Physical Quantities and Units

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(a) *Physical quantity*:

Def. Anything that can be …**measured**…… and is represented by it's …**magnitude (numerical) value**…
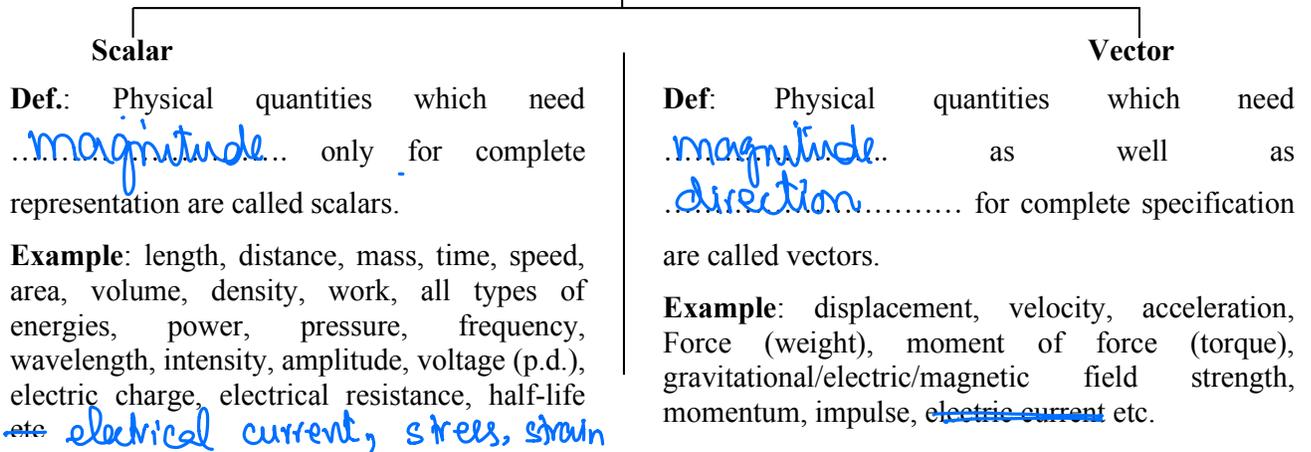
along with a …**unit**….. is called physical quantity.

Example table:

S. No.	Physical quantity	symbol	magnitude	S.I. unit	Measuring device/equation
1.	Length	*l,x,d,s,h*	80	metre (m)	Trundle Wheel, Pedometer, Measuring tape, Metre rule, Vernier caliper, Micrometer screw gauge)
2.	Mass	*m, M*	45	kilogram (kg)	Top pan balance, lever balance
3.	speed	*u, v*	30	metre /second (ms^{-1})	Speedometer
4.	Current	*I*	2	ampere (A)	Ammeter
5.	Charge	*Q, q*	20	coulomb (C)	Electroscope
6.	Acceleration	*a*	60	m s^{-2}	$a = (v-u) / t$
7.	Resistance	*r, R*	2	ohm (Ω)	Ohm meter, $R = V / I$

Categories of physical quantities:

Scalar ← Work = (F)(d) → Parallel
Vector ← Moment = (F)(d) → Perpendicular

Two categories

Scalar

Def.: Physical quantities which need …**magnitude**… only for complete representation are called scalars.

Example: length, distance, mass, time, speed, area, volume, density, work, all types of energies, power, pressure, frequency, wavelength, intensity, amplitude, voltage (p.d.), electric charge, electrical resistance, half-life ~~etc~~ **electrical current, stress, strain**

Vector

Def: Physical quantities which need …**magnitude**… as well as …**direction**……… for complete specification are called vectors.

Example: displacement, velocity, acceleration, Force (weight), moment of force (torque), gravitational/electric/magnetic field strength, momentum, impulse, ~~electric current~~ etc.

Types of Physical Quantities:

Two Types

Base Quantities   Derived Quantities

(b) Base Quantities:

Def. **Physical quantities which are not derived from other quantities and are considered as building blocks of Physics.**

Example: **They are seven in number.**

S. No.	Physical quantity	symbol	S.I. unit	Measuring device/equation
1.	Length	*l*	metre (m)	Measuring tape, Metre rule, Vernier caliper, Micrometer screw gauge)
2.	Mass	*m*	kilogram (kg)	Top pan balance, lever balance
3.	Time	*t*	second (s)	Stopwatch

4.	Electric current	I	ampere (A,mA)	Ammeter	
5.	Thermodynamic Temperature	T	kelvin (K)	Thermometer	
6.	Amount of substance	n	mole (mol)		
7.	Luminous intensity		candela (cd)		

(c) **Derived Quantities**:

Def. *Physical quantities which are the* ..Product., quotient (ratio).. *or union of* ***product and quotient*** *of base quantities are called derived quantities.*

Examples:

(i) Product:

$$Volume = l \times W \times h$$
$$Area = l \times W$$

$$Charge: \quad Q = It$$

(ii) Quotient: (Ratio)

$$speed = \frac{Distance}{time}$$

(iii) Union of product and quotient:

acceleration (*a*)

$$a = \frac{\Delta V}{\Delta t} = \frac{\frac{\Delta L}{\Delta t}}{\Delta t}$$

$$a = \frac{\Delta L}{\Delta t^2}$$

density (*ρ*)

$$\rho = \frac{m}{V}$$
$$= \frac{m}{L \times L \times L}$$
$$= \frac{m}{L^3}$$

force (*F*)

$$F = ma$$
$$= (m)\left(\frac{\Delta L}{\Delta t^2}\right)$$

Pressure (P)

$$P = \frac{F}{A}$$
$$= \frac{m\left(\frac{\Delta L}{\Delta t^3}\right)}{L^2}$$
$$= \frac{m}{L \Delta t^3}$$

work (*W*)

$$W = (F)(d)$$
$$= \left(\frac{m \Delta L}{\Delta t^2}\right)(L)$$
$$= \frac{m \Delta L^2}{\Delta t^2}$$

voltage (*V*)

$$V = \frac{W}{Q}$$
$$= \frac{\frac{m \Delta L^2}{\Delta t^2}}{It}$$
$$= \frac{m \Delta L^2}{I \Delta t^3}$$

$$R = \frac{V}{I} = \frac{\frac{m \Delta L^2}{I \Delta t^3}}{I} = \frac{m \Delta L^2}{I^2 \Delta t^3}$$

(d) **Significance of SI units:**

1. **To identify a physical Quantity:** SI is a standard set by the authorities and is recognised all over the world. All physical quantities are measured in the SI units. For example,

   (i) Rs. 80 / kg identify the physical quantity….mass…….

   (ii) Rating written on an electric iron is 220 V and 5 A. So 'V' represent …p:d/ voltage and 'A' represent …..current…….. needed for its proper working.

   (iii) m s^{-1} represent …Speed/velocity.

   (iv) N represent ……Force………….

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2. **To check the homogeneity** ▬▬▬▬ **of physical equations:**
An equation is said to be homogeneous if all the terms used in it has the same unit. For example,

(i) $$s = ut + (½)at^2$$

$S \longrightarrow m$

$ut \longrightarrow (ms^{-1})(s) = m$

$\frac{1}{2}at^2 \longrightarrow (ms^{-2})(s)^2 = m$

Physical Qty $\rightarrow 4$
$\underline{S, u, t, a}$
Base Qty $\rightarrow 2$
$\underline{S, t}$
Derived Qty $\rightarrow 2$
$\underline{u, a}$
Terms $\longrightarrow 3$
$\underline{S, ut, \frac{1}{2}at^2}$

(ii) $$P = h\rho g$$

$P \longrightarrow P = \frac{F}{A} = \frac{ma}{A} = \frac{(kg)(ms^{-2})}{m^2} = kg\,m^{-1}s^{-2}$

$h\rho g \longrightarrow h\left(\frac{m}{V}\right)g = (m)\left[kg\,m^{-3}\right](ms^{-2}) = kg\,m^{-1}s^{-2}$

Physical Qty $\rightarrow 4$
$\underline{P, h, \rho, g}$
Base Qty $\rightarrow 1$
$\underline{h}$
Derived Qty $\rightarrow 3$
$\underline{P, \rho, g}$
Terms $\longrightarrow 2$
$\underline{P, h\rho g}$

Note:
1. Only homogeneous equation is correct and is valid.
2. In homogeneous equation, the balancing of base units provides a means of finding the units of an unknown quantity.

Example: Show that *pressure + (½)(density) × (speed)² = constant* is a homogeneous and find the base units of the constant.

$\underline{Pressure} : P = \frac{F}{A} = \frac{ma}{A} = \frac{(kg)(ms^{-2})}{m^2} = kg\,m^{-1}s^{-2}$

$\underline{\frac{1}{2}\rho v^2} : (kg\,m^{-3})(ms^{-1})^2 = (kg\,m^{-3})(m^2 s^{-2}) = kg\,m^{-1}s^{-2}$

So constant also has same unit ie

$\left(kg\,m^{-1}s^{-2}\right)$

3. There may be some equations which are homogeneous but still incorrect if,
(a) **a term is added or deleted**

$S = ut + \frac{1}{2}at^2 + vt$

$10 = 3 + 7 + \square$

$S = \frac{1}{2}at^2 \longrightarrow ut$ is deleted

$S = ut + vt + \frac{1}{2}at^2 \longrightarrow vt$ is added

$S = ut - vt + \frac{1}{2}at^2 \longrightarrow vt$ is subtracted

(b) **a co-efficient of a term in an equation is modified**

$S = ut + \frac{1}{2}at^2$

$10 = 3 + 7$

$S = ut + \frac{3}{2}at^2 \longrightarrow 3$ with $\frac{1}{2}at^2$ is modified.

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Q.1. The elastic potential energy E is given by

$$E = C\rho^2 g^2 A l_0^3$$

where ρ is the density of the metal,
  g is the acceleration of free fall,
  A is the cross-sectional area of the wire
  and C is a constant.
  Determine the SI base units of C.

l_0 – initial length

$$C = \frac{E}{\rho^2 g^2 A l_0^3} = \frac{(F)(d)}{\rho^2 g^2 A l_0^3}$$

$$= \frac{(kg\, m\, s^{-2})(m)}{(kg\, m^{-3})^2 (m\, s^{-2})^2 (m^2)(m)^3}$$

$$= \frac{kg\, m^2\, s^{-2}}{kg^2\, m^{-6+2+2+3}\, s^{-4}} = kg^{-1}\, m\, s^2$$

$E \to (F)(d) = (ma)(d)$
$\quad = (kg\, m\, s^{-2})(m) = kg\, m^2\, s^{-2}$
$A \to m^2$
$\rho \to \dfrac{m}{V} = kg\, m^{-3}$
$g \to m\, s^{-2}$
$l_0 \to m$

{*Q. 1(b-ii)/9702/21-22/O/N/13*} – [3 marks]

Q. 2. The time T for a satellite to orbit the Earth is given by

$$T = \sqrt{\left(\frac{KR^3}{M}\right)}$$

where R is the distance of the satellite from the centre of the Earth,
  M is the mass of the Earth,
  and K is a constant.
  Determine the SI base units of K.

$$T^2 = \frac{KR^3}{M} \Rightarrow K = \frac{MT^2}{R^3}$$

$$K = \frac{(kg)(s)^2}{m^3} = kg\, m^{-3}\, s^2$$

{*Q. 2(a)/9702/23/O/N/13*} – [2 marks]

(f) Prefixes (Multiples and submultiples of 10)

Evaluate

d) $\dfrac{(9G)(4c)(M)}{(6P)(6d)}$

$= \dfrac{(10^9)(10^{-2})(10^6)}{(10^{-12})(10^{-1})}$

$= \dfrac{10^{13}}{10^{-13}}$

$= 10^{26}$

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

vi) $\dfrac{(10^5 G)(10^{-9} p)}{(c)(10 \mu)}$

$= \dfrac{(10^5)(10^9)(10^{-9})(10^{-12})}{(10^{-2})(10)(10^{-6})}$

$= \dfrac{10^{-7}}{10^{-7}}$

$= 10^0 = 1$

1(g) Estimation

Q. 1 Give an SI unit and an estimate of the magnitude of each of the following physical quantities. (Marks will be awarded for the correct order of magnitude of each estimate, not necessary for its accuracy).

Physical Quantity	Magnitude	unit
the weight of an adult		
the power of a hair drier		
the energy required to bring to the boil a kettle full of water		
the resistance of a domestic lamp		
the wavelength of visible light		
Mass of a cricket ball		

Q. 2 Make reasonable estimates of the following quantities.

(a) mass of an apple

mass = ... kg [1]

(b) number of joules of energy in 1 kilowatt-hour

number = ... [1]

(c) wavelength of red light in a vacuum

wavelength = ...m [1]

(d) pressure due to a depth of 10 m of water

pressure = ... Pa [1]

{Q. 1/June 2002/9702}

Q. 3 Make estimates of the following quantities.

(a) the speed of sound in air

speed = ……………………………………. [1]

(b) the density of air at room temperature and pressure

density = ……………………………… [1]

(c) the mass of a protector

mass = ……………………………… [1]

(d) the volume, in cm^3, of the head of an adult person

volume = ……………………………… [1]

{Q. 1/June 2005/9702}

Q.4 Make reasonable estimates of the following quantities.

(a) the frequency of audible sound wave

frequency = ……………………………… Hz [1]

(b) the wavelength, in nm, of ultraviolet radiation

wavelength = …………………………… nm [1]

(c) the mass of a plastic 30 cm ruler

mass = ……………………………………. g [1]

(d) the density of air at atmospheric pressure

density = ………………………………kg m^{-3} [1]

{Q. 1/June 2008/9702}

Q. 5 Make estimates of the following quantities:

(a) Length of a car ………………….....   **(b)** diameter of a hair ……………………….

(c) diameter of an atom ………………   **(d)** diameter of a nucleus …………………

(e) mass of an adult human ……………   **(f)** The diameter of a pencil ………………

(g) Volume of a pea ………………….   **(h)** The speed of a jumbo jet ………………..

(i) The temperature of the human body ……… **(j)** The height of ceiling in a room ………….

1(g) Estimation (Answers)

Q. 1 Give an SI unit and an estimate of the magnitude of each of the following physical quantities. (Marks will be awarded for the correct order of magnitude of each estimate, not necessary for its accuracy).

Physical Quantity	Magnitude	unit
the weight of an adult $W = mg$ $= (\quad)(9.81)$	585 to 980	N
the power of a hair drier $P = VI$ $= (220)(1.5+2)$	400 to 1000	W
the energy required to bring to the boil a kettle full of water $Q = mc\Delta\theta = (1)(4200)(100-25)$	7500 to 315000	J
the resistance of a domestic lamp $P = \dfrac{v^2}{R} \Rightarrow 60 = \dfrac{(220)^2}{R}$	240 to 960	Ω
the wavelength of visible light $\underset{400nm}{V} \longrightarrow \underset{700nm}{R}$	400 to 700 $\times 10^{-9}$	m
Mass of a cricket ball 150g to 200g	0.175	kg

Q. 2 Make reasonable estimates of the following quantities.

(a) mass of an apple   150 to 200g

         mass = <u>allow 50 g to 500 g</u> [1]

(b) number of joules of energy in 1 kilowatt-hour $1kwh = (1)(1000)(w)(60\times60-1) = 3.6\times10^6 J$

         number = <u>allow 3M J to 4M J</u> [1]

(c) wavelength of <u>red light</u> in a vacuum   700nm

         wavelength = <u>allow 600 to 800 n m</u> [1]

(d) pressure due to a depth of 10 m of water $P = h\rho g$ $= (10)(1000)(9.81)$

         pressure = <u>allow 5 × 10⁴ to 5× 10⁵ Pa</u> [1]

         {Q. 1/June 2002/9702}

Q. 3 Make estimates of the following quantities.

(a) the speed of sound in air   330 to 340ms⁻¹

         speed = <u>*allow 100 ms⁻¹ to 900 ms⁻¹*</u> [1]

(b) the density of air at room temperature and pressure

         density = <u>*allow 0.5 kg m⁻³ to 1.5 kg m⁻³*</u> [1]

(c) the mass of a protector   8 to 10g

         mass = <u>5 to 50 g</u> [1]

(d) the volume, in cm³, of the head of an adult person

         volume = <u>allow 2 × 10³ cm³ to 9 × 10³ cm³</u> [1]

         {Q. 1/June 2005/9702}

Q. 4 Make reasonable estimates of the following quantities.

(a) the frequency of audible sound wave

         frequency = <u>*allow anything in the range* 20 Hz *to* 20 kHz</u> [1]

(b) the wavelength, in nm, of ultraviolet radiation $1\times10^{-8} = 10\times10^{-9} = 10nm$

         wavelength = <u>*allow anything in the range* 10 nm *to* 400 nm</u> [1]

(c) the mass of a plastic 30 cm ruler   25 to 30g

         mass = <u>*allow anything in the range* 10 g *to* 100 g</u> [1]

(d) the density of air at atmospheric pressure

         density = <u>*allow anything in the range* 0.1 kg m⁻³ to 10 kg m⁻³</u> [1]

(e) Mass of wooden mette rule = 50 to 90g

         {Q. 1/June 2008/9702}

Q. 5 Make estimates of the following quantities:

(a) Length of a car___4m___   (b) diameter of a hair ___5 × 10⁻⁴ m___

(c) diameter of an atom___3 × 10⁻¹⁰ m___   (d) diameter of a nucleus___6 × 10⁻¹⁵ m___

(e) mass of an adult human _55 to 95 kg_   (f) The diameter of a pencil _0.5 to 1 cm_

(g) Volume of a pea ___0.5 cm³___   (h) The speed of a jumbo jet___220 m s⁻¹___

(i) The temperature of the human body _310 K_   (j) The height of ceiling in a room _2.5-3.5m_

         37°C   9 to 11 feet

Physical Quantities and Units

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1. Which of the following is **not** an SI base unit (Systeme International Units)?
A Kelvin (K)   **B** coulomb (C)
C second (s)   D Ampere (A)

2. Which of the following quantities do **not** carry any units?

A	Refractive Index	Impulse
B	Electric potential	Electric field strength
C	Strain	Power / Energy
D	Refractive Index	Strain

3. What is the special name given to the unit of electromotive force of a battery, and what are the base units of electromotive force?

Handwritten: $V = \dfrac{W}{Q}$ $V = \dfrac{(F)(d)}{It} = \dfrac{(ma)(d)}{It}$
$= \dfrac{(kg\, ms^{-2})(m)}{A\,s} = kg\, m^2 A^{-1} s^{-3}$

  A V, kg m² s⁻³ A⁻¹ → V, kg m² s⁻³ A⁻¹
  B N, kg m s⁻²
  C N, kg m² s⁻³ A⁻¹
  D V, kg m s⁻²

4. The electrical power, *P* dissipated in a resistor of resistance *R* when a current *I* passes through the resistor is given by $P = I^2 R$. How may *R* be expressed in **base units**?
A A² kg⁻¹ m⁻² s³   B kg m² s⁻² A⁻²
C kg m² s⁻³ A⁻²   D W A⁻²

Handwritten: kg m² A⁻² s⁻³

5. Which of the following pairs of quantities are both scalars?
A speed, velocity   **B** current, charge
C pressure, force
D electric potential, work

6. The Young's modulus of a material *E* is given by
$$E = (F / A) / (e / l)$$
Handwritten: $E = \dfrac{FL}{Ae} \rightarrow \dfrac{m}{m}$

Where
F = force exerted on cross-sectional area *A* of the material.
e = deformation produced (an extension or compression)
l = original length of the material.
E possesses a unit similar to
A work   B power
C energy   **D** pressure

7. Which is a pair of SI base units?

	A		B	
A	ampere	B	joule	D
B	coulomb	D	second	B
C	kilogram	B	kelvin	B
D	metre	B	newton	D

8. If *p* is the momentum of an object of mass *m*, then the expression p² / m has the same units as
A acceleration   **B** energy
C force   D impulse

9. When a beam of light is incident on a surface, it delivers energy to the surface. The intensity of the beam is defined as the energy delivered per unit area per unit time.
What is the unit of intensity, expressed in SI base units?
A kg m⁻² s⁻¹   B kg m² s⁻³   C kg s⁻²   **D** kg s⁻³

10. Which of the following definitions is correct and uses only quantities rather than units?
A Density is mass per cubic metre. *(volume)* ✗
B Potential difference is energy per unit current. *(charge)* ✗
C Pressure is force per unit area.
D Speed is distance travelled per second. *(time)* ✗

11. Which of the following statements is **false**?
A A homogeneous equation is a physical correct equation.
B The principle of homogeneity of an equation cannot determine the value of a unitless constant in an equation. ✓
C For an equation to be physically correct, it must have dimensional consistency. ✓
D The principle of homogeneity of an equation ~~of an equation~~ cannot discriminate between two quantities having the same units (e.g. length of pendulum string, radius of pendulum bob).

12. Which of the following has different SI units from the other.
A stress x strain   B stress / strain
C potential energy per unit volume
D Moment of a force

13. The unit of strain are
Handwritten: $\varepsilon = \dfrac{\Delta L}{L} \rightarrow \dfrac{m}{m} = 1$
A mass / (length x time²)   B (length)⁻¹
C length   **D** no units

14. What is the **SI** base unit of pressure?
Handwritten: $P = \dfrac{F}{A} = \dfrac{ma}{A} = \dfrac{(kg)(ms^{-2})}{m^2} = kg\, m^{-1} s^{-2}$
A kg m s⁻²   B kg m² s⁻²
C kg m⁻¹ s⁻²   D kg m⁻² s⁻²

15. A sphere of radius '*r*' moving with a velocity '*V*' under steamline conditions in a viscous fluid experiences a retarding force, given by $F = KrV$, where '*K*' is constant. The units of '*K*' are
Handwritten: $K = \dfrac{F}{rV} = \dfrac{kg\, ms^{-2}}{(m)(ms^{-1})} = kg\, m^{-1} s^{-1}$
A kg m² s⁻¹   B kg s⁻¹ m⁻¹
C kg m⁻² s⁻²   D kg m s⁻²

16. which one of the following pairs of electrical units are the units **not** equivalent?
A J s⁻¹; W   B J C⁻¹; V
C A s⁻¹; C   D N c⁻¹; V m⁻¹

17. What is the ratio 1 µm / 1 Gm ?
Handwritten: $\dfrac{1 \times 10^{-6}}{1 \times 10^{9}} = 10^{-6-9} = 10^{-15}$
A 10⁻³   B 10⁻⁹   C 10⁻¹²   **D** 10⁻¹⁵

Note
For formulae see back side of this work sheet

Handwritten (bottom): $\dfrac{p^2}{m} = \dfrac{(mv)^2}{m} = \dfrac{m^2 v^2}{m} = m v^2 = \tfrac{1}{2} m v^2 = $ Kinetic energy

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Formulae

1. **Refractive index**: Refractive index = speed of light in vacuum or air ; $n = c / v$
speed of light in any medium

2. **Impulse**: Impulse = (Force)(time) = Change of momentum ; $F\Delta t = m(v - u)$

3. **Electric Potential**: Electric Potential = Work done / charge ; $V = W / Q$

4. **Electric field strength**: Electric field strength = Force / charge = P.d/ distance ; $E = F / Q = V / d$

5. **Strain**: Strain = extension / original length ; $\varepsilon = e / l$

6. **Stress**: Stress = force / cross-sectional Area ; $6 = F / A$

7. **Moment of a force**: Torque = (force)(perpendicular distance) ; $\tau = (F)(d)$

8. **Momentum**: Momentum = (mass)(velocity) ; $P = mv$

Answer grid:

Q.No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
Answer																	

Paper 2 (Structured theory) :

1. For each of the four concepts listed in the left hand column, place a tick by the correct example of that concept in the appropriate box. [4]

   Concept

   A **base** quantity   mole [ ]   length [✓]   kilogram [ ]

   A **base** unit   coulomb [ ]   ampere [✓]   volt [ ]

   A **scalar** quantity   torque [ ]   velocity [ ]   kinetic energy [✓]

   A **vector** quantity   mass [ ]   weight [✓]   density [ ]

2. Complete following table to show each quantity and its unit. [4]

quantity	unit
speed	m s^{-1}
density $\rho = \dfrac{m}{V}$	kg m^{-3}
frequency	s^{-1}
electric field strength	N C^{-1}, Vm^{-1}, kg m A^{-1} s^{-3}
momentum (m v)	kg m s^{-1}

$$f = \frac{1}{T}$$

$$E = \frac{F}{Q} \quad , \quad E = \frac{V}{d}$$

3. (a) With the aid of an example, explain the statement "The magnitude of a physical quantity is written as the product of a number and a unit".

   F = 80 N
   80 — numerical value obtained from Newton meter
   N — Unit to represent force. [2]

   (b) Explain why an equation must be homogeneous with respect to the units if it is to be correct.
   Only homogeneous equations can be subtracted, added or compared. [1]

   (c) Write down an equation which is homogeneous, but still incorrect.
   $S = Ut \boxed{-} \boxed{Vt} + \dfrac{7}{2} at^2$ [1]

CIE Questions on Physical Quantities and Units

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1. A cylindrical tube rolling down a slope of inclination θ moves a distance L in time T. The equation relating these quantities is

$$L \left(3 + \frac{a^2}{P}\right) = QT^2 \sin\theta$$

Where a is the internal radius of the tube and P and Q are constants.
Which line gives the correct units for P and Q?

	P	Q
A	m^2	$m^2 s^{-2}$
B	m^2	ms^{-2}
C	m^2	$m^3 s^{-2}$
D	m^3	ms^{-2}

{Q.4/Nov. 2011/9702/11}

2. Which pair of units are both SI base units?
A ampere, degree Celsius   **B** ampere, Kelvin
C coulomb, degree Celsius   D coulomb. Kelvin
{Q.1/Nov.2005,June 2002/9702-1}

3. The prefix 'centi' indicates x 10^{-2} Which line in the table correctly indicates the prefixes micro, nano and pico? 10^{-12} 10^{-6} 10^{-9}

	x 10^{-12}	x 10^{-9}	x 10^{-6}
A	nano	Micro	pico
B	nano	Pico	micro
C	pico	Nano	micro
D	pico	Micro	nano

{Q.2/Nov.2005, Nov 2002/9702-1}

4. Which quantity is measured in electronvolts (eV)?
A electric charge   B electric potential
C energy $V = \frac{W}{Q}$ D power
{Q.1/Nov. 2011/9702/12}
$QV = W \Rightarrow (1e)(v) = W$ ie energy ✓

5. Which group of quantities contains only vectors?
A acceleration, displacement, speed
B acceleration, work, electric field strength
C displacement, force, velocity
D power, electric field strength, force
{Q.1/Nov. 2011/9702/13}

6. To check calculations, the units are put into the following equations together with the numbers. Which equation must be **incorrect**?
A force = 300 J / 6 m   **B** power = 6000 J × 20 s
C time = 6 m / 30 m s^{-1} D velocity = 4 m s^{-2} × 30 s
{Q.1/June 2011/9702/11}

7. Which of the following definitions is correct and uses only quantities rather than units?
A Density is mass per cubic metre.
B Potential difference is energy per unit current.
C Pressure is force per unit area.
D Speed is distance travelled per second.
{Q.2/Nov.2004/9702-1}

8. When a beam of light is incident on a surface, it delivers energy to the surface. The intensity of the beam is defined as the energy delivered per unit area per unit time. What is the unit of intensity, expressed in SI base units?
A kg m^{-2} s^{-1} B kg m^2 s^{-3} C kg s^{-2} **D** kg s^{-3}
{Q.3/Nov.2004/9702-1}

9. Which of the following could be measured in the same units as force?
A energy / distance   B energy x distance
C energy / time   D momentum x distance
{Q.2/June.2004/9702-1}

10. The notation μs is used as an abbreviation for a certain unit of time.
What is the name and value of this unit?

	name	value
A	microsecond	10^{-6} s
B	microsecond	10^{-3} s
C	millisecond	10^{-6} s
D	millisecond	10^{-3} s

{Q.3/June.2004/9702-1}

11. A student measures a current as 0.5 A. Which of the following correctly expresses this result?
A 50mA   B 50MA   C 500mA   D 500MA
50×10^{-3} 50×10^{6} {Q.1/Nov.2003/9702-1}
$= 0.05A$ $50000000A$ $\frac{500}{1000} = 0.5A$

12. The momentum of an object of mass m is p. Which quantity has the same base units as p^2/m?
A energy   B force   C power   D velocity
{Q.3/Nov.2000/9702-1}

13. The unit of work, the joule, may be defined as the work done when the point of application of a force of 1 newton is moved a distance of 1 metre in the direction of the force. $W = (F)(d) = (ma)(d)$
Express the joule in terms of the base units of mass, length and time, the kg, m and s. $= (kg\,ms^{-2})(m)$ $= kg\,m^2 s^{-2}$
A kg m^{-1} s^2 **B** kg m^2 s^{-2}
C kg m^2 s^{-1} C kg s^{-2}
{Q.2/June.2003/9702-1}

14. Which formula could be correct for the speed v of ocean waves in terms of the density ρ of sea water, the acceleration of free fall g, the depth h of the ocean and the wave length λ.
A $v = \sqrt{g\lambda} = \sqrt{(ms^{-2})(m)} = \sqrt{(ms^{-1})} = ms^{-1}$ B $v = \sqrt{g/h} = \sqrt{\frac{ms^{-2}}{m}} = s^{-1}$
C $v = \sqrt{\rho gh} = \sqrt{(kg\,m^{-3})(ms^{-2})(m)} = \sqrt{kg\,m^{-1} s^{-2}} = kg^{\frac{1}{2}} m^{-\frac{1}{2}} s^{-1}$ D $v = \sqrt{g/\rho}$
{Q.3/June.2002/9702-1}

15. Which of the following is a base quantity with its correct S.I. unit?

	Quantity	Unit
A	Current ✓	A ✓
B	Mass ✓	G ✗ kg
C	Temperature ✓	°C ✗ K
D	weight ✗	N ✗

{Q.1/ Nov. 2001/8702-1}

16. Four physical quantities P, Q, R and S are related by the equation $P = Q - RS$. Which statement must be correct for the equation to be homogeneous?
A P, Q, R and S all have the same units ✗
B P, Q, R and S are all scalar quantities. ✗
C The product RS has the same units as P and Q.
D The product RS is numerically equal to (Q and P)
{Q.1/Nov. 1999/9243/1}

17. Show that   *Pressure = density* x (*speed*)^2 is homogeneous equation.   {Q.1 (b)//June 01/8702-2}

(2) Which of the following quantities do **not** carry any units?

sheet 1

A	Refractive Index n	Impulse
B	Electric potential	Electric field strength(E)
C	Strain(ε)	Power / Energy
(D)	Refractive Index	Strain

A	$n = \dfrac{\sin 1}{\sin 2} = 1$	$(F)(t) = (ma)(t)$ $= (kg\,ms^{-2})(s)$ $= kg\,m\,s^{-1}$
B	$V = \dfrac{W}{Q} = \dfrac{Fd}{It}$ $= \dfrac{(ma)(d)}{It}$ $= \dfrac{(kg\,ms^{-2})(m)}{(A)(s)}$ $= kg\,m^2 A^{-1} s^{-3}$	$E = \dfrac{F}{Q} = \dfrac{ma}{It}$ $= \dfrac{(kg)(ms^{-2})}{(A)(s)}$ $= kg\,m\,A^{-1} s^{-3}$
C	$\varepsilon = \dfrac{\Delta L}{L} = \dfrac{m}{m}$ $= 1$	$\dfrac{P}{E} = \dfrac{\frac{E}{t}}{E}$ $\dfrac{E}{t} \div E$ $\dfrac{E}{t} \times \dfrac{1}{E} = \dfrac{1}{t}$ $\dfrac{1}{s} = s^{-1}$
(D)	1	1

Q.4)

Sheet 1

$P = I^2 R$

$\dfrac{W}{t} = I^2 R \Rightarrow \dfrac{(F)(d)}{t} = I^2 R \Rightarrow \dfrac{(ma)(d)}{t} = I^2 R$

$R = \dfrac{mad}{I^2 t}$

$= \dfrac{(kg)(ms^{-2})(m)}{(A)^2(s)} = kg\,m^2 A^{-2} s^{-3}$

Q9) Intensity $= \dfrac{\frac{E}{A}}{t} = \dfrac{E}{At} = \dfrac{Fd}{At} = \dfrac{(ma)(d)}{At}$

sheet 1

$= \dfrac{(kg\,ms^{-2})(m)}{(m^2)(s)} = kg\,s^{-3}$

Which of the following has different SI units from the other.

A stress x strain   **B** stress / strain
C potential energy per unit volume
D Moment of a force

(A) $\left(\frac{F}{A}\right) \times \left(\frac{\Delta L}{L}\right) = \left(\frac{ma}{A}\right)\left(\frac{\Delta L}{L}\right) = \left(\frac{kg\,m\,s^{-2}}{m^2}\right)\left(\frac{m}{m}\right) = kg\,m^{-1}s^{-2}$

(B) $\frac{\frac{F}{A}}{\frac{\Delta L}{L}} = \left(\frac{F}{A}\right)\left(\frac{L}{\Delta L}\right) = kg\,m^{-1}s^{-2}$

(C) $\frac{mgh}{V} = \frac{(kg)(m\,s^{-2})(m)}{m^3} = kg\,m^{-1}s^{-2}$

(D) $(F)(d) = (ma)(d) = (kg\,m\,s^{-2})(m) = kg\,m^{2}s^{-2}$

$= kg\,m\cdot s$

which one of the following pairs of electrical units are the units **not** equivalent?

A J s⁻¹; W ✓   **B** J C⁻¹; V ✓
C A s⁻¹; C   **D** N C⁻¹; V m⁻¹ ✓

(A) Power: $P = \frac{W}{t}$

$W = \frac{J}{s}$

(C) $Q = It$

$C = (A)(s)$

(B) $V = \frac{W}{Q}$

$V = \frac{J}{C}$

(D) Electric field strength (E)

$E = \frac{F}{Q} = \frac{N}{C}$

Also $E = \frac{V}{d} = \frac{Volt}{metre}$

Q. 2

Sheet
page No.3

A cylindrical tube rolling down a slope of inclination θ moves a distance L in time T. The equation relating these quantities is

$$L\left(3 + \frac{a^2}{P}\right) = QT^2 \sin\theta$$

Where a is the internal radius of the tube and P and Q are constants.

$$3L + \frac{a^2 L}{P} = QT^2 \sin\theta$$

m

$$\frac{(m^2)(m)}{P = \boxed{m^2}}$$

$$\boxed{m\,s^{-2}}\,(s^2)$$

Q.7

Sheet 3

To check calculations, the units are put into the following equations together with the numbers. Which equation must be **incorrect**?

A force = 300 J / 6 m ✓   B power = 6000 J ⊗ 20 s ✓
C time = 6 m / 30 m s⁻¹   D velocity = 4 m s⁻² × 30 s ✓

{Q.1/June 2011/9702/11}

(A) $N = \dfrac{300\,Nm}{6\,m}$

✓
$N = 50\,N$ ✓

(c) $t = \dfrac{6\,m}{30\,m\,s^{-1}} = 0.20\,s$

(B) $P = \dfrac{W}{t}$

(D) $V = (4\,m\,s^{-2})(30\,s)$
$= 120\,m\,s^{-1}$

$Power = \dfrac{6000\,J}{20\,s}$ ✓

The momentum of an object of mass m is p. Which quantity has tehsame base units as p^2/m?

A enrgy   **B** force   **C** power   **D** velocity

{Q.3/Nov.2000/9702-1}

$$\frac{p^2}{m} = \frac{(mv)^2}{m} = \frac{m^2 v^2}{m} = mv^2$$

$$= \frac{1}{2}mv^2 \text{ (Energy)}$$

Show that   *Pressure = density* x *(speed)²*   is homogeneous equation.   *{Q.1 (b)//June 01/8702-2}*

L.H.S: Pressure : $P = \dfrac{F}{A} = \dfrac{ma}{A} = \dfrac{(kg)(ms^{-2})}{m^2}$

$$= kg \, m^{-1} s^{-2} \quad\quad\quad (1)$$

R.H.S: $\rho v^2 = \left(\dfrac{m}{V}\right)(v^2) = \left(\dfrac{kg}{m^3}\right)(m s^{-1})^2$

$$= \left(\dfrac{kg}{m^3}\right)(m^2 s^{-2}) = kg \, m^{-1} s^{-2} \quad\quad\quad (2)$$

Estimations and Approximations :-

(1) Diameter of a nucleus $= 10^{-14}$ m or 10^{-15} m

(2) Diameter of an atom $= 10^{-10}$ m

(3) Diameter of an Alpha particle $= 10^{-14}$ m

(4) Unified atomic mass unit $= u =$ mass of $\frac{1}{12}g$ of C-12 isotope
(i.e average mass of a nucleons)

$$= 1.66 \times 10^{-27} \text{ kg}$$

(5) Mass of an Alpha particle (Helium nucleus - $^4_2 He$)

$$= 4u$$
$$= 4(1.66 \times 10^{-27}) = 6.64 \times 10^{-27} \text{ kg}$$

(6) Speed of sound at $0°c$ in

air $\longrightarrow$ 330 ms^{-1}

water $\longrightarrow$ 1500 ms^{-1}

Concrete $\longrightarrow$ 5000 ms^{-1}

Steel $\longrightarrow$ 6000 ms^{-1}

(7) Speed of electromagnetic (em) waves in air or vacuum : $c = 3.00 \times 10^8 \text{ ms}^{-1}$

(8) Electromagnetic spectrum

order	Gamma ray	X-Rays	U.V.	visible light	Infra-red	Micro waves	Radio waves
f / Hz	10^{20}	10^{18}	10^{16}	10^{14}	10^{12}	10^{10}	10^{8}
λ / m	10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-4}	10^{-2}	$10^{0} = 1$

(9) <u>Visible spectrum</u>:

order	V	I	B	G	Y	O	R
λ/nm	400	450	500	550	600	650	700

$$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8}{500 \times 10^{-9}}$$

$$= \underline{\qquad} \ s^{-1}$$

(10) Mass of an apple: $m = 120$ to 180 g

(11) Density of air at s.t.p: $\rho = 0.5$ to 1.5 g cm^{-3}

(12) Normal human body temperature $= 36.9°c$

$\approx 37°c$ or 310K

(13) Mass of an Adult person: $m = 55$ kg to 90 kg

(14) Density of water : $\rho = 1000$ kg m^3

(15) Specific heat capacity of water: $c = 4200$ Jkg^{-1}k^{-1}

or $c = 4000$ Jkg^{-1}k^{-1}

(16) Energy required to heat water in a kettle to its boiling point.

$$Q = mc(\theta_2 - \theta_1)$$

$$= (1)(4200)(100 - 25)$$

$$= 315000 \ J$$

(17) Audible frequency range: 20Hz to 20,000Hz

(18) Time taken to complete a 100m race.
$$t = 10s$$

(19) Kinetic energy required to run a 100m race: $E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{d}{t}\right)^2$

$$E_K = \frac{1}{2}(80)\left(\frac{100}{10}\right)^2$$

$$= 4000 J$$

(20) Pressure due to 10m depth of water
$$P = h\rho g$$
$$= (10)(1000)(10) = 1.0 \times 10^5 \text{ Pa}$$

(21) No. of Joules of energy in 1 kWh
$$= (1)(1000)(W)(60 \times 60 s)$$
$$= 3.6 \times 10^6 \text{ Ws}$$
$$= 3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ}$$

(22) Electron volt (eV) is the unit of energy.
$$V = \frac{W}{Q}$$

$$QV = W$$
$$(1e)(1V) = (1.60 \times 10^{-19}) \text{ J}$$
$$\boxed{1eV = 1.60 \times 10^{-19} J}$$

(23) Frequency of AC for Domestic appliance:

$$f = 50 \, Hz$$

(24) Operating voltage of Domestic appliance

$$V = 220V \text{ to } 240V$$

(25) Power of Domestic filament lamp

$$P = 25W \text{ to } 1000W$$

(26) Resistance of Domestic filament lamp

$$P = \frac{V^2}{R} \Rightarrow 60 = \frac{(220)^2}{R}$$

$$R = 800 \, \Omega$$

(27) Volume of head of an adult person:

$$d = \frac{x+y}{2}$$

$$V_{sphere} = \frac{4}{3} \pi r^3$$

$$r = \frac{d}{2}$$
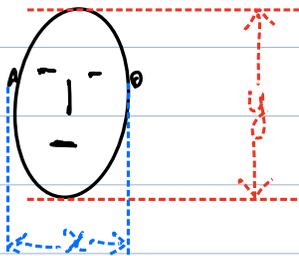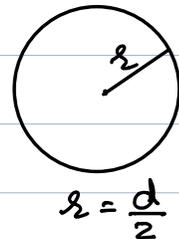
$$V_{Head} = \frac{V_{sphere}}{2}$$

Measurements and Errors:-

Reading : Single determination taken directly from a measuring device.

Measurement := Reading 1 ⟷ (Arithmetic operation $+, -, \times, \div$) ⟷ Reading 2

$$T = \frac{t}{20} =$$

12.0 cm

measurew

0   20.0cm

20.0 ~ 0
= 20.0 cm
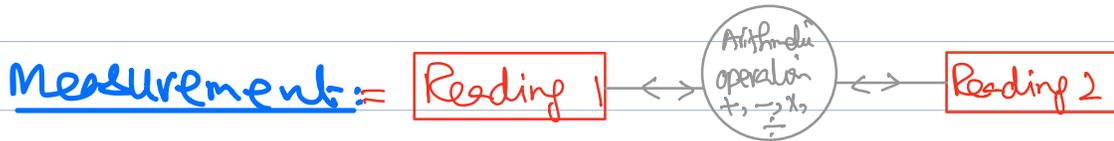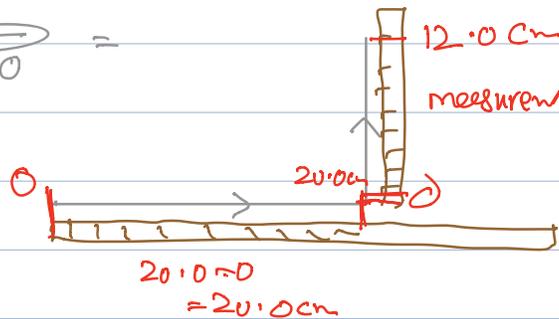
$$20.0 + 12.0 = 32.0 \text{ Cm.}$$

Types of Errors:

(a) Systematic error ⟶ Observer
                      ⟶ Apparatus

(b) Random error ⟶ technique or enviroment

(c) Absolute error / uncertainty ⟶ Measuring device

(d) Fractional error
                  ⟶ Percentage error ⟶ to evaluate accuracy.

(e) Arithmetic errors
            ⟶ +, -, ×, ÷

(f) Power rule error.

(a) <u>**Systematic error:**</u>

<u>Characteristic:</u> Constant sign and magnitude

<u>Sources</u> :(i) <u>Observer</u>

→ Weak eye sight
→ Weak persistence of vision
→ Colour blindness
→ Human reaction time error
       (0.2s to 0.4s)
→ Lack of knowledge

4V   E   B 8V

2V ✓

4V   E   B 8V

4V ✓
2V ✗
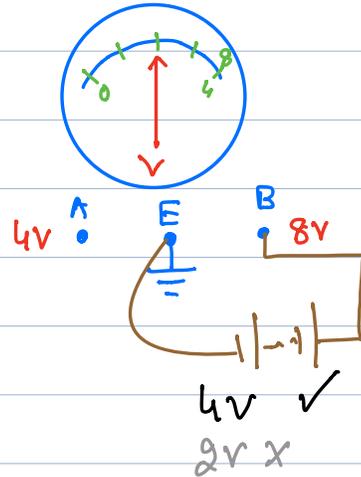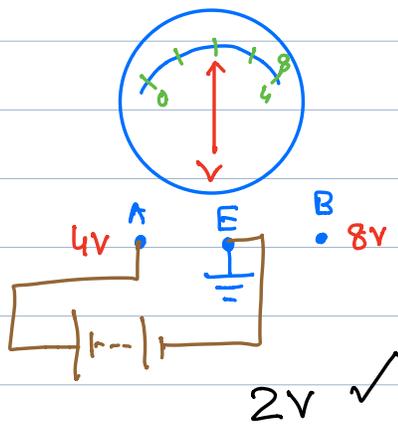
(ii) <u>Instrument</u>:-

→ Zero error
→ A watch which runs fast or slow and show 5 minutes greater or lesser time in 24 hours

<u>Method to (eliminate) Systematic error:-</u>

$V = V_2 - V_1$

(1) Subtract two values/readings with systematic error or get the gradient of graph.

Zero error of voltmeter

$$R = gradient = \frac{V_2 - V_1}{I_2 - I_1}$$
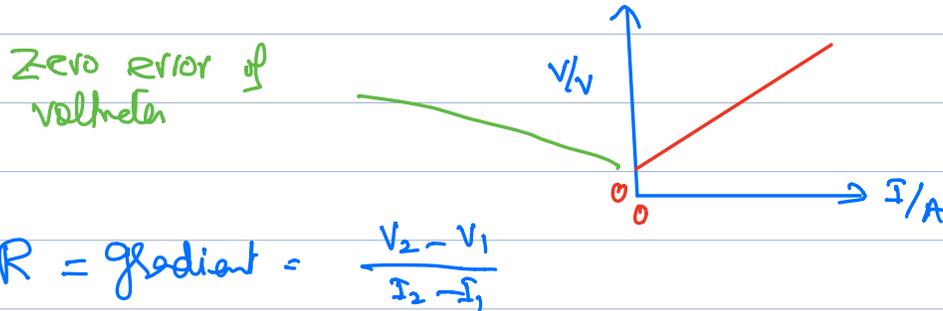
(2) Measure zero error and make use of zero correction technique.

(b) **Random error:-**
Characteristics: Variable sign and magnitude
Examples:

(i) Parallax error.

A 4.9cm
B 5.0cm
C 5.1cm
D 5.2cm

(ii) Fluctuation in the least significant digit of digital measuring devices.

fan

2.45 kg

2.44 —
2.45 kg
2.46 —

(iii) Change in the environmental factors during experiment

(iv) pivot friction in analogue measuring device.

(v) Background radiation.

Methods to (reduce) random error:-

(1) Take greater no. of readings and get their average or draw line of best fit.

(2) Avoid parallax error.

Q1)
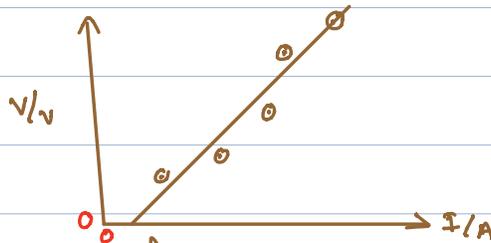
which feature of graph represent the existance of

i) Systematic error ⟶ x-intercept shows zero error in Ammeter

(ii) Random error ⟶ Scattering of plots about the line.

Q.2) Which technique is used to reduce random error using micrometer screw gauge in

measuring diameter of a

(i) Uniform wire: Measure several diameters along the length of wire and get their mean. $\langle d \rangle = \dfrac{d_1 + d_2 + d_3}{3}$

(ii) non-uniform wire:

Measure several diameters at the same position by rotating the wire and get their average.

(C) Absolute error / uncertainty :-

Def. It is the half of smallest graduation on a measuring device.

Notation: $\pm \Delta$ (error's value)

Note: Absolute error must be in 1 s.f.

Example:
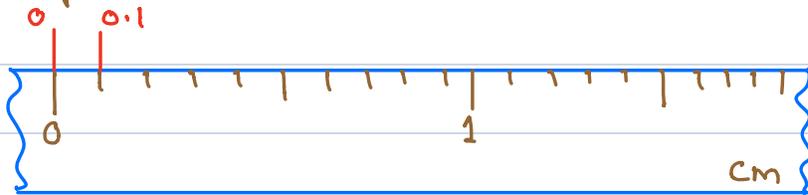
Absolute error $= \dfrac{0.1 \sim 0}{2} = \pm 0.05 \, cm$

Representation of a value along with absolute error :-

Notation :-

Physical Qty = Value in same no. of d.p as in absolute error $\pm$ Absolute error in 1 s.f.

$R_1 = 0 \pm 0.05 \text{ cm}$ $L = ?$ $R_2 = 1.4 \pm 0.05 \text{ cm}$
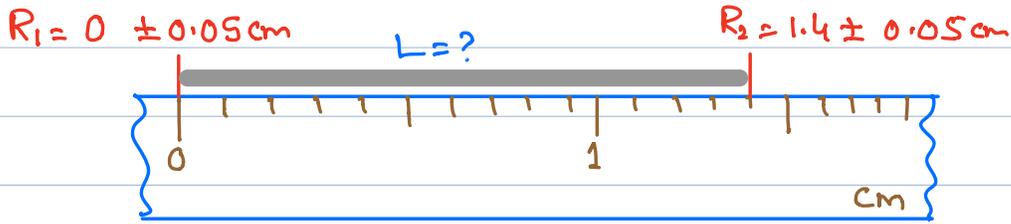
$$L = (1.4 - 0) \pm (0.05 + 0.05)$$
$$L = 1.4 \pm 0.1 \text{ cm}$$

Direct method) → Absolute error in CASE of a <u>measuring device</u> is its smallest graduation.

Example.

S.No	Device	Smallest graduation	Absolute error
1.	Metre rule	0.1 cm	± 0.1 cm
2.	Vernier Caliper	0.01 cm	± 0.01 cm or ± 0.1 mm
3.	Micrometer Screw Gauge	0.01 mm	± 0.01 mm
4.	Thermometer	$0.5 \,^{\circ}C$	$\pm 0.5 \,^{\circ}C$
5.	Protector	1°	1°
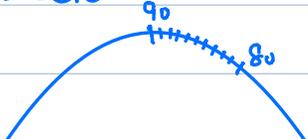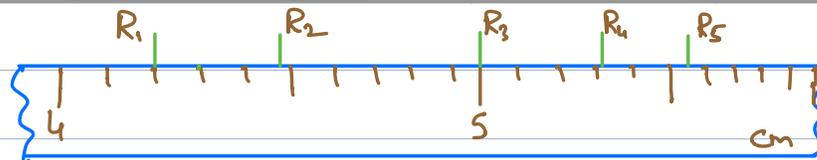
Example:

$R_1 = 4.2 \pm 0.1 \text{ cm}$, $R_3 = 5.0 \pm 0.1 \text{ cm}$
$R_2 = 4.5 \pm 0.1 \text{ cm}$, $R_4 = 4.3 \pm 0.1 \text{ cm}$
$R_5 = 5.6 \pm 0.1 \text{ cm}$

Mathematical errors:-

(a) Fractional errors:

Formula: Fractional error $= \dfrac{\text{Absolute error}}{\text{Value}}$

Example: $L = 20.4 \pm 0.1\,cm$

Fractional error in length: $\dfrac{\Delta L}{L} = \dfrac{0.1}{20.4} =$

(a) Percentage errors:

Formula: Percentage error $= \dfrac{\text{Absolute error}}{\text{Value}} \times 100$

Example: $L = 20.4 \pm 0.1\,cm$

Percentage error in length: $\dfrac{\Delta L}{L} \times 100 = \left(\dfrac{0.1}{20.4}\right) 100$

$$= \quad \%$$

Note: Percentage error is a measure of degree of accuracy ie smaller the %age error, higher is the accuracy.

(C) Arithmetic errors:-

(i) Addition:-

Formula: Addition $= \left(\begin{array}{c}\text{Sum of}\\\text{values}\end{array}\right) \pm \left(\begin{array}{c}\text{Sum of absolute}\\\text{errors}\end{array}\right)$

Example: $L_1 = 12.4 \pm 0.1\,cm$

$L_2 = 30.6 \pm 0.2\,cm$

$L = (L_1 + L_2) \pm (\Delta L_1 + \Delta L_2)$

$$L = (12.4 + 30.6) \pm (0.1 + 0.2)$$

$$L = 43.0 \pm 0.3 \text{ cm}$$

(ii) Subtraction :-

Formula : Subtraction = $\left(\begin{array}{c}\text{Difference of} \\ \text{values}\end{array}\right) \pm \left(\begin{array}{c}\text{Sum of absolute} \\ \text{errors}\end{array}\right)$

Example : $L_1 = 12.4 \pm 0.1 \text{ cm}$

$L_2 = 30.6 \pm 0.2 \text{ cm}$

Calculate $(L_2 - L_1)$ along with its absolute error.

$$L = (L_2 - L_1) \pm (\Delta L_2 + \Delta L_1)$$

$$L = (30.6 - 12.4) \pm (0.2 + 0.1)$$

$$L = 18.2 \pm 0.3 \text{ cm}$$

(iii) Multiplication :-

Formula : Multiplication = $\left(\begin{array}{c}\text{Product of} \\ \text{values}\end{array}\right) \pm \left(\begin{array}{c}\text{Sum of fractional} \\ \text{error of each} \\ \text{quantity}\end{array}\right)\left(\begin{array}{c}\text{Product of} \\ \text{values}\end{array}\right)$

Example : If $V = 2.8 \pm 0.2 \text{V}$

$I = 3.1 \pm 0.1 \text{A}$

Calculate Power $(P = VI)$ along with its error.

$$P = VI \pm \left(\frac{\Delta V}{V} + \frac{\Delta I}{I}\right)(VI)$$

$$P = (2.8)(3.1) \pm \left(\frac{0.2}{2.8} + \frac{0.1}{3.1}\right)(2.8 \times 3.1)$$

$$P = 8.68 \pm 0.9 \text{ W}$$

Value must have same no. of d.p. as we have in absolute error.

$$P = 8.7 \pm 0.9 \text{ W}$$

(iv) Division:-

Formula: Division $= \begin{pmatrix} \text{Ratio of} \\ \text{values} \end{pmatrix} \pm \begin{pmatrix} \text{Sum of fractional} \\ \text{error of each} \\ \text{quantity} \end{pmatrix} \begin{pmatrix} \text{Ratio of} \\ \text{values} \end{pmatrix}$

Example: If $V = 2.8 \pm 0.2 V$

$I = 3.1 \pm 0.1 A$

Calculate Resistance $(R = \frac{V}{I})$ along with its error.

$$R = \frac{V}{I} \pm \left(\frac{\Delta V}{V} + \frac{\Delta I}{I} \right) \left(\frac{V}{I} \right)$$

$$R = \frac{2.8}{3.1} \pm \left(\frac{0.2}{2.8} + \frac{0.1}{3.1} \right) \left(\frac{2.8}{3.1} \right)$$

$$R = 0.903 \pm 0.094 \, \Omega$$

But Absolute error must be true in 1 s.f. and Value must have same no. of d.p. as we have in absolute error.

$$R = 0.90 \pm 0.09 \, \Omega$$

Power rule errors:

(1) If $x = a^m$

Formula: Fractional error in x: $\frac{\Delta x}{x} = m \left(\frac{\Delta a}{a} \right)$

Example: If Length of a cube

$$L = 2.5 \pm 0.1 \, cm$$

Calculate Fractional error in volume.

$V = L^3$	$V = (L)(L)(L)$
$\frac{\Delta V}{V} = 3 \left(\frac{\Delta L}{L} \right) = 3 \left(\frac{0.1}{2.5} \right)$	$\frac{\Delta V}{V} = \frac{\Delta L}{L} + \frac{\Delta L}{\Delta L} + \frac{\Delta L}{L} = 3 \left(\frac{\Delta L}{L} \right)$
$= 0.12$	$\frac{\Delta V}{V} = 0.12$

Q)

$$L = 12.4 \pm 0.1 \, cm$$

$$k = 3.6 \pm 0.2 \, cm \, s^{-2}$$

$$T = \sqrt{\frac{L}{k}} \quad \Rightarrow \quad T = \left(\frac{L}{k}\right)^{1/2}$$

(a) Calculate

i) Value of T

$$T = \sqrt{\frac{12.4}{3.6}} = 1.86 \, s$$

ii) Fractional error in T

$$\frac{\Delta T}{T} = \frac{1}{2}\left[\frac{\Delta\left(\frac{L}{k}\right)}{\frac{L}{k}}\right] = \frac{1}{2}\left[\frac{\Delta L}{L} + \frac{\Delta k}{k}\right]$$

$$\frac{\Delta T}{T} = \frac{1}{2}\left[\frac{0.1}{12.4} + \frac{0.2}{3.6}\right] = 0.032$$

(iii) Absolute error in T

$$\frac{\Delta T}{T} = 0.032 \Rightarrow \frac{\Delta T}{1.86} = 0.032 \Rightarrow \Delta T = 0.05958$$

(b) Express value of T along with its absolute error.

$$T = 1.86 \pm 0.06 \, s$$

(2) If $x = a^m \, b^n$

Formula: Fractional error in x:

$$\frac{\Delta x}{x} = m\left(\frac{\Delta a}{a}\right) + n\left(\frac{\Delta b}{b}\right)$$

Example: If $I = 4.2 \pm 0.2 A$

$$R = 10.2 \pm 0.1 \, \Omega$$

Calculate

i) Electrical Power $P = I^2 R$

$$P = (4.2)^2 (10.2)$$
$$= 180W$$

(ii) Fractional error in Power

$$\frac{\Delta P}{P} = 2\left(\frac{\Delta I}{I}\right) + 1\left(\frac{\Delta R}{R}\right)$$

$$= 2\left(\frac{0.2}{4.2}\right) + \left(\frac{0.1}{10.2}\right) = 0.105$$

(iii) Absolute error in Power

$$\frac{\Delta P}{P} = 0.105 \implies \frac{\Delta P}{180} = 0.105$$

$$\Delta P = 18.9W$$

(iv) Express value of Power along with its absolute error.

$$P = 180 \pm 20W$$

{ Absolute error must be in 1sf, so 18.9W is
  1sf = 20W

---

(3) If $x = \dfrac{a^m}{b^n}$

Formula: Fractional error in x:

$$\frac{\Delta x}{x} = m\left(\frac{\Delta a}{a}\right) + n\left(\frac{\Delta b}{b}\right)$$

Example: If $V = 4.2 \pm 0.2 V$
$$R = 10.2 \pm 0.1 \Omega$$

Calculate

(i) Electrical Power $P = \dfrac{V^2}{R}$

$$P = \frac{(4.2)^2}{10.2} = 1.73W$$

(ii) Fractional error in Power

$$\frac{\Delta P}{P} = 2\left(\frac{\Delta V}{V}\right) + \frac{\Delta R}{R}$$

$$\frac{\Delta P}{P} = 2\left(\frac{0.2}{4.2}\right) + \frac{0.1}{10.2}$$

$$= 0.105$$

(ii) Absolute error in Power

$$\frac{\Delta P}{P} = 0.105 \Rightarrow \frac{\Delta P}{1.73} = 0.105$$

$$\Delta P = 0.182 \, W$$

(iv) Express value of Power along with its absolute error.

$$P = 1.7 \pm 0.2 \, W$$

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1. When asked to determine the resistance R of a given conductor from 6 sets of voltage V and current I readings, student **A** plotted V against I and obtained the gradient of the plot while student **B** found R by averaging 6 sets of (V, I) readings. Which of the following statements is **correct**?

(A) Procedure taken by student **A** will only reduce random errors computed for R.

(B) Procedure taken by student **B** will only reduce the systematic errors in finding R. *(random)*

(C) Procedure taken by student **A** reduces both systematic and random errors.

(D) Procedure taken by student **B** is basically the same in effect as taken by student A.

2. Which of the following experimental techniques reduces the systematic error of the quantity being investigated?

(A) timing a large number of oscillations to find a period *(random error) ↓*

(B) measuring several antinodal distances on a standing wave to find the mean internodal distance. *(random error) ↓*
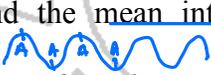
(C) measuring the diameter of a wire repeatedly and calculating the average. *(random error) ↓*

(D) Adjusting an ammeter to remove its zero error before measuring a current. *(Systematic error) ↓*

3. When comparing *systematic* and *random* errors, the following pairs of properties of errors in an experimental measurement may be considered:

P_1 : error can possibly be eliminated *(Systematic)*

P_2 : error cannot possibly be eliminated *(Random)*

Q_1 : error is of constant sign and magnitude *(Systematic)*

Q_2 : error is of varying sign and magnitude *(random)*

R_1 : error will be reduced by averaging repeated measurements *(Random)*

R_2 : error will not be reduced by averaging repeated measurements. *(Systematic)*

Which properties apply to **random** errors?

(A) P_1 , Q_1 , R_2 (B) P_1 , Q_2 , R_2

(C) P_2 , Q_2 , R_1 (D) P_2 , Q_1 , R_1

4. Which experimental technique reduces the systematic error of the quantity being investigated?

(A) adjusting an ammeter to remove its zero error before measuring a current *(systematic)*

(B) measuring several internodal distances on a standing wave to find the mean internodal distance *(random)*

(C) measuring the diameter of a wire repeatedly and calculating the average *(random)*

(D) timing a large number of oscillations to find a period *(random)*

5. A micrometer screw gauge is used to measure the diameter of a copper wire. The reading with the wire in position is shown in diagram 1. The wire is removed and the jaws of the micrometer are

closed. The new reading is shown in diagram 2

Diagram 1

Sleeve scale — 0 — 2.5mm
Thimble scale — 15 — 10 — 9 — 5
9 × 0.01 = 0.09
2.5 + 0.09 = 2.59mm

Diagram 2

0 — 20 — 15 — 14 — 10
14 × 0.01 = + 0.14mm
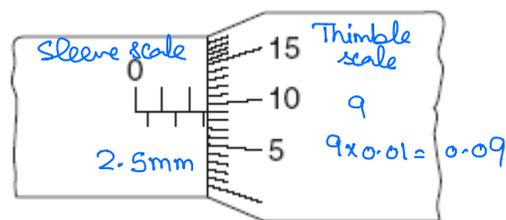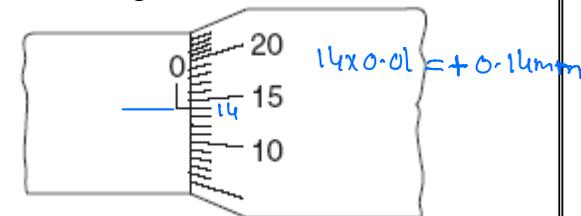
diameter = 2.59 ~ 0.14 = 2.45mm

What is the diameter of the wire?

(A) 1.90mm   (B) 2.45mm

(C) 2.59mm   (D) 2.73mm

6. Which of the following recorded measurements of a physical quantity has the greatest percentage uncertainty?

$\frac{1}{243} \times 100 =$ %
$\frac{0.2}{76.4} \times 100 =$

(A) (243 ± 1) g   (B) (76.4 ± 0.2) mm

(C) (22.43 ± 0.01) s   *$\frac{0.01}{22.43} \times 100 =$ %*

(D) (36.4 ± 0.5) mA   *$\frac{0.5}{36.4} \times 100 = 1.37\%$*

7. The resistance of an unknown resistor can be found by formula $R = V/I$.

The voltmeter reading has a 3 % uncertainty and the ammeter has a 2% uncertainty.

What is the uncertainty in the calculated resistance?

(A) 1.5%   (B) 5 %   (C) 3%   (D) 6%

8. A thermometer can be read to an accuracy of $\pm$ 0.5 °C. This thermometer is used to measure a temperature rise from 40 °C to 100 °C.

What is the percentage uncertainty in the measurement of temperature rise?

(A) 0.5%   (B) 0.8%   (C) 1.3%   (D) 1.7%

9. In an experiment, the length and breadth of a rectangular card was found to be (64 ± 2) mm and (47 ± 1) mm respectively.

The uncertainty in the **area is at most**

(A) 75 mm^2 (B) 150 mm^2

(C) 100 mm^2 (D) 200 mm^2

10. An experiment is done to measure the resistance of a wire.

The current in the wire is 1.0 ± 0.2 A and the potential difference across the wire is 8.0 ± 0.4 V.

What is the resistance of the wire and its uncertainty?

(A) (8.0 ± 0.2) Ω

(B) (8.0 ± 0.6) Ω

(C) (8 ± 1) Ω

(D) (8 ± 2) Ω

11. The dimensions of a cube are measured with vernier calipers.
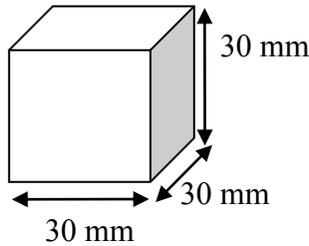
30 mm
30 mm
30 mm

The measured length of each side is 30 mm. If the vernier calipers can be read with an uncertainty of ± 0.1 mm, what does this give for the approximate uncertainty in the value of its volume?

(A) 1/27 % (B) 0.3 % (C) 1/3 % **(D)** 1%

12. The diameter, height and mass of a given cylinder are found to be $(3.6 ± 0.1)$ cm, $(2.8 ± 0.1)$ cm and $(56 ± 1)$g respectively. The density of the cylinder can be quoted as

(A) $(1.97 ± 0.22)$ g cm^{-3}
(B) $(1.9 ± 0.2)$ g cm^{-3}
(C) $(2.00 ± 0.22)$ g cm^{-3}
(D) $(2.0 ± 0.2)$ g cm^{-3}

13. In an experiment, a radio-controlled car takes $2.50 ± 0.05$ s to travel $40.0 ± 0.1$ m. $v = \frac{d}{t} \pm \left[\frac{\Delta d}{d} + \frac{\Delta t}{t}\right]\left[\frac{d}{t}\right]$
What is the car's average speed and the uncertainty in this value? $v = \frac{40.0}{2.50} \pm \left[\frac{0.1}{40} + \frac{0.05}{2.50}\right]\left[\frac{40.0}{2.50}\right]$

(A) $16 ± 1$ m s^{-1} (B) $16.0 ± 0.2$ m s^{-1}
(C) $16.0 ± 0.4$ m s^{-1} (D) $16.00 ± 0.36$ m s^{-1}

$v = 16.0 ± 0.36$ m s^{-1}
$v = 16.0 ± 0.4$ m s^{-1}

14. In a simple electrical circuit, the current in a resistor is measured as $(2.50 ± 0.05)$ mA. The resistor is marked as having a value of $4.7\ \Omega ±$ 2%. $\frac{\Delta R}{R} \times 100 = 2\%$ $P = I^2 R$ $\frac{\Delta P}{P} \times 100 = 2\left(\frac{\Delta I}{I}\right)100 + \left(\frac{\Delta R}{R}\right)100$
If these values were used to calculate the power dissipated in the resistor, what would be the percentage uncertainty in the value obtained?

(A) 2 % (B) 4 % **(C)** 6 % (D) 8 %
$= 2\left(\frac{0.05}{2.50}\right) + 2\% = 4\% + 2\% = 6\%$

15. A student makes measurements from which she calculates the speed of sound as 327.66 ms^{-1}. She estimates that her result is accurate to ±3 %. $\frac{\Delta v}{v} \times 100 = 3\%$
Which of the following gives her result expressed to the appropriate number of significant figures? $\frac{\Delta v}{v} = \frac{3}{100} \Rightarrow \frac{\Delta v}{327.66} = \frac{3}{100}$

(A) 327.7 ms^{-1} (B) 328 ms^{-1}
(C) 330 ms^{-1} (D) 300 ms^{-1}
$\Delta v = 9.8$ ms^{-1}
in 1.8.f, $\Delta v = 10$
So 327.66 ms^{-1} to the nearest 10
$v = 330$ ms^{-1}

16. The power loss P in a resistor is calculated
Using the formula $\frac{\Delta P}{P} \times 100 = 2\left(\frac{\Delta v}{v}\right)100 + \left(\frac{\Delta R}{R}\right)100$
$\frac{\Delta v}{v} \times 100 = 3\%$ $P = V^2/R$. $= 2(3\%) + 2\%$
$\frac{\Delta R}{R} \times 100 = 2\%$ $= 8\%$
The uncertainty in the potential difference V is 3% and the uncertainty in the resistances R is 2%. What is the uncertainty in P?

(A) 4% (B) 7% **(C)** 8% (D) 11%

17. The following are the readings of a travelling microscope when the cross-wires are aligned at opposite ends of a diameter of a capillary bore.
Next pages
$R_1 = (21.14 ± 0.01)$ cm
$R_2 = (20.98 ± 0.01)$ cm
What is the maximum percentage uncertainty in the area of the cross-section of the capillary bore?
(A) 13 %   (B) 25 %
(C) 18 %   (D) 29 %

18. Using a micrometer, the diameter of apiece of wire was found to be $(0.15 ± 0.01)$ mm. The area of cross-section of the wire may be quoted as
(A) $0.01767 ± 0.00236$ mm^2 3sf
(B) $0.0176714 ± 0.002356$ mm^2 4sf
(C) $(1.76 ± 0.24) \times 10^{-2}$ mm^2 2sf
(D) $(0.018 ± 0.002)$ mm^2 1sf

19. The wall thickness of a cylindrical glass tube is determined by measuring its external and internal diameters with the help of vernier calipers. If the readings obtained are $(27.23 ± 0.01)$ cm and $(24.15 ± 0.01)$ cm respectively, the wall thickness of the glass tubing is
(A) $3.08 ± 0.02$ cm   (B) $1.54 ± 0.02$ cm
(C) $3.08 ± 0.01$ cm   (D) $1.54 ± 0.01$ cm

20. A student finds the density of liquid by measuring its mass and its volume. The following is a summary of his measurements. $m_\ell = (70 - 20) ± (1 + 1)$
Mass of empty beaker $= (20 ± 1)$ g $= 50 ± 2$ g
Mass of empty beaker + liquid $= (70 ± 1)$ g
Volume of liquid $= (10.0 ± 0.6)$ cm^3
He correctly calculates the density of the liquid as 5.0 g cm^{-3}. $\frac{\Delta \rho}{\rho} = \frac{\Delta m}{m} + \frac{\Delta v}{v} \Rightarrow \frac{\Delta \rho}{5.0} = \frac{2}{50} + \frac{0.6}{10}$
What is the uncertainty in this value?
(A) 0.3 g cm^{-3} **(B)** 0.5 g cm^{-3} $\Delta \rho = 0.5$
(C) 0.6 g cm^{-3} (D) 2.6 g cm^{-3}

21. A student uses a metre rule to measure the length of an elastic band before and after stretching it. The lengths are recorded as
band before stretching, $L_o = 50.0 ± 0.1$ cm
band after stretching, $L_s = 51.6 ± 0.1$ cm.
Determine
(a) the change in length $(L_s - L_o)$, quoting your answer with its uncertainty,
$L_s - L_o = (51.6 - 50.0) ± (0.1 + 0.1)$
$(L_s - L_o) = \underline{1.6 ± 0.2}$ cm **[1]**

(b) the fractional change in length, $\frac{(L_s - L_o)}{L_o}$
$\frac{L_s - L_o}{L_o} = \frac{1.6}{50.0} = 0.032$
fractional change = ……………. **[1]**

(c) the uncertainty in your answer in **(b)**. $\Delta\left(\frac{L_s - L_o}{L_o}\right) = ?$
$\frac{\Delta\left(\frac{L_s - L_o}{L_o}\right)}{\frac{L_s - L_o}{L_o}} = \frac{\Delta(L_s - L_o)}{L_s - L_o} + \frac{\Delta L_o}{L_o}$

$\frac{\Delta\left(\frac{L_s - L_o}{L_o}\right)}{0.032} = \frac{0.2}{1.6} + \frac{0.1}{50}$

$\Delta\left(\frac{L_s - L_o}{L_o}\right) = 0.004$

uncertainty = ………………… **[3]**

Q.7) The resistance of an unknown resistor can be found by formula **R=V/I**.

$\frac{\Delta V}{V} \times 100 = 3\%$ The voltmeter reading has a 3 % uncertainty and the ammeter has a 2% uncertainty.

$\frac{\Delta I}{I} \times 100 = 2\%$ What is the uncertainty in the calculated resistance?

(A) 1.5%   (B) 5 %   (C) 3%   (D) 6%

$$R = \frac{V}{I}$$

$$\frac{\Delta R}{R} \times 100 = \left(\frac{\Delta V}{V}\right)100 + \left(\frac{\Delta I}{I}\right)100$$

$$= 3\% + 2\%$$

$$= 5\%$$

Q.8) A thermometer can be read to an accuracy of ± 0.5 °C. This thermometer is used to measure a

$\Delta \theta = \pm 0.5 \, \overset{\circ}{C}$ temperature rise from 40 °C to 100 °C. What is the percentage uncertainty in the measurement of temperature rise?

(A) 0.5%   (B) 0.8%   (C) 1.3%   (D) 1.7%

$$\theta_1 = 40.0 \pm 0.5 \, \overset{\circ}{C}$$

$$\theta_2 = 100.0 \pm 0.5 \, \overset{\circ}{C}$$

$$\theta = (100.0 - 40.0) \pm (0.5 + 0.5)$$

$$= 60 \pm 1 \, \overset{\circ}{C}$$

$$\frac{\Delta \theta}{\theta} \times 100 = \frac{1}{60} \times 100 = 1.7\%$$

Q.9) In an experiment, the length and breadth of a rectangular card was found to be L= (64 ± 2) mm and B= (47 ± 1) mm respectively.

The <u>uncertainty</u> in the **area is at most**

(A) 75 mm²   (B) 150 mm²
(C) 100 mm²   (D) 200 mm²

$$A = (L)(B)$$

$$\frac{\Delta A}{A} = \frac{\Delta L}{L} + \frac{\Delta B}{B}$$

$$\frac{\Delta A}{(64)(47)} = \frac{2}{64} + \frac{1}{47}$$

$$\Delta A = 158$$

But ΔA <u>must</u> be in 1 s.f.

Q.10)

An experiment is done to measure the resistance of a wire.

$I =$

The current in the wire is 1.0 ± 0.2 A and the potential difference across the wire is 8.0 ± 0.4 V $= V$

What is the resistance of the wire and its uncertainty?

(A) $(8.0 \pm 0.2)\ \Omega$
(B) $(8.0 \pm 0.6)\ \Omega$
(C) $(8 \pm 1)\ \Omega$
(D) $(8 \pm 2)\ \Omega$ ✓

$R = \dfrac{V}{I}$

$R = \dfrac{V}{I} \pm \left(\dfrac{\Delta V}{V} + \dfrac{\Delta I}{I} \right)\left(\dfrac{V}{I} \right)$

$R = \dfrac{8.0}{1.0} \pm \left(\dfrac{0.4}{8.0} + \dfrac{0.2}{1.0} \right)\left(\dfrac{8.0}{1.0} \right)$

$= 8.0 \pm 2\ \Omega$

$R = 8 \pm 2\ \Omega$

Q. 11)

The dimensions of a cube are measured with vernier calipers.
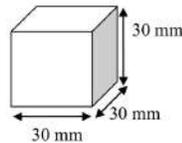
30 mm
30 mm
30 mm

The measured length of each side is 30 mm. If the vernier calipers can be read with an uncertainty of ± 0.1 mm, what does this give for the approximate uncertainty in the value of its volume?

(A) 1/27 %   (B) 0.3 %   (C) 1/3 %   (D) 1% ✓

$L = 30.0 \pm 0.1\ mm$

$V = L^3$

$\dfrac{\Delta V}{V} \times 100 = 3\left(\dfrac{\Delta L}{L} \right) 100$

$= 3\left(\dfrac{0.1}{30.0} \right) 100$

$= 1\%$

Q. 12)

The diameter, height and mass of a given cylinder are found to be (3.6 ± 0.1) cm, (2.8 ± 0.1) cm and (56 ± 1)g respectively. The density of the cylinder can be quoted as

(A) (1.97 ± 0.22) g cm^{-3}
(B) (1.9 ± 0.2) g cm^{-3}
(C) (2.00 ± 0.22) g cm^{-3}
(D) (2.0 ± 0.2) g cm^{-3}

$d = 3.6 \pm 0.1\ cm$
$h = 2.8 \pm 0.1\ cm$
$m = 56 \pm 1\ g$

$\rho = \dfrac{m}{V} = \dfrac{m}{\pi r^2 h}$

$\rho = \dfrac{m}{\pi \left(\frac{d}{2} \right)^2 h} \Rightarrow \rho = \dfrac{m}{\dfrac{\pi d^2 h}{4}} = \dfrac{4m}{\pi d^2 h}$

$\rho = \dfrac{4m}{\pi d^2 h} \pm \left[\dfrac{\Delta m}{m} + 2\left(\dfrac{\Delta d}{d} \right) + \dfrac{\Delta h}{h} \right]\left[\dfrac{4m}{\pi d^2 h} \right]$

$\rho = \dfrac{4(56)}{(3.14)(3.6)^2(2.8)} \pm \left[\dfrac{1}{56} + 2\left(\dfrac{0.1}{3.6} \right) + \dfrac{0.1}{2.8} \right]\left[\dfrac{4(56)}{(3.14)(3.6)^2(2.8)} \right]$

$= 1.97 \pm 0.22\ g\ cm^{-3}$

But Absolute error is in 1 S.F.

$\rho = 2.0 \pm 0.2\ g\ cm^{-3}$

Q.17)

The following are the readings of a travelling microscope when the cross-wires are aligned at opposite ends of a diameter of a capillary bore.

$$R_1 = (21.14 \pm 0.01) \text{ cm}$$
$$R_2 = (20.98 \pm 0.01) \text{ cm}$$

What is the maximum percentage uncertainty in the area of the cross-section of the capillary bore?

(A) 13 %   (B) 25 %
(C) 18 %   (D) 29 %

W

R_1

R_2

$R_1 = 21.14 \pm 0.01 \text{ cm}$

$d = (21.14 - 20.98) \pm (0.01 + 0.01)$
$d = 1.6 \pm 0.02 \text{ cm}$

$R_2 = 20.98 \pm 0.01 \text{ cm}$
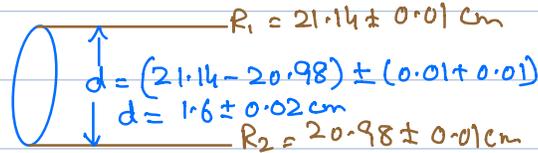
$$A = \frac{\pi \, d^2}{4}$$

$$\frac{\Delta A}{A} \times 10 = 2 \left(\frac{\Delta d}{d} \right) 100 = 2 \left(\frac{0.02}{1.6} \right) 100 = 25\%$$

Q.19)

$d_i = 24.15 \pm 0.01 \text{ cm}$

The wall thickness of a cylindrical glass tube is determined by measuring its external and internal diameters with the help of vernier calipers. If the readings obtained are (27.23 ± 0.01) cm and (24.15 ± 0.01) cm respectively, the wall thickness of the glass tubing is

(A) 3.08 ± 0.02 cm   (B) 1.54 ± 0.02 cm
(C) 3.08 ± 0.01 cm   (D) 1.54 ± 0.01 cm

t t

$d_e = 27.23 \pm 0.01 \text{ cm}$
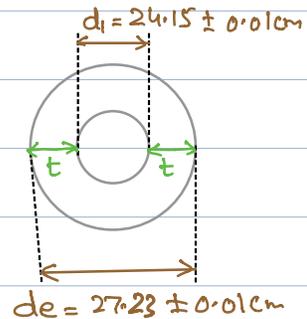
$$2t = d_e - d_i$$
$$= (27.23 - 24.15) \pm (0.01 + 0.01)$$
$$2t = 3.08 \pm 0.02 \text{ cm}$$
$$t = \frac{3.08}{2} \pm \frac{0.02}{2} \Rightarrow t = 1.54 \pm 0.01 \text{ cm}$$

1   The volume V of liquid flowing in time t through a pipe of radius r is given by the equation

$$\frac{V}{t} = \frac{\pi P r^4}{8Cl}$$

where P is the pressure difference between the ends of the pipe of length l, and C depends on the frictional effects of the liquid.

An experiment is performed to determine C. The measurements made are shown in Fig. 1.1.

$\frac{V}{t}$ / $10^{-6}\,m^3\,s^{-1}$	$P/10^3\,N\,m^{-2}$	r/mm	l/m
1.20 ± 0.01	2.50 ± 0.05	0.75 ± 0.01	0.250 ± 0.001

Fig. 1.1

(a) Calculate the value of C.

$$C = \frac{\pi P r^4}{8\left(\frac{V}{t}\right)(l)}$$

$$= \frac{(3.14)(2.50 \times 10^3)(0.75 \times 10^{-3})^4}{8(1.20 \times 10^{-6})(0.250)}$$

$$C = 1.04 \times 10^{-3} \quad \text{................................ } N\,s\,m^{-2} \text{ [2]}$$

(b) Calculate the uncertainty in C.

$$\frac{\Delta C}{C} = \frac{\Delta P}{P} + 4\left(\frac{\Delta r}{r}\right) + \frac{\Delta\left(\frac{V}{t}\right)}{\frac{V}{t}} + \frac{\Delta l}{l}$$

$$\frac{\Delta C}{1.04 \times 10^{-3}} = \frac{0.05}{2.50} + 4\left(\frac{0.01}{0.75}\right) + \frac{0.01}{1.20} + \frac{0.001}{0.250}$$

$$\Delta C = 0.089 \times 10^{-3}$$

uncertainty = $\pm 0.089 \times 10^{-3}$ .... $N\,s\,m^{-2}$ [3]

(c) State the value of C and its uncertainty to the appropriate number of significant figures.

$$C = (1.04 \pm 0.09) \times 10^{-3}$$

$$C = (1.04 \text{ .... } \pm \text{ .... } 0.09) \times 10^{-3} \quad N\,s\,m^{-2} \text{ [1]}$$

Precision

Concept: Degree of refinement in a reading/measurement.

Note:-

(1) The precision of a measuring device is defined by its absolute error i.e smaller the absolute error, greater is the precision. For example

* Micrometer (0.01mm) is more precise than Vernier Caliper (0.01cm) which is more precise than metre rule (0.1cm).
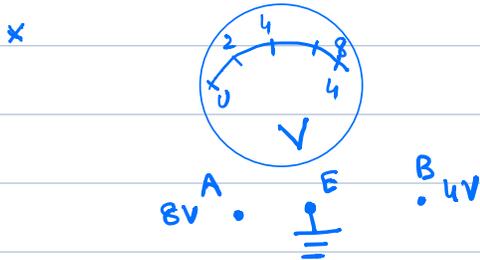
$V_{AE} = \pm 2V$

$V_{EB} = \pm 1V$

Connectivity between E and B provide more precise reading than between A and E.

(2) Readings/measurements are precise if their mean deviation is small.

g/ms^2	Student A Deviation	g/ms^2	Students B Deviation
9.81	9.82-9.81 = 0.01	9.84	9.84-9.83 = 0.01
10.6	10.6-9.82 = 0.78	9.80	9.83-9.80 = 0.03
11.4	11.4-9.82 = 1.58	9.78	9.83-9.78 = 0.05
7.86	9.82-7.86 = 1.96	9.90	9.90-9.83 = 0.07
9.44	9.82-9.44 = 0.38	9.81	9.83-9.81 = 0.02

Mean g: $\langle g \rangle = \dfrac{9.81+10.6+11.4+7.86+9.44}{5}$
$= 9.82$

Mean g = $\langle g \rangle = \dfrac{9.84+9.80+9.78+9.90-9.81}{5}$
$= 9.83$

Mean deviation

Mean deviation

$$= \frac{0.01+0.78+1.58+1.96+0.38}{5}$$

$$= 0.942$$

$$= \frac{0.1+0.03+0.05+0.07+0.02}{5}$$

$$= 0.036$$

Therefore, student B results are more precise than student A.

(3) A smaller spread/range in the measurement increases precision e.g.

Range of Student's A results = 11.4 − 7.86 = 3.54

Range of Student's B results = 9.90 − 9.78 = 0.12

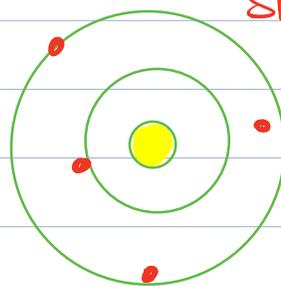Therefore, student's B results are more precise than student A.

no. of readings, n

x
Physical Quantity (x)

Min   Smaller spread   Max

greater precision.

n

Min   Larger spread   Max

x
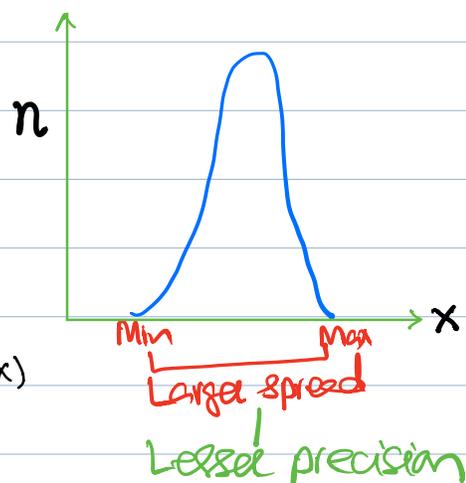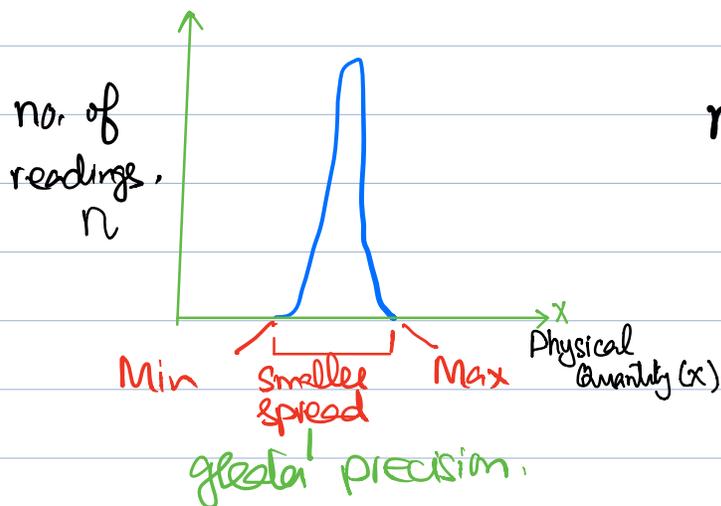
Lesser precision
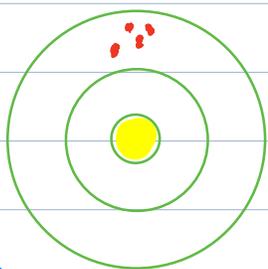
Student A

Smaller gap in red

Student B

Larger gap b/w red

dots shows greater precision   dots shows lesser precision

(4) Precision of a calculated result depends upon the no. of significant figures stated as per rule.

1 s.f	2 s.f.	3 s.f
2	2.0	2.00
0.2	0.20	0.200
0.02	0.020	0.0200
0.002	0.0020	0.00200
20	20	20.0
200	200	200

2×10^2 — 200

2.0×10^2

20.0×10^1
2.00×10^2

Rule on 2.sf. The final answer should be equal to or one better than the least no. of s.f. of data used in calculation. e.g.

$$2.sf \swarrow \frac{(9.4)^{\nearrow 3sf} (84.6)^{\nearrow 8sf}}{280.3_{\searrow 4sf}} = 2.8371031$$

Here final answer should be either in 2sf (2.8) or 1 better ie 3sf 2.84, Also 2.84 is more precise than 2.

(5) A random error in the reading or measurement losses the precision

ACCURACY:-

Def, Reading or measurement is accurate if it is close to the real value.

Note

1) Percentage error is a measure of accuracy i.e smaller the percentage error, higher is the accuracy. e.g.

$L_1 = 24.2 \pm 0.1 cm$	$L_2 = 12.2 \pm 0.1 cm$
Percentage error in L_1	Percentage error in L_2:
$\dfrac{\Delta L_1}{L_1} \times 100 = \dfrac{0.1}{24.2} \times 100$	$\dfrac{\Delta L_2}{L_2} \times 100 = \dfrac{0.1}{12.2} \times 100$
$= 0.41\%$	$= 0.82\%$

L_1 is more accurate than L_2 but both are equally precise (same absolute error and same no. of s.f)

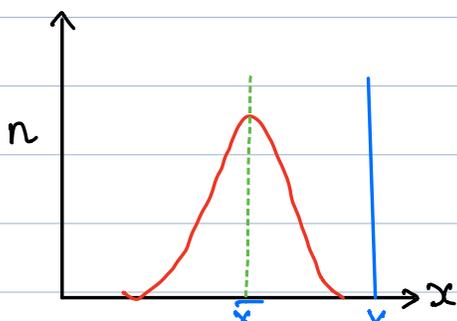(2) A Systematic error (zero error) in measurements reduces the accuracy.

(3) Readings/measurements are accurate if their mean value is closer to the real value.
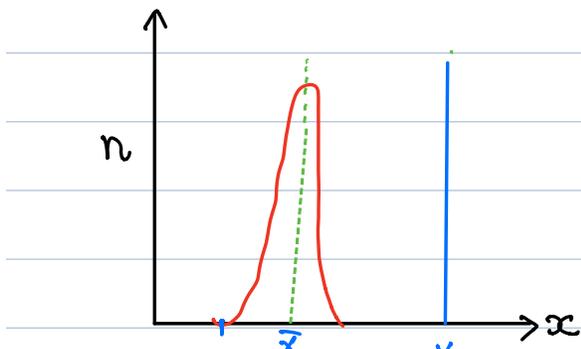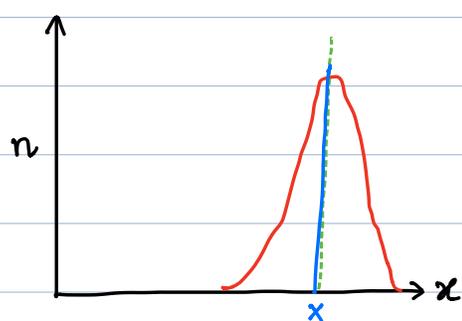
Precise but not accurate
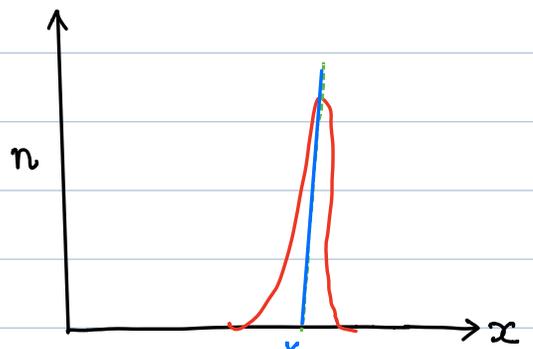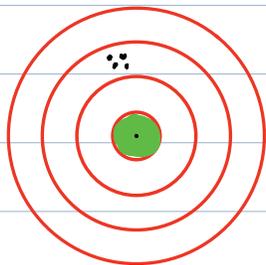
Precise as well as accurate
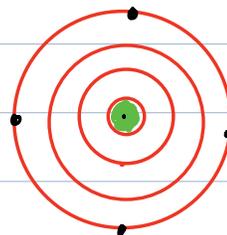
Neither precise nor accurate
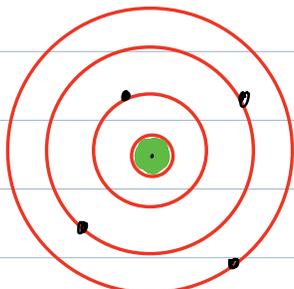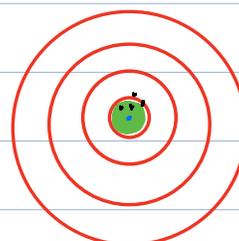
Accurate but not precise

2)

Precise but not accurate

Neither precise nor accurate

Neither precise nor accurate

Precise as well as accurate

Measurements using Cathode Ray Oscilloscope :-

<u>Note</u>:

(1) The scale associated with <u>x-plates</u> is called <u>time base control or x-plate sensitivity</u> and represent time interms of no. of divisions ie 4ms/cm.

(2) The scale associated with <u>Y-plates</u> is the <u>gain control or Y-plate sensitivity</u> and represent voltage interms of no. of divisions. ie. 6V/cm.

<u>Formula</u>:-

(1) Time period = $\left(\begin{array}{c} \text{no. of units to represent} \\ \text{one pattern in a} \\ \text{repeated waveform} \end{array} \right) \left(\begin{array}{c} \text{x-plate} \\ \text{sensitivity} \end{array} \right)$

(ii) Frequency = $\dfrac{1}{\text{Time period}}$

(iii) Peak voltage (value) = $\left(\begin{array}{c} \text{no. of units to} \\ \text{represent the} \\ \text{amplitude position} \end{array} \right) \left(\begin{array}{c} \text{Y-plate} \\ \text{sensitivity} \end{array} \right)$

Calibration curves and graduations on scales :-
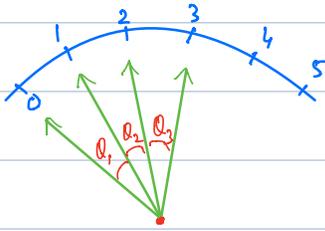
$\theta_1 = \theta_2 = \theta_3 = \cdots$	$\theta_1 < \theta_2 < \theta_3 < \theta_4 < \theta_5$	$\theta_1 > \theta_2 > \theta_3 > \theta_4 > \theta_5$
$\Delta\theta$ = Constant	$\Delta\theta$ = Increase	$\Delta\theta$ = Decrease
Sensitivity = $\dfrac{\text{change of deflecting angle}}{\text{change in physical Qty}}$ = Constant	Sensitivity = Increase	Sensitivity = Decrease
So above scale is equally sensitive for all values of physical Quantity.	Above scale is more sensitive for larger values of physical quantity.	Above scale is more sensitive for smaller values of Physical quantity
$\dfrac{\Delta\theta}{\text{Physical Qty}}$ = Gradient = Constant	Gradient = Increase	Gradient = Sensitivity = Decrease
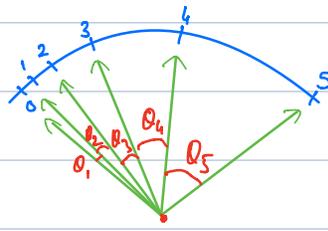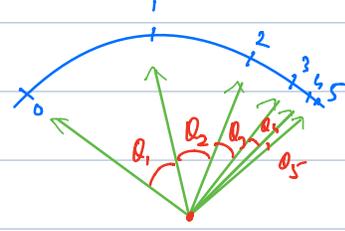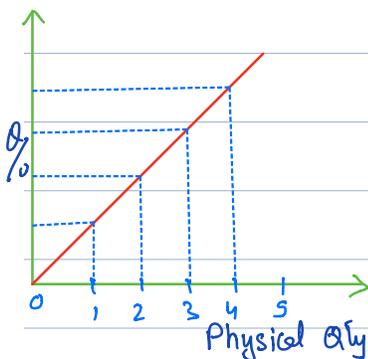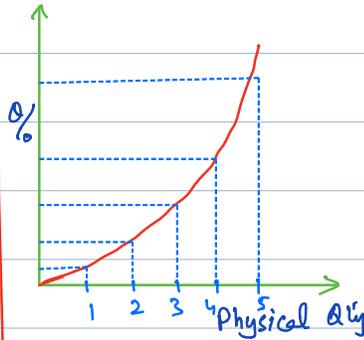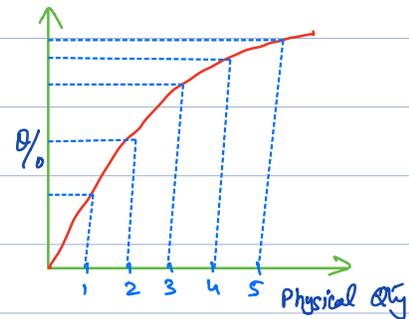
MEASUREMENTS & ERRORS

1 One end of a wire is connected to a fixed point. A load is attached to the other end so that the wire hangs vertically.

The diameter d of the wire and the load F are measured as

$$d = 0.40 \pm 0.02 \, \text{mm},$$
$$F = 25.0 \pm 0.5 \, \text{N}.$$

(a) For the measurement of the diameter of the wire, state

(i) the name of a suitable measuring instrument,

...........................micrometer screw gauge.................................[1]

(ii) how random errors may be reduced when using the instrument in **(i)**.

take several diameters along the length of wire and their averaged diameter.

....[2]

(b) The stress σ in the wire is calculated by using the expression

$$\sigma = \frac{4F}{\pi d^2}.$$

(i) Show that the value of σ is $1.99 \times 10^8 \, \text{N m}^{-2}$.

$$\sigma = \frac{4(25.0)}{(3.14)(0.40 \times 10^{-3})^2}$$

$$\sigma = 1.99 \times 10^8 \, \text{Nm}^{-2}$$

[1]

(ii) Determine the percentage uncertainty in σ.

$$\left(\frac{\Delta \sigma}{\sigma}\right) 100 = \left(\frac{\Delta F}{F}\right) 100 + 2\left(\frac{\Delta d}{d}\right) 100$$

$$= \left(\frac{0.5}{25}\right) 100 + 2\left(\frac{0.02}{0.40}\right) 100$$

$$= 12\%$$

percentage uncertainty = ...% [2]

(iii) Use the information in **(b)(i)** and your answer in **(b)(ii)** to determine the value of σ, with its absolute uncertainty, to an appropriate number of significant figures.

$$\frac{\Delta \sigma}{\sigma} = \frac{12}{100} \Rightarrow \Delta \sigma = \left(\frac{12}{100}\right)(1.99 \times 10^8)$$

$$\Delta \sigma = 2.4 \times 10^7$$

But Absolute error must be in 1sf

$$\Delta \sigma = 2 \times 10^7$$

$\sigma = $ .... $(2.0$ .... $\pm$ .... $0.2\,) 10^8$ .... $N\,m^{-2}$ [2]

$1.99 \times 10^8 \pm 2 \times 10^7$

$= 2.0 \times 10^8 \pm 0.2 \times 10^8$

[Total: 8]

{*Q. 1/Nov. 17/9702/22*}

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2. A double-slit interference experiment is used to determine the wavelength of light from a monochromatic source.

The following measurements are used.

$$x = \frac{\lambda D}{a} \Rightarrow \lambda = \frac{xa}{D}$$

slit separation $a = 0.50 \pm 0.02$ mm

fringe separation $x = 1.7 \pm 0.1$ mm

$$\frac{\Delta \lambda}{\lambda} \times 100 = \left(\frac{\Delta x}{x}\right)100 + \left(\frac{\Delta a}{a}\right)100 + \left(\frac{\Delta D}{D}\right)100$$

distance between slits and screen $D = 2.000 \pm 0.002$ m

$$= \left(\frac{0.1}{1.7}\right)100 + \left(\frac{0.02}{0.50}\right)100 + \left(\frac{0.002}{2.000}\right)100$$

What is the percentage uncertainty in the calculated wavelength? $= \quad \%$

A 0.1% **B** 1% **C** 6% **D** 10%

{*Q. 5/Nov. 17/9702/21*}

---

3. A school has a piece of aluminium that it uses for radioactivity experiments. Its thickness is marked as 3.2 mm. A student decides to check this value. He has vernier calipers which give measurements to 0.1 mm and a micrometer which gives measurements to 0.01 mm.

Which statement **must** be correct?

A The micrometer gives a more accurate measurement.

B The micrometer gives a more precise measurement.

C The vernier calipers give a more accurate measurement.

D The vernier calipers give a more precise measurement.

{*Q. 4/Nov. 17/9702/23*}

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4. Four possible sources of error in a series of measurements are listed.

1 an analogue meter whose scale is read from different angles parallex error → Random

2 a meter which always measures 5% too high Systematic

3 a meter with a needle that is not frictionless, so the needle sometimes sticks slightly
└ Random error

4 a meter with a zero error —— Systematic

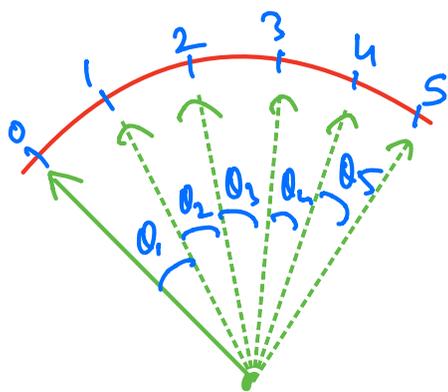Which errors are random and which are systematic?

	random error	systematic error
A	1 and 2	3 and 4
B	1 and 3	2 and 4
C	2 and 4	1 and 3
D	3 and 4	1 and 2

{*Q. 5/Nov. 17/9702/23*}

PRECISION AND ACCURACY

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1. A series of measurements of the acceleration of free fall g is shown in the table. Which set of results is precise *[range]* but not accurate? *[average]*

[P and A]
[NP and A]
[NP and NA]

	g / ms^{-2}				
A	9.81	9.79	9.84	9.83	9.79
B	9.81	10.12	9.89	8.94	9.42
C	9.45	9.21	8.99	8.76	8.51
(D)	8.45	8.46	8.50	8.41	8.47

[Max] *[Min]*

2. A steel rule can be read to the nearest millimetre. It is used to measure the length of a bar whose true length is 895 mm. Repeated measurements give the following readings. *[$\frac{892+891+892+891+892}{5}=891.5$]*

length / mm 892, 891, 892, 891, 891, 892

Are the readings accurate and precise to within 1 mm? *[895−891.5 = 3.5mm]* *[Range = 892−891 = 1mm]*

	results are accurate to within 1 mm	results are precise to within 1 mm
A	No	No
(B)	No	Yes
C	Yes	No
D	yes	Yes

3. A student carries out a series of determinations of the acceleration of free fall g. The table shows the results. *[Average = $\frac{4.91+4.89+4.88+4.90+4.93+4.92}{6}$ = 4.905]*

g /m s^2	4.91	4.89	4.88	4.90	4.93	4.92

What can be said about this experiment?
A It is accurate and precise. *[Precision = Range = 4.93−4.88 = 0.05]*
B It is accurate and not precise.
C It is not accurate and not precise.
(D) It is not accurate and precise

4. A quantity x is measured many times. The number N of measurements giving a value x is plotted against x. The true value of the quantity is x_o.
Which graph best represents precise measurements with poor accuracy?

[A: Precise Accurate]
[B: Precise Not accurate; smaller range Precision ↑]
[C: Neither Precise nor accurate; x_o Larger range Precision ↓]
[D: Accurate but not precise]

5. A quantity X is measured many times. A graph is plotted showing the number n of times a particular value of X is obtained. X has a true value X_o

Which graph could be obtained if the measurement of X has a large systematic error but a small random error? *[(Accuracy) ↓↓]* *[(Precision) ↑↑]*

[A: No Systematic or Random error]
[(B): Random error X; Systematic error ✓]
[C: Random error: ✓; Systematic error: ✓]
[D: Random error: ✓; Systematic error: X]

6. The following graph is obtained when a voltmeter is calibrated.

[Absolute error = 1V]

Which of the following best describes the voltmeter?

	significant systematic error	significant random error	high precision obtained	High accuracy obtained
A	/			/
(B)	✓		✓	
C		/		/
D		/	/	

7. A micrometer, reading to ±0.01 mm, gives the following results when used to measure the diameter d of a uniform wire: *[$\frac{1.02+1.02+1.01+1.02+1.02}{5}$ = 1.018]*

1.02 mm, 1.02 mm, 1.01 mm, 1.02 mm, 1.02mm

When the wire is removed and the jaws are closed, a reading of −0.02 mm is obtained. Which of the following gives the value of d with a precision appropriate to the micrometer?

A 1.0 mm   B 1.00 mm
C 1.038 mm   **(D)** 1.04 mm

[Accurate diameter = 1.018 + 0.02 = 1.038mm]
[d = 1.038 ± 0.01 mm] *[2dp]* *[2dp d=1.04 mm]*

Answer Grid

Q. No	1	2	3	4	5	6	7

Calibration curves and graduations on Scales:
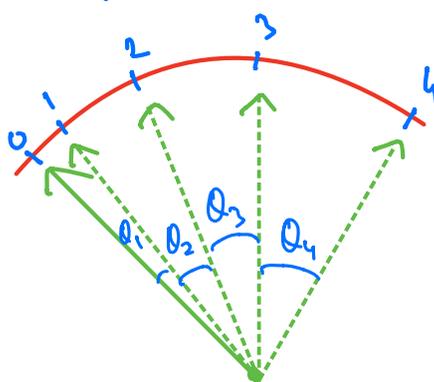

Column 1:

$\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5$

$\Delta\theta = 0$

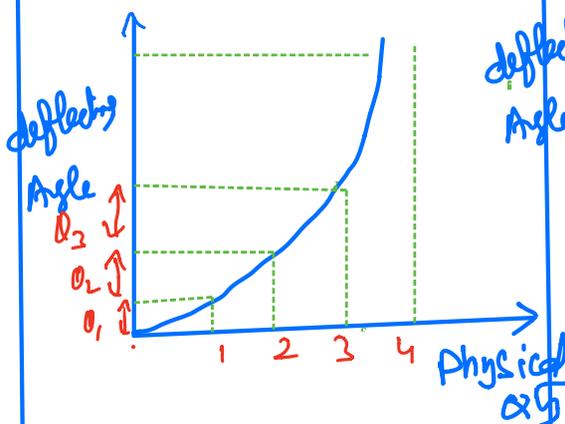Sensitivity $= \dfrac{\Delta\theta}{\Delta(\text{Physical Qty})}$

$=$ Gradient of graph

Above scale is equally sensitive for all values of Physical quantity
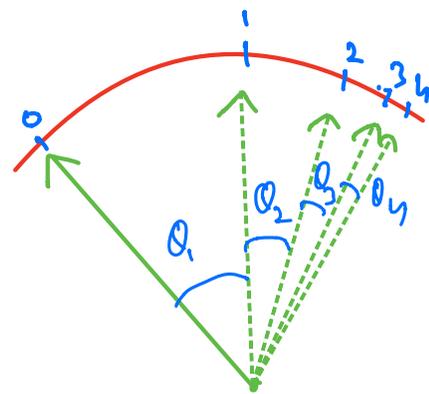
Column 2:

$\theta_1 < \theta_2 < \theta_3 < \theta_4$

ie $\Delta\theta \uparrow$

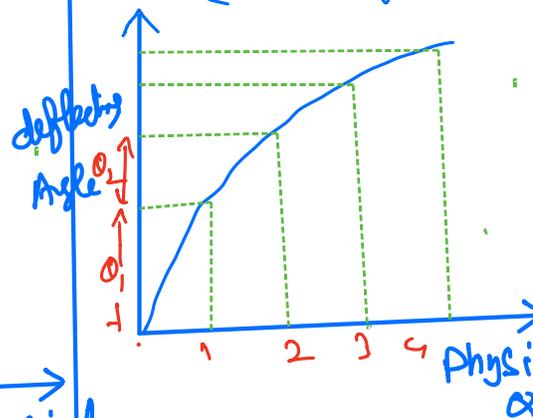Sensitivity $= \dfrac{\Delta\theta}{\Delta(\text{Physical Qty})}$

$=$ (Gradient) $\uparrow$

Above scale is more sensitive for greater value of physical qty.

Column 3:

$\theta_1 > \theta_2 > \theta_3 > \theta_4$

i.e $\Delta\theta \downarrow$

(Sensitivity) $\downarrow$

as $\left(\dfrac{\Delta\theta}{\Delta t}\right) \downarrow$

Above scale is more sensitive for smaller value of physical Qty.

ESTIMATION & CALIBRATION CURVES

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1. What is a reasonable estimate of the diameter of an alpha particle?
A 10^{-15} m   **B** 10^{-12} m   **C** 10^{-9} m   **D** 10^{-6} m

2. For which quantity is the magnitude a reasonable estimate?
A frequency of a radio wave   500 pHz
B mass of an atom   500 μg
C the Young modulus of a metal   500 kPa
D wavelength of green light   500 nm

3. What is a correct order of magnitude estimate for the diameter of a typical atomic nucleus?
**A** 10^{-14} m   **B** 10^{-18} m   **C** 10^{-22} m   **D** 10^{-26} m

4. An Olympic athlete of mass 80 kg competes in a 100 m race. $E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{d}{t}\right)^2 = \frac{1}{2}(80)\left(\frac{100}{10}\right)^2$
What is the best estimate of his mean kinetic energy during the race?
A 4×10^2 J   **B** 4×10^3 J
C 4×10^4 J   **D** 4×10^5 J

5. What is a reasonable estimate of the average kinetic energy of an athlete during a one hundred metre race that takes 10 s?
A 40 J   **B** 400 J   **C** 4 000 J   **D** 40 000 J

6. The diagram shows the graduations of a correctly calibrated ammeter. When the current is zero, the pointer is at 0.
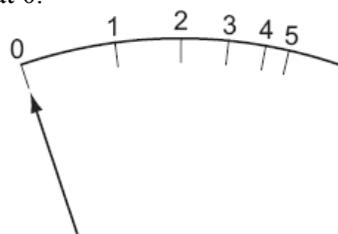
The ammeter is accidentally readjusted so that when the current is zero, the pointer is at X.
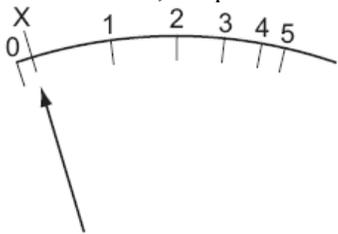
Which calibration graph best represents the response of the readjusted ammeter?
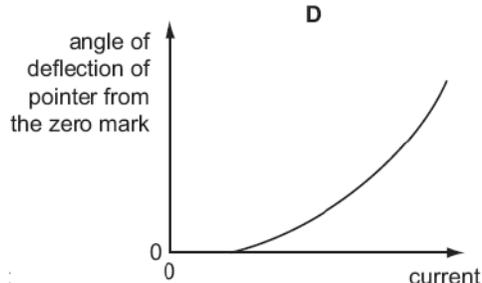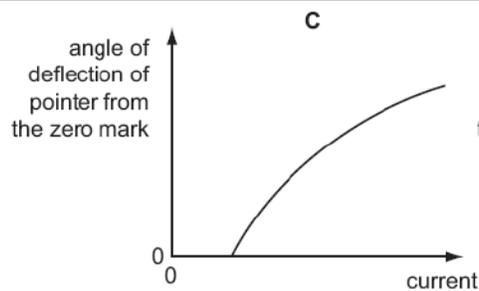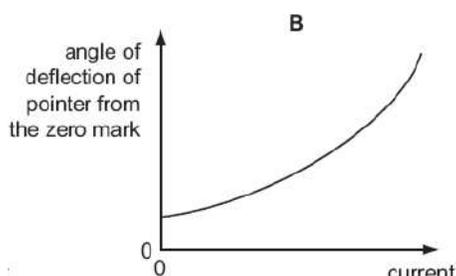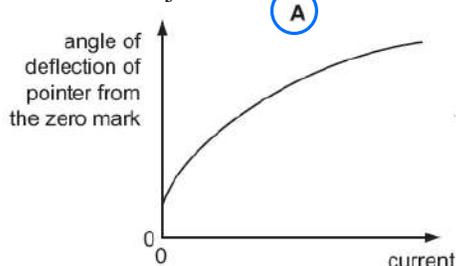
7. The deflection of the needle of an ammeter varies with the current passing through the ammeter as shown in the graph.
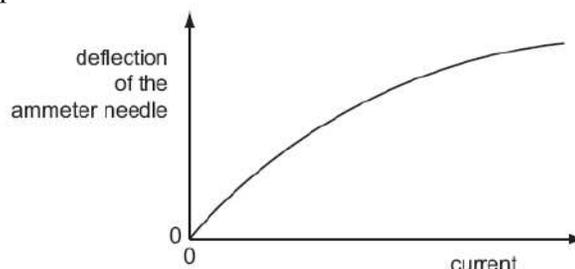
Which diagram could represent the appearance of the scale of this meter?
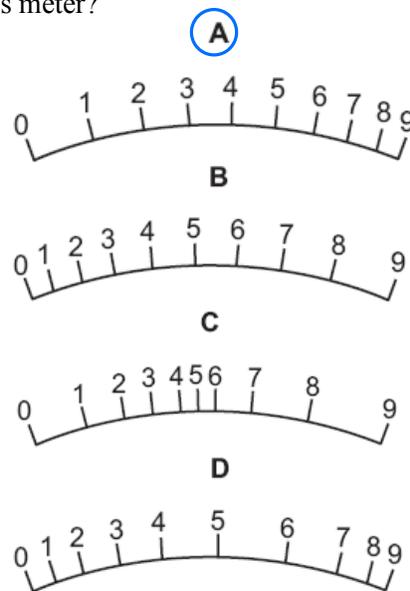
8. What is the reading shown on this milliammeter?
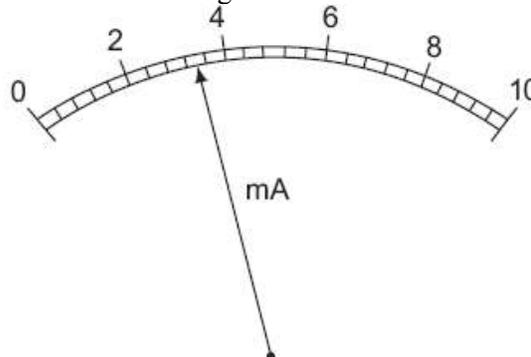
A 2.35 mA   **B** 2.7 mA
C 3.4 mA   **D** 3.7 mA

$L/cm =$ 10.4, 10.8, 9.6, 9.9, 10.0

Calculate

i) Average value of L

$$<L> = \frac{10.4 + 10.8 + 9.6 + 9.9 + 10.0}{5} = 10.14 = 10.1 \, cm$$

(ii) Absolute error in L

$$\Delta L = \frac{Max \; value - Min \; value}{2} = \frac{10.8 - 9.6}{2} = \frac{1.2}{2}$$
$$= 0.6 \, cm$$

(iii) Fractional error in L

$$\frac{\Delta L}{L} = \frac{0.6}{10.1} = 0.0594$$

(iv) Percentage error in L

$$\frac{\Delta L}{L} \times 100 = 0.0594 \times 100 = 5.94\%$$

Note: If repeated readings are taken then uncertainity/absolute error is the half of the range.

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1. A whale produces sound waves of frequency 5 Hz. The waves are detected by a microphone and displayed on an oscilloscope.

What is the time-base setting on the oscilloscope?

A 0.1 ms div^{-1} **B** 1 ms div^{-1}
C 10 ms div^{-1} **D** 100 ms div^{-1}

{Q.4/June 15/11}

2. A cathode-ray oscilloscope (c.r.o.) is used to display the trace from a sound wave. The time-base is set at 5 μs mm^{-1}

1 cm

1 cm

What is the frequency of the sound wave?

A 6.7 Hz   **B** 67 Hz
C 6.7 kHz   **D** 67 kHz.

{Q25/June 15/13}

3. A cathode-ray oscilloscope (c.r.o.) is connected to an alternating voltage. The following trace is produced on the screen.

1 cm

1 cm

The oscilloscope time-base setting is 0.5 ms cm^{-1} and the Y-plate sensitivity is 2 V cm^{-1}.
Which statement about the alternating voltage is correct?

A The amplitude is 3.5 cm.
B The frequency is 0.5 kHz.
C The period is 1 ms.
D The wavelength is 4 cm.

{Q3/June 14/12}

4. The display on a cathode-ray oscilloscope shows the signal produced by an electronic circuit.
The time-base is set at 5.0 ns per division and the Y-gain at 10 V per division.

What is the frequency of the signal?

A 2.0×10^{-8} Hz   **B** 2.5×10^{-2} Hz
C 5.0×10^{7} Hz   **D** 3.1×10^{8} Hz

{Q.5/June 14/13}

5. A signal that repeats periodically is displayed on the screen of a cathode-ray oscilloscope.

The screen has 1 cm squares and the time base is set at 2.00 ms cm^{-1}.
What is the frequency of this periodic signal?

A 50 Hz   **B** 100 Hz   **C** 125 Hz   **D** 200 Hz

{Q.4/Nov 13/11,12}

6. The Y-input terminals of a cathode-ray oscilloscope (c.r.o.) are connected to a supply of amplitude 5.0 V and frequency 50 Hz. The time-base is set at 10 ms per division and the Y-gain at 5.0 V per division.
Which trace is obtained?

A   B

C   D

{Q6/June 13/11 & Q4/Nov 06}

Answer Grid:

Q. No.	1	2	3	4	5	6
Answer	D	C	B	C	B	D

A source of radio waves sends a pulse towards a reflector. The pulse returns from the reflector and is detected at the same point as the source. The emitted and reflected pulses are recorded on a cathode-ray oscilloscope (c.r.o.) as shown in Fig. 2.1.
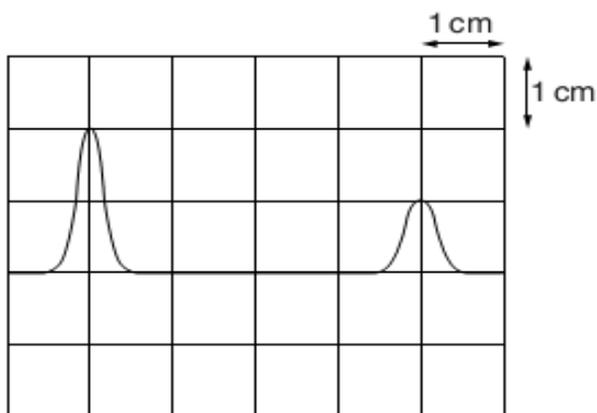

Fig. 2.1

The time-base setting is $0.20\,\mu s\,cm^{-1}$.

(a) Using Fig. 2.1, determine the distance between the source and the reflector.

distance = ... m [4]

(b) Determine the time-base setting required to produce the same separation of pulses on the c.r.o. when sound waves are used instead of radio waves.
The speed of sound is $300\,m\,s^{-1}$.

....

....

....[3]

Answer Key

(a) $d = v \times t$ C1
$t = 0.2 \times 4$ (allow $t = 0.2 \times 2$)   C1
$d = 3 \times 10^8 \times 0.8 \times 10^{-6}$ OR $3 \times 10^8 \times 0.4 \times 10^{-6}$ C1
$d = 240$ m hence distance from source to reflector = 120 m   A1   [4]

(b) speed of sound 300 cf speed of light 3×10^8 OR time = 240 / 300 (= 0.8)
                                                  OR time = 120 / 300 (= 0.4)   C1
sound slower by factor of 10^6 OR time for one division 0.8 / 4
                                      OR time for one division 0.4 / 2   C1
time base setting 0.2 s cm^{-1} [unit required]   A1   [3]