Work done , Energy and Power

WORK, ENERGY AND POWER

WORK

Work (W) is the product force (F) acting on an object and the displacement (Δx) in the direction of the force. Work is a scalar.

SI unit: joule (J) 1 J = 1 N m

Formulae: $W = F\Delta x\cos\theta$

When does a force do work on an object?

- A force must be in a direction, which is parallel to the direction of displacement.

ENERGY

Energy (E) is the ability to do work (W).

Potential energy (E_P) is the energy of an object due to its position in a gravitational field.

Kinetic energy (E_K) is the energy of an object due to its motion.

The mechanical energy (M_E) of an object is the sum of its potential and kinetic energy.

POWER

Power (P) is the rate at which work is done.

Power is a scalar quanity.

$P = \frac{W}{\Delta t}$ $\boldsymbol{P} = \frac{E}{\Delta t}$

$\boldsymbol{P = Fv}$ (where v is constant)

SI Unit: Watt ***(W)***

Work is NOT done on an object by a force, when:

- No force is applied.
- The object is not displaced.
- The force and the displacement are perpendicular to each other.

Energy is a scalar quantity.

$E_P = m.g.h \quad E_K = \frac{1}{2}mv^2 \quad M_E = E_K + E_P$

SI unit: Joule **(J)**

The law of conservation of mechanical energy states that total mechanical energy of a =n isolated system is conserved (remains constant).

Thus, between any two points (A and B) in an isolated system, mechanical energy is equal.

$M_{E(A)} = M_{E(B)} \quad (E_K + E_P)_A = (E_K + E_P)_B$

***1 W = 1 J.s**$^{-1}$*

A Watt of power is when a joule of work is done per second.

OR

When a joule of energy is transferred per second.

Practical units in technology

1 ***kW*** = 1000 ***W***

1 ***hp*** = 746 ***W***

Work is defined as the product of the force acting on an object and the displacement in the direction of the force.
Force ***(F)*** and displacement ***(Δx)*** are both vector quantities; thus, work is a scalar quantity.

For work done:

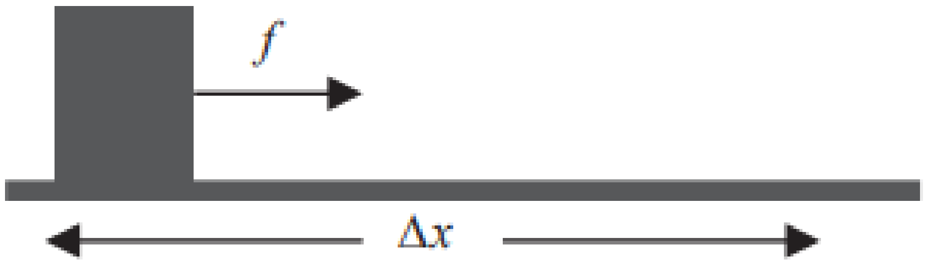
$$\boldsymbol{W = F\Delta x\cos\theta}$$

SI units of measurement
Work is measured in joules.
Force (F) is measured in Newtons (N).
Displacement (Δx) is measured in metres (m).

$$\boldsymbol{1\ J = 1\ N\cdot m}$$

When is work done on an object?

- The force doing work on the object and the displacement can be in the same direction: ***θ = 0º***. This is positive work.

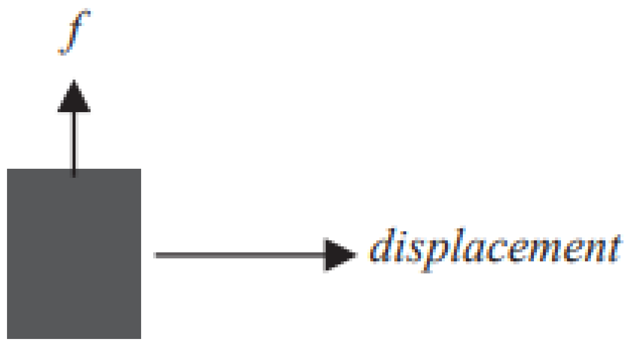


Force ***(F)*** and the displacement ***(Δx)*** of the object have the same direction

- The force doing the work and the displacement are in opposite directions, $\theta = 180^o$. Then the force (F) is doing negative work.

Force ***(F)*** and the displacement ***(Δx)*** of the object are in opposite directions.

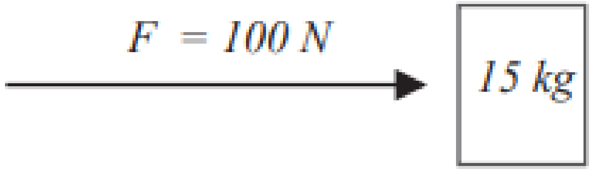
- If the force is perpendicular to direction of the displacement, NO work is done on the object by the force: $\theta = 90^o$.



Force ***(F)*** and the displacement ***(Δx)*** of the object are perpendicular.

Example
Work done by a force in the direction parallel to that of displacement of the object.

A constant force F of magnitude 100 N acts on a block of mass 15kg that is resting on a surface. A constant frictional force of 20 N acts on the block and the block moves a distance of 80cm.



Calculate:

a. The work done on the block by force F.

Solution

$W = F\Delta x\cos\theta$

$W = 100(0,8)\cos 0^{\circ}$

$W = 80$ J (Force F does work in the direction of displacement)

b. The work done on the block by frictional force.

Solution

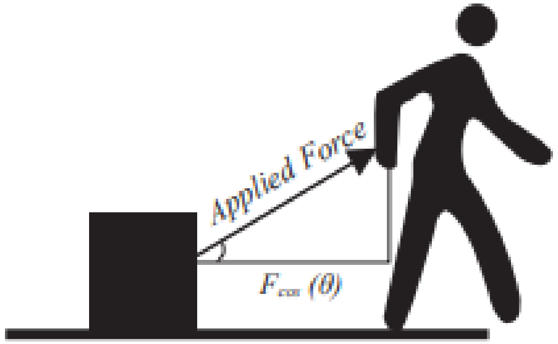
$W = f\Delta x\cos\theta$

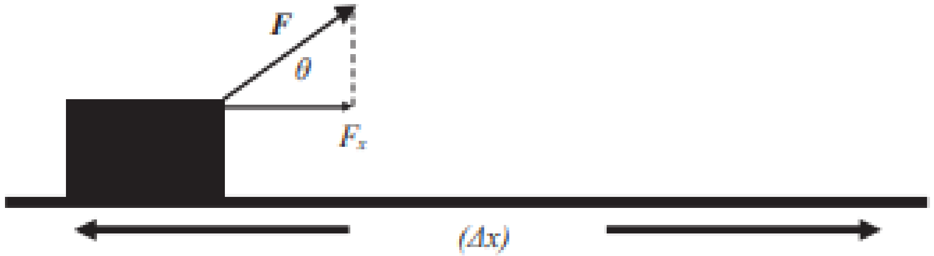
$W = 20(0,8)\cos 180^{\circ}$

$W = -16$ J (Frictional force does work in the opposite direction of displacement.)

Work done on an object by a force acting at an angle to the horizontal

Consider the following situation…





From trigonometrical ratios:
$F_x = FA\cos\theta$
$F_y = FA\sin\theta$

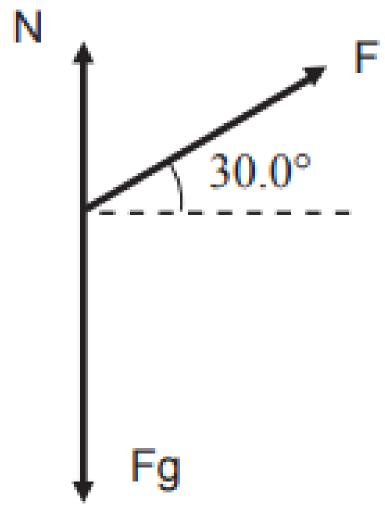
Note that in the above case, the horizontal component is actually doing work, thus work done on the object:
$W = F_x\Delta x\cos\theta$

Example

A man cleaning a frictionless floor pulls a vacuum cleaner with a force F of magnitude 50 N at an angle of 30° with the horizontal.

a. Draw a labelled free body diagram showing all the forces that act on the vacuum cleaner.

Solution



b. What is the magnitude of the work done by the weight of the vacuum cleaner? Explain briefly.

Solution

0 J – the weight is acting perpendicular to the displacement of the vacuum cleaner; therefore, no work is done.

c. Calculate the work done by the force F on the vacuum cleaner as the vacuum cleaner is displaced 3 m to the right.

Solution

$W = F\Delta x\cos\theta$

$W = (50)(3,0) \cos 300$

$W = 129,9$ J

5.3 ENERGY

5.3.1 Mechanical Energy

Definitions

Energy is the capacity to do work.

In order for work to be done, energy must be transferred from one form to another.

Energy is a scalar quantity.

SI unit: joule (J)

When work is done on a system, energy is transferred to the system. The two types of energy that we focus on are: gravitational potential energy and kinetic energy.

The mechanical energy of an object is the sum of its potential and kinetic energy.

Thus $M_E = mgh + \frac{1}{2}mv^2$

Example

A technician at a construction site accidentally drops a concrete block with a mass of 8kg from a scaffold, which is 10m above the ground. Ignore the effects of air resistance.

a) Calculate the mechanical energy of the block.

Solution

When the block drops, it starts from rest, that is, its speed is 0m/s; therefore, its kinetic energy just before it falls, is zero:

$$ME = mgh + \tfrac{1}{2}mv^2$$
$$ME = 8(9{,}8)10 + 0$$
$$ME = 784\ J$$

b) Calculate how much gravitational potential energy the block possesses when it is has fallen half the distance.

Solution

$$E_p = mgh$$
$$E_p = 8(9{,}8)5$$
$$E_p = 392\ J$$

c) Calculate the speed of the block when it reaches the ground.

Solution

$$M_{E(top)} = M_{E(bottom)}$$
$$784 = mgh + \tfrac{1}{2}mv^2$$
$$784 = 0 + \tfrac{1}{2}(8)v^2$$
$$v = 14 m{\bullet}s^{-1}$$

5.4 POWER

Power is the rate at which work is done.

$$P = \frac{W}{\Delta t} \qquad P = \frac{\Delta E}{\Delta t}$$

SI unit of power is the watt **(W).**

Necessary conversions of units must be done when doing calculations:

- Work or energy must be in joules (J).
- Time must be in seconds (s).

1 watt = 1 J.s^{-1}

Practical units of power in technology are:

1**kW** = 1000 **W**
1 horsepower **(hp)** = 726 **W**

Because work is energy transfer, power is also the **rate at which energy is expended.**

A 100-W light bulb, for example, expends 60J of energy per second.

Great power means a large amount of work or energy is developed in a short time. For example, when a powerful car accelerates rapidly, it does a large amount of work and consumes a large amount of fuel in a short time.

Example

1 If a motor is rated at 5.60kW, how much work can it do in 20 minutes?

2. A tow-truck is pulling a trailer up a steep hill. If it has a 5hp engine, how much work does the truck do in a minute?

Solution

1.

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

$$5{,}6 \times 1000 = \frac{W}{20 \text{x} 60}$$

$$W = 6720 \text{ kJ}$$

2.

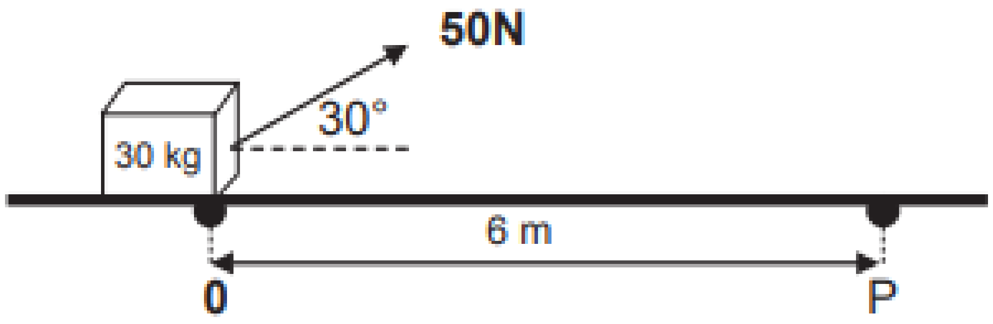
$$P = \frac{W}{\Delta t}$$

$$5 \times 746 = \frac{W}{60}$$

$$W = 223{,}8 \text{ kJ}$$

Exercises

A worker pulls a crate with a mass of 30kg from rest along a horizontal floor, by applying a constant force of magnitude 50 N at an angle of 30° to the horizontal. A frictional force of



magnitude 20 N acts on the crate whilst it is moving along the floor.

6.1 Define the term work.

6.2 Draw a labelled force diagram that shows all the forces that act on the block.

6.3 Calculate the:

- 6.3.1 magnitude of the horizontal component of the applied force.
- 6.3.2 work done by the horizontal component of the applied force.
- 6.3.3 work done due to the frictional force acting on the box.