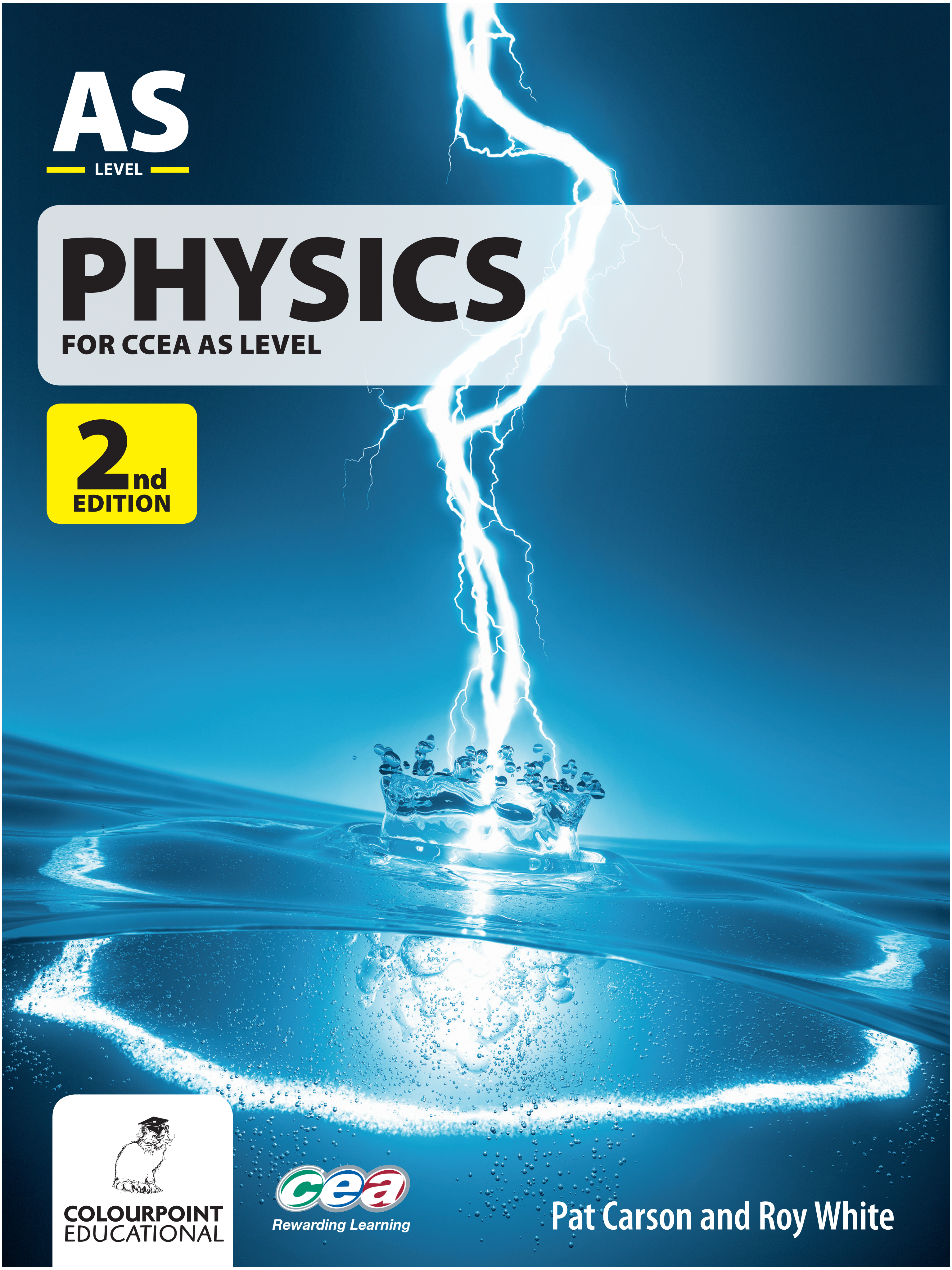
AS
LEVEL

PHYSICS

FOR CCEA AS LEVEL

2nd EDITION



Pat Carson and Roy White

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cea Rewarding Learning

Print ISBN: 978 1 78073 097 4

eBook ISBN: 978 1 78073 296 1

Second Edition
Second Impression with minor amendments 2019

Layout and design: April Sky Design, Newtownards

COLOURPOINT
EDUCATIONAL

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Unit AS 1:

Forces, Energy and Electricity

1.1 Physical Quantities

Students should be able to:

1.1.1 Describe all physical quantities as consisting of a numerical magnitude and unit

1.1.2 State the base units of mass, length, time, current, temperature, and amount of substance and be able to express other quantities in terms of these units

1.1.3 Recall and use the prefixes T, G, M, k, c, m, μ, n, p and f, and present these in standard form

Physical quantities

Physics is a science which relies heavily on measurement. To understand any physical phenomenon we have to be able to measure physical quantities. Examples of physical quantities include mass, length, time, force and energy.

To describe a physical quantity we first define a characteristic **unit**. To state a measurement of some physical quantity, for example force, we need to state two things:

1 Magnitude (size) – a numerical value

2 Unit

So a force of 25 newtons would be written as **25 N.**

International System of Units (SI units)

In 1971 it was agreed by the scientific community to use seven quantities as base quantities. This formed the basis of the International System of Units, abbreviated SI from its French name. In this system it was agreed that **only one unit** would be used to measure any physical quantity. However, multiples and submultiples of these base units or quantities are commonly used. Length is measured in metres (m), but multiples such as kilometres (km) and submultiples such as centimetres (cm) and millimetres (mm) are in common use.

Base units

The SI system defines seven base units from which all other units are derived. The table below shows the six base units that you will come across in this A level course.

Quantity	Unit	Symbol
mass	kilogram	kg
time	second	s
length	metre	m
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol

Prefixes for units

The table below lists the names of common multiples and submultiples of SI units.

Prefix	Multiplying factor	Symbol
femto	10^{-15}	f
pico	10^{-12}	p
nano	10^{-9}	n
micro	10^{-6}	μ
milli	10^{-3}	m
centi	10^{-2}	c
kilo	10^{3}	k
Mega	10^{6}	M
Giga	10^{9}	G
Tera	10^{12}	T

Derived units

Many SI units are derived, i.e. they are defined in terms of two or more base units. For example, velocity is measured in metres per second, written as m s^{-1}. Some derived units have names, such as the newton (N) and the volt (V), but many do not.

The **name** of a unit when written in full is all in lower case, for example newton, joule and hertz. The **symbol** has a capital letter, for example N, J and Hz.

Do not add an 's' to indicate plural, for example 15 newtons is written as 15 N. If you write this as 15 Ns then you are stating that the physical quantity is 15 newton seconds and this is a measurement of impulse (momentum change) and not force.

Converting derived units to base units

It is sometimes useful to write a physical quantity in terms of its base units. Energy is measured in joules (a derived unit). What are the base units of energy? To calculate the base units for energy we can use any valid formula for energy, such as the following for kinetic energy, E_k:

$E_k = ½mv^2$ (the ½ has no unit because it is a number)

In terms of physical quantities, we can write:

unit for energy = unit for mass × unit for velocity × unit for velocity

= kg × m s^{-1} × m s^{-1}

= kg × m^2 × s^{-2}

The base units of kinetic energy are therefore kg m^2 s^{-2}. These are also the base units of **any form of energy** and of **work**.

Homogeneous equations

For an equation to be valid it is necessary, though not sufficient, for the units on both sides of the equality sign to be the same. Such equations are called **homogeneous**. Thus, the equation **force = (momentum change) ÷ time taken** is homogeneous because both sides have base units of kg m s^{-2}. On the other hand, the equation **pressure = momentum × volume** is **inhomogeneous** because the left hand side has base units of kg m^{-1} s^{-2}, but the right hand side has base units of kg m^4 s^{-1}. Inhomogeneous equations are nonsensical.

Exercise 1.1

1 Express each of the following physical quantities in base units.
If the derived unit of this physical quantity has a name then state it.

(a) Work (Work = force × distance moved)
(b) Power (Power = work done ÷ time taken)
(c) Momentum (Momentum = mass × velocity)
(d) Acceleration (Acceleration = velocity change ÷ time taken)
(e) Force (Force = mass × acceleration)
(f) Frequency (Frequency = speed ÷ wavelength)

2 On the planet Krypton the same laws of Physics apply as on the Earth. However, the inhabitants of Krypton have decided to use force (F), acceleration (A) and time (T) as their base units.
What are the base units of energy on the planet Krypton?

3 A simple pendulum consists of a mass on the end of a length of string. If the length of the string is L and g is the acceleration of free fall, then the time to complete one oscillation, called the period, is T, where:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Show that the base units of both sides of the equation are identical.

4 A mass attached to a spring will oscillate up and down when disturbed. The period T of such oscillations is given by:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

The mass is m and k is the spring constant, i.e. the force needed to stretch the spring by 1 m.
The units of k are N m^{-1}.
Show that the equation is homogeneous in terms of the base units on each side.

1.2 Scalars and Vectors

Students should be able to:

- **1.2.1** Distinguish between and give examples of scalar and vector quantities
- **1.2.2** Resolve a vector into two perpendicular components
- **1.2.3** Calculate the resultant of two coplanar vectors by calculation or scale drawing, with calculations limited to two perpendicular vectors
- **1.2.4** Solve problems that include two or three coplanar forces acting at a point, in the context of equilibrium

A vector is a physical quantity that needs magnitude, a unit and a direction.

A scalar is a physical quantity that requires only magnitude and a unit.

For example, speed is a scalar but velocity is a vector; mass is a scalar, but weight is a vector.

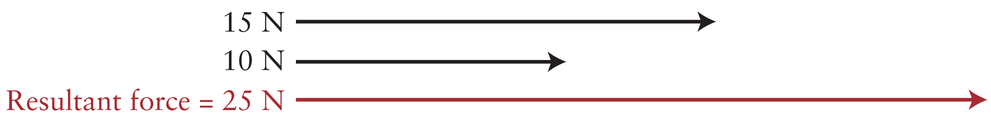
The table below lists some of the vectors and scalars that you will encounter in the AS course.

Vector	Scalar
Displacement	Distance
Velocity	Speed
Acceleration	Rate of change of speed
Force	Time
Electric current	Electric charge
Momentum	Kinetic energy
	Temperature
	Area
	Volume
	Mass

Combining vectors

When we add vectors we have to take into account their direction as well as magnitude. If the directions are in the same straight line then we can define any vector acting to the right as positive and any acting to the left as negative. When we add two or more vectors, the final vector is called the **resultant**.

For two forces of 15 N and 10 N acting in the same direction, the resultant is 25 N.

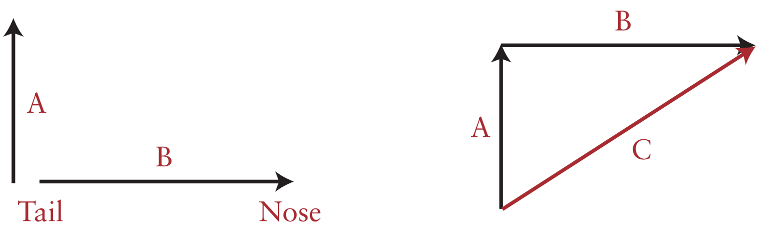


For two forces of 15 N and 10 N acting in opposite directions, the resultant is 5 N in the direction of the larger force.

Adding and subtracting vectors

If the vectors are not in a straight line then we use the **nose to tail method** to find the resultant.

The vector diagram on the left (below) shows two vectors, A and B. The resultant of these two vectors is C where **C** = **A** + B. The vector diagram on the right is obtained by placing the tail of vector B at the nose of vector A. The resultant, C, is the line joining the tail of A to the nose of B.

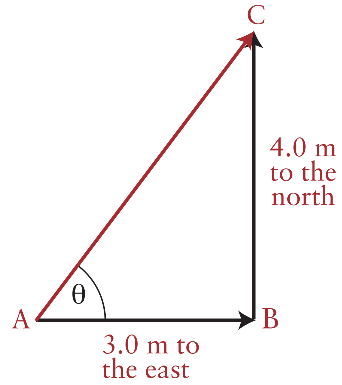


The resultant of subtracting the vector B from A is another vector, D, where **D = A – B**. The vector **–B** is a vector of the **same magnitude as B** but in the **opposite direction.** Effectively we add the negative vector, so **D = A + (–B)** as shown in the diagram on the right (below).

To emphasise that certain quantities are vectors, we sometimes underline them ($\underline{A}$) or draw an arrow above them ($\vec{A}$) to show direction. In books, vectors are often shown in bold type (**A**).

Worked Examples

1 Linda moved 3.0 m to the east (AB) and then 4.0 m to the north (BC), as shown in the diagram on the right. What is her displacement from the starting point?



Solution

$AC^2 = AB^2 + BC^2$

$= 3^2 + 4^2 = 25$

$AC = \sqrt{25} = 5.0$ m

So although she has moved a total distance of 7.0 m, her displacement is 5.0 m (AC) from the start. Since displacement is a vector, a magnitude and a direction are both needed. So we also need to calculate the direction.

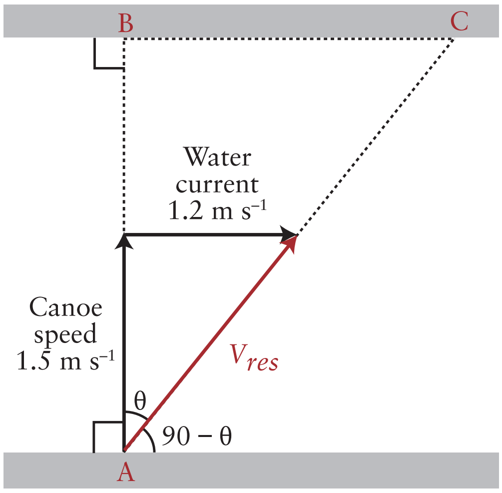
tan θ = opposite ÷ adjacent = 4 ÷ 3 = 1.333 giving θ = 53.13°

So Linda's finishing point has a displacement of 5.0 m from her starting point, at an angle of 53.13° to the north of east.

The above problem can also be solved using a **scale drawing**. For example, using a scale of 2 cm = 1 m, **use a ruler** to draw a horizontal line, AB, 6 cm long to represent the 3.0 m travelled due east. Now, from B draw a vertical line 8 cm long to represent the 4.0 m travelled due north. Suppose this vertical line ends at point C. **Join *AC*** to obtain the resultant displacement.

On the diagram AC will be 10 cm long, and with a scale of 2 cm = 1 m, it represents a real displacement of 5.0 m. Finally **use a protractor to measure the angle at C**. You should obtain an angle of 53° if sufficient care is taken.

2 The diagram on the right shows a canoe moving across a river at 1.5 m s^{-1} while the water moves to the right at 1.2 m s^{-1}. If the canoeist sets off at A with the intention of rowing to B, he would not reach B, but would reach the opposite bank of the river at C. What is the canoeist's resultant velocity?



Solution

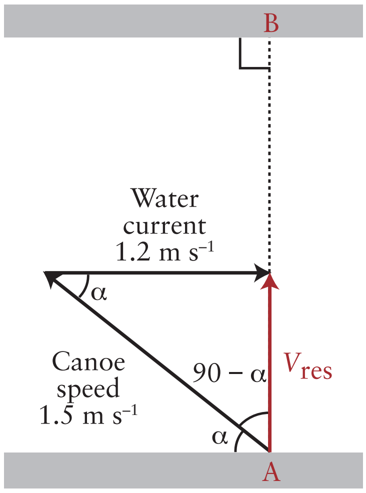
The resultant velocity $\boldsymbol{v}_{res}$ is the vector sum of the speed of the canoe and the speed of the water current.

$v_{res}^{\ 2} = 1.5^2 + 1.2^2$

$v_{res} = \sqrt{3.69} = 1.9$ m s^{-1}

The direction in which the canoe moves makes an angle θ with the line AB, which is perpendicular to the bank. So tan θ = opp ÷ adj = 1.2 ÷ 1.5 = 0.8 giving θ = 38.7°.

3 If the canoeist in Example 2 wants to cross from A to B, clearly he must paddle the canoe upstream. The direction in which he moves must combine with the speed of the river so that the resultant velocity is in the direction A to B. At what angle must he direct the canoe, and what is his resultant velocity?



Solution

The angle to the bank that he must now direct the canoe is α.

$$\begin{aligned} \cos \alpha &= \text{adj} \div \text{hyp} \\ &= 1.2 \div 1.5 \\ &= 0.8 \end{aligned}$$

Giving an angle $\alpha = 36.9°$.

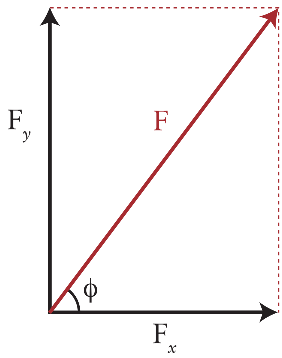
The resultant velocity is then obtained:

$$\begin{aligned} \sin \alpha &= \text{opp} \div \text{hyp} \\ &= v_{res} \div 1.5 \\ 0.6 &= v_{res} \div 1.5 \\ v_{res} &= 0.9 \text{ m s}^{-1} \end{aligned}$$

Components of a vector

It is often useful to split or **resolve** a vector into two parts or components. Each component tells you the effect of the vector in that direction. It is common to have these components act in directions that are perpendicular to each other, for example vertically and horizontally.

The diagram on the right shows a vector, F, that has been resolved into two components, which are at right angles to each other. The magnitude of the two components can be calculated as follows:



$\sin \phi = \text{opp} \div \text{hyp} = F_y \div F$

$\boldsymbol{F_y = F \sin \phi}$

$\cos \phi = \text{adj} \div \text{hyp} = F_x \div F$

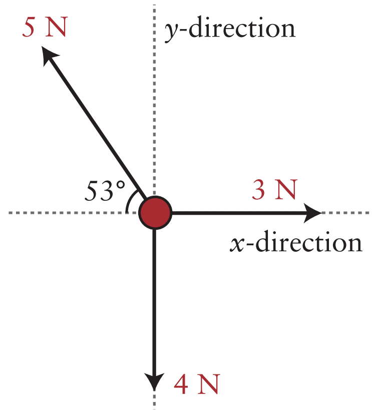
$\boldsymbol{F_x = F \cos \phi}$

Equilibrium of forces

If we consider the forces acting in two perpendicular directions, such as up and down, left and right, then **the object is in equilibrium if the up forces equal the down forces and the forces acting to the left equal those acting to the right.** This is known as **translational equilibrium**.

Worked Example

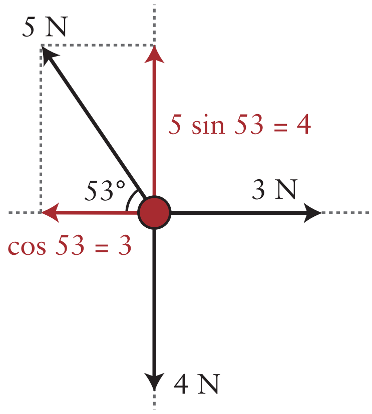
1 The object in the diagram on the right is acted upon by three forces that make angles with each other as shown. Is the object in translational equilibrium?



Solution

The object is in translational equilibrium if the resultant force is equal to zero. So to answer this question we must first resolve the forces in the x-direction and the y-direction.

In the diagram on the right the 5 N force has been resolved into its components, one in the x-direction and the other in the y-direction.



As you can see, the forces in the x-direction are equal and opposite, **and** the forces in the y-direction are also equal and opposite.

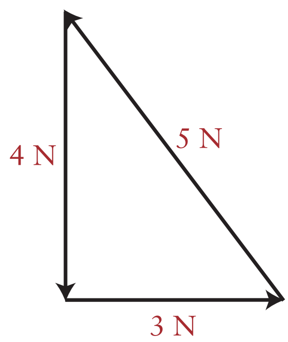
The resultant force is zero and therefore the object is in translational equilibrium.

Triangle of forces

Force is a vector. Each of the forces acting on an object can be represented by a line, the length of which indicates the size of the force and the direction of which represents the angle each force makes with the x and y directions.

When an object is in equilibrium the forces acting on it, taken in order, can be represented in size and direction by the sides of a closed triangle.

The phrase 'taken in order' means that the arrows showing the force directions follow each other in the **same direction** around the triangle.



The three forces in the worked example above are in equilibrium. This means that they can be represented by a closed triangle as shown in the diagram on the right.

We sometimes need to find the force needed to restore equilibrium when two forces that are not perpendicular to each other are acting on a body. The magnitude and direction of this additional force can be found either by scale drawing or by calculation, where we resolve the vectors into their components and then add. The next worked example considers such a problem.