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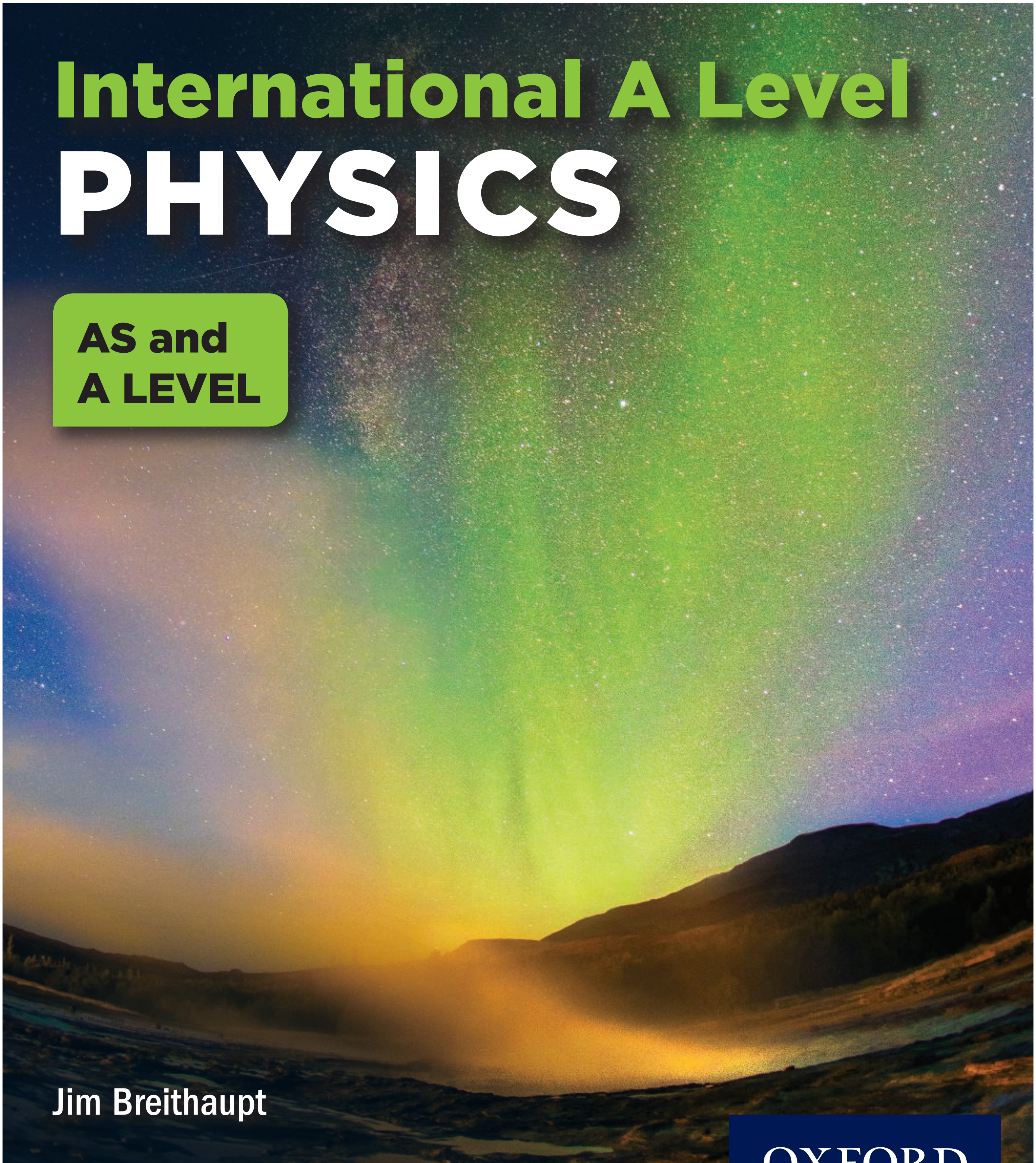

International A Level
PHYSICS

AS and
A LEVEL

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OXFORD

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Section 5

Answers to the Practice Questions and Section Questions are available at www.oxfordsecondary.com/oxfordaqaexams-alevel-physics

Derived units written in terms of their base units can be used to check equations. The physical quantities on each side of an equation must match in terms of base units.

If they don't match, the equation cannot be correct. For example, consider

- the equation $v = \sqrt{2gR}$, which is used to calculate the escape speed v of an object from the surface of a planet of radius R and surface gravitational field strength g

  Left-hand side base units = $\mathrm{m\,s^{-1}}$

  Right-hand side base units = $\sqrt{\mathrm{m\,s^{-2}} \times \mathrm{m}} = \mathrm{m\,s^{-1}}$

The equation has the same combination of base units on each side, so it is correct – we say it is **homogeneous** in terms of the base units.

- the equation $W = QV$ is used to calculate the work done W to move a charge Q through a potential difference V

  Left-hand side base units (see Table 3) = $\mathrm{kg\,m^2\,s^{-2}}$

  Right-hand side base units = $(\mathrm{A\,s}) \times (\mathrm{kg\,m^2\,s^{-3}\,A^{-1}}) = \mathrm{kg\,m^2\,s^{-2}}$

The equation has the same combination of base units on each side, so it is homogeneous. Note that for simple equations such as this, homogeneity can be checked faster by recalling basic relationships between physical quantities. In this example, one volt is one joule per coulomb, so the unit of QV is the joule per coulomb × the coulomb, which is the joule.

The links between different units do not need to be made through the SI base units. For example, the volt (V) is the joule per coulomb ($\mathrm{J\,C^{-1}}$), which is a useful link to remember as it helps you to develop your understanding of potential difference.

There are some units in the A Level specification that are not SI units but they are used in specific situations for convenience. Those listed below are in common use.

1. The **atmosphere** (atm) is a unit of pressure equal to the mean pressure of the atmosphere at sea level and is equal to 101 kPa.
2. The **electron volt** (eV) is a unit of energy defined as the work done when an electron moves through a p.d. of 1 V.
   $1\,\mathrm{eV} = 1.6 \times 10^{-19}\,\mathrm{J}$.
   Note that $1\,\mathrm{MeV} = 10^6\,\mathrm{eV} = 1.6 \times 10^{-13}\,\mathrm{J}$
3. The **kilowatt hour** (kW h) is a unit of energy equal to the energy supplied to a one kilowatt appliance in one hour, which is 3.6 MJ.
4. The **light year** is the distance travelled in space by light in one year.
5. The **litre** is a unit of volume equal to $10^{-3}\,\mathrm{m^3}$.

Practical work in physics
Moving on from GCSE

In the laboratory

The experimental skills you will develop during your course are part of the tools of the trade of every physicist. Data loggers and computers are commonplace in modern physics laboratories, but awareness on the part of the user of precision, reliability, errors, and accuracy are just as important as when measurements are made with much simpler equipment. Let's consider in more detail what you need to be aware of when you are working in the physics laboratory.

Safety and organisation

Your teacher will give you a set of safety rules and should explain them to you. You must comply with them at all times. You must also use your common sense and organise yourself so that you work safely. For example, if you set up an experiment with pulleys and weights, you need to ensure they are stable and will not topple over.

Working with others

Most scientists work in teams, each person cooperating with other team members to achieve specific objectives. This is effective because, although each team member may have a designated part to play, the exchange of ideas within the team often gives greater insight and awareness as to how to achieve the objectives.

In your AS Level practical activities, you will often work in a small group in which you need to cooperate with the others in the group so everyone understands the objectives of the practical activity and everyone participates in planning and carrying out the activity.

Planning

At AS Level, you may be asked to plan an experiment or investigation. The practical activities you carry out during your course should enable you to prepare a plan. Here are the key steps in drawing up a plan:

1 Decide in detail what you intend to investigate. Note the independent and dependent variables you intend to measure, and note the variables that need to be controlled. The other variables need to be controlled to make sure they do not change. A **control variable** that can't be kept constant would cause the **dependent variable** to alter.

2 Select the equipment necessary for the measurements. Specify the range of any electrical meters you need.

3 List the key stages in the method you intend to follow and make some preliminary measurements to check your initial plans. Consider safety issues before you do any preliminary tests. If necessary, modify your plans as a result of your preliminary tests.

4 If the aim of your investigation is to test a hypothesis or theory or to use the measurements to determine a physical quantity (e.g., resistivity), you need to know how to use the measurements you make. See Analysis and evaluation on page 7 for notes about how to process and use measurement data.

Carrying out instructions and recording your measurements

In some investigations, you will be expected to follow instructions supplied to you either verbally or on a worksheet. You should be able to follow a sequence of instructions without guidance. Part of the direct assessment of your practical work is on how well you follow instructions. However, always remember safety first and, if the instructions are not clear, ask your teacher to clarify them.

When you record your measurements, tabulate them with a column for the independent variable and one or more columns for the dependent variable to allow for repeat readings and average values, if appropriate. The table should have a clear heading for each of the measured variables, with the unit shown after the heading, as below.

Single measurements of other variables (e.g., control variables) should be recorded together, immediately before or after the table. In addition, you should record the precision (i.e., the least detectable reading) of each measurement. This information is important when you come to analyse and evaluate your measurements.

▼ **Table 1** *Tabulating the measurements from an investigation of p.d. against current for a wire*

Potential difference / V	Current / A			Average current / A
	1st set	2nd set	3rd set	

length of wire / m = ______

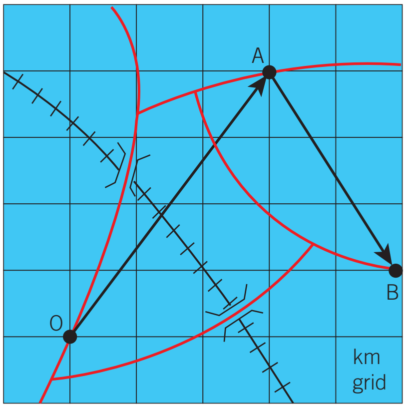
diameter of wire / mm = ______, ______, ______

average diameter of wire / mm = ______

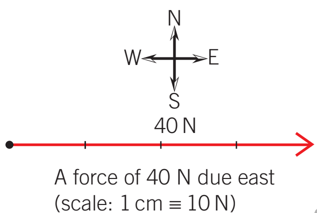
1 Forces in equilibrium
1.1 Vectors and scalars

Learning objectives:
- → Define a vector quantity.
- → Describe how we represent vectors.
- → Explain how we add and resolve vectors.

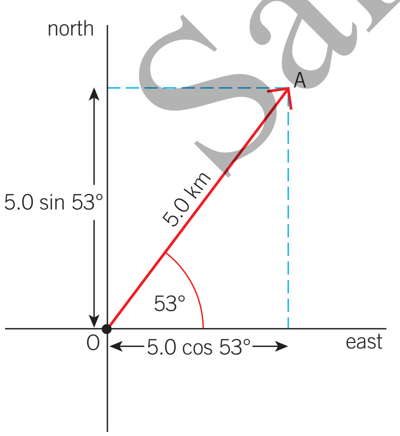
Specification reference: 3.2.1



▲ **Figure 1** *Map of locality*



▲ **Figure 2** *Representing vectors*



▲ **Figure 3** *Resolving a vector*

Representing a vector

Imagine you are planning to cycle to a friend's home several kilometres away from your home. The **distance** you travel depends on your route. However, the direct distance from your home to your friend's home is the same, whichever route you choose. Distance in a given direction, or **displacement**, is an example of a **vector** quantity because it has magnitude and direction. In Figure 1, suppose your home is at point O on the map and your friend's home is at A. The road distance you would cycle from O to A is greater than the direct distance or displacement from O to A. This is represented by the arrow from O to A.

A vector is any physical quantity that has a direction as well as a magnitude.

Further examples of vectors include velocity, acceleration, weight and force.

A scalar is any physical quantity that is not directional.

For example, distance is a scalar because it takes no account of direction. Further examples of scalars include mass, density, volume, and energy.

Any vector can be represented as an arrow. The length of the arrow represents the magnitude of the vector quantity. The direction of the arrow gives the direction of the vector.

- **Displacement** is distance in a given direction. As shown in Figure 1, the displacement from one point to another can be represented on a map or a scale diagram as an arrow from the first point to the second point. The length of the arrow must be in proportion to the least distance between the two points.
- **Velocity** is speed in a given direction. The velocity of an object can be represented by an arrow of length in proportion to the speed pointing in the direction of motion of the object.
- **Force and acceleration** are both vector quantities and therefore can each be represented by an arrow in the appropriate direction and of length in proportion to the magnitude of the quantity.

Resolving a vector into two perpendicular components

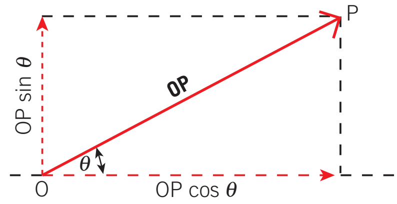
This is the process of working out the components of a vector in two perpendicular directions from the magnitude and direction of the vector. Figure 3 shows the displacement vector OA represented on a scale diagram that also shows lines due north and due east. The components of this vector along these two lines are $5.0 \cos 53°$ km (= 3.0 km) along the line due east and $5.0 \sin 53°$ km (= 4.0 km) along the line due north.

In general, to resolve any vector into two perpendicular components, draw a diagram showing the two perpendicular directions and an arrow to represent the vector. Figure 4 shows this diagram for a vector OP. The components are represented by the projection of the vector onto each line. If the angle θ between the vector OP and one of the lines is known,

- the component along that line = OP $\cos\theta$ and
- the component perpendicular to that line (i.e., along the other line) = OP $\sin\theta$.

Thus a force F can be resolved into two perpendicular components:

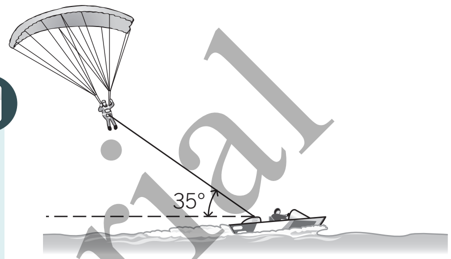
- **$F\cos\theta$ parallel to a line at angle θ to the line of action of the force and**
- **$F\sin\theta$ perpendicular to the line.**



▲ **Figure 4** *The general rule for resolving a vector*

Worked example

A paraglider is pulled along at constant height at steady speed by a cable attached to a speedboat as shown in Figure 5. The cable pulls on the paraglider with a force of 500 N at an angle of 35° to the horizontal. Calculate the horizontal and vertical components of this force.



▲ **Figure 5**

Solution

Because the force on the paraglider is at an angle of 35° below the horizontal, the horizontal and vertical components of this force are:

- $500\cos 35° = 410\,\text{N}$ horizontally to the right
- $500\sin 35° = 287\,\text{N}$ vertically downwards.

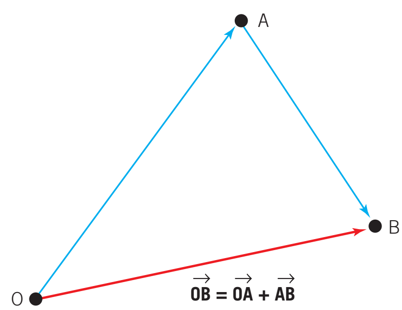
Addition of vectors using a scale diagram

Let's go back to the cycle journey in Figure 6. Suppose when you reach your friend's home at A, you then go on to another friend's home at B. Your journey is now a two-stage journey:

- **Stage 1, from O to A,** is represented by the displacement vector $\overrightarrow{\mathbf{OA}}$.
- **Stage 2, from A to B,** is represented by the displacement vector $\overrightarrow{\mathbf{AB}}$.

Figure 6 shows how the overall displacement from O to B, represented by vector $\overrightarrow{\mathbf{OB}}$, is the result of adding vector $\overrightarrow{\mathbf{AB}}$ to vector $\overrightarrow{\mathbf{OA}}$. The **resultant** is the third side of a triangle, where OA and AB are the other two sides.

$$\overrightarrow{\mathbf{OB}} = \overrightarrow{\mathbf{OA}} + \overrightarrow{\mathbf{AB}}$$



▲ **Figure 6** *Displacement from O to B*

Use Figure 6 to show that the resultant displacement $\overrightarrow{\mathbf{OB}}$ is 5.1 km in a direction 11° North of due East.

Any two vectors of the same type can be added together using a scale diagram. For example, Figure 7a shows a ship pulled via cables by two tugboats. The two pull forces F_1 and F_2 acting on the ship are at 40° to each other. Suppose the forces are both 8.0 kN. Figure 7b shows how

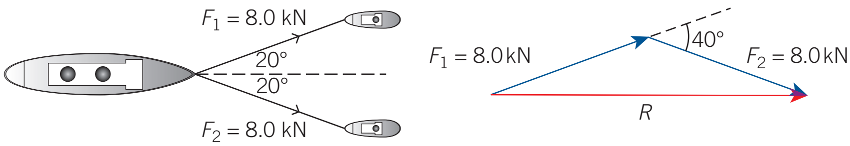
Hint

Since $\overrightarrow{\mathbf{OA}}$ and $\overrightarrow{\mathbf{AB}}$ are vectors, the lengths do not add directly.

Study tip

Drawing vector diagrams requires a ruler and careful drawing.

you can find the **resultant *R*** (combined effect) of the two forces using a scale diagram.

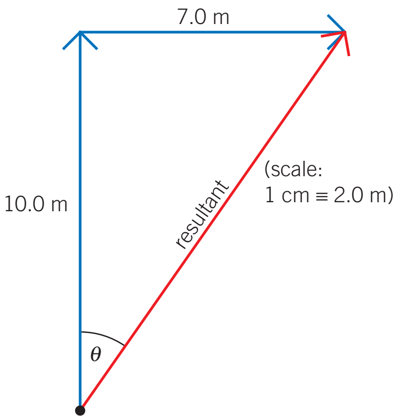


a *Overhead view* **b** *Scale diagram*

▲ **Figure 7** *Adding two forces using a scale diagram*

Addition of two perpendicular vectors using a calculator

1 Adding two displacement vectors that are at right angles to each other



▲ **Figure 8** *Adding two displacements at right angles to each other*

Suppose you walk 10.0 m forward then turn through exactly 90° and walk 7.0 m. At the end, how far will you be from your starting point? The vector diagram to add the two displacements is shown in Figure 8, drawn to a scale of 1 cm to 2.0 m. The two displacements form the two shorter sides of a right-angled triangle with the overall displacement, the resultant, as the hypotenuse. Using a ruler and a protractor, the resultant displacement can be shown to be a distance of 12.2 m at an angle of 35° to the initial direction. You can check this using

- Pythagoras's theorem for the distance $(= (10.0^2 + 7.0^2)^{\frac{1}{2}})$
- the trigonometry equation $\tan\theta = \dfrac{7.0}{10.0}$ for the angle θ between the resultant and the initial direction.

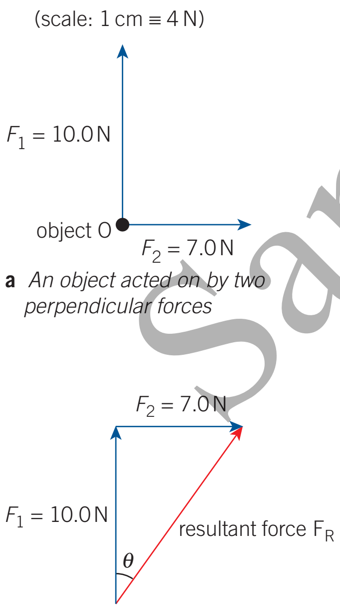
2 Two forces acting at right angles to each other

Figure 9 shows an object O acted on by two forces F_1 and F_2 at right angles to each other. The vector diagram for this situation is also shown. The two forces in the vector diagram form two of the sides of a right-angled triangle in which the resultant force is represented by the hypotenuse.

As explained above, the magnitude and direction of the resultant force can be worked out to give a magnitude of 12.2 N and a direction of 35° to the 10 N force.

In general, if the two perpendicular forces are F_1 and F_2, then

- **the magnitude of the resultant $F = (F_1^{\,2} + F_2^{\,2})^{\frac{1}{2}}$ and**
- **the angle θ between the resultant and F_1 is given by $\tan\theta = \dfrac{F_2}{F_1}$**



a *An object acted on by two perpendicular forces*

b *Vector diagram for* **a**

▲ **Figure 9**

Adding two vectors that are at angle θ to each other

Consider an object, O, acted on by forces F_1 and F_2 at angle θ to each other, as shown in Figure 10a. The magnitude and direction of the resultant force F_R can be found by resolving one of the forces into components that are parallel and perpendicular to the other force, as shown in Figure 10b.

- Resolving F_1 parallel and perpendicular to F_2 gives $F_1\cos\theta$ for the parallel component and $F_1\sin\theta$ for the perpendicular component.
- Adding the components in each direction therefore gives the parallel component of F_R as $F_1\cos\theta + F_2$ and the perpendicular component as $F_1\sin\theta$.

Using Pythagoras's theorem to find the magnitude of the resultant force gives

$$F_R = [(F_1\cos\theta + F_2)^2 + (F_1\sin\theta)^2]^{\frac{1}{2}}$$

Because $\sin^2\theta + \cos^2\theta = 1$ for all angles of θ, it can be shown that

$$F_R{}^2 = F_1{}^2 + F_2{}^2 + 2F_1F_2\cos\theta$$

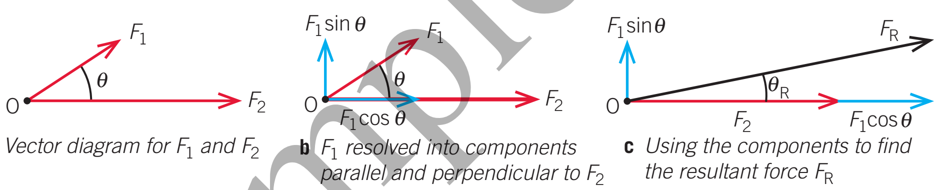
Using the trigonometry rule for tan θ to find θ_R, the angle between the resultant force and F_2, gives

$$\tan\theta_R = \frac{F_1\sin\theta}{(F_1\cos\theta + F_2)}$$

Note:

The resultant of two vectors that act along the same line has a magnitude that is:

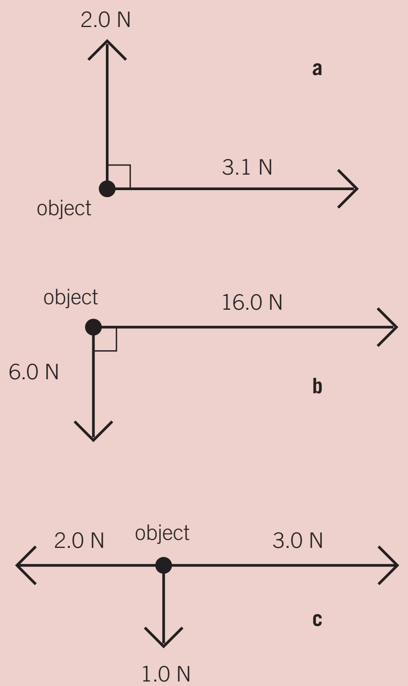
- the **sum,** if the two vectors are in the *same* direction. For example, if an object is acted on by a force of 6.0 N and a force of 4.0 N, both acting in the same direction, the resultant force is 10.0 N
- the **difference,** if the two vectors are in *opposite* directions. For example, if an object is acted on by a 6.0 N force and a 4.0 N force in opposite directions, the resultant force is 2.0 N in the direction of the 6.0 N force.



▲ **Figure 10** *Using a calculator to find a resultant force*

Summary questions

1 Figure 11 shows three situations **a–c** where two or more known forces act on an object. For each situation, calculate the magnitude and direction of the resultant force.

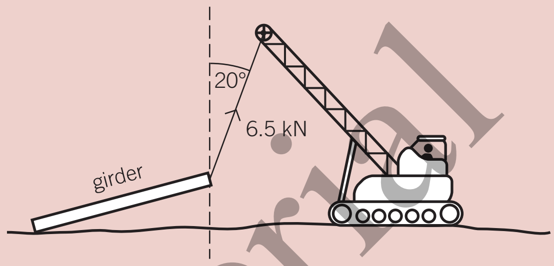


▲ **Figure 11**

2 Calculate the magnitude and direction of the resultant force on an object which is acted on by a force of 4.0 N and a force of 10 N that are

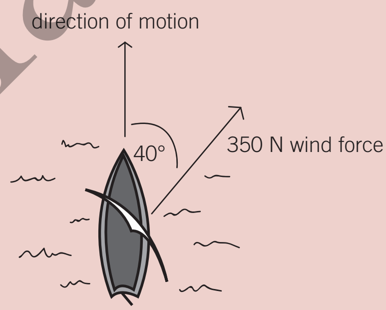
- **a** in the same direction
- **b** in opposite directions
- **c** at right angles to each other
- **d** at 35° to each other.

3 A crane is used to raise one end of a steel girder off the ground, as shown in Figure 12. When the cable attached to the end of the girder is at 20° to the vertical, the force of the cable on the girder is 6.5 kN. Calculate the horizontal and vertical components of this force.



▲ **Figure 12**

4 A yacht is moving due north as a result of a force, due to the wind, of 350 N in a horizontal direction of 40° east of due north, as shown in Figure 13.



▲ **Figure 13**

Calculate the component of the force of the wind:

- **a** in the direction the yacht is moving
- **b** perpendicular to the direction in which the yacht is moving.