Chapter 7: Newton's Laws of motion and force diagrams (Rev A)

Newton's Laws of Motion

Newton's three laws are fundamental to our understanding of mechanics. The biggest problems that students face with these laws are:

- Failing to learn the 3 laws and their order
- Grappling mentally with the concept that an object can be moving without there being any force acting on the object
- Grappling with the concept that an object may be stationary and yet accelerating at the same time
- Getting confused about which forces are acting on which objects

Let us deal with each of these in turn.

YOU WILL BE REQUIRED TO BE ABLE TO STATE NEWTON'S 3 LAWS OF MOTION ... SO THEY NEED TO BE LEARNED!

Let's make this as simple as possible.

Newton's 1st Law is all about objects that are not accelerating.

'An object will remain stationary or at constant speed in a straight line unless some external resultant force acts'.

Let's go back to Key Stage 2!

- Forces **are** pushes or pulls.
- Forces **cause objects to** change speed / change direction / change shape

We need to be a bit careful here. When we are discussing the effect of forces on motion, we need to consider if there is a **resultant force** (a net force/overall force/unbalanced force).

It is also worth emphasising that any change of direction implies that there is an acceleration. Acceleration = change of velocity / time and if the direction is changing then the velocity vector is changing (even if the speed is constant). **Many students struggle with this concept.**

If there is no resultant force then there can be no change of speed and no change of direction, or as Newton's 1st Law states the object remains stationary (it is stationary and it doesn't start moving) or remains at constant speed in a straight line.

Example - If you were an astronaut doing a space-walk with no gravity at all and no atmosphere. Suppose you were moving at 0.1 m/s, you would keep on moving forever in the same direction, unless something imposed a force on you to stop you.

<u>Newton's 2nd Law</u> is all about objects that are accelerating i.e. they are:

- Speeding up, or
- Slowing down, or
- Changing direction

For this to happen there **has to be** an external **resultant force**.

'When an external resultant force acts on an object, the object will accelerate in the direction of the resultant force and the acceleration will be directly proportional to the resultant force.'

Newton's 2nd Law is linked to the equation **F = ma**
<u>Resultant</u> force = mass x acceleration

Example 1 - If you kick a stationary ball, the ball starts to move in the direction you kicked. The more force you kick with, the greater the acceleration.

Example 2 – A ball is moving towards you and you kick it. There is a resultant force on the ball and it slows down, stops momentarily and then rebounds back in the direction it came from. There has been a change of speed and direction.

Example 3 – You let go of a ball. The moment you let go, the only force acting on the ball is its weight (it is not moving yet – so there is no drag). The ball is still stationary at this moment, but you know that it will be moving a moment later. This means it is accelerating, but for this infinitesimally small amount of time is not moving!

This is hard to accept, but it must be true because otherwise nothing could ever start to move.

<u>Newton's 3rd Law</u> is all about TWO objects. It is the one that so many people refer to as 'each action has an equal but opposite reaction'. If you learned Newton's 3rd Law this way then erase your memory right now! It does not do Newton the justice he deserves and just leads to woolly thinking. Learn it this way:

'If Object A exerts a force on Object B, then Object B exerts an equal but opposite force on Object A'

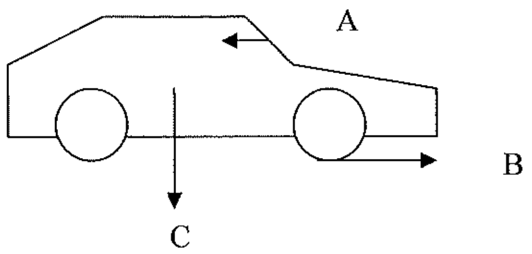
There are 3 very important points here:

- There are 2 forces being discussed , BUT one acts on Object A and the other acts on Object B. They do NOT both act on one object.
- The forces are equal in magnitude but opposite in direction.
- The forces **<u>must</u>** be the same type of force eg both gravitational forces, or both electrical forces, or both frictional forces, or both normal contact forces.

Force Diagrams

Because it is so easy to misapply Newton's Laws of Motion we draw what is known as free body force diagrams. These show the object in empty space with all the forces acting on that object and nothing else.

The diagrams may look a bit odd, but it helps us to avoid mistakes.



What is force A? ………………………………………………………

Push or pull? ………………………………………………………

What object is doing the pushing or pulling? ………………………………………

What is force B? ………………………………………………………

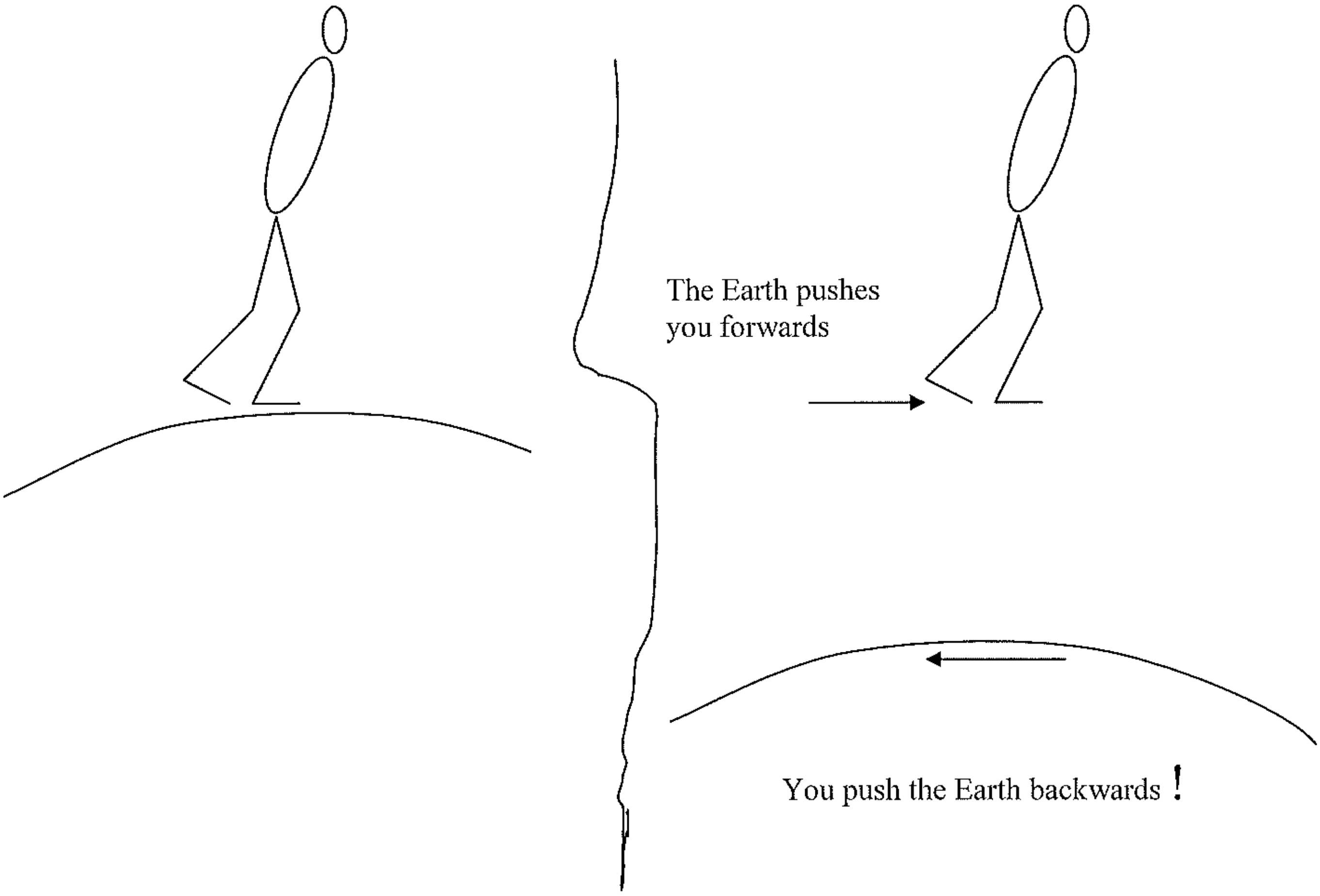
Push or pull? ………………………………………………………

What object is doing the pushing or pulling? ………………………………………

What is force C? ………………………………………………………

Push or pull? ………………………………………………………

What object is doing the pushing or pulling? ………………………………………



Example – When you walk you push back on the ground, and in accordance with Newton's 3rd Law, the ground pushes forwards on you with an equal but opposite force. As a result, the push of the ground on you makes you accelerate forwards. But that is not the end of the story, because you are pushing backwards on the ground so the ground accelerates backwards. Yes, the Earth's motion will change because of your push, but you don't notice this because of the Earth's huge mass (and so it acceleration , given by $a=F/m$ is tiny)

Prove this to yourself. Start running on soft sand. You will see the sand accelerate backwards.

Exercise

1. Some people refer to press-ups as push-ups.
   What is pushing up?

   Explain.

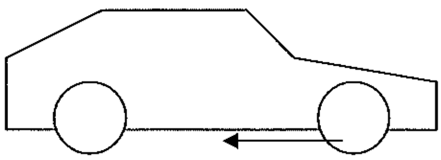
2. A pupil was answering a SATs question about air resistance. He said that the air resistance was caused by the front of the car hitting air particles. Why was he not awarded full marks for his answer?

3. The navigator of a plane plots a straight course from London to New York. The pilot follows this course exactly at a constant speed and constant altitude (height).
Does this comply with Newton's 1st or Newton's 2nd Law?

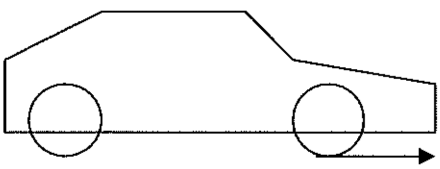
Explain your answer.

4. Look at the diagrams of the cars below. The arrows show the horizontal forces acting on the car. NOTE the vertical forces have not been shown. In what direction is the car moving? Explain how you know.

a)



b)



Comment on what will happen to the car and whether the diagram is likely to be correct.

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