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Physical Quantities and Units

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You are already familiar with much of this chapter but it does contain a large amount of detail that you must use accurately. Using units and quantities correctly and showing your workings are very important skills to practice so that you avoid making errors, particularly when writing up practical work or when writing answers to tests.

Physical quantities

All measurements of physical quantities require both a numerical value and a unit in which the measurement is made. For example, your height might be 1.73 metres. The number and the unit in which it is measured need to be kept together because it is meaningless to write 'height = 1.73'. The numerical value is called the **magnitude of the quantity** and the magnitude has meaning only when the unit is attached. In this particular case it would be correct to write 'height = 173 centimetres', since there are 100 centimetres in a metre. You can help avoid making mistakes when converting units by using this method.

Write the conversion as an equation.

$$1.73\,\text{m} = 1.73\,\text{m} \times 100\,\frac{\text{cm}}{\text{m}} = 173\,\text{cm}$$

The m on the top cancels with an m on the bottom so you are certain the conversion is the right way round. Many students make the mistake of not reviewing what they have written in an equation to make sure it makes sense.

Teacher's Tip

Look out for incorrect statements. Check you write numbers and units correctly and do not write, for example, 1.73 cm = 173 m.

Other conversions are not necessarily so obvious.

Another matter of convention with units concerns the way they are written on graph axes and in tables of values. You might often use or see a statement such as 'energy/joule' or in an abbreviated form 'E/J'. This means the quantity energy divided by its SI unit, the joule. For example

$$\frac{\text{energy}}{\text{joule}} = \frac{780\ \text{joule}}{\text{joule}} = 780$$

The figure 780 is now just a number with no unit. That is what will appear in a table of values or on a graph so there is no need to add the unit to every value in tables or graphs, provided the unit is shown on the heading or axis.

In order to answer the questions given, you will need to use the prefixes on multiples and sub-multiples of units. Table 1.1 shows the meaning of each term you might have to use.

Table 1.1

Prefix	Abbreviation	Multiplying factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

So, for example, light of wavelength 456 nm is a wavelength of 456×10^{-9} m. This will equate to 4.56×10^{-7} m or 0.000 000 456 m. Always be careful with any of these prefixes and double check to see that you are not using them the wrong way round. It is amazing how often some students will, for example, find the speed of a car as an unrealistic 0.0052 m s^{-1} when it ought to be 52 m s^{-1}. The reason for the difference is that at some stage in the calculation the student has divided by 100 when he or she should have multiplied.

SI units (Système International d'unités)

All the units you use during your AS course are called the SI units. They are derived from five base units. These are, together with the abbreviation used for each, as follows:

- the kilogram (kg) as the unit of mass,
- the metre (m) as the unit of length,
- the second (s) as the unit of time,
- the ampere (A) as the unit of electric current and
- the kelvin (K) as the unit of absolute temperature.

The definition of these five units is amazingly complicated and you are not required to know the definitions. Each definition is very precise and enables national laboratories to measure physical quantities with a high degree of accuracy.

Although you do not need to know these definitions, you will need to know how many other definitions of SI units are derived from the base units. All the definitions and their corresponding units are given in this book, when required in appropriate chapters. Knowledge of units is essential since every numerical question you might have to answer will be dependent upon using units.

To find the expression of a unit in base units it is necessary to use the definition of the quantity. For example, **the newton (N), as the unit of force, is defined by using the equation**

force = mass × acceleration.

So, $1\,\text{N} = 1\,\text{kg} \times 1\,\text{m s}^{-2}$ or $1\,\text{N} = 1\,\text{kg m s}^{-2}$.

Estimating physical quantities

In making estimates of physical quantities it is essential that you do not just guess a value and write it down. It is important to include the method you use, not just the numerical values. Answers you write might have numerical values stretching from 10^{-30} to 10^{40}. You need to remember some important values, to one significant figure, in SI units. The following list is by no means complete but is a starting point.

Do not forget that various atomic sizes and masses may be given in the exam paper data.

mass of an adult	70 kg
mass of a car	1000 kg
height of a tall man	2 m
height of a mountain	5000 m
speed of car on a high-speed road	30 m s^{-1}
speed of a plane	300 m s^{-1}
speed of sound in air at sea level	300 m s^{-1}
weight of an adult	700 N
energy requirement for a person for one day	10 000 000 J
power of a car	60 kW
power of a person running	200 W
pressure of the atmosphere	100 000 Pa
density of water	1000 kg m^{-3}
A few astronomical values are useful too.	
distance from the Earth to the Moon	400 000 km
distance from the Earth to the Sun	150 000 000 km
radius of the Earth	6000 km
mass of the Earth	6×10^{24} kg

Once you have some basic data you can use it to find an approximate value for many quantities. As a general rule, always get your values into SI units, even though you may well remember some values in non-SI units. Never use non-SI units such as miles, yards, pounds, etc.

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For example, a question might ask you to estimate a value for the kinetic energy of a cruise liner. 'Estimate' means the values you choose do not have to be precise, but they should be sensible. A suitable answer to this question might look like this:

Mass of cruise liner estimated as 20 000 tonnes

$$1 \text{ tonne} = 1000\,\text{kg}$$

$$\text{so mass of cruise liner} = 20\,000 \times 1000 = 2 \times 10^7\,\text{kg}$$

$$\text{Speed of cruise liner} = 15\,\text{m s}^{-1} \text{ (half the speed of a car)}$$

$$\begin{aligned}\text{Kinetic energy} &= \tfrac{1}{2}mv^2\\ &= 0.5 \times 2 \times 10^7 \times 15^2\\ &= 2 \times 10^9\,\text{J (to 1 significant figure).}\end{aligned}$$

Scientific equations

You also need to be able to check the *homogeneity* of any equation. This means that both sides of any equation must have the same units.

For example, consider the equation for kinetic energy $E_k = \frac{1}{2}mv^2$.

The unit of energy (the joule) is the unit of force × distance, i.e. the unit of mass × acceleration × distance. So the unit of E_k is kg × m s^{-2} × m, which simplifies to kg m^2 s^{-2}.

Looking at the right-hand side of the equation for kinetic energy, the unit of $\frac{1}{2}mv^2$ is kg × m^2 × s^{-2}, which is the same as the unit of E_k (the $\frac{1}{2}$ has no unit).

This means that the equation for kinetic energy is homogeneous.

If you ever find that the units on both sides of an equation are not the same, then either the equation is incorrect or you have made a mistake somewhere.

Vectors and scalars

A vector is a quantity that has direction as well as magnitude; a scalar is a quantity with magnitude only.

Table 1.2 lists quantities in their correct category.

Table 1.2

Scalars	Vectors
mass	displacement
length	velocity
time	acceleration
area	force
volume	momentum
density	
speed	
pressure	
work	
energy	
power	

Combining vectors

Adding or subtracting scalars is just like adding or subtracting numbers, as long as you always remember to include the unit. Adding vectors can be difficult; subtracting vectors can be even more difficult. Forces are vector quantities. When adding two forces together the total force is called the resultant force. The resultant force is not an actual force at all. It is just the sum of all the forces acting on an object. The forces that we add might be caused by different things, for example one force could be a gravitational force and the other could be an electrical force. It might seem impossible for a force of 8 N to be added to a force of 6 N and get an answer 2 N, but it could be correct if the two forces acted in opposite directions on an object. In fact, for these two forces a resultant force can have any magnitude between a maximum of 14 N and a minimum of 2 N, depending on the angle that the forces have with one another. In order to find the resultant of these two forces, a triangle of forces is used, as shown in Figure 1.1. The two vectors are drawn to scale, with 1 cm representing 2 N.

The mathematics of finding the resultant can be difficult but if there is a right angle in the triangle things can be much more straightforward.

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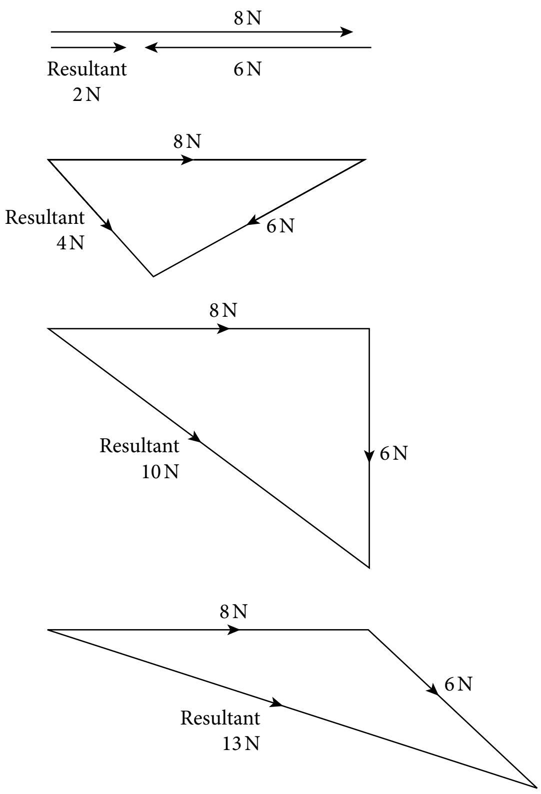

Figure 1.1 Addition of vectors

Subtracting vectors also makes use of a vector triangle. Note that you can always do subtraction by addition. If you want to know how much money you can spend if you want to keep \$20 out of a starting sum of \$37, then instead of \$37 – \$20 = \$17 you can think 'what needs to be added to 20 to get 37'.

To subtract vector B from vector A, a triangle of vectors is used in which –(vector B) is added to vector A. This is shown in Figure 1.2. Note that A + (–B) is the same as A – B.

Resolution of vectors

Not only is it possible for you to add vectors, it is often useful to be able to split a single vector into two. This process is called **resolution** of a vector and almost always resolution means to split one vector into two components at right angles to one another. This is illustrated in Figure 1.3.

In Figure 1.3(a) an object has velocity v at an angle θ to the horizontal. The velocity can be considered equivalent to the two other velocities shown. $v \sin\theta$ is its vertical component and $v \cos\theta$ is its horizontal component. In Figure 1.3(b), force F is the force the sloping ground exerts on a stationary object resting on it. (This force will be equal and opposite to the weight of the object.) F can be resolved into two components. $F \sin\phi$ is the force along the slope and is the frictional force that prevents the object sliding down the slope. $F \cos\phi$ is the component at right angles to the slope.

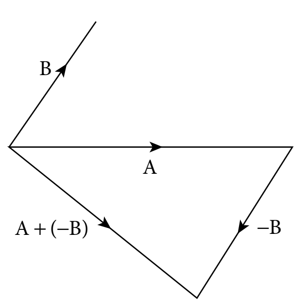

Figure 1.2 Subtraction of vectors

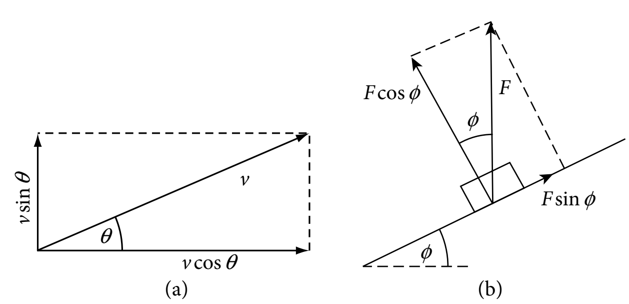

Figure 1.3 Resolution of a vector

Chapter Summary

- ✓ Almost all physical quantities require a numerical value and a unit.
- ✓ The units used throughout the book are SI units.
- ✓ Some physical quantities have direction. These are called vectors and can be added using a vector triangle.
- ✓ Quantities without direction are called scalars. These are added arithmetically.

Progress Check

1.1 Convert
(a) 2.86 kilograms into grams,
(b) 0.0543 kilograms into grams,
(c) 48 grams into kilograms,
(d) 3.8 hours into seconds,
(e) 6 500 000 seconds into days.

1.2 Convert
(a) 1.00 square metres into square centimetres,
(b) 7.38 cubic metres into cubic centimetres,
(c) 6.58 cubic centimetres into cubic metres,
(d) a density of 3.45 grams per cubic centimetre into kilograms per cubic metre,
(e) a speed of 110 kilometres per hour into metres per second.

1.3 Derive the base units for
(a) the joule, the unit of energy
(b) the pascal, the unit of pressure
(c) the watt, the unit of power.

1.4 Use base units to show whether or not these equations balance in terms of units. (Note: this does not mean that the equations are correct.)
(a) $E = mc^2$
(b) $E = mgh$
(c) power = force × velocity
(d) $p = \rho gh$

1.5 Estimate the following quantities.
(a) The energy required for you to go upstairs to bed.
(b) The average speed of a winner of a marathon.
(c) The power requirement of a bird in a migration flight.
(d) The vertical velocity of take-off for a good high jumper.
(e) The acceleration of a sports car.
(f) The density of the human body.
(g) The pressure on a submarine at a depth of 1000 m.

1.6 Explain why these suggested estimates are incorrect.
(a) The power of a hot plate on a cooker is 2 W.
(b) The speed of a sub-atomic particle is 4×10^8 m s^{-1}.
(c) The hot water in a domestic radiator is at a temperature of 28 °C.
(d) The pressure of the air in a balloon is 15 000 Pa.
(e) The maximum possible acceleration of a racing car is 9.81 m s^{-2}.

1.7 Using a copy of Figure 1.2, determine the value of vector B – vector A.

1.8 A car changes speed from 30 m s^{-1} to 20 m s^{-1} while turning a corner and changing direction by 90°. What is the change in velocity of the car? State the angle of the resultant velocity of the car relative to the initial velocity.

1.9 The Moon moves around the Earth in a circular orbit of radius 3.84×10^8 m. Its speed is 1020 m s^{-1}. Deduce
(a) the time taken for a complete orbit of the Earth,
(b) the angle the Moon moves through in 1.00 s,
(c) the change in velocity of the Moon in 1.00 s.

1.10 An athlete, just after the start of a race, has a force of 780 N exerted on her by the ground and acting at an angle of 35° to the vertical. What is the weight of the athlete and what is the force causing her horizontal acceleration?

1.11 A kite of weight 4.8 N, shown in Figure 1.4, is being pulled by a force in the string of 6.3 N acting in a direction of 27° to the vertical.

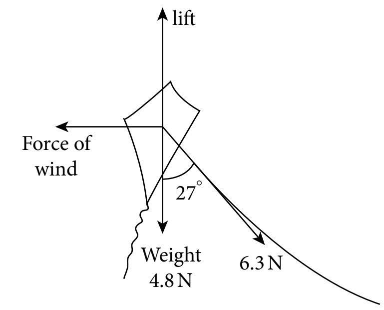

Figure 1.4

(a) Resolve the force in the string into horizontal and vertical components.
(b) Assuming that the kite is flying steadily, deduce the upward lift on the kite and the horizontal force the wind exerts on the kite.

