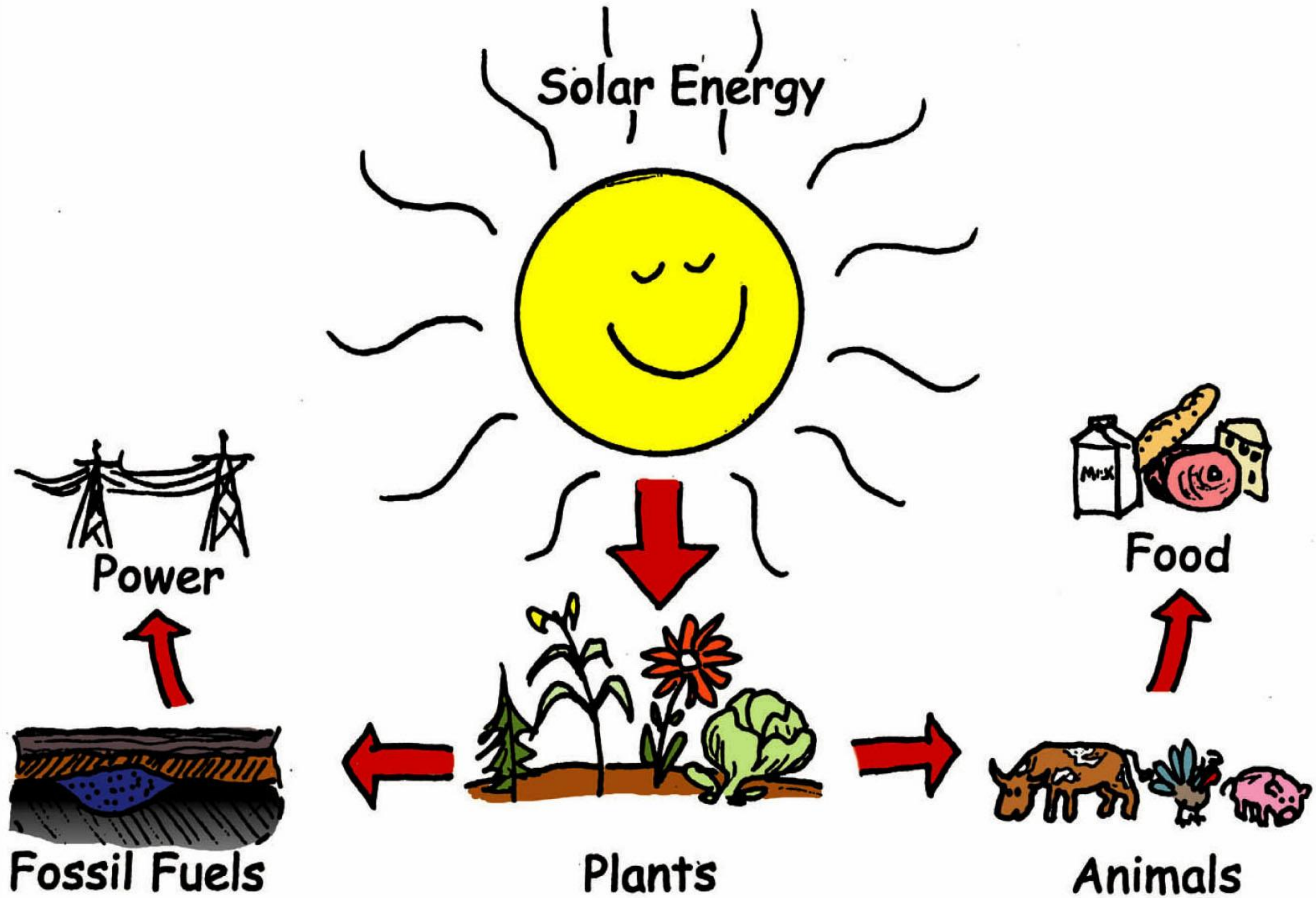
Energy

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


Solar Energy
Power
Food
MILK
Fossil Fuels
Plants
Animals

Work

- Easiest to start with the notion of work
- Work = Force X 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

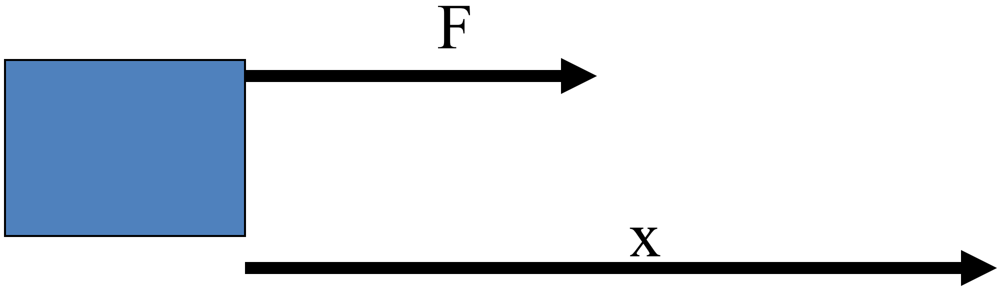
Work

- 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:

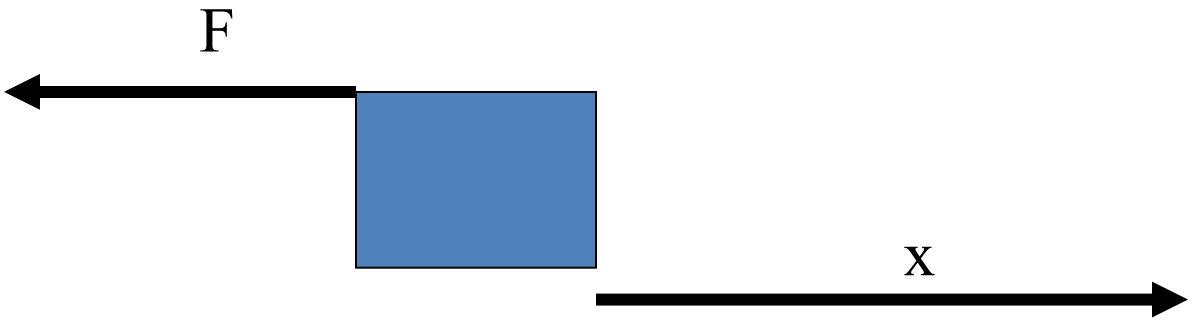
$$W = Fx$$



Work

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

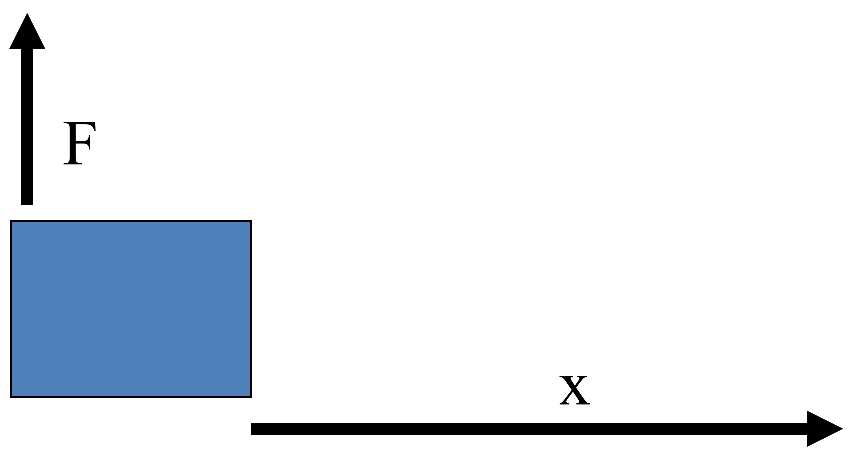
$$W = -Fx$$



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***.

$$\mathbf{W = 0}$$



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

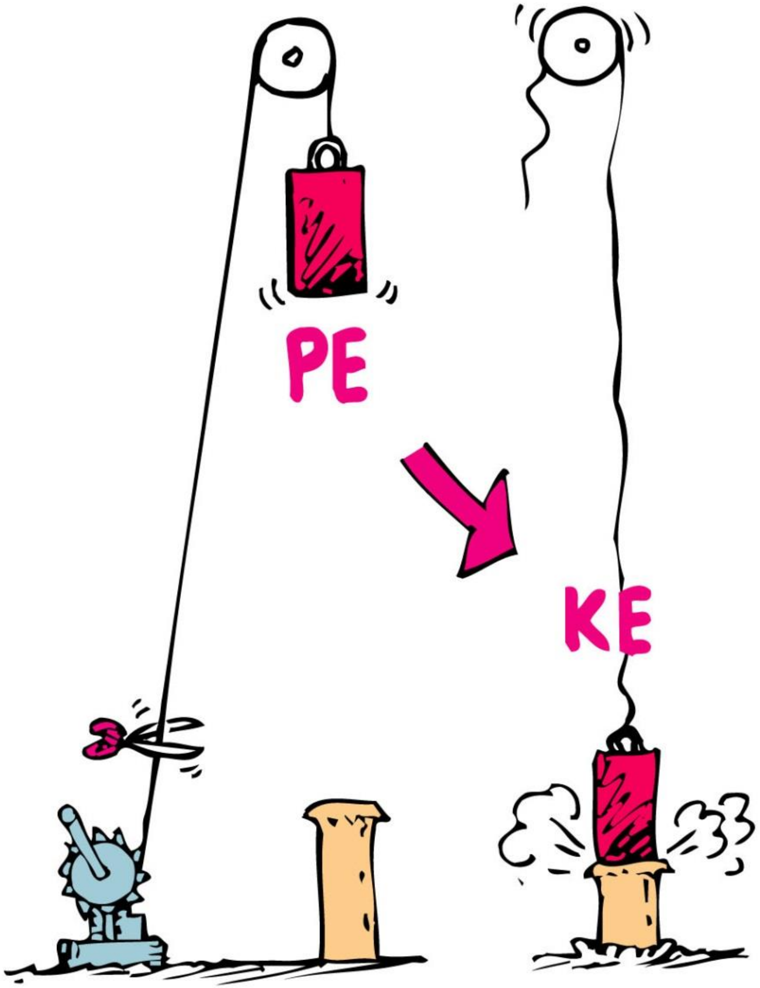
- If we lift an object from the floor into the air, it has the potential to do work for us
- This ability to do work is called POTENTIAL ENERGY
- Other forms of potential energy include the compression of a spring, the stored energy in coal or oil, the stored energy in a uranium nucleus

Potential Energy

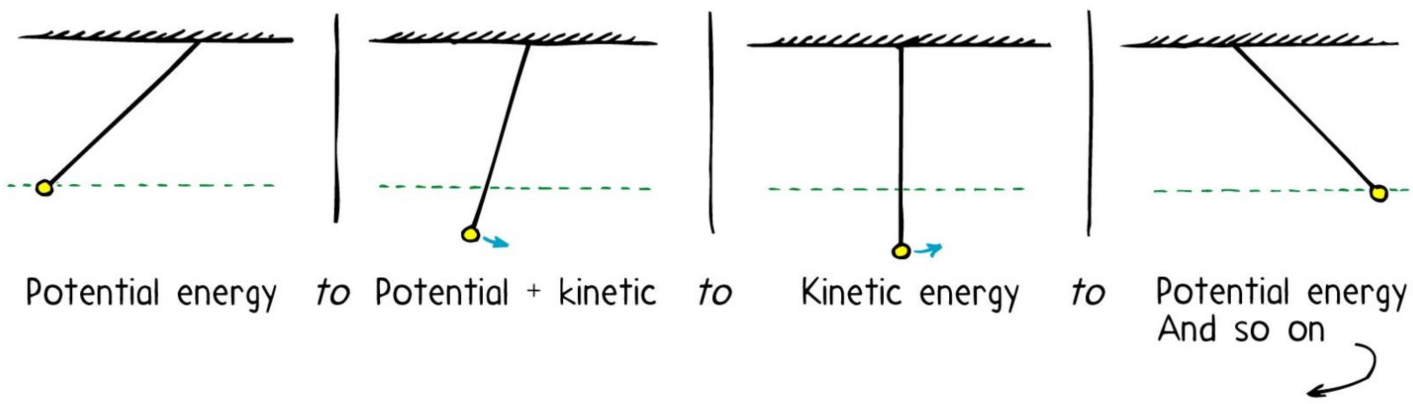
- Gravitational potential energy is simple to calculate
- Gravitational Potential Energy = weight X height

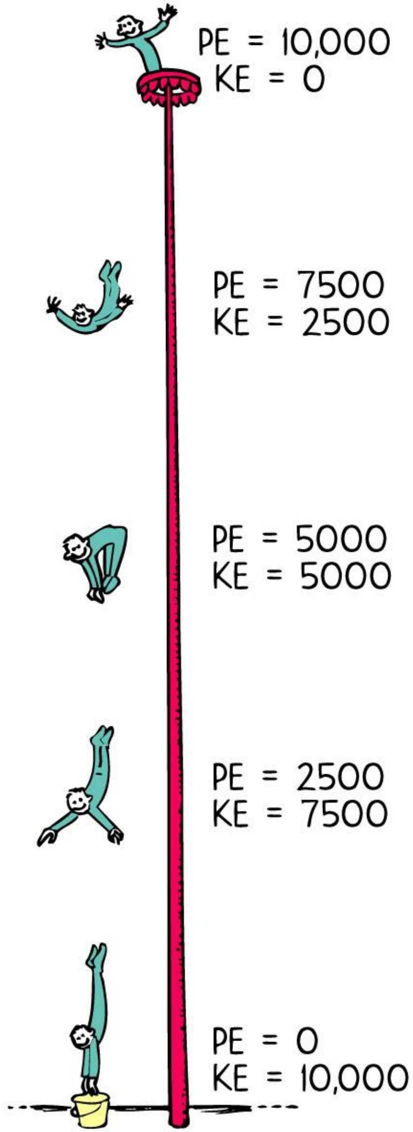
$$PE = mgh$$

Energy Conversion



Energy Conversion




PE = 10,000
KE = 0
PE = 7500
KE = 2500
PE = 5000
KE = 5000
PE = 2500
KE = 7500
PE = 0
KE = 10,000

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

work = force x distance

= 5 kN x 30 cm

= 5000 N x 0.30 m

work = 1500 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

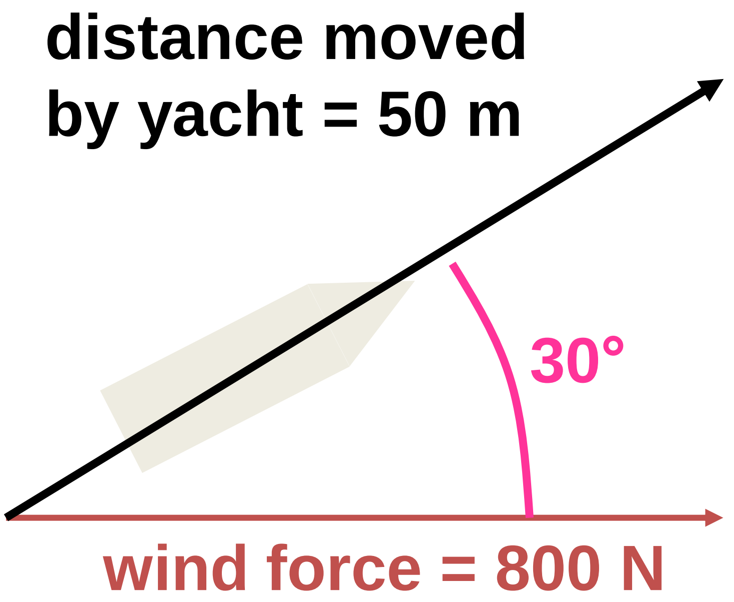
the distance moved upwards equals (12 x 20cm) = 2.4m

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 ϑ

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

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

$= 40\,000 \times 0.8660$

work = 34 600 J

Worked Example 4

Calculate the kinetic energy of a car of mass 800 kg moving at 6 ms^{-1}

$E_K = ½\ m\ v^2$

$= ½ \times 800kg \times (6ms^{-1})^2$

$= ½ \times 800 \times 36$

$= 400 \times 36$

kinetic energy = 14 400 J

Worked Example 5

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

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

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

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

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

$25 = v^2$

$v = \sqrt{25}$

speed = 5.0 ms^{-1}

Worked Example 6

Calculate the braking distance a car of mass 900 kg travelling at an initial speed of 20 ms^{-1} if its brakes exert a constant force of 3 kN.

k.e. of car = ½ m v^2

= ½ x 900kg x $(20ms^{-1})^2$

= ½ x 900 x 400

= 450 x 400

k.e. = 180 000 J

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

W = F s

180 000 J = 3 kN x ***s***

180 000 = 3000 x ***s***

s = 180 000 / 3000

braking distance = 60 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 Nkg^{-1})

$\Delta E_P = m\ g\ \Delta h$

= 200 g x 9.8 Nkg^{-1} x 30 cm

= 0.200 kg x 9.8 Nkg^{-1} x 0.30 m

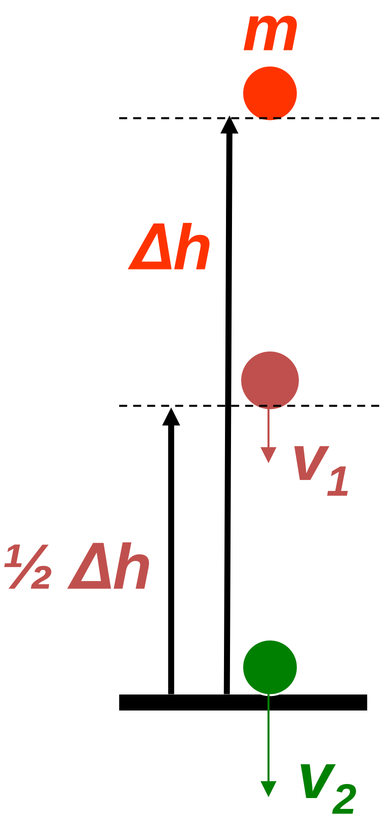
change in g.p.e. = 0.59 J

Falling objects

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

$\Delta E_K = \Delta E_P$

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



gpe = $mg\Delta h$
ke = 0

gpe = ke
gpe = $\frac{1}{2} mg\Delta h$
ke = $\frac{1}{2} mv_1^2$

gpe = 0
ke = $\frac{1}{2} mv_2^2$
ke = $mg\Delta h$

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 Nkg^{-1}

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

gpe = mgΔh

= 40 x 9.8 x 2.0

max gpe = 784 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 J

v^2 = (2 x 784) / 40

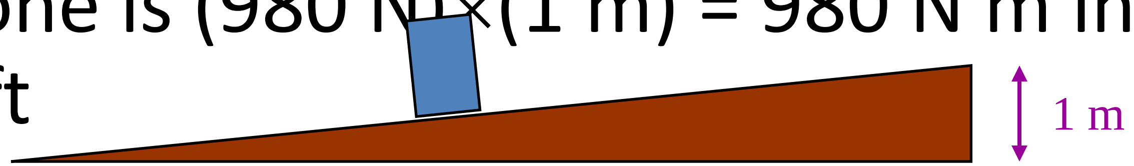
v^2 = 39.2

$v = \sqrt{39.2}$

max speed = 6.3 ms^{-1}

Ramp Example

- Ramp 10 m long and 1 m high
- Push 100 kg all the way up ramp
- Would require *mg* = 980 N of force to lift directly (brute strength)
- Work done is (980 N)×(1 m) = 980 N m in direct lift



- Extend over 10 m, and only 98 N is needed

Work Examples

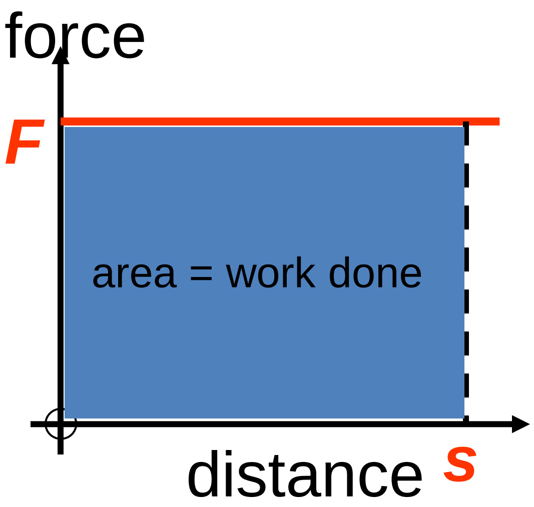
- How much work does it take to lift a 30 kg suitcase onto the table, 1 metre high?

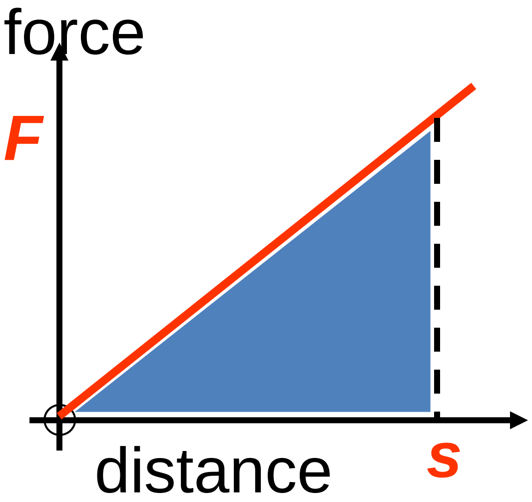
  $$W = (30\ \text{kg}) \times (9.8\ \text{m/s}^2) \times (1\ \text{m}) = 294\ \text{J}$$

- 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

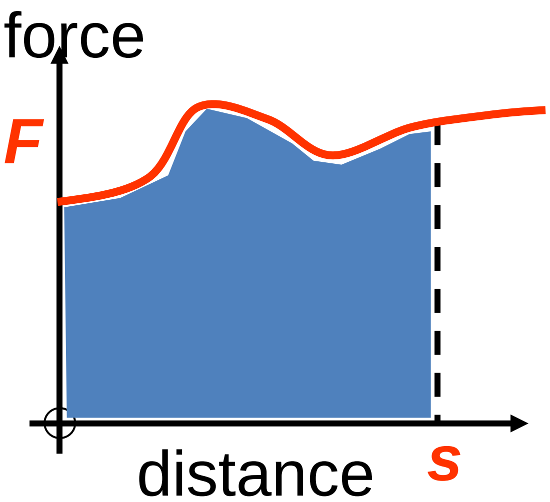
The area under the curve is equal to the work done.





area = work

= ½ *F s*

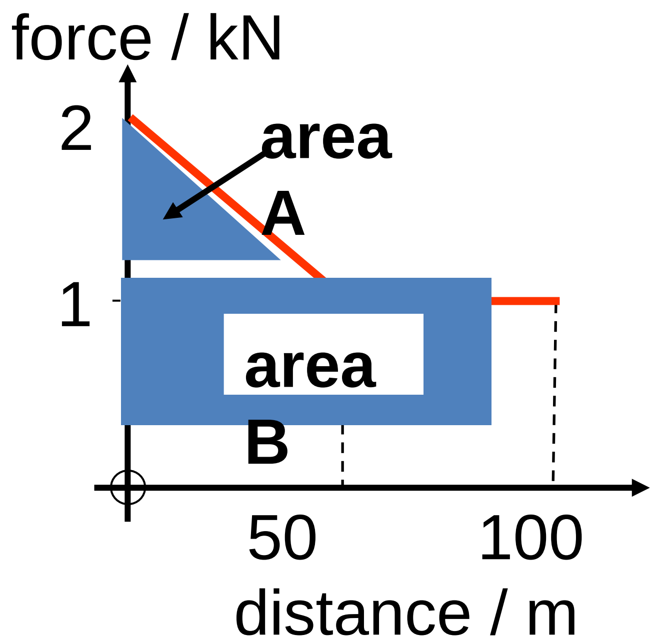


area = work

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

= area A + area B

= (½ x 1k x 50)
+ (1k x 100)

= (25k) + (100k)

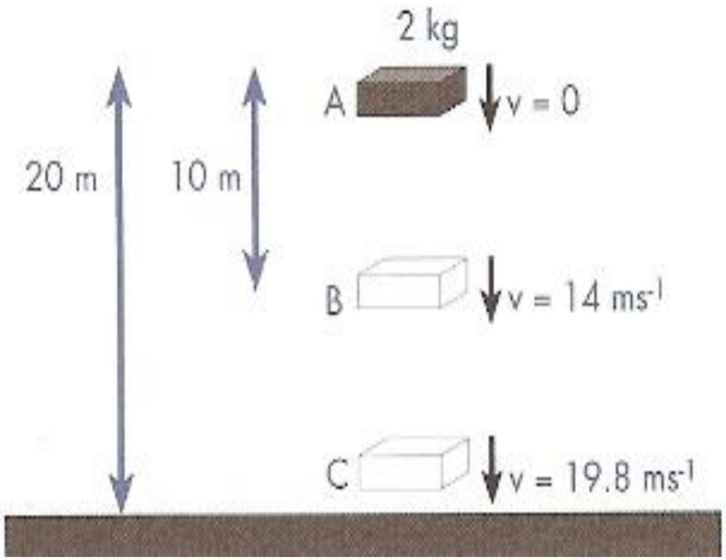
work = 125 kJ

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: $E_P = 392\,J$, $E_K = 0$, $E_T = 392\,J$

At position B: $E_P = 196\,J$, $E_K = 196\,J$, $E_T = 392\,J$

At position C: $E_P = 0$, $E_K = 392\,J$, $E_T = 392\,J$

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***.

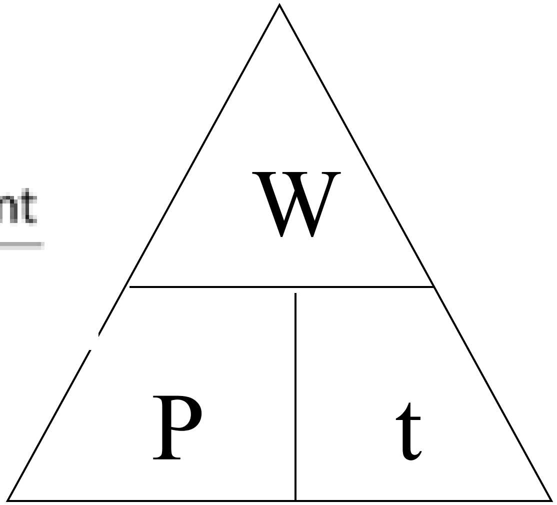
Power

- 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 $\rightarrow$ 700 W output!
- Shuttle puts out a few GW (gigawatts, or 10^9 W) of power!

Power

- Power is the rate work is done.

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



Deduce further:

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

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

$\therefore$ *Power* can also be defined by: $P = Fv$

Power

- Units of power: 1 Joule/sec = 1 ***Watt***
- 1000 Watts = 1 ***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

-

-

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

$$\text{also } P = \frac{F.s}{t} = Fv_{av}$$

P	=	power (Js^{-1} or Watts)
W	=	work (J)
ΔE	=	change in energy
t	=	time (s)
F	=	force (N)
v_{av}	=	average velocity

Power Example 1

- A student (50kg) climbs stairs of vertical height 7m in 9s.
- Lifting force = weight: =mg=50x10=500N
- Work done: Fxd = 500 x 7 = 3500J
- PE gained = mgh = 50x10x7=3500J
- Power = E/t = 3500/9 = 389 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
- $= \frac{1}{2}mv^2 = \frac{1}{2} \times 800 \times 20^2 = 160\,000J$
- Power =work done/time taken
- =160 000/40 = 4000W 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=10N/kg)
- mgh= 1500x10x12=180 000
- Power = work done/time
- 180 000/15 = 12000w 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:

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

(a)

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

(b) $E_K = \frac{1}{2}mv^2$
$= (\frac{1}{2})(20)(2.5)^2$
$= 62.5\ J$

(c) $s = ut + \frac{1}{2}at^2$
$= 0 + (\frac{1}{2})(0.50)(5)^2$
$= 6.25\ m$

hence $W = Fs$
$= (30)(6.25)$
$= 187.5\ J$

(d) 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 kmh^{-1} and slows down to 30.0 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:

(a) The car's initial kinetic energy.
(b) The work done by the brakes in slowing the car down.
(c) The average force applied by the brakes.

(a) E_K = ?
m = 1120 kg
v = 80 kmh^{-1}
= 22.2 ms^{-1}

$E_K = \frac{1}{2}mv^2$
$= (\frac{1}{2})(1120)(22.2)^2$
$= 2.76 \times 10^5$ J

(b) W = ΔE_K
u = 80 kmh^{-1}
= 22.2 ms^{-1}
v = 30 kmh^{-1}
= 8.33 ms^{-1}

Work done = Change in kinetic energy
$= E_{K\,(initial)} - E_{K\,(final)}$
$= (\frac{1}{2})(1120)(22.22)^2 - (\frac{1}{2})(1120)(8.33)^2$
$W = 2.76 \times 10^5 - 3.89 \times 10^4$
$= 2.38 \times 10^5$ J

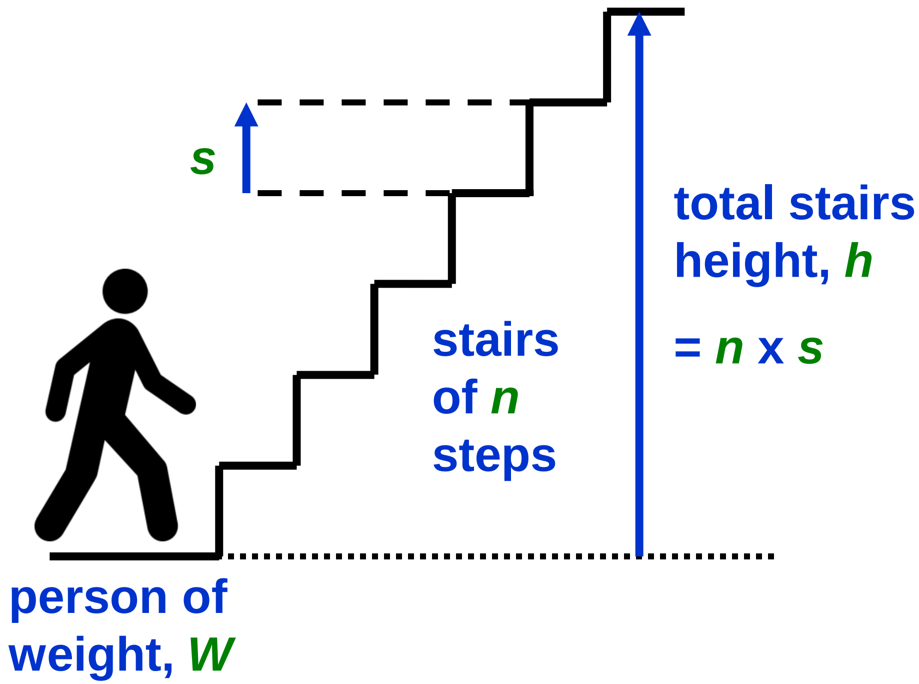
(c) W = 2.37×10^5 J
F = ?
s = 100 m

$W = Fs$
$F = \frac{W}{s} = \frac{2.38 \times 10^5}{100}$
$= 2.38 \times 10^3$ N

Answers

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

Measuring a person's power



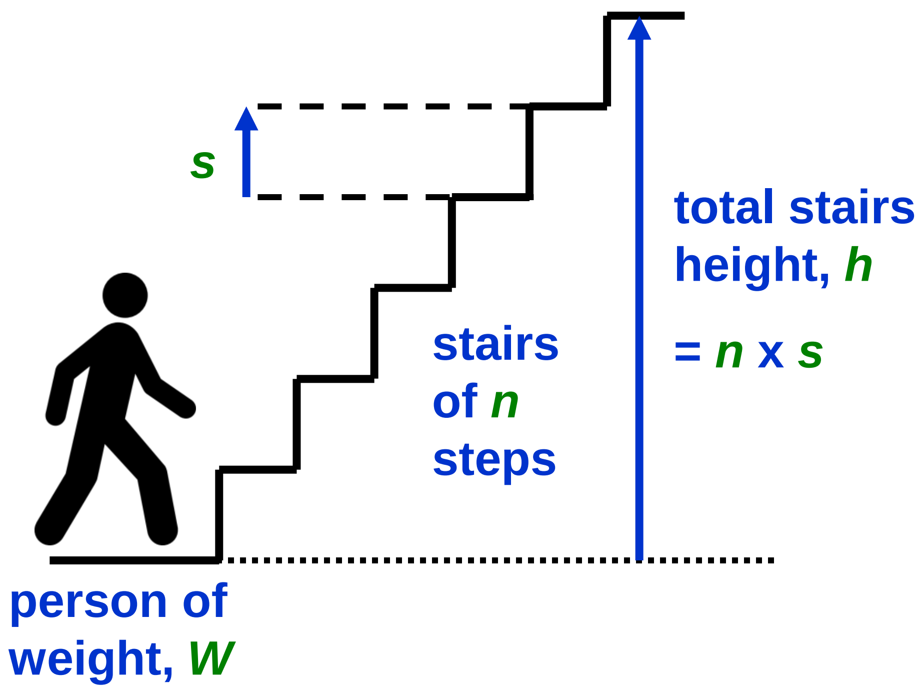
1. Measure the weight, ***W*** of person using weighing scales.

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*** x ***h***
= ***W*** x ***n*** x ***s***

4. Power of the person
= work done / time taken
= (***W*** x ***n*** x ***s***) / ***t***

Example calculation



Weight of person, ***W*** = 800N
Time taken, ***t*** = 3.0 seconds

Stairs:
number of steps, ***n*** = 12
height of step = 0.20m
total stair height, ***h***
= 12 x 0.20m = 2.4m

Work done
= weight x height
= 800N x 2.4m = 1920J

Power = 1920J / 3.0s
= 640W

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.

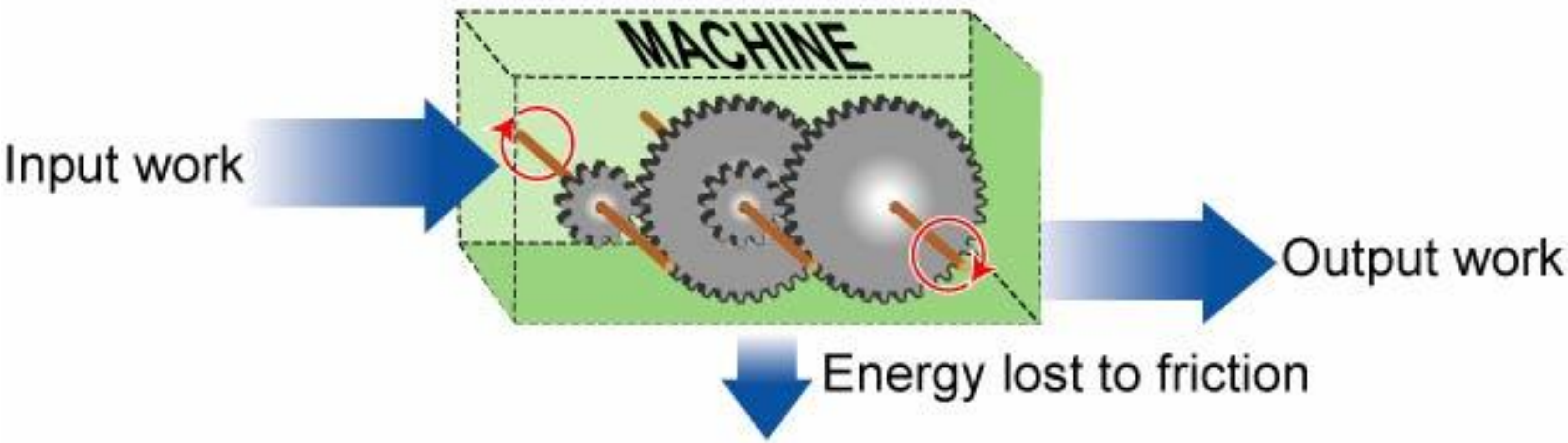
Power is measured in ___watts___, symbol W.

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

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

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

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

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 m s^{-1}, is found to require a power of 200 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) × speed (v)

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

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.