26 April 2020

Chapter Three ENERGY, WORK, POWER AND MACHINES

Specific objectives

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

a) *Describe energy transformations*
b) *State the law of conservation of energy*
c) *Define work, energy, power and state their SI units*
d) *Define mechanical advantage velocity ratio and efficiency of machines*
e) *Solve numerical problems involving work, energy, power and machines.*

Content

1. *Forms of energy and energy transformations*
2. *Sources of energy*
    - *Renewable*
    - *Non- renewable*
3. *Law conservation of energy*
4. *Work ,energy and power (work done by resolved force not required)*
5. *Kinetic and potential energy*
6. *Simple machines*
7. *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.***

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Examples

Describe the energy transformation that takes place in each of the following:

a) A car battery is used to light a bulb

Chemical → Electrical → Heat / Light

b) Coal is used to generate electricity

Chemical → Kinetic Energy of rotating turbines → Electrical Energy

c) A pendulum bob swing to and fro

P.E → K.E → P.E → K.E → P.E

d) Water at the top of a waterfall falls and its temperature rises on reaching the bottom

P.E → K.E → Heat

Work and Energy

- Work is defined as the product of force and distance moved in the direction of application of the force.

$$\boldsymbol{work\ done, W = force, F \times distance\ moved\ in\ the\ direction\ of\ the\ applied\ force, d}$$

$$\boldsymbol{W = F \times d}$$

- 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).***

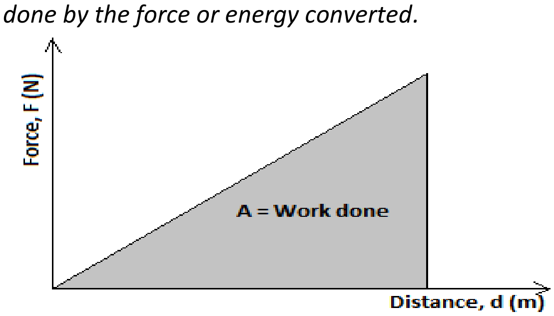
  $\boldsymbol{1\ joule\ (J)\ =\ 1\ newton\ metre\ (Nm)}$

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 doneisequivalent to energy converted while doing work.

II. The area under force-distance graph represents work done by the force or energy converted.



Examples

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

Solution

$work\ done, W = force, F \times distance$

$work\ done = mg \times distance$

$= (50 \times 10)N \times 2.4\ m = 1200\ J$

b) ***A laborer who carries a load of mass 42kg to a height of 4.0m***

Solution

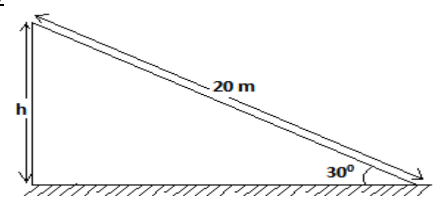
$work\ done, W = force, F \times distance$

$work\ done = mg \times distance$

$= (42 \times 10)N \times 4.0\ m = 1680\ J$

2. A man of mass 70 kg walks up a track inclined at an angle of 30^0 to the horizontal. If he walks 20 m, how much work does he do?

Solution



$work\ done, W = force, F \times distance$

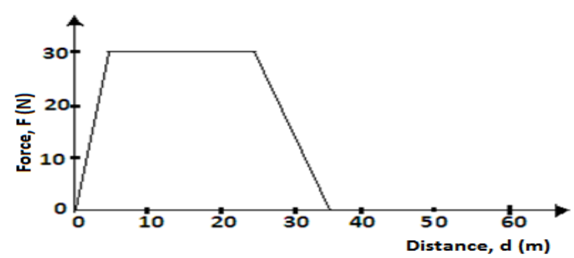
$work\ done = mg \times distance, h$

$= (70 \times 10)N \times (20\ sin\ 30)m = 7000\ J$

Exercise

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.

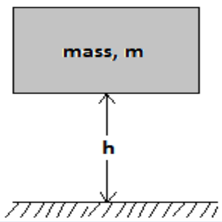


Calculate the total work done by force

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.



$$\begin{aligned} &\text{Potential energy, P.E gained} \\ &= \text{work done in raising the block} P.E \\ &= \text{weight of the block X height} \\ &P.E = mgh \end{aligned}$$

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.

$$\text{work done} = \text{Force} \times \text{distance moved in direction of force}$$
$$\text{work done} = \text{Average Force} \times \text{change in length of spring}$$
$$(\text{compression or extension})\ \text{work done} = \frac{o+F}{2} \times e;$$
$$\text{work done} = \frac{F}{2} \times e\,,$$
$$\text{but } F = ke, \text{where } k \text{ is the spring constant } \therefore$$
$$\text{work done} = \left(\frac{1}{2}ke\right)e,$$
$$\text{work done} = \frac{1}{2}ke^2$$

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;

$$\begin{aligned} &\text{work done in accelerating the body} \\ &= \text{the K.E gained by the body} \\ &= \text{Force}, F \times \text{distance}, s \end{aligned}$$

Method 1

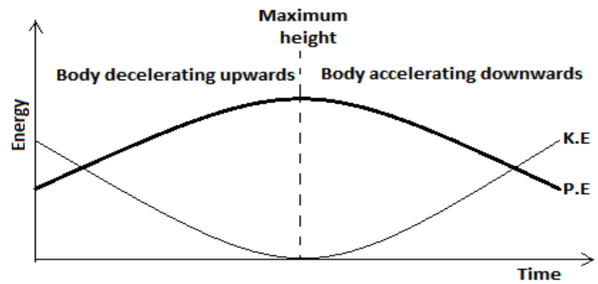
$$K.E = F \times s\ ;$$
$$K.E = ma \times (\text{average velocity} \times \text{time})$$
$$K.E = m\left(\frac{v-u}{t}\right) \times \left(\frac{u+v}{2} \times t\right)$$
$$K.E = m\left(\frac{v-0}{t}\right) \times \left(\frac{0+v}{2} \times t\right) = \frac{mv}{t} \times \frac{vt}{2}$$
$$K.E = \frac{1}{2}mv^2$$

Method2

$$K.E = F \times s\ ;\ K.E = ma \times \left(ut + \frac{1}{2}at^2\right)$$
$$K.E = m\left(\frac{v-u}{t}\right) \times \left(0 \times t + \frac{1}{2}\left(\frac{v-u}{t}\right)t^2\right)$$
$$K.E = m\left(\frac{v-0}{t}\right) \times \left(\left(0 \times t + \frac{1}{2}\left(\frac{v-0}{t}\right)t^2\right)\right) = \frac{mv}{t} \times \frac{vt}{2}$$
$$K.E = \frac{1}{2}mv^2$$

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 raises 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;$\textbf{total energy}, E = P.E + K.E = \textbf{Constant}.$

Examples

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

a) Calculate the velocity of the stone just before it strikes the ground.

b) 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

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

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

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

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

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

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

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

Exercise

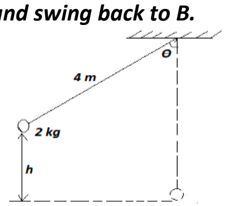
1. A stone of mass 5 kg moves through a horizontal distance 10 m from rest. If the force acting on the stone is 8 N, calculate:

a) the work done by the force

b) the kinetic energy gained by the stone

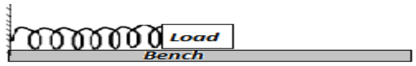
c) the velocity of the stone

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.***



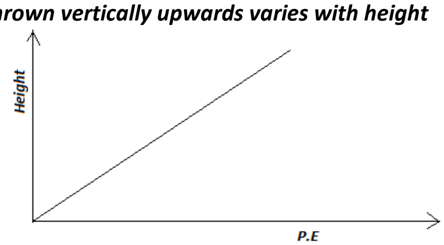
Given that the maximum velocity at the lowest point B is 2.5ms^{-1}. Find the height h from which the ball is released

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 leavees 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***



On the same axes plot a graph of the kinetic energy of the ball

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.**

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

- The ***SI*** unit of power is ***the watt***; named after ***the physicist James Watt.***

$$\boldsymbol{1\ watt(W) = 1 joule\ per\ second\ (Js^{-1})}$$

<u>Relationship between power and velocity</u>

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

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

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

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

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***

<u>Solution</u>

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

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

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?

<u>Solution</u>

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

$$power = \frac{60 \times 1000}{15 \times 60} = 66.67\ W$$

<u>Exercise</u>

1. ***A crane lifts a load of 200 kg through a vertical distance of 3.0m in 6 seconds. Determine the;***
   I. ***Work done***
   II. ***Power developed by the crane***
2. ***A load of 100N is raised 20m in 50s. Calculate;***
   I. ***The gain in potential energy***
   II. ***The power developed***
3. ***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)***
4. ***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)***
5. ***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.***

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