Mechanics

GCSE overview

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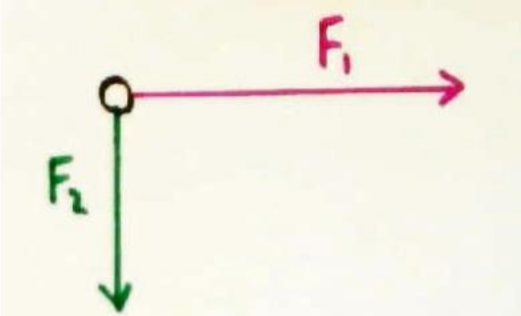
Vectors and Scalars

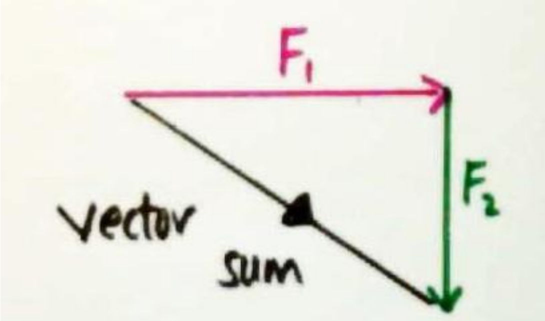
- Vectors have magnitude (size) and direction
  - examples include velocity, displacement, force, acceleration
- Scalars have magnitude (size) alone
  - examples include mass, time, energy, speed, distance
- Vectors should be drawn as arrows pointing in the correct direction.
- The length of the arrow should be drawn to scale (for example, 1cm : 5N)

Adding vectors

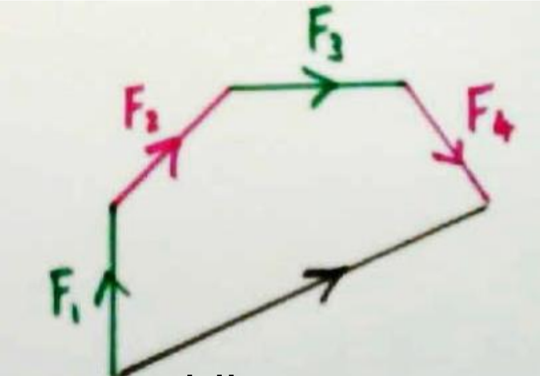
- **Vector addition is best shown by joining the vector arrows nose-to-tail.**



Actual situation

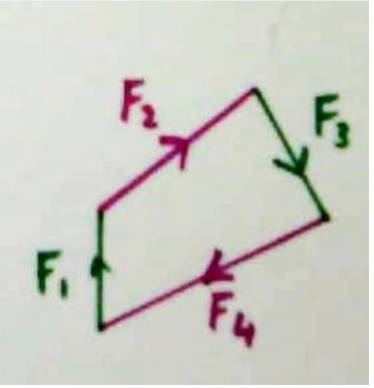


Vector diagram

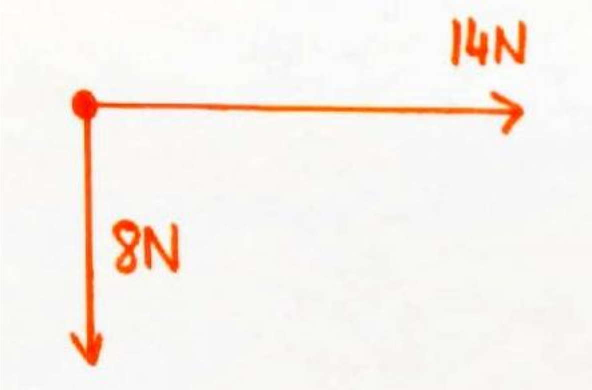


Adding 4 vectors

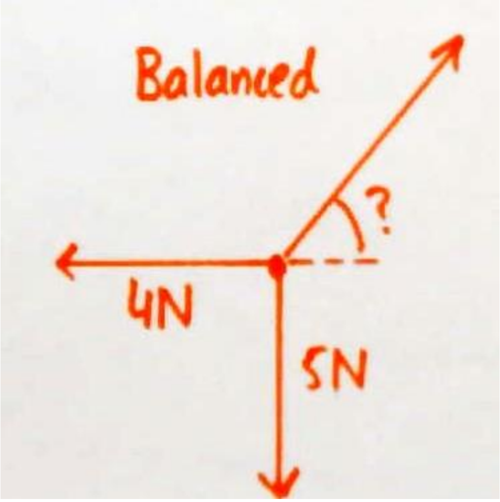
If arrows form a loop,
vector sum = 0



Vector addition practice



Give the magnitude and direction of the sum



Give the magnitude and direction of the diagonal force needed to balance the other two forces

Calculating velocity

Displacement s measures your location

Velocity v measures how much your displacement changes each second

$$v = \frac{s}{t}$$

Velocity is measured in m/s

Average velocity = $\frac{\text{Total displacement}}{\text{Total time taken}}$

Example: a car travels 9400m in 12 minutes

time = 12x60s = 720s

velocity = $\frac{s}{t} = \frac{9400}{720} = 13$m/s

Introducing Acceleration

A van can accelerate from 0 to 60mph (that is 27m/s) in 10s.

This means, that each second, it gains a speed of 6mph (2.7m/s).

The acceleration of the van is 6mph each second (6mph/s).

In SI units, the acceleration is 2.7m/s each second, written $2.7\,m/s^2$.

The acceleration is the velocity change each second.

Calculating acceleration

Acceleration measures how much your velocity changes each second

$$a = \frac{v - u}{t} = \frac{\text{change in velocity}}{\text{time taken}}$$

Acceleration is measured in m/s^2 (m/s gained each second)

Example **A motorcycle accelerates from 13m/s to 25m/s in 2.5s**

Change in velocity $v - u = 25 - 13 = 12$**m/s**

Acceleration = $\frac{\Delta v}{t} = \frac{12}{2.5} = 4.8$**m/s^2**

Acceleration and Direction

We use positive numbers to represent velocities upwards and negative numbers to represent velocities downwards.

The acceleration of a dropped object $g = -10\ m/s^2$.

If you throw something upwards at 30m/s, the velocity changes…

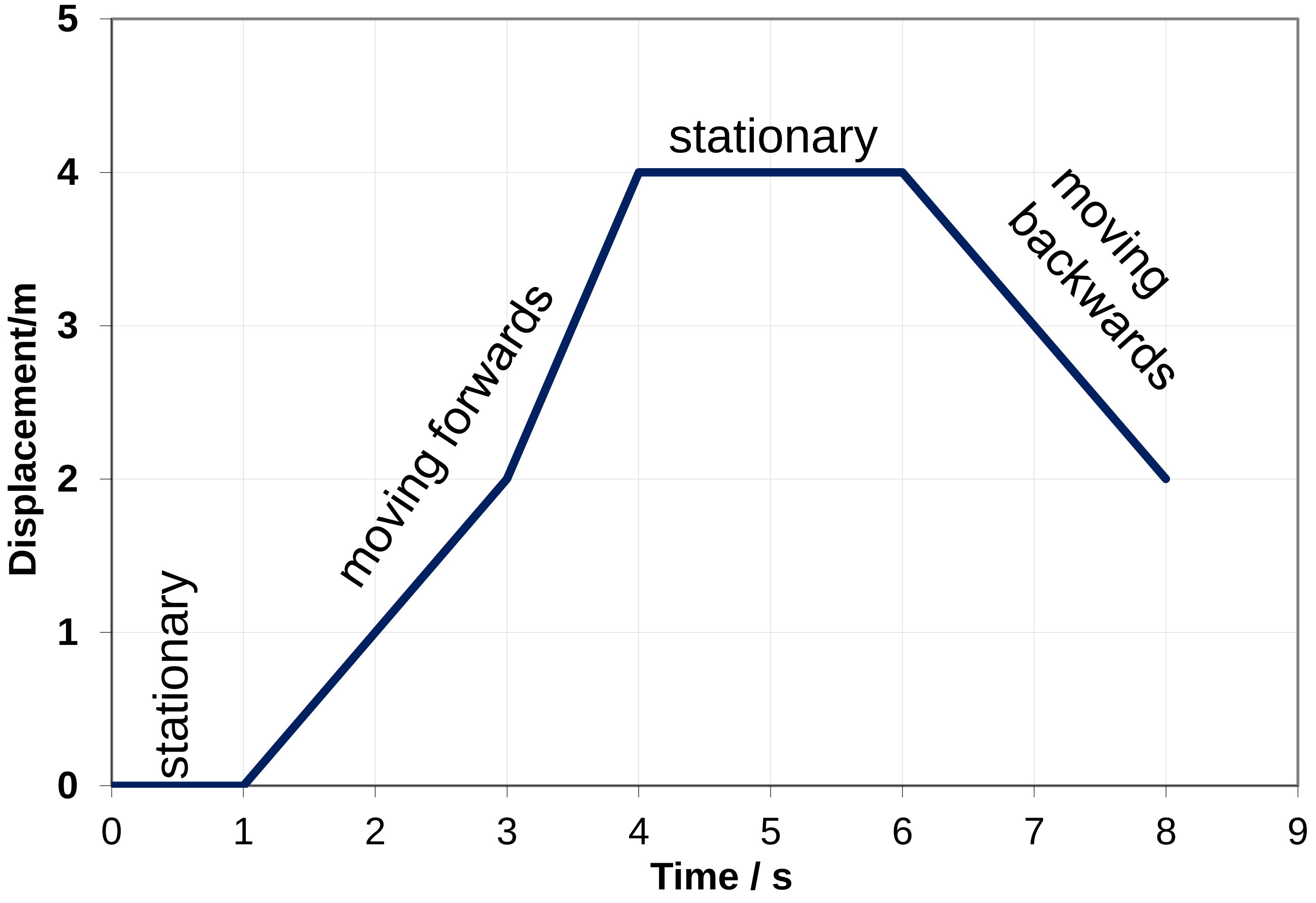
Time	Start	1s	2s	3s	4s	5s
Velocity	30m/s	20m/s	10m/s	0m/s	-10m/s	-20m/s
Direction	---------Going up--------			At peak	---Coming down---	

Acceleration practice

1. An aeroplane on a runway has an acceleration of $2.5 m/s^2$.
   How much time does it take to speed up from 0 to 45m/s?

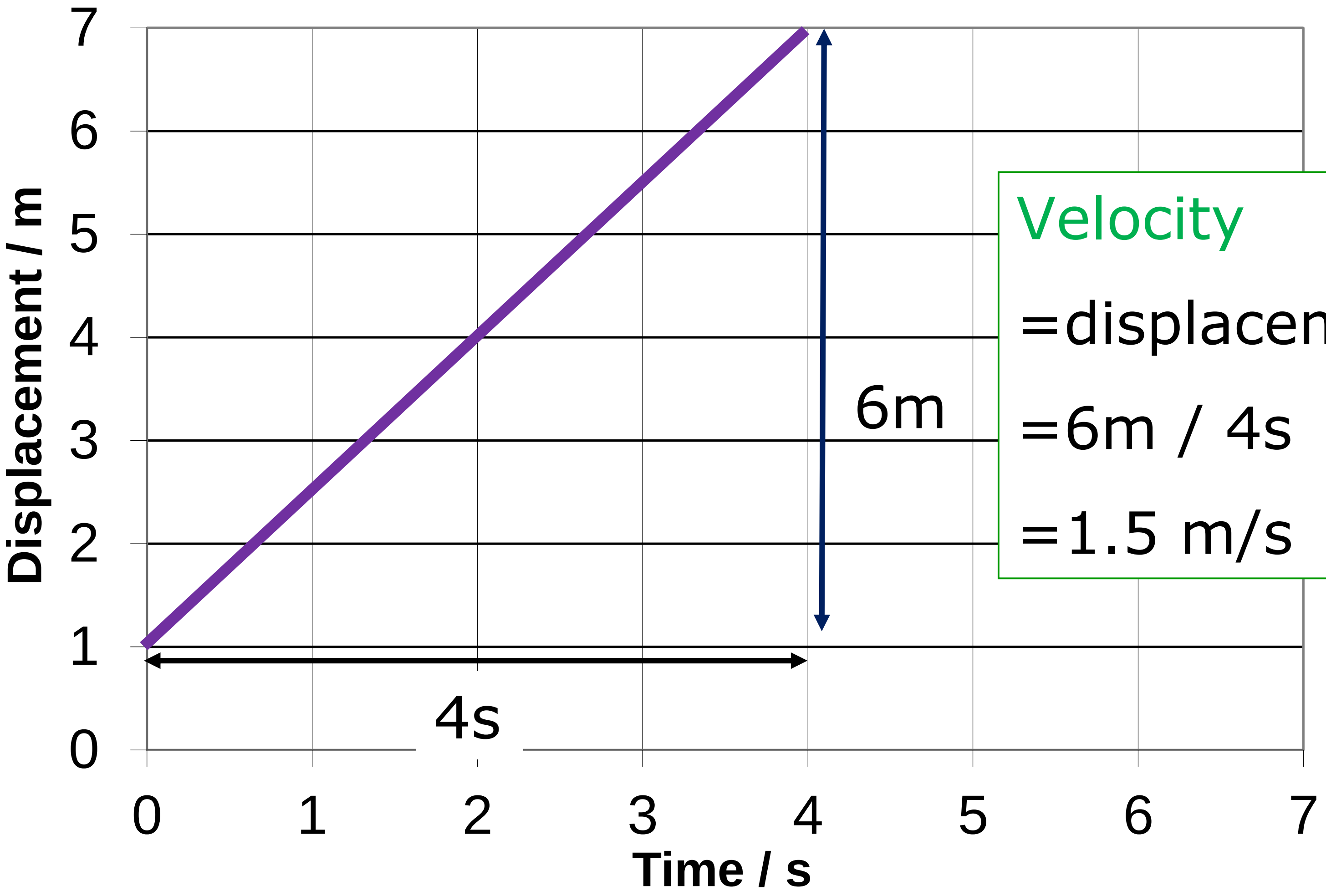
2. A stone is thrown upwards vertically at 8m/s.
   What is its velocity 1.2s later?
   Neglect air resistance, and take $g = 10 m/s^2$.

Displacement – time graphs



Graph shows distance of object from the starting point at each moment in time.

Calculations from displacement graphs



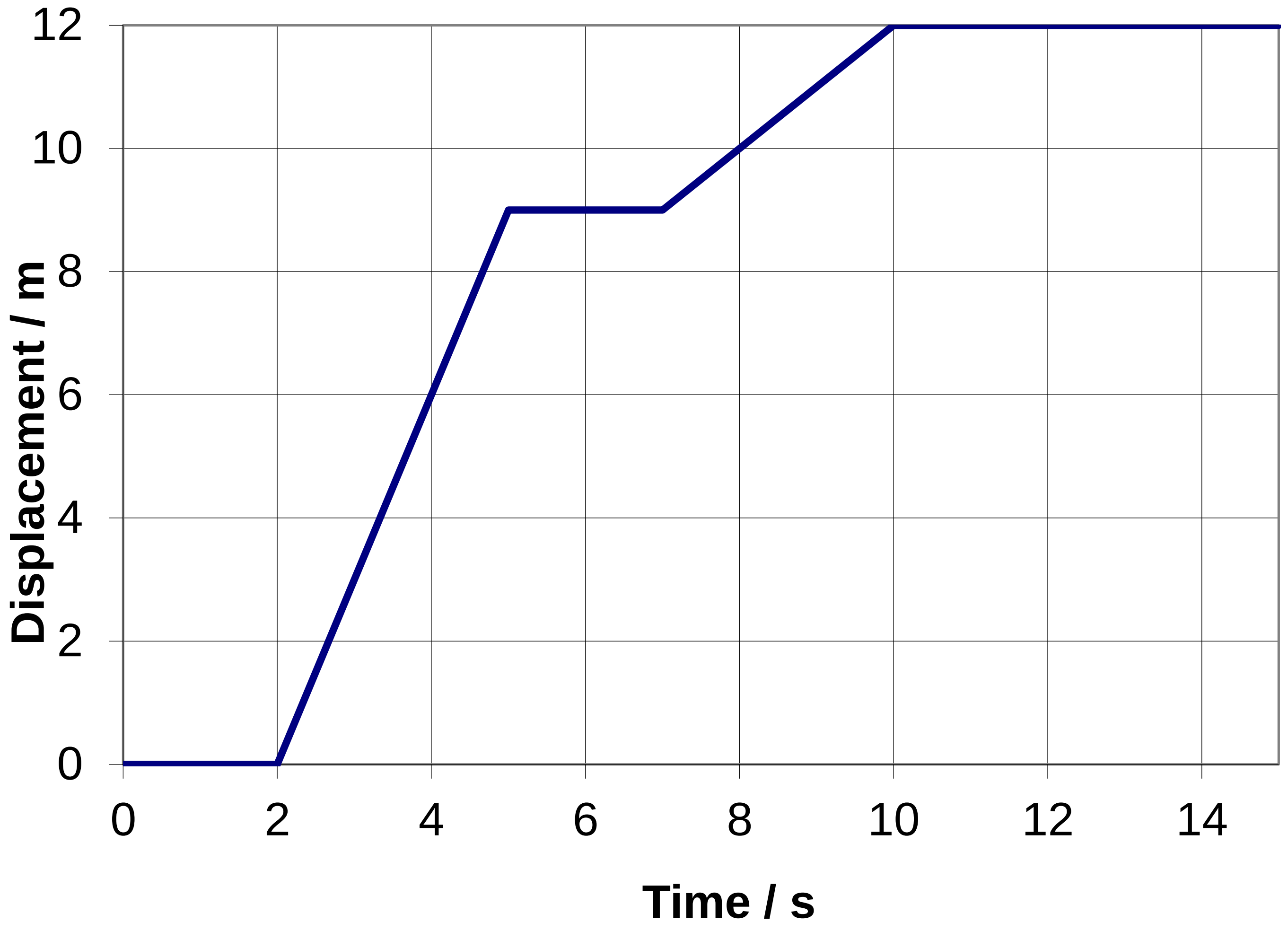
Velocity

=displacement / time

=6m / 4s

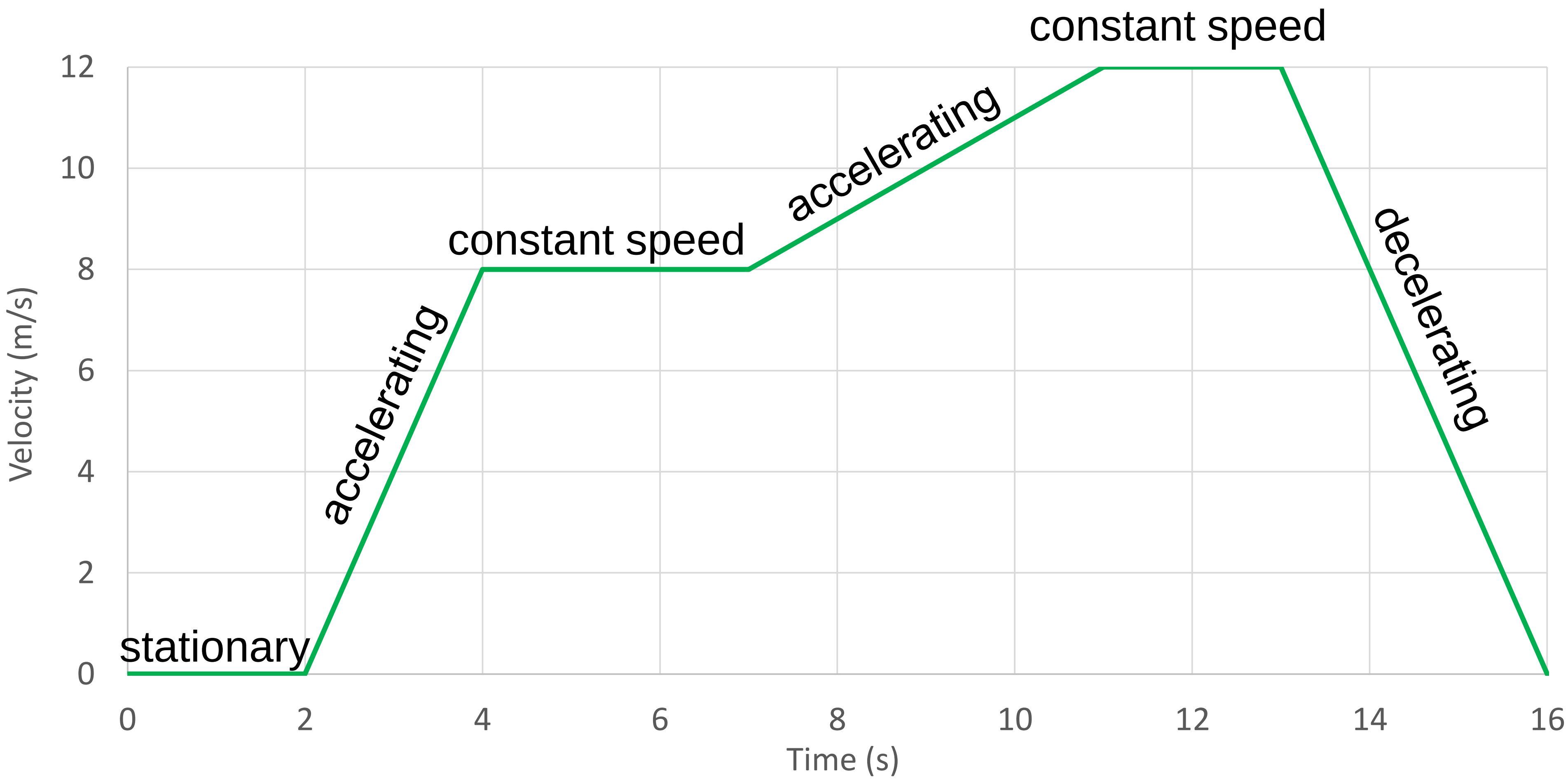
=1.5 m/s

Displacement graph practice

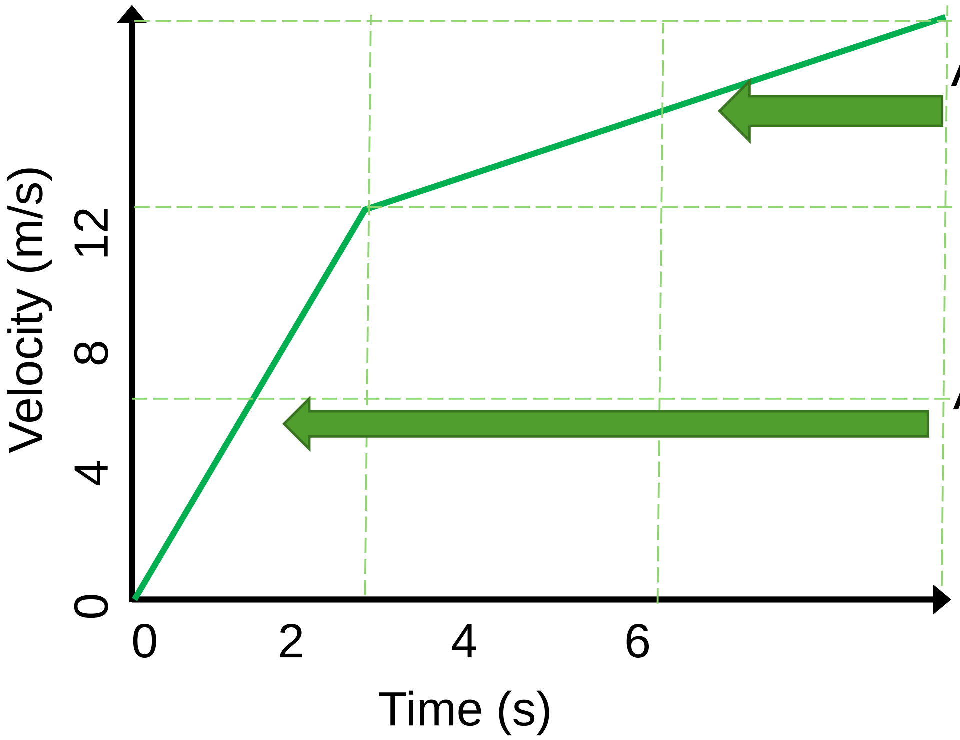


1. When is the object stationary?
2. When is the motion fastest?
3. What is the velocity between 2 and 4s?
4. What is the velocity between 8 and 10s?
5. What is the average velocity over the whole 15s?

Velocity – time graphs



Acceleration on a velocity graph



Acceleration of this part:

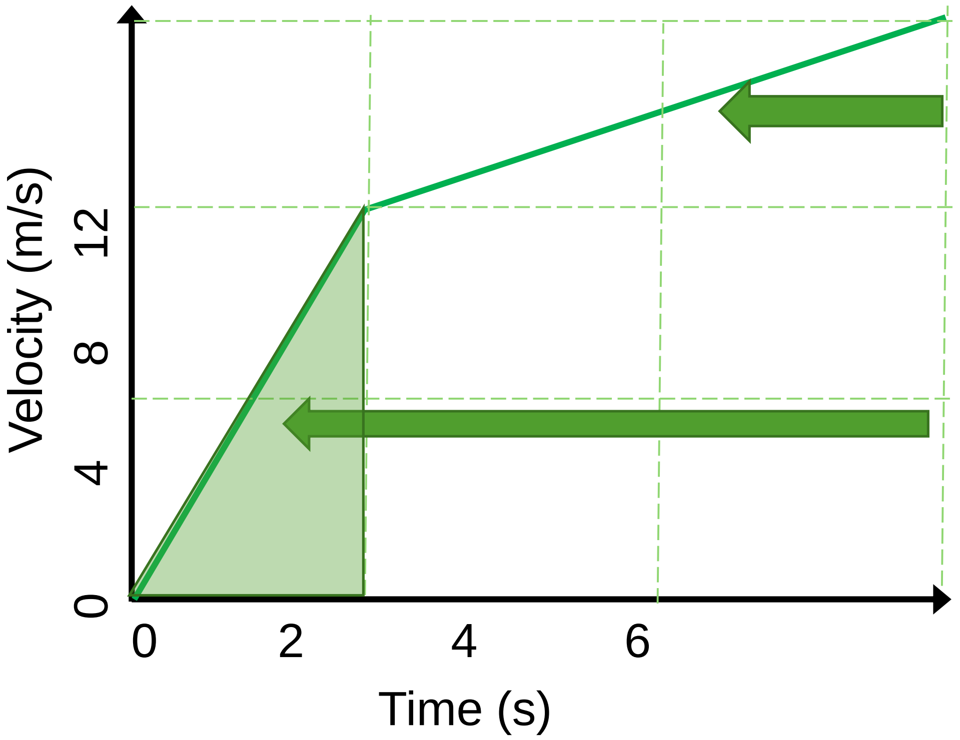
$$= \frac{\text{velocity change}}{\text{time taken}} = \frac{12-8}{6-2} = \frac{4}{4} = 1\ \text{m/s}^2$$

Acceleration of this part:

$$= \frac{\text{velocity change}}{\text{time taken}} = \frac{8-0}{2-0} = \frac{8}{2} = 4\ \text{m/s}^2$$

The acceleration is the gradient of the velocity-time graph.

Displacement on a velocity graph



Displacement of this part

= Average velocity x Time taken

$= \frac{8+12}{2} \times (6-2) = 10 \times 4 = 40\text{m}$

Displacement of this part

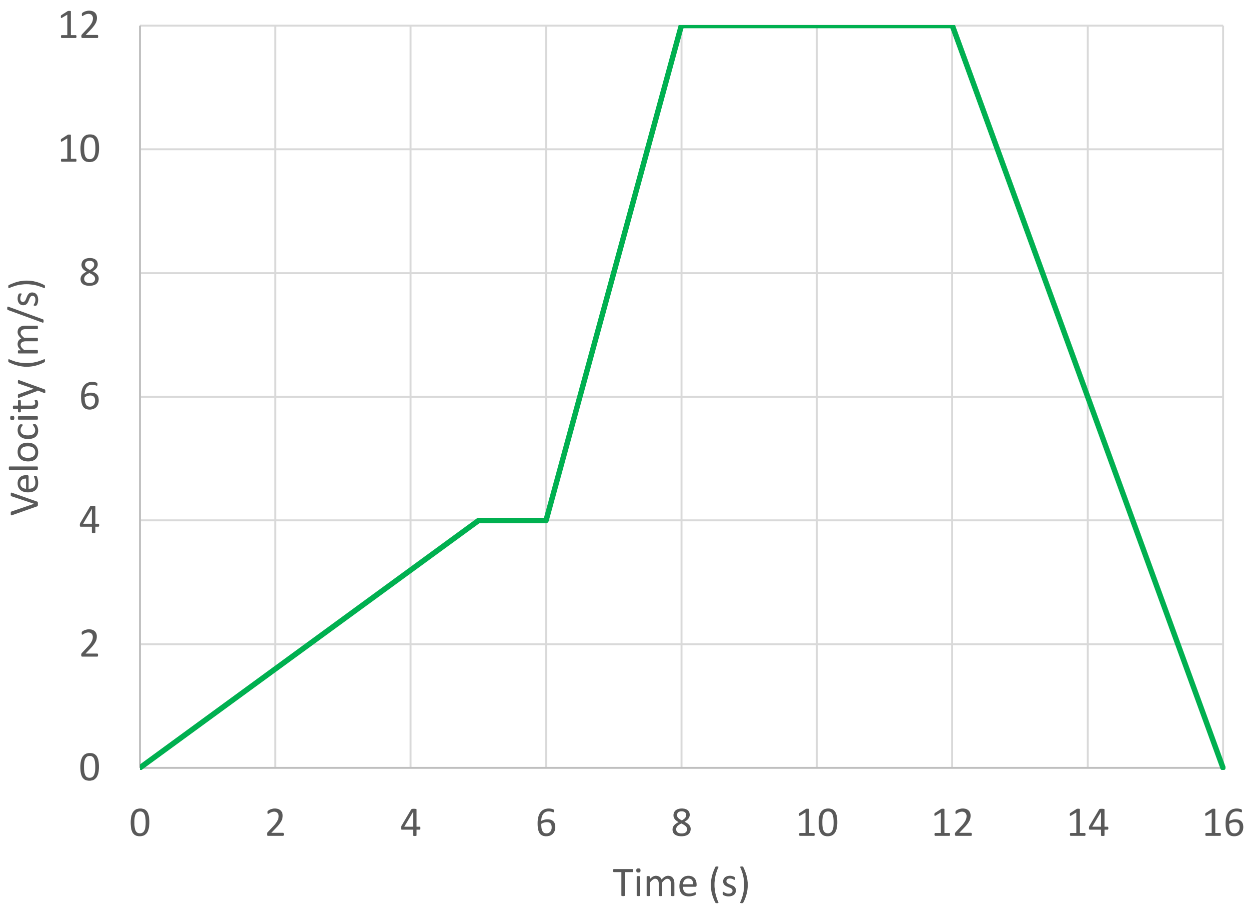
= Average velocity x Time taken

$= \frac{0+8}{2} \times (2-0) = 4 \times 2 = 8\text{m}$

Total displacement = 8m + 40m = 48m

The displacement is the area under the line on a velocity-time graph.

Velocity graph practice



1. At what time(s) is the object stationary?
2. What is the top speed?
3. Calculate the acceleration in the first section of the graph.
4. How far does the object travel between 8s and 12s?
5. How far does the object travel between 12s and 16s?

Constant acceleration situations

- **Where force is steady (e.g. motion under gravity alone)**
  - u = starting velocity, v = final velocity
  - $v = u + at$
  - $v^2 = u^2 + 2as$
- **Example: calculate s if a=6ms^{-2}, u=0ms^{-1}, v=50ms^{-1}**
  - Re-arrange: $s = \frac{v^2-u^2}{2a} = \frac{50^2-0^2}{2\times 6} = 208\mathrm{m}$
- **Derivation:**
  - $s = \frac{u+v}{2}t$ and $a = \frac{v-u}{t}$
  - Putting the equations together gives $s = \frac{u+v}{2} \times \frac{v-u}{a} = \frac{v^2-u^2}{2a}$, so $v^2 = u^2 + 2as$

Constant acceleration practice

1. How fast is a tennis ball after it has been falling for 100m? Assume that the ball was dropped.

2. How much time will the ball have taken to fall 100m?

3. A ball is thrown upwards at 15m/s. How high does it rise before it starts falling down?

Resultant force and acceleration

Resultant force is the vector sum of the forces acting on an object.

If we count ← as negative, and → as positive,

the two forces are -4N and +10N, which add to +6N.

The acceleration is equal to the resultant force acting on each kilogram:

$$a = \frac{F}{m} = +\frac{6}{4} = +1.5\mathrm{m/s^2}$$

Resultant force practice

1. What is the acceleration of a 12 000kg bus if the driving force is 5600N, and there is 3200N of friction?

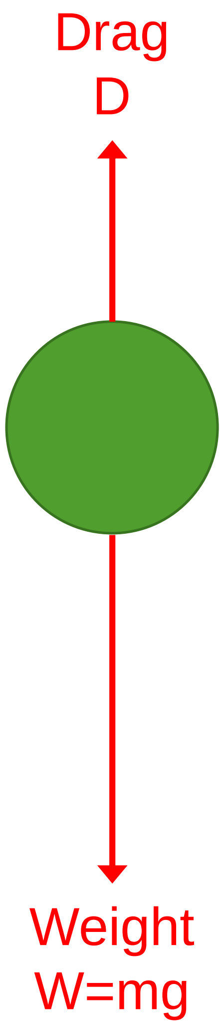
2. What is the initial acceleration of a 150g model rocket if the engine's thrust is 6.0N, and its weight is 0.15N?

3. Work out the acceleration of 100g and 300g masses when dropped if there is no air resistance. A 100g mass has a weight of 1.0N.

Weight and Drag

- Weight is the downwards force on an object because of gravity.
- Weight ($W=mg$) depends on
  - m, the mass of the object in kg, and
  - g, the strength of the gravitational field (on Earth g=10N/kg)
- Drag is a force between an object and its surrounding fluid (liquid or gas) which resists its motion.
- Drag depends on
  - the speed of the object (usually drag gets four times stronger when the speed doubles)
  - the cross sectional area of the object

Terminal velocity



- When an object falls, two forces act – drag and weight
- Initially, v=0, D= 0 and acceleration = $\frac{W}{m} = \frac{mg}{m} = g$
- As object speeds up,
  - drag increases,
  - resultant force $W - D$ decreases, and
  - acceleration reduces
- When $D = W$, it has a steady speed called terminal velocity

Drag practice

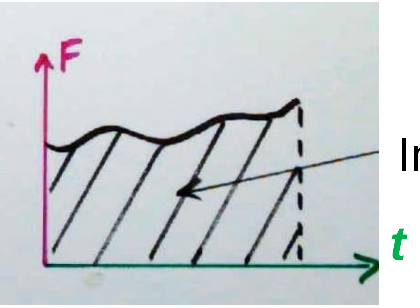
1. If an 80kg person skydives and has a terminal velocity of 72m/s, calculate their acceleration when falling at 45m/s. The drag acting on them is 310N

2. When falling at terminal velocity, their parachute opens, and the drag increases. State what will happen to their weight, acceleration and velocity (will it get increase, reduce or stay the same).

3. With the parachute, they will reach a new terminal velocity. Once this has happened, how large is the drag?

Momentum

- Momentum = mass x velocity
  - Momentum is a vector quantity, measured in $kgms^{-1}$
  - Internal forces within a system do not change the total momentum
- Impulse = Force x time
  - Impulse is measured in Ns
  - If the force varies,
    - impulse = average force x time
    - impulse is area under F-t graph



- Impulse = change of momentum

Newton's Laws of motion

- **First Law – if no unbalanced force acts on an object, its momentum will not change.**
  - this means that its velocity will not change. It will either remain stationary, or moving at a steady speed in the same direction.
- **Second Law – the rate of change of momentum is proportional to the force applied**
  - momentum change = impulse (in SI units) $mv - mu = Ft$
  - for steady mass systems, we have $F = ma$
- **Third Law – where two objects interact, the forces which act on the two objects are equal and opposite**
  - the momentum gain of the one object is equal to the loss of the other

Momentum example - impulse

A model rocket motor produces a force of 5.0N for 0.8s, and is fitted to a 120g rocket. If it were fired horizontally on a frictionless test bed, how fast would it be going after the engine has ‘burnt out’?

Momentum example - conservation

In a school experiment, an 800g motion trolley is travelling at 1.34m/s when it collides with (and sticks to) a 1600g motion trolley. In the absence of other forces, how fast will it be going after the collision?

Momentum practice

1. Calculate the final speed of a 720kg car accelerated by an 850N force from rest for 2.5s.

2. Calculate the force needed to keep a conveyor belt going at $1.5 ms^{-1}$ if 32kg of initially stationary sand lands on it every second.

3. The speed of a 30g projectile is measured by firing it into a 5.00kg bag of sand. When the projectile embeds itself into the bag, the bag starts moving at $0.89 ms^{-1}$. How fast was the projectile travelling?

Thinking and braking distance

Thinking distance

Distance travelled after driver notices the problem, but before the brakes are applied.

Doubles when speed doubles.

Also affected by

- state of mind of driver (e.g stress or tiredness)
- distractions
- alcohol / drug use

Braking distance

Distance travelled after brakes are applied until vehicle stops.

Quadruples when speed doubles

Also affected by

- condition of road surface (e.g. if wet, muddy or icy)
- condition of tyres and brakes

Crash – application to road safety

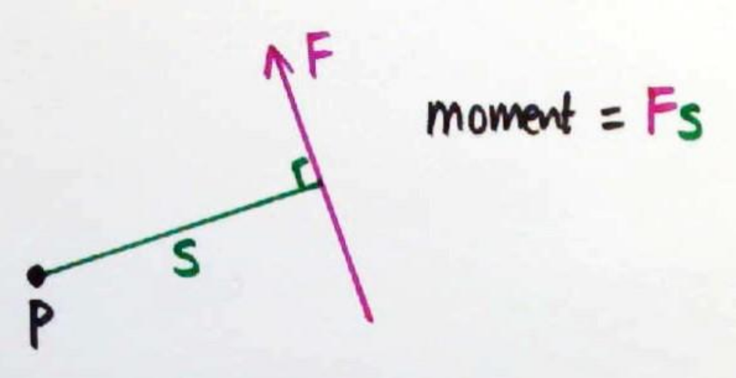
Devices like seat belts, crumple zones and airbags all increase the time in which the driver comes to a stop after a serious collision.

They are best explained in terms of momentum:

- A moving vehicle has momentum.
- When it is stopped, the momentum reduces to zero.
- The momentum change = Ft,
- so if t is made larger, F becomes smaller,
- and there is less chance of injury.

Moments

- The moment of a force (in Nm or Ncm) about a point
  = Force x perpendicular distance
- Principle of moments: equilibrium if
  total clockwise ↻ moment = total anticlockwise ↺ moment
- Draw weight from centre of mass



Moments – a balancing problem

- Aim: to calculate the force *F*.
- Take moments about pivot

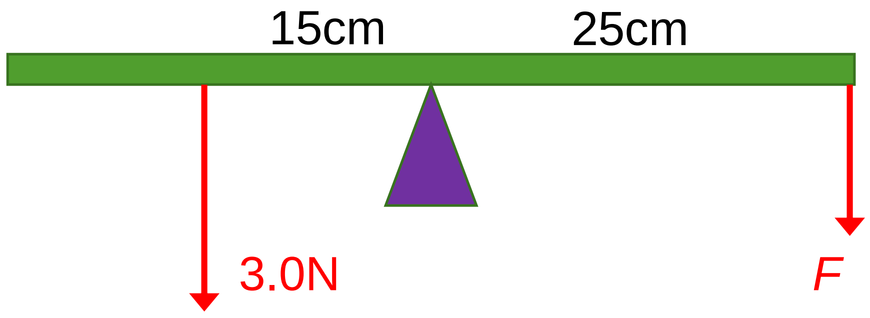
  ↺ moment = 3.0Nx15cm = 45Ncm

  ↻ moment = F x 25cm

- For equilibrium

  45 = 25F

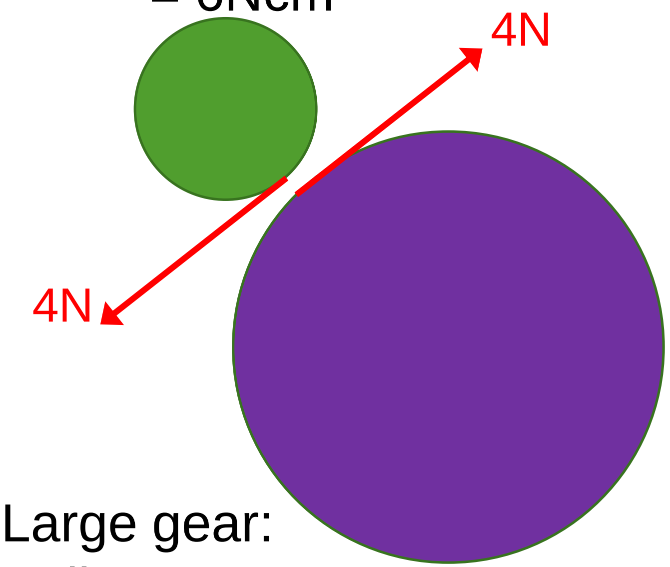
  F = 1.8N



Moments and gears

- When there are balanced forces on a lever
  - the moments of each force are equal
  - the forces may be different
  - the force nearer the pivot is stronger
- When two gears (cogs) are balanced
  - the forces on the two gears are equal
  - the moments may be different
  - the larger gear has the stronger moment

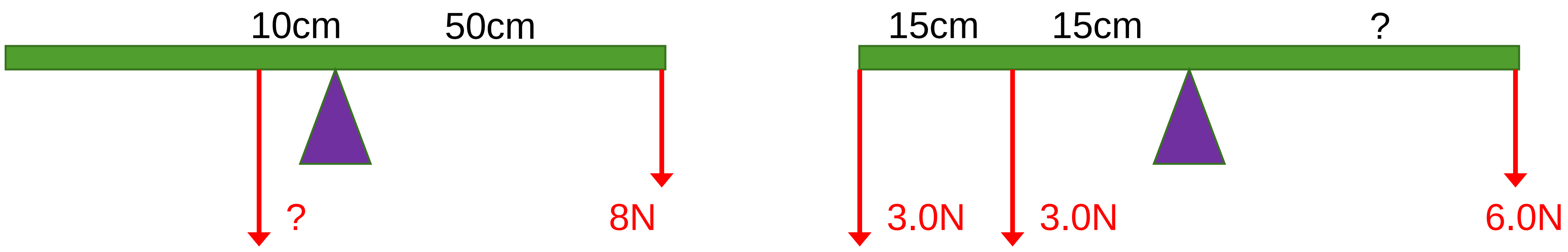
Small gear:
radius = 1.5cm
moment = 1.5x4
= 6Ncm



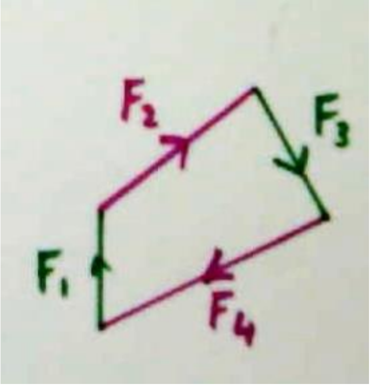
Large gear:
radius = 3.0cm
moment = 3.0x4 = 12Ncm

Moments practice

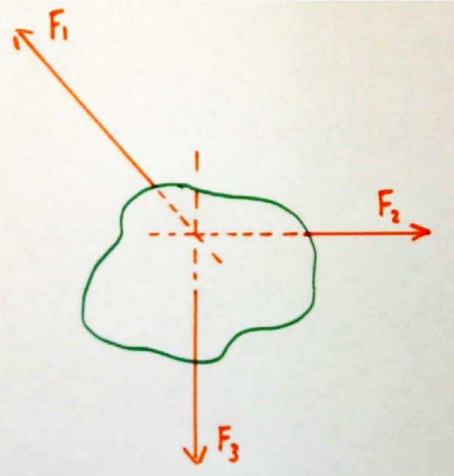
- Work out the force or distance labelled ‘?’.



Equilibrium



- An object will be in equilibrium if
- 1. There is no resultant force on it
  - This means that the x-components of all forces sum to zero (as do the y-components and z-components)
  - Alternatively, if the forces are drawn as nose-to-tail arrows, they form a closed shape
- 2. The total moment about a point is zero (you can choose any point)
  - If all of the force lines pass through a point on the object, this will automatically be true.



Springs

Providing it is not stretched too far, a spring obeys Hooke's Law. This means the each extra newton of tension (stretching force) causes the same extra extension of the spring.

Tension = spring constant x extension $$F = ke$$

Spring constant measured in N/m or N/cm

Elastic deformation means no permanent damage, and the spring will return to its original length when the force is removed.

Plastic (or inelastic) deformation is permanent.

Spring practice

1. How much force does it take to stretch a 23N/cm spring from 12cm to 14cm long?

2. What will the extension of a 3.3kN/m spring be when a 100N force is applied?

3. It takes a 50N force to stretch a spring from 78mm to 104mm. Calculate the spring constant in N/m.

Links

GCSE Topic Revision

https://isaacphysics.org/pages/gcse_topic_index#gcse_revision

Consolidation Programme

https://isaacphysics.org/pages/summer_programmes_2021