Newton's First and Second Laws

In the 1660s, a chap called Isaac Newton worked out his dead useful Laws of Motion. Here are the first two.

A Force is Needed to Change Motion

This may seem simple, but it's important. Newton's First Law says that a resultant force (p.181) is needed to make something start moving, speed up or slow down:

> If the resultant force on a stationary object is zero, the object will remain stationary. If the resultant force on a moving object is zero, it'll just carry on moving at the same velocity (same speed and direction).

So, when a train or car or bus or anything else is moving at a constant velocity, the resistive and driving forces on it must all be balanced. The velocity will only change if there's a non-zero resultant force acting on the object.

1) A non-zero resultant force will always produce acceleration (or deceleration) in the direction of the force.
2) This "acceleration" can take five different forms: starting, stopping, speeding up, slowing down and changing direction.

Acceleration is Proportional to the Resultant Force

1) The larger the resultant force acting on an object, the more the object accelerates — the force and the acceleration are directly proportional. You can write this as $F \propto a$.
2) Acceleration is also inversely proportional to the mass of the object — so an object with a larger mass will accelerate less than one with a smaller mass (for a fixed resultant force).
3) There's an incredibly useful formula that describes Newton's Second Law:

$$F = m \times a$$

Resultant force (N), Mass (kg), Acceleration (m/s²)

Large Decelerations can be Dangerous

1) Large decelerations of objects and people (e.g. in car crashes) can cause serious injuries. This is because a large deceleration requires a large force — $F = m \times a$.
2) The force can be lowered by slowing the object down over a longer time, i.e. decreasing its deceleration.
3) Safety features in vehicles are designed to increase collision times, which reduces the force, and so reduces the risk of injury. For example, seat belts stretch slightly and air bags slow you down gradually. Crumple zones are areas at the front and back of a vehicle which crumple up easily in a collision, increasing the time taken to stop.

EXAMPLE: Estimate the resultant force acting on a car stopping quickly from 15 m/s.

1) Estimate the deceleration of the car — you did that for this example on page 146.
   The car comes to a stop in ~1 s.
   $a = (v - u) \div t = (0 - 15) \div 1 = -15$ m/s²
2) Estimate the mass of the car.
   Mass of a car is ~1000 kg.
3) Put these numbers into Newton's 2nd Law.
   $F = m \times a$
   $= 1000 \times -15 = -15\ 000$ N

The force here is negative as it acts in the opposite direction to the motion of the car.

4) The brakes of a vehicle do work on its wheels (see p.180). This transfers energy from the vehicle's kinetic energy store to the thermal energy store of the brakes. Very large decelerations may cause the brakes to overheat (so they don't work as well). They could also cause the vehicle to skid.

Accelerate your learning — force yourself to revise...

Newton's First Law means that an object moving at a steady speed doesn't need a net force to keep moving.

Q1 Find the resultant force needed to accelerate an 80 kg man on a 10 kg bike at 0.25 m/s². [2 marks]

Newton's First and Second Laws

Warm-Up

Use the words and phrases below to correctly fill in the gaps in the passage.
You don't have to use all of them, but each one can only be used once.

Newton's .... Law of motion says that an object will remain stationary or moving at .... if there is .... resultant force acting on it.

If there is .... resultant force acting on the object, it will ....

a constant velocity	accelerate	a zero	First
a non-zero	Second	remain stationary	an increasing speed

1 A rocket moves at a constant speed in space. In order to change its speed, it turns on its thrusters, accelerates to the desired speed and then turns them off again. (Grade 4-6)

a) The mass of the rocket is 110 000 kg and it accelerates at 5.0 m/s^2.
What is the force provided by the thrusters?

- ☐ **A** 550 000 N
- ☐ **B** 55 000 N
- ☐ **C** 22 000 N
- ☐ **D** 220 000 N

[1]

b) State why the rocket continues moving at a constant speed after turning off its thrusters.

....

....

[1]

[Total 2 marks]

2 A vase is knocked from a shelf. As the vase begins to fall, the resultant force acting on it is 38 N. Acceleration due to gravity is 10 m/s^2. Calculate the mass of the vase. (Grade 4-6)

Mass = ... kg

[Total 3 marks]

3 A sailboat has a mass of 60 kg and is accelerating at 0.4 m/s^2. The wind acting on the sail provides a force of 44 N. The drag from the water acts in the opposite direction. Grade 6-7

Calculate the force of the drag acting on the boat. Show your working.

Force = ... N
[Total 4 marks]

4 A car is travelling at 14 m/s when it hits a wall. It experiences a large, constant deceleration and quickly comes to a stop. Grade 6-7

a) Explain why very large decelerations can be dangerous.

....

....
[2]

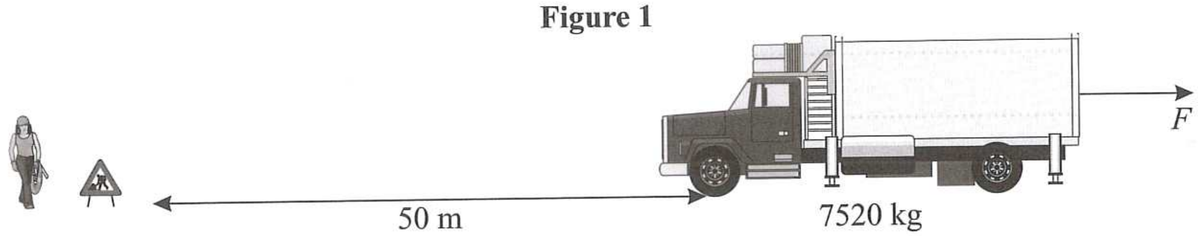
b) Estimate the size of the resultant force acting on the car during the collision.

Force = ... N
[5]

[Total 7 marks]

5 **Figure 1** shows a 7520 kg lorry. The driver spots a hazard ahead and applies the brakes. The lorry decelerates uniformly and comes to a stop 50 m after the brakes are applied. Estimate the braking force needed to stop the lorry. Grade 7-9

Figure 1



Force = ... N
[Total 5 marks]

Exam Practice Tip

Watch out for questions talking about constant or uniform acceleration over a distance. They can be tricky with lots of steps. In the exam, use the equation from the equation sheet that links velocity, acceleration and distance to find the acceleration (or deceleration) of an object. Then stick it into Newton's 2nd Law to find the resultant force on the object.