

NEWTON'S SECOND LAW

FORCE, MASS AND ACCELERATION

Newton followed up his first law about balanced forces with a second law that describes how an object will accelerate if there is an unbalanced or resultant force acting on it. When the forces are balanced an object will remain at rest or travel at a constant speed in a straight line. But when the forces are not balanced the velocity cannot remain constant. It will change. The acceleration tells you how quickly the velocity is changing.

The acceleration of an object (produced by an unbalanced force) is:

- directly proportional to the magnitude of the unbalanced force,
- in the same direction as the unbalanced force
- inversely proportional to the mass of the object.

$$F = m a$$

Symbol	Definition	Unit	Unit symbol
F	force	newton	N
m	mass	kilograms	kg
a	acceleration	metres per second squared	m/s^2

This formula defines the newton.

One **newton** is defined as the **force** that makes a mass of **1 kg** **accelerate** at **1 ms^{-2}**

EXAMPLE

1. A car of mass 1 000 kg has an unbalanced force of 1 600 N acting on it. what will be its acceleration?

$$\begin{aligned} F &= ma \\ 1600 &= 1000 \times a \\ a &= \frac{1600}{1000} \\ a &= 1.6 \text{ ms}^{-2} \end{aligned}$$

RESULTANT FORCES

When several forces act on one object, they can be replaced by one force, which has the same effect. **This single force is called the resultant or unbalanced force.**

CALCULATIONS USING $F = ma$ FOR MORE THAN ONE FORCE

If there is more than one applied force in a problem then draw a free body diagram and mark on all the known forces.

Use this to calculate the resultant force (F in the equation) before using the equation $F = ma$.

When adding more than one vector they must be added “tip to tail”. That means that the tip of the first vector must point at the tail of the next vector.

EXAMPLES

1. A car of mass 1 000 kg experiences friction equal to 500 N. If the engine force is 1 300 N, what will be the car’s acceleration?



Resultant or unbalanced force = $1300 - 500 = 800 \text{ N}$

$$F = 800 \text{ N}$$

$$m = 1\,000 \text{ kg}$$

$$F = ma$$

$$800 = 1000 \times a$$

$$a = \frac{800}{1000}$$

$$a = 0.8 \text{ ms}^{-2}$$

2. Given that the tank below has a mass of 6000 kg, calculate its acceleration.



Resultant force = $2000 - 1200 =$

$$F_{UN} = 800 \text{ N}$$

$$m = 6\,000 \text{ kg}$$

$$F = ma$$

$$800 = 6000 \times a$$

$$a = \frac{800}{6000}$$

$$a = 0.133 \text{ ms}^{-2}$$

NEWTON’S SECOND LAW QUESTIONS

1. Calculate the force needed to accelerate a 5 kg mass at 3 ms^{-2} .
2. Calculate the acceleration produced on a 12 kg mass acted on by a force of 30 N.
3. Calculate the mass when a Force of 12 N acts to produce an acceleration of 2 ms^{-2} .
4. Calculate the force which will accelerate $250g$ at 2 ms^{-2} ?
5. Calculate the force required to accelerate a 10 tonne lorry at 1.5 ms^{-2}
(1 tonne = 1000 kg)
6. State two reasons why a car will have a smaller acceleration in similar conditions when a roof rack is added.
7. Describe an experiment to investigate the effect of varying the unbalanced force acting on a fixed mass.
8. A car of mass 1200 kg experiences friction equal to 500 N when travelling at a certain speed. If the engine force is 1400 N, determine the car’s acceleration.

9. A car of mass 2000 kg has a total engine force of 4500 N. The frictional drag force acting against the car is 1700 N. Calculate the acceleration of the car.
10. Two girls push a car of mass 1000 kg. Each pushes with a force of 100 N and the force of friction is 120 N. Calculate the acceleration of the car.
11. A boat engine produces a force of 10000 N and the friction and water resistance total 3500 N. If the mass of the boat is 2000 kg, calculate its acceleration.
12. A careless driver tries to start his car with the hand brake still on. The engine exerts a force of 2500 N and the hand brake exerts a force of 1300 N. The car moves off with an acceleration of 1.2 ms^{-2} . Calculate the mass of the car.
13. A car of mass 1200 kg can accelerate at 2 ms^{-2} with an engine force of 3000 N. Determine the total frictional force acting on the car.
14. A helicopter winches an injured climber up from a mountainside. The climber's mass is 65 kg.
 - a) Calculate the weight of the climber.
 - b) If he is accelerated upwards at 1.0 ms^{-2} , determine the unbalanced force required.
 - c) Calculate the total upwards force produced by the helicopter.
15. An 800 kg car is accelerated from 0 to 18 ms^{-1} in 12 seconds.
 - a) Calculate the resultant force acting on the car.
 - b) At the end of the 12 s period the brakes are operated and the car comes to rest in a time of 5 s. Calculate the average braking force acting on the car.

HOMEWORK

1. A boy of mass 45 kg slides down a chute at a leisure centre. His acceleration is initially 2 ms^{-2} . Calculate the force acting on him.
2. A car's engine applies a force of 3000 N, and this accelerates it at 4 ms^{-2} . Calculate the mass of the car.
3. Explain, using the theory of forces, how a seat belt can prevent injury in a car crash.
4. Explain the term *balanced forces*.
5. State the equivalent of balanced forces.
6. State Newton's First Law.
7. The diagram below illustrates the forces acting on a motorbike. The combined mass of the bike and rider is 125 kg.

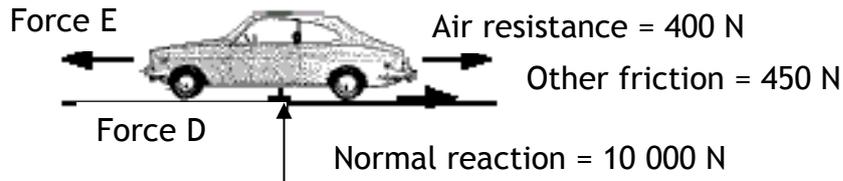


- (a) Calculate the resultant force acting on the bike.
 - (b) Calculate the acceleration of the bike.
8. Look at the pairs of forces acting on the objects below. In each case, state the resultant force and the direction in which it is acting.



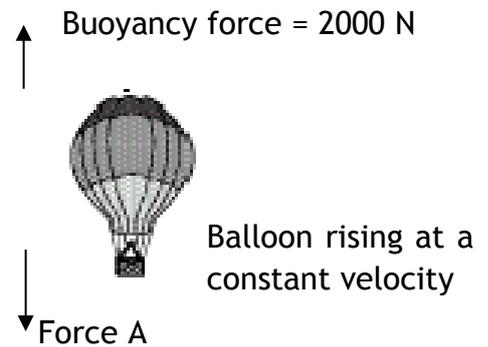
BALANCED FORCES AND NEWTON'S FIRST LAW QUESTIONS

1. The diagram below shows the forces acting on a car moving at constant velocity.



- Make a statement about the forces acting on this car.
 - Calculate the magnitude of the engine force E.
 - Calculate the weight of the car.
2. The diagram shows the forces acting on a balloon as it rises.

- Calculate the size of force A.
- If the balloon was falling at a constant velocity, determine the size of force A.



- State Newton's First Law.
- Explain, using Newton's First Law, why passengers without seat belts in a moving car appear to be "thrown forwards" in the car, when the car stops suddenly
- Explain how a parachutist reaches a terminal velocity.