OCR (B) Physics GCSE

Chapter 4: Explaining Motion

Summary Notes

(Contents in bold is for Higher Tier Only)

P4.1 What are Forces?

Newton's Third Law

Newton's third law states that: whenever two objects interact, the forces they exert on each other are equal and opposite. Examples of this law include:

- Rocket taking off: The rocket exerts a force on the gases being ejected. The gases apply a force equal in magnitude but in opposite direction on the rocket, which lifts it off the surface.
- A book on a table: The weight of the book (from the Earth) = the pull of the book on the Earth

A force is a push or pull that acts on an object due to the interaction with another object. All forces between objects are either:

Non-Contact - the objects are physically separated.
- Electrostatic - The charges cause a force of attraction/repulsion
- Gravitational attraction - The mass creates a force of attraction

Contact - the objects are physically touching
- Normal contact force, which is felt in opposite direction to contact; The force is perpendicular to the planes of contact
- Friction - The surfaces and their roughness cause friction when moved in contact

Vectors

Interaction forces can be represented as vectors. A vector has magnitude and direction whereas a scalar has just magnitude. Generally, scalars cannot be negative, but vectors can be, as a set direction is positive.

Examples

Scalar Quantity	Vector Quantity
Speed	Velocity
Distance	Displacement
Mass	Weight
Time	Acceleration
Energy	Force

Imagine a ball thrown off a cliff, displacement is 0 at height of cliff, above the cliff the ball has positive displacement, and below the clifftop the ball has negative displacement.
- In long answer questions, you may be able to decide where the "0" point of a vector may lie, for example you could set zero to be bottom of cliff, so the ball will never have negative displacement
- Speed is only velocity when given a direction, so thrown 10ms-1 is its speed but thrown 10ms-1 at 30° above the horizontal is the velocity

Vectors can be represented by arrows, with their size/length representing the vector magnitude

Gravity

All matter has a gravitational field and attracts all other matter. The larger the mass, the stronger the field, the greater the attraction. The force exerted on a mass by the gravitational field, in Newtons:

$$Weight = Mass \times Gravitational\ Field\ Strength$$

$$W = mg$$

Weight, W, in newtons, N and mass, m, in kilograms, kg.
You need to recall that on earth, $g = 10$

Weight can be measured by:

- a force meter (also known as calibrated spring-balance) .
- Weighing scale measures the force you exert, and then divides by 10 to give mass

Same person, on two different planets?

- Their mass is the same
- The gravitational field strength, g, at the two planets will be different (i.e. not 10 for both)
- so, their weight will be different on both.

Acceleration in free fall is due to gravity, and is the same as g, i.e. $10 ms^{-2}$

The weight of an object is considered to act through the object's centre of mass

P4.2 How can we Describe Motion?

Motion

- Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity.
- Displacement includes both the distance an object moves, measured in a straight line from the start point to the finish point and the direction of that straight line. Displacement is a vector quantity.
- Speed does not involve direction. Speed is a scalar quantity.
- Velocity, which is a vector quantity, is speed in a given direction.

The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing.

Typical Speeds

Wind	5-7ms-1
Sound	330ms-1
Walking	1.5ms-1
Running	3ms-1
Cycling	6ms-1
Bus	14km/h
Train	125miles/h
Plane	900km/h

Distance can be measured in mm, cm, m and km and time measured in ms, s, mins and hours. Depending on lengths involved, use appropriate units:

$$Speed = \frac{Distance}{Time}$$

Remember to convert units to make sure everything is equivalent!

Average speed for non-uniform motion:

- Work out TOTAL TIME and TOTAL DISTANCE
- Then use:

$$Average\ Speed = \frac{Total\ Distance}{Total\ Time}$$

- E.g. 3 sections of different speeds to travel distances, use time=distance/speed to work out total time, then sum the different distances, then use above.

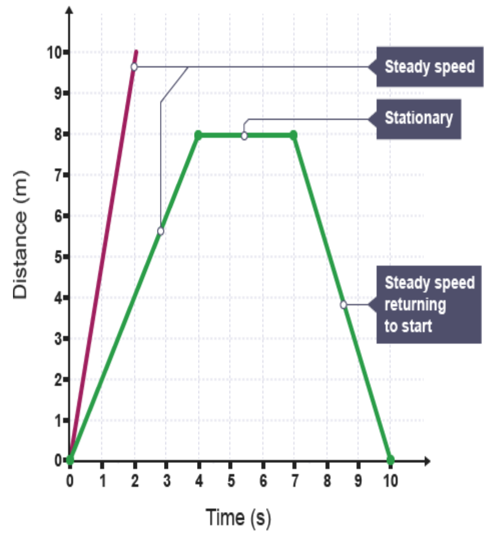
$$a = \frac{v-u}{t}$$

$$v^2 = u^2 + 2as$$

Where acceleration, a, in ms^{-2}, final velocity, v, and initial velocity, u, in ms^{-1}, displacement, s, in m, time, t, in s.

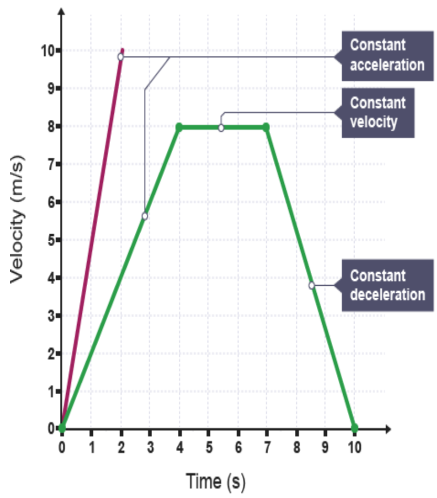
Graphs

Displacement-Time Graphs



- Gradient is velocity
- Sharper gradient means faster speed
- Negative gradient is returning back to starting point
- Horizontal line means stationary
- 0 Distance means that it is back to starting point
- Area under line = nothing
- Curved Line means that the velocity is changing (acceleration)
- **If an object is accelerating, its speed can be determined by drawing a tangent and calculating the gradient of the distance-time graph.**

Velocity-Time Graphs



- Gradient is acceleration
- Sharper gradient means greater acceleration
- Negative gradient is deceleration
- Horizontal line means constant speed
- 0 Velocity means that it is stationary
- **Area under line = distance travelled**
    - **Sometimes counting the squares is the best method for a curved line**
- Curved Line means that the acceleration is changing

Average Speed - This is for when the speed changes during the motion. Use overall distances and timings to work out average speed

P4.3 What is the Connection between Forces and Motion?

Newton's First Law

An object has a constant velocity unless acted on by a resultant force
If a resultant force acts on the object, it will accelerate

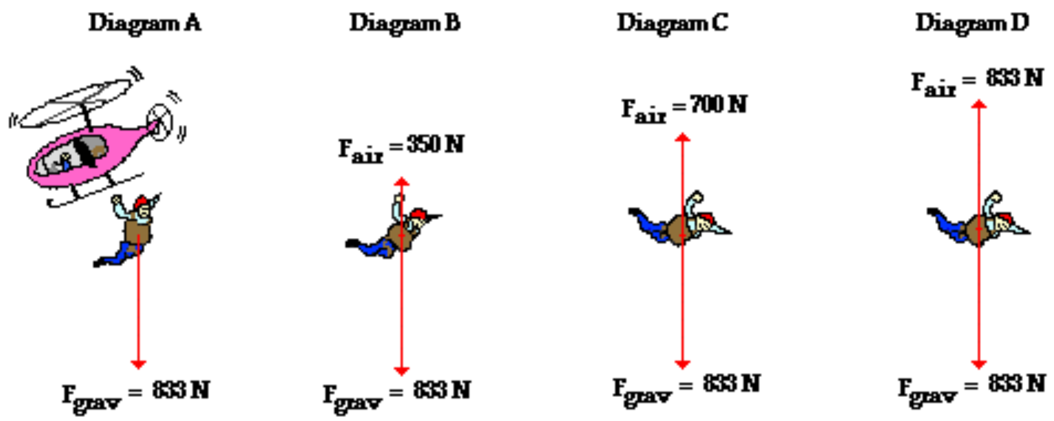
- Acceleration is change in velocity over time
- So, the velocity will change
- Either the direction or speed of the object will change (or both)

If no resultant force acts on the object

- And the object is stationary, it will remain stationary
- And the object is moving, it will continue to move at the same velocity

Resultant force is a single force representing the sum of all the forces acting on an object. If more than one force act along a straight line, the resultant can be found by adding (acting in the same direction) or subtracting (acting in opposite directions) them.

Skydiver example



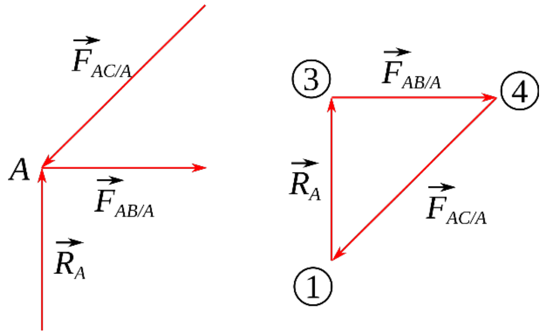
- Forces that act are air resistance and weight
- Initially, the skydiver has no air resistance and the *only* force acting on him is weight
- As he falls, he accelerates, increasing his speed (A)
    - Resultant is simply 833N down
- As air resistance increases, the *resultant* force from weight *decreases* (B)
    - Resultant is 833 – 350 = 483N down
- So acceleration decreases, so he is not speeding up as quickly (C)
    - Resultant is 133N down
- Eventually they are equal and balance, so there is *no* resultant force (D)
    - Resultant = 0
- So there is *no* acceleration when the resultant force is 0 they travel at terminal velocity.
- Free Body Diagrams show the forces (and their directions) acting on an object, like for the skydiver above

Resolving Forces

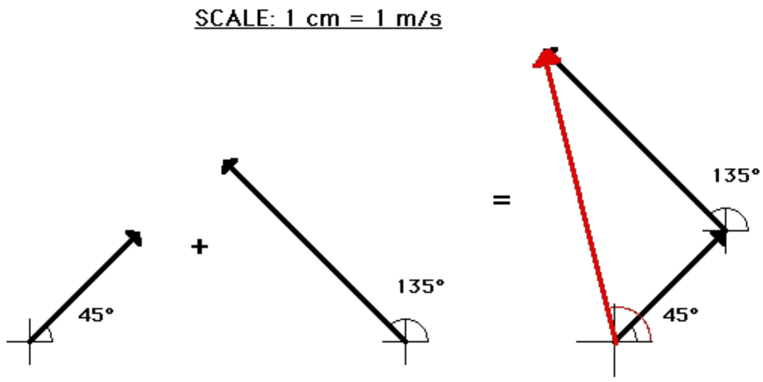
A force F at angle to the ground can be resolved parallel and perpendicular to the ground. Using Pythagoras' Rule, the two components are as shown:

$$a^2 + b^2 = c^2$$

$$F^2 = (Fcos\theta)^2 + (Fsin\theta)^2$$



Scale drawings can be used to illustrate the vector addition of two or more forces in order to determine equilibrium or resultant force.



Momentum

$$Momentum = Mass \times Velocity$$

$$p=mv$$

Where p is the momentum in kilograms metres per second $kgms^{-1}$, m is the mass in kilograms kg and v the velocity metres per second ms^{-1}.

- **Momentum is always conserved in a collision or explosion (where there are no external forces like friction, air resistance, electrostatic attraction etc.)**
- **In collisions:**

  Total Momentum Before= Total Momentum After

- **So, two marbles colliding, each will have momentum before and after the collision**
- **Remember momentum is a vector**

Newton's Second Law

The acceleration of an object is proportional to the resultant force acting on the object, and inversely proportional to the mass of the object.

$$F = ma$$

where F is the force in newtons N, m is the mass in kg and a is the acceleration in m/s^2.

The tendency for objects to continue in uniform velocity (or stay at rest) is inertia; The measure of how difficult it is to change the velocity of an object

$$Intertial\ Mass = \frac{Force}{Acceleration}$$

Newton's Second Law: Force is equal to the rate of change of momentum

$$F = \frac{m(v-u)}{t}$$

Where force, F, is in N, mass, m, is in kg, final velocity, v, and initial velocity, u, is in ms^{-1}, time t, is in s.

$$\Delta p = Ft$$

Where Δp is change in momentum in kgms-1.

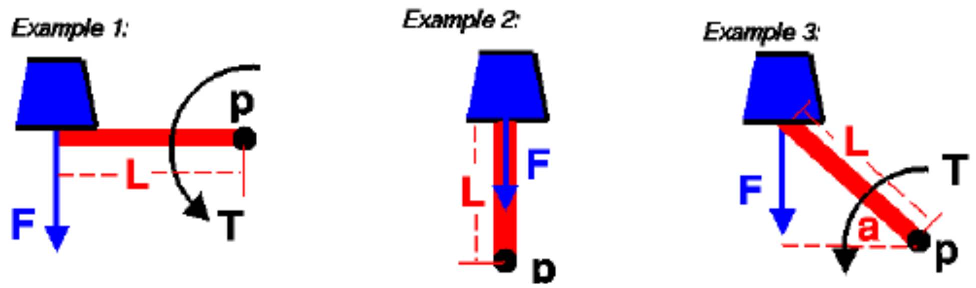
Circular Motion

Imagine a car travelling round a roundabout at constant speed. While its speed is constant, its direction is constantly changing – so its velocity is constantly changing therefore it is accelerating.

If an object was travelling in a circular motion, the object is constantly changing direction, therefore the velocity, which is a vector that depends on the movement and the direction, is constantly changing. A change in velocity is defined as acceleration, so although the object isn't speeding up, it is accelerating due to the changing direction.

Moments and Rotation (Physics only)
For an object attached to a pivot point (a point which it can rotate about, but cannot move away from);

- If a force is applied along a line passing through the pivot (see diagram), the object does not rotate, and is just held still.
- If there is a distance between the pivot and the line of action of the force, the object rotates about the pivot, in the direction of the force applied.
- If the force is applied not perpendicular to the object we need to consider the perpendicular distance from pivot to line of force



Example 1: M = FL, Example 2: M = 0, Example 3: M = FLcosa

$$M=Fd$$

where moment of a force, M, in newton-metres Nm, force F in newtons N and distance d is the perpendicular distance from the pivot to the line of action of the force, in metres m.

Example of moments: Bike Riding – pressing your foot down on the pedal, causes a moment about the pivot, turning the pedal arms.

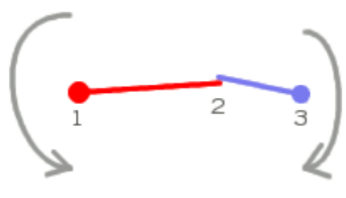
Equilibrium is when:

sum of anticlockwise moments=sum of clockwise moments

Levers and Gears (Physics only)

Levers and gears are used to transmit rotational forces. Gears can change speed, force or direction by rotation. For an example when the first gear is supplying the force:

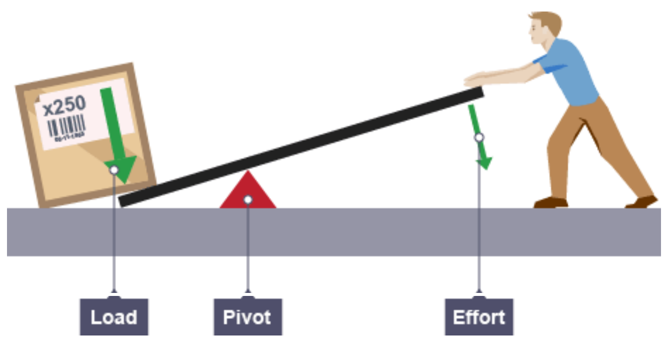
- If connected to a gear with fewer teeth (i.e. a smaller gear)
  - The second gear will turn faster
  - But with less force
  - In opposite direction to first gear
- If connected to a gear with more teeth (i.e. a larger gear)
  - Turns slower
  - More force
  - In opposite direction



The second gear will always turn in the opposite direction

- Blue gear is supplying the power
- To increase the power, a larger gear is used for the secondary (red)
- As the force on the red gear is a further distance from its pivot, the momentum of the larger gear is greater

Levers use the principle of moments to reduce the force needed to perform a certain task. They increase the perpendicular distance over which the force acts such that they work as force multipliers on the load.



Stopping Distances

After seeing a hazard, before you react, during reaction time you travel X metres in the Thinking Distance. Then after you react, causing the car to slow down, you stop over Y metres in the Braking Distance.

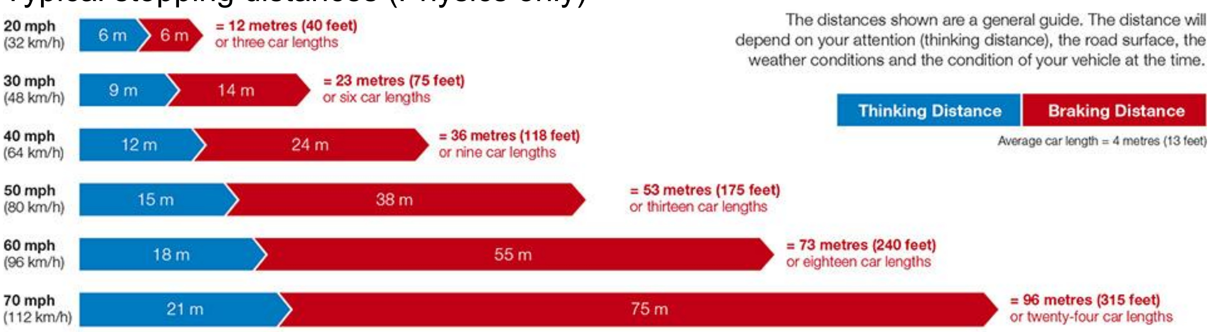
Stopping Distance = X + Y

Thinking Distance
- Speed
- Affected by reaction time
- Concentration
- Tiredness
- Distractions
- Influence of drugs/alcohol

Braking Distance
- Speed
- Poor road conditions (icy, wet)
- Bald tires (low friction)
- Worn brake pads
- Weight (more passengers)

Greater the speed, the greater distance travelled during the same time (reaction time)

Typical stopping distances (Physics only)



Reaction Times vary 0.2-0.9s for each person. Reaction times are measured by the "ruler drop". Drop a ruler through the person's open hand, the time it takes to catch it can be determined by:
s=ut+12at2

$$S = ut + \frac{1}{2}at^2$$

where u=0 and a=g, so,

$$t = 2gs$$

Where s is the distance the ruler travels through the hand, t is the reaction time.

When a force is applied to the brakes of a vehicle:
- Work is done by the brakes (by friction) onto the wheel so the vehicle's KE reduces and the temperature of the brakes increase
- Greater the speed = greater braking force needed to stop the car (over the same distance)
- So greater force = greater acceleration; This may lead to brakes overheating and a loss of control, which is dangerous

Safety Features (Physics only)
When braking hard, there is a large deceleration, so, a large force is felt on the passengers and the cars. This can be dangerous, as the force felt can cause injury (neck whiplash etc.). This can be explained by the equation below:

$$\Delta p = Ft$$

large deceleration = large change in momentum over a short time, so a large force exerted on the object

Seatbelts
- **Without these, when hard braking you will keep moving and not decelerate, causing to fly through the windshield**
- **These strap you in, but also stretch under large forces**
- **Stretching increases the distance moved slightly, but extends the impact time more for passengers to stop**
- **This decreases the rate of change of momentum and therefore reduces the force**

Crumple zones
- **Without these, the car would be a solid metal block, which would immediately stop during a crash instead of "softening" the blow slightly**
- **"softer" areas at the front of the car, which crumple upon a crash**
- **It absorbs energy to deform and compact**
- **It increases the impact time for the car to stop**
- **This reduces acceleration and force on passengers**

Air Bags
- **Without these your head will whip forward during a crash, hitting the steering wheel or whipping back to hit the back of the head, which would cause serious neck energy**
- **These inflate instantaneously upon a crash**
- **Your head hits this and slows down**
- **Increases the impact time for the head to stop moving**
- **Reduces the force on the neck**

P4.4 How can we describe Motion in terms of Energy Transfers?

Energy

A system is an object or group of objects. When a system changes, the way energy is stored also changes:
- Ball rolling and hitting a wall
  - System is moving ball
  - When it hits the wall, (some of) the kinetic energy is transferred as sound
- Vehicle slowing down
  - System is vehicle moving
- When it slows down, kinetic transfers to thermal due to friction between wheels and brakes

Kinetic Energy

$$E_k = \frac{1}{2}mv^2$$

Where m is the mass in kilograms, kg, v is the speed, in metres per second, m/s and the kinetic energy, E_k, in joules, J.

Gravitational Potential Energy

$$E_p = mgh$$

Where E_p, is the gravitational potential energy, in Joules, J g is the gravitational field strength (9.8ms-2), in newtons per kilogram, N/kg, and ‘h’ is the height in metres, m.

Work

$$W = Fs$$

Where Work Done, W, is in joules J, the force, F is in newtons N and the distance, s is in metres m.

- Distance is the distance moved along the line of action of the force
- Work done is when energy is transferred from the object doing the work to another form
- One joule of work is done when a force of one newton causes a displacement of one metre. 1 joule = 1 newton-metre
- Work done against frictional forces causes a rise in temperature of the object

Power

Power is defined as the rate at which energy is transferred or the rate at which work is done.

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

The power, P, is in watts, W, the energy transferred E, is in joules, J, the time t, in seconds, s and the work done W, in joules, J.