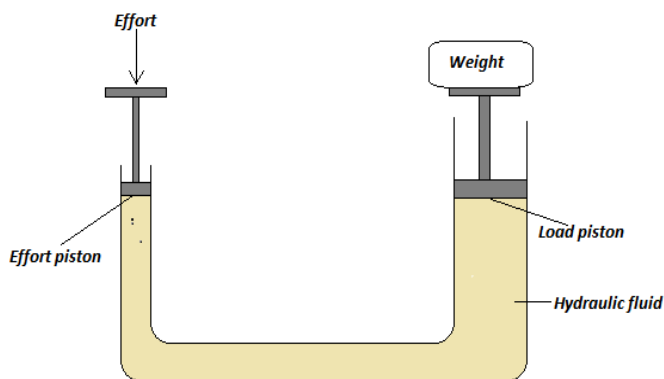
- They are found in posh mills, sewing machines, motor engines etc. If the radius of the driver pulley is R and that of the driven pulley is r , the belt turns a distance of $2\pi R$ when the driving wheel makes the revolution. The load wheel (driven wheel) at the same time makes

$$\frac{2\pi R}{2\pi r} = \frac{R}{r} \text{ revolutions}$$

$$V.R = \frac{\text{number of revolutions made by effort}}{\text{number of revolutions made by load}} = \frac{1}{\frac{R}{r}} = \frac{r}{R}$$

$$V.R = \frac{\text{radius of driven wheel}}{\text{radius of driver wheel}}$$

8. Hydraulic machines



When the effort piston moves downwards the load piston is pushed upwards.

$$\text{volume of liquid that leaves effort cylinder} = \text{volume of liquid that enters load cylinder}$$

$$\text{distance moved by effort} \times \text{cross-section of effort piston} = \text{distance moved by load} \times \text{cross-section area of piston}$$

$$\frac{\text{distance moved by effort}}{\text{distance moved by load}} = \frac{\text{cross-section area of load piston}}{\text{cross-section area of effort piston}}$$

$$\text{Velocity ratio} = \frac{2\pi R^2}{2\pi r^2} = \frac{R^2}{r^2}$$

The radius of the effort piston of a hydraulic lift is 2.1cm while that of the load piston is 8.4cm. This machine is used to raise a load of 180kg at a constant velocity through a height of 5m. Given that the machine is 75% efficient, calculate:

- The effort needed
- The energy wasted in using this machine.

Solution

$$(a) \eta = \frac{M.A}{V.R} \times 100\% \text{ but,}$$

$$V.R = \frac{\text{cross-section area of load piston}}{\text{cross-section area of effort piston}} = \frac{\pi R_L^2}{\pi R_E^2}$$

$$V.R = \frac{\pi \times 0.084^2}{\pi \times 0.021^2} = 16$$

$$75 = \frac{M.A}{16} \times 100\% \Rightarrow M.A = \frac{75 \times 16}{100} = 12$$

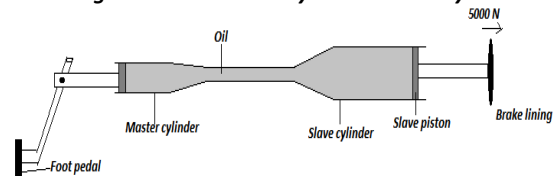
$$E = \frac{L}{M.A} \Rightarrow E = \frac{180 \times 10}{12} = 150 \text{ N}$$

(b) 25 % of work input is equivalent to energy wasted, i.e. 15 % of ((work output)/Efficiency $\times 100$)

$$\frac{25}{100} \times \left(\frac{1800 \times 5}{75} \times 100 \right) = 3000 \text{ N}$$

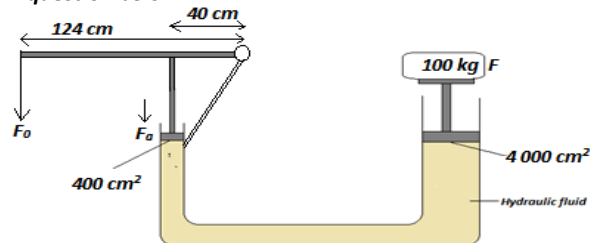
Exercise

- The diagram below shows hydraulic brake system.



- State three properties of the hydraulic brake oil.
- A force of 20N is applied on a foot pedal to a piston of areas 50cm² and this causes stopping force of 5000N.
 - Pressure in the master cylinder
 - Area of the slave piston
 - Velocity ratio of the system

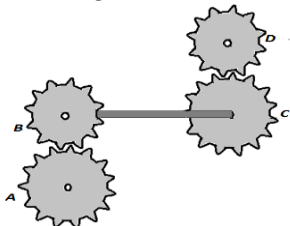
- Study the figure below of a hydraulic lift and answer the question below.



The areas of cross-sections of the pistons and the length of the arm are as indicated. Find F_o , M.A and efficiency of the machine.

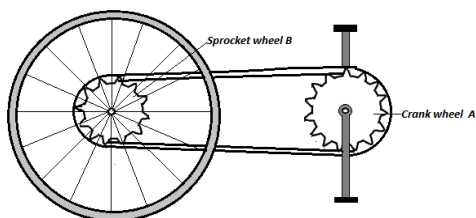
Revision Exercise

1. The figure below shows a system of gears for transmitting power. Gear A has 200 teeth and act as the driving gear. Gears Band C with 40 teeth and 100 teeth respectively are mounted on the same axle and they transmit motion to the last gear D which has 50 teeth.



- I. In what direction(s) would gear C and D rotate? If gear A is rotated in clockwise direction.
 - II. Find the velocity ratio of the gear system
2. The figure below shows the rear wheel of a bicycle and the crank wheel A, connected to the sprocket B by a chain. If wheel A has 40 teeth while B has 25 teeth and the radius of the rear wheel is 42 cm, calculate:

- a) the velocity ratio of the machine,
- b) the distance travelled by the bicycle in one revolution of the crank wheel.



3. The pulley system above has a MA OF 3 calculate: i) the total work done when a load of 60N is raised through a height of 9m.ii) the efficiency of the machine.

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