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4.4 Newton's Law of Motion

PHYSICS

AQA A Level Revision Notes

4.4 Newton's Laws of Motion

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4.4.1 Newton's First Law

Newton's First Law

- Newton's First Law states:

  A body will remain at rest or move with constant velocity unless acted on by a resultant force

- If the forces on a body are balanced (the resultant force is 0), the body must be either:
  - At rest
  - Moving at a constant velocity

- Since force is a vector, it is easier to split the forces into **horizontal** and **vertical** forces
- If the forces are balanced:
  - The forces to the left = the forces to the right
  - The forces up = the forces down

- The resultant force is the single force obtained by combining **all** the forces on the body

Worked Example

If there are no external forces acting on the car, other than friction, and it is moving at a constant velocity, what is the value of the frictional force F?

SINCE THE CAR IS MOVING AT CONSTANT VELOCITY, THERE IS NO RESULTANT FORCE.

THIS MEANS THE DRIVING AND FRICTIONAL FORCES ARE BALANCED.

F IS ALSO EQUAL TO 6 kN

Newton's Second Law

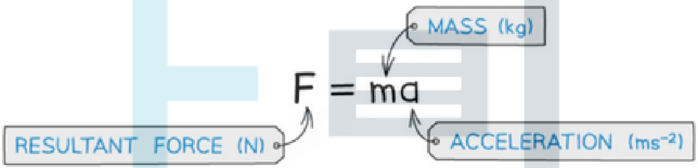
- Newton's Second Law states that:

The resultant force on an object is equal to its rate of change in momentum.

- This change in momentum is in the **same direction** as the resultant force
- Or, in other words:

The resultant force on an object with constant mass is directly proportional to its acceleration.

- This change in momentum is in the **same direction** as the resultant force
- This can also be written as:



- This relationship means that objects will **accelerate** if there is a **resultant force** acting upon them
- These two definitions are derived from the definition of momentum as follows:

$$\text{Momentum } p = mv$$

$$\text{Rate of change in momentum} = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t}$$

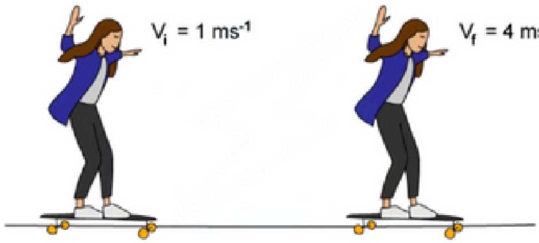
$$\text{Force } F = m\frac{\Delta v}{\Delta t}$$

$$\text{Since } a = \frac{\Delta v}{\Delta t},\ \mathbf{F = ma}$$

- An unbalanced force on a body means it experiences a resultant force
  - If the resultant force is along the direction of motion, it will speed up (accelerate) or slow down (decelerate) the body
  - If the resultant force is at an angle, it will change the direction of the body

Worked Example

A girl is riding her skateboard down the road and increases her speed from 1 m s^{-1} to 4 m s^{-1} in 2.5 s. If the force driving her forward is 72 N, calculate the combined mass of the girl and the skateboard.



STEP 1

NEWTON'S SECOND LAW STATES THE RESULTANT FORCE IS EQUAL TO THE RATE OF CHANGE IN MOMENTUM

$$F = \frac{\Delta p}{\Delta t}$$

STEP 2

FIND CHANGE IN MOMENTUM Δp

Δp = FINAL MOMENTUM − INITIAL MOMENTUM

$$\Delta p = mv_f - mv_i$$

STEP 3

SUBSTITUTE ALL VALUES INTO NEWTON'S SECOND LAW

$$72 \text{ N} = \frac{m(4-1)}{2.5}$$

MASS m IS CONSTANT SO CAN BE TAKEN OUT AS FACTOR

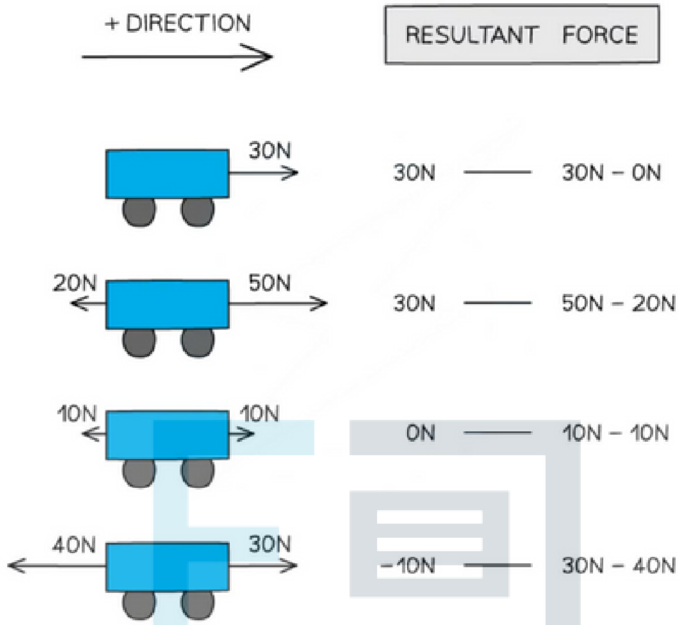
STEP 4

REARRANGE FOR MASS m

$$m = \frac{72 \times 2.5}{3} = 60 \text{ kg}$$

Resultant Force

- Since force is a vector, every force on a body has a magnitude and direction
- The resultant force is, therefore, the **vector sum** of all the forces acting on the body
- The direction is given by either the positive or negative direction as shown in the examples below



Resultant forces on a body can be positive or negative depending on their direction

- The resultant force could also be at an angle, in which case addition of vectors with calculation or scale drawing is used to find the magnitude and direction of the resultant force

Acceleration

- Since acceleration is a vector, it can be either positive or negative depending on the direction of the resultant force
  - If the resultant force is in the **same** direction as the motion of an object, the acceleration is **positive**
  - If the resultant force is in the **opposite** direction to the motion of an object, the acceleration is **negative**
- An object may continue in the same direction however with a resultant force in the opposite direction to its motion, it will slow down and eventually come to a stop
- If drag forces are ignored, or severely reduced, the acceleration is **independent** of the **mass** of an object
  - This has been shown in experiments by astronauts who have dropped a feather and a hammer on the Moon from the same height
  - Both the hammer and feather drop to the Moon's surface **at the same time**

Worked Example

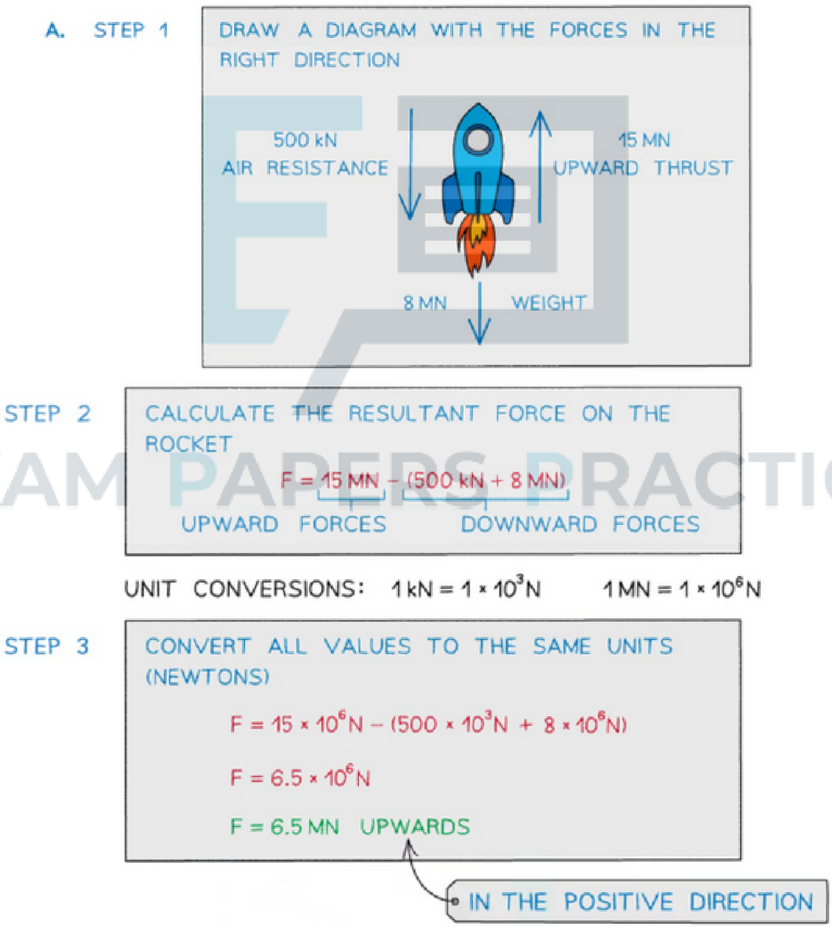
A rocket produces an upward thrust of 15 MN and has a weight of 8 MN.

A. When in flight, the force due to air resistance is 500 kN.

What is the resultant force on the rocket?

B. The mass of the rocket is 0.8×10^5 kg.

Calculate the acceleration of the rocket and the direction its going in.



B. STEP 1 — NEWTONS SECOND LAW

$F = ma$

STEP 2 — REARRANGE FOR ACCELERATION a

$a = \frac{F}{m}$

STEP 3 — SUBSTITUTE IN VALUES FOR F AND m

$a = \frac{6.5 \times 10^6 N}{0.8 \times 10^5 kg} = 81\ ms^{-2}$ UPWARDS

ACCELERATION IS ALWAYS IN THE SAME DIRECTION AS THE RESULTANT FORCE

Exam Tip

The direction you consider positive is your choice, as long as the signs of the numbers (positive or negative) are consistent throughout the question. It is a general rule to consider the direction the object is initially travelling in as positive. Therefore all vectors in the direction of motion will be positive and opposing vectors, such as drag forces, will be negative.

4.4.3 Newton's Third Law

Newton's Third Law

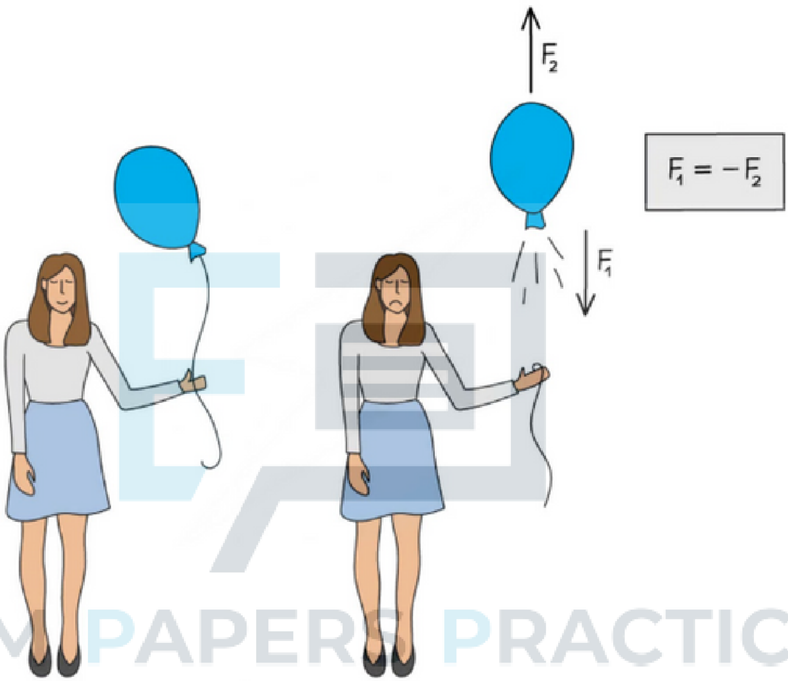
- Newton's Third Law states:

  If body A exerts a force on body B, then body B will exert a force on body A of equal magnitude but in the opposite direction

- This means that every force has a paired equal and opposite force
  - Newton's Third Law force pairs must act on two **different** objects
  - Newton's Third Law force pairs must also be of the **same type** e.g. gravitational or frictional

Worked Example

Using Newton's third law describe why when a balloon is untied, it travels in the opposite direction.

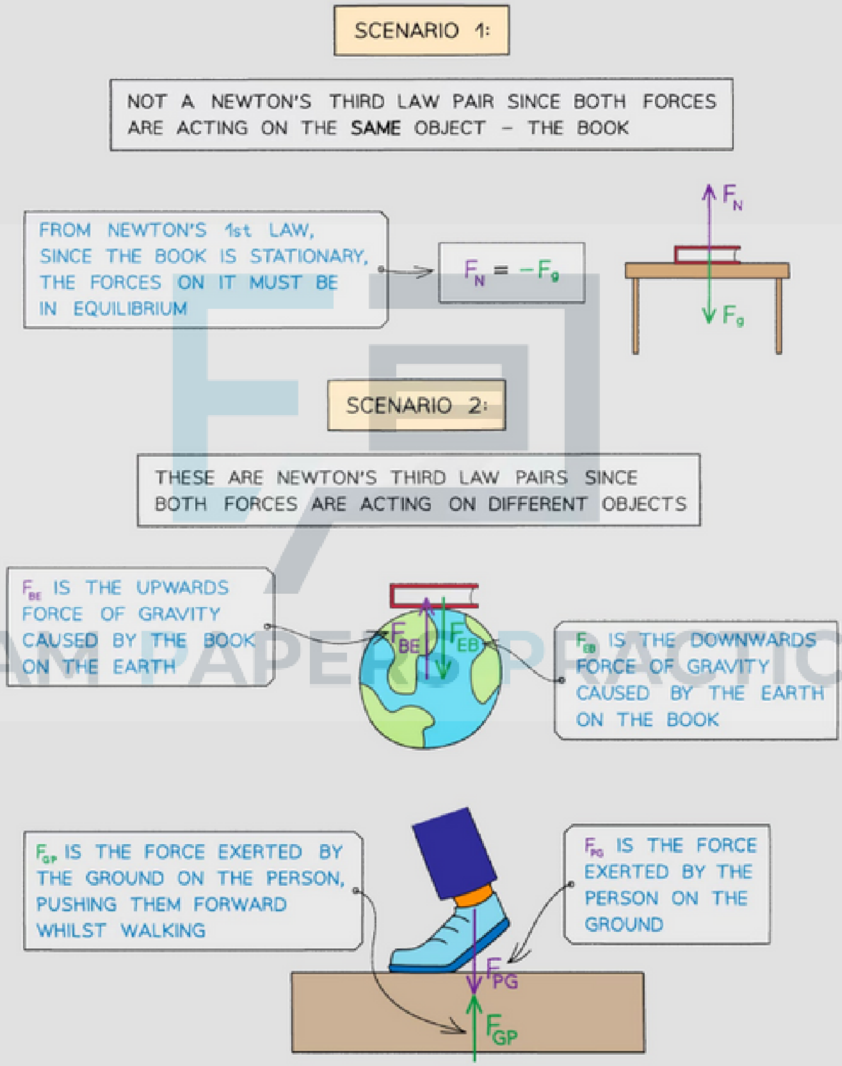


THE AIR INSIDE THE BALLOON WILL RUSH OUT WITH THE FORCE F_1.

THIS WILL PRODUCE AN EQUAL AND OPPOSITE FORCE ON THE BALLOON F_2 FORCING THE BALLOON TO MOVE THROUGH THE AIR IN THE OPPOSITE DIRECTION.

Exam Tip

You may have heard Newton's Third Law as: 'For every action is an equal and opposite reaction'. However, try and avoid using this definition since it is unclear on **what** the forces are acting on and can be misleading.



Newton's Third Law force pairs are only those that act on different objects