TOPIC 1 Physical Quantities, Units and Measurement

Objectives

Candidates should be able to:

(a) show understanding that all physical quantities consist of a numerical magnitude and a unit
(b) recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
(c) 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)
(d) show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth
(e) state what is meant by scalar and vector quantities and give common examples of each
(f) add two vectors to determine a resultant by a graphical method
(g) 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
(h) describe how to measure a short interval of time including the period of a simple pendulum with appropriate accuracy using stopwatches or appropriate instruments

NOTES

1.1 Physical Quantities and SI Units

1. Physical quantities consist of:
   (a) Numerical magnitude – denotes the size of the physical quantity.
   (b) Unit – denotes the physical quantity it is expressing.

2. Physical quantities can be classified into:
   (a) Basic quantities

Basic Quantity	Name of SI Unit	SI Unit
length	metre	m
mass	kilogram	kg
time	second	s
thermodynamic temperature	kelvin	K
amount of substance	mole	mol

   (b) Derived quantities – defined in terms of the basic quantities through equations. SI units for these quantities are obtained from the basic SI units through the equations.

Example 1.1

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad \text{(Unit for mass: kg, Unit for volume: m}^3\text{)}$$

$$\text{Therefore unit for density} = \frac{\text{kg}}{\text{m}^3} = \text{kg/m}^3$$

3. (a) Units of measurements: SI units are used as standardised units in all measurements in the world. SI is the short form for "International System of Units".
   (b) Other Units:

Length	Mass	Time
1 km = 1000 m	1 kg = 1000 g	1 h = 60 min
1 m = 100 cm	1 g = 1000 mg	1 min = 60 s
1 cm = 10 mm		

4. Examples of some derived quantities and their units:

Derived Quantity	SI Unit
area	m^2
volume	m^3
density	kg/m^3
speed	m/s

A complete list of key quantities, symbols and units used for the O Level examination can be found in the syllabus.

1.2 Prefixes, Symbols and Orders of Magnitude

1. Physical quantities can be very large, like 23 150 000 000 m, or very small, like 0.000 000 756 m. Writing down such numbers can be time consuming and error-prone. We use prefixes to indicate decimal sub-multiples and multiples of the SI units to make writing such numbers easier.

2. Some prefixes of the SI units are as follows:

Prefix	**Multiple**	**Symbol**	**Factor**	**Order of Magnitude**
Tera	1 000 000 000 000	T	10^{12}	12
Giga	1 000 000 000	G	10^{9}	9
Mega	1 000 000	M	10^{6}	6
Kilo	1000	k	10^{3}	3
Deci	0.1	d	10^{-1}	–1
Centi	0.01	c	10^{-2}	–2
Milli	0.001	m	10^{-3}	–3
Micro	0.000 001	μ	10^{-6}	–6
Nano	0.000 000 001	n	10^{-9}	–9
Pico	0.000 000 000 001	p	10^{-12}	–12

The ones in bold are specifically required in the syllabus.

Example 1.2

(a) 0.000 0031 m = 3.1 μm = 3.1×10^{-6} m

(b) 0.000 000 0012 s = 1.2 ns = 1.2×10^{-9} s

3. When measurements are too large or too small, it is convenient to express them in standard form as follows:

   $M \times 10^{N}$

   M lies in the range of: $1 \leqslant M < 10$

   N denotes the order of magnitude and is an integer.

4. Orders of magnitude are often being used to estimate numbers which are extremely large to the nearest power of ten.

   E.g.

   (a) Estimate the number of strands of hair on a person's head.

   (b) Estimate the number of breaths of an average person in his lifetime.

5. The following tables show how the orders of magnitude are used to compare some masses and lengths.

Mass/kg	Factor
Electron	10^{-30}
Proton	10^{-27}
Ant	10^{-3}
Human	10^{1}
Earth	10^{24}
Sun	10^{30}

Length/m	Factor
Radius of a proton	10^{-15}
Radius of an atom	10^{-10}
Height of an ant	10^{-3}
Height of a human	10^{0} ($10^{0} = 1$)
Radius of the Earth	10^{7}
Radius of the Sun	10^{9}

Example 1.3

Find the ratio of the height of a human to that of an ant.

Ratio of height of human to that of an ant = $\dfrac{10^{0}}{10^{-3}} = 10^{3} = 1000.$

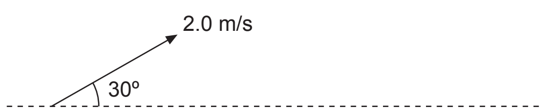
1.3 Scalars and Vectors

1. A scalar quantity – has only magnitude but does not have direction.
   E.g. mass, distance, time, speed, work, power.

2. A vector quantity – has both magnitude and direction.
   E.g. weight, displacement, velocity, acceleration, force.

   Example 1.4

   The velocity of a particle can be stated as: "speed of particle = 2.0 m/s and it is moving at an angle of 30° above the horizontal".

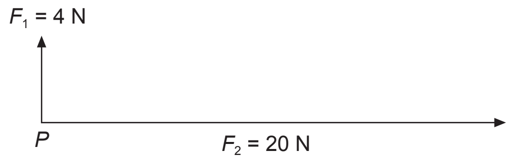


1.4 Addition of Vectors

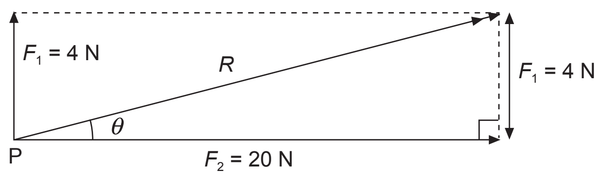
1. Involves magnitude and direction.

Example 1.5

Find the resultant force R at point P due to F_1 and F_2.



Method 1: Trigonometric Method



Using Pythagoras' Theorem:

$R = \sqrt{(F_1)^2 + (F_2)^2}$

$R = \sqrt{4^2 + 20^2} = \sqrt{416}$

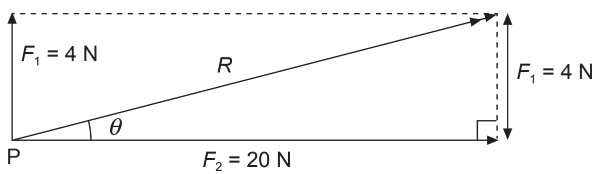
$R =$ 20.4 N

R is at an angle θ above the horizontal

$\tan\,\theta = \dfrac{F_1}{F_2} = \dfrac{4}{20} = \dfrac{1}{5}$

$\theta = 11.3°$

Method 2: Graphical Method



(Not drawn to scale)

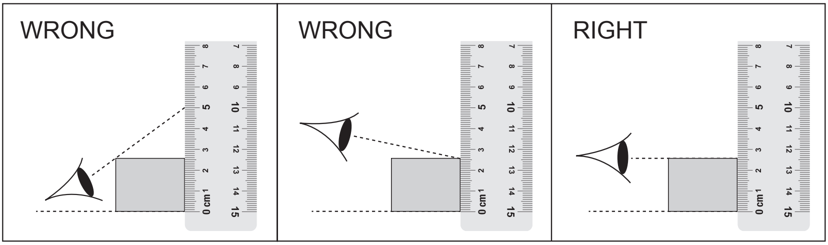
Step 1: Select an appropriate scale
E.g. 1 cm to 2 N.
Step 2: Draw a parallelogram of vectors to scale.
Step 3: Measure the diagonal to find R.
Step 4: Use the protractor to measure angle θ.

1.5 Measurement of Length

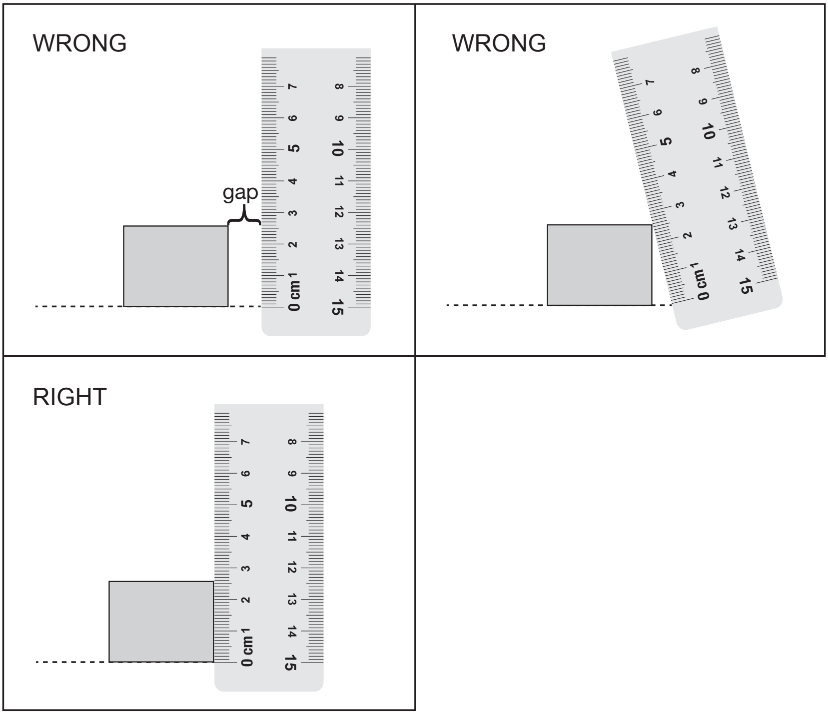
1. Choice of instrument depends on the degree of accuracy required.

Range of length, *l*	Instrument	Accuracy	Example
l > 100 cm	Measuring tape	± 0.1 cm	waistline of a person
5 cm < l < 100 cm	Metre rule	± 0.1 cm	height of an object
1 cm < l < 10 cm	Vernier calipers	± 0.01 cm	diameter of a beaker
l < 2 cm	Micrometer screw gauge	± 0.001 cm	thickness of a length of wire

2. How parallax errors can occur during measurement:
   (a) incorrect positioning of the eye



   (b) the object is not touching the marking of the scale
   (for measuring tape and metre rule, ensure that the object is **in contact** with the scale)



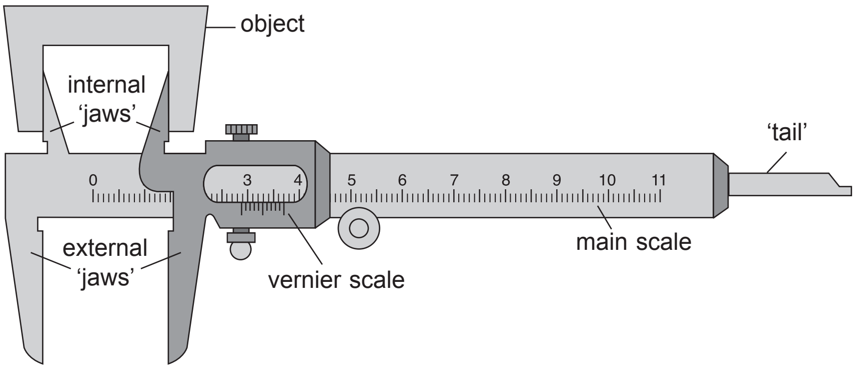
3. A measuring instrument can give precise but not accurate measurements, accurate but not precise measurements or neither precise nor accurate measurements.

   (a) Precision is how close the measured values are to each other but they may not necessarily cluster about the true value. Zero errors and parallax errors affect the precision of an instrument.

   (b) Accuracy is how close a reading is to the true value of the measurement. The accuracy of a reading can be improved by repeating the measurements.

4. **Vernier calipers**

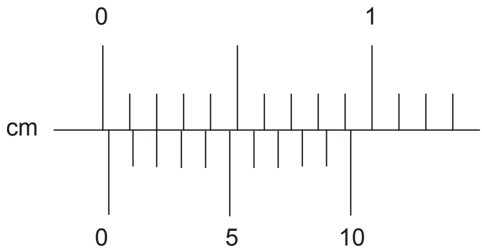
A pair of vernier calipers can be used to measure the thickness of solids and the external diameter of an object by using the external jaws. The internal jaws of the caliper are used to measure the internal diameter of an object. The tail of the caliper is used to measure the depth of an object or a hole. Vernier calipers can measure up to a precision of ±0.01 cm.



Precautions: Check for zero error and make the necessary correction.

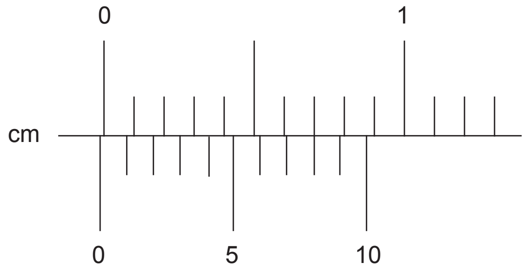
Example 1.6

(a) Positive zero error:



Zero error = +0.02 cm

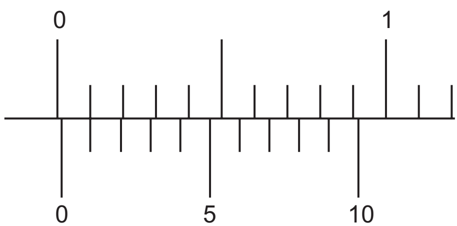
(b) Negative zero error:



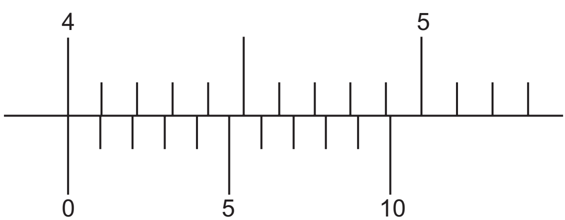
Zero error = –0.02 cm

Note: In (b), the pair of vernier calipers is built with an existing zero error. There is a negative reading without any object between its jaws. The vernier scale is pushed 0.02 cm to the left.

Example 1.7
When the jaws of a pair of vernier calipers are closed, the vernier caliper reading is as shown.



When the same pair of vernier calipers is used to measure the diameter of a beaker, the vernier caliper reading is as shown.

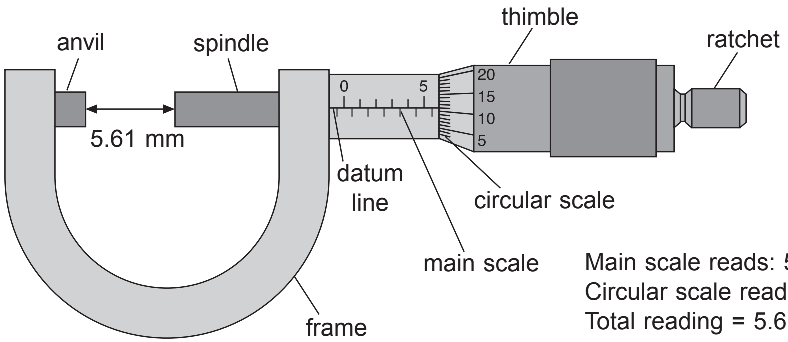


What is the diameter of the beaker?

Solution

Zero Error = +0.01 cm
Reading = 4.00 + 0.01 = 4.01 cm
Actual reading = 4.01 − 0.01 = 4.00 cm

5. Micrometer screw gauge

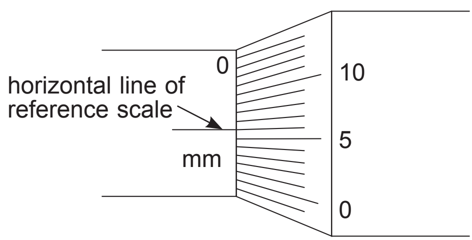


Main scale reads: 5.50 mm
Circular scale reads: 0.11 mm
Total reading = 5.61 mm

Precautions:
(a) Ensure that the jaws of the micrometer screw gauge are completely closed by turning the ratchet until you hear a ‘click’ sound.
(b) Check that the ‘0’ mark of the thimble scale is completely in line with the horizontal line of the reference scale. If not, there is zero error.

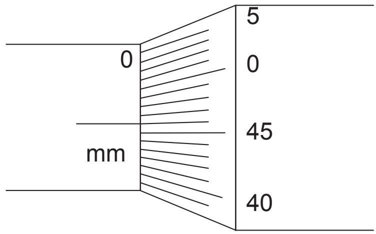
Example 1.8

(a) Positive zero error: ‘0’ mark is below the horizontal line



Zero error = +0.06 mm

(b) Negative zero error: '0' mark is above the horizontal line



Zero error = –0.04 mm

Example 1.9

A micrometer screw gauge is used to measure the thickness of a plastic board. When the jaws are closed without the plastic board in between, the micrometer reading is shown in Fig. (a).

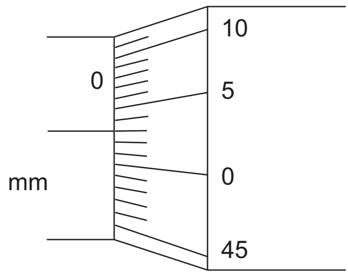


Fig. (a)

With the jaws closed around the plastic board, the micrometer reading is shown in Fig. (b).

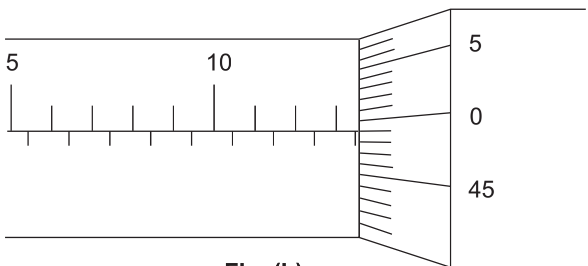


Fig. (b)

What is the thickness of the plastic board?

Solution

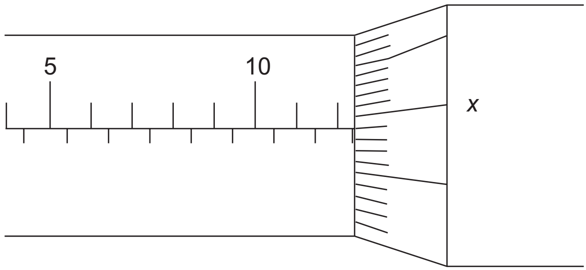
Zero error = +0.03 mm

Reading = 13.5 + 0.49 = 13.99 mm

Actual thickness of plastic board = 13.99 – (+0.03) = 13.96 mm

Example 1.10

The micrometer reading as shown in the figure is 12.84 mm.



What is the value of x on the circular scale?

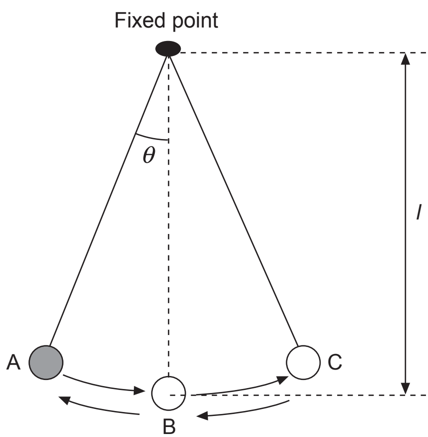
Solution

Reading = 12.5 + reading on the circular scale = 12.84 mm

Reading on the circular scale = 12.84 – 12.5 = 0.34 mm

Since the marking x is 1 mark above 0.34 mm, the value of x is 35.

6. Period of oscillation of a simple pendulum.



(a) (i) One oscillation – One complete to-and-fro movement of the bob from point A to B to C and back to A.

(ii) Period, T – Time taken for one complete oscillation.

(iii) Amplitude – The distance between the rest position of the bob (point B) to the extreme end of the oscillation (either point A or point C).

(b) Steps to find the period of oscillation:

Step 1: Take the total time for 20 oscillations.

Step 2: Repeat **Step 1**.

Step 3: Take the average of the two timings.

Step 4: Divide the average in **Step 3** by 20 to obtain the period.

(c) The period of the pendulum, T, is affected only by its length, l, and the acceleration due to gravity, g.

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

T is not affected by the mass of the pendulum bob.

Example 1.11

A pendulum swings backwards from B to A and forwards to C passing through B, he middle point of the oscillation. The first time the pendulum passes through B, a stopwatch is started. The thirtieth-time the pendulum passes through B, the stopwatch is stopped and the reading taken is 25.4 seconds. What is the period of the pendulum?

Solution

$$\text{Period} = \frac{\text{Total time taken}}{\text{Number of oscillations}}$$

$$= \frac{25.4}{15}$$

$$= 1.69 \text{ s}$$