Chapter 10

Density

Pressure

Gravity

Moments

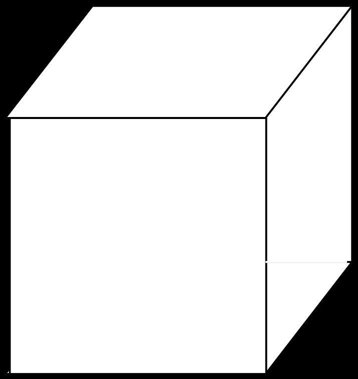
Density

Mass per unit volume

Mass of 1 m^3

$$density = \frac{mass}{volume}$$

rho $$\rho = \frac{m}{V}$$

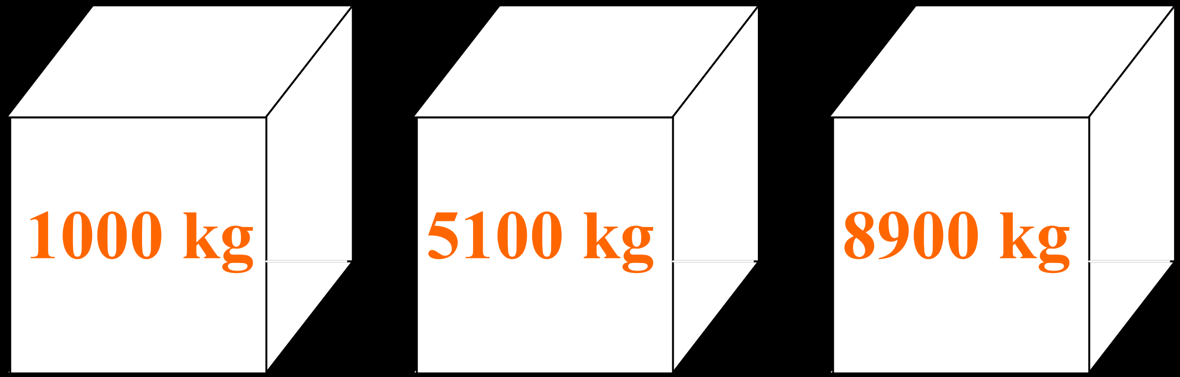


1m x 1m x 1m

Units of density = $kg\ m^{-3}$

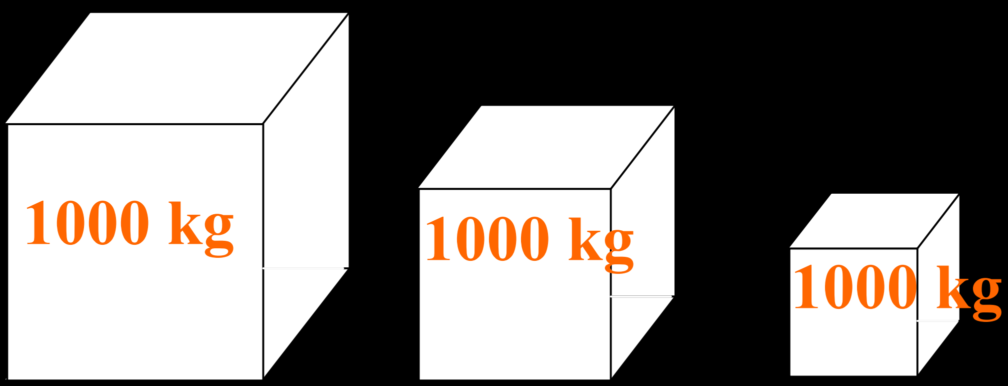
Density is a scalar

Density



Each has a volume of 1 m^3.

Which has the greatest density?



Each has the same mass (1000 kg)

Which has the greatest density?

Density Values Solids

Material	Density kg m^{-3}	Density g cm^{-3}
Water	1000	1.00
Aeroboard	20	0.02
Cork	200	0.20
Wood (Cedar)	550	0.55
Aluminium	2700	2.70
Iron	7800	7.80
Copper	8900	8.90
Lead	11400	11.40
Mercury	13600	13.60
Gold	19300	19.30

Most Dense Metal

Osmium 22500 kg m^{-3}

Least Dense Materials

Gases

What will float in water?

Density Values Liquids & Gases

Material	Density kg m^{-3}	Density g cm^{-3}
Water	1000	1.00
Petrol	700	0.70
Alcohol	810	0.81
Sea-Water	1030	1.03
Sulphuric Acid	1840	1.84
Mercury	13600	13.60
Hydrogen	0.09	0.0001
Air	1.3	0.0013
Carbon Dioxide	2.0	0.0020

Mix Water & Petrol

Which floats to the top?

Oil spills

P1 A piece of wood has a volume of 0.02 m^3 and a mass of 10 kg. Find its density.

$$\rho = \frac{m}{V} = \frac{10}{0.02}$$

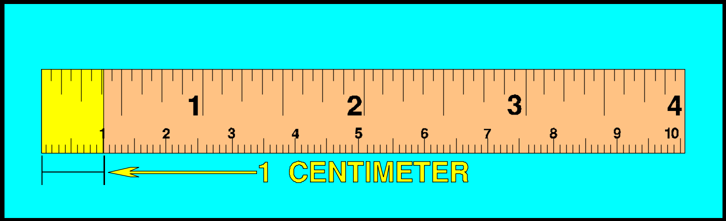
$$= 500\ kg\ m^{-3}$$

P2 A piece of copper of mass 420 g has a volume of 47.19 cm^3. What is its density in kg m^{-3}?

$$1\ cm = 10^{-2}\ m$$

$$1\ cm^2 = (10^{-2})^2 = 10^{-4}\ m^2$$

$$1\ cm^3 = (10^{-2})^3 = 10^{-6}\ m^3$$



$$\rho = \frac{m}{V} = \frac{0.42}{47.19 \times 10^{-6}}$$

$$= 8.9 \times 10^{3}\ kg\ m^{-3}$$

P2 The density of aluminium is 2.7×10^3 kg m^{-3}.

What is the volume of 120 g of aluminium?

$$\rho = \frac{m}{V} \Rightarrow V = \frac{m}{\rho} = \frac{120 \times 10^{-3}}{2.7 \times 10^{3}}$$

$$= 4.44 \times 10^{-5}\ m^{3}$$

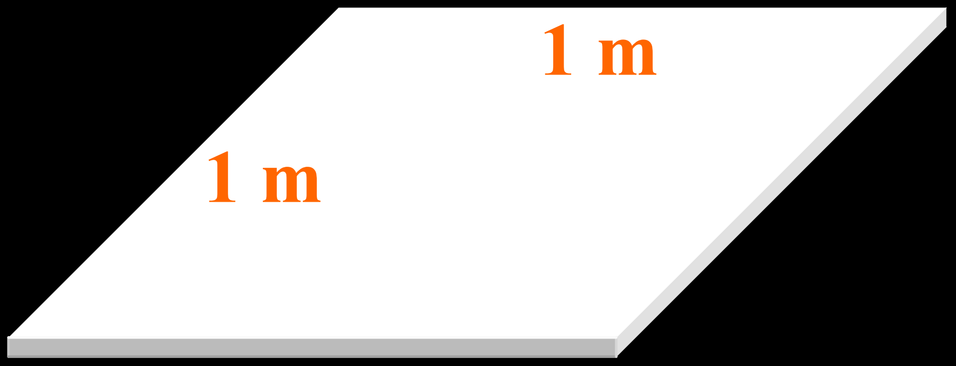
Pressure

Force per unit area

Force on 1 m^2

$$Pressure = \frac{Force}{Area}$$

$$P = \frac{F}{A}$$



Units of Pressure = N m^{-2} = the pascal (Pa)

Pressure is a scalar

The Pascal in Basic Units

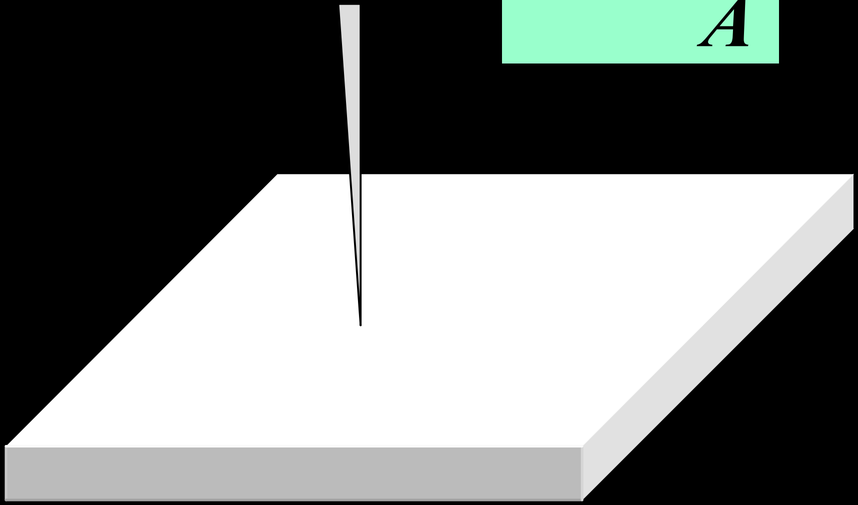
$$P = \frac{F}{A}$$

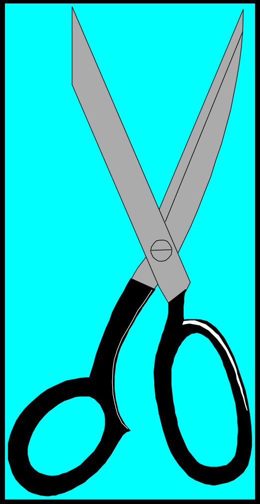
$$F = ma$$

$$1\ \text{Pa} = 1\ \text{N m}^{-2}$$
$$= 1\ (\text{kg m s}^{-2})\ \text{m}^{-2}$$
$$= 1\ \text{kg m}^{-1}\ \text{s}^{-2}$$

High or Low Pressure ??

$$P = \frac{F}{A}$$





P4 **A force of 600 N acts evenly on a surface of area 5 m^2**

What pressure does it exert?

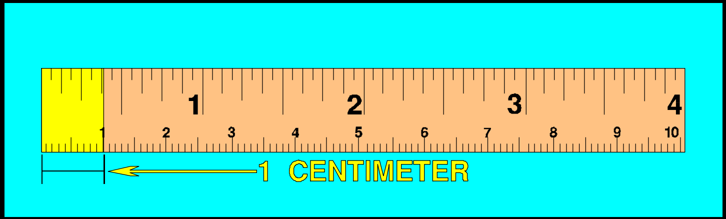
$$P = \frac{F}{A} = \frac{600}{5} = 120\ Pa$$

P5 **A force of 40 N acts on an area of 25 cm².**

What pressure does it exert?

$$1\ \text{cm} = 10^{-2}\ \text{m}$$

$$1\ \text{cm}^2 = (10^{-2})^2\ \text{m}^2 = 10^{-4}\ \text{m}^2$$



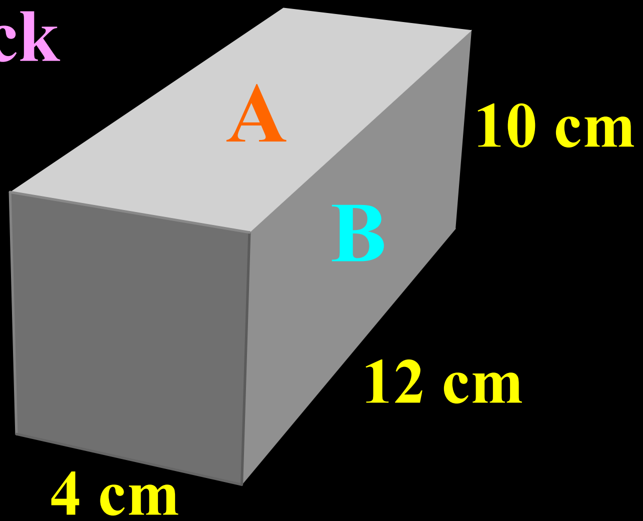
$$P = \frac{F}{A} = \frac{40}{25 \times 10^{-4}}$$

$$= 16{,}000\ \text{Pa}$$

P6 The diagram shows a rectangular block of mass 5 kg resting on a horizontal table.

Find the value of the pressure if,

(i) side A is on the table, (ii) side B is on the table.



Force acting on table = Weight of block

$= mg = (5)(9.8) = 49$ N

(i) Side A: $P = F \div A$

$= 49 \div (0.04 \times 0.12)$

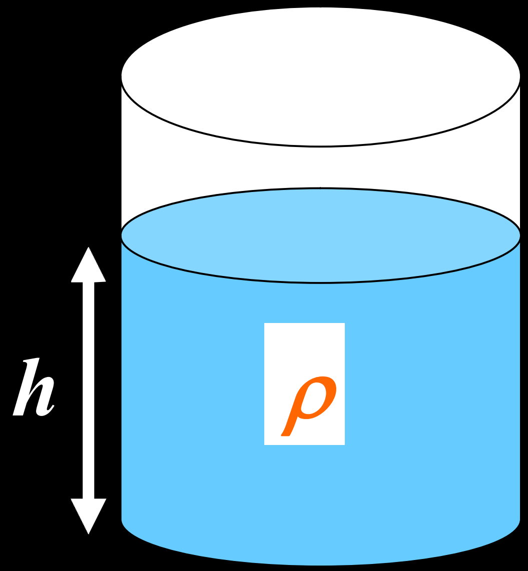
$= 1.02 \times 10^4$ Pa

(ii) Side B: $P = F \div A$

$= 49 \div (0.10 \times 0.12)$

$= 4.08 \times 10^3$ Pa

Pressure Due To A Liquid



Pressure in a liquid depends on

depth and density

Pressure at a depth *h*

$$= P = \rho g h$$

Pressure is caused by the weight of the liquid.

P7 Find the pressure due to the mercury at a depth of 76 cm in a container of mercury.
(Density of mercury = 1.36×10^4 kg m^{-3})

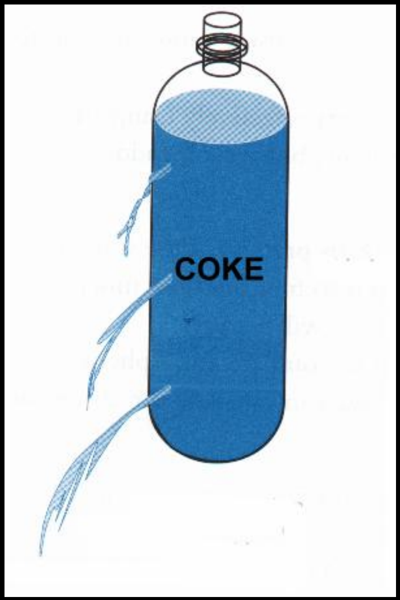
$$P = \rho g h = (1.36 \times 10^4)(9.8)(0.76)$$

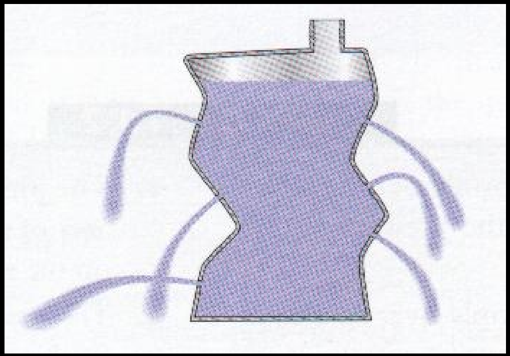
$$= 1.01 \times 10^5 \text{ Pa}$$

Mercury Barometer

Pressure In A Liquid ...

- Increases with depth
- acts perpendicular to any surface put in the liquid
- is the same in all directions





P8 A rectangular wooden block has dimensions 14 cm x 12 cm x 20 cm. It is placed with its upper surface at a depth of 30 cm in a basin of water as in the diagram.

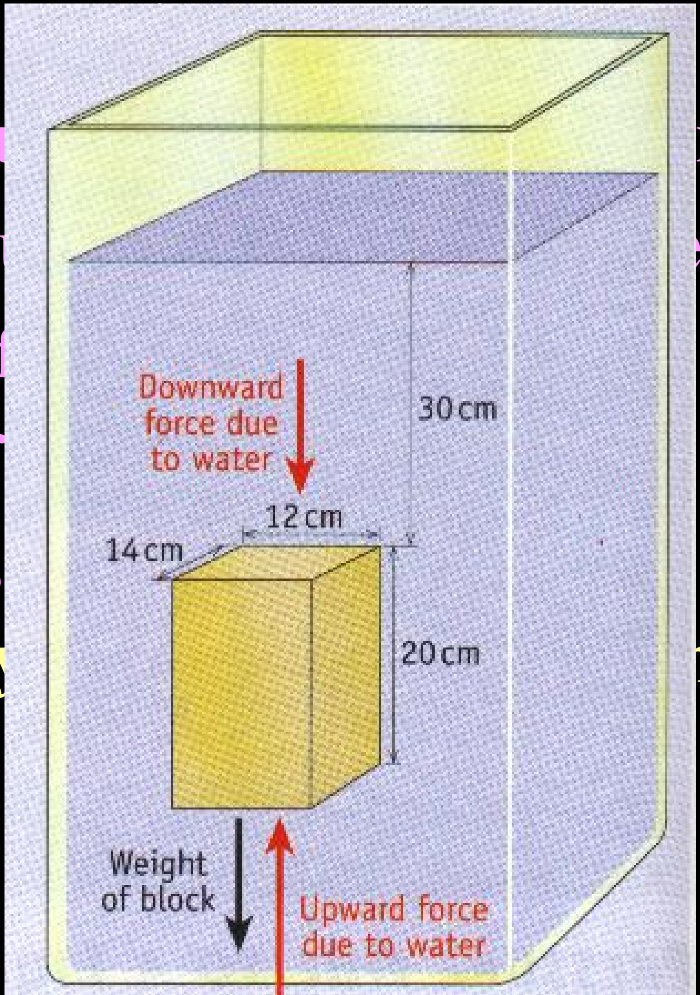


Fig. 10.6

(i) the pressure on the upper su… r,

(ii) the pressure on the lower s… r,

(iii) the force on the upper surf…

(iv) the force on the lower surf…

(v) If the weight of the block is … sink or float? (Density … m^{-3})

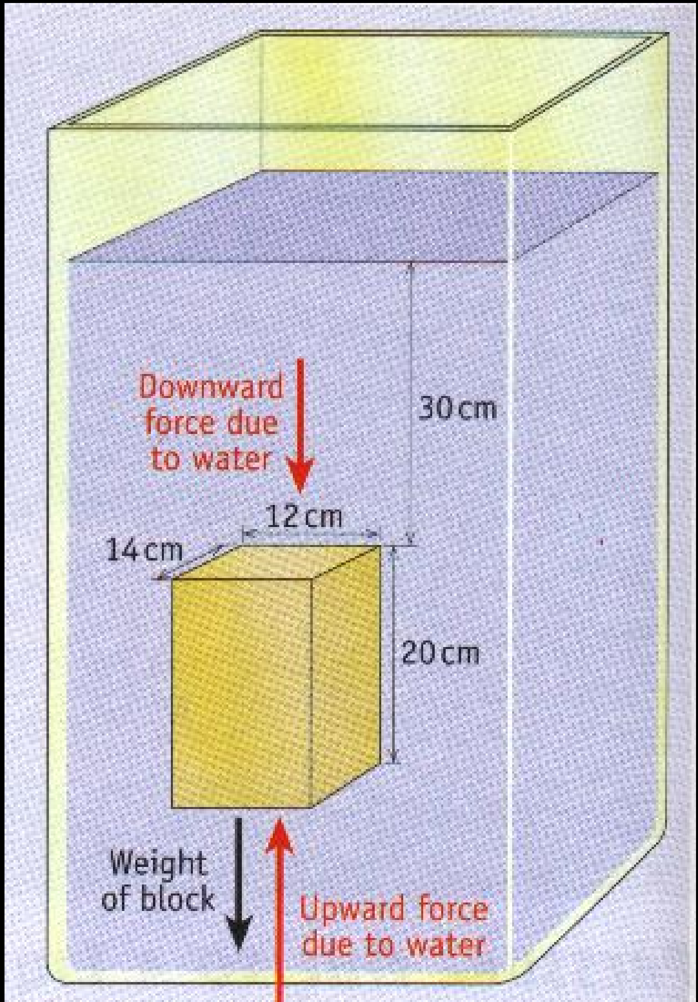


Fig. 10.6

(i) Pressure at top = $\rho g h$

= (1000)(9.8)(0.30)

= 2930 Pa

(ii) Pressure at bottom = $\rho g h$

= (1000)(9.8)(0.50)

= 4900 Pa

(iii) $F = PA$ = (2930)(0.12 x 0.14)

= 49.4 N

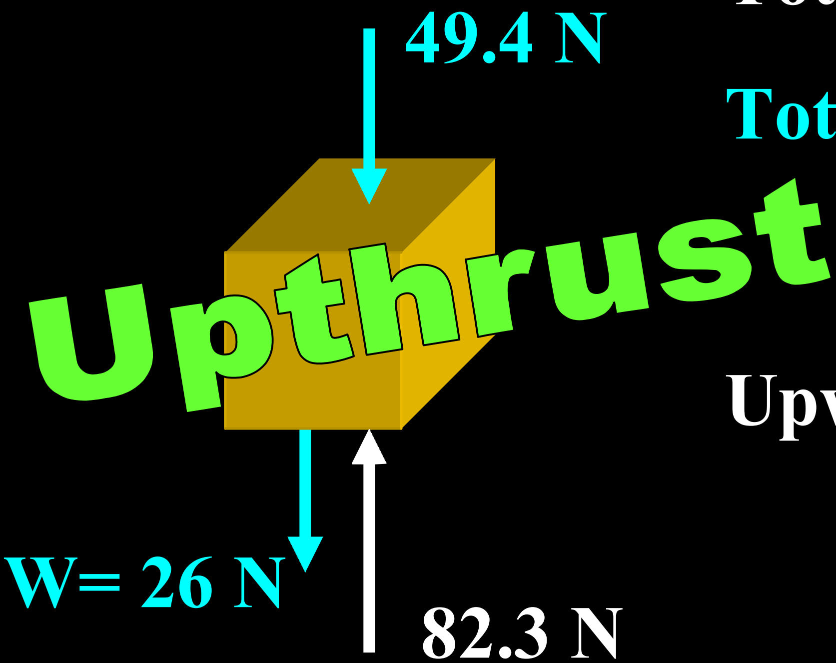
(iv) $F = PA$ = (4900)(0.12 x 0.14)

= 82.3 N

Sink or Float?

or Upthrust = (82.3 - 49.4) = 32.9 N

Upthrust > Weight ⇒ Floats



Total upward force = 82.3 N

Total downward force = 49.4 + 26

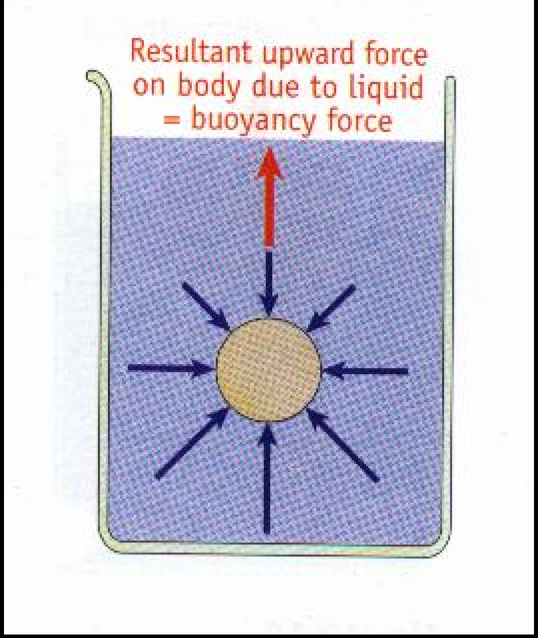
= 75.4 N

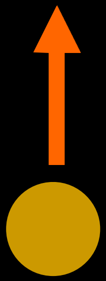
Upward force > Downward force

⇒ Floats

Upthrust

- Archimedes Principle
- Law of Floatation





Upthrust
or **Buoyancy Force**

Archimedes

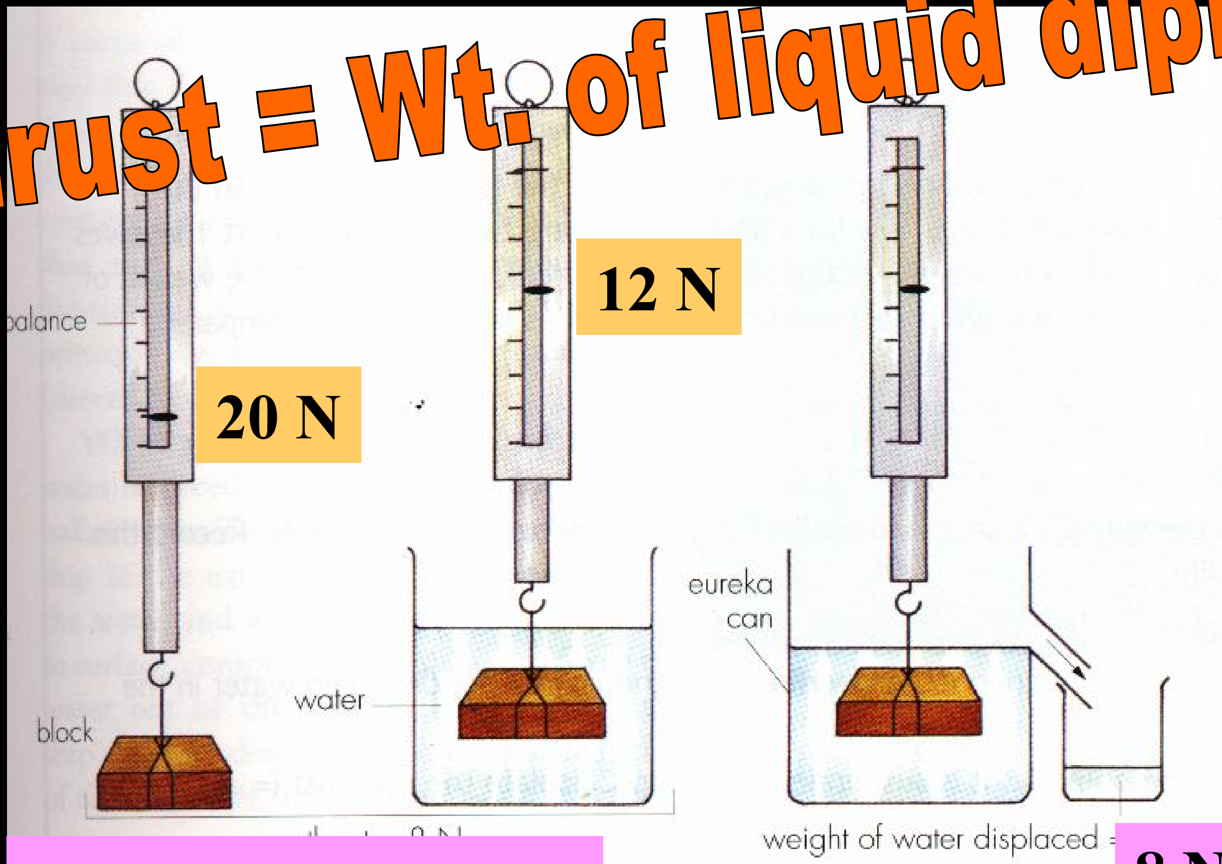
Archimedes Principle

When an object is partially or completely immersed in a fluid

Upthrust = Weight of fluid displaced

Archimedes Principle

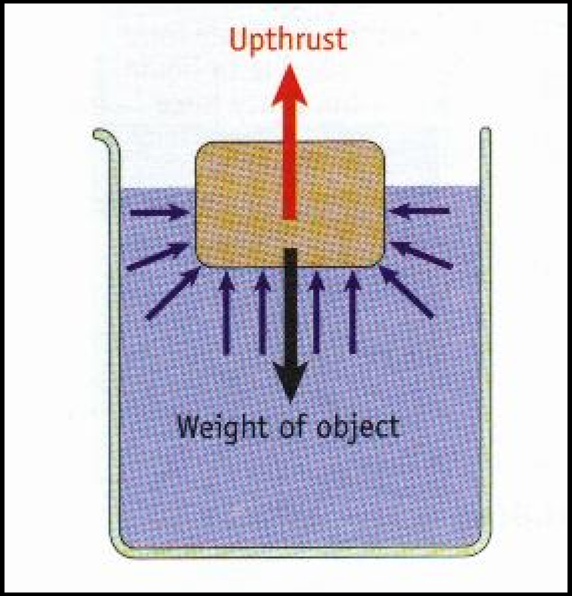
Upthrust = Wt. of liquid diplaced



8 N

Upthrust = (20 - 12)
= 8 N

Law Of Floatation



Since objects floats …

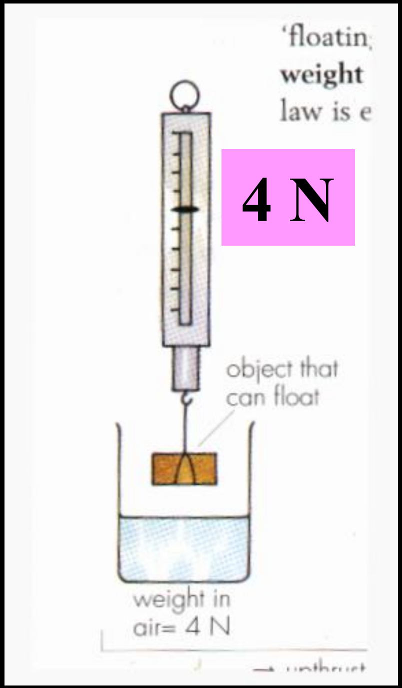
Wt. of floating body = Upthrust

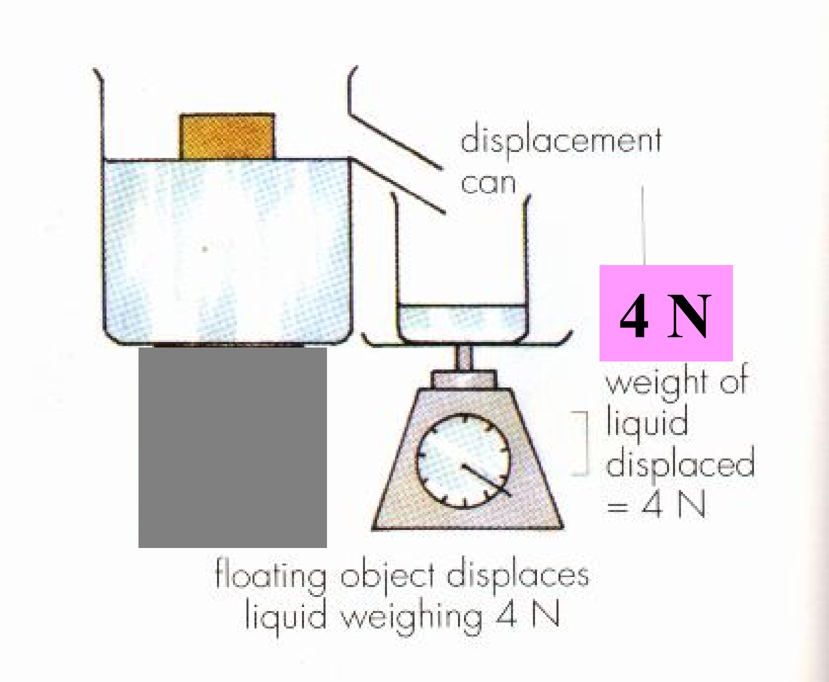
Wt. of floating body

= Wt. of liquid displaced

Law Of Floatation

Wt. of floating object = Wt. of liquid displaced





Hydrometer

Scale … density
e.g 700 - 1200

Bulb for buoyancy

Lead shot … upright

Based on …

Law of Floatation

(Wt. of hydrometer

= Wt. of liquid displaced)

The denser the liquid …

the higher the hydrometer floats

Uses Of The Hydrometer

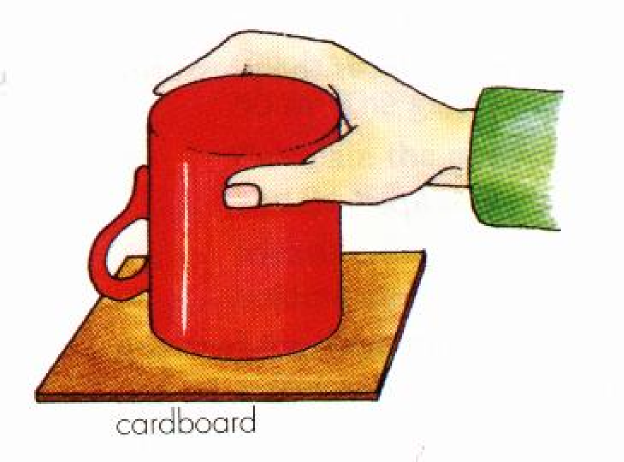
- » % of alcohol in beers & wines
- » Density of H_2SO_4 in car battery … state of charge
- » Milk … how much cream

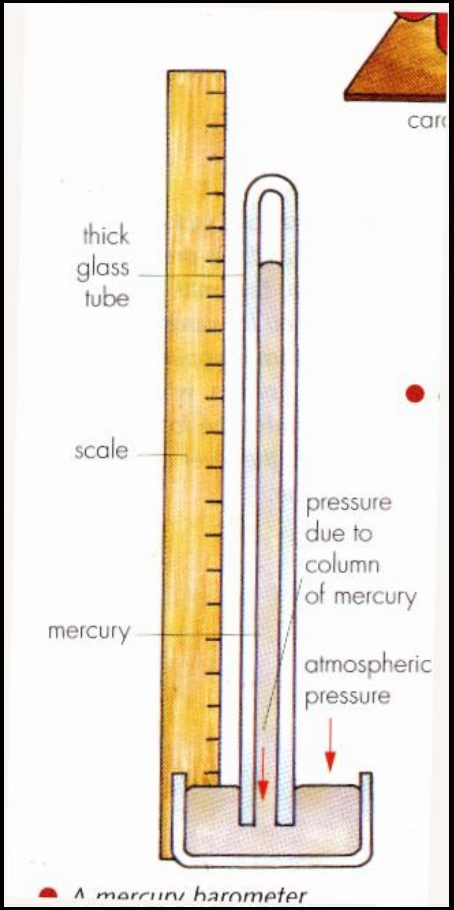
Explain the physical principles behind these:

(i) a hydrometer can measure the density of a liquid
(ii) a submarine can both sink and float.

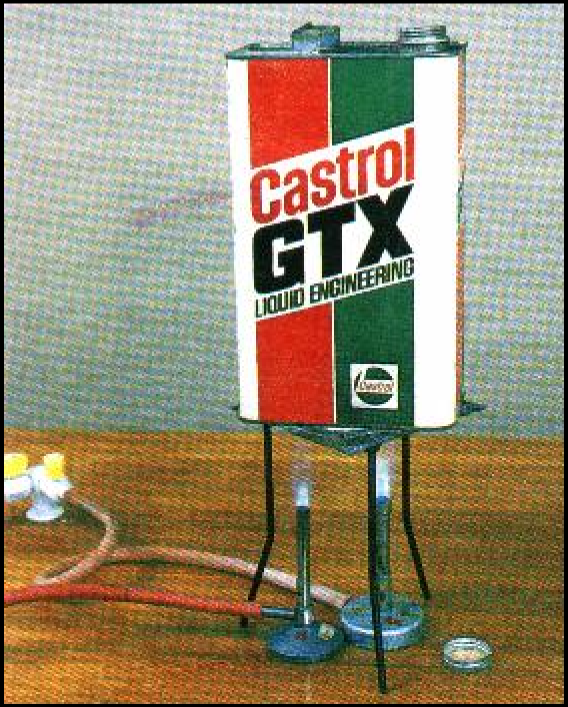
Pressure In Gases

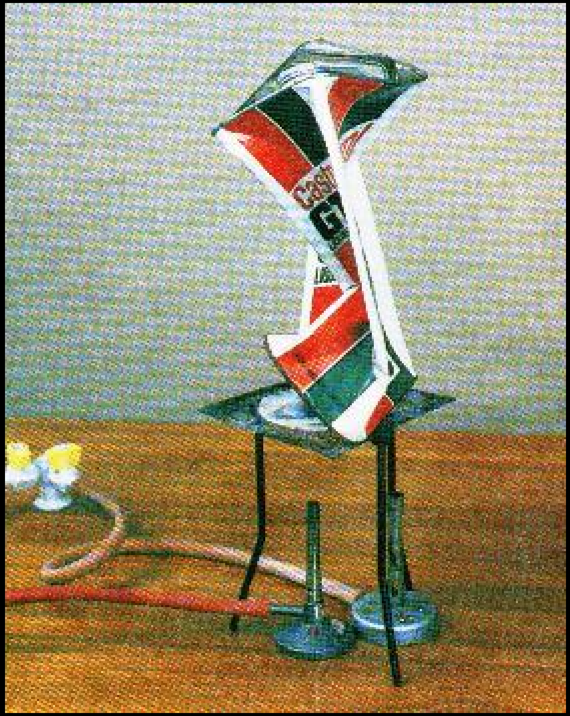
Atmospheric Pressure



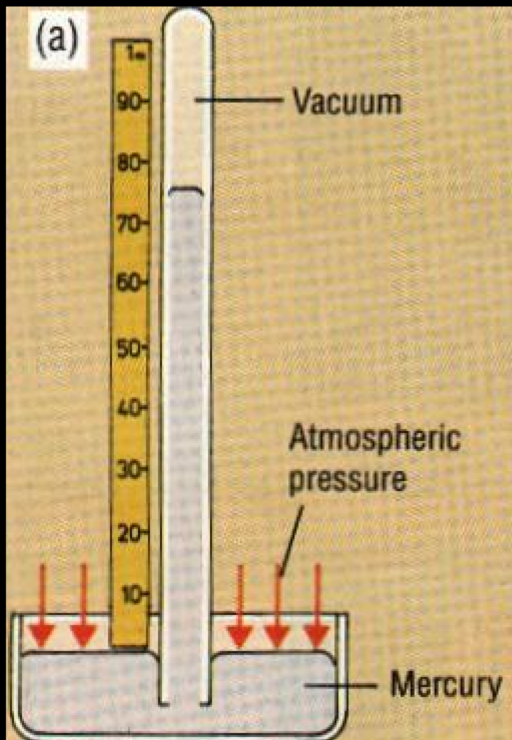


To Demonstrate Atmospheric Pressure

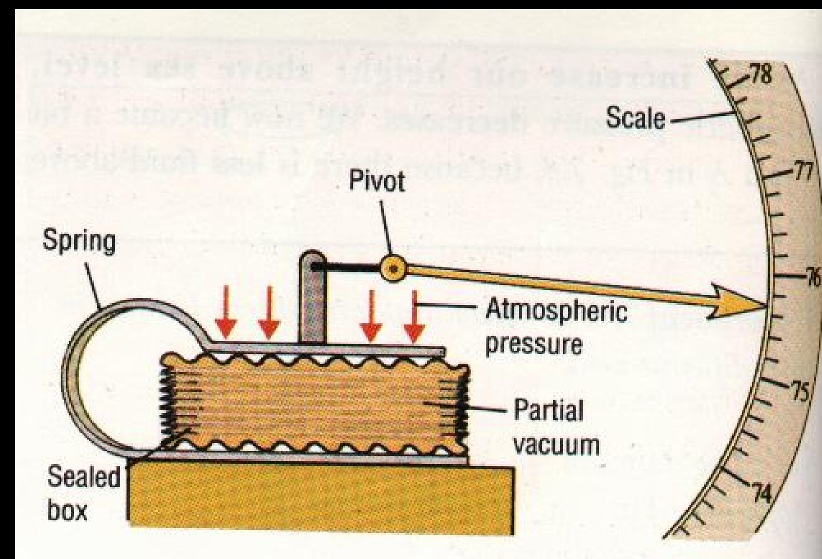




To Measure Atmospheric Pressure

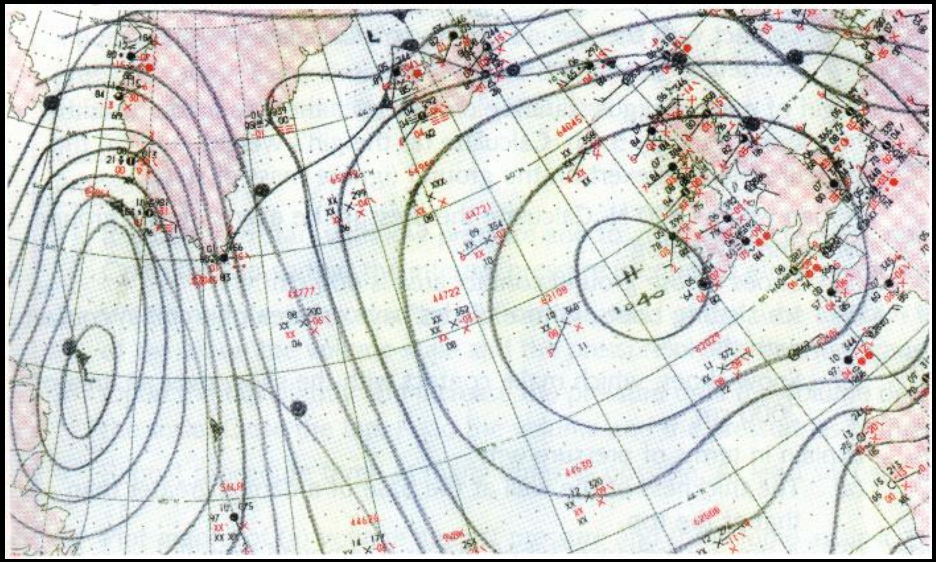


Atmospheric Pressure = 1.0 x 10^5 Pa



Atmospheric Pressure = 760 mm Hg

Weather & Atmospheric Pressure



High Pressure

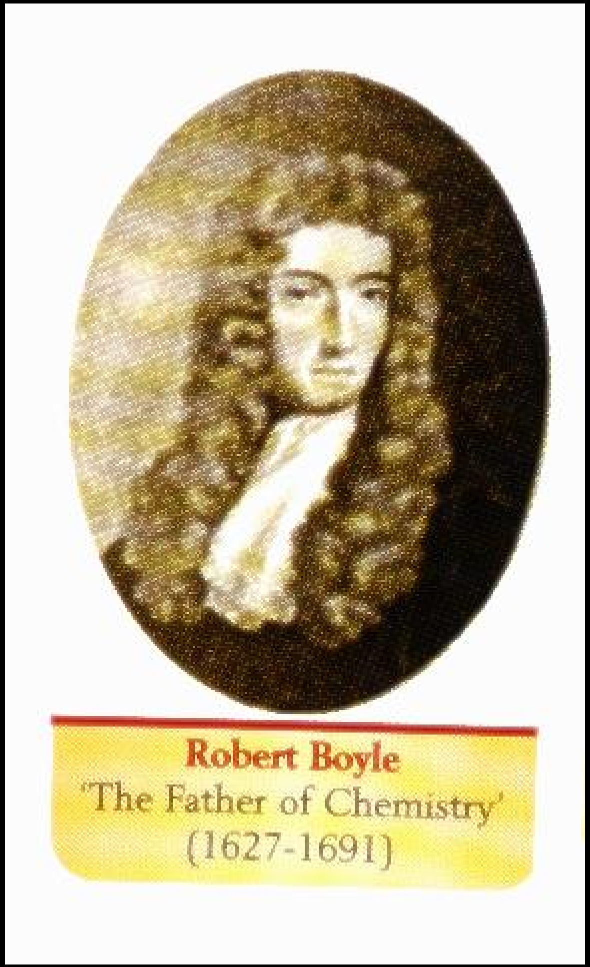
Low Pressure

Other Environments

- Mountains (High Altitude) — Oxygen
- Aircraft — Pressurised
- Spacecraft — Artificial Atmosphere
- Deep-Sea Diving — “the bends”

Atmospheric Pressure doubles every 10 m
Nitrogen into blood
Decompression

Robert Boyle

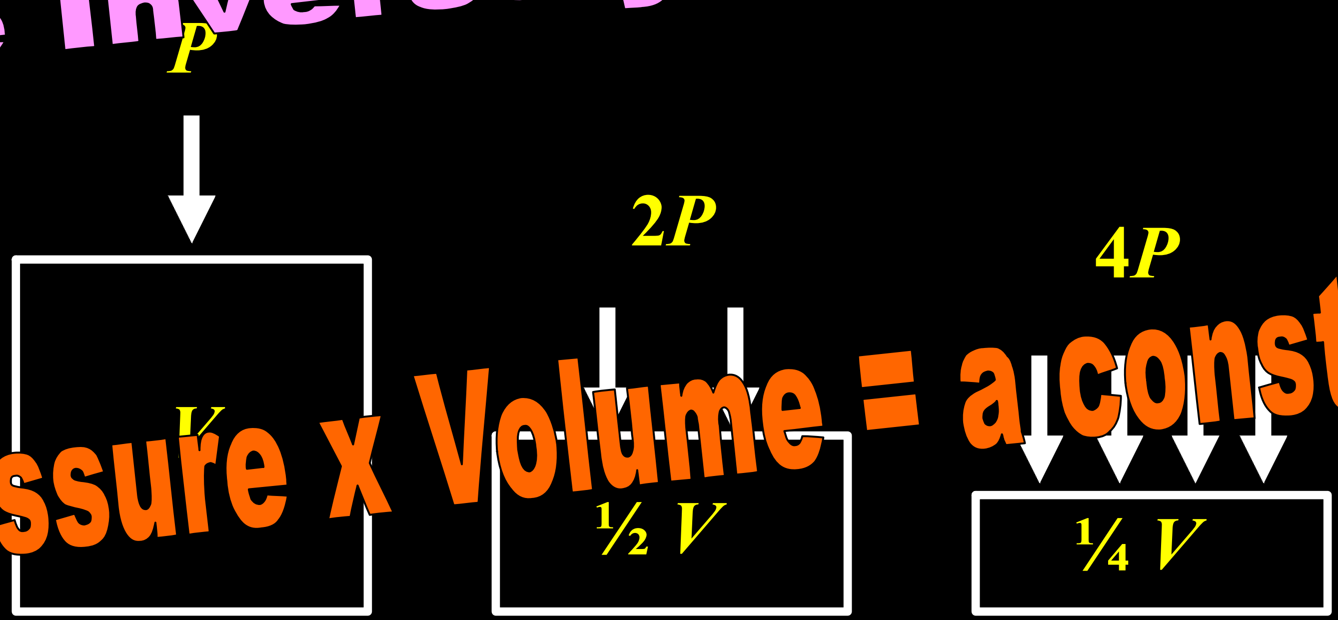


- Born in Lismore Castle
- 14th child of the Earl of Cork
- A lot of vacuum work
- Designed his own vacuum pump
- Showed lead and feather fall at same rate in vacuum
- Showed sound does not pass through a vacuum
- First to collect a gas
- Law = 1662
- Investigated nature of air
- Candle will not burn if air removed

Boyle's Law

How the volume of a gas
depends on
the pressure applied to the gas ...

Pressure and Volume are Inversely Proportional



Pressure x Volume = a constant

Boyle's Law

Pressure is inversely proportional to Volume
for a fixed mass of gas
at constant temperature

$$P \;\alpha\; \frac{1}{V}$$

$$P = k\left(\frac{1}{V}\right)$$

$$PV = k$$

$$PV = \mathrm{k}$$

for a fixed mass of gas
at constant temperature

Boyle's Law

$$PV = k$$

$$\Rightarrow \; P_1V_1 = P_2V_2$$

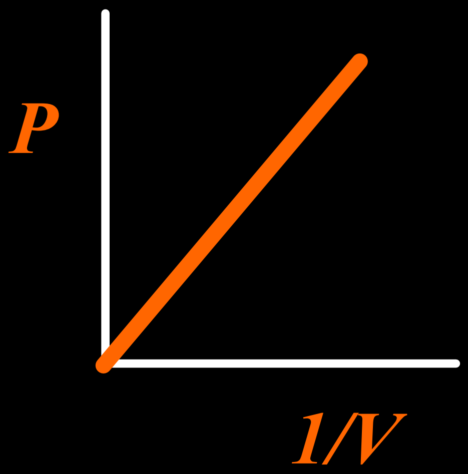
P9 **The volume of a certain mass of gas is 600 cm^3 at a pressure of 1 x 10^5 Pa. Find its volume if the pressure changes to 3.2 x 10^5 Pa, the temperature remaining constant.**

$$P_1V_1 = P_2V_2$$

$$(1 \times 10^5)(600) = (3.2 \times 10^5)\, V_2$$

$$V_2 = 187.5 \text{ cm}^2$$

To Verify Boyle's Law



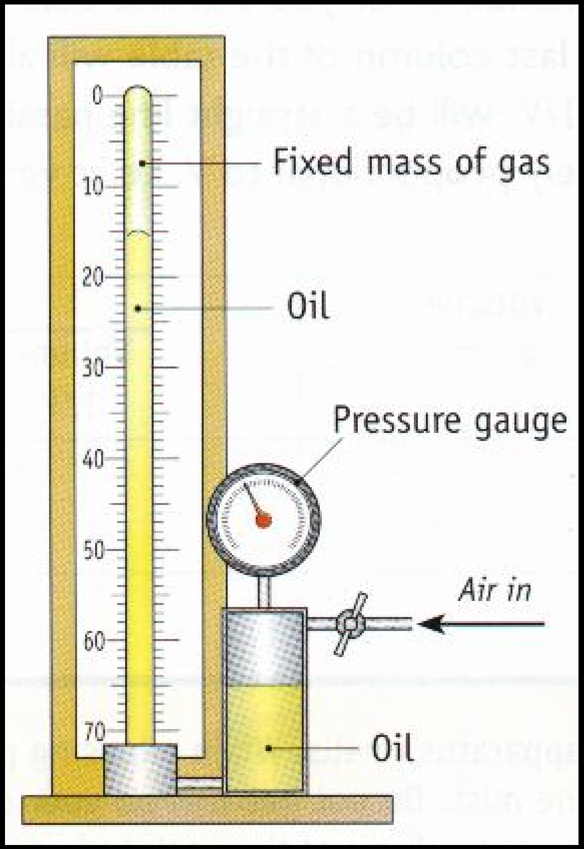
"SLTO"

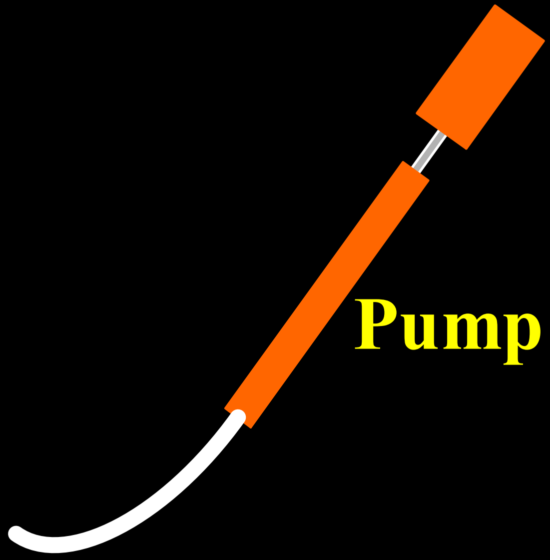
$\Rightarrow$ $P \alpha \ 1/V$

<u>or</u> **Show that PV = a constant**

Expt. - To Verify Boyle's Law

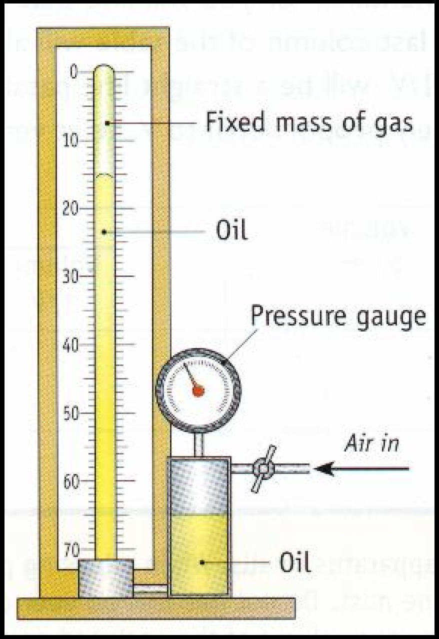
Apparatus





Expt. - To Verify Boyle's Law

Procedure



1. Apply different pressures .. pump and take readings.
2. Measure …
   - *P* and *V*
3. *P* = (gauge reading + atm. press.)
   V is read from the volume scale.
4. Repeat - different pressures (use the pump)
   - to graph.

Expt. - To Verify Boyle's Law

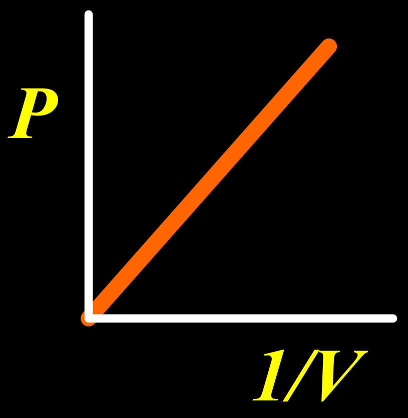
Results

P / atm.	V / cm^3	$1/V$	PV
1.0	45.2	0.022	45
1.5	30.4	0.033	46
2.0	23.1	0.043	46
2.5	18.4	0.054	46
3.0	15.1	0.066	45
3.5	12.8	0.078	45
4.0	11.4	0.088	46
4.5	9.9	0.101	45

Precautions

- Temp. constant … 1 minute
-

Method 1



"SLTO"

$\Rightarrow P \propto 1/V$

Method 2

$PV = \text{a constant}$

$\Rightarrow P \propto 1/V$

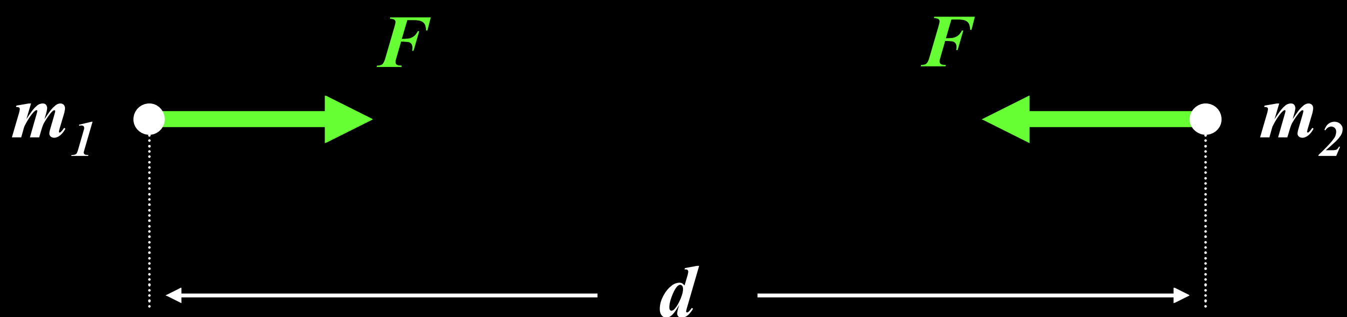
Gravitation

Isaac Newton

1666

Masses attract each other

Newton's Law Of Universal Gravitation



$$F \; \alpha \; m_1$$

$$F \; \alpha \; m_2$$

$$F \; \alpha \; \frac{1}{d^2}$$

$$\Rightarrow \quad F \; \alpha \; \frac{m_1 m_2}{d^2}$$

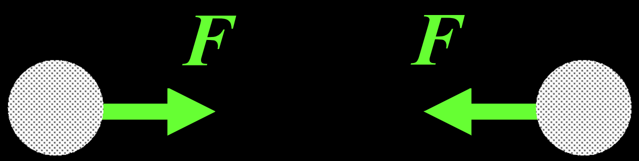
$$\Rightarrow \quad F = G \frac{m_1 m_2}{d^2}$$

Newton's Law Of Universal Gravitation

$$F = G\frac{m_1 m_2}{d^2}$$

Henry Cavendish (1731)

$G = 6.7 \times 10^{-11}$ … tiny



Two golf balls, 30 cm apart

$F = 7.5 \times 10^{-12}$ N

Compare: Your weight = ??

~ 750 N

Newton's Law Of Universal Gravitation

The gravitational force between two bodies is negligible unless …

at least one of the bodies has a very large **mass**

Example:

You and the Earth

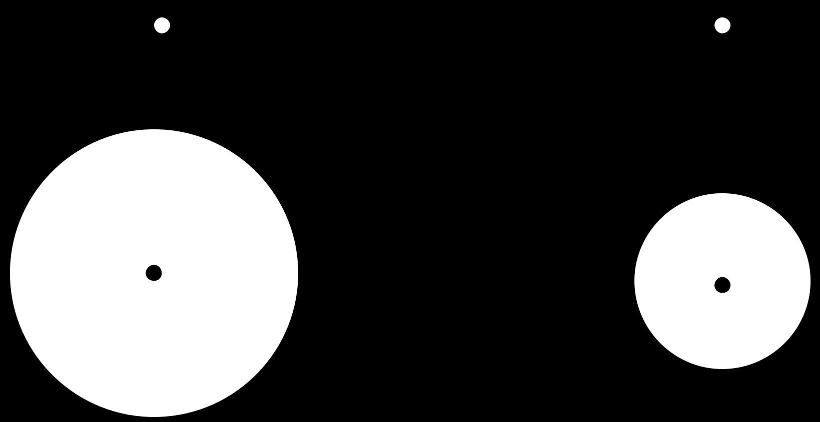
$F = ??$

750 N

Newton's Law Of Universal Gravitation

Point Masses

But …



Inverse Square Law

$$F \, \alpha \, \frac{1}{d^2}$$

$$y \, \alpha \, \frac{1}{x^2}$$

The units of G = ??

$$F = G\frac{m_1 m_2}{d^2}$$

$$\Rightarrow G = \frac{Fd^2}{m_1 m_2}$$

$$\Rightarrow Units\ of\ G = \frac{Nm^2}{kg.kg}$$

$$N\ m^2\ kg^{-2}$$

P10 **Find the gravitational force of attraction between two steel spheres, each of mass 80 kg, if the distance between their centres is 0.5 m.**
($G = 6.7 \times 10^{-11}$ N m^2 kg^{-2})

$$F = \frac{G m_1 m_2}{d^2} = \frac{(6.7 \times 10^{-11})(80)(80)}{(0.5)^2}$$

$$= 1.72 \times 10^{-6} \ N$$

P11 Find the **gravitational attraction** between a man of mass **90 kg** and the **Earth** when the man is standing on the surface of the Earth. (Mass of Earth = 6.0×10^{24} kg, radius of Earth = 6.4×10^{6} m, $G = 6.7 \times 10^{-11}$ N m^2 kg^{-2})

$$= \frac{G m_1 m_2}{d^2} = \frac{(6.7 \times 10^{-11})(6.0 \times 10^{24})(90)}{\ldots}$$

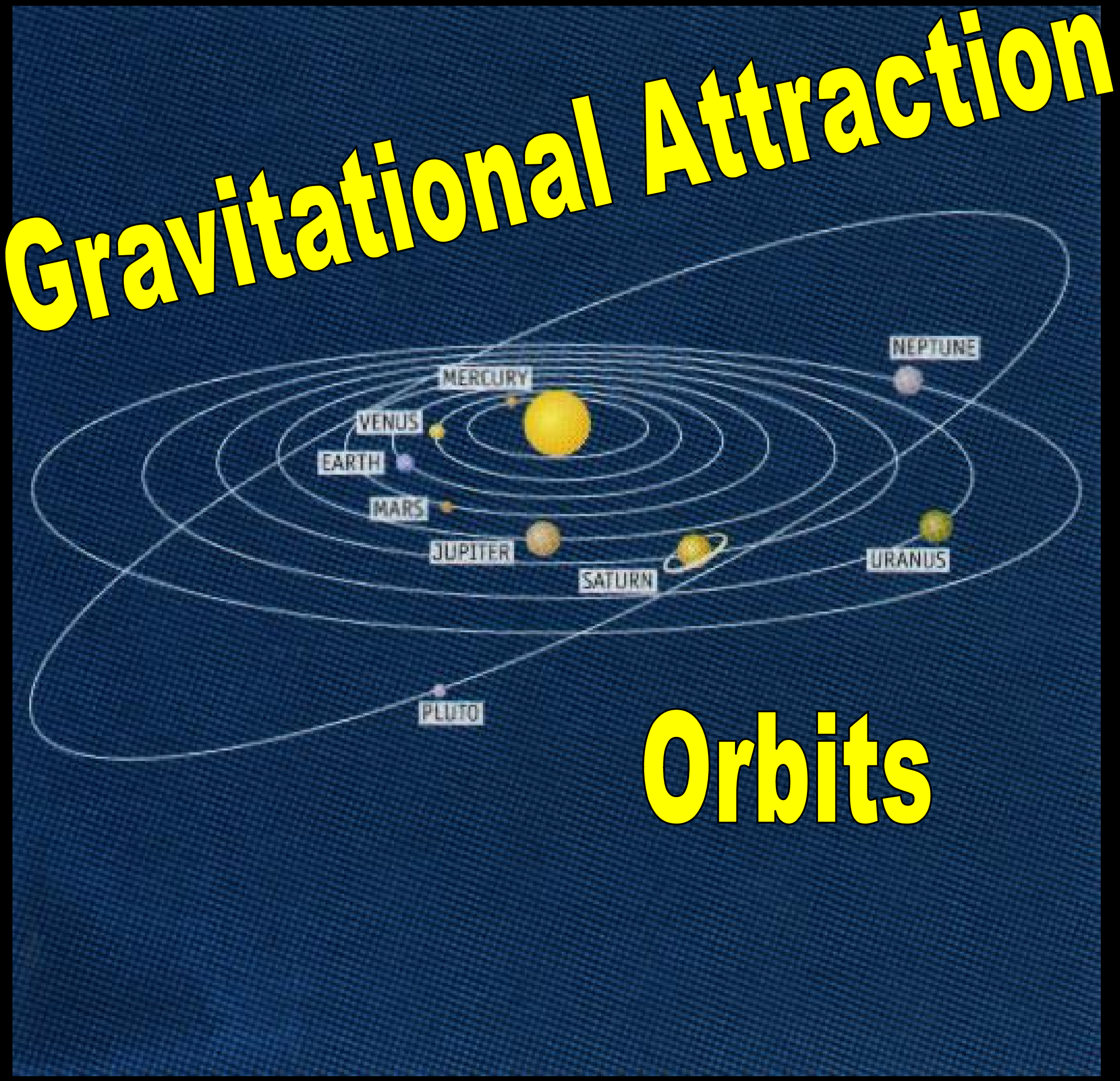
$= 883\ N$

or

F = Weight = mg = (90)(9.81) = 883 N

Solar System

Also … Satellites & Moons



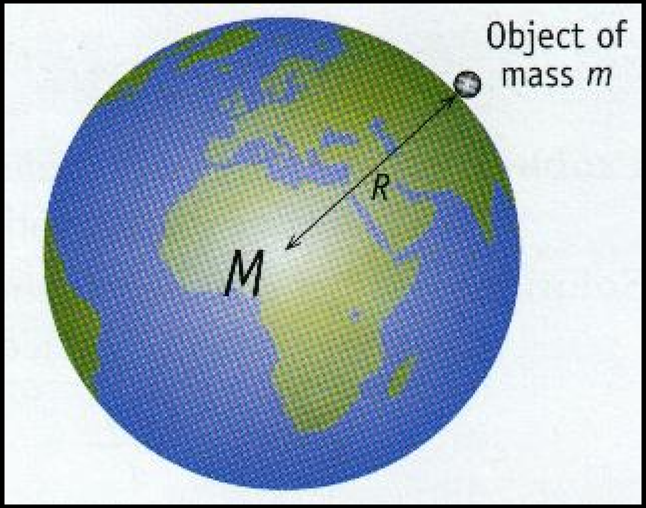
Is There An Atmosphere?

Moon … no atmosphere

There is no … ets / moons

si … k

Gravity & Weight



$$W = \frac{GMm}{R^2}$$

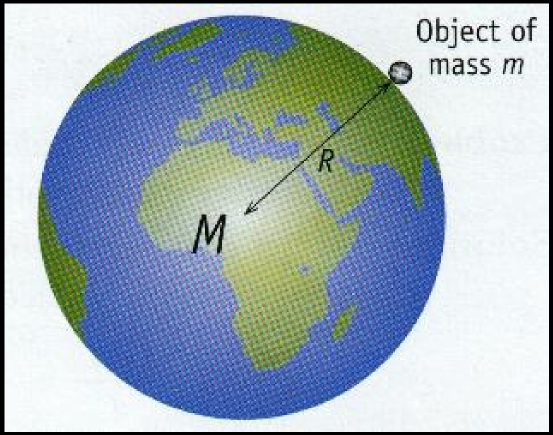
$$W = mg$$

$$\Rightarrow \quad mg = \frac{GMm}{R^2}$$

$$\Rightarrow \quad g = \frac{GM}{R^2}$$

Gravity & Weight

$$g = \frac{GM}{R^2}$$



g **depends on …**

M (Mass of the Earth)

R (Radius of the Earth)

Why is *g* slightly greater at the poles than at the equator?

Poles:	$g = 9.832 \text{ m s}^{-2}$
Equator:	$g = 9.780 \text{ m s}^{-2}$
Cork:	$g = 9.812 \text{ m s}^{-2}$

Difference = 0.052 m s^{-2} (Rotation accounts for 0.034 of this)

Planets / Moon

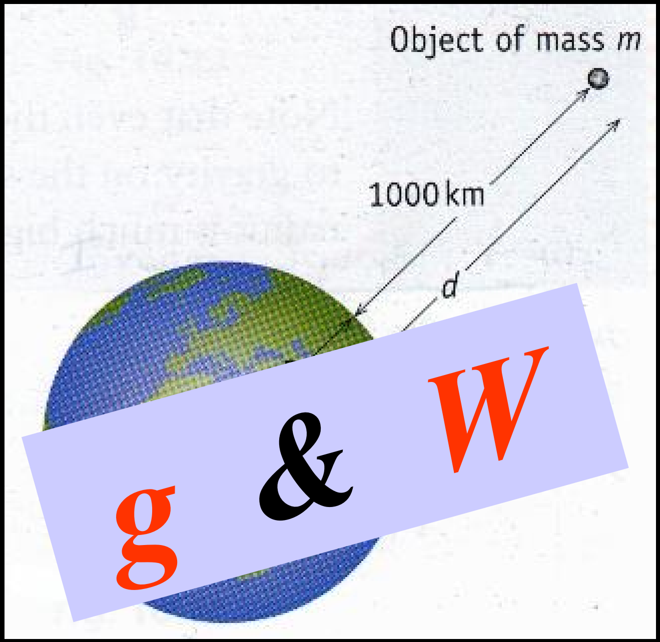
Planet	g / m s^{-2}
Mercury	3.6
Venus	8.8
Earth	9.8
Mars	3.7
Jupiter	25.5
Saturn	11.4
Uranus	9.4
Neptune	14.0
Moon	1.62

$$g = \frac{GM}{R^2}$$

Where would it be difficult to walk?

Where would it be easy to walk?

Variation With Height



$$g = \frac{GM}{R^2}$$

$$g = \frac{GM}{d^2} \qquad g = \frac{GM}{(R+h)^2}$$

1000 km height: g **= 7.3 m s^{-2}**

Mt. Everest

(8.9 km) g **= 9.76 m s^{-2}** approx

P12 **Find the acceleration due to gravity on Mars, given that the radius of Mars is 3.4×10^6 m and the mass of Mars is 6.6×10^{23} kg.**

Hence find the weight of a 90 kg mass on Mars.

$$g = \frac{GM}{R^2} = \frac{(6.7 \times 10^{11})(6.6 \times 10^{23})}{(3.4 \times 10^6)^2} = 3.8 \text{ m s}^{-2}$$

$$\text{Weight of mass} = mg = (90)(3.8) = 342 \text{ N}$$

P13 Find acceleration due to gravity 1000 km above the Earth's surface. What is the weight of a woman of mass 60 kg at this height?

$$g = \frac{GM}{(R+h)^2} = \frac{(6.7 \times 10^{11})(6.0 \times 10^{24})}{(6.4 \times 10^{6} + 1000 \times 10^{3})^2} = 7.3\ m\ s^{-2}$$

$$Weight = mg = (60)(7.3) = 438\ N$$

P14 Given that g on the surface of the Earth is 9.8 m s^{-2}, at what height above the Earth's surface is acceleration due to gravity equal to half its value on the surface of the Earth.

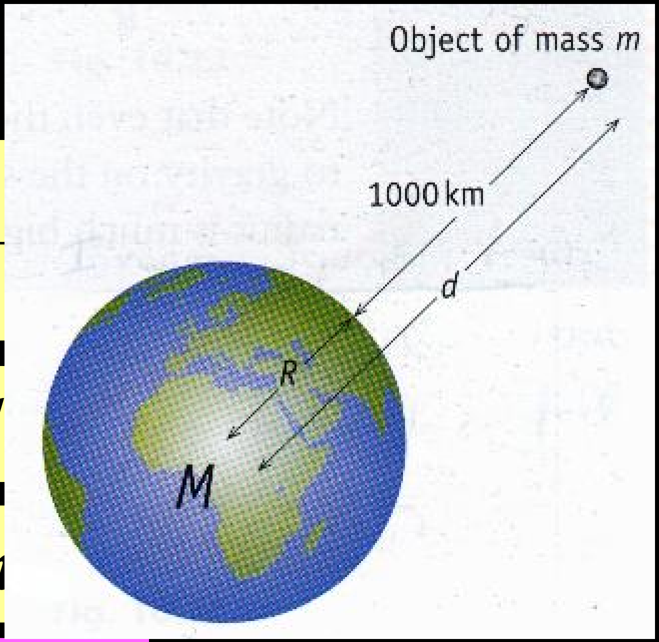
$$g = \frac{GM}{d^2}$$

$$4.9 = \frac{(6.7 \text{ x}$$

$$(R + h) = 9.1$$

$$(6.4 \text{ x } 10^6 + h$$

$$h = 2.7 \text{ x } 10^6 \text{ m}$$



P15 Find the acceleration due to gravity on the surface of Jupiter, given that the mass of Jupiter is 318 times the mass of the Earth and that the radius of Jupiter is 11 times the radius of the Earth.

$$g = \frac{GM}{R^2} = \frac{(6.7 \times 10^{11})(318 \times 6.0 \times 10^{24})}{(11 \times 6.4 \times 10^{6})^2} = 25.8 \ m \ s^{-2}$$

or

$$g \ \alpha \ M \Rightarrow g \times 318$$

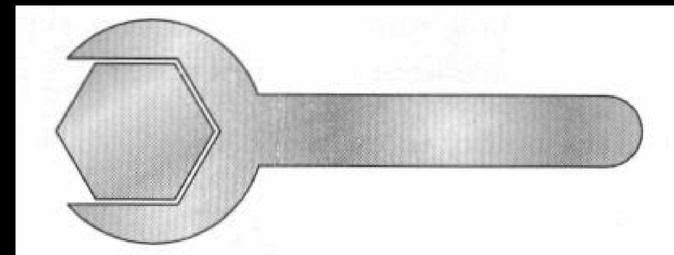
$$g \ \alpha \ \frac{1}{R^2} \Rightarrow g \div 11^2$$

$$Ans. = 9.8 \times 318 \div 11^2$$

$$= 25.8 \ m \ s^{-2}$$

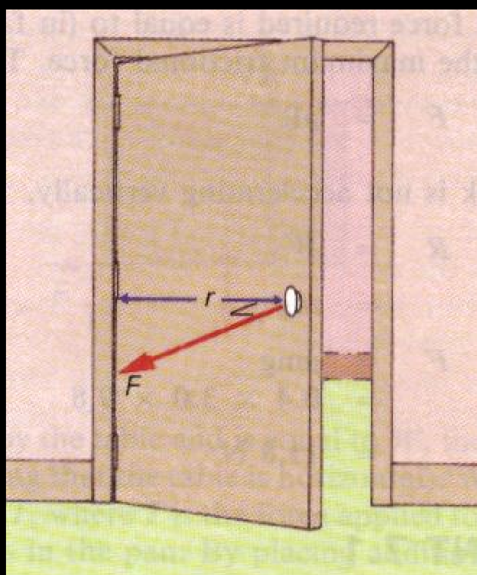
The Turning Effect Of A Force

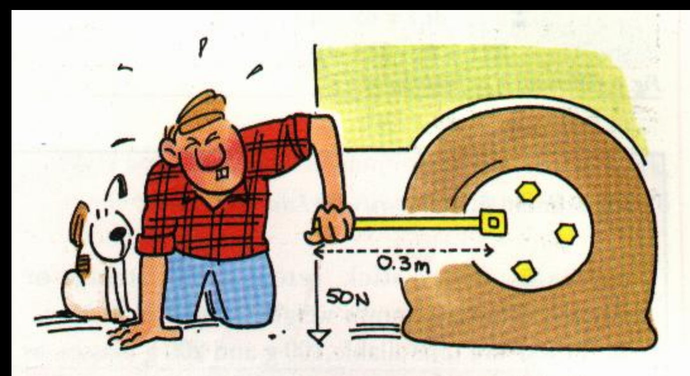
A force can accelerate a body.



But a force can also …

turn or rotate a body.



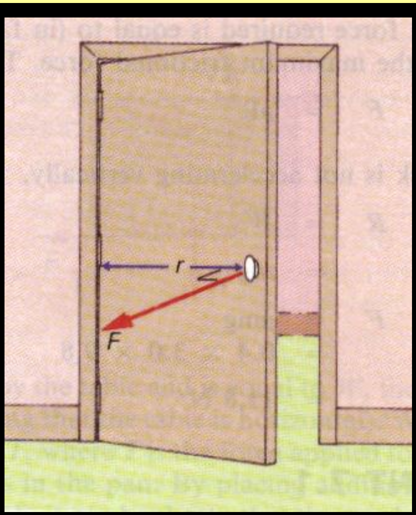


The Turning Effect Of A Force

Size of the turning effect ... **Moment Of Force**

Moment of Force

= Force x Perpendicular Distance from ...



$M = F \times d$

Moment Of Force

Unit of Moment = ??

N m

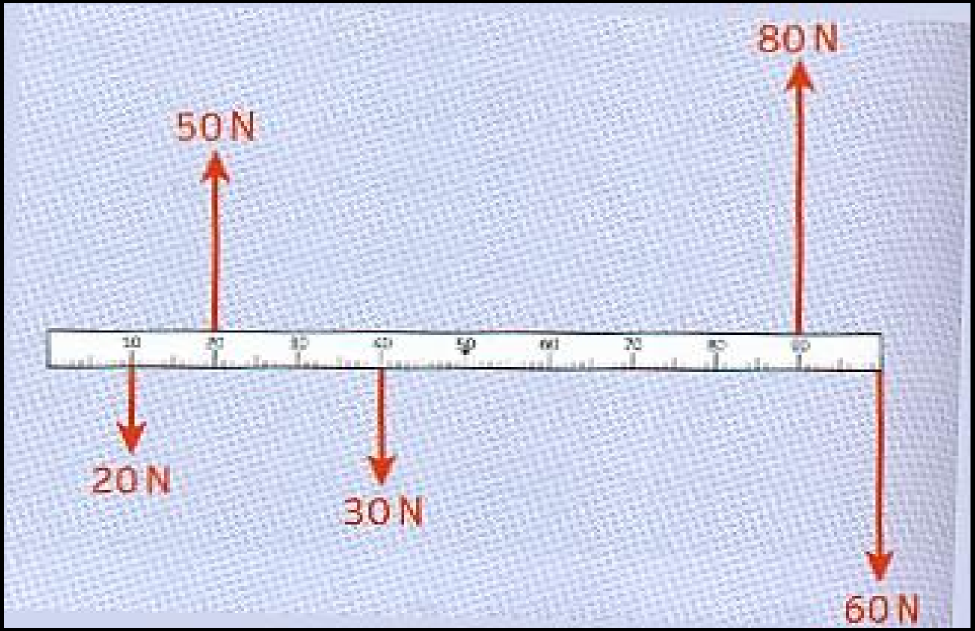
A scalar quantity

Clockwise & Anticlockwise Moments

Clockwise = +

Anticlockwise = -

P17 The diagram shows a number of forces acting on a metre stick. Find the sum of the moments of theses forces about the centre of the metre stick.



Clockwise Moments

= (50)(30) + (60)(50)

= 4500 N cm

Anticlockwise Moments

= (20)(40) + (30)(10) + (80)(40)

= 4300 N cm

Sum of Moments = + 4500 - 4300

= + 200 N cm

Clockwise

Equilibrium

A body is said to be in equilibrium when …

- **the body as a whole is not accelerating**
- **the body is not rotating with angular acceleration**

Equilibrium

$$\sum F = 0$$

$$\sum T = 0$$

Conditions For Equilibrium …

1. **The vector sum of the forces in any direction is zero.**

2. **The algebraic sum of the moments about any point is zero.**

P18 A metre stick is in equilibrium under the action of the forces shown. Find the value of the force *X*.

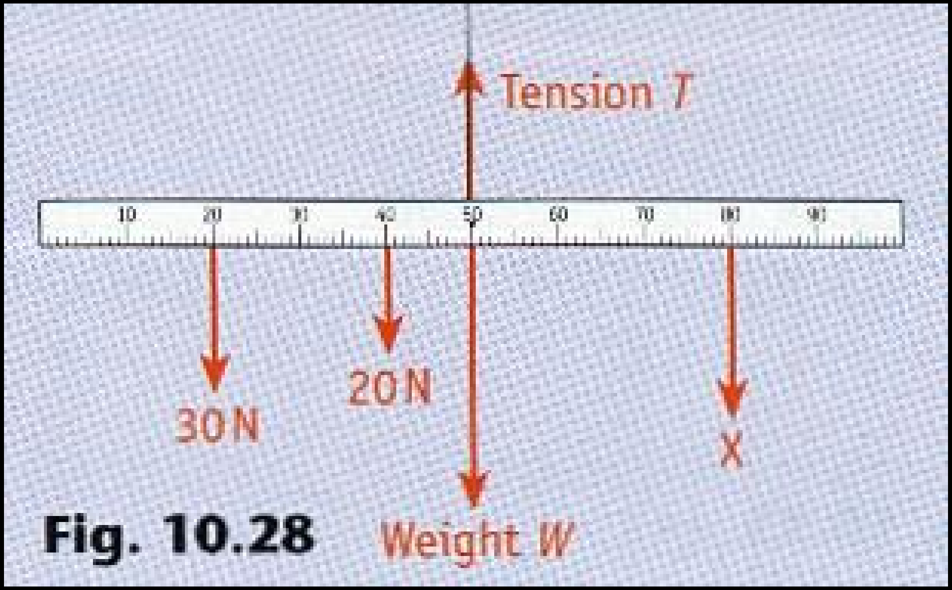


Fig. 10.28

Take moments about 50 cm.

Clockwise Moments

= (X)(30)

Anticlockwise Moments

= (30)(30) + (20)(10)

Equilibrium ⇒ (X)(30) = (30)(30) + (20)(10)

⇒ X = 36.7 N

P19 A uniform beam of length 4 m and weight 200 N rests on two supports. Find the values of the upward force each support exerts on the beam *X*.

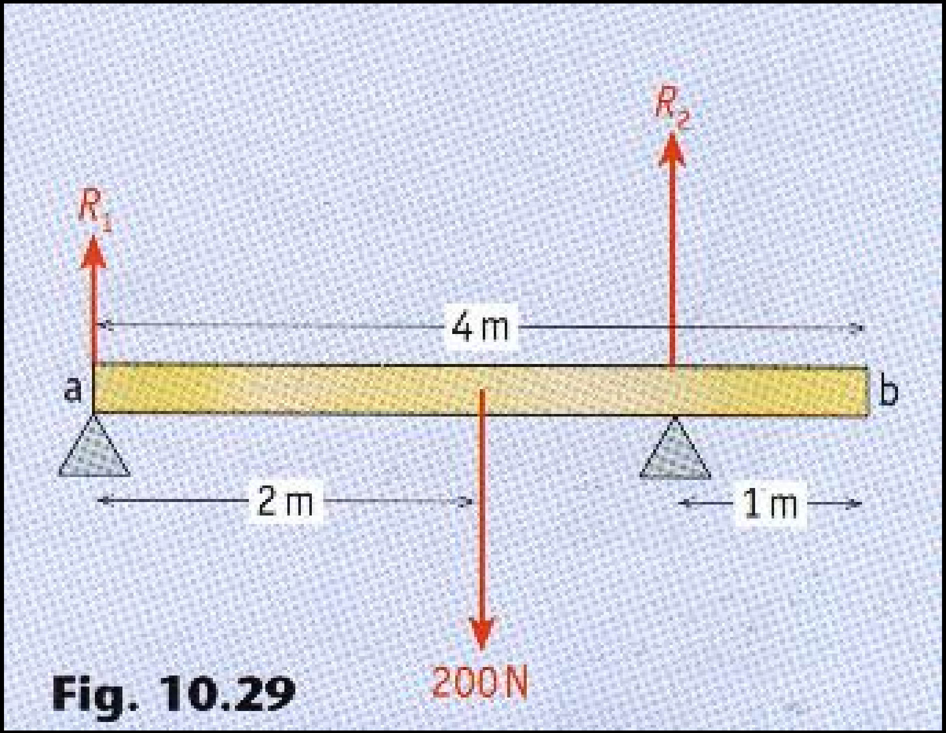


Fig. 10.29

Sum of upward forces = Sum of downward forces

$R_1 + R_2 = 200$

Take moments about *a*.

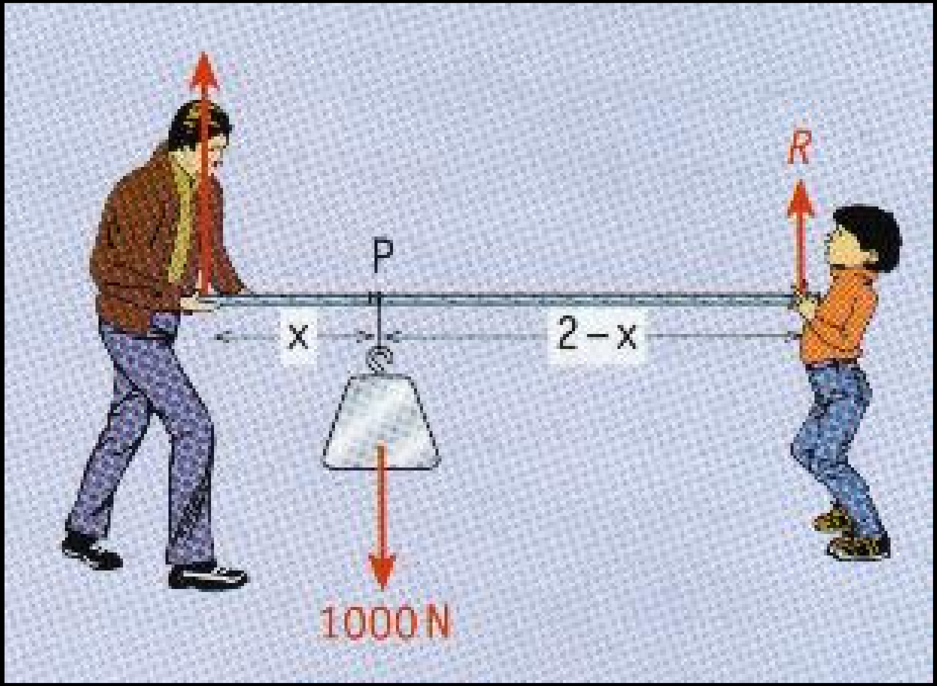
Cl. Moms. = Anti. Moms.

$(200)(2) = (R_2)(3)$

$R_2 = 133\text{ N}$

$R_1 = 67\text{ N}$

P20 **The 2 m long rod is horizontal and has a negligible weight. If the man is to exert three times the upward force as the boy, where must the weight hang?**



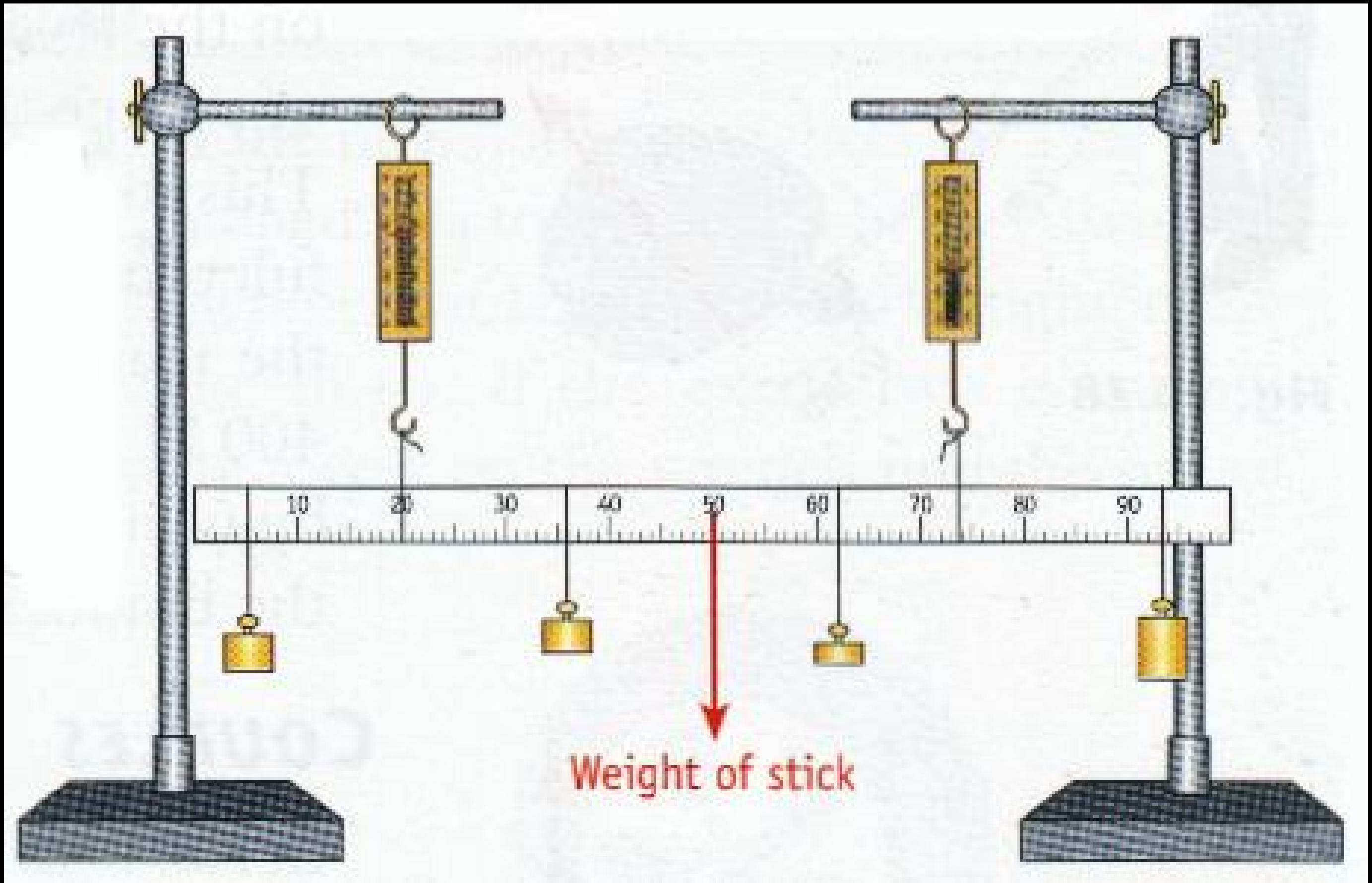
Take moments about *p*.

Clockwise = +

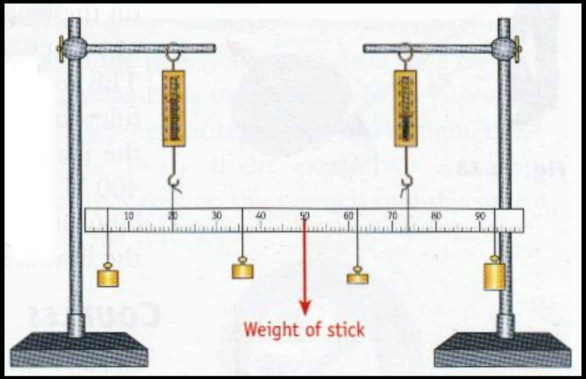
$$+ (3R)(x) - (R)(2 - x) = 0$$

$$x = 0.5 \text{ m}$$

Expt. To Investigate The Laws of Equilibrium For Coplanar Forces



Expt. To Investigate The Laws of Equilibrium



PROCEDURE

1. Equilibrium by …

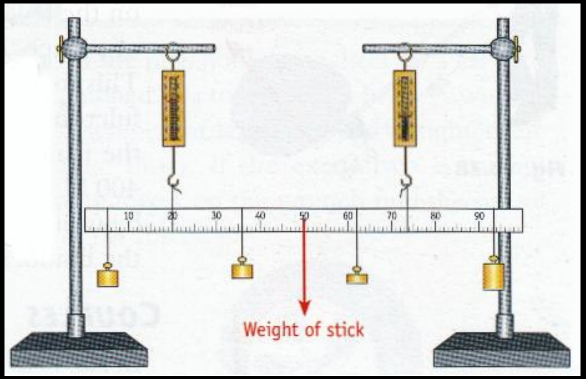
2. Find the centre of gravity …

   Measure the weight of metre stick (W).
   Record weight of each weight (W_1, W_2, W_3, W_4).
   Record each spring balance reading (R_1, R_2) .
   Choose some point to take moments about.
   Record distance of each above (7) from this point.

3. Record the weights using a spring balance.

4. Repeat … other weights/positions …

Expt. To Investigate The Laws of Equilibrium



RESULTS

1. Forces up = Forces down

$R_1 + R_2 = W + W_1 + W_2 + W_3 + W_4$

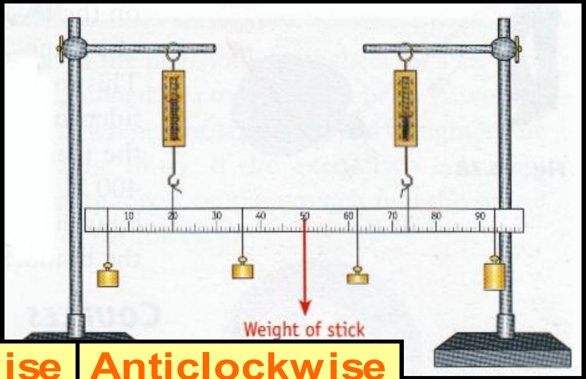
2. About any point,

Sum of clock. moments = Sum of anticl. Moments

e.g. about 0 cm …

$R_1.d_1 + R_2.d_2 = W.x + W_1.x_1 + W_2.x_2 + W_3.x_3 + W_4.x_4$

Expt. To Investigate The Laws of Equilibrium



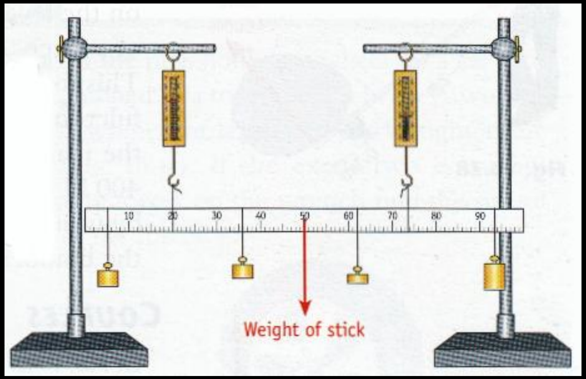
RESULTS

Force / N		Clockwise or Anticlockwise	Distance To Point (0 cm)	Clockwise Moment	Anticlockwise Moment
R1	20	Anticlockwise	20		400
R2	40	Anticlockwise	80		3200
W	2	Clockwise	50	100	
W1	10	Clockwise	10	100	
W2	20	Clockwise	30	600	
W3	28	Clockwise	100	2800	

Sum of upward forces = 20 + 40 = = 60 N
Sum of downward forces = 2 + 10 = 60 N
Therefore ... Sum of the upward forces = Sum of the downward forces

Sum of the clockwise moments = 100 + 100 + 600 + 2800 = 3600 N cm
Sum of the anticlockwise moments = 400 + 3200 = 3600 N cm
Therefore ... Sum of clockwise moments = Sum of anticlockwise mome

Expt. To Investigate The Laws of Equilibrium



PRECAUTIONS

- **Metre stick horizontal**
  … how would you check?
- **Strings vertical … how would you check?**
- **Repeat … other weights / positions … why?**
- **Etc.**

Levers

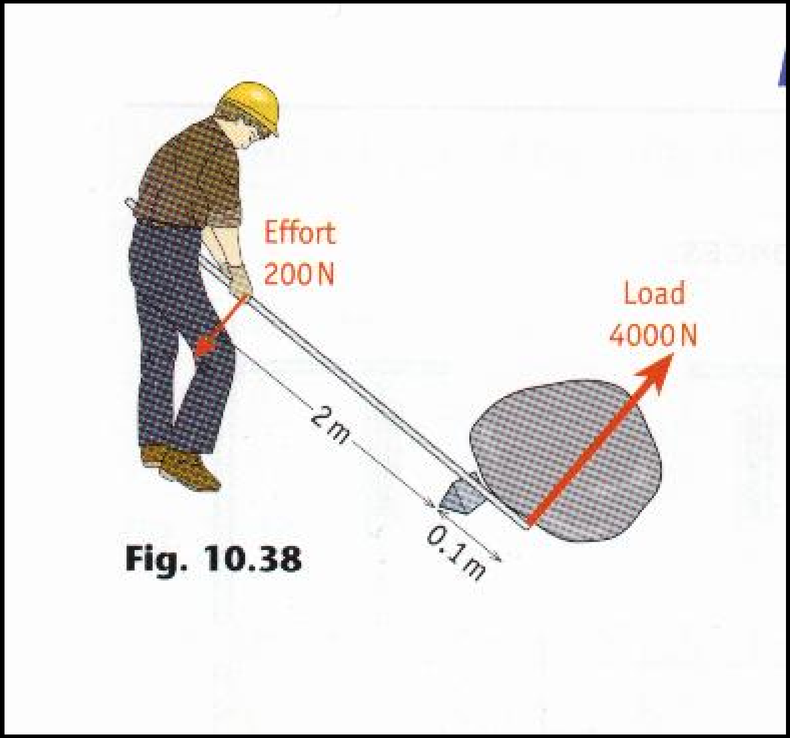


Fig. 10.38

Turning Moment Needed

= 4000 x 0.1 = 400 N m

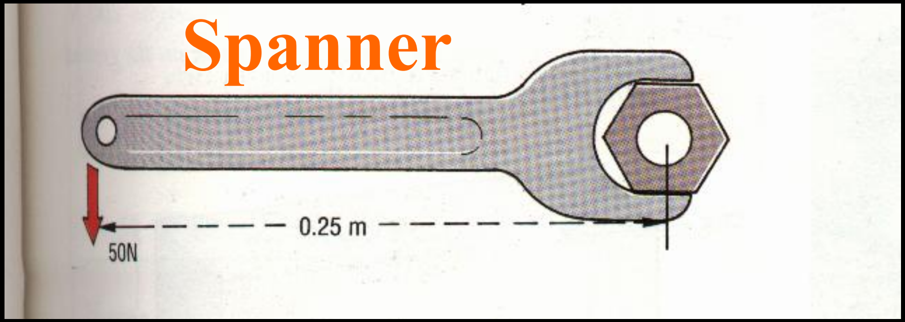
Turning Moment Supplied

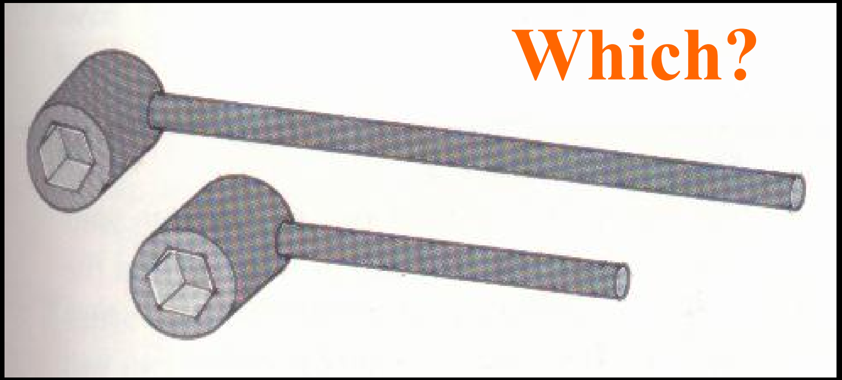
= 200 x 2 = 400 N m

A 200 N force does the "work" of a 4000 N force.

A rigid body that is free to rotate about a fixed point called the fulcrum.

Examples Of Levers





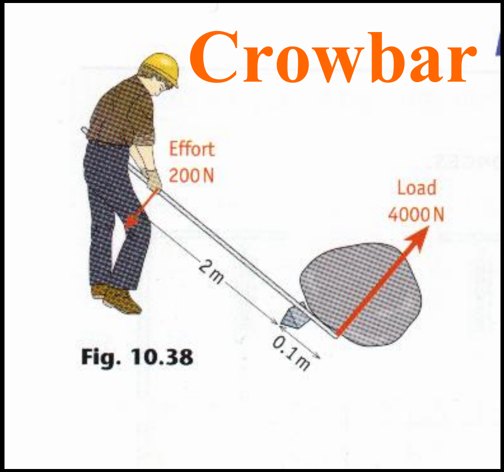
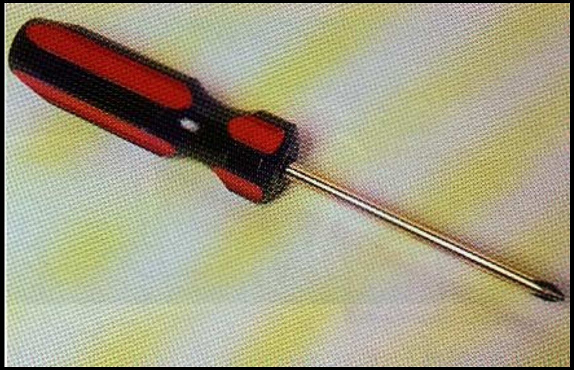


Fig. 10.38



Scissors
Tweezers
Wheelbarrow
Door .. Handle
etc.

Couple

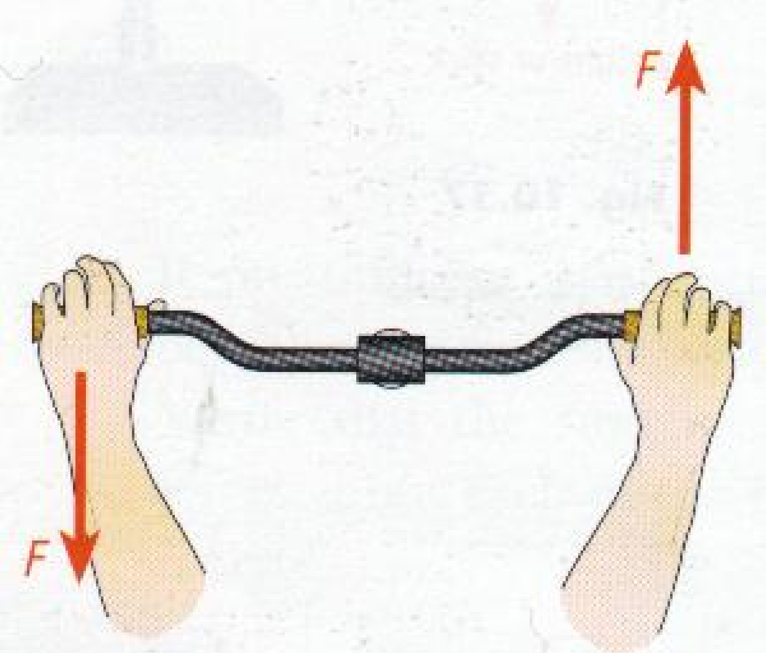


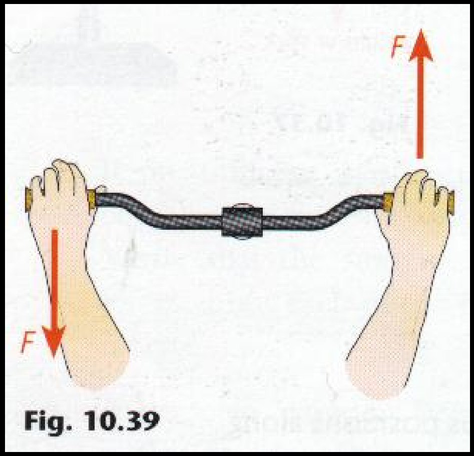
Fig. 10.39

- Two parallel forces
- of same magnitude
- in opposite directions
- not in line

$\sum F = ??$

Is there a resultant turning moment ??

Couple



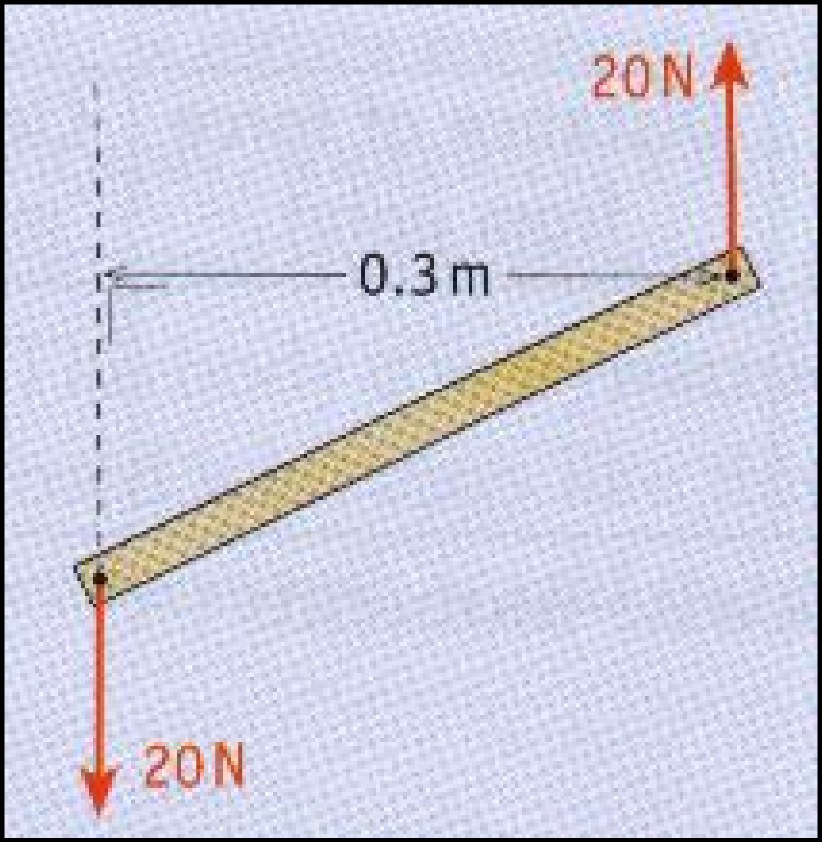
A couple produces a turning effect without acceleration.

$$T = Fd$$

Moment Of Couple (Torque)

= Force x *Perpendicular* Distance Between Them

P21 Find the moment of this couple.

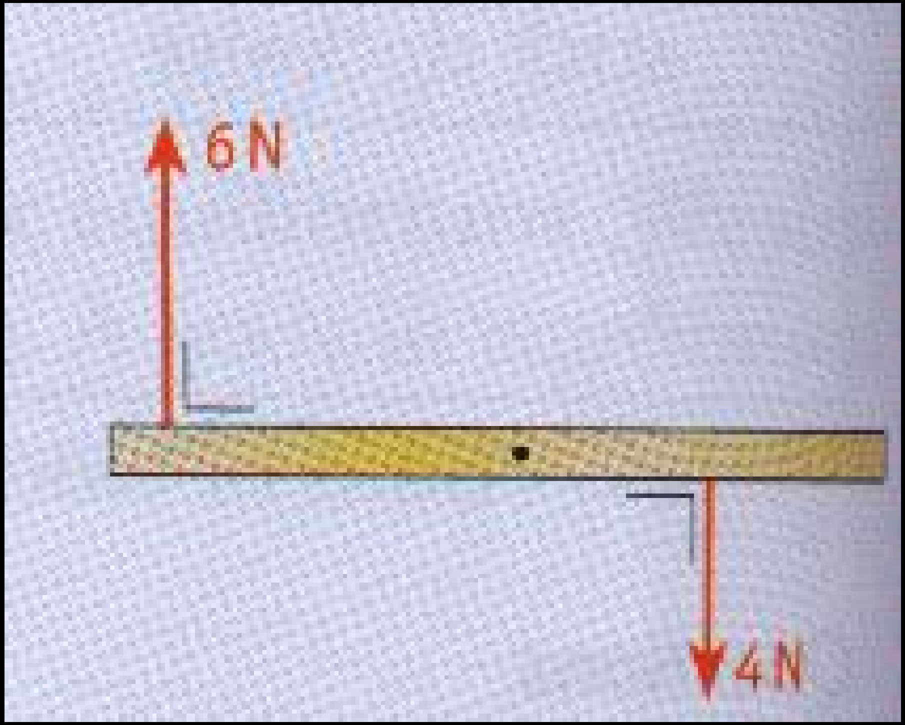


$T = F.d$

$T = 20 \times 0.3$

$T = 6 \text{ N m}$

P22 Forces of magnitude 6 N and 4 N act on a stick as shown. Describe the resulting motion of the stick.



Resultant force = + 6 - 4

= + 2 N

2 N up

Accelerates upwards

It rotates since the +4N (of the 6N) and the -4N are a couple.