Forces + Motion Revision Notes

Vector + Scalar Quantities

Scalar quantity has only magnitude or size only

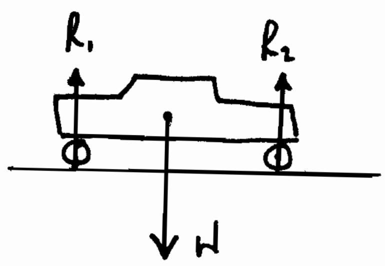
eg. mass, energy, distance, speed, temperature

Vector quantity has both magnitude + direction

eg. velocity, acceleration, force, displacement, weight

Vector quantities are often represented as arrows, where the length represents the magnitude of the vector and the direction is shown by the arrow head

eg



W = weight of car

$R_1 + R_2$ = Normal reaction forces.

Mass (kg) - Property of a body that is irrespective of location. eg. a man has a mass of 70kg both on the Earth and on the Moon.

Weight (N) - The weight of an object depends on both the mass and the ~~location~~ gravitational field strength of the object:

$$\text{Weight} = \text{Mass} \times \text{Gravitational Field Strength}.$$

$$\text{Weight} = M \times g$$

$$N = \cancel{kg} \times N/\cancel{kg}$$

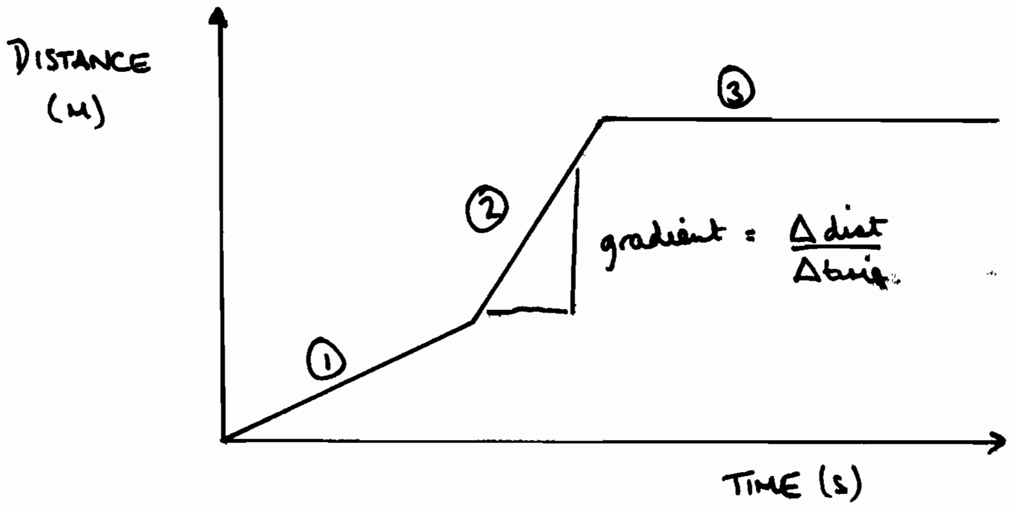
Earth's Gravitational Field Strength, g, = 10 N/kg (unless specified otherwise in GCSE papers)

Moon Gravitational Field Strength, g_{moon} = 1.6 N/kg

∴ Weight of man of mass 70kg on Earth = $M \times g = 70 \times 10 = \underline{700N}$

on Moon = $M \times g_{moon} = 70 \times 1.6 = \underline{112N}$

DISTANCE - TIME GRAPHS



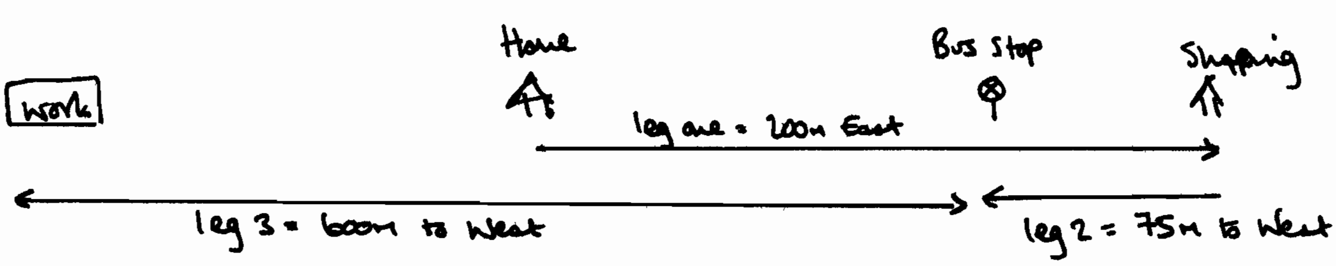
- Graph shows how the distance travelled by an object changes over time.
- The gradient of the graph ⇒ gradient = $\frac{\Delta \text{Distance}}{\Delta \text{time}}$ = Speed

∴ ① ⇒ object moving at a constant speed. ([illegible] gradient).
② ⇒ Object increases it speed. (steeper gradient).
③ ⇒ Object stationary (gradient = 0).

SPEED, DISTANCE, TIME RELATIONSHIP

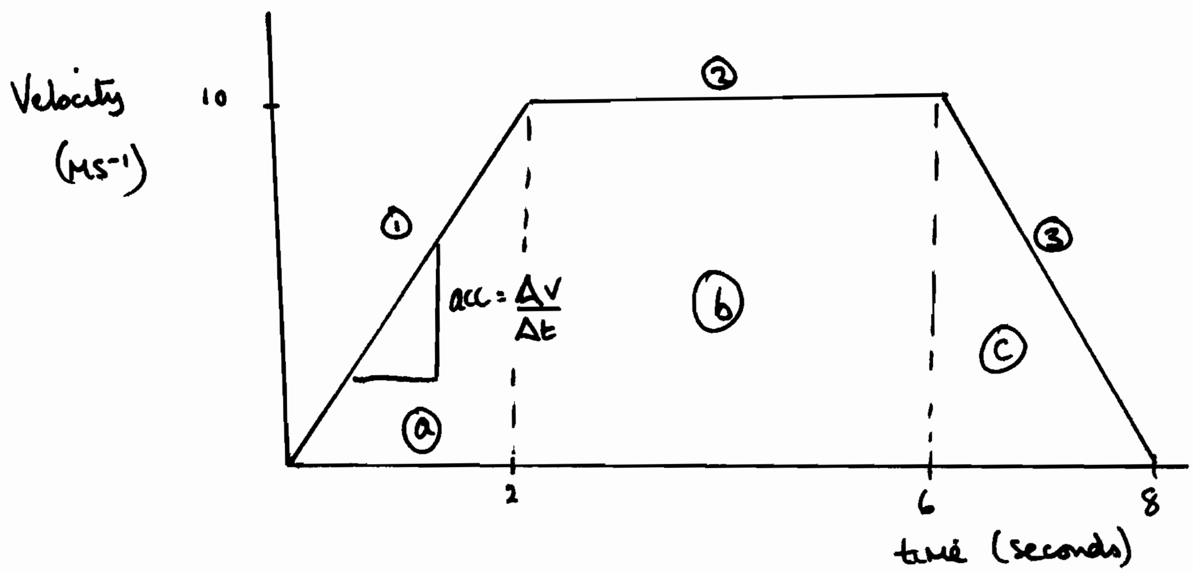
- The gradient of the above graph ⇒ Speed = $\frac{\Delta \text{distance (m)}}{\Delta \text{time (s)}}$
- Speed is measured in m/s or ms^{-1}
- Speed is a scalar quantity ∴ no defined direction. Velocity is speed in a specific direction.
- Distance is a SCALAR quantity, whilst displacement is the VECTOR equivalent.

DISPLACEMENT: Mark starts at home & makes a journey to the shop, the bus stop and then work: What is his displacement



∴ Displacement = +200m - 75m - 600m = 4[illegible]75m WEST.

VELOCITY - TIME GRAPHS.



- Velocity - Time graphs tell us 2 important things:

+ ① Gradient of the graph = the acceleration

The equation for acceleration => $\boxed{a = \frac{v-u}{t}}$ where a = acceleration
v = final velocity
u = initial velocity
t = time taken.

$\therefore$ for ① $\Rightarrow$ $a = \frac{10MS^{-1} - 0\ MS^{-1}}{2} = \underline{5MS^{-2}}$

- The units of acceleration are MS^{-2} or M/S^2 or $M/S/S$.

for ② the gradient = 0 $\therefore$ no acceleration => CONSTANT VELOCITY.

for ③ $a = \frac{v-u}{t} = \frac{0 - 10MS^{-1}}{2} = \underline{-5MS^{-2}}$ the negative gradient is called a DECELERATION

+ ② the second important fact is:

AREA UNDER A VELOCITY - TIME GRAPH = DISPLACEMENT

[Remember that $D = S \times t$] $\therefore$ it follows.

From graph → area a = triangle $\therefore$ area $= \frac{1}{2} b \times h$

$= \frac{1}{2} \times 2S \times 10MS^{-1}$

DISPLACEMENT $= \underline{5M}$

- By summing areas ⓐ + ⓑ + ⓒ we can get the total displacement by the object.

FORCES

- A force is effectively a PUSH or a PULL on an object.
- FORCE is a vector quantity
- IMPORTANT FORCES:

WEIGHT - due to the gravitational field strength.

TENSION - When an object is pulled at both ends. eg. rope in tug of war

COMPRESSION - When an object pushed at both ends eg. pillar in building

FRICTION - resistive force between two objects that opposes motion eg. brick sliding over desk, brake pads against brakes in a car.

Normal Reaction - The contact force exterted by the surface that supports an object, and it acts perpendicular to the surface (hence Normal).

NEWTONS 3 LAWS - help us understand how forces affect mechanical situations.

NEWTONS 1ST LAW - objects continue to move at constant velocity (which may be ZERO) until they acted upon by a resultant force.

Simplified this can be stated as: When no unbalanced forces acts on an object, its state of motion will be unchanged. Either a body remains at rest, or it carries on moving in a straight line at a constant velocity.

NEWTONS 2nd LAW

Newton discovered that for a fixed mass : $F_R \propto a$

and for a constant resultant force F_R : $a \propto \frac{1}{M}$

This gives Newton IInd Law

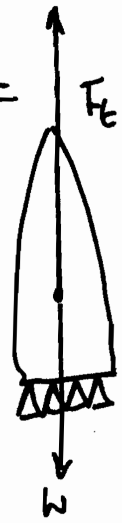
$$F_{resultant} = \text{Mass} \times \text{acceleration} \quad \text{or} \quad \vec{F} = Ma$$

$\therefore$ A force of 1N acceleration a mass of 1kg at $1\,ms^{-2}$

• It is vital that the term 'resultant force' is understood:

The resultant force is the 'unbalanced force'.

<u>Example</u>



Spaceshuttle:

Engine produced an upward thrust force F_T

Spaceshuttle has Weight of W.

<u>FACT</u>: F_T must be greater that W for spaceshuttle to lift off.

∴ What is the resultant force, and ∴ the acceleration

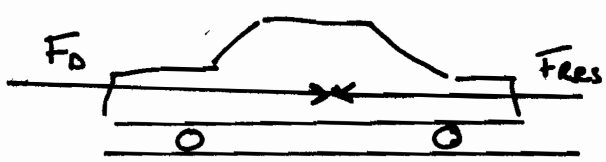
$$F_R = M.a.$$

but $F_R = F_T - W$ ∴ $(F_T - W) = Ma$

effectively, the resultant force = "the difference" or unbalanced force.

<u>EXAMPLE</u>

CAR is travelling on motorway.



F_D = Force driving from engine

F_{RES} = Drag forces from air resistance etc.

Three possible scenarios:

① Car accelerates ∴ $F_D > F_{res}$ ∴ $F_D - F_{res} = F_R = Ma$

∴ a = +ve acceleration.

② Car at Constant Velocity ∴ $F_D = F_{res}$ ∴ $F_R = 0$ ∴ $a = 0$

③ Car decelerates ∴ $F_D < F_{res}$ ∴ $F_D - F_{res} = -F_R = Ma$

∴ a = -ve acceleration

or DECELERATION.

Understanding Terminal Velocity

- Terminal Velocity is reached due to the changing Resultant Force on an object. Let us look at the sequence of events:

① A ball is released from a given height: time = 0 $(t=0)$

Mass = M,

- Ball has a weight W due to mass M, and the gravitational field.
- Initially the resistive forces on the ball are zero as it has not started to collide with air molecules that will resist its path.

$$\therefore \quad F_R = Ma$$

$$F_R = W \quad \therefore \quad W = Ma \quad \Rightarrow \quad \cancel{M}.g = \cancel{M}.a$$

$$a = g.$$

② As t increase, the object starts to build up opposing resistive forces.

F_{res} increases as the object accelerates

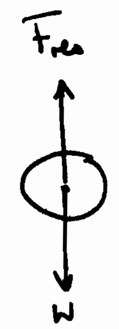
W remains, of course, constant

However $W > F_{res}$

$$\therefore \quad F_R = Ma$$

$$W - F_{res} = Ma \quad \therefore \quad a \downarrow, \text{ but the object still accelerates.}$$

③ t ↑ further - we get to the stage where the resistive forces are equal to the weight.



$F_{res} = W$ ∴ $F_R = W - F_R = 0$

∴ $a = 0$

If $a = 0$, the object is at constant speed - or TERMINAL VELOCITY

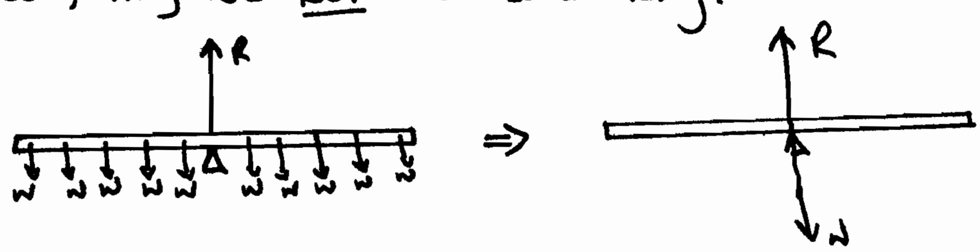
CENTRE OF MASS + CENTRE OF GRAVITY

Centre of Mass of a body - is the point through which any applied force produces translation but no rotation.

Whereas,

Centre of Gravity - is the point at which the resultant force of gravity acts ⇒ the place where a single force equal to the weight of the object can replace the billions upon billions of individual gravitational forces acting on each particle that makes up the object.

In all GCSE problems it is normal for the CofM and the CofG to be in the same place, however, they are NOT the same thing.



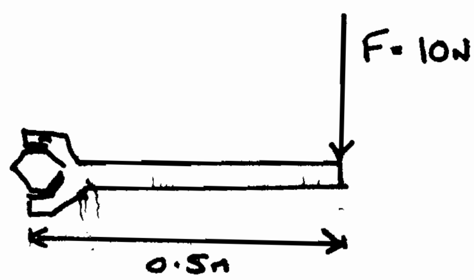
W acts at the CofG.

TURNING EFFECTS - MOMENTS

- The turning effect of a force F about some axis is called its MOMENT.
- This can be thought of as the 'leverage' of a force, and is increased if the force is made larger <u>or</u> if its line of action is farther from the point considered.
- If the force acts in a plane perpendicular to the rotation axis, the moment is defined by:

Moment = magnitude of force × perpendicular distance of the line of action of the force from the axis of rotation.

Units = Nm.



$\therefore$ Moment $= F \times d$

$= 10 \times 0.5$

$= \underline{5\ \text{Nm}}$

- Moments can be used to analyse several different systems.

For a system to be in EQUILIBRIUM i.e. forces are balanced, then:

The sum of the clockwise moments = sum of anticlockwise moments

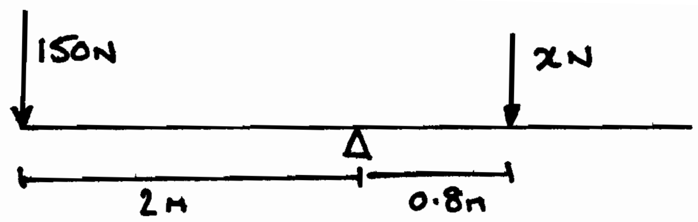
$$\sum \circlearrowright \text{moments} = \sum \circlearrowleft \text{moments}.$$

- We will analyse 2 basic systems

(1) A see-saw.

(2) A bridge structure.

(1)



Δ = fulcrum or pivot.

Determine the weight of x.

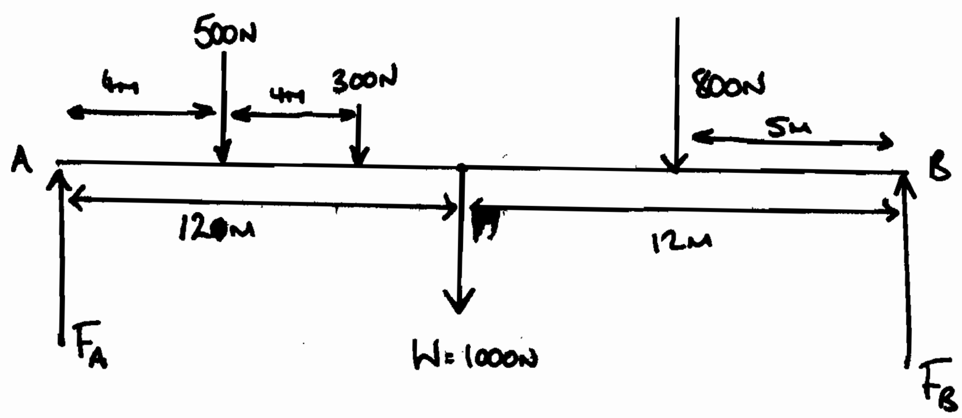
For equilibrium : Σ clockwise moment = Σ anticlockwise moments

$$0.8M \times x = 2M \times 150N$$

$$0.8x = 300$$

$$\underline{x = 375N}$$

(2)



Force F_A and F_B are the supports of the bridge

$\therefore$ $F_A + F_B = 500N + 300N + 1000N + 800N$ (Forces up = forces down)

$F_A + F_B = 2600N$ (must be for equilibrium.)

- Taking moments about point A:

Σ clockwise moments = Σ anticlockwise moments

$\therefore$ $(500N \times 4M) + (300N \times 8M) + (1000N \times 12) + (800N \times 19M) = F_B \times 24M$

$$31600\ Nm = F_B \times 24M$$

$$\underline{F_B = 1317N}$$

Using $F_A + F_B = 2600N$ $\Rightarrow$ $\underline{F_A = 1283N}$

By moving the weights F_A & F_B will vary in magnitude.

HOOKE'S LAW

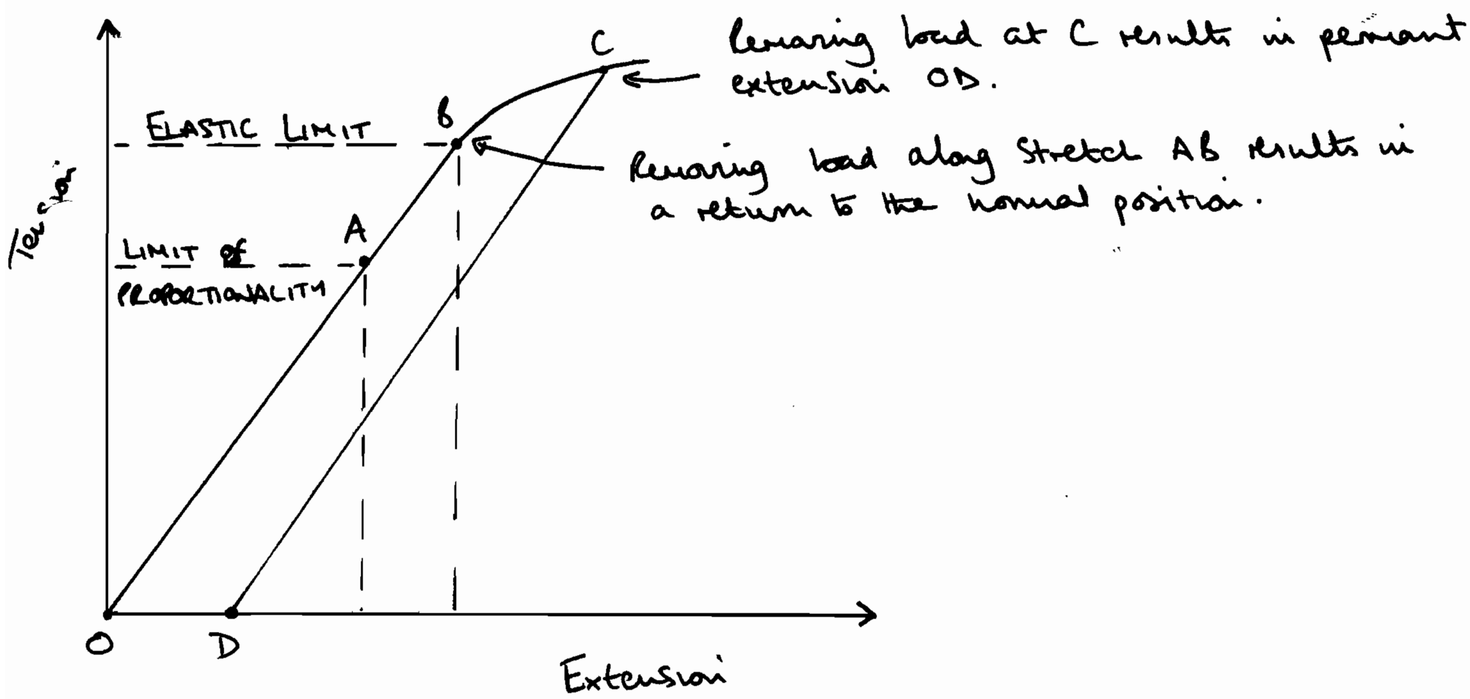
- For many objects the force F required to maintain an extension, x, is directly proportional to the extension.

$F \propto x$ which gives $F = kx$

Where k is the spring constant and is a measure of the 'stiffness' in Nm^{-1}

Hooke's Law is usually ~~obeyed~~ obeyed up to some maximum value of the applied force, and beyond that the relation between force and extension is 'non-linear'.

STRETCHING A HELICAL STEEL SPRING:



Spring Constant: $k = \frac{F}{x}$ equal gradient of graph in the linear region.

Limit of Proportionality: beyond this point (A) the graph is non-linear.

Elastic behaviour: means that the ~~load~~ spring returns to zero extension when the load is removed.

Elastic Limit: beyond this point (B) the spring suffers permanent deformation, and does not return to zero extension when the load is removed.

Plastic Deformation: permanent structural change, after which the spring will not return to zero extension when the load is removed.

In the elastic region, the applied forces extend the bonds between particles in the material. Permanent or plastic deformation occurs when bonds break and particles move ~~&~~ or flow past one another to new positions.

SPRINGS IN SERIES + PARALLEL.

SERIES

We know that for Hooke's law

$$F = ke$$

F = force, k = spring constant, e = extension

Having in series effectively reduces the stiffness of the system:

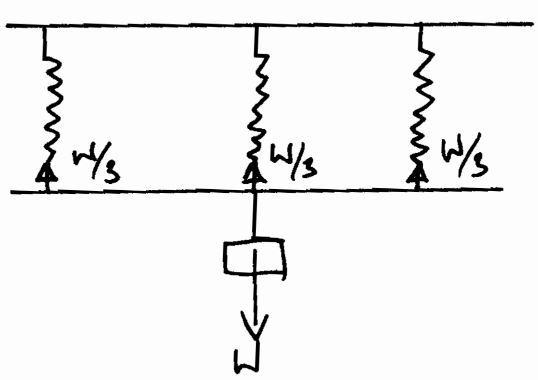
Series $\Rightarrow \frac{k}{n}$

$$\therefore \quad F = \frac{k}{n} \cdot e$$

$$\therefore \quad e = \frac{Fn}{k} \quad \therefore \; e \uparrow \text{ factor } n$$

The arrangement is less stiff than a single spring.

PARALLEL



From Hooke's law:

$$F = ke$$

For parallel $\Rightarrow nk$

$$\therefore \quad F = nke$$

$$\therefore \quad e = \frac{F}{nk} \quad \therefore \; e \downarrow \text{ by factor } 1/n.$$

This system is stiffer than a single spring

Springs in series and parallel

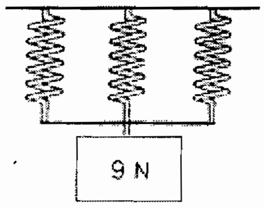


Fig. 1.1

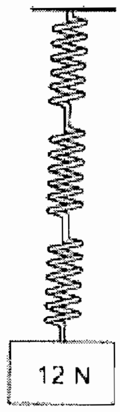


Fig. 1.2

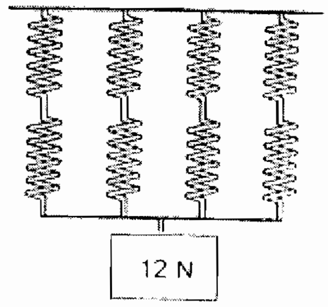


Fig. 1.3

Identical springs are used in the arrangements shown above. The diagrams are not shown to scale, and the unstretched lengths of the springs are in fact different in the four diagrams. In Fig. 1.1, the 9 N weight hangs 1.5 cm below the unstretched position of the springs.

(a) Calculate the total extensions of the arrangements in Fig. 1.2 and 1.3 for the loads shown.

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