Topic 5 Forces

5.1.1 A vector quantity has direction

eg : displacement, velocity, acceleration, force (including weight)

A scalar quantity doesn't

eg : distance,.speed, time, mass

5.1.2 A force is an action of one object on another, either a push or pull which can cause a change of motion or a change in shape

Contact forces : friction, air resistance, normal contact force, tension

Non-contact forces : gravity, electric force, magnetic force

5.1.3 Weight = the force of gravity

= mass x gravitational field strength

W = m x g

N kg N/kg g = 10N/kg near Earth

5.1.4 Resultant force = the sum of all the forces acting on an object

(taking into account their direction)

H A FORCE CAN BE RESOLVED INTO TWO COMPONENTS AT RIGHT ANGLES

TWO FORCES CAN BE ADDED BY PUTTING ONE ON THE END OF THE OTHER

AND APPLYING PYTHAGORAS THEOREM

(OR YOU CAN DRAW A SCALE DIAGRAM)

It is best to consider next :-

5.6.2.1 Newton's 1st law

If there is no resultant force acting on an object then the object maintains a constant velocity (which could be zero)

5.6.2.2 Newton's 2nd law

If there is a resultant force acting on an object then the object will accelerate

$$\text{Acceleration} = \frac{\text{Resultant force}}{\text{Mass}} \qquad a = \frac{F}{m}$$

m/s^2 N/kg

5.6.2.3 Newton's 3rd law

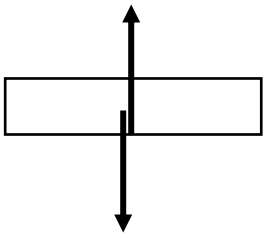
Every action has an equal but opposite reaction

If object A pushes object B forwards then object B pushes object A backwards

If an object is moving and pushing air in front of it, the air must push back on the object. This is the cause of air resistance.

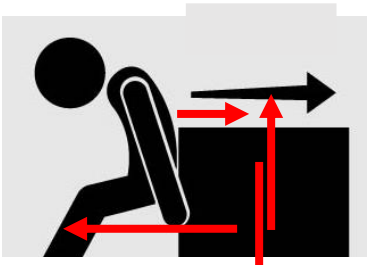
At this stage, test your knowledge and understanding :-

1. The picture shows the forces acting on a 200g book resting on a bench



(a) How does the picture show force to be a vector quantity ?
(b) How does the picture indicate that the forces are the same size ?
(c) Label the forces acting on the book
(d) Which of the forces is a contact force ? which is a non-contact force ?
(e) Work out the size of each force
(f) Why must the upwards force be the same size as the downwards force ?

2. Work out the resultant force in each picture



5N
Push

8N
Normal
Contact

10N friction Weight 8N

5N
Push

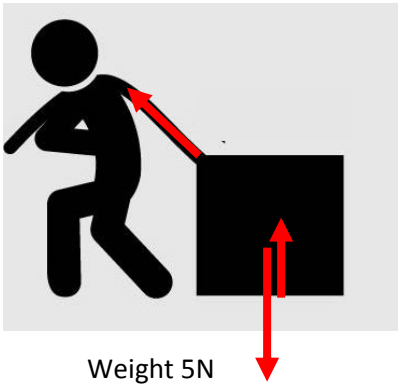
Same
weight
and
Contact

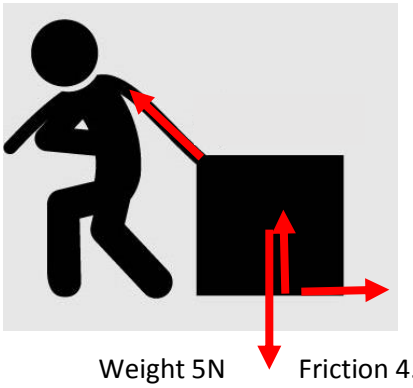
1N friction 1N

If the object being pushed is initially stationary, what does each object do ?

What if each object is initially moving to the right ?

HIGHER





If the object being pushed is initially stationary, what does each object do ?

What if each object is initially moving to the right ?

Forces and Motion

5.6.1.1 Distance = how far you go including changes of direction — scalar

Displacement = how far you are from your starting point measured in a straight line — vector

5.6.1.2 Speed = $\frac{\text{distance}}{\text{time}}$ $v = \frac{d}{t}$ — scalar

* m/s

5.6.1.3 Velocity = $\frac{\text{displacement}}{\text{time}}$ $v = \frac{s}{t}$ — vector

* usually preceded by the word average because rarely constant

An object moving round a circle with a constant speed is changing its velocity due to its change in direction

5.6.1.5 Acceleration = $\frac{\text{change of velocity}}{\text{time}}$ $a = \frac{v - u}{t}$ $\frac{m/s}{s}$ — vector

m/s^2

u = starting velocity, v = final velocity

negative velocity = deceleration

An equation that may be given to you is $v^2 - u^2 = 2as$

Now practise what you have learned :-

1. A postman walks 60m east, realises he has dropped a letter, so walks back 20m to pick it up.

   What was the total distance travelled ? and the final displacement ?

   If the time for the journey was 40s, what was the average speed ?

   what was the average velocity ?

HIGHER

2. Another postman walks 40m east and 30m south.

   What was the total distance travelled ? and the final displacement ?

   If the time for the journey was 30s, what was the average speed ?

   what was the average velocity ?

3. A Ferrari can accelerate from 0 to 60mph in 2s.

   1 mile = 1600m

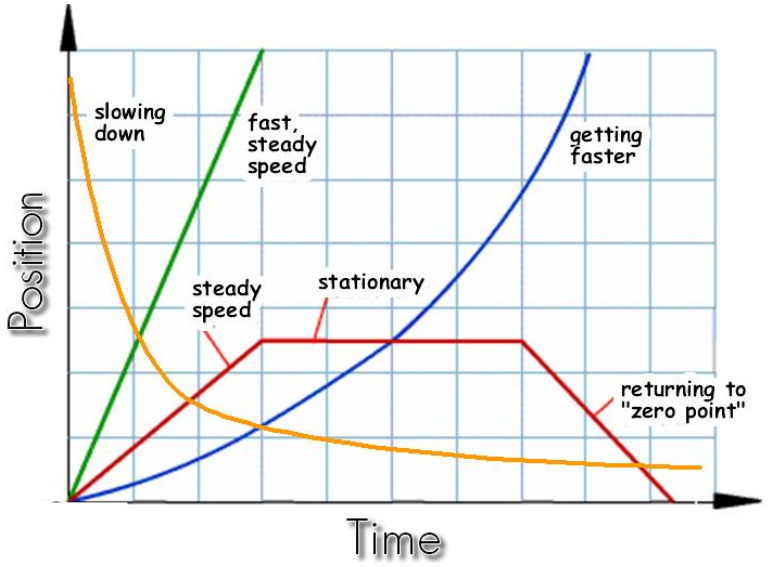
   Work out the acceleration of the Ferrari

4. Mr Thompson's Nissan Micra accelerates from 20m/s to 30m/s, travelling 25m in the process. Work out the acceleration.

Motion Graphs

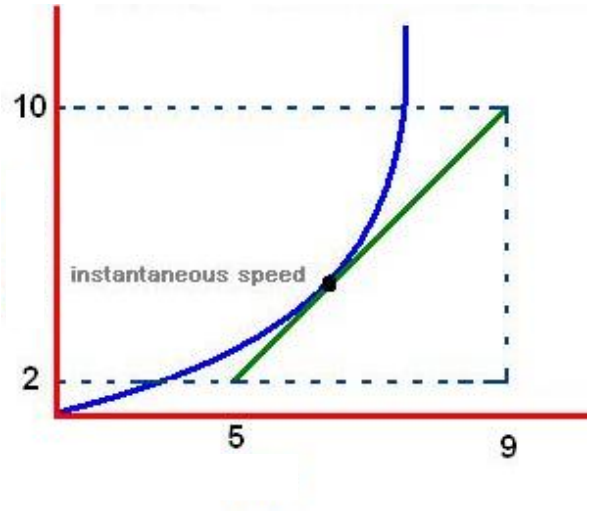
5.6.1.4 Distance v. Time graphs

Gradient = Speed



HIGHER : IF THERE IS ACCELERATION THEN THE GRADIENT OF A TANGENT IS THE INSTANTANEOUS SPEED

d/ m



Instantaneous speed at the black dot is :-

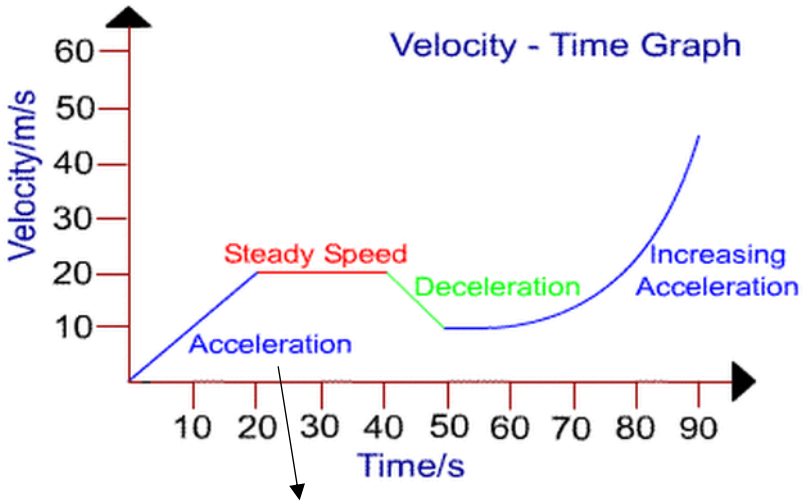
$$\frac{(10 - 2)\ \text{m}}{(9 - 5)\ \text{s}}$$

$$= 2\ \text{m/s}$$

5.6.1.5 Velocity v. time graphs

Gradient = acceleration

Distance travelled = area under graph



The acceleration = $\frac{(20 - 0)\ m/s}{20\ s} = 1 m/s^2$

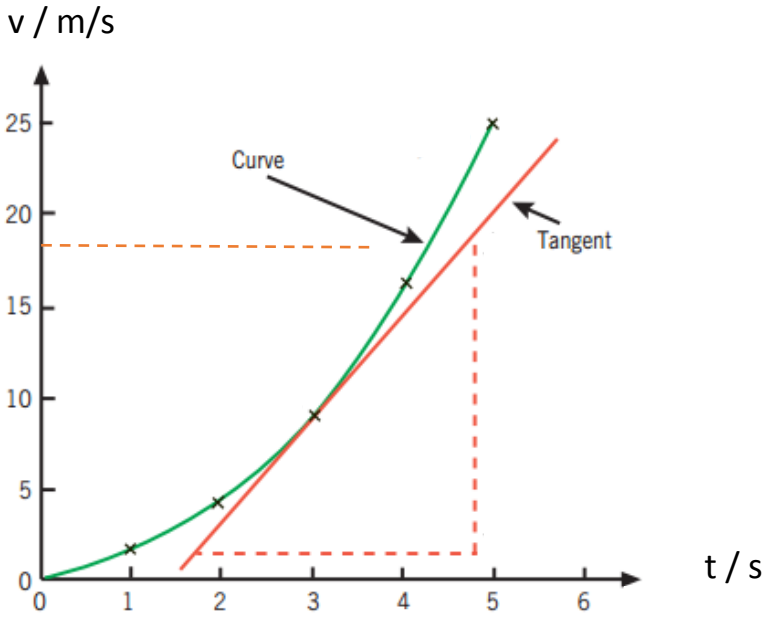
The distance travelled during that acceleration = ½ x 20s x 20m/s = 200m

The distance travelled whilst at steady speed = 20s x 20m/s = 400m

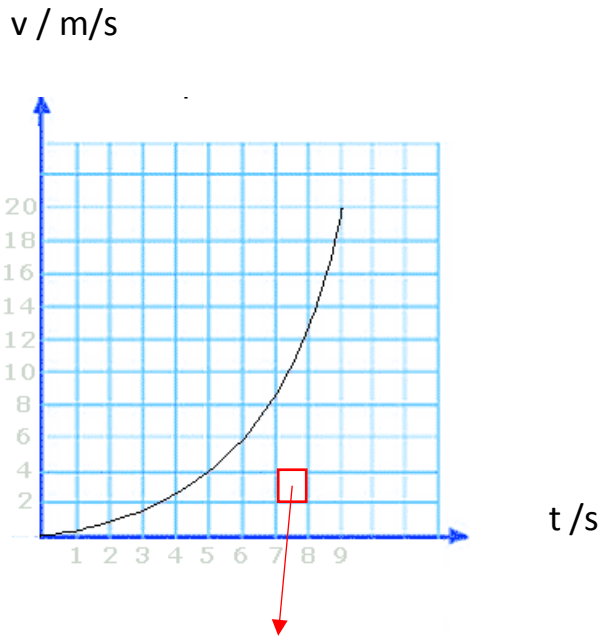
HIGHER

GRADIENT OF A TANGENT AT ANY POINT IS INSTANTANEOUS ACCELERATION

AREA UNDER A CURVE CAN BE FOUND BY APPROXIMATING HOW MANY SQUARES THERE ARE UNDER IT



The instantaneous acceleration at 3s is $\frac{(18 - 2)\ m/s}{(4.8 - 1.7)\ s} = 5.16\ m/s^2$



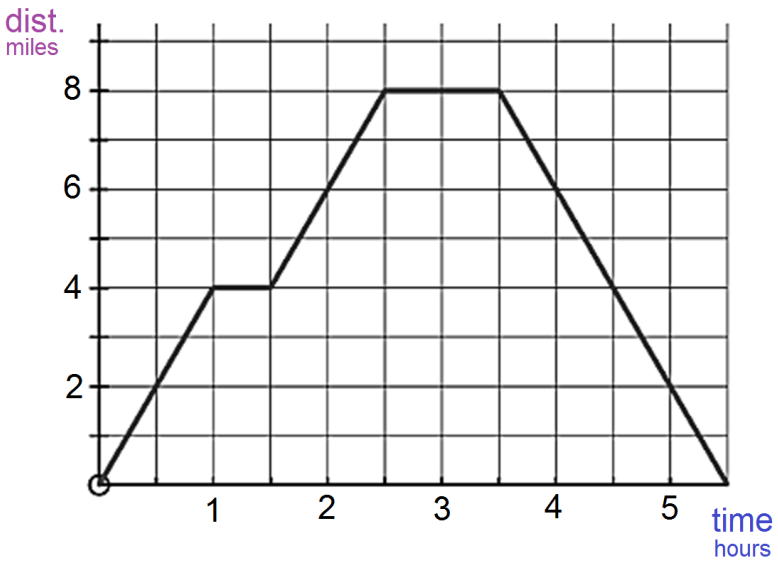
One small square = 1s x 2m/s = 2m

The number of little squares under the curve = 22

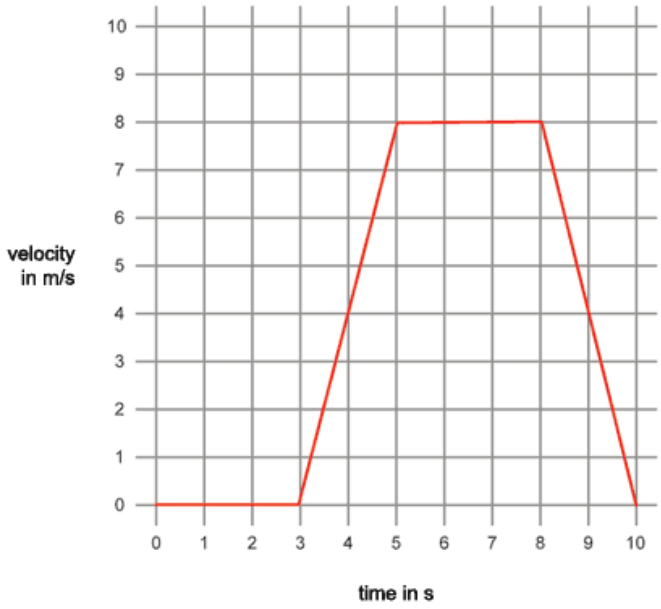
The distance travelled = 22 x 2m = 44m

Now practise what you have learned :-

1. Work out the average speeds of the object having the following graph :-

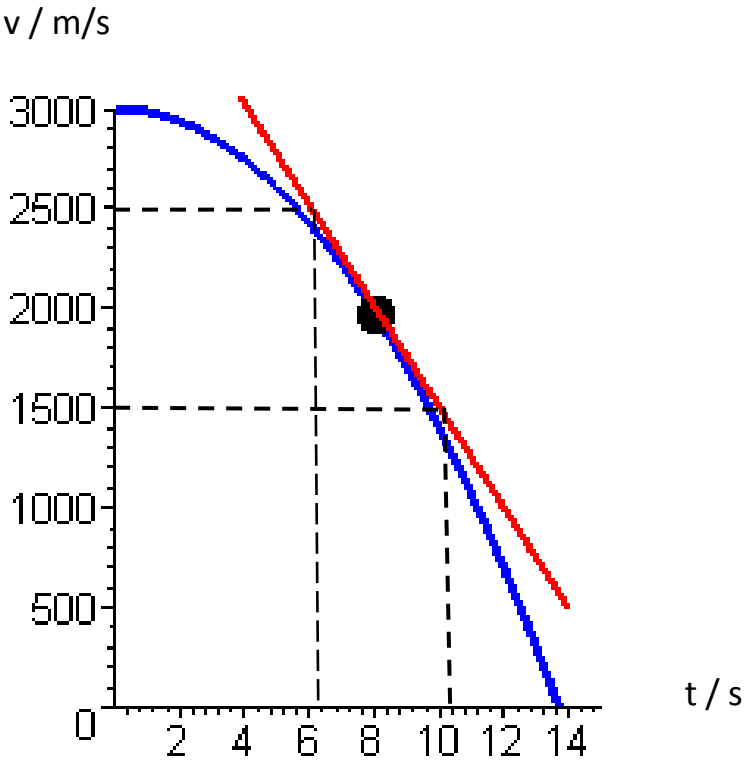


2. Work out the accelerations and distances travelled by this object :-

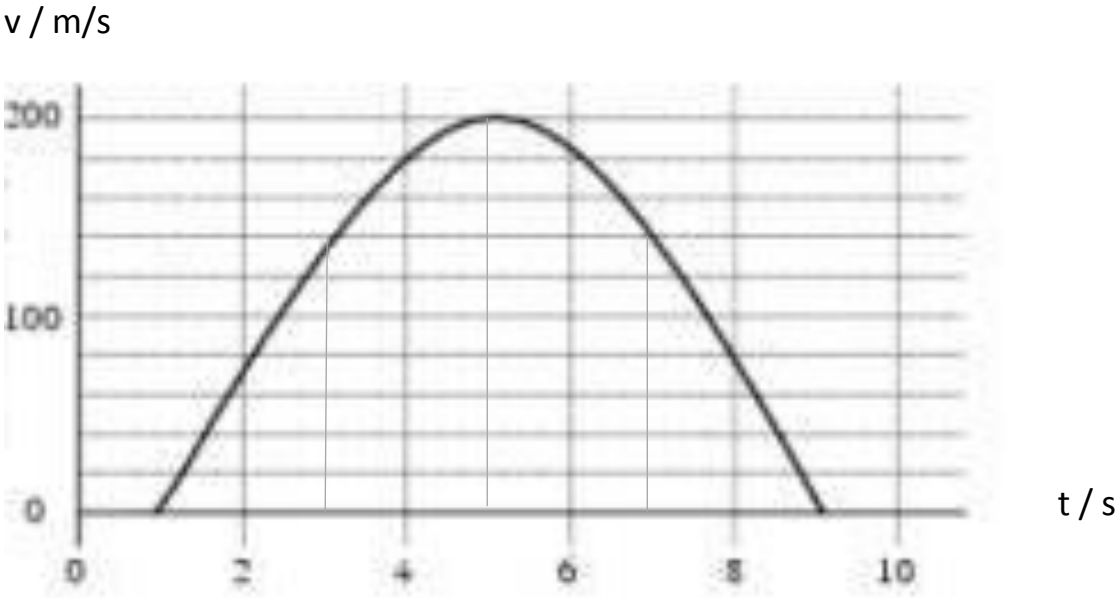


3.

HIGHER : WORK OUT THE INSTANTANEOUS ACCELERATION OF THE OBJECT AT THE POINT SHOWN:-



4. WORK OUT THE DISTANCE TRAVELLED BY THE OBJECT :-



5.2 Work is done when a force moves

Work done = Force x displacement W = F s

Joules N m

Work done overcoming friction causes heat to be produced

Work done by a resultant force increases an object's kinetic energy

5.6.3 Forces and braking

Overall stopping distance = thinking distance + braking distance

1 2

1 How far you travel whilst thinking = speed x reaction time

is larger if you are driving faster and if you are not alert

is proportional to speed (doubling speed doubles thinking distance)

2 How far you travel whilst braking

is larger if you are driving faster and if the tyres or brakes are worn

and the road is wet or icy

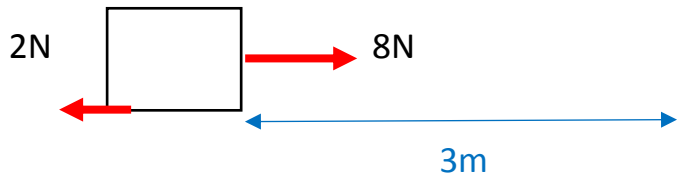
Kinetic energy converts into heat when work is done by the brakes

$\frac{1}{2} m v^2 = F s$

Braking distance is proportional to speed squared

Practise what you have learned :-

1. An 8N force pulls an object 3m along a surface that exerts a 2N frictional force



(a) Calculate the work done against friction (that produces heat)

(b) Calculate the work done accelerating the object (increasing its kinetic energy)

2. A standard car is travelling at 30mph (13.3 m/s) on a standard road.
   The reaction time of an alert driver is 0.6s.

(a) Calculate the thinking distance

The braking distance for that car is 16m

(b) What are the following at 60mph ?

(i) Thinking distance (ii) Braking distance

5.7 Momentum = mass x velocity

kgm/s kg m/s

is conserved during an interaction if no external force acts

Momentum before the interaction = Momentum after the interaction

An interaction that conserves kinetic energy as well as momentum is elastic

An interaction that converts kinetic energy into other energies is inelastic

When a resultant force acts on an object there is a change of momentum

$$F = ma = m\left(\frac{v-u}{t}\right) = \frac{mv-mu}{t}$$

If the impact time of that force is increased then the impact force is decreased for a given change of momentum

Seat Belts, Air Bags and Crumple Zones all apply this idea

Practise what you have learned :-

1. A 600 kg car, travelling at 20m/s, collides with an 800kg car that is travelling at 10m/s. the two cars stick and move off together

(a) Form an equation for the momentum before and after the collision and use it to work out the velocity of the cars moving together

(b) Work out the total kinetic energy of the cars before and after the collision

(c) Is the collision elastic or inelastic ?

2. An electron is moving at one tenth of the speed of light (0.1c)
It approaches another stationary electron.
The stationary electron is repelled and moves off at one fifth of the speed of light (0.2c)

(a) Form a momentum equation and use it to work out the final velocity of the original electron

(b) Work out the total kinetic energy of the electrons before and after the interaction

(c) Is the interaction elastic or inelastic ?

3. A 50g egg is dropped onto the floor
If it hits the floor travelling at 10m/s, stops and breaks in 0.1s, what force must the floor exert on the egg ?

4. A carton of eggs is dropped from the same height onto the same floor
Explain why the eggs in the carton are less likely to break

4.5.3 Forces and Elasticity

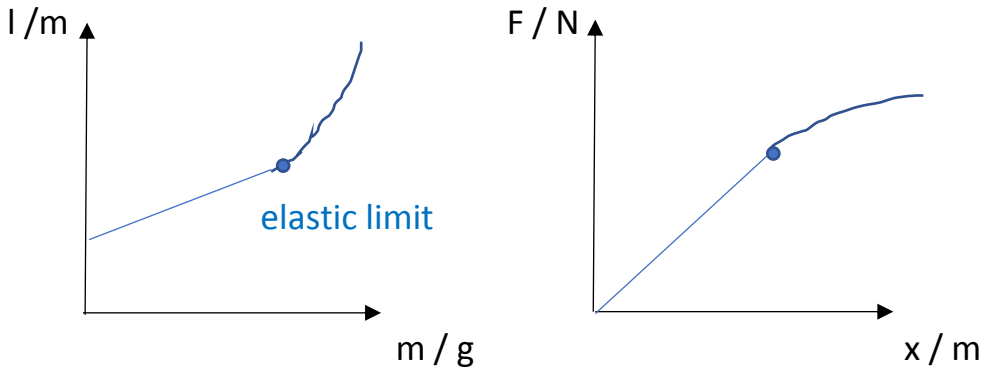
A pulling force can cause an object to stretch

A pushing force can cause an object to squash

A spring behaves elastically up to an elastic limit

If the force is removed the spring returns to its original length

An investigation into the stretching of a spring might involve hanging masses on it and measuring its length. The mass can then be converted to weight and the extension, x , worked out by subtracting the original length of the spring from the stretched length



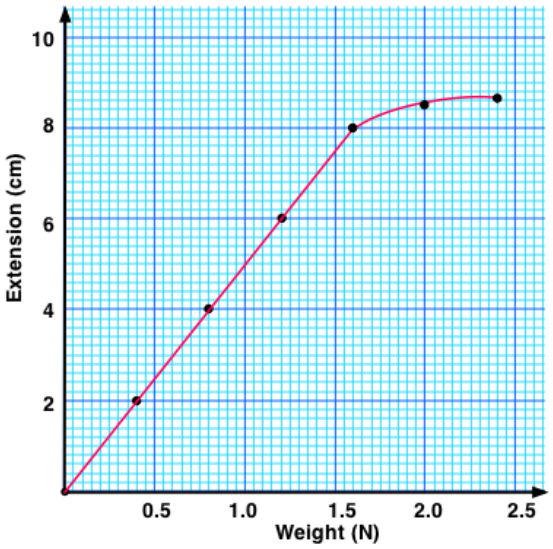
Hooke's law : Force = spring constant x extension F = k x

(gradient) N N/m m

Work done stretching a spring = area under graph = ½ F x = ½ k x^2

Practise what you have learned :-

1. A spring is found to extend in the following way



(a) Work out the spring constant

(b) Work out the extension for a force of 0.6N

(c) Work out the force required to stretch the spring by 6.2cm

(d) Calculate the work done stretching the spring by 8cm

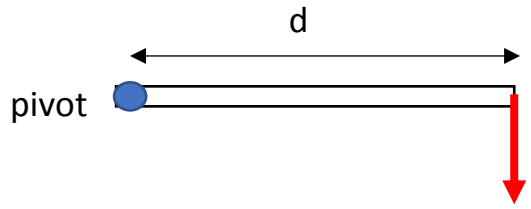
2. 20J of work was done stretching another spring by 50cm

(a) Work out the spring constant

(b) Work out the force required to stretch the spring by that much

5.4 The turning effect of a force is called its Moment

Moment of a force = Force x perpendicular distance from pivot



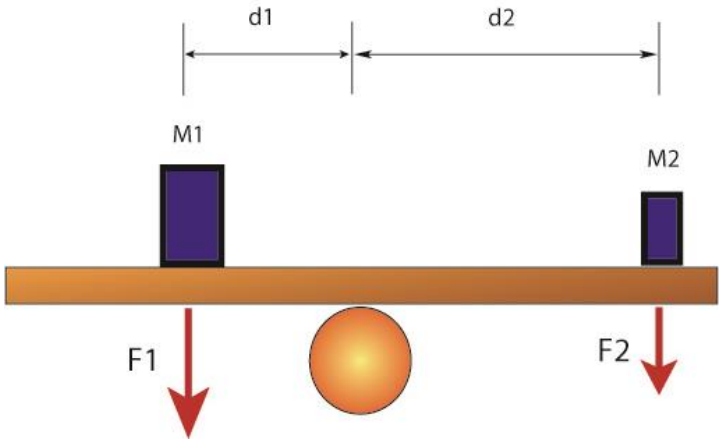
$M = F\ d$

Nm N m

If more than one turning force acts on an object then the Principle of moments applies :-

For equilibrium (balance)

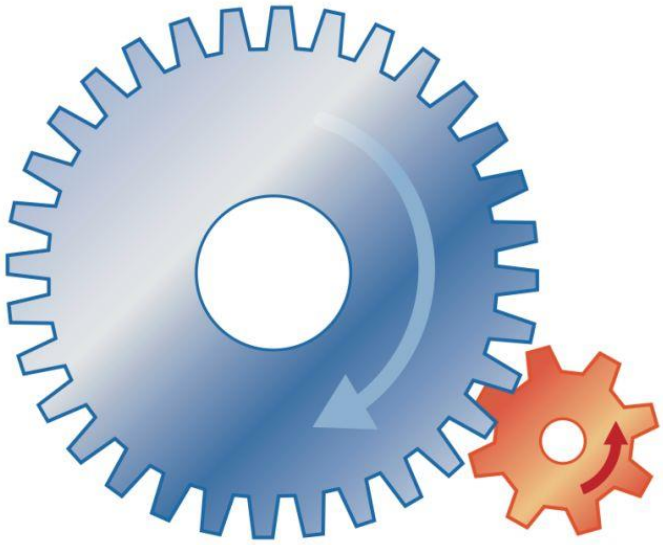
the sum of the clockwise moments = the sum of the clockwise moments



$F_1 \times d_1 = F_2 \times d_2$

Gears are slotted wheels on axles which turn and can be arranged to transfer circular motion

32 1 2

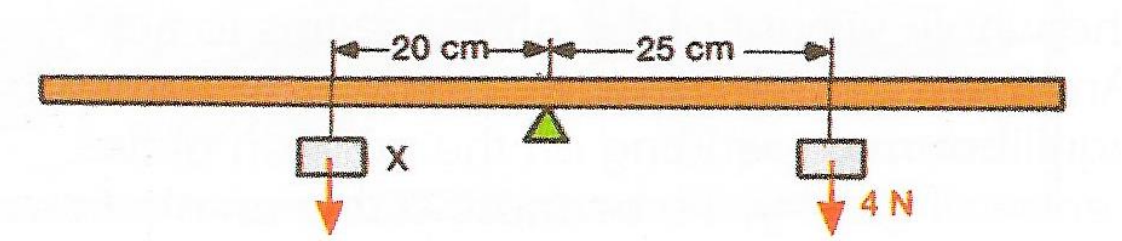


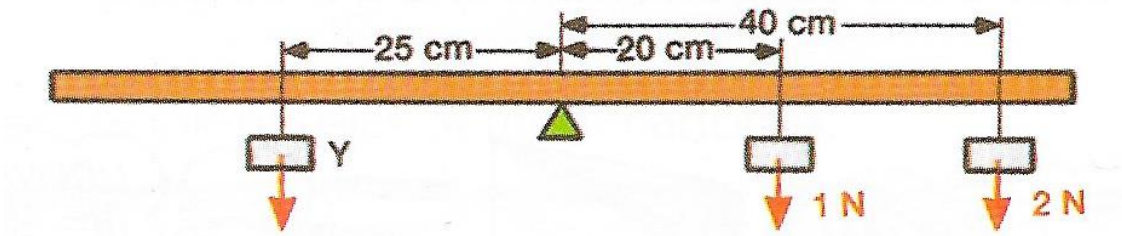
For every complete rotation of the large gear, the small gear does 8 rotations but the turning force of the small gear is 8 times less than the large gear
(note also how the direction of rotation changes)

By arranging gears in certain ways we can increase speed or force but not both

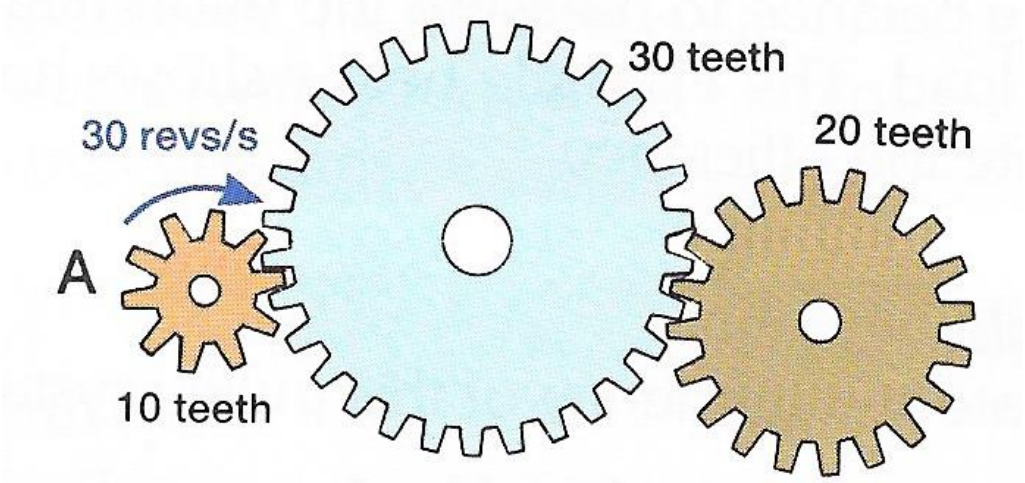
Practise what you have learned :-

Work out the weights of X and Y in the following pictures





State the direction of rotation of the gears in the following picture and the number of revolutions per second



C

Also GCSE Physics only

5.5.1 The squashing effect of a force is called Pressure

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad p = \frac{F}{A} \quad \frac{N}{m^2}$$

or Pascal

5.5.2 Liquid pressure = density x gravitational field strength x depth

$$p = \rho \times g \times h$$

Pa kg/m^3 N/kg m

If a solid is submerged in a liquid, more pressure acts on the bottom than higher up so the solid feels a buoyancy force (or upthrust)

5.5.3 Atmospheric pressure decreases with height because gravity pulls air particles downwards so the density of air is lower the higher up you go

Practise what you have learned :-

1. A 20g cube of sides 4cm sits on a bench
   Work out the pressure it exerts on the bench

2. Water has a density of $1000kg/m^3$

(a) Work out the pressure on the bottom of a cube that has sunk to a depth of 2m in water

(b) Calculate the upthrust on the cube if its sides are 4cm long.