Notes for Class 9ᵗʰ

Physics

Chapter 6

NAME: _____

F.NAME: _____

CLASS:_____ SECTION: _____

Work and Energy

COMPREHENSIVE QUESTIONS

Q1: Define work and explain how work is calculated if force is applied at an angle.
Ans: Work:
Work is said to be done when a force displaces a body in its own direction.

Or

The product of force and displacement is called work.

Explanation:
In our daily life, when someone hold a body in state of rest no work is done because it does not cover any displacement. In the scientific sense, work is said to be done, when a force acts on a body, there must be motion or displacement by a body in the direction of the force.
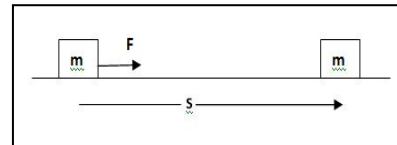
Mathematically:
When an object moves distance "S" in the direction of applied force "F" then work done is given as:

$$\textbf{Work = force} \times \textbf{Displacement}$$

$$\vec{W} = \vec{F} \times \vec{S}$$

Or $\qquad$ W = FS

Force making at Angle θ:
Sometime force is not perfectly applied in the direction of motion. In that case, the direction of force and the direction of motion of a body is not same. So, when a body is moving in horizontal direction and force "F" is applied making certain angle "θ" with the horizontal. In such situation, the force is resolved into its rectangular components. According to definition of work, horizontal component of force "F_x" i-e $\cos\theta$ displaces a body through distance "S" horizontally. So, mathematically work done can be written as:
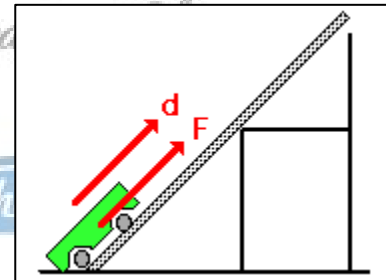
W = F_x x S $\qquad\qquad$ ∴ F_x = $F\cos\theta$
W = $F\cos\theta$ x S
Or, W= $FS\cos\theta$

Quantity and Unit of work:
Work done is a scalar quantity and the SI unit of work is Joule, denoted by "J" and can be defined as:
$\qquad$ W = FS
So, $\qquad$ 1J = 1N .1m
Or, $\qquad$ **1J = 1Nm**

Q2: Define Kinetic Energy. Derive the expression used for kinetic energy.

Ans: <u>**Kinetic Energy:**</u>

The energy possessed by a body due to its motion is called kinetic energy.

Examples:

All moving objects have kinetic energy i-e.

1. Moving car or train
2. Blowing wind
3. Flowing water etc.

<u>**Explanation:**</u>

The object mass and its speed are contributing to its kinetic energy. When the body is at rest, there is no kinetic energy present in it. It means the velocity of a body is zero, its kinetic energy is also zero. So, greater the mass or velocity of a body, greater will be the kinetic energy. It is denoted by **"E_K".**

<u>**Mathematical Form:**</u>

Mathematical, kinetic energy is one half the product of an object's mass "m" and the square of its velocity "v".

$$E_k = \frac{1}{2} mv^2$$

<u>**Quantity and Unit:**</u>

Kinetic energy is a scalar quantity and the SI unit of "E_k" is Joule (J)

<u>**Derivation of formula:**</u>

Consider a body of mass "m" which is placed on a smooth surface. As the body is at rest, so its initial velocity "v_i" is zero. A force "F" is applied on the body and the body moves from point "A" to "B" after covering the distance "S". At point "B" final velocity "v_f" of the body becomes "v".

We know that when a force "F" is applied on a body and it covers some distance "S" then work "W" can be written as:

$$W = F \times S$$

This is the work done by the body due to its motion. So, it appears as the kinetic energy i-e.

$$W = E_K$$
$$F \times S = E_k$$

Or $\quad$ **$E_K = F \times S$** -------------eq (i)

According to Newton's second law of motion

$$F = ma$$

In order to find distance "S" covered by the body, we use third equation of motion.

$$2aS = v_f^2 - v_i^2$$

As $v_f = v$ & $v_i = 0$, By putting the values

$$2aS = (v^2) - (0)^2$$
$$2aS = v^2 - 0$$
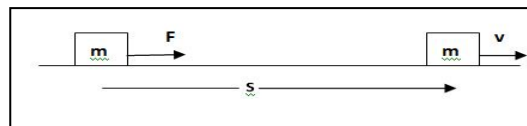$$2aS = v^2$$

Divide "2a" on both sides

$$\frac{2aS}{2a} = \frac{v^2}{2a}$$
$$s = \frac{v^2}{2a}$$

Now, putting the value of "F" And "S" in Eq (i)

$$E_k = F \times S$$
$$E_k = ma \times \frac{v^2}{2a}$$

Or $\quad E_k = \frac{1}{2} mv^2$

This equation shows the relation between kinetic energy of a moving object with its mass and velocity.

Q3: What is potential Energy? Prove that gravitational potential energy of a body of mass "m" at a height "h" above the surface of earth is given by mgh.

Ans: Potential Energy:

The energy possessed by a body due to its position or configuration in a force field is called potential energy.

Explanation:

Potential energy can be produced by changing the position of a body horizontally or vertically that is said to be elastic potential energy. For example, doing work on an elastic band by stretching it stores potential energy in the elastic bond. Also a battery contains both chemical and electrical potential energy. When an object raised above the ground, it has gravitational potential energy due to its raised position.

Gravitational Potential Energy:

When a body is taken to a height with respect to earth, here work is done against the force of gravity then potential energy stored in a body will be termed as gravitational potential energy. It is denoted by "$E_{GP.E}$". If we release the body from that height, it will accelerate and gain kinetic energy as its velocity increases. Thus "$E_{GP.E}$" can be released and have the ability to do useful work.

Mathematical Form:

Mathematically, gravitational potential energy is the product of mass "m", the acceleration due to gravity "g" and the change in height "h".

$$E_{GP.E} = mgh$$

Derivation of Gravitational Potential Energy:

Consider a body of mass "m" is taken to certain height "h" due to applied force "F". The work done can be written as.

$$W = F \times S \quad \text{----------------- (i)}$$

This is the work done by the body due to its height. So, it is considered as gravitational potential energy then eq (i) becomes

$$W = E_{GPE}$$
$$F \times S = E_{GPE}$$
Or, $\quad E_{GPE} = F \times S$

As we know that,

Force "F" is equal to weight of body i-e F = W and S = h

$$E_{GPE} = W \times h$$
As we know, $\quad W = mg$
$$E_{GPE} = mg \times h$$
Or, $\quad \mathbf{E_{GPE} = mgh}$
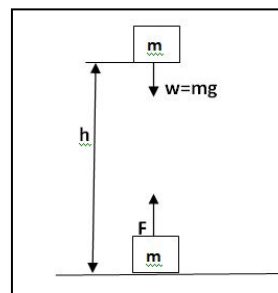
Q4: State the law of conservation of energy and mass energy conversion relation.

Ans: Law of Conservation of Energy:

Statement:

The law of conservation of energy states that:

"Energy can neither be created nor destroyed in any process. It can be converted from one from to another but the total amount of energy remains constant".

Examples:
- In radio, electrical energy is converted into sound energy.
- In light bulb, electrical energy is converted into heat and light energy.
- In electric motor, electrical energy is converted into mechanical energy.

Mass Energy Equivalence / Equation:

According to Einstein's mass energy equation "The energy "E" of a physical system is numerically equal to the product of its mass "m" and the speed of light "c" squared. It is also known as mass energy equivalence.

Mathematical Form:

Mathematical, mass energy equation can be written as:

Energy = mass X the speed of light squared

$$E = m \times c^2$$

Or **$E = mc^2$**

Where the speed of light is constant having value of $3 \times 10^8 \text{ ms}^{-1}$, however this value needs to be squared.

This equation shows the relationship between mass and energy that mass and energy are same physical entities and can be changed into each other.

Q5: Explain briefly major sources of energy. Such fossil fuels, wind, solar, biomass, nuclear and thermal energy.

Ans. Major sources of energy:

The major sources of energy are described below:

1. **Fossil Fuels:**

Coal, oil and natural gas are called fossil fuels because they are non – renewable resources that formed when prehistoric plants and animals died and were gradually buried by layers of rock. Over million of years, different types of fossil fuels i-e coal, oil or gas are formed.

Coal is most abundant fossil fuel in world, with an estimated reserve of one million metric tons.

Crude oil is refined into many different types of energy products i-e gasoline, jet fuel and heating oil. Oil produces more energy than same amount of Coal.

Natural gas is often a byproduct of oil; it is the mixture of gases the most common of which is methane. The main advantage of natural gas is that it is easy to transport.

Most of the energy that we use comes from fossil fuels which are burned in power stations, factories, homes and vehicles etc. It is consumed in more than 80 % of the world demand for energy. The disadvantage is that burning of fossil fuels caused atmospheric pollution.

2. **Wind Energy:**

The kinetic energy of the wind is currently used in many parts of the world to generate electricity. It is a renewable resource that can be used again and again. It is ecofriendly source of energy but require very large open space.

3. **Solar Energy:**

Solar energy is the energy obtained from sunlight. The energy from direct sun light can be used to produce electricity. Today, solar cells are used to power everything from calculators and watches to small cities. The energy obtained from sunlight is 100% free and very eco-friendly. It doesn't cause any pollution. However, just like wind energy, huge land area is required to produce electricity.

4. **Bio – mass:**
  "Bio" means life so bio – mass is the energy from living things. The term "bio mass" refers to the material from which we get bio-energy. Biomass is produced when the sun's solar energy is converted into plant matter (carbohydrates) by the process of photosynthetic. Only green plants and photosynthetic algae, containing chlorophyll, are able to use solar energy. The simplest process employed to make use of this energy is eating. In this way, we are taking advantage of the energy stored as biomass.

5. **Geothermal Energy:**
  Geo means "earth" and thermal means "heat". So, geothermal energy is the heat energy obtained from earth's core. The thermal energy contained within Earth's core result from energy trapped almost 5 billion years ago during the formation of planets. It is a natural renewable resource and doesn't cause any pollution. In many countries, geothermal energy is used to generate electricity.

6. **Nuclear Energy:**
  Nuclear fission is the process of splitting large atoms i-e uranium into two or more pieces, which releases a huge amount of energy in the form of radiation or heat. The heat is used to boil water that is further used to produce electricity, In nuclear reactor, small quantities of fuel produce large amount of energy ($E=mc^2$). The advantage is that major portion of heat energy is used for useful purpose while some part of energy is wasted that can cause pollution and it is harmful for the humans.

Q6: Define and explain efficiency.
Ans. Efficiency:
  Efficiency is the ratio of useful energy or work output to the total energy or work input.
Or
  It is the ratio between work done by the machine and work done on the machine.
Mathematical Form:

$$\text{Efficiency} = \frac{useful\ output\ work}{input\ work}$$

$$\text{Efficiency} = \frac{W_0}{W_i}$$

  or

$$\text{Efficiency} = \frac{useful\ energy\ output}{energy\ input}$$

$$\text{Efficiency} = \frac{E_o}{E_i}$$

Percentage efficiency:
  Efficiency is always expressed in percentage. It is defined as the ratio of useful energy provided by a device to the energy required to operate the device or machine. Mathematically the percentage efficiency is calculated as follow.

$$\textbf{Efficiency} = \frac{E_o}{E_i} \textbf{ X 100\%}$$

Or

$$\textbf{Efficiency} = \frac{W_o}{W_i} \textbf{ X 100 \%}$$

Efficiency has no unit.

Explanation:

The efficiency of any machine describes the extent to which it converts the energy given as an input into the required form of energy obtained from a machine as an output. As we know, energy can neither be created nor destroyed. Like a light energy. While the bulb is transforming potential energy (Stored in it) into the required form of energy i.e. light energy while some part of its energy is lost or wasted. That lost energy is transformed into heat energy.

Thus it is not possible to have a machine with 100% efficiency because friction lowers the efficiency of a machine. So, work output is always less than work input.

Examples:

1.   In light bulb 5% of the electrical energy transforms into light energy while the rest of given energy is wasted in the form of heat energy. So we say, the efficiency of light bulb is only 5% out of 100%.

2.   If a petrol engine does 25 joule of useful work for every 100 joule of energy supplied to it, then its efficiency will be 25%.

Q7. Define and explain power.

Ans. POWER:

Power is defined as the time rate at which work is done or time rate at which energy is converted.

Mathematical Form:

Mathematically, power can be written as:

$$\text{Power} = \frac{work}{time}$$

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

Or **(in terms of energy)**

$$\text{Power} = \frac{Energy}{time}$$

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

EXPLANATION:

As we know, power is a measure of how fast work is done or how fast energy is being converted from one form to another. Let suppose, there are two persons 'A' and 'B'. They both are having equal masses. Person 'A' runs 5 meters in 1 min while person 'B' also runs 5 meter in 3 mins. So, it shows that person 'A' is more powerful than person 'B' because both have performed the same work but person 'A' takes less time to cover a distance of 5 m than person 'B' and he has performed work faster than 'B'. Also his energy is quickly converted from one form to another. So, we relate work or energy with time which shows how much power is consumed in given time period.

QUANTITY AND UNIT:

Power is a scalar quantity. The SI unit of power is watt (W) where as 1 watt is equal to 1 Joule (J) per 1 second (s). i-e

$$\mathbf{1\ W =\ 1Js^{-1}}$$

OTHER UNITS OF POWER:

A larger unit is often used for power is the "horse power (hp)" where as one horse power is equal to 746 W. i-e

1hp = 746 W

Another commercial unit of power is "kilowatt hour (kWh)" where as one kilowatt hour is the energy converted or consumed in 1 hour at constant rate of 1000 Js^{-1} or 1kW. I-e

$$1kWh = 1000 \times 3600$$
$$1kWh = 3600000$$

or   **$1kWh = 3.6 \times 10^6$ J**

TOPIC WISE QUESTIONS

Q1: Define energy and explain different types of energy.

Ans: <u>Energy:</u>

         Energy is defined as the ability to do work.

<u>SI Unit:</u>

         The SI Unit of energy is Joule (J).

<u>Types / Forms of Energy:</u>

         There are different types of energy which are as follow:

1. **<u>Kinetic Energy:</u>**

     The energy possessed by a body due to its motion is called kinetic energy. If an object is moving, it has kinetic energy i.e. a person running, a river flowing, or a car traveling on a road are the examples of kinetic energy.

2. **<u>Potential energy:</u>**

     The energy possessed by a body due to the position, arrangement or state of the object is called potential energy. It is the energy that is stored in an object that has potential to do work. So, when the position, arrangement or state of the object changes, the stored energy will be released.

For example, chemical potential energy is stored in the food you eat or the energy stored in stretched elastic band.

3. **<u>Chemical Energy:</u>**

     Chemical energy is the stored energy in the bonds of chemical compounds such as atoms and molecules. These bonds can take many different forms, like it is the energy stored in food, gasoline in chemical combination. For example, striking a match stick or breaking light sticks releases chemical energy.

4. **<u>Heat Energy:</u>**

     Heat energy is also known as thermal energy. Heat is a transfer of energy from one part of a substance to another or from one object to another due to difference in temperature. For example, burning of fire transfer the energy to keep room warm.

5. **<u>Electrical Energy:</u>**

     The energy produced by electrons moving through a substance is called electrical energy. We mostly see electric energy in batteries and from the outlets in our homes. It lights our homes, and runs all our appliances. Electrical energy is major source of energy that is used in homes, offices, schools, industries etc.

6. **<u>Sound Energy:</u>**

Sound energy is produced when an object is made to vibrate. Sound energy travels out as waves in all directions. Sound needs a medium to travel through such as air, water, Woods etc. For example, voices, whistles, horns and musical instruments produced sound energy.

7. <u>Nuclear Energy</u>:

Nuclear energy is the energy that is released when the nuclei of atoms are spilt (fission) or fused together (fusion). Nuclear energy is used in nuclear power plants to generate electricity. It is also used in sun and atomic bonds.

8. <u>Radiant energy</u>:

Radiant energy is a combination of heat and light energy. It travels as an electromagnetic wave. Light energy like sound energy travels in all direction in waves. For example, the microwave cooks food on the basis of radiant energy. Other examples of radiant energy are the glowing coils on a toaster, the sun and even headlights on cars.

ASSIGNMENTS

6.1 During a tug – of – war, team A pulls on team B by applying a force of 1100 N to the rope between them. The rope remains parallel to the ground. How much work does team A do if they pull team B towards them a distance of 2.0 m?

Given data:
Force = F = 1100N
Distance = S = 2m
Find:
Work done = W = ?
Solution:
As we know that
$$W = F \times S$$
$$= 1100 \times 2$$
$$W = 2200 \text{ J}$$
Or **W = 2.2 × 10³J**

6.2 A bullet of mass 30g travels at a speed of 400ms⁻¹. Calculate its kinetic energy.
Given Data:
Mass = m = 30g
$$= \frac{30}{1000} kg$$
$$= 0.03 \text{ kg}$$
Speed = v = 400m/s
Find:
Kinetic Energy = E_k = ?
Solution:
As we know that
$$E_k = \frac{1}{2} mv^2$$
Putting values
$$= \frac{1}{2}(0.03)(400)^2$$
$$E_k = (0.5)(0.03)(400)^2$$
$$E_k = 0.5 \times 0.03 \times 160000$$

$E_k = 2400$ J

6.3 An object of mass 10 kg is lifted vertically through a height of 5m at a constant speed. What is the gravitational potential energy gained by the object?

Given Data:

Mass = m = 10 kg

Height = h = 5m

Acceleration due to gravity = g = 9.8 m/s^2

Find:

Gravitational potential energy = E_p = ?

Solution:

As we know that

$$E_p = mgh$$

Putting values

$$E_p = 10 \times 9.8 \times 5$$
$$E_p = 490 \text{ J}$$

6.4 How much energy is generated when mass of 1 g is completely converted into energy?

Given Data:

Mass = m = 1 g

$$= \frac{1}{1000} \text{ kg}$$
$$= 0.001 \text{ kg}$$

Speed of light = c = 3 ×10^8 m/s

Find:

Energy = E = ?

Solution:

By Einstein equation

$$E = mc^2$$

Putting value

$$E = (0.001)(3 \times 10^8)^2$$
$$= 0.001 \times 9 \times 10^{16}$$
$$= 0.009 \times 10^{16}$$
$$= 9 \times 10^{-3} \times 10^{16} \text{ J}$$
$$= 9 \times 10^{-3+16} \text{ J}$$
$$E = 9 \times 10^{13} \text{ J}$$

6.5 An electric heater is heated at 250W. Calculate the quantity of heat generated in 10 minutes.

Given Data:

Power = P = 250 W

Time = t = 10 min

$$= 10 \times 60 \text{ sec}$$
$$= 600 \text{ sec}$$

Find:

Quantity of heat is work done = W = ?

Solution:

As we know that

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

or **W = P ×t**

Putting values

$$W = 250 \times 600 \text{ J}$$
$$= 150000 \text{ J}$$
$$= 150 \times 10^3 \text{ J}$$
W = 150 kJ

NUMERICALS

1. Determine the work done in each of the following cases:

a. Kicking a soccer ball forward with a force of 40 N over a distance of 15 cm.

Given data:

Force = F = 40 N

Distance = S = 15 cm = $\frac{15}{100}$m = 0.15 m

Find:

Work done = W = ?

Solution:

As we know that

W = F × S
$$= 40 \times 0.15$$
W = 6J

b.   Lifting a 50 kg barbell straight up 1.95 m

Given data:

Mass of barbell = m = 50 kg

Acceleration due to gravity = g = 9.8 m/s^2

Distance = S = 1.95m

Find:

Work done = W = ?

Solution:

By using formula

W = F ×S – (i)

As we know that

F = mg

Putting value

$$= 50 \times 9.8$$
F = 490 N

Now putting values in eq (i)

W = F × S
$$= 490 \times 1.95$$
W = 955.5J
$$= 9.55 \times 10^2 \text{ J}$$
W = 9.6 × 10^2 J

2. Calculate the velocity of a 1.2 kg falling star (meteorite) with 5.5 × 10^8 J of energy.

Given data:

Mass = m = 1.2 kg

Energy = E = 5.5×10^8 J

Find:

Velocity = v = ?

Solution:

As we know that

$$E_K = \frac{1}{2} mv^2$$

Rearranging the formula

$$2 E_K = mv^2$$

$$\frac{2E_k}{m} = v^2$$

$$\text{or} \qquad v^2 = \frac{2E_k}{m}$$

Taking square root on both sides

$$\sqrt{v^2} = \sqrt{\frac{2E_k}{m}}$$

$$v = \sqrt{\frac{2E_k}{m}}$$

Putting values

$$= \sqrt{\frac{2 \times 5.5 \times 10^8}{1.2}}$$

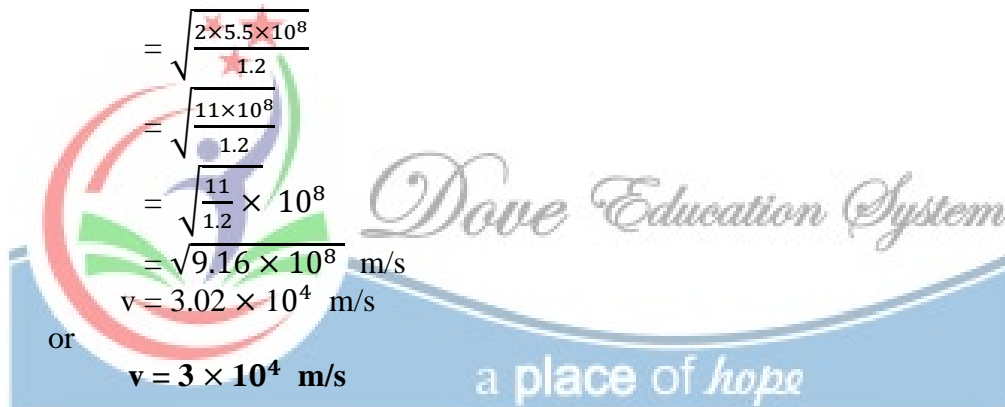$$= \sqrt{\frac{11 \times 10^8}{1.2}}$$

$$= \sqrt{\frac{11}{1.2} \times 10^8}$$

$$= \sqrt{9.16 \times 10^8} \text{ m/s}$$

$$v = 3.02 \times 10^4 \text{ m/s}$$

or

$$v = 3 \times 10^4 \text{ m/s}$$

3. Calculate the gravitational potential energy of a 2000 kg piano.

a. Resting on the floor.

Given data:

Mass = m = 2000 kg

Height = h = 0 m

Acceleration due to gravity = g = 9.8 m/s^2

Find:

Gravitational potential energy = E_p = ?

Solution:

As we know that

$$E_p = mgh$$

Putting value

$$= 2000 \times 9.8 \times 0$$

$$E_p = 0 \text{ J}$$

b.   With respect to the basement floor, 1.9m below.

Given data:

Mass = m = 2000 kg

Height = h = 1.9m

Acceleration due to gravity = g = 9.8 m/s^2

Find:

Gravitational potential energy = E_p = ?

Solution:

As we know that

$$E_p = mgh$$

Putting values

$$= (2000) \times 9.8 \times 1.9$$
$$E_p = 37240 \text{ J}$$
$$\mathbf{E_p = 3.7 \times 10^4 \text{ J}}$$

4.An elevator weighting 5000 N is raised to a height of 15.0m in 10.0s, how much power is developed?

Given data:

Weight of elevator = W= mg = 5000 N

Height = h = 15 m

Time = t = 10 Sec

Find:

Power = P = ?

Solution:

As we know that

$$P = \frac{E_P}{t} \text{ ---------- (1)}$$

For finding E_P, we know that

$$E_p = mgh$$
$$= 5000 \times 15$$
$$E_p = 75000 \text{ J}$$

Putting value of E_P in eq 1

$$P = \frac{E_P}{t}$$
$$= \frac{75000}{10} \text{ W}$$
$$\mathbf{P = 7500 \text{ W}}$$

5.What power is required for a ski – hill chair lift that transports 500 people (average mass 65 kg) per hour to an increased elevation of 1200 m?

Given data:

Average mass of one person = 65 kg

Mass of 500 peoples = m = 500 × 65 kg

m= 32500 kg

Height = h = 1200m

Acceleration due to gravity = 9.8 m/s^2

Time = 1 hour

= 1 × 60 × 60 sec

= 3600 sec

Find:

Power = P = ?

Solution:

As we know that

$$P = \frac{E_P}{t} \text{ ------- (i)}$$

So,

$$E_p = mgh$$
$$= 32500 \times 9.8 \times 1200$$
$$\mathbf{E_p = 382200000 \text{ J}}$$

Eq(i) =>

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

Putting values

$$= \frac{382200000}{3600} \text{ W}$$
$$= 106166.6 \text{ W}$$
$$= 1.06166 \times 10^5 \text{ W}$$
$$\mathbf{P = 1.06 \times 10^5 W}$$

6. How long will it take a 2750 – W motor to lift a 385 – kg sofa set to a sixth - story window 16.0 m above?

Give Data:
   Power = P = 2750 W
   Mass = m = 385 Kg
   Height = h = 16.0m
   Acceleration due to gravity = g = 9.8 m/s^2
   Time = t = ?

Solution:
As we know that

$$\mathbf{P = \frac{W}{t}} \text{ -----------------(i)}$$

Here

$$W = E_p = mgh$$

Putting values

$$W = 385 \times 9.8 \times 16 \text{ J}$$
$$W = 60368 \text{ J}$$

Now eq (i) becomes

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

Putting Value

$$t = \frac{60368}{2750} \text{ sec}$$
$$= 21.9 \text{ Sec}$$
$$\text{Or}$$
$$\mathbf{t = 22 \text{ Sec}}$$

7.   How much work can a 2.0 hp motor do in 1.0h?
Data:
Power = P = 2hp
$$= 2 \times 746 \text{ W} \qquad \therefore \text{ 1hp = 746 W}$$

= 1492 W

Time = t= 1 hour

= 1 hour

= 1 × 60 × 60 Sec

= 3600 Sec

Find:

Work done = W = ?

Solution:

As we know that

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

or   W = P×t

= 1492×3600

= 5371200 J

= 5.37×10⁶J

W = 5.4 × 10⁶ J