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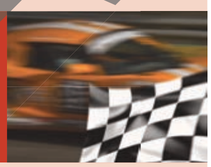

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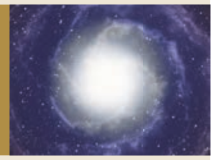

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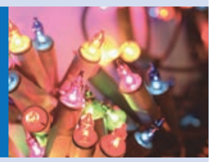

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01 Physical Quantities, Units and Measurement

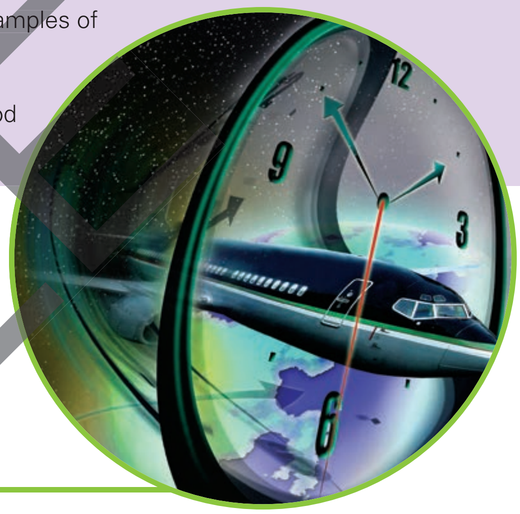
How do scientists describe the physical universe?

In this section, we shall examine how a small set of physical quantities and units is used to describe all other physical quantities. These base quantities and their units can be used with prefixes (e.g. milli, centi and kilo) to describe the physical properties of objects ranging from as small as an atom to as large as the Earth.

Learning Outcomes

After completing this chapter, students should be able to:

- show an understanding that all physical quantities consist of a numerical magnitude and a unit
- recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
- use the following prefixes and their symbols to indicate decimal sub-multiples and multiples of the SI units: nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G)
- show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth
- describe how to measure a variety of lengths with appropriate accuracy by means of tapes, rules, micrometers and calipers, using a vernier scale as necessary
- describe how to measure a short interval of time including the period of a simple pendulum with appropriate accuracy using stopwatches or appropriate instruments
- state what is meant by *scalar* and *vector* quantities and give common examples of each
- add two vectors to determine a resultant by the graphical method



PhysicsMystery

What is time?

Time is one of the most important physical quantities known to man but is understood by few. It is invisible and cannot be felt, but we know that as time passes, the world changes. Physical quantities such as length, mass and temperature vary with time. We cannot stop time but physicists tell us that we can slow down time, if we move at a velocity close to the speed of light.

In the 1985 movie 'Back to the Future', Hollywood dazzled science fiction fans with the intriguing idea of travelling back and forth in time. Is time travel really possible? What is time? Can we define time? How do we measure time? As you read this chapter, look for clues about the nature of time and how scientists established a standard by which they could measure time. Then, solve the mystery.

Exploring Another Perspective

Engage a partner and investigate how fast you or your partner can respond to a given stimulus. Find out more about your own human reaction time and how this affects the accuracy of data collection.

1.1 What is the physical universe?

Slightly over a hundred years ago, a person living then would probably say that the physical universe consisted of what the naked eye could see. Today, if that same person were still alive, he would marvel at how the old perception of the universe had undergone a remarkable transformation.

In 1900, many scientists had doubts about the existence of electrons; now, physicists have discovered an incredulously complex microcosm of over 400 types of subatomic particles. At the turn of the 20^{th} century, many people still did not know what really lay beyond the deep blue sky. In the 21^{st} century, astronomers have stumbled on an unimaginably large universe. They think there are more than 100 billion galaxies in the universe. They also think the universe is getting bigger. To understand this complex physical universe, scientists have had to define new physical quantities, produce new standards for measurement, and create new scales and new mathematical methods to describe nature.

Figure 1.1 A small section of the universe through our deep blue sky

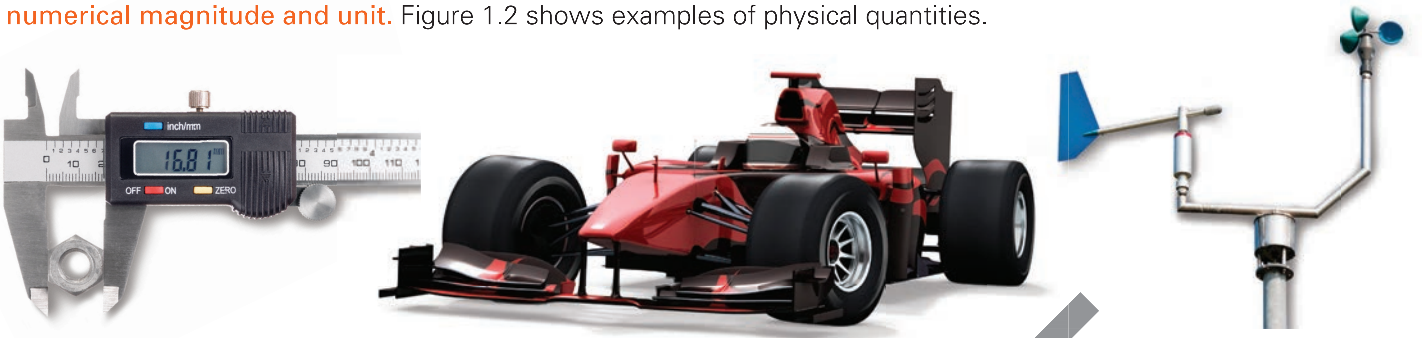
1.2 What are physical quantities?

Since the dawn of civilisation, human beings have always asked many questions about the world, the things we see and our experiences in life.

How far is your cave? How fast can you walk? How heavy is a car? How long does it take to travel from Singapore to New York by plane? At what temperature does water boil?

To answer all these questions, we need to take measurements. The questions above involve the measurement of physical quantities like length, speed, mass, time and temperature. Measurement of physical quantities is an essential part of physics.

A **physical quantity** is a quantity that can be measured and consists of a numerical magnitude and unit. Figure 1.2 shows examples of physical quantities.



Length = 16.81 mm | Mass = 640 kg | Velocity = 5.00 m s^{-1}

Figure 1.2 Examples of physical quantities

There are two types of physical quantities – **base quantities** and **derived quantities**. There are altogether seven base quantities – length, mass, time, electric current, temperature, amount of substance and luminous intensity. They are used as the basic 'building blocks' of all other physical quantities and they are sometimes called fundamental quantities. We can define them by describing a procedure for measuring them. For example, the standard unit of mass is a platinum-iridium cylinder kept at the International Bureau of Weights and Measures in France (Figure 1.3).

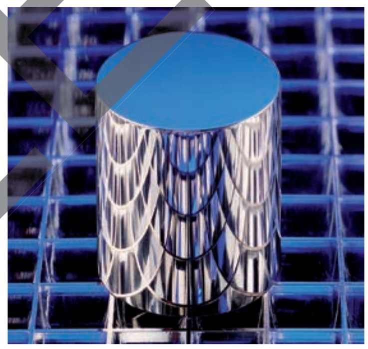


Figure 1.3 The standard unit of mass is a platinum-iridium cylinder.

All other quantities like area, volume, density, speed, acceleration and force can be derived from base quantities through a defining equation. For example, speed is defined as distance travelled per unit time and it can be expressed as an equation shown in Figure 1.4. Speed is a derived quantity related to the base quantities of length and time.

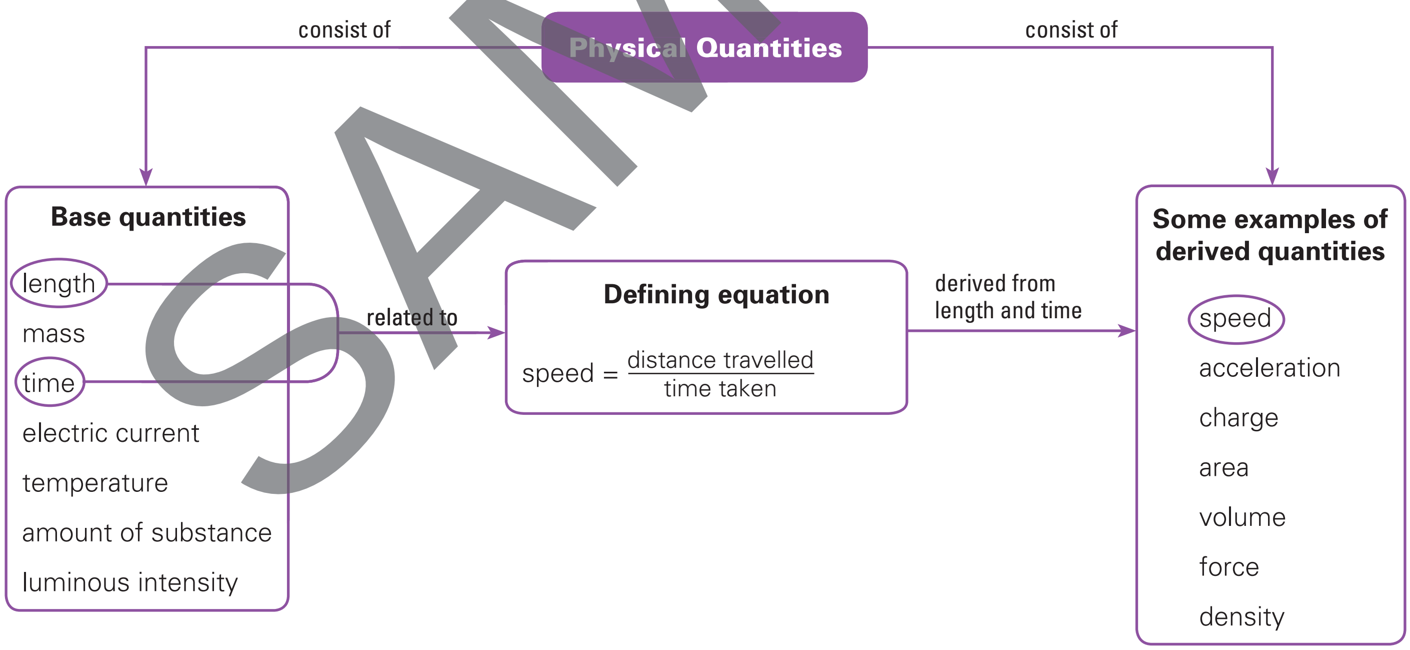


Figure 1.4 Physical quantities

1.3 Why do we need SI units?

A measurement without units is meaningless. For example, can you understand someone if he told you that he took 10 to finish a job? Does he mean 10 seconds, 10 minutes, 10 hours, 10 days or 10 months? If we want to report the result of a measurement of a certain quantity effectively, we must define the unit for the quantity.

Scientists have agreed on a single system of units (or **standards**) for the measurement of physical quantities. In 1960, the 11th General Conference of Weights and Measures recommended an International System of Units (abbreviated to SI) based on the metric system of measurement. This marked the first time in world history that a single system of units had been established internationally. The system makes reporting and communicating results to others much easier. Singapore officially adopted the metric system in 1971.

The seven base units are shown in Table 1.1. All other derived quantities like volume, density, speed, charge and heat capacity can be expressed in terms of these base quantities (Table 1.2).

Base quantity	Name of unit	Symbol for unit
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Table 1.1 Base quantities and SI units

Derived quantity	Relationship between base and derived quantities	Symbol for unit	Special name
Area	length × width	m^2	
Volume	length × width × height	m^3	
Density	mass ÷ volume	$kg\ m^{-3}$	
Speed	distance ÷ time	$m\ s^{-1}$	
Acceleration	change in velocity ÷ time	$m\ s^{-2}$	
Force	mass × acceleration	$kg\ m\ s^{-2}$	newton (N)
Charge	current × time	A s	coulomb (C)
Heat capacity	energy ÷ change in temperature	$J\ K^{-1}$	

Table 1.2 Some derived quantities and their SI units

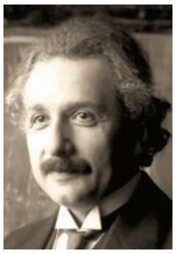
Mystery Clue

Sir Isaac Newton discovered calculus and laid the theoretical foundation for classical or Newtonian mechanics.

Albert Einstein proposed the Theory of Relativity. Both of their discoveries have affected our interpretation and perception of time.

How did Newton and Einstein describe time?


Isaac Newton


Albert Einstein

Physics in **Society**

A little history: Units of measurement

In the old Chinatown markets of Singapore in the 1960s, colloquial use of imperial units from the United Kingdom was widespread. The foot – a common unit used to measure the length of a piece of cloth – was originally the length of a Roman's foot. It was standardised in the 12th century by King Henry I of England. Other units such as inch, yard and mile were also widely used in Singapore. The knot was used to measure the speed of bumboats on the Singapore River. It was originally measured by letting a knotted rope secured to a piece of wood, float out behind a boat, and seeing how many knots floated away from the boat in a set time. Other common units such as *gantang*, *chupak*, *kati* and *tahil* were used in trade transactions near the Singapore River. At that time, the use of metre and kilogram – commonly known as the metric system – was adopted by only a few major trading companies.

Discussion

1. What were the disadvantages of using many different systems of measurement?
2. How did the adoption of the metric system in 1971 help in the growth and development of science, technology and commerce in Singapore?

1.4 Why do we need prefixes?

When we measure quantities which are very big or very small, it is difficult to write down the measured values. The chances of making a mistake in writing the number may be quite high. For example, the distance from the Earth to the Sun is about 150 000 000 000 m. On the other hand, an atom has a diameter of about 0.000 000 000 1 m. We use prefixes to simplify the writing of such numbers.

The main prefixes that we need to know are shown in Table 1.3.

Very big or very small numbers can also be written in scientific notation. It is written as $A \times 10^n$ where $1 \le A < 10$ and n is an integer. 'A' unambiguously indicates the number of significant digits in a measurement.

e.g. (a) Distance from Earth to Sun
$= 150\ 000\ 000\ 000$ m
$= 1.5$ m $\times 10^{11}$ m
$= 150$ Gm

(b) Diameter of an atom
$= 0.000\ 000\ 000\ 1$ m
$= 1 \times 10^{-10}$ m
$= 0.1$ nm

Prefix	Symbol	Factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
**hecto*	h	10^{2}
**deca*	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

* hecto and deca are not commonly used in physics calculations

Table 1.3 Prefixes of SI units

Orders of Magnitude of Quantities

It is often useful to be able to estimate the size, or order of magnitude of a quantity. The order of magnitude is the power of 10 to which the number is raised. Specifically, to get the order of magnitude of a given quantity, we round off to the closest power of 10 (e.g. 75 kg is rounded off to 10^2 kg). Figures 1.5, 1.6 and 1.7 show the orders of magnitude of several physical quantities.

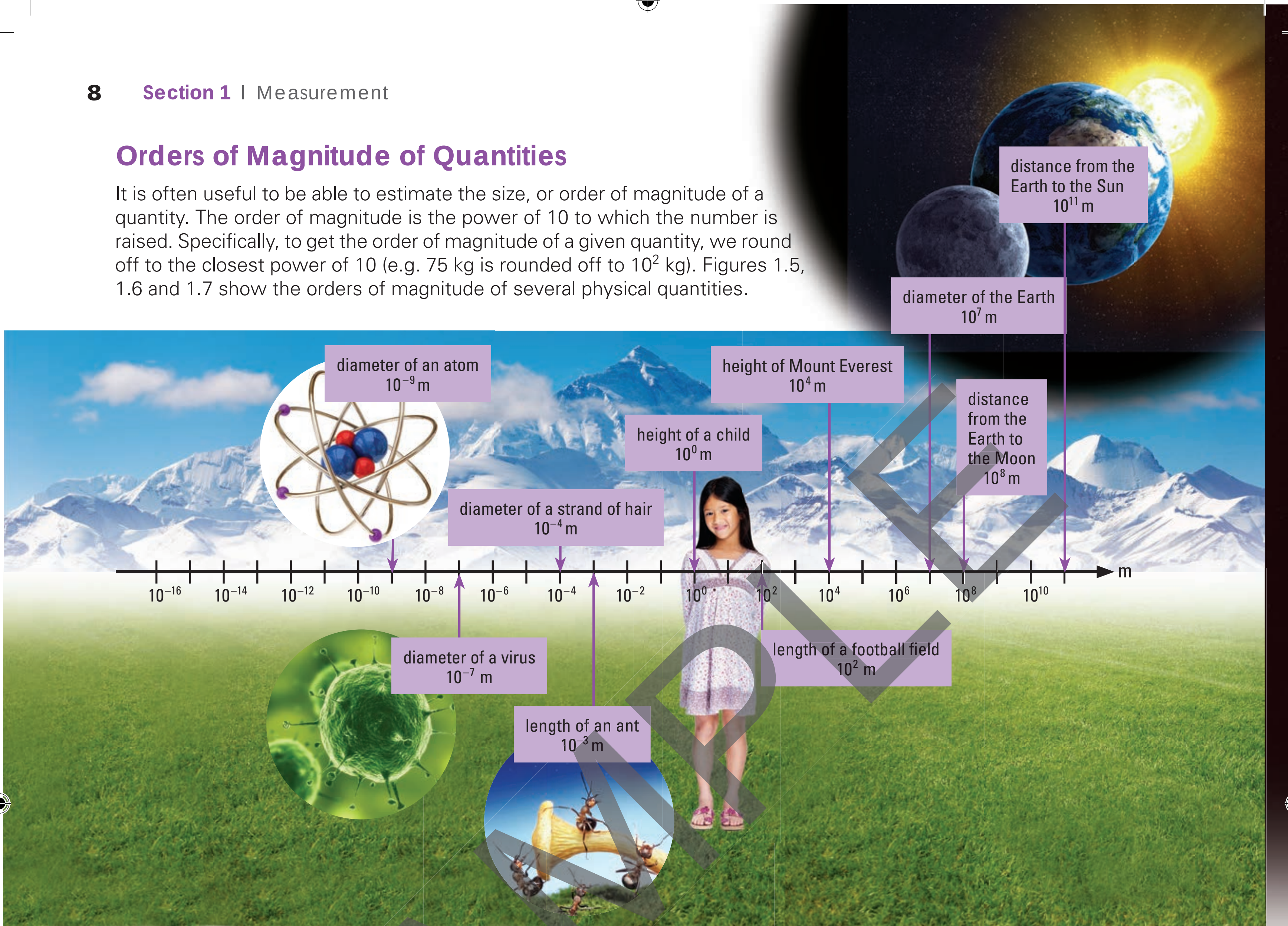


Figure 1.5 Order of magnitude of length

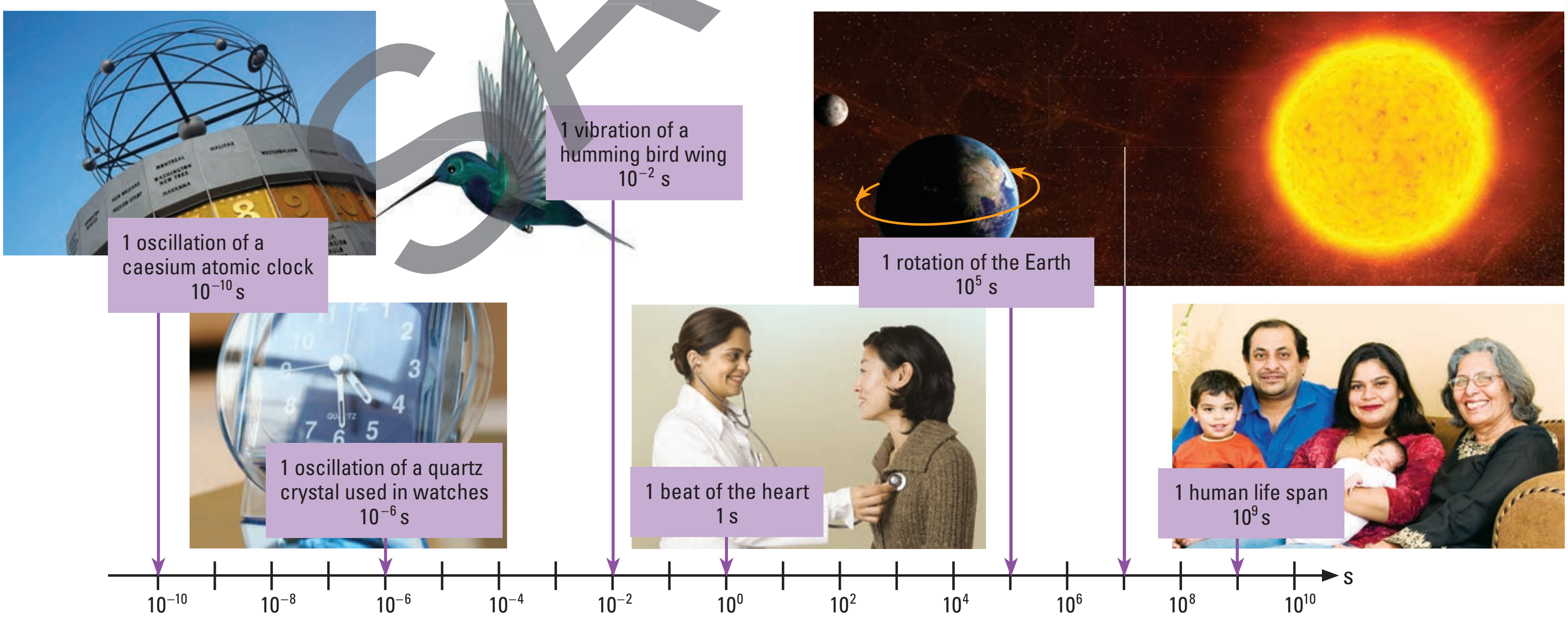


Figure 1.6 Order of magnitude of time

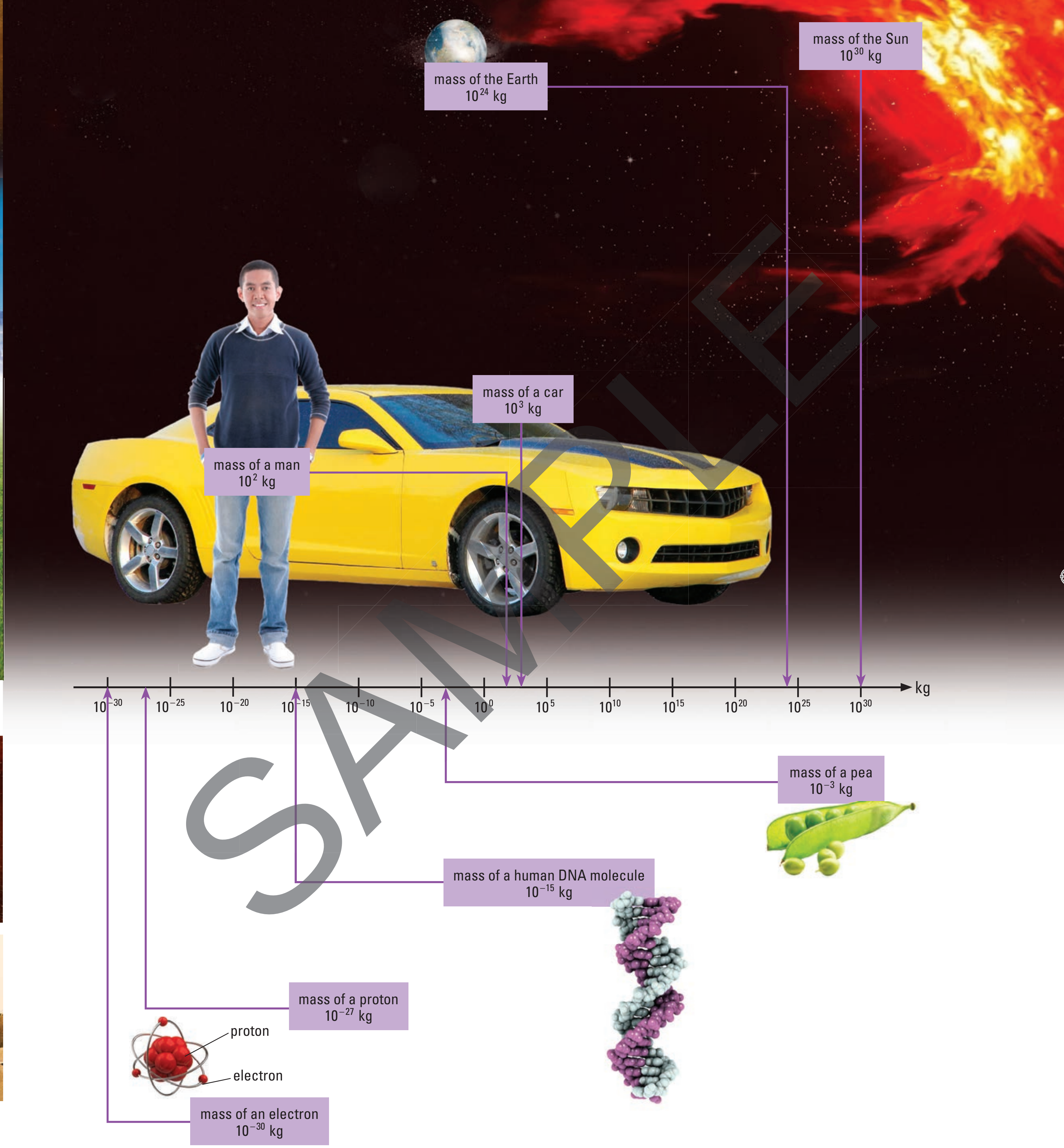


Figure 1.7 Order of magnitude of mass

Conversion of Units

Physical quantities can be expressed in different units. The conversion of units is an important skill in physics calculations. It can be done by multiplying the original measurement with a conversion factor. Two commonly used conversion factors are

$$1000 \text{ m} = 1 \text{ km} \quad \text{or} \quad 1 \text{ m} = \frac{1}{1000} \text{ km}$$

$$3600 \text{ s} = 1 \text{ h} \quad \text{or} \quad 1 \text{ s} = \frac{1}{3600} \text{ h}$$

To convert 0.25 km into m, multiply the original measurement with a conversion factor:

$$\begin{aligned} 0.25 \text{ km} &= 0.25 \times 1 \text{ km} \\ &= 0.25 \times 1000 \text{ m} \\ &= 250 \text{ m} \end{aligned}$$

To convert 500 m s^{-1} into km h^{-1}, we rewrite the physical quantity before multiplying the numerator and denominator with the correct conversion factor.

$$\begin{aligned} 500 \text{ m s}^{-1} &= \frac{500 \times 1 \text{ m}}{1 \text{ s}} \\ &= \frac{500 \times \frac{1}{1000} \text{ km}}{\frac{1}{3600} \text{ h}} \\ &= 1800 \text{ km h}^{-1} \end{aligned}$$

To convert 7 cm^2 into m^2, we multiply the original measurement with the conversion factor twice.

$$\begin{aligned} 7 \text{ cm}^2 &= 7 \times 1 \text{ cm} \times 1 \text{ cm} \\ &= 7 \times \frac{1}{100} \text{ m} \times \frac{1}{100} \text{ m} \\ &= 0.0007 \text{ m}^2 \end{aligned}$$

Theory Workbook
• Exercise 1A

Section Review

Skills Practice

1. Convert 90 km h^{-1} into m s^{-1}.
2. Convert 20 m s^{-1} into km h^{-1}.
3. Convert 1 mm^3 into m^3.

Questions

Rewrite the following quantities using suitable prefixes.

1. (a) 5 000 000 J
   (b) 0.0009 s
   (c) 485 000 N
2. Rewrite the following measurements in the units suggested.
   (a) 760 mm in m
   (b) 4.5 μs in s
   (c) 2.5 ms in μs
3. How many bytes of memory space are there in a 500 GB hard disk? [B in GB stands for byte]

Physics Inquiry 1

Predict

You are provided with a pair of scissors and a strip of paper of dimension 1.0 cm by 1.0 cm. Predict the number of times you can cut the paper in half.

Observe

1. Cut the piece of paper into half.
2. Determine the number of times it can be done.
3. What is the smallest length you can get?

Explain

What conditions are required if you want the width of the paper to be 1 nm?

1.5 How do we measure length?

No measurement is ever perfectly accurate. Even with high precision instruments some error is inevitable. There are two main types of errors. They are random errors and systematic errors.

Random and Systematic Errors

Random Error

Random errors occur in all measurements. They arise when observers estimate the last figure of a reading on an instrument. Measuring the time taken for a traffic light to change from red to green will differ from observer to observer. The timings do not always coincide and this is due to random errors. They also include things such as background noise or mechanical vibrations in the laboratory. They alter the measurements unexpectedly. Random errors cannot be predicted.

The best way to minimise such errors is to take a large number of readings and average them. Discard any freak results before averaging.

Systematic Error

Systematic errors are not random but constant. They may cause an experimenter to consistently underestimate or overestimate a reading. Systematic errors may be due to the equipment being used – for instance, a voltmeter with zero error, or they may be due to environmental factors – for instance, the weather conditions on a particular day.

Systematic errors cannot be reduced by averaging, but they can be eliminated if we know the sources of the errors.

Make it Right!

Bob claimed that he could define time easily by simply using the formula:

$$\text{Time} = \frac{\text{Distance travelled}}{\text{Speed}}$$

Is Bob right? If he is wrong, can you help him clear his misconception?

Figure 1.8 Voltmeter with zero error

Measuring Tape and Metre Rule

A measurement is the process by which a physical quantity is compared to a standard unit. In length measurement, the standard unit used in the laboratory is the SI unit, the **metre**. Instruments like the measuring tape and metre rule are calibrated in metres and subdivided into centimetres and millimetres. The smallest division on the measuring tape and metre rule is 1 mm, or 0.1 cm or 0.001 m. This is also known as the precision of the instrument. If we want to express the length of a 20 mm bar in centimetres or metres, we can write it as 2.0 cm or 0.020 m to reflect the precision of the instrument used.

For more precise measurement, a vernier caliper or micrometer screw gauge may be used. Table 1.4 shows the range and precision of some measuring instruments.

We can use the measuring tape to measure relatively long lengths. For shorter lengths, a metre rule or a shorter ruler will be more effective (Figure 1.9). The correct way to read the scale on a ruler is shown in Figure 1.10. The eye must be positioned so that the line of sight is at a right angle to the scale. This avoids parallax error, which may be due to incorrect positioning of the eye. Parallax error may also be due to the object not being on the same level as the markings of the scale.

Practical Workbook
• Activity A1

Instrument	Range of measurement	Precision
Measuring tape	0–5 m	0.1 cm
Metre rule	0–1 m	0.1 cm
Vernier caliper	0–15 cm	0.01 cm
Micrometer screw gauge	0–2.5 cm	0.01 mm

Table 1.4 Range and precision of some measuring instruments

Figure 1.9 Measuring tape and metre rule

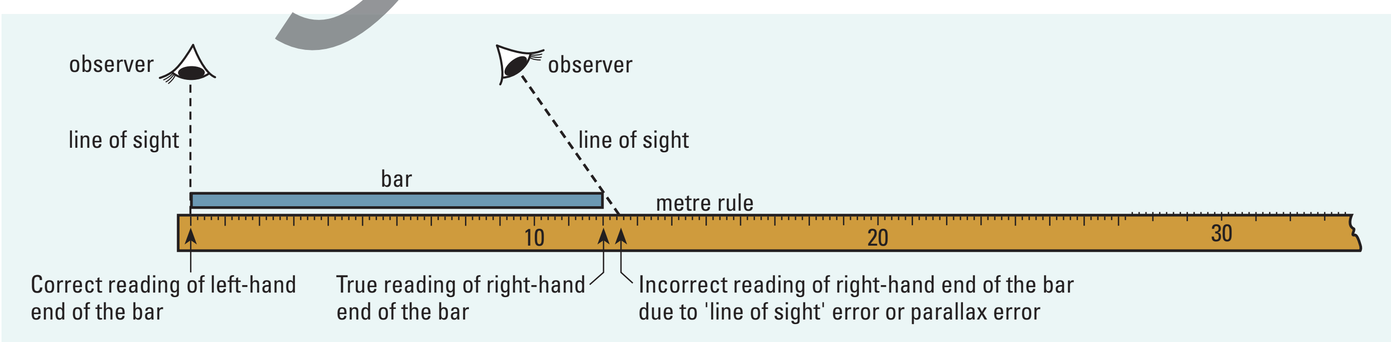


Figure 1.10 Parallax error

Some instruments do not read exactly zero when there is nothing being measured. This causes zero error. This may happen because the scales are out of alignment or some minor fault is present in the instrument. These instruments are usually still accurate as long as you add or subtract the zero error from the reading shown on the scale.

Caliper

To measure the diameters of cylinders or circular objects, a caliper is used. It consists of two pointed jaws that can be rotated about a screw. When the jaws point outward, the caliper is extended to touch the inner surface of a beaker. The caliper is then removed and the jaws are placed on a metre rule scale to obtain a measurement for the inner diameter (Figure 1.11). When the jaws are rotated so that they are pointing inward, the caliper can grip the external surface of the beaker. The external diameter of the beaker can be determined by using a metre rule to measure the distance between the two jaws (Figure 1.12).

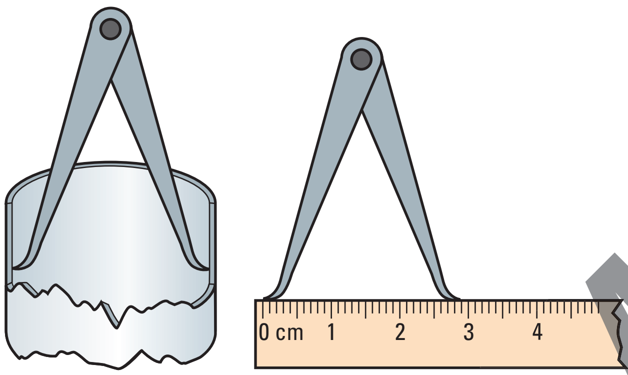


Figure 1.11 Measuring the inner diameter

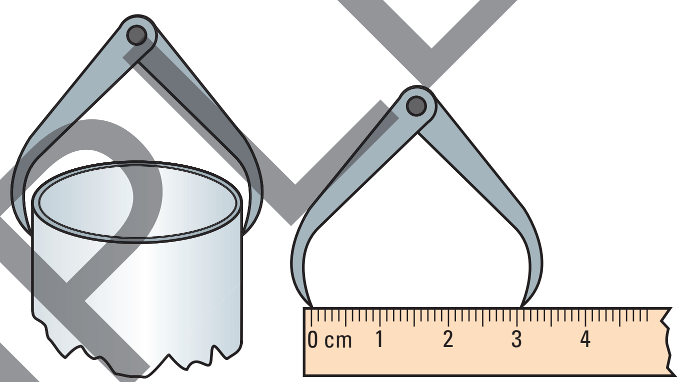


Figure 1.12 Measuring the external diameter

Vernier Caliper

A vernier caliper is used to measure short lengths such as the internal and external diameters of a test tube. The vernier caliper allows us to measure to a precision of 0.01 cm. Figure 1.13 shows a vernier scale. It consists of a 9 mm long scale divided into 10 divisions. The scale shows the object being measured is between 2.4 cm long and 2.5 cm long. To find the second decimal number (given by the distance AB), we look for a marking on the vernier scale which coincides with a marking on the main scale.

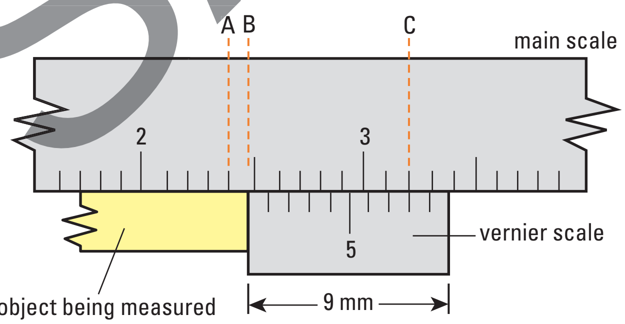


Figure 1.13 A vernier scale

Here the eighth marking on the vernier scale coincides with the marking at C on the main scale. This means that the distance AB is 0.08 cm, i.e. the length of the object is 2.48 cm.

Mystery Clue

If you have done some research into exploring the meaning of time, you may realise that time is a puzzle and a paradox. You may agree with Bishop Aurelius Augustine when he said "What then is time? If someone asks me, I know. If I wish to explain it to someone who asks, I know not." In view of this difficulty, is time definable?

Figure 1.14 shows how a vernier caliper is used to measure the diameter of a nut. The reading shown is 2.21 cm. The instrument also has a pair of inside jaws which can be used to measure the internal diameters of tubes and containers. The depth bar at the end can be used to measure the depth of a container.

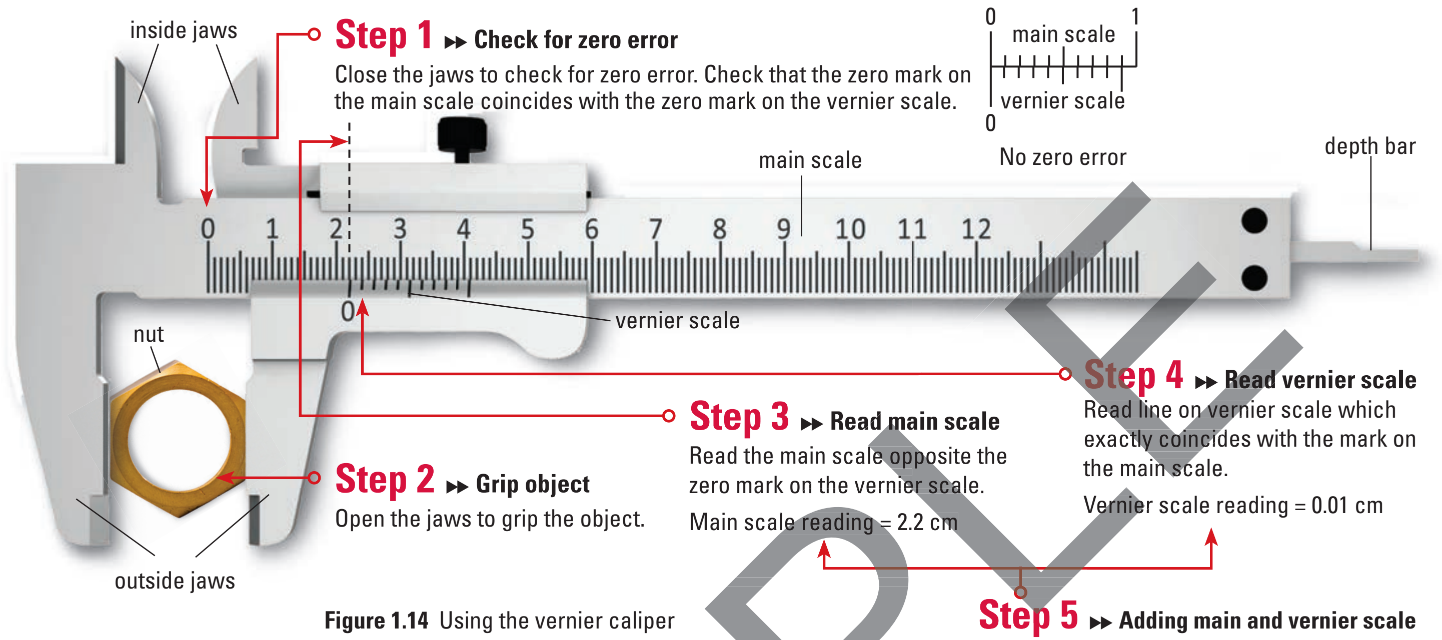


Figure 1.14 Using the vernier caliper

When the two jaws of the vernier caliper touch each other, the zero marks on the main scale and on the vernier scale should coincide. If they do not coincide, there is a zero error in the vernier caliper. Table 1.5 illustrates ways to deal with the zero error after taking measurements with the vernier caliper.

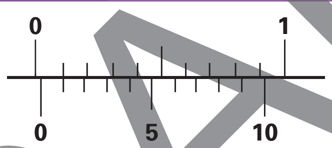
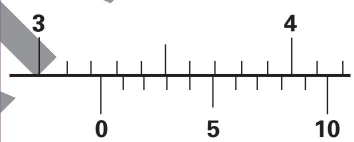
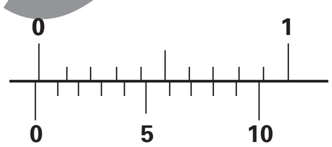
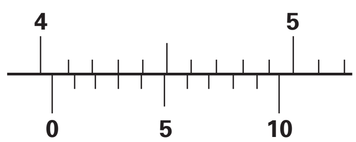
Zero error	Observed reading	Corrected reading
The zero mark on the vernier scale lies on the right of the zero mark on the main scale.  Zero error is positive. The first marking on the vernier scale coincides with a marking on the main scale. Zero error = +0.01 cm	 Observed reading = 3.24 cm	Corrected reading = Observed reading – Zero error = 3.24 cm – 0.01 cm = 3.23 cm
The zero mark on the vernier scale lies on the left of the zero mark on the main scale.  Zero error is negative. The second marking from the '10' mark on the vernier scale coincides with a marking on the main scale. Zero error = –0.02 cm	 Observed reading = 4.03 cm	Corrected reading = Observed reading – Zero error = 4.03 cm – (–0.02 cm) = 4.05 cm

Table 1.5 Dealing with zero error for a vernier scale

Micrometer Screw Gauge

Practical Workbook
• Activity A2

To measure the diameter of fine wires, the thickness of paper and other short lengths, a micrometer screw gauge (commonly known as micrometer) is used. The micrometer allows us to measure to a precision of 0.01 mm. The micrometer has two scales – the main scale on the sleeve and the circular scale on the thimble (Figure 1.15). There are 50 divisions on the thimble. One complete turn of the thimble moves the spindle by 0.50 mm.

Hence each division represents a length of $\frac{0.50 \text{ mm}}{50} = 0.01$ mm.

Follow the steps illustrated in Figure 1.16 to measure the diameter of a screw.

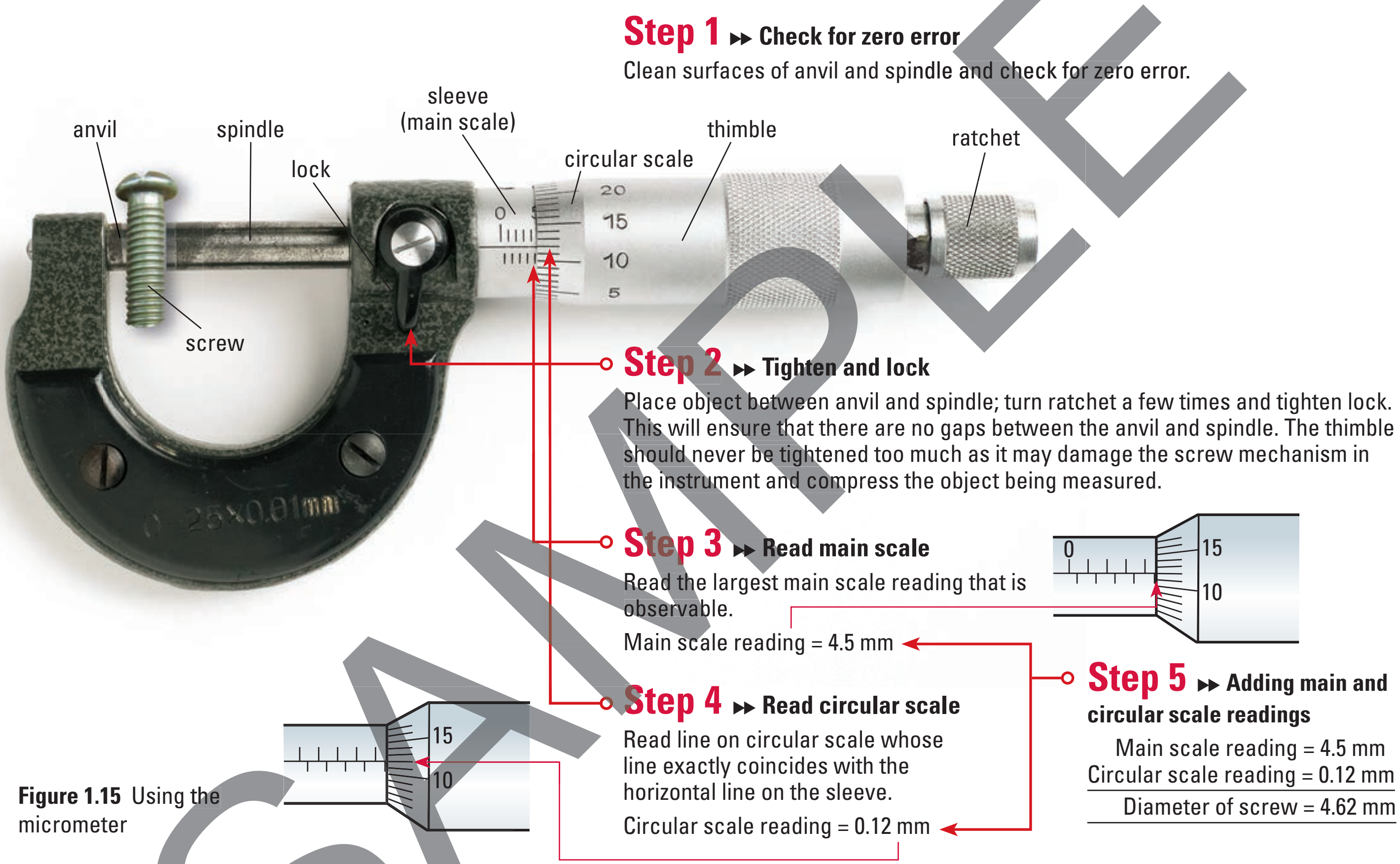


Figure 1.15 Using the micrometer

When the anvil and spindle touch each other, the zero marks on the main scale and the circular scale should coincide. If they do not coincide, there is zero error in the micrometer. Table 1.6 illustrates ways to deal with the zero error after taking measurements with the micrometer.

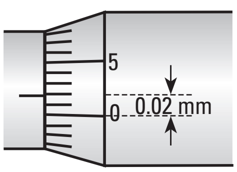
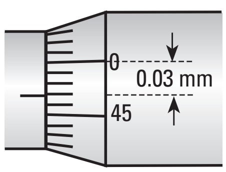
Positive zero error	Negative zero error
This occurs when the zero mark on the circular scale is below the horizontal line on the main scale.	This occurs when the zero mark on the circular scale is above the horizontal line on the main scale.
 Zero error = +0.02 mm Corrected measurement = 4.62 – 0.02 = 4.60 mm	 Zero error = –0.03 mm Corrected measurement = 4.62 – (–0.03) = 4.65 mm

Table 1.6 Dealing with zero error for a micrometer

16 How do we measure time?

To measure a time interval, a timing device is used. Such devices may be mechanical or electronic. They include ordinary clocks and watches, stopwatches, ticker-tape timers and electronic light gate timers. Timing devices need to be checked periodically to ensure that they do not run too fast or too slow. The SI unit for time is the **second**.

Stopwatch

Stopwatches are used to measure short intervals of time. There are two types of stopwatches: the digital stopwatch and the analogue stopwatch. The digital stopwatch is more precise as it can measure time in intervals of 0.01 s while the analogue stopwatch can only measure time in intervals of 0.1 s.

Before giving the result of the time measurement, it is important to consider the errors involved. For instance, if you use a digital stopwatch to time a race, you should not give the time to the nearest 0.01 s. The watch may be precise, but your reaction time in starting and stopping the watch will be more than a few hundredths of a second (typically 0.3 s).

Figure 1.16 Stopwatches

Ticker-tape Timer

This is an electrical device making use of the oscillations of a steel strip to mark short intervals of time. The steel strip vibrates 50 times a second and makes 50 dots in a second on a paper tape being pulled past it (Figure 1.17).

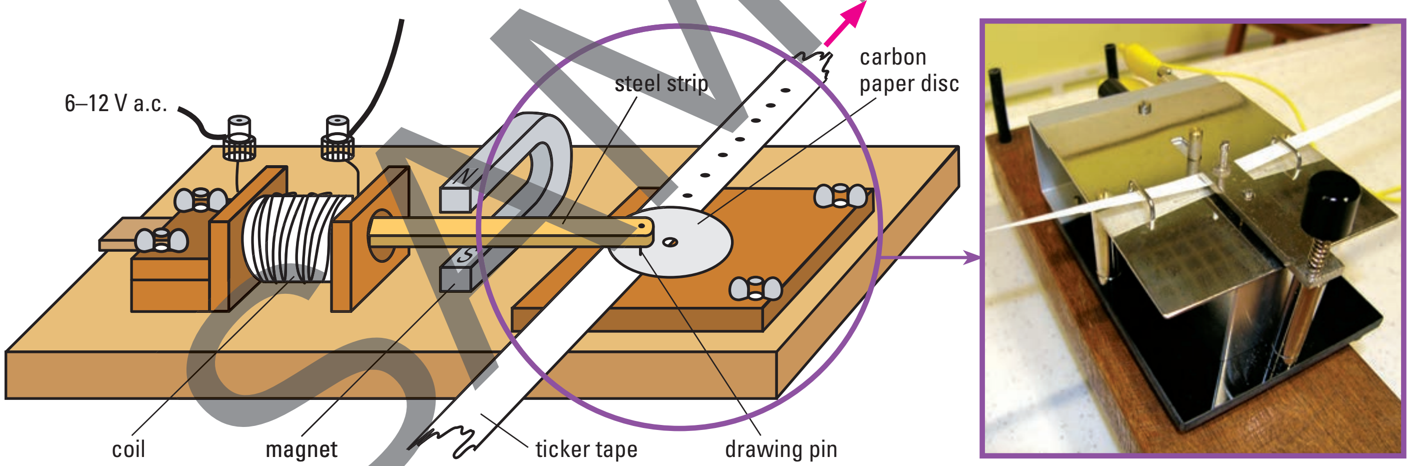


Figure 1.17 Ticker-tape timer

The space between two consecutive dots represents a time interval of 1/50 s or 0.02 s. If there are 10 spaces on a piece of tape, the time taken for the tape to pass through the timer is (10 × 0.02 s) = 0.20 s. This section of the tape is also known as a 10-dot tape (Figure 1.18). Note that the counting starts from zero.

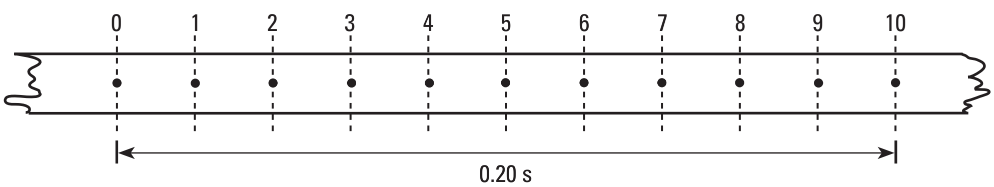


Figure 1.18 A 10-dot tape

Physics **Inquiry** 2

Predict

Predict how the period of a pendulum will change when its length is changed. You are provided with a pendulum bob, string, metre rule, retort stand, weight, coins and stopwatch.

Practical Workbook
• Experiment 3

Background

A simple pendulum (Figure 1.19) is a suspended bob that is set into oscillatory motion. The swinging bob repeats its oscillation at regular intervals. The time taken for the pendulum to complete an oscillation (i.e. from O → A→ O → B → O) is called the period of oscillation. This provides a convenient way to measure short time intervals.

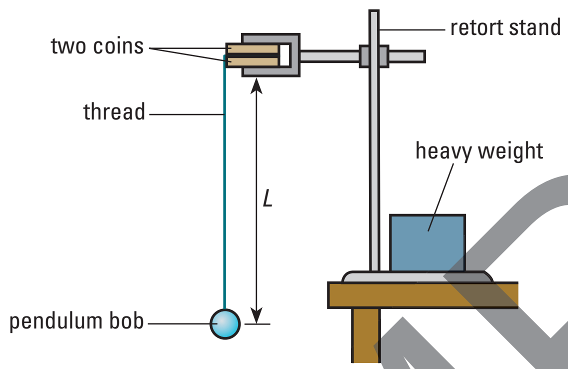
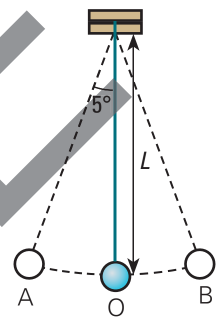


Figure 1.19 Experimental set-up



Provided that the swing is not too big, the period of oscillation of a pendulum is always constant when the length is fixed.

Observe

1. Displace the pendulum slightly (≤ 5°) and allow it to oscillate.
2. Time 20 oscillations using a stopwatch. Record the reading as t_1.
3. Repeat steps (1) and (2) and record the reading as t_2.
4. Calculate the average time, t, for 20 oscillations and then the period, or time for one oscillation, T. Record your results in Table 1.7.

Length	Time for 20 oscillations			Period
L/cm	t_1/s	t_2/s	Average t/s	T/s

Table 1.7

5. Repeat steps (1) to (4) for different values of length, L (90.0 cm, 80.0 cm, 70.0 cm, 60.0 cm and 50.0 cm).
6. Compare the values of T for the various lengths of the pendulum.

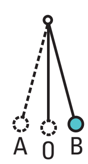
Explain

1. What is the reason for giving a small angular displacement to the pendulum bob instead of a larger angle?
2. How does the period, T, change as the length, L, of the pendulum decreases?

Make it Right!

Bob's Lab Report

1. Measure the length of the string with a short ruler.
   Length of string (pendulum)
   = 90.000 cm = 0.9 cm
2. Displace pendulum bob to an angle of 80° from the vertical. As a precaution, hold the bob as still as possible with the left hand. Hold the digital stopwatch with the right hand and start timing at position A. Stop timing when the bob returns to position A again.
   Time of oscillation or period = 2



3. Repeat (2) to obtain another period and calculate the average.
   Time of another period = 2.15 s
   Average time of oscillation
   $= \frac{1}{2}(2 + 2.15)$
   = 2.075

Conclusion: From the results, the period changes when the length changes.

Bob's report is filled with errors. Write a memo to Bob to correct all his errors and misconceptions.

Light Gate

A light gate is a digital sensor (sensing either on or off) which consists of an infra-red transmitter and a receiver mounted in a strong frame with a small gate gap. Light gates are primarily designed for use in timing. They can be used to record the starting time, finishing time and duration of an event. When used with appropriate software, the light gate becomes a very powerful tool as time, speed and acceleration can be studied.

The set-up in Figure 1.20 allows the light gate to record the time taken for the card of length, *L*, to pass through the gate. When the front of the card reaches the light beam, the light is blocked and the timer starts. When the end of the card passes the light beam, the light beam is no longer blocked and the timer stops.

Measurements made with electronic sensors are more precise and more accurate than measurements made by people using stopwatches. The electronic measurements do not suffer from human errors such as reaction time or misreading of scales. This means that the results are more reliable.

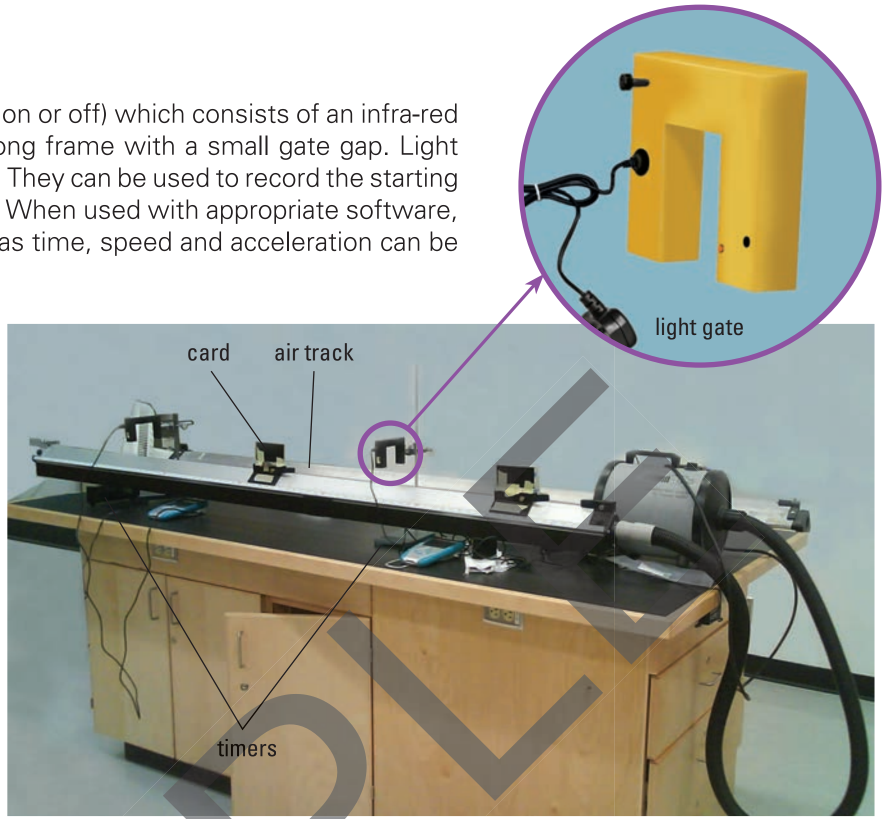


Figure 1.20 Using light gates with an air track

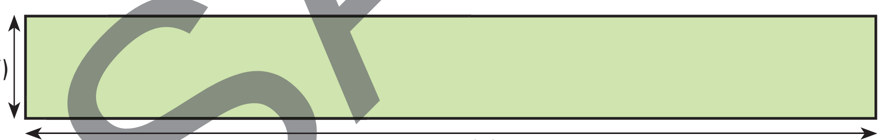
Section Review

Skills Practice

The precision of a metre rule is 1 mm or 0.1 cm or 0.001 m.

Measure the length (*L*) and width (*W*) with your ruler.

width (*W*)



length (*L*)

Record your measurements below:

L_1 = ______mm L_2 = ______cm L_3 = ______cm

W_1 = ______mm W_2 = ______cm W_3 = ______cm

Questions

1. A boy measures the length of a table and says it is 1.515 m long. Is this a reasonable answer? What do you think is the instrument used? If he had measured it with a measuring tape marked in millimetres, write down what would have been a reasonable answer for him to give.

2. Before the invention of clocks and watches, time intervals were measured by various methods. Name a few, stating what form of periodic motion they relied on and discuss their accuracy.

Theory Workbook
- Exercise 1B
- Exercise 1D

17 What are scalars and vectors?

Earlier we described a physical quantity as one that consists of a numerical magnitude and a unit. If we say that the temperature of a room is 19 °C, we have described the temperature of the room quite completely. However, numerical values do not always give a complete description. If we walk 10 m towards the east in a straight line, this quantity is called displacement. It requires both a number and a direction for a complete description. Physical quantities can either be scalar quantities or vector quantities.

Scalar quantities are quantities that have magnitude only.
Vector quantities are quantities that have both magnitude and direction.

Some examples of scalar and vector quantities are given in Table 1.8.

Scalars	Vectors
Distance	Displacement
Speed	Velocity
Mass	Weight
Time	Acceleration
Pressure	Force
Energy	Moment of a force
Temperature	

Table 1.8 Scalar and vector quantities

Addition of Scalars

The addition of scalar quantities is very simple. Scalars are added using simple arithmetic. For example, 4 kg plus 6 kg always gives the answer 10 kg.

Addition of Vectors

The addition of vector quantities is not as straightforward as that of scalars. The directions of vector quantities must also be considered. The addition of two or more vectors of the same kind produces a resultant vector. This resultant vector represents the combined action of its original vectors. The simplest vector addition involves parallel vectors or vectors along a straight line. This is illustrated in Table 1.9.

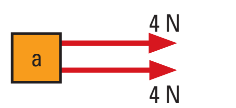
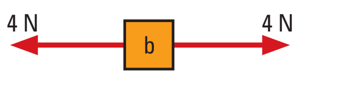
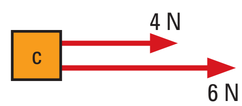
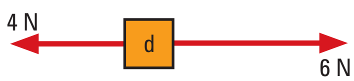
(a) Two forces of magnitude 4 N acting in the same direction add up to give a resultant force of 8 N. Parallel vectors can be added algebraically.		Resultant force = 4 N + 4 N = 8 N to the right
(b) Two forces of magnitude 4 N acting in opposite directions cancel out to give no resultant force. The negative of vector A is a vector of the same magnitude but with the opposite direction. It can be written as (–A).		Resultant force = 4 N – 4 N = 0 N
(c) Forces of 4 N and 6 N acting in the same direction add up to give a resultant force of 10 N. Parallel vectors can be added algebraically.		Resultant force = 6 N + 4 N = 10 N to the right
(d) Forces of 4 N and 6 N acting in opposite directions add up to give a resultant force of 2 N. Adding parallel vectors acting in opposite directions involves the subtraction of one vector from the other.		Resultant force = 6 N – 4 N = 2 N to the right

Table 1.9 Examples of adding forces (vectors) in a straight line

Vectors acting at an angle to each other can be added graphically by using the parallelogram method or vector triangle method.

Vectors can be represented graphically by arrows. The length of the arrow represents the magnitude of the vector. The direction of the arrow represents the direction of the vector. This is illustrated in Figure 1.21.

Mystery Clue

Time seems to flow from the past to the present and into the future. Does this mean that time has direction? Is time a scalar quantity or a vector quantity?

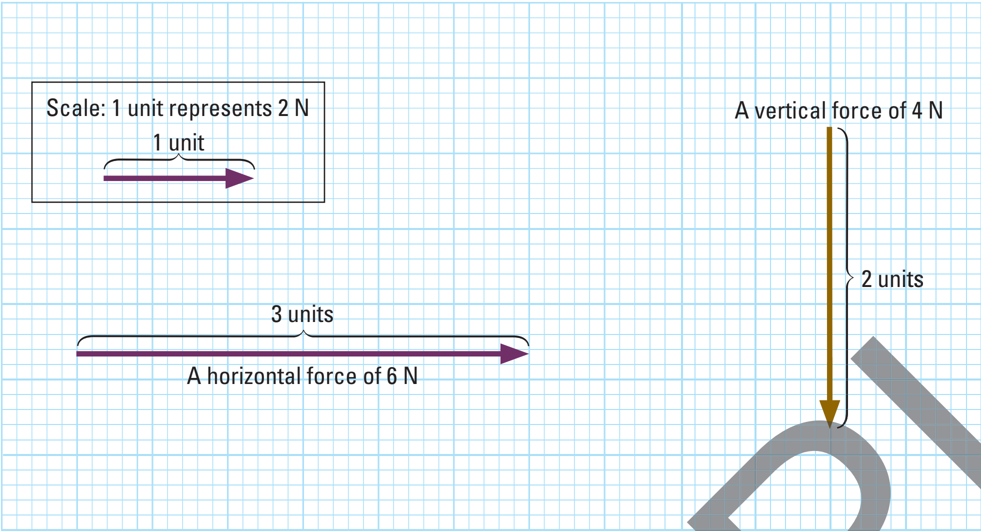


Figure 1.21 Representation of vector quantities

Parallelogram Method

The parallelogram law of vector addition states that if two vectors acting at a point are represented by the sides of a parallelogram drawn from that point, their resultant is represented by the diagonal which passes through that point of the parallelogram.

Worked Example

Figure 1.22 shows two forces, $F_1 = 4$ N and $F_2 = 6$ N, acting on a body with an angle of 45° between them. What is the resultant force, ***R***?

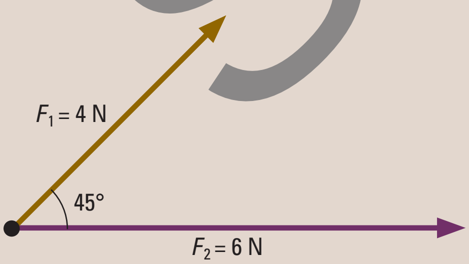
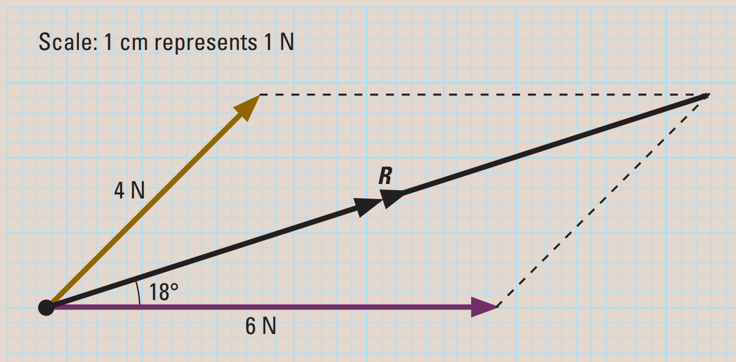


Figure 1.22

Solution

Using a scale of 1 cm : 1 N, the resultant force, ***R***, is 9.3 N and it makes an angle of 18° with the 6 N force.



Vector Triangle Method

In Figure 1.23, the vectors, ***A*** and ***B***, are represented by arrows drawn to scale.

In Table 1.10 (a), the head of vector ***A*** is moved to touch the tail of vector ***B***. In Table 1.10 (b), the head of vector ***B*** is moved to touch the tail of vector ***A***. Regardless of the order in which the vectors are added, the same resultant vector can be drawn.

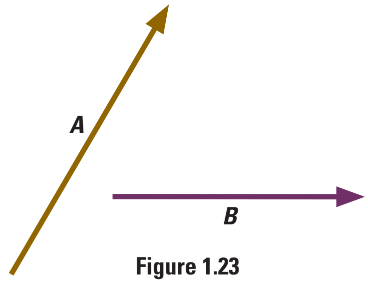


Figure 1.23

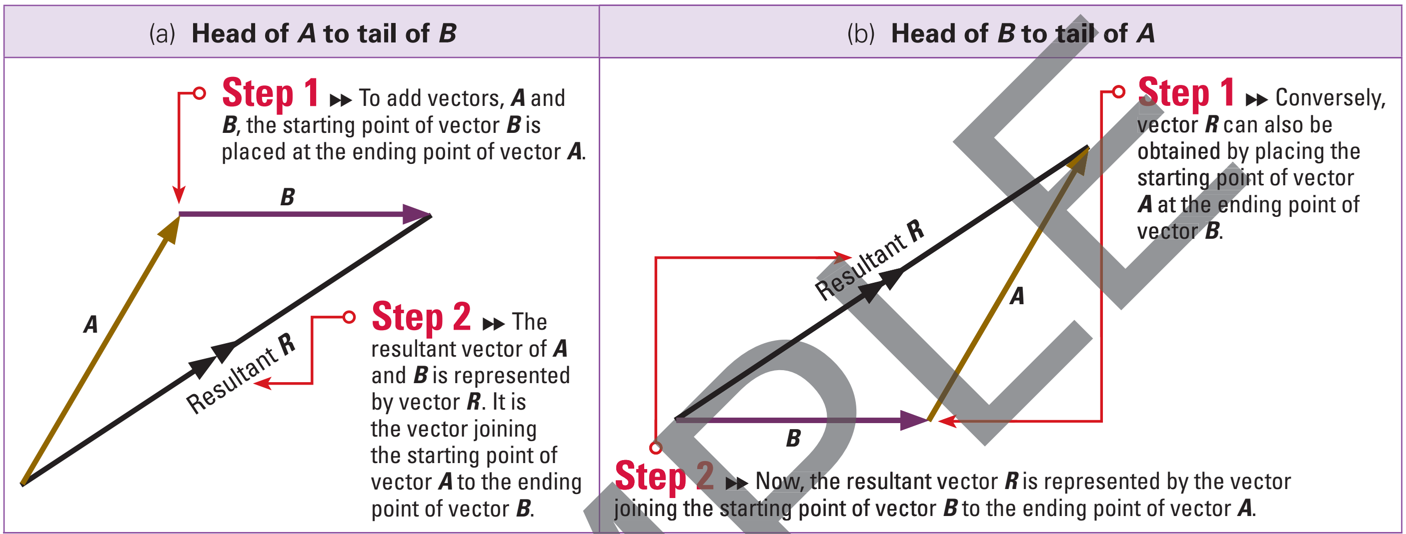


Table 1.10 Adding vectors using the vector triangle method

Section Review

Skills Practice

Equal forces acting in opposite directions produce zero resultant force. Equal forces acting in the same direction produce the maximum resultant force. Equal forces acting at an angle to each other produce a resultant that can be determined by the parallelogram method or the vector triangle method. How can a resultant of 4 N be obtained from two forces of magnitude 4 N?

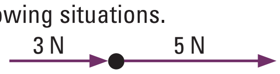
Theory Workbook
• Exercise 1C

Questions

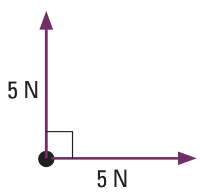
1. Determine the resultant force in each of the following situations.

(a)

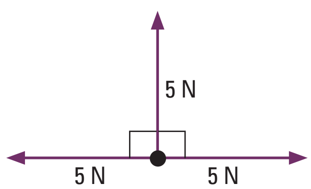
(b)



(c)



(d)

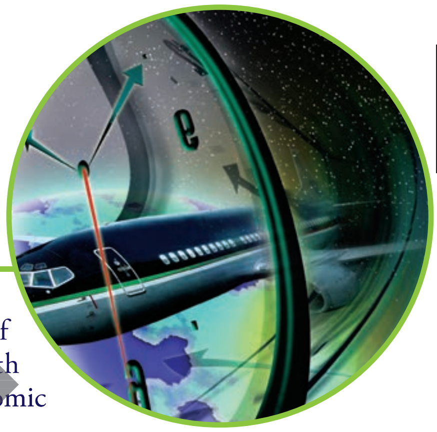


2. Two forces of magnitude 5 N and 8 N act on a body. What are the maximum and minimum resultant forces that can act on the body?

3. Two forces, ***P*** and ***Q***, act on a body. The maximum and minimum resultant forces that can act on the body are 13 N and 7 N respectively. What are the magnitudes of ***P*** and ***Q***?

Solving the Mystery

What is time?



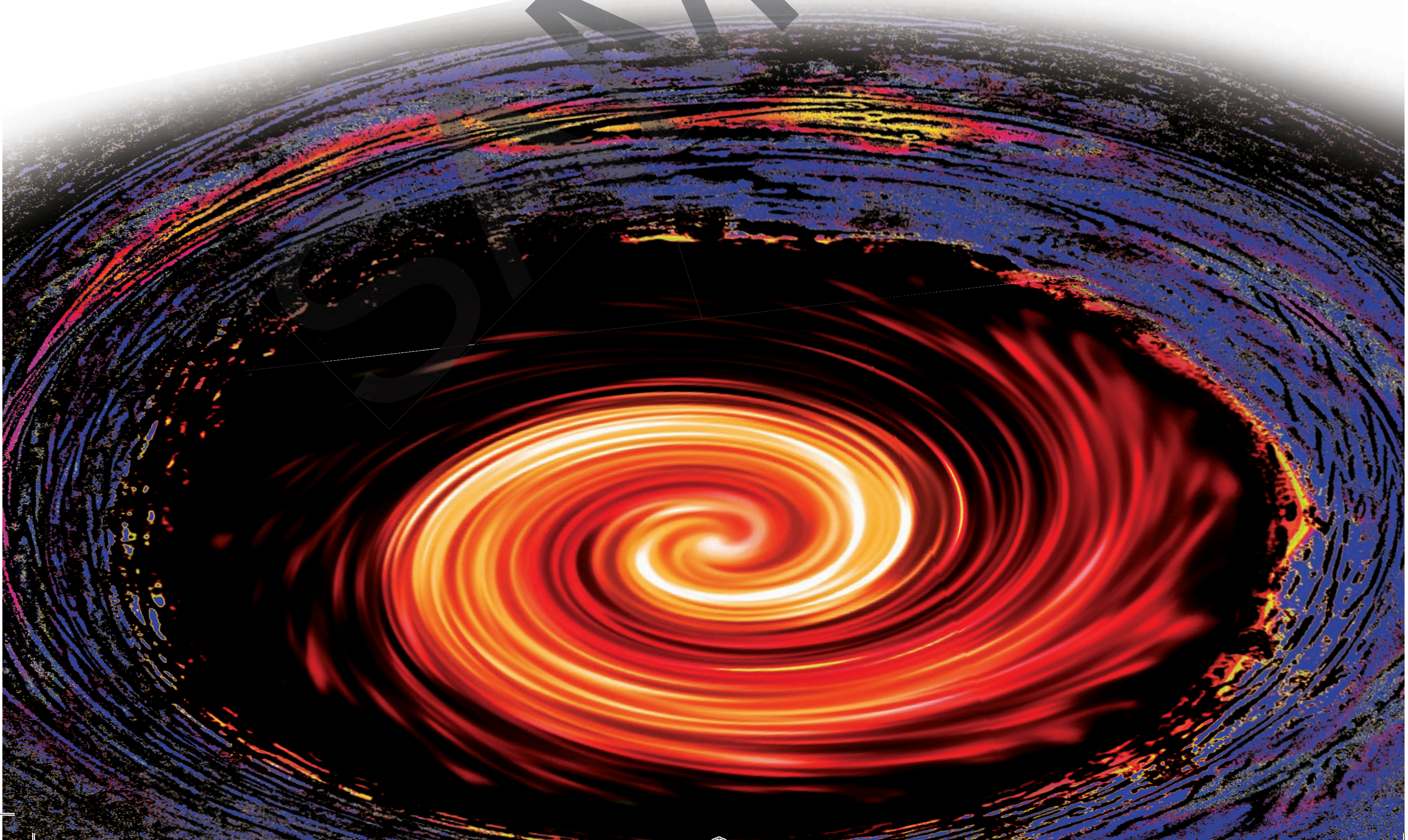
In the 17th century, Sir Isaac Newton suggested that time was absolute – this meant that an accurate clock would register the same time anywhere in the universe. However, according to Albert Einstein's special relativity, a clock is fastest according to an observer who is at rest with the clock. When the clock is moving with respect to the observer, it runs slower. This difference could not be detected at low speed but is significant enough to make the Global Positioning System (GPS) useless if this is not taken into account. GPS satellites with atomic clocks, located 20 000 km above the ground, orbit the Earth at 14 000 km h^{-1}. The error in the atomic clocks due to time slowing down would result in an error of 10 km per day if left uncorrected. The atomic clocks on the satellites are corrected by computers taking into effect their location in a gravitational field and their high speed.

It is difficult to explain the nature of time and it is doubtful whether time is definable in the first place. It is much easier and more practical to associate time with how it is measured in terms of years, hours, minutes or seconds. This is done through clocks and many time-measuring devices. To measure time accurately, we only need to specify the interval between two distinct events. Advances in technology have allowed scientists to measure time intervals with a possible error of 1 second in about 10^8 years. Although we do not fully understand the nature of time, we can still measure it to a very high degree of accuracy with a caesium atomic clock.

Infer
How will human reaction time influence the accuracy of experimental results? How can human reaction time be measured more accurately?

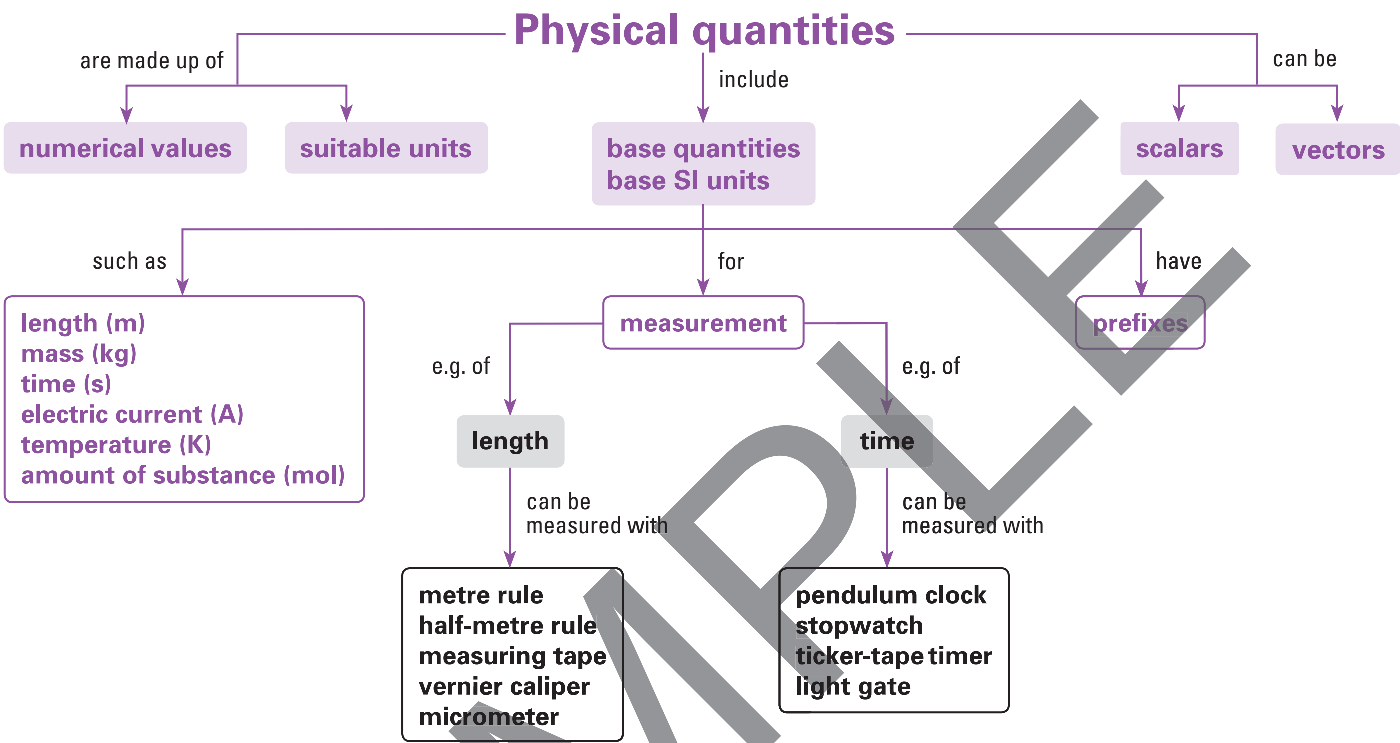
Connect
How do we reduce the influence of human reaction time in data collection?

Further Thoughts
How would you measure time with a ruler?



01 Chapter Review

Concept Link



Check and Associate

I. Key Words

Find out how these key words are connected to each other.

accurate	base quantities	derived quantities
length	magnitude	physical quantity
physical universe	precision	scalars
SI Units	standards	time
vector quantities		

II. Self-Check

1. I can explain ________________/13 key words or phrases.
2. I can do ________________/15 practice questions.
3. What is the key concept in this chapter? State and explain your choice.

Self-Management

I. Misconception Analysis

Think carefully about the following statements. Are they true or false? Check the answers at the back of the book to see whether you have any misconceptions.

1. A physical quantity must have both magnitude and unit. **True/False**
2. Base quantities and base units are the same. **True/False**
3. Derived quantities are not physical quantities. **True/False**
4. The SI units for length, mass and time are the metre, gram and second respectively. **True/False**
5. Prefixes are used to express big numbers only. **True/False**
6. Vectors that are not parallel cannot be added arithmetically. **True/False**

7. The period of oscillation for a pendulum increases with length. **True/False**

8. A reading should be recorded as 10.0 cm instead of 10 cm when the measuring instrument is a metre rule. **True/False**

9. Zero error can be eliminated by taking more readings. **True/False**

10. Parallax error is due to the incorrect positioning of the eye when taking readings. **True/False**

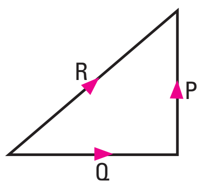
Practice

I. Multiple Choice Questions

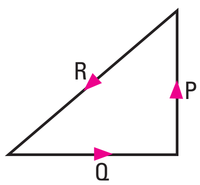
1. Which list contains only base quantities?
   (A) Length, weight, time
   (B) Weight, length, temperature
   (C) Mass, temperature, time
   (D) Electric current, weight, length ( )

2. Which diagram correctly shows the addition of vectors P and Q?

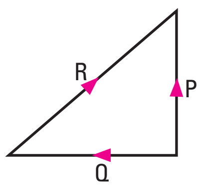
(A)



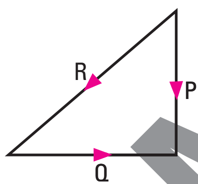
(B)



(C)



(D)



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3. A student uses a ticker-tape timer to investigate the movement of a trolley. The ticker-tape timer puts 50 dots on the ticker tape every second. The tape obtained is shown in Figure 1.24.

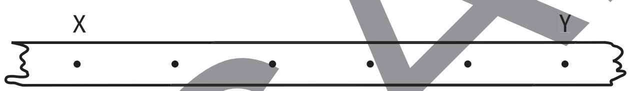

Figure 1.24

What is the time interval corresponding to the distance between X and Y on the tape?
   (A) 0.05 s (B) 0.06 s
   (C) 0.10 s (D) 0.12 s ( )

4. Which list contains only scalar quantities?
   (A) Acceleration, velocity, distance
   (B) Length, mass, speed
   (C) Distance, force, speed
   (D) Force, length, time ( )

5. A force of 3 N and a force of 7 N act on the same body but in different directions. Which value cannot be the resultant force on the body?
   (A) 3 N (B) 4 N
   (C) 7 N (D) 9 N ( )

6. A student has been asked to determine, as accurately as possible, the dimensions of a wooden floor tile. The tile is about 0.4 m long, 0.08 m wide and 0.003 m thick. Which instruments can measure each of these dimensions accurately?

	Length	Width	Thickness
(A)	metre rule	vernier caliper	micrometer
(B)	metre rule	micrometer	vernier caliper
(C)	micrometer	vernier caliper	metre rule
(D)	vernier caliper	metre rule	micrometer

( )

7. The time taken for the pendulum to swing from X to Y is 2.0 s. What is the time for one oscillation of the pendulum?
   (A) 1.0 s
   (B) 2.0 s
   (C) 3.0 s
   (D) 4.0 s ( )

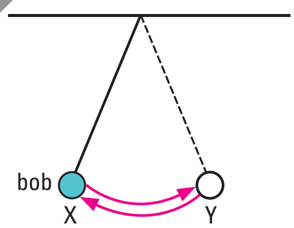

Figure 1.25

8. A micrometer is used to measure the diameter of a copper wire. The reading with the wire in position is shown in Figure 1.26. The wire is removed and the anvil and spindle of the micrometer are closed. The new reading is shown in Figure 1.27. What is the diameter of the wire?

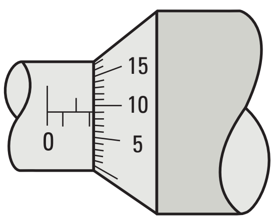

Figure 1.26

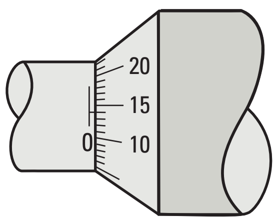

Figure 1.27

   (A) 0.95 mm (B) 1.45 mm
   (C) 1.59 mm (D) 1.73 mm ( )

9. Figure 1.28 shows part of a vernier scale. What is the reading shown?
   (A) 32.5 mm
   (B) 35.5 mm
   (C) 40.0 mm
   (D) 44.5 mm

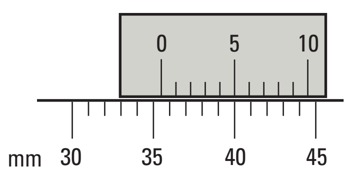

Figure 1.28

( )

10. Which of the following is the longest length?
(A) 3.54×10^{5} μm (B) 3.54×10^{-1} mm
(C) 3.54×10^{2} cm (D) 3.54×10^{-2} m ( )

II. Structured Questions

1. Using the data given, complete Table 1.11 with the appropriate measurement for the physical quantities.

1.8 m	6000 km	4×10^{8} m	1×10^{-4} m	10 000 m

Physical quantity	Measurement
Height of Mount Everest	
Radius of the Earth	
Thickness of paper	
Distance from the Earth to the Moon	
Height of a person	

Table 1.11

2. (a) Which of the physical quantities below are vectors?
force, acceleration, distance, pressure, mass, speed
(b) When two forces of 10 N are added, the magnitude of the resultant force depends on the angle between the two forces.
(i) Describe how it is possible to produce a zero resultant force.
(ii) Describe how it is possible to produce a resultant force of 20 N.
(iii) Draw a vector diagram to show how a resultant force of about 10 N may be obtained.

3. (a) The age of the Earth is 10^{17} s. What is the age of the Earth in years?
(b) Suppose your hair grows at the rate of 0.08 cm per day. What is the rate at which it grows in nanometres per second?
(c) The highway speed limit for a car is 70 km h^{-1}. What is the speed limit in m s^{-1}?
(d) The density of water is 1 g cm^{-3}. What is the density of water in kg m^{-3}?

4. Five identical steel balls are measured with a rule graduated in centimetre, as shown in Figure 1.29.

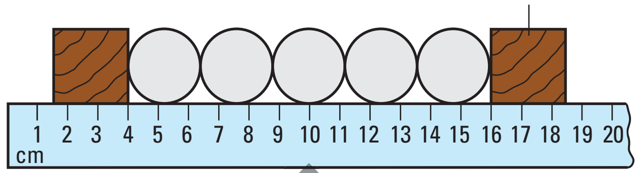

Figure 1.29

(a) What is the diameter of one ball?
(b) Which instrument would be most suitable for measuring the diameter of a single ball?

5. (a) Table 1.12 shows measurements of the diameter of a rod using instruments P, Q and R. Name the instruments in the space provided.

Instrument	Name of instrument	Diameter/cm
P		1.6
Q		1.62
R		1.623

Table 1.12

(b) To measure the diameter of a wire P, a student coiled the wire on a pencil and measured the length for 20 turns of the wire. Figure 1.30 shows the actual size of the two objects.

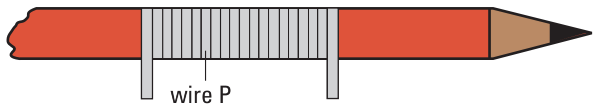

Figure 1.30

(i) Using a ruler, measure the length of 20 turns of wire.
(ii) What is the diameter of wire P?
(iii) Name an instrument in the laboratory that is more suitable for measuring the diameter of wire P.

Real-World Learning Experience

Purpose

To investigate how human reaction time is measured

Learning Task

Set-up

1. Discuss in a small group, how you would define human reaction time.

2. Check the Internet on how human reaction time can be measured.

3. Identify appropriate tools in your school laboratory or at home that you can use to take the measurements.

Implementation

1. If the measurement is conducted in your school, ensure that permission is obtained from your teacher.

2. Observe all safety precautions.

3. Repeat the procedure several times and determine the average human reaction time.

Questions for Understanding

1. How will the presence of human reaction time affect the accuracy of your results?

2. Is there an obvious change in human reaction time as a person ages?