

TOPIC

7

Energy, Work and Power

Objectives

Candidates should be able to:

- (a) show understanding that kinetic energy, potential energy (chemical, gravitational, elastic), light energy, thermal energy, electrical energy and nuclear energy are examples of different forms of energy
- (b) state the principle of conservation of energy and apply the principle to new situations or to solve related problems
- (c) calculate the efficiency of an energy conversion using the formula $\text{efficiency} = \frac{\text{energy converted to useful output}}{\text{total energy input}}$
- (d) state that kinetic energy $E_k = \frac{1}{2}mv^2$ and gravitational potential energy $E_p = mgh$ (for potential energy changes near the Earth's surface)
- (e) apply the relationships for kinetic energy and potential energy to new situations or to solve related problems
- (f) recall and apply the relationship $\text{work done} = \text{force} \times \text{distance moved in the direction of the force}$ to new situations or to solve related problems
- (g) recall and apply the relationship $\text{power} = \frac{\text{work done}}{\text{time taken}}$ to new situations or to solve related problems

NOTES.....

7.1 Energy

1. Different forms: kinetic energy (*KE*), elastic potential energy, gravitational potential energy (*GPE*), chemical potential energy, thermal energy.
2. SI unit: Joule (J)
3. Principle of Conservation of Energy: The total energy in a system remains constant and cannot be created or destroyed. It can only be converted from one form to another without any loss in the total energy.

7.2 Gravitational Potential Energy (GPE) and Kinetic Energy (KE)

1. Take the surface of the Earth to be the reference level ($GPE = 0$).

GPE of an object of mass m at height h above surface:

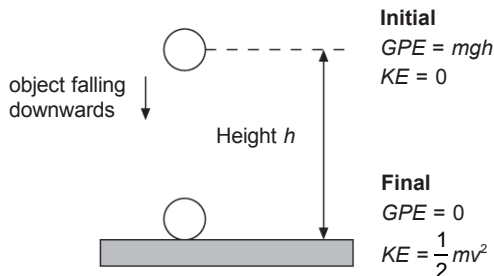
$$GPE = mgh$$

2. KE of a moving object of mass m , with a velocity v is

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

Example 7.1

For a free-falling object of mass m , its gravitational potential energy is converted into kinetic energy. Take ground level as reference level ($GPE = 0$).



Apply the Principle of Conservation of Energy and assuming there is no air resistance:

Total energy at height h = Total energy at ground level

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

Velocity of object, $v = \sqrt{2gh}$

Note: The total energy of the object is constant throughout its fall, not just at the two positions used in the above calculation.

($GPE + KE = \text{Total energy} = \text{Constant}$)

7.3 Work

1. Energy is required for an object to do work.
2. Defined as the product of applied force (F) and the distance moved (s) in the direction of the force.

$$W = Fs$$

Unit: J

3. No work is done if the applied force F does not displace the object along the direction of the force.

7.4 Power

1. Defined as the rate of work done.

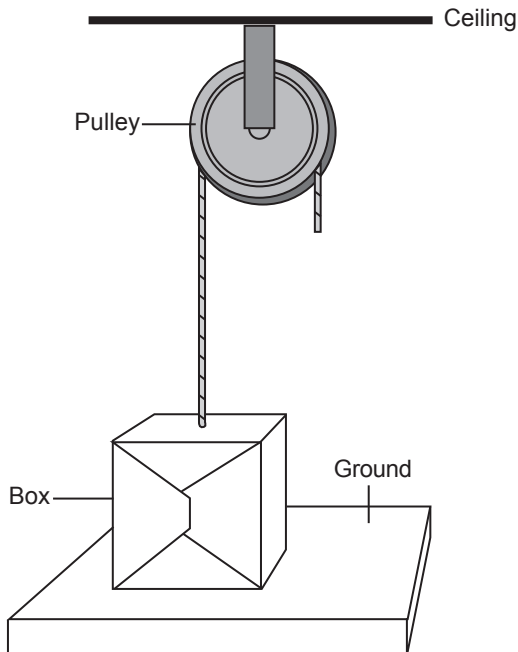
$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

2. SI unit: Watt (W) or J s^{-1}
3. Efficiency of an energy/ power conversion:

$$\begin{aligned}\text{Energy} &= \frac{\text{Energy converted into useful output}}{\text{Total energy output}} \times 100\% \\ &= \frac{\text{Useful power output}}{\text{Total power output}} \times 100\%\end{aligned}$$

Example 7.2

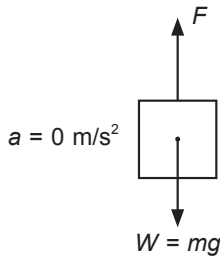
A box with a mass of 30 kg can be lifted by a light rope threaded through a smooth pulley.



- (a) If the box is lifted at a constant speed from the ground to a height of 2.0 m in 4.0 s, what is the power required?
- (b) If the box is lifted with a constant acceleration of 1.5 m/s^2 from rest to a height of 3.0 m above the floor, what is the power required?
- Take g , the gravitational field strength as 10 N/kg .

Solution

- (a) Draw a free body diagram of the box and identify all the forces acting on it.



- F – Applied force
 W – Weight of the box
 R – Resultant force on the box
 s – Displacement of the box from the ground

Take forces acting upwards to be positive.

Using Newton's 2nd Law,

$$F - mg = 0$$

$$\therefore F = mg$$

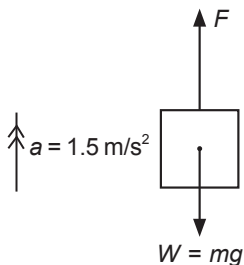
$$= (30)(10)$$

$$= 300 \text{ N}$$

Power required = rate of work done

$$\begin{aligned} &= \frac{Fs}{t} \\ &= \frac{300 \times 2.0}{4.0} \\ &= 150 \text{ W} \end{aligned}$$

(b)



F – Applied force

W – Weight of the box

R – Resultant force on the box

Take forces acting upwards to be positive.

Using Newton's 2nd Law,

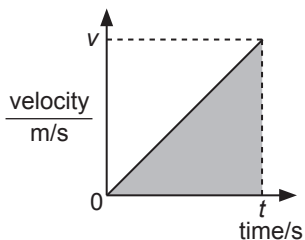
$$F - mg = ma$$

$$F - 300 = 30 \times 1.5$$

$$F = 45 + 300$$

$$F = 345 \text{ N}$$

Sketch the speed-time graph of the box to obtain the time taken for the box to move to a height of 3.0 m above the ground.



t – time required for the box to reach a height of 3.0 m.

v – final velocity of the box

From the graph, we can obtain the velocity (gradient of graph) and the total displacement of the box.

Gradient of velocity-time graph,

$$a = \frac{v - u}{t} = \frac{v - 0}{t}$$

$$1.5 = \frac{v}{t}$$

$$v = 1.5t \text{ ----- (1)}$$

Area under the graph (shaded) = Displacement s of box from the ground

$$s = \frac{1}{2} \times \text{Base} \times \text{Height} = \frac{1}{2} \times t \times v$$

$$s = \frac{1}{2} vt$$

$$\frac{1}{2} vt = 3.0 \text{ ----- (2)}$$

Substitute (1) into (2):

$$\frac{1}{2} (1.5t)t = 3.0$$

$$\frac{3}{4} t^2 = 3.0$$

$$t^2 = 4.0$$

$$(t - 2.0)(t + 2.0) = 0$$

$$t = 2.0 \text{ s (since } t > 0)$$

$$\text{Power required} = \frac{345 \times 3.0}{2.0}$$

$$= 518 \text{ W (to 3 s.f.)}$$