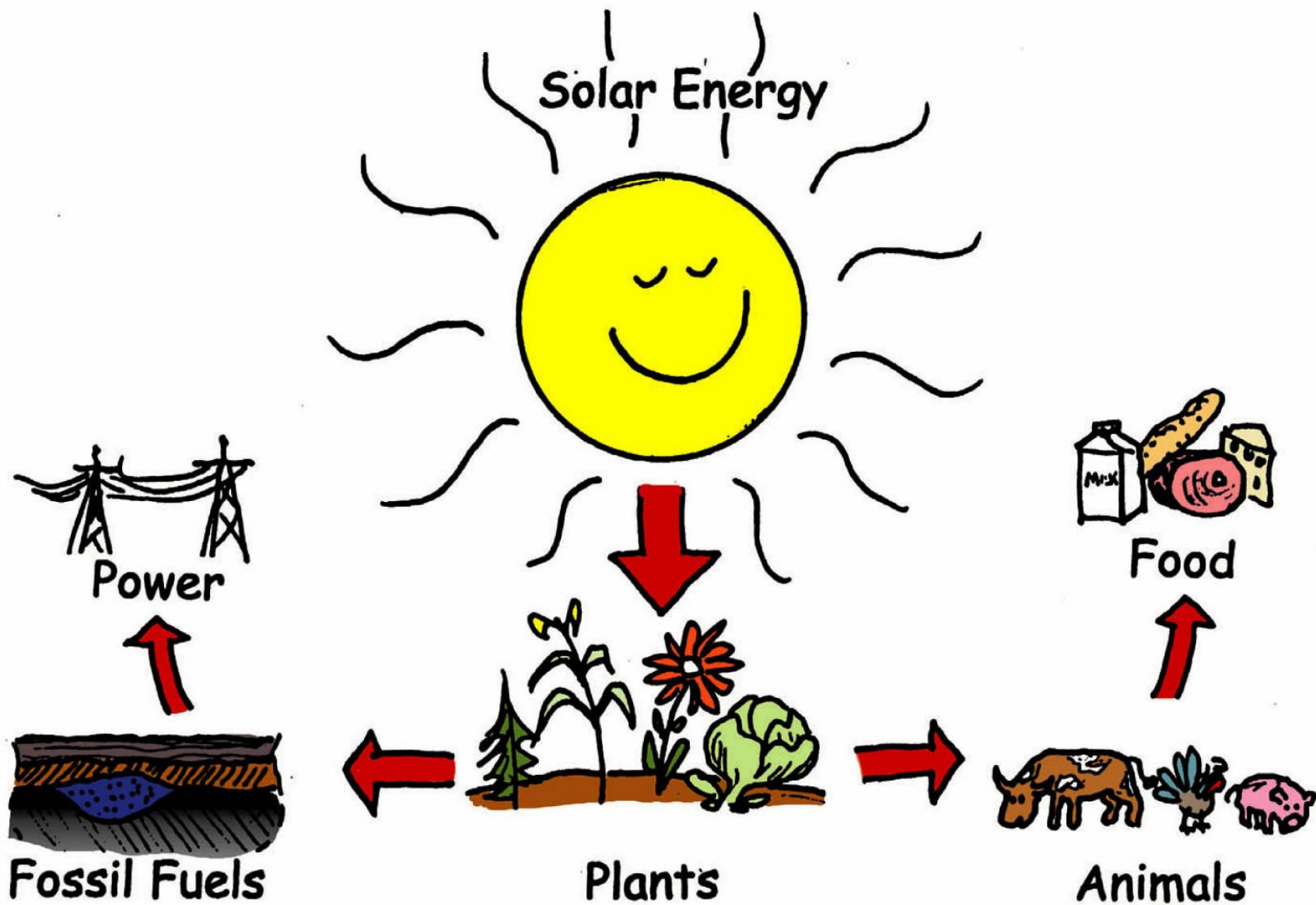


# Energy

Physics Year 11 Term 1 Week 7

# Energy

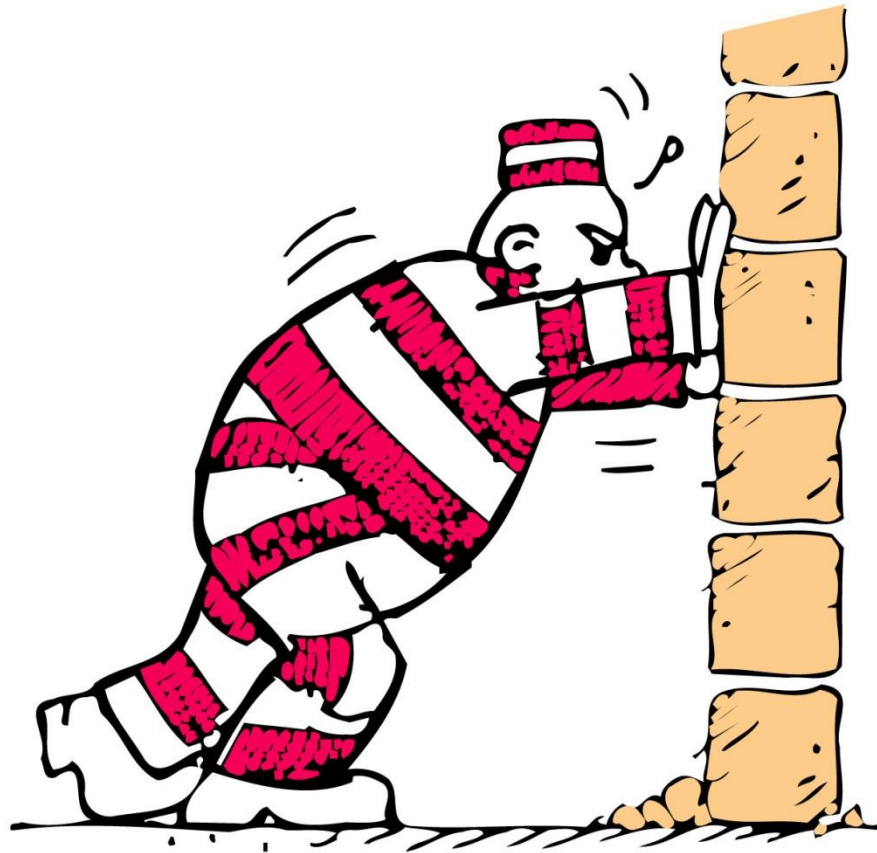
- According to Einstein, a counterpart to mass
- An enormously important but abstract concept
- Energy can be stored (coal, oil, a watch spring)
- Energy is something moving objects have



# Work

- Easiest to start with the notion of work
- $Work = Force \times Distance$
- Lift a box from the floor, you apply a force to overcome gravity
- Multiply that force by the distance through which you apply the force and you calculate the amount of work accomplished

# Is this Work?



# Work

- Unit is the JOULE
- A Joule is a newton-metre
- When the kinetic energy of an object changes, *work* has been done on the object.
- Work is a *scalar* quantity.

- the energy required to lift a small apple one metre straight up.
- the energy released when that same apple falls one metre to the ground.
- the energy delivered by a 1 watt solar panel every second.
- the kinetic energy of a tennis ball moving at 23 km/h

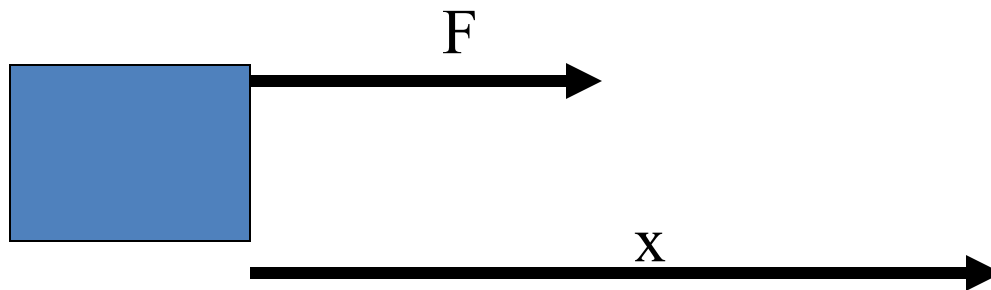
# Work

- Work depends on:
  - The **amount** of force applied to the object.
  - The **distance** that the object moves while the force is applied.
  - The **direction** of the force with respect to the direction the object moves.

# Work

- If the force on the object is in the direction the object moves, the work done is:

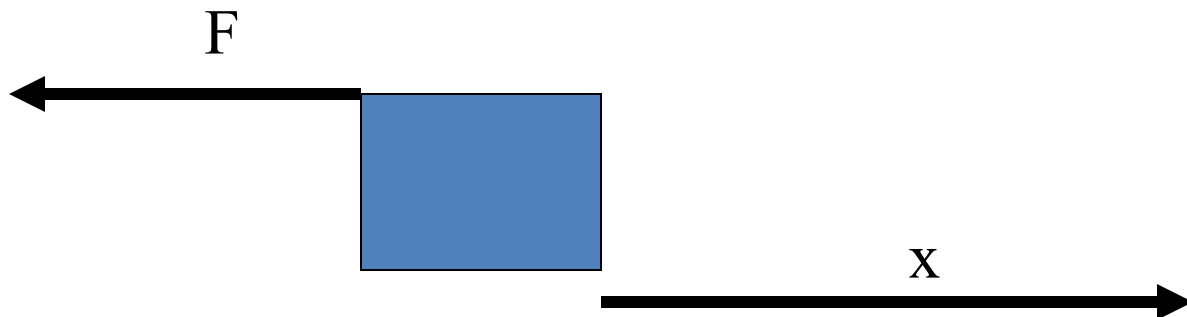
$$W = Fx$$



# Work

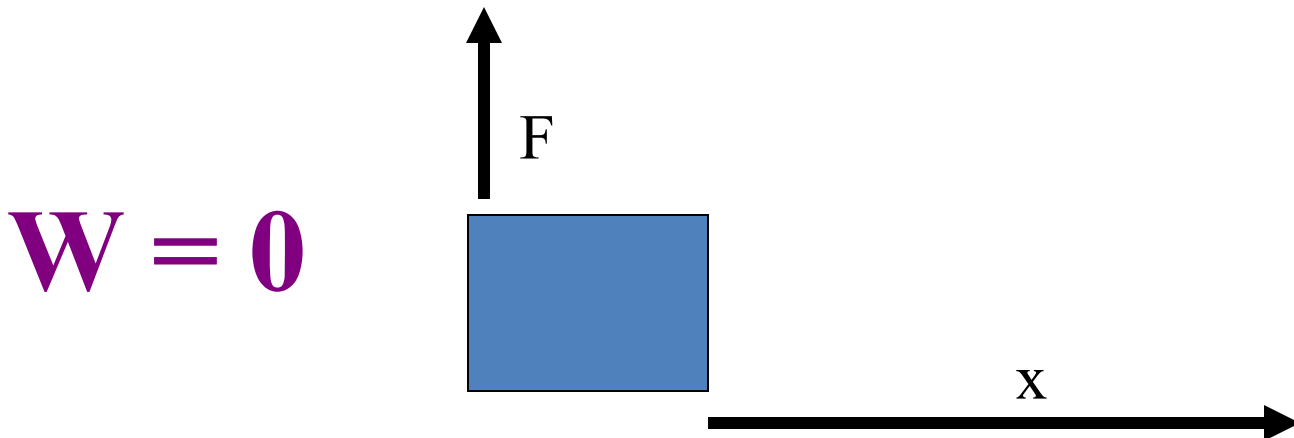
- If the direction of the force is *opposite* the direction the object moves, work is:

$$W = -Fx$$



# Force is *NOT* Work

- If the force is *perpendicular* to the direction the object moves, the work done is *0*.
- If the object *doesn't move*, the work done is *0*.



# Kinetic Energy

- If an object is *moving*, it has *energy*. (Be careful, the converse of this statement is *not* always true!)
- This energy is called *kinetic energy* - the *energy of motion*.

# Kinetic Energy

- An object's *kinetic energy* depends on:
- the object's *mass*.
  - Kinetic energy is *directly proportional* to mass.
- the object's *speed*.
  - Kinetic energy is *directly proportional* to the *square* of the object's speed.

# Kinetic Energy

- In symbols:

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

# Kinetic Energy

- Kinetic energy is a *scalar* quantity.
- Common units of kinetic energy: *Joules*
  - An object with mass of 1 kg, moving at 1 m/s, has a kinetic energy of 0.5 Joule.

# Work and Kinetic Energy

- The work done on an object by the *net* force equals the object's *change* in kinetic energy.

$$W_{net} = \Delta KE$$

# Potential Energy

- Sometimes work is *not* converted directly into kinetic energy. Instead it is “stored”, or “hidden”.
- *Potential energy* is *stored energy* or *stored work*.
- *Potential energy* is energy that an object (system) has due to its *position* or *arrangement*

# Potential Energy

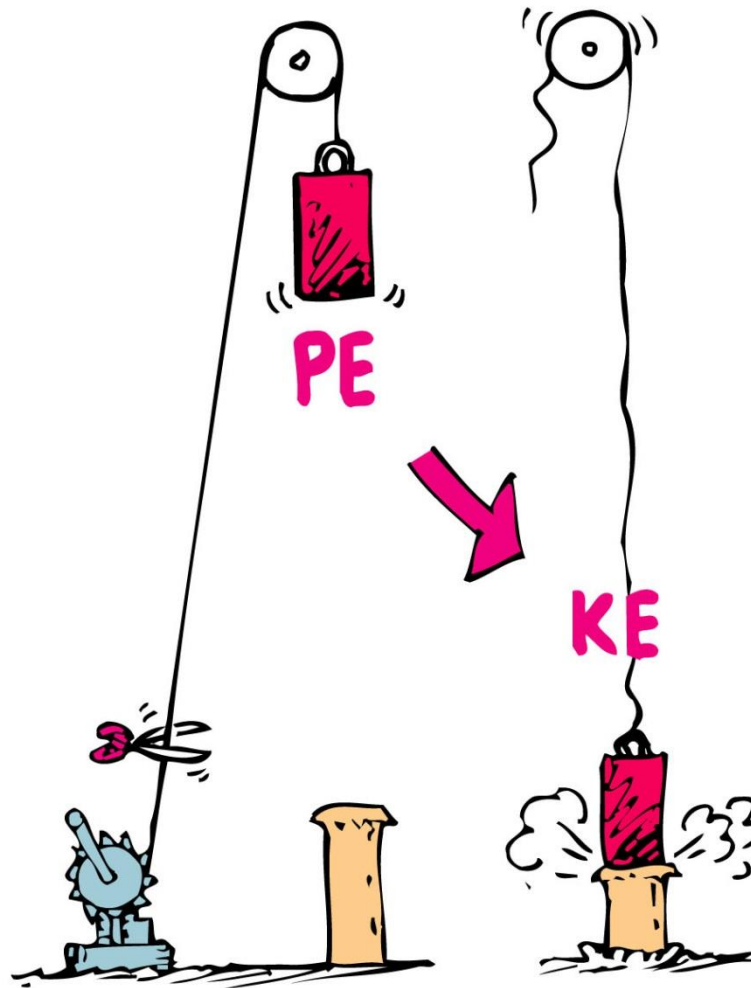
- If we lift an object from the floor into the air, it has the potential to do work for us
- This ability to do work is called POTENTIAL ENERGY
- Other forms of potential energy include the compression of a spring, the stored energy in coal or oil, the stored energy in a uranium nucleus

# Potential Energy

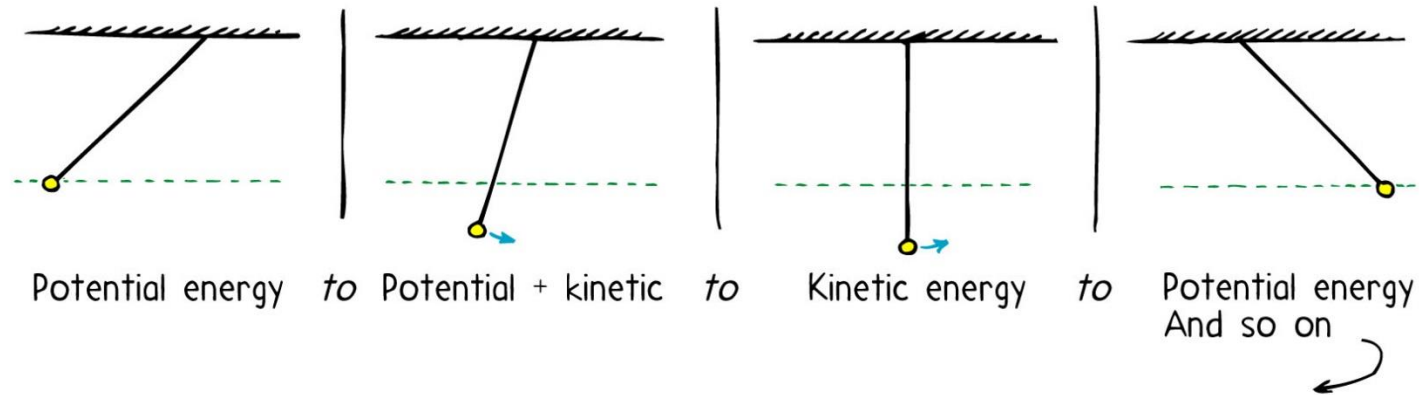
- Gravitational potential energy is simple to calculate
- Gravitational Potential Energy = weight X height

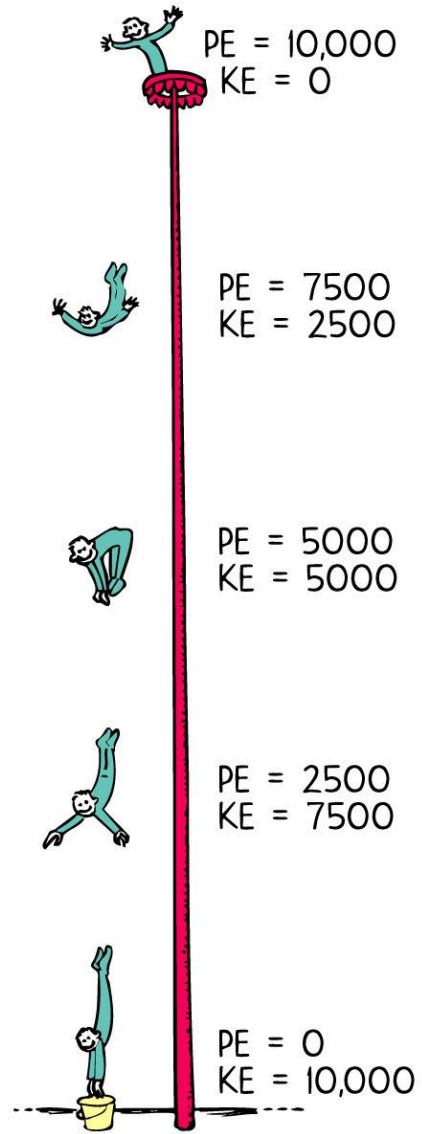
$$PE = mgh$$

# Energy Conversion



# Energy Conversion





# Mechanical Energy

- *Mechanical Energy* = PE + KE

# Worked Example 1

*Calculate the work done when a force of 5 kN moves through a distance of 30 cm*

$$\text{work} = \text{force} \times \text{distance}$$

$$= 5 \text{ kN} \times 30 \text{ cm}$$

$$= 5000 \text{ N} \times 0.30 \text{ m}$$

$$\text{work} = 1500 \text{ J}$$

# Worked Example 2

*Calculate the work done by a child of weight 300N who climbs up a set of stairs consisting of 12 steps each of height 20cm.*

***work = force x distance***

the child must exert an upward force equal to its weight

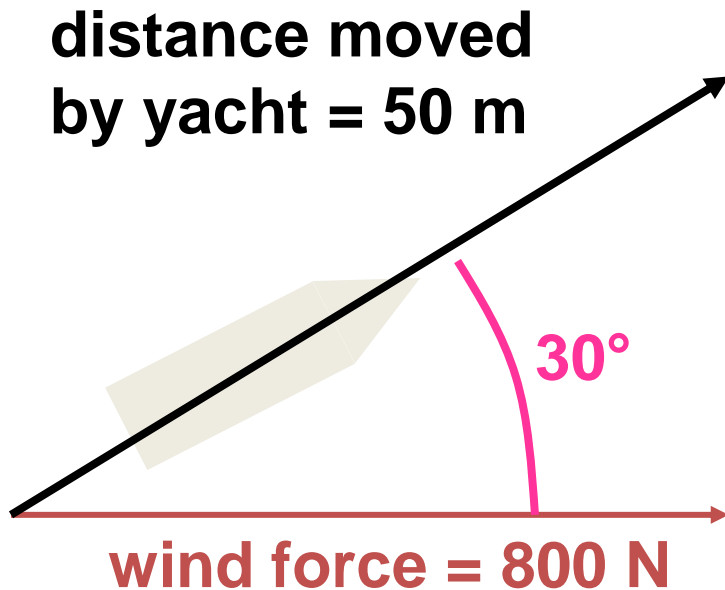
the distance moved upwards equals  $(12 \times 20\text{cm}) = 2.4\text{m}$

work = 300 N x 2.4 m

**work = 720 J**

# Worked Example 3

Calculate the work done by the wind on the yacht in the situation shown below:



$$W = F s \cos \theta$$

$$= 800 \text{ N} \times 50 \text{ m} \times \cos 30^\circ$$

$$= 40\,000 \times \cos 30^\circ$$

$$= 40\,000 \times 0.8660$$

$$\text{work} = 34\,600 \text{ J}$$

# Worked Example 4

*Calculate the kinetic energy of a car of mass 800 kg moving at 6 ms<sup>-1</sup>*

$$E_K = \frac{1}{2} m v^2$$

$$= \frac{1}{2} \times 800\text{kg} \times (6\text{ms}^{-1})^2$$

$$= \frac{1}{2} \times 800 \times 36$$

$$= 400 \times 36$$

$$\text{kinetic energy} = 14\,400 \text{ J}$$

# Worked Example 5

*Calculate the speed of a car of mass 1200kg if its kinetic energy is 15 000J*

$$E_K = \frac{1}{2} m v^2$$

$$15\,000\text{J} = \frac{1}{2} \times 1200\text{kg} \times v^2$$

$$15\,000 = 600 \times v^2$$

$$15\,000 \div 600 = v^2$$

$$25 = v^2$$

$$v = \sqrt{25}$$

$$\text{speed} = 5.0 \text{ ms}^{-1}$$

# Worked Example 6

*Calculate the braking distance a car of mass 900 kg travelling at an initial speed of 20 ms<sup>-1</sup> if its brakes exert a constant force of 3 kN.*

$$\begin{aligned} \text{k.e. of car} &= \frac{1}{2} m v^2 \\ &= \frac{1}{2} \times 900 \text{kg} \times (20 \text{ms}^{-1})^2 \\ &= \frac{1}{2} \times 900 \times 400 \\ &= 450 \times 400 \\ \text{k.e.} &= 180\,000 \text{ J} \end{aligned}$$

The work done by the brakes will be equal to this kinetic energy.

$$W = F s$$

$$180\,000 \text{ J} = 3 \text{ kN} \times s$$

$$180\,000 = 3000 \times s$$

$$s = 180\,000 / 3000$$

$$\text{braking distance} = 60 \text{ m}$$

## Worked Example 7

*Calculate the change in g.p.e. when a mass of 200 g is lifted upwards by 30 cm.*

*( $g = 9.8 \text{ Nkg}^{-1}$ )*

$$\Delta E_p = m g \Delta h$$

$$= 200 \text{ g} \times 9.8 \text{ Nkg}^{-1} \times 30 \text{ cm}$$

$$= 0.200 \text{ kg} \times 9.8 \text{ Nkg}^{-1} \times 0.30 \text{ m}$$

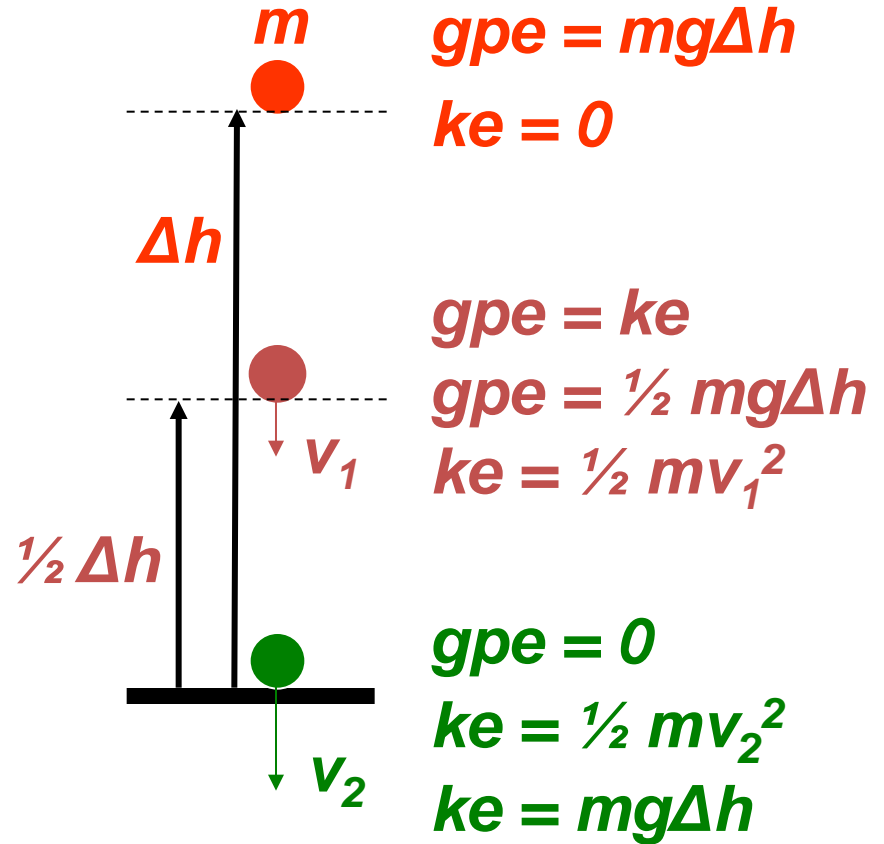
$$\text{change in g.p.e.} = 0.59 \text{ J}$$

# Falling objects

If there is no significant air resistance then the initial gravitational energy of an object is transferred into kinetic energy.

$$\Delta E_K = \Delta E_P$$

$$\frac{1}{2} m v^2 = m g \Delta h$$



# Worked Example 8

*A child of mass 40 kg climbs up a wall of height 2.0 m and then steps off. Assuming no significant air resistance calculate the maximum:*

*(a) gpe of the child*

*(b) speed of the child*

$$g = 9.8 \text{ Nkg}^{-1}$$

(a) max gpe occurs when the child is on the wall

$$gpe = mg\Delta h$$

$$= 40 \times 9.8 \times 2.0$$

$$\text{max gpe} = 784 \text{ J}$$

(b) max speed occurs when the child reaches the ground

$$\frac{1}{2} m v^2 = m g \Delta h$$

$$\frac{1}{2} m v^2 = 784 \text{ J}$$

$$v^2 = (2 \times 784) / 40$$

$$v^2 = 39.2$$

$$v = \sqrt{39.2}$$

$$\text{max speed} = 6.3 \text{ ms}^{-1}$$

# Work Examples

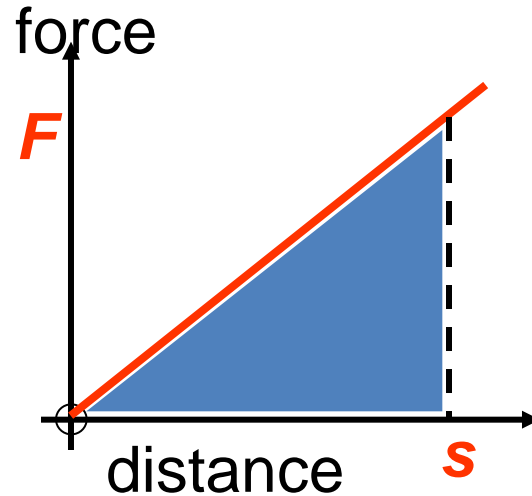
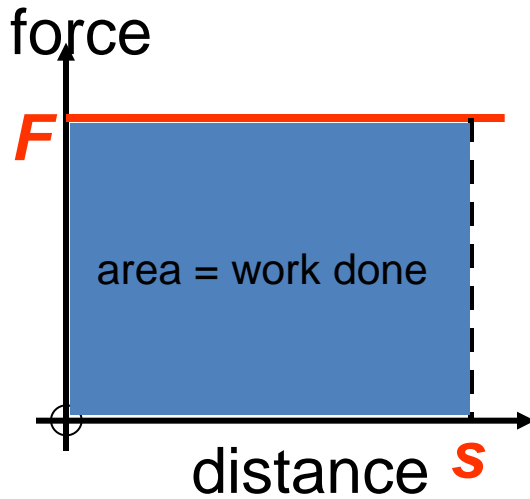
- How much work does it take to lift a 30 kg suitcase onto the table, 1 metre high?

$$W = (30 \text{ kg}) \times (9.8 \text{ m/s}^2) \times (1 \text{ m}) = 294 \text{ J}$$

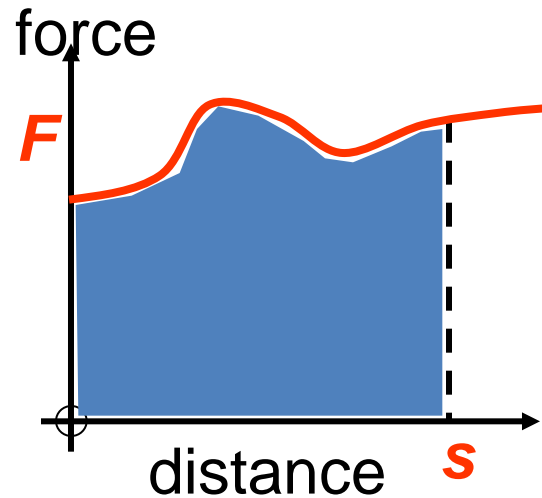
- Unit of work (energy) is the N·m, or Joule (J)
  - One Joule is 0.239 calories, or 0.000239 Calories (food)
- Pushing a crate 10 m across a floor with a force of 250 N requires 2,500 J (2.5 kJ) of work
- Gravity does 20 J of work on a 1 kg (10 N) book that it has pulled off a 2 metre shelf

# Force-distance graphs

The area under the curve is equal to the work done.



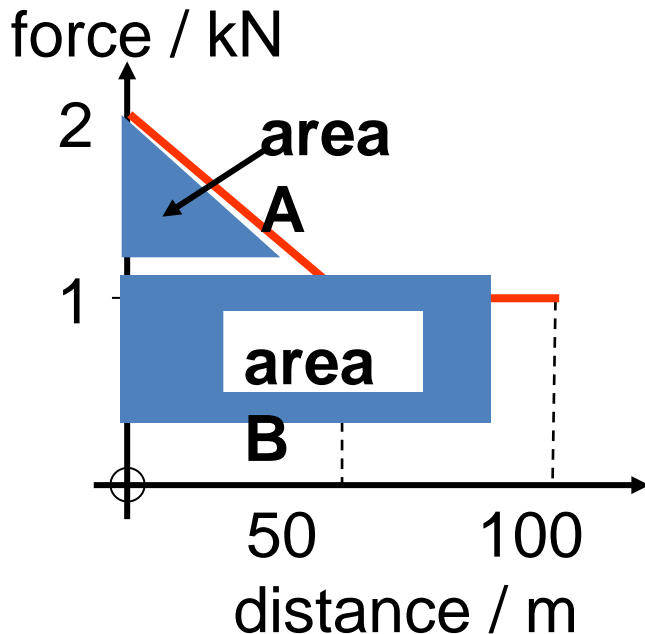
$$\begin{aligned} \text{area} &= \text{work} \\ &= \frac{1}{2} F s \end{aligned}$$



area = work  
found by counting squares on the graph

# Question

Calculate the work done by the brakes of a car if the force exerted by the brakes varies over the car's braking distance of 100 m as shown in the graph below.



**Work = area under graph**

$$= \text{area A} + \text{area B}$$

$$= \left(\frac{1}{2} \times 1\text{k} \times 50\right) + (1\text{k} \times 100)$$

$$= (25\text{k}) + (100\text{k})$$

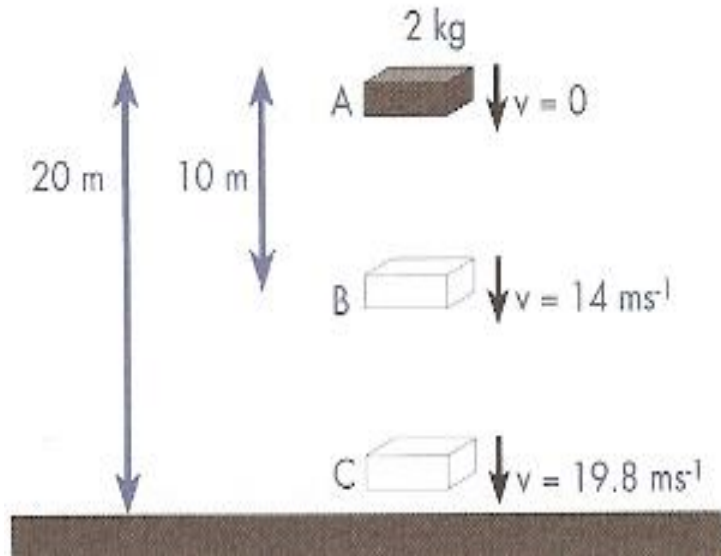
**work = 125 kJ**

# Conservation of Energy

- Perhaps the most important discovery of the past two centuries
- *In the absence of external work input or output, the energy of a system remains unchanged. Energy cannot be created or destroyed.*
- Remember from Einstein, that mass is a form of energy

$$E=mc^2$$

# Conservation of Energy Example



At position A:  $E_p = 392 \text{ J}$ ,  $E_k = 0$ ,  $E_T = 392 \text{ J}$

At position B:  $E_p = 196 \text{ J}$ ,  $E_k = 196 \text{ J}$ ,  $E_T = 392 \text{ J}$

At position C:  $E_p = 0$ ,  $E_k = 392 \text{ J}$ ,  $E_T = 392 \text{ J}$

# Conservative Forces

- Energy or work is stored when a force does work “against” a force such as the *gravitational force* or a Hooke’s Law (spring) force.
- Forces that store or hide energy are called *conservative forces*.

# Power



- Power is simply energy exchanged per unit time, or how fast you get work done (Watts = Joules/sec)
- One horsepower = 745 W
- Perform 100 J of work in 1 s, and call it 100 W
- Run upstairs, raising your 70 kg (700 N) mass 3 m (2,100 J) in 3 seconds → 700 W output!
- Shuttle puts out a few GW (gigawatts, or  $10^9$  W) of power!

# Power

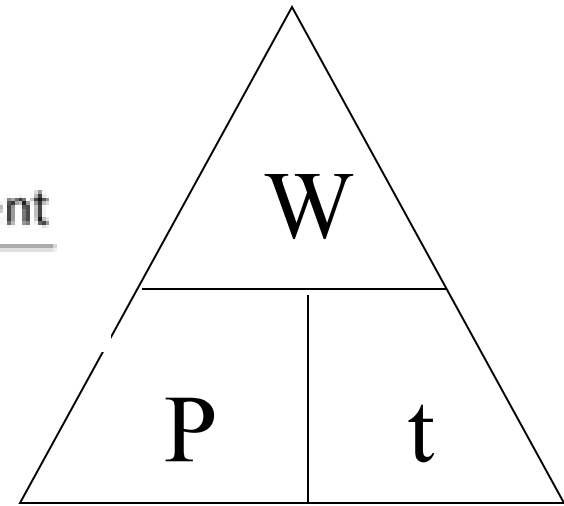
- Power is the rate work is done.

$$\text{Power} = \frac{\Delta \text{Work}}{\text{time}}$$

Deduce further:

$$\text{Power, } P = \frac{\text{work done}}{\text{time taken}} = \frac{\text{force} \times \text{displacement}}{\text{time taken}}$$

$$= \text{force} \times \frac{\text{displacement}}{\text{time taken}} = \text{force (F)} \times \text{velocity (v)}$$



$\therefore$  Power can also be defined by:

$$P = Fv$$

# Power

- Units of power:  $1 \text{ Joule/sec} = 1 \text{ *Watt*}$
- $1000 \text{ Watts} = 1 \text{ *kilowatt*}$
- Power is a *scalar* quantity.
- The work done every second
- The rate at which work is done or the rate at which E is consumed

# Power

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

also  $P = \frac{F \cdot s}{t} = F v_{av}$

P = power ( $\text{Js}^{-1}$  or Watts)

W = work (J)

$\Delta E$  = change in energy

t = time (s)

F = force (N)

$v_{av}$  = average velocity

# Power Example 1

- Mark (50kg) climbs stairs of vertical height 7m in 9s.
- Lifting force = weight:  $=mg=50 \times 10=500\text{N}$
- Work done:  $F \times d = 500 \times 7 = 3500\text{J}$
- PE gained =  $mgh = 50 \times 10 \times 7=3500\text{J}$
- Power =  $E/t = 3500/9 = 389\text{ W}$

# Power Example 2

- Car (800kg) travelling at 20m/s is brought to rest in 40s. What is the power of the brakes?
- Work done = KE lost

# Power Example 2

- Car (800kg) travelling at 20m/s is brought to rest in 40s. What is the power of the brakes?
- Work done = KE lost
- $= \frac{1}{2} mv^2 = \frac{1}{2} \times 800 \times 20^2 = 160\,000\text{J}$
- Power = work done/time taken
- $= 160\,000/40 = 4000\text{W}$  or 4kW

# Power Example 3

- Crane lifts a load of 1200kg onto a building of height 12m. The carrier of the load has a mass of 300kg. What minimum power must the motor of the crane develop to lift the load in 15s?
- Work done = PE gained ( $g=10\text{N/kg}$ )
- $mgh = 1500 \times 10 \times 12 = 180\,000$
- Power = work done/time
- $180\,000/15 = 12000\text{w}$  or 12kW

# Example

A 20 kg block initially at rest has a force of 30 N applied to it for 5.0 seconds. Assume that the force of friction is constant and is 20 N. Find:

- The velocity after 5 seconds.
- The kinetic energy after 5 seconds.
- Work done by the 30 N force in this time.
- Why are (b) and (c) not equal?



$$\begin{aligned} \text{(a)} \quad F(\text{nett}) &= 10\text{ N} & F &= ma \\ m &= 20\text{ kg} & \therefore a &= F/m = 10/20 \\ u &= 0 & &= 0.50\text{ ms}^{-2} \\ a &= ? & \text{also } v &= u + at \\ t &= 5.0\text{ s} & &= 0 + (0.5)(5) \\ v &= ? & &= 2.5\text{ ms}^{-1} \end{aligned}$$

$$\begin{aligned} \text{(b)} \quad E_k &= \frac{1}{2}mv^2 \\ &= (\frac{1}{2})(20)(2.5)^2 \\ &= 62.5\text{ J} \end{aligned}$$

$$\begin{aligned} \text{(c)} \quad s &= ut + \frac{1}{2}at^2 \\ &= 0 + (\frac{1}{2})(0.50)(5)^2 \\ &= 6.25\text{ m} \end{aligned}$$

$$\begin{aligned} \text{hence } W &= Fs \\ &= (30)(6.25) \\ &= 187.5\text{ J} \end{aligned}$$

- Much of the work has been done to overcome friction and has been converted to heat (etc) rather than kinetic energy.

# Example

A car of mass 1120 kg is travelling at  $80.0 \text{ kmh}^{-1}$  and slows down to  $30.0 \text{ kmh}^{-1}$  as it approaches a road works site. The car's reduced speed is achieved by applying the brakes over a distance of 100.0 m. Determine:

- The car's initial kinetic energy.
- The work done by the brakes in slowing the car down.
- The average force applied by the brakes.

$$\begin{array}{ll} \text{(a) } E_K & = \quad ? \\ m & = 1120 \text{ kg} \\ v & = 80 \text{ kmh}^{-1} \\ & = 22.2 \text{ ms}^{-1} \end{array} \qquad \begin{array}{ll} E_K & = \frac{1}{2}mv^2 \\ & = (\frac{1}{2})(1120)(22.2)^2 \\ & = 2.76 \times 10^5 \text{ J} \end{array}$$

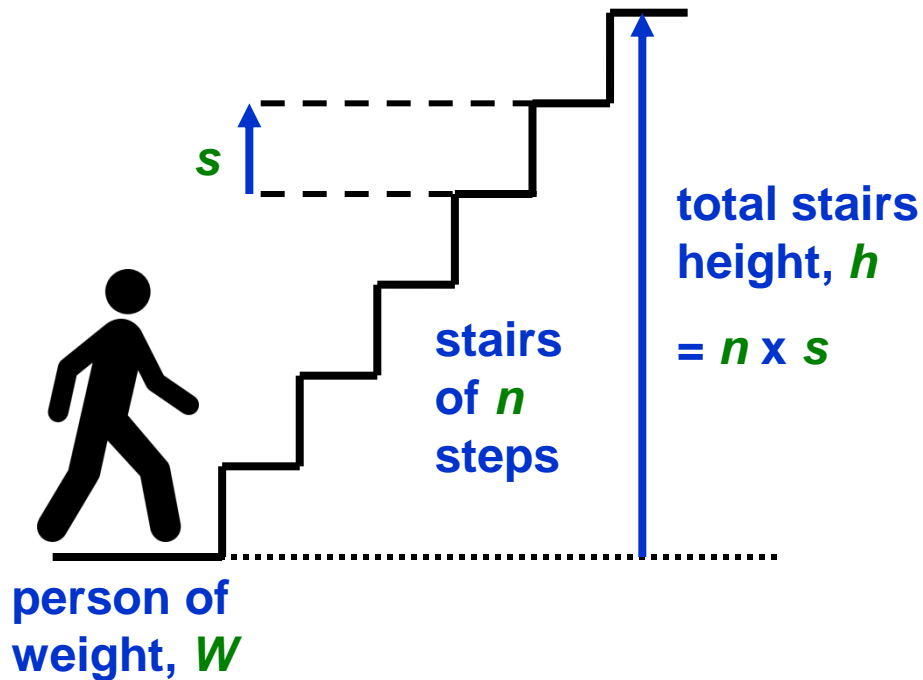
$$\begin{array}{ll} \text{(b) } W & = \Delta E_K \\ u & = 80 \text{ kmh}^{-1} \\ & = 22.2 \text{ ms}^{-1} \\ v & = 30 \text{ kmh}^{-1} \\ & = 8.33 \text{ ms}^{-1} \end{array} \qquad \begin{array}{ll} \text{Work done} & = \text{Change in kinetic energy} \\ & = E_{K(\text{initial})} - E_{K(\text{final})} \\ & = (\frac{1}{2})(1120)(22.2)^2 - (\frac{1}{2})(1120)(8.33)^2 \\ W & = 2.76 \times 10^5 - 3.89 \times 10^4 \\ & = 2.38 \times 10^5 \text{ J} \end{array}$$

$$\begin{array}{ll} \text{(c) } W & = 2.37 \times 10^5 \text{ J} \\ F & = \quad ? \\ s & = 100 \text{ m} \end{array} \qquad \begin{array}{ll} W & = Fs \\ F & = \frac{W}{s} = \frac{2.38 \times 10^5}{100} \\ & = 2.38 \times 10^3 \text{ N} \end{array}$$

# Answers

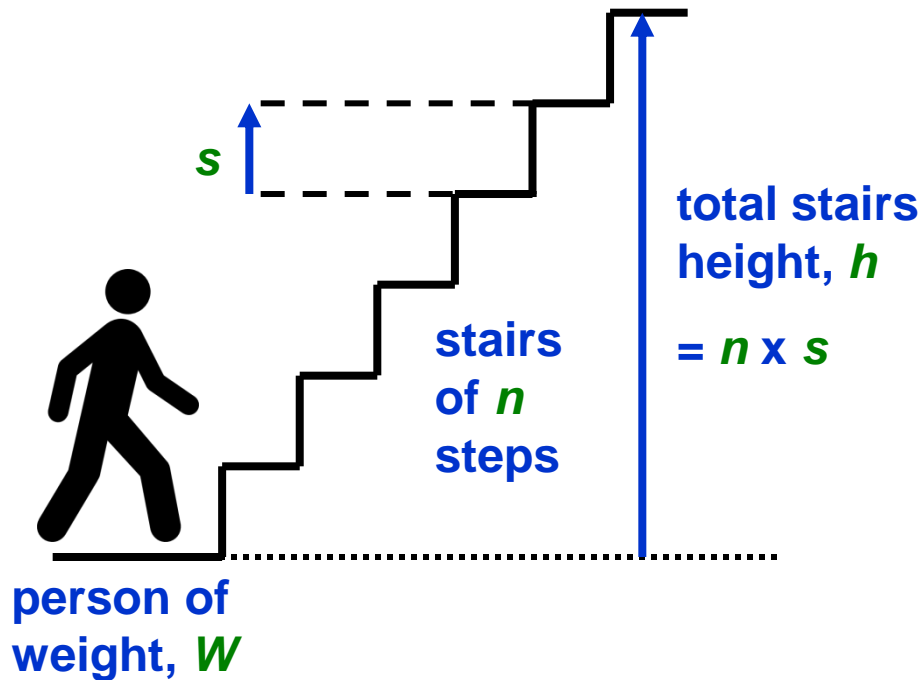
<i>energy transfer</i>	<i>work done</i>	<i>time</i>	<i>power</i>
600 J	<b>600 J</b>	120 s	<b>5 W</b>
440 J	<b>440 J</b>	<b>20 s</b>	22 W
<b>28 800 J</b>	<b>28 800 J</b>	2 hours	4 W
<b>2500 J</b>	2.5 kJ	50 s	<b>50 W</b>

# Measuring a person's power



1. Measure the weight,  $W$  of person using weighing scales.
2. Measure the time taken for the person to run up a flight of stairs of height,  $h$
3. Work done  
= weight x height  
=  $W \times h$   
=  $W \times n \times s$
4. Power of the person  
= work done / time taken  
=  $(W \times n \times s) / t$

# Example calculation



Weight of person,  $W = 800\text{N}$

Time taken,  $t = 3.0$  seconds

Stairs:

number of steps,  $n = 12$

height of step =  $0.20\text{m}$

total stair height,  $h$

$= 12 \times 0.20\text{m} = 2.4\text{m}$

Work done

$= \text{weight} \times \text{height}$

$= 800\text{N} \times 2.4\text{m} = 1920\text{J}$

Power =  $1920\text{J} / 3.0\text{s}$

**$= 640\text{W}$**

## Choose appropriate words to fill in the gaps below:

Power is a measure of how quickly a device does work.

Power is equal to work done in joules divided by the time taken.

The power of a device is also equal to the rate at which a device transforms energy from one form to another.

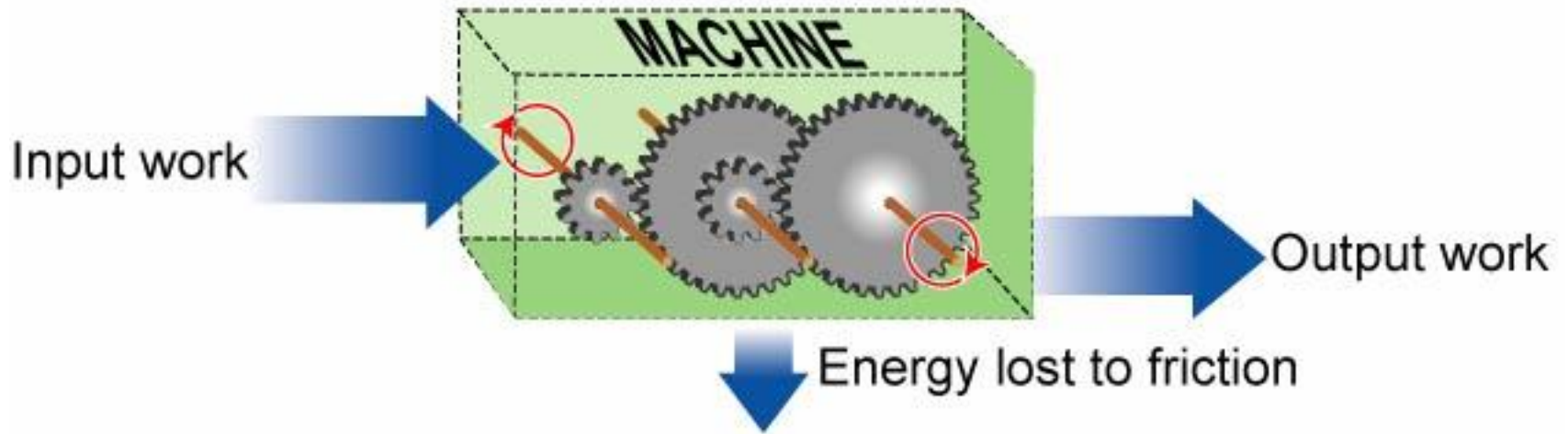
Power is measured in watts, symbol W.

A one kilowatt motor will perform one thousand joules of work every second.

### **WORD SELECTION:**

second    quickly    power    thousand  
watts    joules    energy

# Efficiency



$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}}$$

# Efficiency

- The efficiency of a machine tells how much of the energy (work) that goes into the machine actually does useful work.
- It is usually expressed as a percent.

$$\text{Efficiency} = \frac{\text{Useful work done}}{\text{Energy input}} \times 100\%$$

# Example

The work efficiency of an electric motor is 80%. It is used to raise a weight of 4.0 N through a vertical height of 200 cm in 5.0 s. Calculate the electric power supplied to the motor.

Useful work output of motor in 5.0 s

$$= \text{force} \times \text{distance moved} = 4.0 \times 2.00 = 8.0 \text{ J}$$

$$= \frac{\text{useful work output}}{\text{energy supplied}} \times 100\% \Rightarrow 80\% = \frac{8.0}{\text{energy supplied}} \times 100\%$$

$$\Rightarrow \text{energy supplied in 5.0 s} = \frac{8.0}{80} \times 100\% = 10 \text{ J}$$

Hence, electric power supplied to the motor,  $P = \frac{E}{t} = \frac{10}{5.0} = 2.0 \text{ W}$

# Example

A scooter, travelling along a straight horizontal path at *constant speed* of  $10.0 \text{ m s}^{-1}$ , is found to require a power of  $200 \text{ W}$  to maintain that speed. Find the resistive force caused by the road acting on it.

Let  $R$  = resistive force,

Power provided by motor ( $P$ ) = tractive force ( $F$ )  $\times$  speed ( $v$ )

$$\Rightarrow P = Fv \quad \Rightarrow F = \frac{P}{v} = \frac{200}{10.0} = 20.0 \text{ N} = R$$

Since the scooter is moving at a constant speed, *i.e.*, acceleration is zero

No net force

Accordingly, all its tractive force is used to overcome friction,  $R$ .