DBS 1012
ENGINEERING SCIENCE

CHAPTER 4
WORK, ENERGY AND POWER

SUMMARY

- This topic explains about the relationship between work, energy and power. Students will exposed to energy changes and mechanical efficiency.

LEARNING OUTCOME:

4.1 Understand the concept of work, energy and power

4.1.1Define work, energy and power

4.1.2 calculate form of energy by using formulas:

a) Kinetic Energy, $E_k = \frac{1}{2} \mathrm{m}v^2$

b) Potential Energy, E_p=mgh

4.1.3 State Principle of Conservation of energy

4.1.4 Describe conversion of energy from one form of energy to another.

4.1.5 Apply the concept and formula of work, energy and power in solving the related problems'

4.1.6 Calculate the efficiency of mechanical system.

Efficiency = $\frac{P_o}{P_{in}} \times 100\%$ and Efficiency = $\frac{E_o}{E_{in}} \times 100\%$

4.1.1 DEFINE WORK, ENERGY AND POWER

- Work done is the product of an applied force and the displacement of an object in the direction of the applied force.

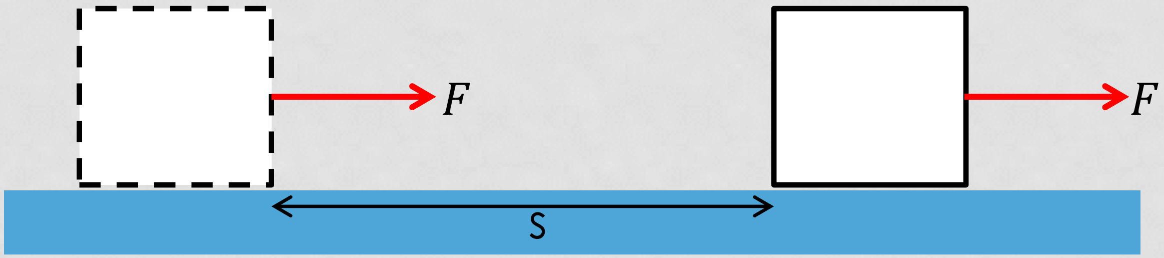


Figure 1 : force and the displacement in the same direction

$$W = F \times s$$

F = force (Newton)
s = displacement (m)
Unit work = J @ Nm

4.1.1 DEFINE WORK, ENERGY AND POWER

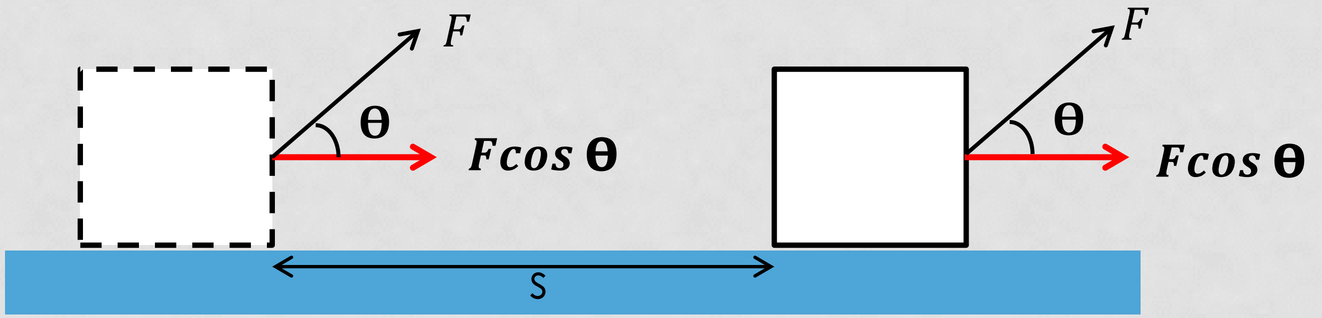


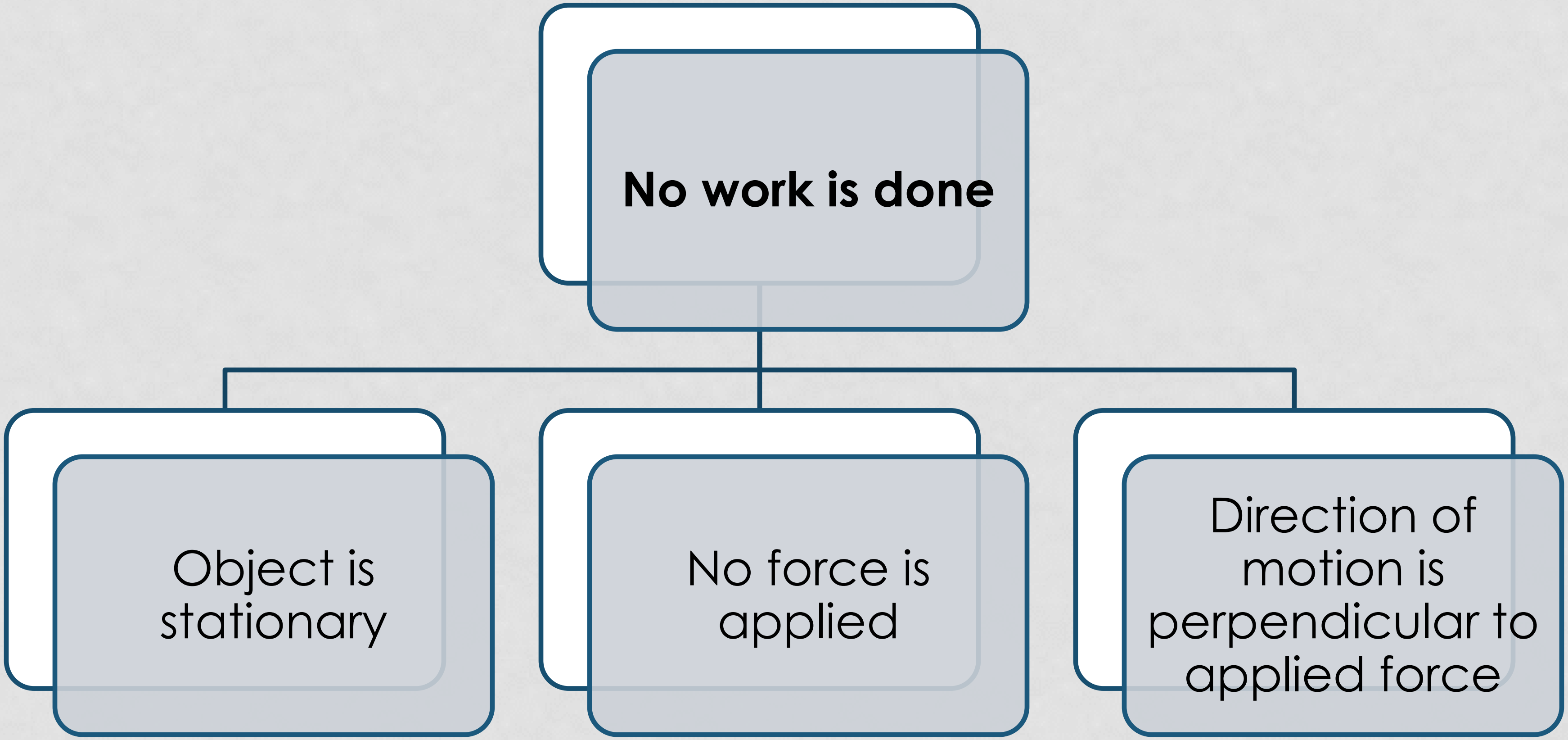
Figure 2 : force and the displacement in different direction

In this situation, we use:

$$W = Fs\cos\theta$$

F = force (Newton)
s = displacement (m)
Unit work = J @ Nm

4.1.1 DEFINE WORK, ENERGY AND POWER



NO WORK IS DONE

Figure 3(a) Pushing a wall

Figure 3(b) a satellite orbiting in space

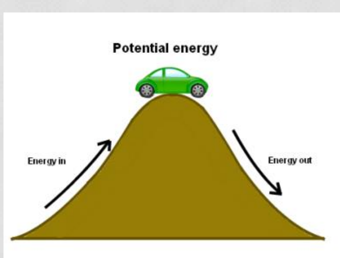
Figure 3 : No work is done

DEFINITION ENERGY, E

- Energy is capacity to do work
- Unit : Joule (J)

Form of energy

- Kinetic energy
- Solar energy
- Electric energy
- Chemical energy
- Nuclear energy
- Gravitational potential energy



GRAVITATIONAL POTENTIAL ENERGY, E_p

- Definition : energy of an object due to its **higher position** in the gravitational field.

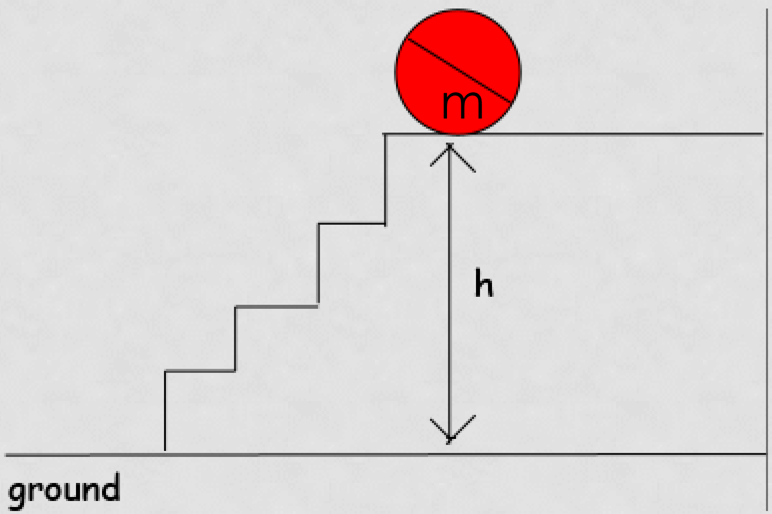


Figure 4: Gravitational Potential Energy

$$E_p = mgh$$

m = mass (kg)
g = gravity acceleration =9.81m/s^2
h= height

KINETIC ENERGY, E_k

- Definition : energy of an object due to its **motion**
- Unit : Joule (J)

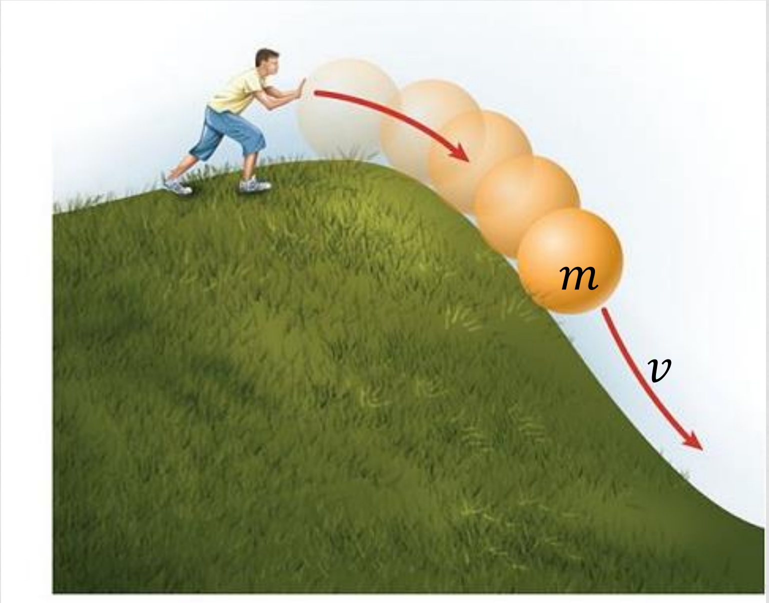


Figure 5: kinetic energy

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

m= mass (kg)

$v = velocity \left(\frac{m}{s}\right)$

DEFINITION POWER, P

- Definition : the rate at which work is done or the amount of work done per second
- Unit : J/s @ Watt

$$\boldsymbol{P} = \frac{\boldsymbol{W}}{\boldsymbol{t}} = \frac{\boldsymbol{mgh}}{\boldsymbol{t}} = \boldsymbol{F} \times \boldsymbol{v}$$

m= mass (kg)

$v = velocity \left(\frac{m}{s}\right)$

$W = work\ (J)$

$t = time\ (s)$

$F = force\ (N)$

$g = gravity\ acceleration = \ 9.81\ m/s^2$

4.1.2 CALCULATE FORM OF ENERGY USING FORMULA E_p AND E_k

EXAMPLE

A car is moving with the velocity of 10 m/s and is having mass of 250 Kg. Calculate its Kinetic energy?

Solution :

The car posses kinetic energy so use formula $\boldsymbol{E_k = \frac{1}{2} mv^2}$

Then,

$$\boldsymbol{E_k = \frac{1}{2} mv^2 = \frac{1}{2}(250)(10^2) = 12500\ J}$$

4.1.2 CALCULATE FORM OF ENERGY USING FORMULA E_p AND E_k

EXAMPLE

A man is carrying a trolley of mass 6 kg and having Kinetic energy of 40 J. Calculate its velocity with which he is running?

Solution :

The man posses kinetic energy so use formula $\boldsymbol{E_k = \frac{1}{2} mv^2}$

Then,

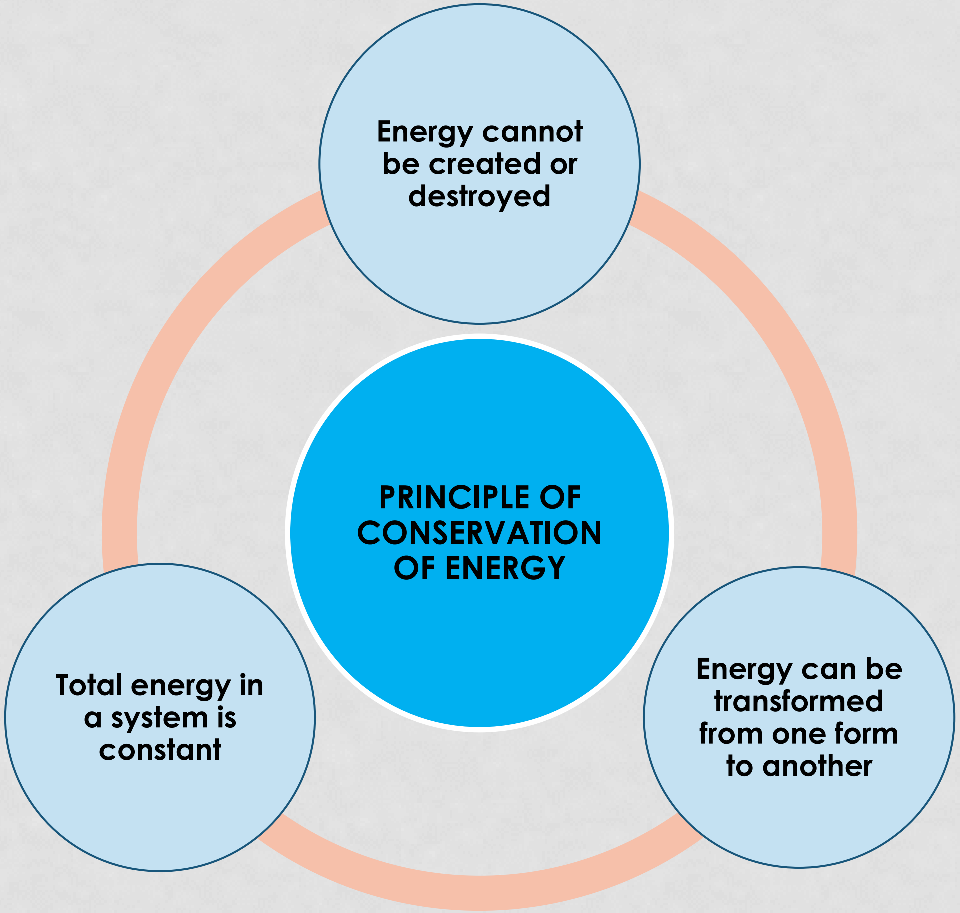
$$\boldsymbol{E_k = \frac{1}{2} mv^2}$$

$$\boldsymbol{40\, J = \frac{1}{2}(6)(v^2)}$$

$$\boldsymbol{v^2 = \frac{40 \times 2}{6} = 13.33}$$

$$v = \sqrt{13.33} = 3.65 \frac{m}{s}$$

4.1.3 STATE PRINCIPLE OF CONSERVATION OF ENERGY



4.1.4 DESCRIBE CONVERSION FROM ONE FORM OF ENERGY TO ANOTHER

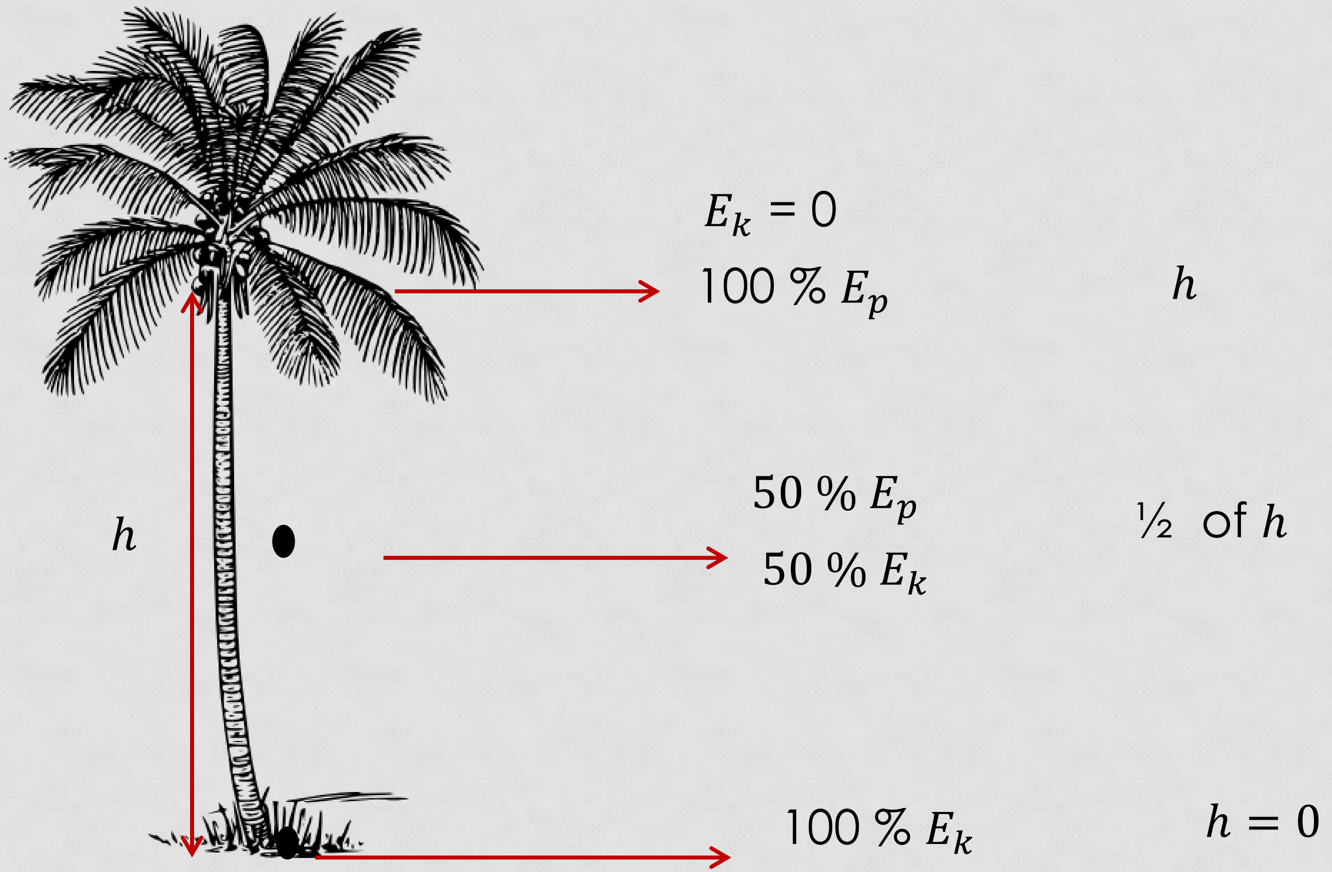


Figure 6(a): Conversion of Energy

4.1.4 DESCRIBE CONVERSION FROM ONE FORM OF ENERGY TO ANOTHER

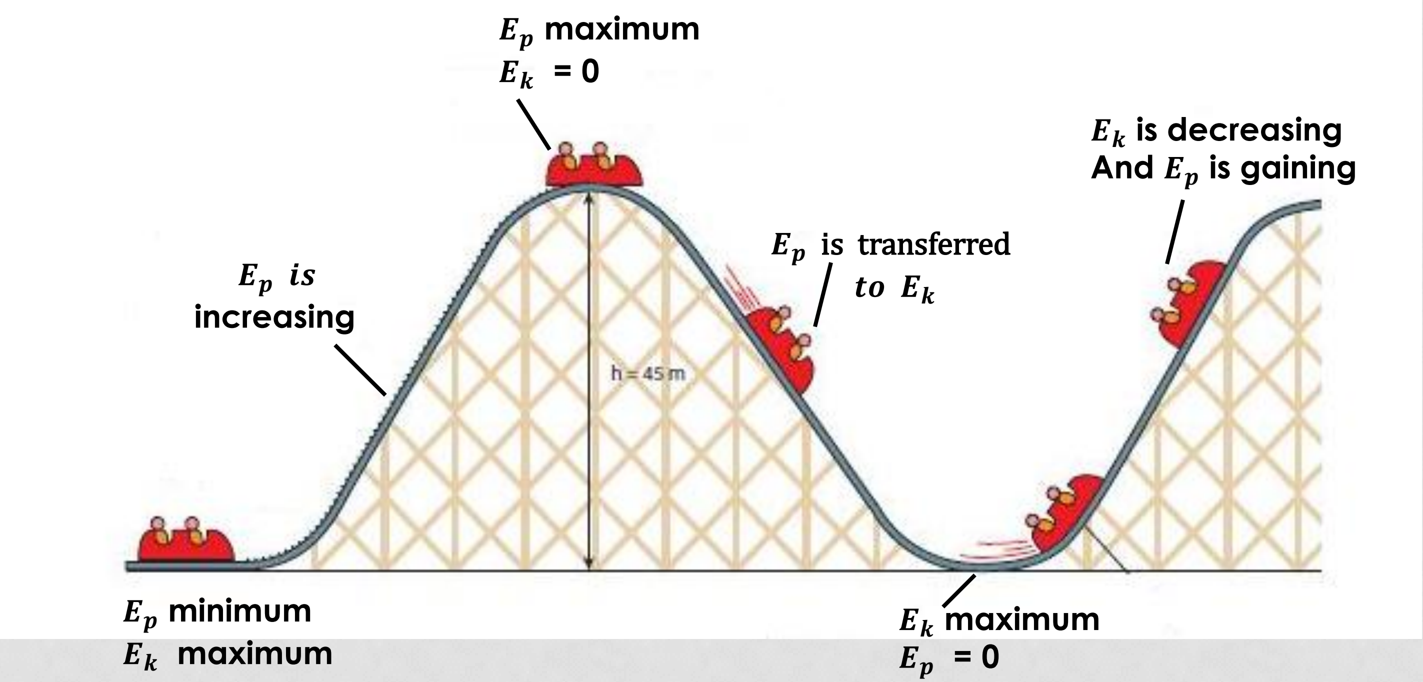


Figure 6(b): Conversion of Energy

L

4.1.4 DESCRIBE CONVERSION FROM ONE FORM OF ENERGY TO ANOTHER

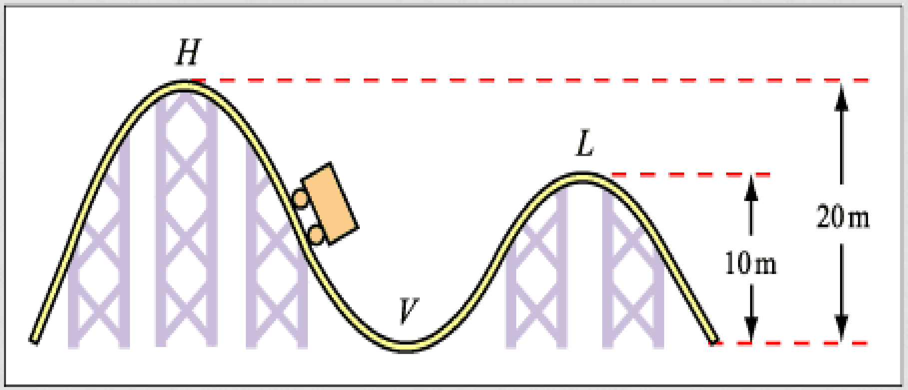
EXAMPLE

Figure below shows a simplified route of a roller coaster. Initially, the cart runs down from the starting point . Neglecting the effects of friction, find its speed at

(a) the "valley" *V*

(b) at the top of second hill *L*

(c) If friction is taken in consideration, will the answers be smaller or larger than that found in part (a) and (b)?



4.1.4 DESCRIBE CONVERSION FROM ONE FORM OF ENERGY TO ANOTHER

Solution :

a) $E_{p\,(at\,H)} = E_{k\,(at\,V)}$

$$\cancel{m}gh = \frac{1}{2}\cancel{m}v^2$$

$$v^2 = 2gh$$

$$v = \sqrt{2gh} = \sqrt{2\left(\frac{9.81m}{s}\right)(20)}$$

$$= 19.81\frac{m}{s}$$

b) $E_{p(at\,H)} + E_{K(at\,H)} = E_{p(at\,L)} + E_{K(at\,L)}$

$$m(9.81)(20) + 0 = m(9.81)(10) + \frac{1}{2}mv^2$$

$$196.2\,m = 98.1\,m + \frac{1}{2}mv^2$$

$$\frac{1}{2}mv^2 = 196.2\text{m} - 98.1\text{m} = 98.1\text{m}$$

$$\cancel{m}v^2 = 196.2\cancel{m}$$

$$v = \sqrt{196.2} = 14.0\frac{m}{s}$$

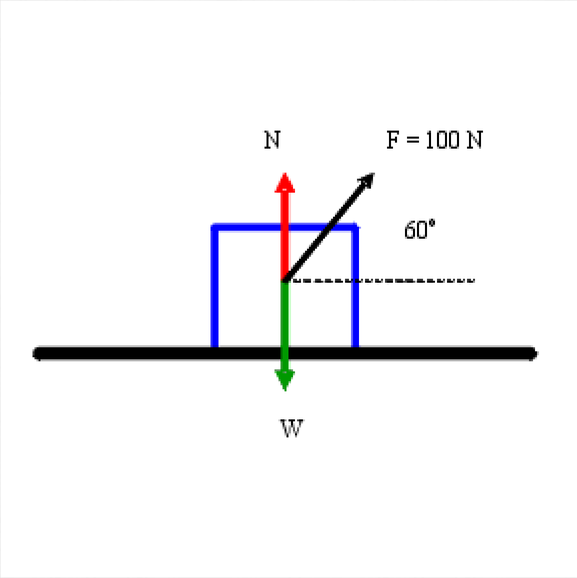
4.1.4 DESCRIBE CONVERSION FROM ONE FORM OF ENERGY TO ANOTHER

c) The results would be smaller than found in part (a) and (b), because some energy is lost by friction.

4.1.5 APPLY THE CONCEPT AND FORMULA OF WORK, ENERGY AND POWER IN SOLVING THE RELATED PROBLEMS

EXAMPLE

A box is dragged across a floor by a 100N force directed 60° above the horizontal. How much work does the force do in pulling the object 8m?



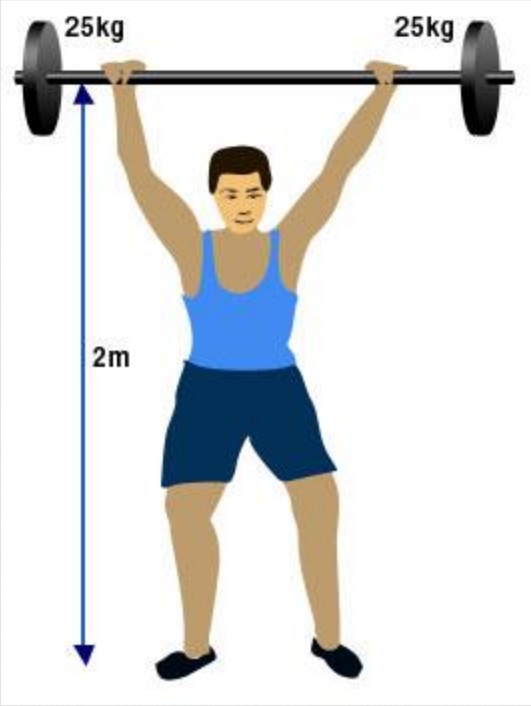
Solution :

$$W = Fs\cos\theta = 100 \times 8\cos 60° = 400Nm = 400\ J$$

4.1.5 APPLY THE CONCEPT AND FORMULA OF WORK, ENERGY AND POWER IN SOLVING THE RELATED PROBLEMS

EXAMPLE

Calculate the work done by the weight lifter in lifting the weights?



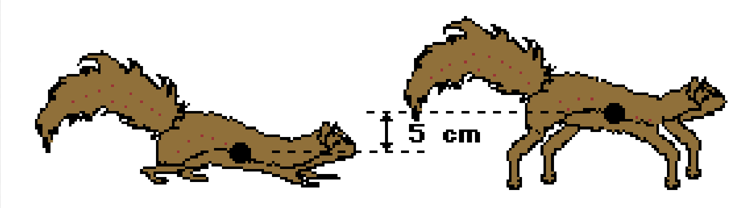
Solution:

$$E_p = \mathrm{F} \times s = \mathrm{mg}$$
$$= (\,25\mathrm{kg} + 25\ \mathrm{kg})\left(\frac{9.81\mathrm{m}}{s^2}\right)(2\mathrm{m})$$
$$= 981\ \mathrm{J}$$

4.1.5 APPLY THE CONCEPT AND FORMULA OF WORK, ENERGY AND POWER IN SOLVING THE RELATED PROBLEMS

EXAMPLE

A tired squirrel (mass of approximately 1 kg) does push-ups by applying a force to elevate its center-of-mass by 5 cm in order to do a mere 0.50 Joule of work. If the tired squirrel does all this work in 2 seconds, then determine its power.



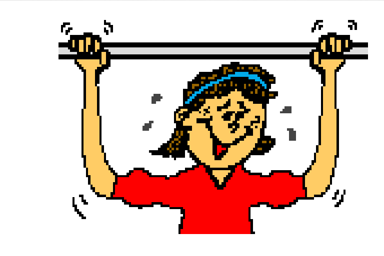
Solution :

$$P = \frac{W}{t} = \frac{0.50J}{2s} = 0.25\ W$$

4.1.5 APPLY THE CONCEPT AND FORMULA OF WORK, ENERGY AND POWER IN SOLVING THE RELATED PROBLEMS

EXAMPLE

When doing a *chin-up*, a physics student lifts her 42 kg body a distance of 0.25 meters in 2 seconds. What is the power delivered by the student's biceps ?



Solution :

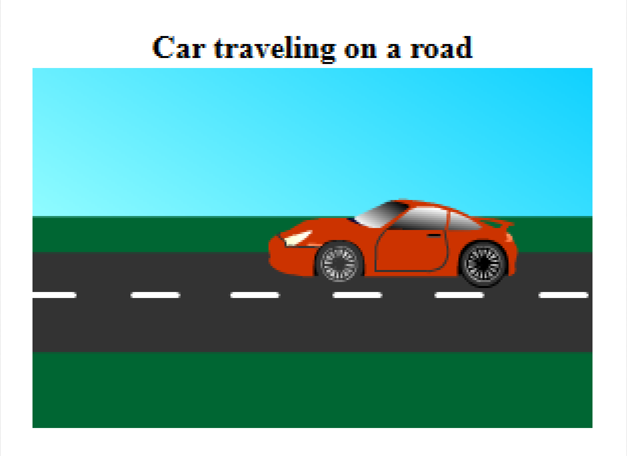
$$P = \frac{W}{t} = \frac{F \times s}{t} = \frac{(mg)s}{t} = \frac{(42)(\frac{9.81m}{s^2})(0.25m)}{2}$$

$$= \ 51.5\,W$$

4.1.5 APPLY THE CONCEPT AND FORMULA OF WORK, ENERGY AND POWER IN SOLVING THE RELATED PROBLEMS

EXAMPLE

A 300 kg car has a kinetic energy of 500 J. Find its speed.



Solution :

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

$$500\, J = \frac{1}{2}(300kg)v^2$$

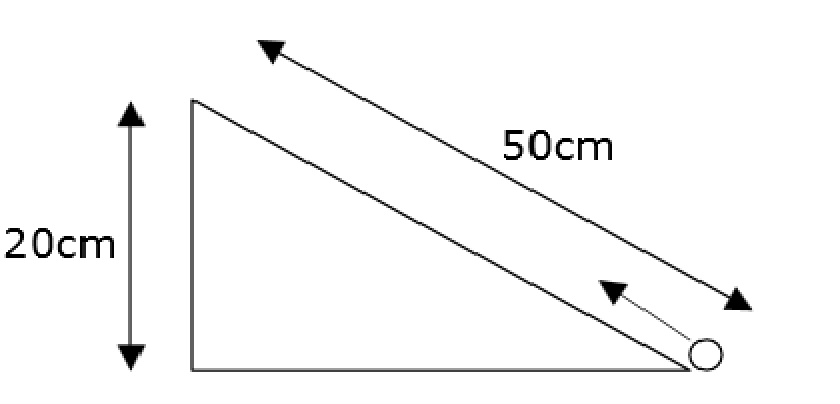
$$v^2 = \frac{500 \times 2}{300} = 3.33$$

$$v = \sqrt{3.33} = 1.83\, m/s$$

4.1.5 APPLY THE CONCEPT AND FORMULA OF WORK, ENERGY AND POWER IN SOLVING THE RELATED PROBLEMS

EXAMPLE

A 800g ball is pulled up a slope as shown in the diagram. Calculate the potential energy it gains



Solution :

$E_p = mgh$

$$= \left(\frac{800}{1000}\right)\left(\frac{9.81m}{s^2}\right)\left(\frac{20}{100}\right) = 1.5696 \text{ J}$$

Converts gram to kg

Converts cm to meter

4.1.6 CALCULATE THE EFFICIENCY OF MECHANICAL SYSTEM

- The efficiency of an engine or machine is defined as:

$$\text{Efficiency}, \eta = \frac{\text{Useful energy output (work done)}}{\text{energy input}} \times 100\%$$

$$= \frac{E_0}{E_{in}} \times 100\%$$

@

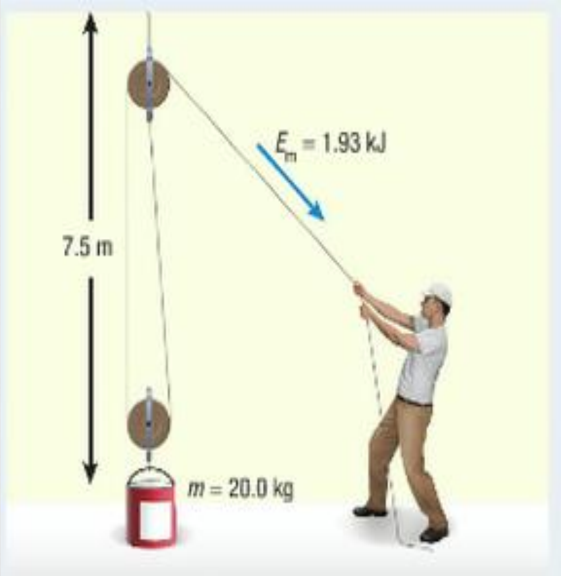
$$\text{Efficiency}, \eta = \frac{\text{Useful power}}{\text{power input}} \times 100\%$$

$$= \frac{P_0}{P_{in}} \times 100\%$$

4.1.6 CALCULATE THE EFFICIENCY OF MECHANICAL SYSTEM

EXAMPLE

Find the efficiency of a rope and pulley system if a painter uses 1.93kJ of mechanical energy to pull on the rope and lift a 20kg paint barrel at constant speed to a height of 7.5m above the ground?



Solution :

$$E_{in} = 1.93\ kJ = 1.93 \times 1000 = 1930\ J$$

$$E_o = mgh = 20 \times 9.81 \times 7.5 = 1471.5\ J$$

Efficiency = $\frac{E_o}{E_{in}} \times 100 = \frac{1471.5}{1930} \times 100 = 76.24\%$

4.1.6 CALCULATE THE EFFICIENCY OF MECHANICAL SYSTEM

EXAMPLE

A heat engine gives out 400 J of heat energy as the useful work. Calculate the energy given to it as input if its efficiency is 40%?

Solution :

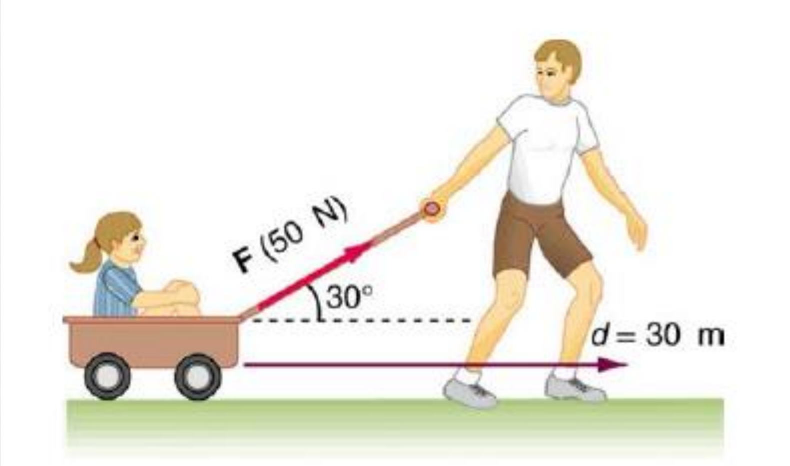
$$\text{Efficiency} = \frac{E_0}{E_{in}} \times 100\%$$

$$40\% = \frac{400J}{E_{in}} \times 100\%$$

$$E_{in} = \frac{400J}{40\%} \times 100\% = 1000\ J$$

EXERCISE

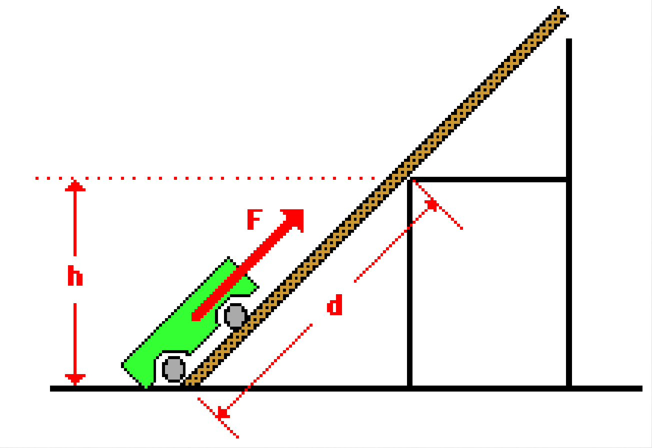
1) How much work is done by the boy pulling his sister 30.0 m in a wagon as shown in the above figure? Assume no friction acts on the wagon.



Answer = 1299.038 J

EXERCISE

2) A cart is loaded with a brick and pulled at constant speed along an inclined plane to the height of a seat-top. If the mass of the loaded cart is 3.0 kg and the height of the seat top is 0.45 meters, then what is the potential energy of the loaded cart at the height of the seat-top?



Answer : E_p = 13.2 J

EXERCISE

3) Determine the kinetic energy of a 625-kg roller coaster car that is moving with a speed of 18.3 m/s.

Answer : E_k = 1.05 x10^5 Joules

REFERENCE

- Keat,Y.E .(1996). Sukses Lengkap SPM fizik. Petaling Jaya: Pustaka Delta Pelajaran Sdn Bhd.
- S.L Chang, K.K.(2011). Focus SPM Physics. Bangi: Penerbitan Pelangi Sdn Bhd.