Forces

When an object is pushed or pulled, we say that a force is exerted on it.

Forces can

- Cause an object to start moving
- Change the speed of a moving object
- Cause a moving object to stop moving
- Change the direction of a moving object
- Change the shape of an object

Force is measured in Newtons (N). We can measure force using a Newton Balance. The Newton Balance has a spring that extends or contracts when a force is applied. The change in spring length is directly proportional to the force applied.

Weight

Weight is a force that is caused by the pull of gravity.

Weight is not the same thing as mass **Mass** is a measure of the **matter** in an object (how many atoms it contains) and is measured in **kilograms** (kg). **Weight** is the **force** exerted by gravity and is measured in **Newtons** (N).

On Earth, an object with a mass of 1 kg will experience a force of 9.8 N due to gravity, i.e. the weight of a 1 kg mass is 9.8 N.

The ratio of weight-to-mass is given the symbol **g**. This ratio of weight-to-mass (**g**) is called the **gravitational field strength**. The units of g are **Newtons per kg** (Nkg^{-1}). The value of g on Earth is **9.8** $\mathbf{Nkg^{-1}}$.

We calculate weight using the equation

Weight = mass x gravitational field strength

or

$$W = mg$$

Example:
What is the weight of an object with mass 5kg?

Solution:
Use

$$\text{Weight} = \text{mass} \times g$$

$$= 5 \times 9.8$$

so

$$\underline{W = 49\ N}$$

When an item is dropped, it accelerates towards the ground under the force of gravity. The acceleration of the object as it falls is equal to g, so a falling object has acceleration (a) given by

$$a = 9.8\ ms^{-2}$$

We have established that g is 9.8 Nkg^{-1} here on Earth but g is different when we go to other planets. The table shows the gravitational field strength for different places in our solar system.

Location	**g (Nkg^{-1})**
Earth	9.8
Jupiter	23
Mars	3.7
The Moon	1.6
Venus	8.9
The Sun	270

Friction

Friction is a force that opposes motion. The friction force is always present when particles slide across one another. Sometimes we want a large friction force (e.g. when we apply car brakes) and other times we want the frictional force to be low (e.g. using oil in a car engine).

Friction can be **increased** by

- Applying brakes
- Opening a parachute

Friction can be **reduced** by

- Using a **lubricant**, such as oil
- Reducing the contact area between moving objects
- Making surfaces smooth (sweeping the ice when curling)
- Making objects more **streamlined** (cars, boats, planes, modern swimming outfits)

Air Resistance (Air Friction)

When an object moves through the air, its shape affects how much air resistance is experienced.

Modern cars are designed with smooth, rounded shapes to reduce air resistance. Air resistance becomes more important at high speed. For example, more extreme designs are used in Formula 1 racing. Aircraft designs are also chosen to reduce air resistance.

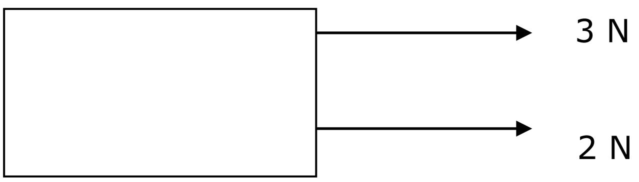
The shaping of objects to reduce air resistance is called **streamlining**. The efficiency of streamlining in a design can be measured using the drag coefficient, C_d. The larger the C_d number, the greater the air resistance the object will experience.

Combining Forces

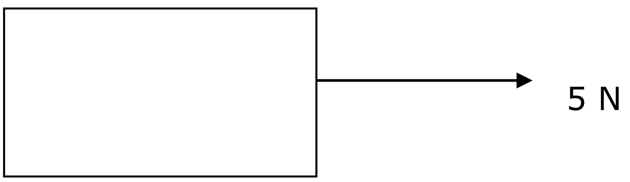
When more than one force acts on an object, we need to work out how the combination of forces will affect the object.

If the forces are acting in the same direction we can add them up to obtain the total force acting in that direction. It is easier to see what is going on if we draw a **Free Body Diagram** to show all of the forces.

If we have a force of 3N and a force of 2N acting in the same direction, we can show this on a free body diagram like this:



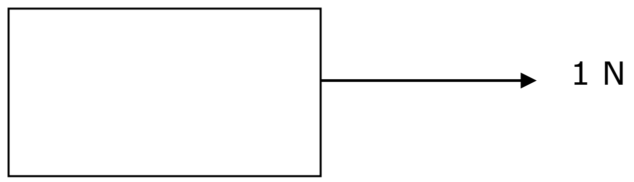
These forces can be combined to show a single force of 5N pulling in the same direction, i.e.



This combined (or net) force is the **resultant force** on the object. In this example, we say that there is a resultant (net) force of 5 N acting on the object.

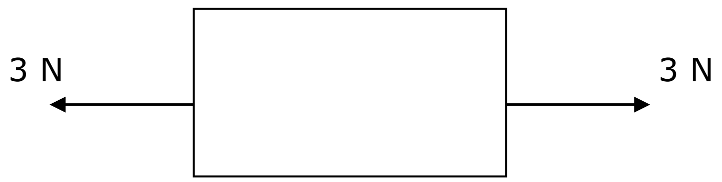
If the forces push/pull in different directions the resultant force is calculated by taking the difference between the forces.
e.g.

In this example, the resultant force would be 1 N acting towards the right.



Balanced Forces

Balanced forces are a special case where the forces acting in each direction are of the same size and cancel each other out, e.g.



In this example, there is **no** net (resultant) force acting on the object.

When balanced forces act on an object

- **The object remains stationary**
- **The speed of the object does not change**
- **Direction does not change**
- **Object shape does not change**

Examples of balanced forces;

- 2 equally-matched tug of war teams
  ➩ the rope does not move

- the force of a car engine being opposed by the force of air resistance (forces are equal in size but opposite in direction)
  ➩ the car travels at constant speed

The importance of balanced forces was first recognised by Sir Isaac Newton.

Newton's 1st Law of motion

"An object will stay at rest or travel at a constant speed if the forces acting on the object are balanced."

Example – seat belts

When a car comes to a halt suddenly, the passengers keep moving forward. There is no force to stop their movement until they collide with the windscreen.
A seat belt provides a force to act against the forward movement. The force from the seat belt causes a deceleration of the passenger and brings him/her to a halt before hitting the windscreen.

Example – terminal velocity

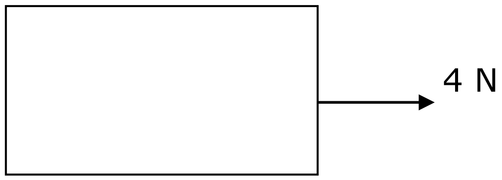
When a skydiver jumps from a plane, the diver accelerates towards the ground at 9.8 ms^{-2} as soon as he leaves the aircraft. As his speed increases, the air resistance opposing his downward motion also increases. Eventually, the air resistance force will be equal to the weight of the diver. Once these forces are balanced, the divers speed remains constant.
We call this constant falling speed the **terminal velocity**.

Unbalanced Forces

Sometimes the different forces on an object are not balanced, i.e. they do not cancel each other out.

Look at this example;

The forces do not cancel each other out. We can redraw a simplified free body diagram showing the resultant 4N force on the object.



The resultant force is 4N to the right. This is an **unbalanced force**.

An unbalanced force can

- **cause an object to start moving**
- **change the speed of a moving object**
- **change the direction of a moving object**

An unbalanced force will cause an object to accelerate (change speed). We can calculate the acceleration using **Newton's 2nd Law of Motion**.

Newton's 2nd Law of Motion

Newton's 2nd Law connects the unbalance force, the acceleration produced by the unbalanced force and the mass of the object.

Newton worked out that

Force = mass x acceleration

And we summarise this as

$$F = ma$$

Example.

A toy car of mass 3 kg accelerates at 5 ms^{-2}. Calculate the force acting on the car.

Solution:

Use F=ma.

Know $m = 3$ kg
$a = 5\ ms^{-2}$

so $F = 3 \times 5$

$F = 15$ N

We can also rearrange **F=ma** to use it to work out the acceleration of an object when the force and mass are known.

Look at this next example.

Example.
A ball of mass 50 g is hit with a steady force of 1 N.
Calculate the acceleration of the ball.

Start with F = ma

Know m = 50 g
F = 1 N

Rearrange formula to get

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

make sure units are correct

m is in grams,

need to get it into kg
m = 50 g = 0.05 kg

$$a = \frac{1}{0.05}$$

so

a = 20 ms^{-2}

When there is more than one force present we can still use F=ma but in these situations **the value of F used is the resultant (net) force**.

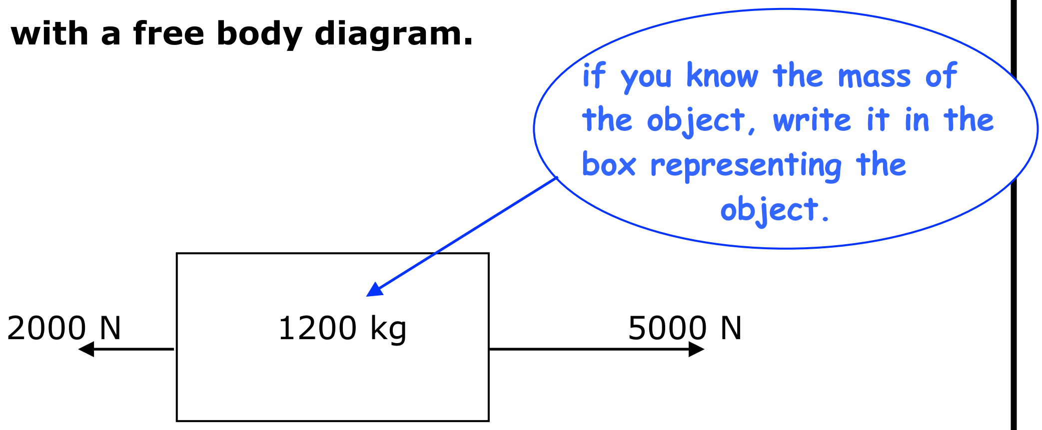
This example shows how to solve a problem with more than one force present.

Example.

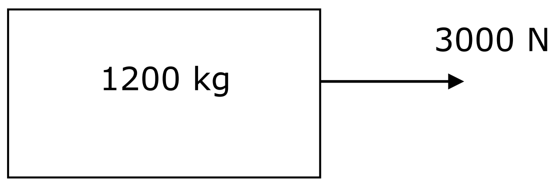
The engine of a car (mass 1200 kg) produces a force of 5000 N. Calculate the acceleration of the car if there is 2000 N of air resistance acting against the motion of the car.

Solution:

Start with a free body diagram.



and simplify the problem to show the net force:



Now use F=ma

$$a = \frac{F}{m} = \frac{3000}{1200}$$

so

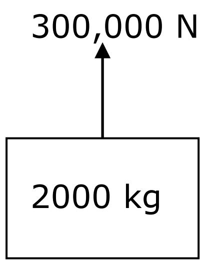
$a = 2.5\ ms^{-2}$

Sometimes a problem based on Newton's 2nd Law (F=ma) doesn't tell you everything and you have to think for yourself before you can solve the problem correctly. This next example falls into this category.

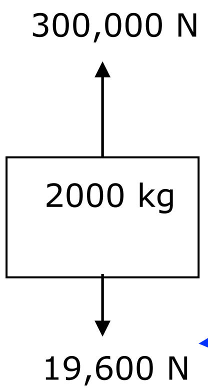
Example.

A rocket of mass 2000 kg produces a thrust of 3×10^5 N from its engines during takeoff. Calculate the acceleration of the rocket.

Solution:
Start with a diagram.



Make sure that you have included all the forces acting on the object, not just the forces given in the question.



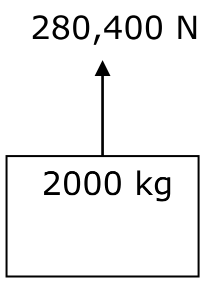
In this example, you need to remember to include the **weight** (downwards force due to gravity) in your free body diagram.

Use W = m x g

= 2000 x 9.8

so

W = 19,600 N



resultant force
use this force in your formula

F =ma

$$280400 = 2000 \times a$$

so the rocket acceleration **<u>a = 140 ms^{-2}</u>** (3 sig figs)