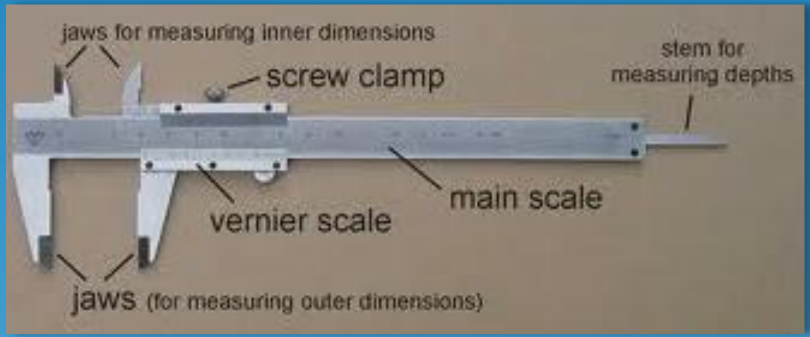

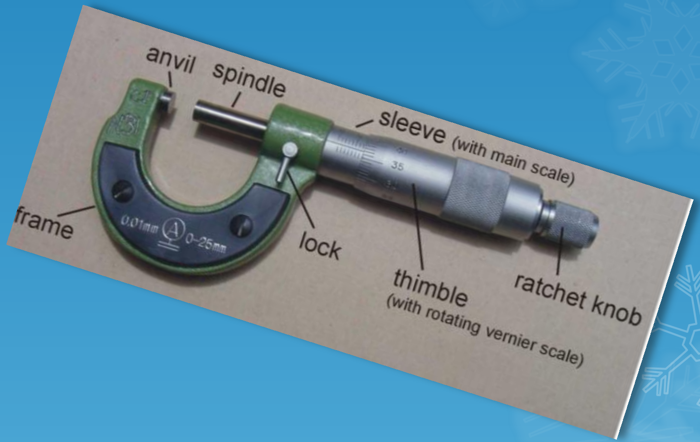

Chap 2
Measurement Techniques

Lim Wan Hong
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Learning outcome

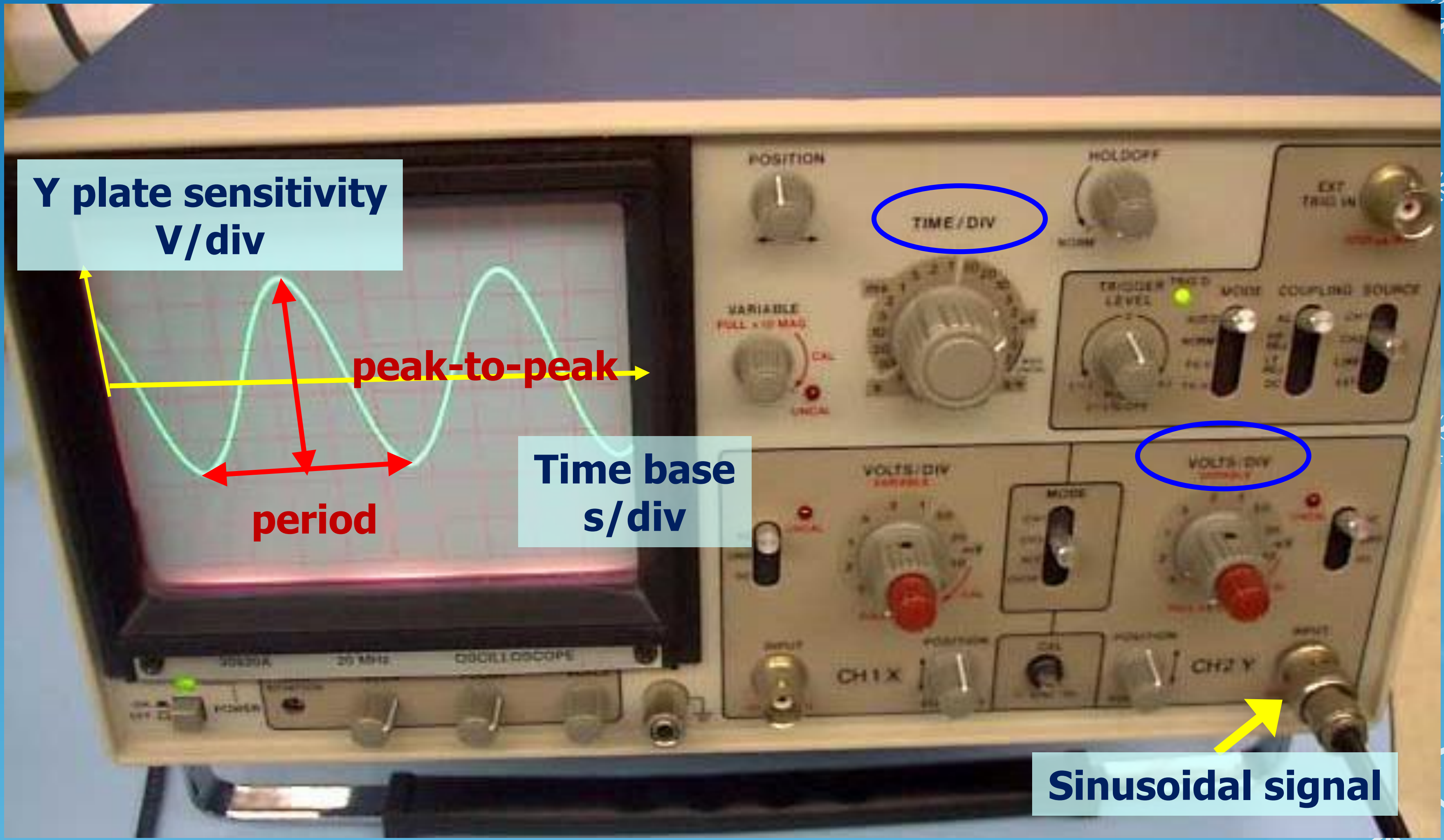
(a) use techniques for the measurement of length, volume, angle, mass, time, temperature and electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus.

Measurements

Practical lesson – A1 & A2

- ruler, vernier scale and micrometer
- Ammeter, voltmeter
- Triple beam balance
- stopwatch

Using cathode-ray oscilloscope (c.r.o.) to measure amplitude, period and frequency



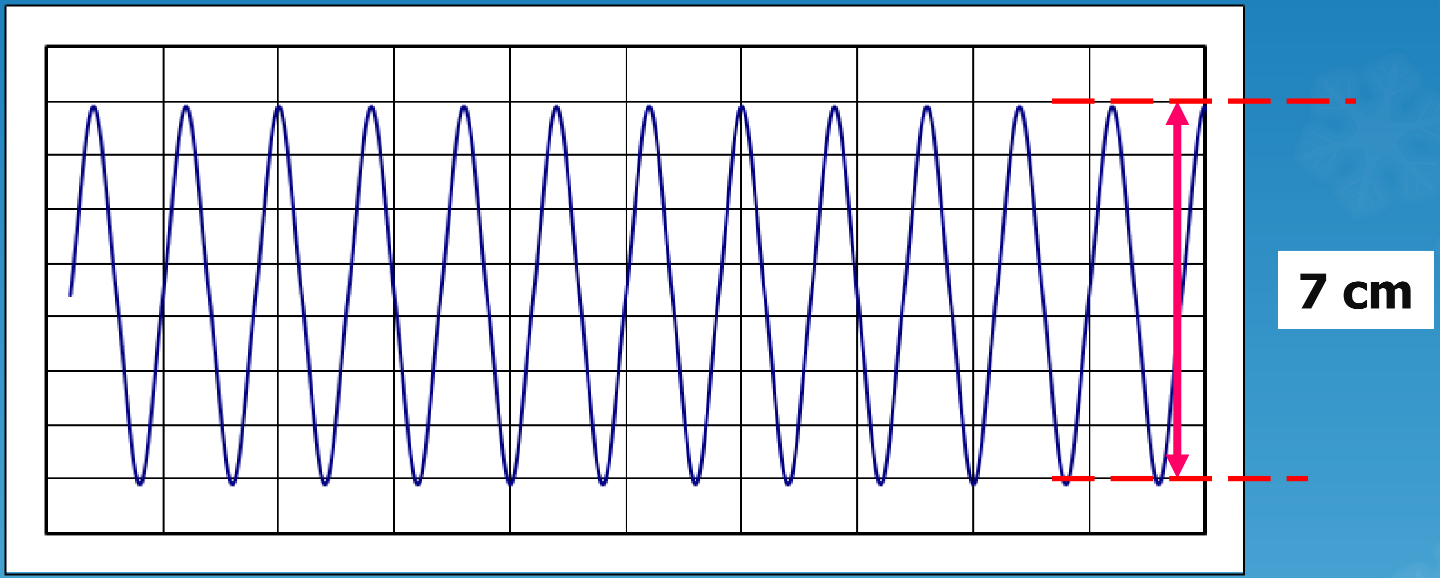
Interactive CRO Website:

http://www.phy.ntnu.edu.tw/java/oscilloscope/oscilloscope.html

http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=34

Using cathode-ray oscilloscope (c.r.o.) to measure amplitude.

Amplitude = number of divisions from peak-to-peak x voltage setting/2



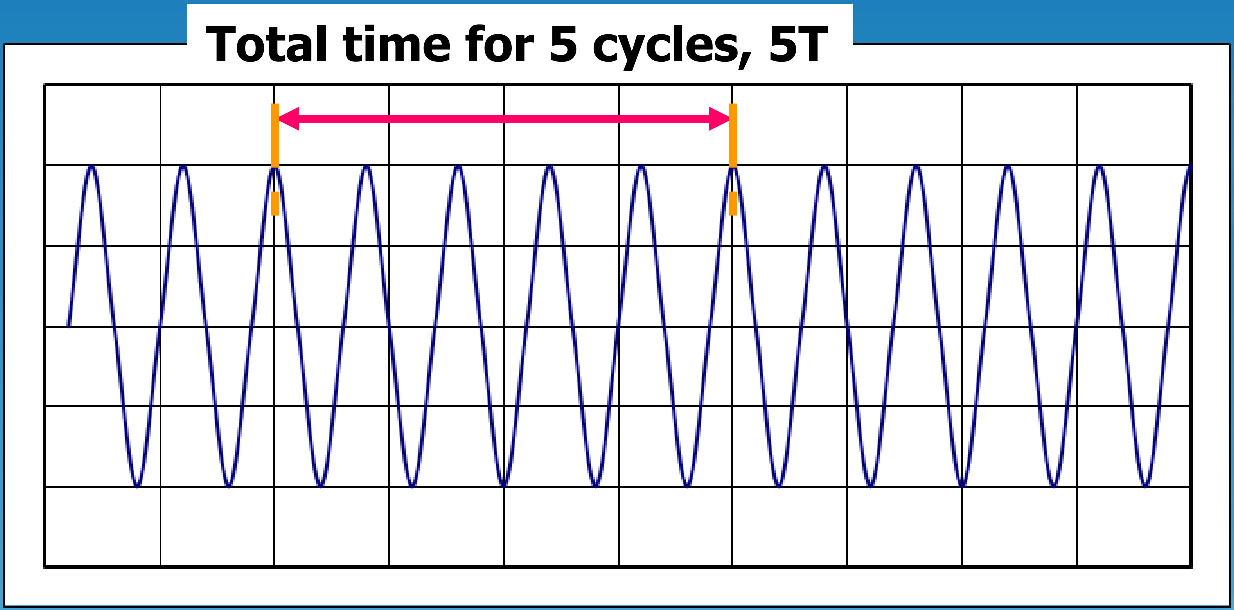
y plate sensitivity is set to be 5 mV per cm

Peak to peak voltage = 5 mV /cm x 7 cm = 35 mV

Amplitude of voltage = 17.5 mV

Using cathode-ray oscilloscope (c.r.o.) to measure period and hence determine frequency

Average period T= number of divisions for n cycles x time base setting/n



Time base is set to be 100 μs per cm

5T = 100 μs /cm x 4 cm = 400 μs

T= 80 μs

Frequency, f = 1/80 μs = 12.5 K Hz

Learning outcomes

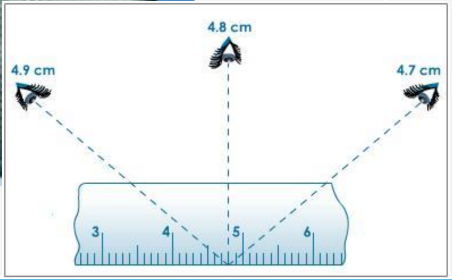
- *(d)* show an understanding of the distinction between systematic errors (including zero errors) and random errors
- *(e)* show an understanding of the distinction between precision and accuracy
- *(f)* assess the uncertainty in a derived quantity by simple addition of actual, fractional or percentage uncertainties

What is meant by systematic errors and random errors?

Systematic errors	Random errors
➢ Errors that result in all the readings taken being faulty in one direction, either all smaller or larger than the actual values ➢ These errors are constant errors that cause all results to be incorrect by roughly the same amount in the same direction	➢ Errors that result in scattering of readings about a mean value ➢ The errors have equal chance of being +ve or –ve

Examples / causes

Systematic errors	Random errors
Zero error: Ammeter with zero/initial reading of −0.2mA causes all the readings taken being 0.2mA larger the actual reading.	Parallax error: eye of observer is not on the same level as the mark on the ruler Inconsistent judgment of experimenter, e.g. uncertainty to judge if a falling object has reached the ground before stopping the stopwatch. What is the nearest scale mark? Fluctuation in the measured quantities



How to eliminate/reduce?

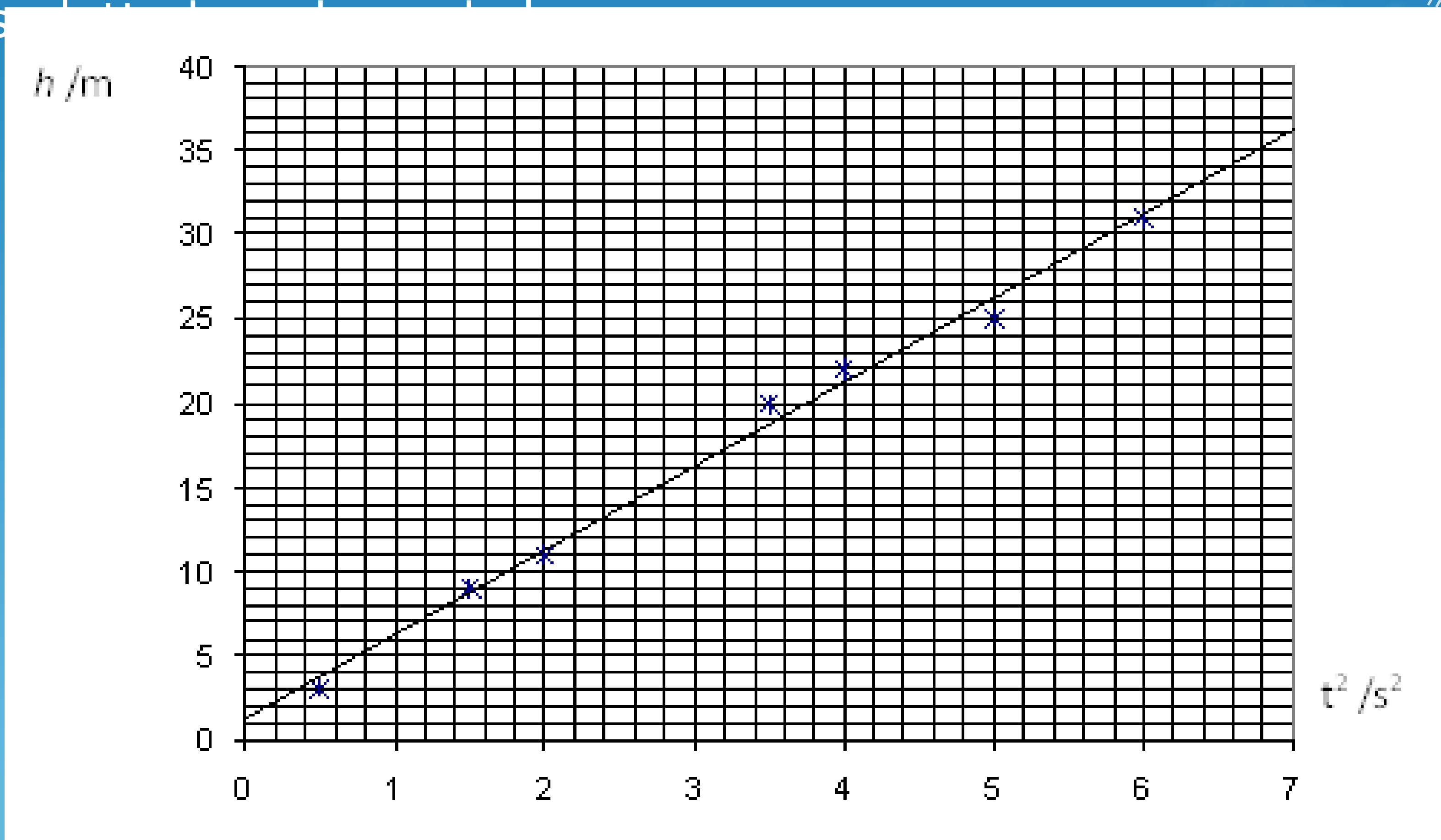
Systematic errors	Random errors
➢ It is can be estimated and eliminated entirely and hence the accuracy of reading is increased. ➢ Cannot be reduced by taking repeated readings. ➢ By varying the instrumentation being used (check the readings with another scale or experimenter)	➢ This error can only be reduced to increase the precision of readings but can not be eliminated totally. ➢ It is reduced by taking repeated readings at different points/angles/times and averaging them.

How to eliminate/reduce?

Systematic errors	Random errors
➢ by using good & systematic experimental technique ➢ To reduce parallax error: Use a pointer and a mirror along the scale, e.g. ammeter, take the pointer reading when the pointer overlaps with its image on the mirror.	➢ measure a set of data & draw a line of best fit. e.g. $s = \frac{1}{2} g t^2$ – plot s vs. t^2 gradient = ½ g. ➢ Use instrument of higher precision, e.g. micrometer screw gauge instead of vernier callipers

Example

The time *t* for a ball to fall from rest through a distance *h* is measured and the acceleration, *g* due to gravity is calculated by $h = \frac{1}{2} g t^2$. Measurements of *t* for several different values of *h* are carried out and a graph of *h* vs. t^2 is



Questions

Explain which features of the graph suggest that there is

(i) systematic error

The line of best fit does not pass through the origin

(ii) random error

Data are scattered along the line of best fit

Accuracy vs. Precision

- **Accuracy** - how close the readings taken to the actual (accepted) values. (How correct it is)
- **Precision** - how close the readings taken among them. It indicates a degree of scattering. Large degree of precision does not necessarily imply accuracy. More decimal places, more precise.

Accuracy vs. Precision

Acceleration of free fall *g* is determined from few measurements as follows. Comments on these measurements.

(1) 4.88 ms^{-2}; 4.91 ms^{-2}; 4.95 ms^{-2}; 4.85 ms^{-2}; 4.90 ms^{-2}

Precise but not accurate

(2) 9.88 ms^{-2}; 7.91 ms^{-2}; 4.95 ms^{-2}; 11.85 ms^{-2}; 12.90 ms^{-2}

Not Precise and not accurate

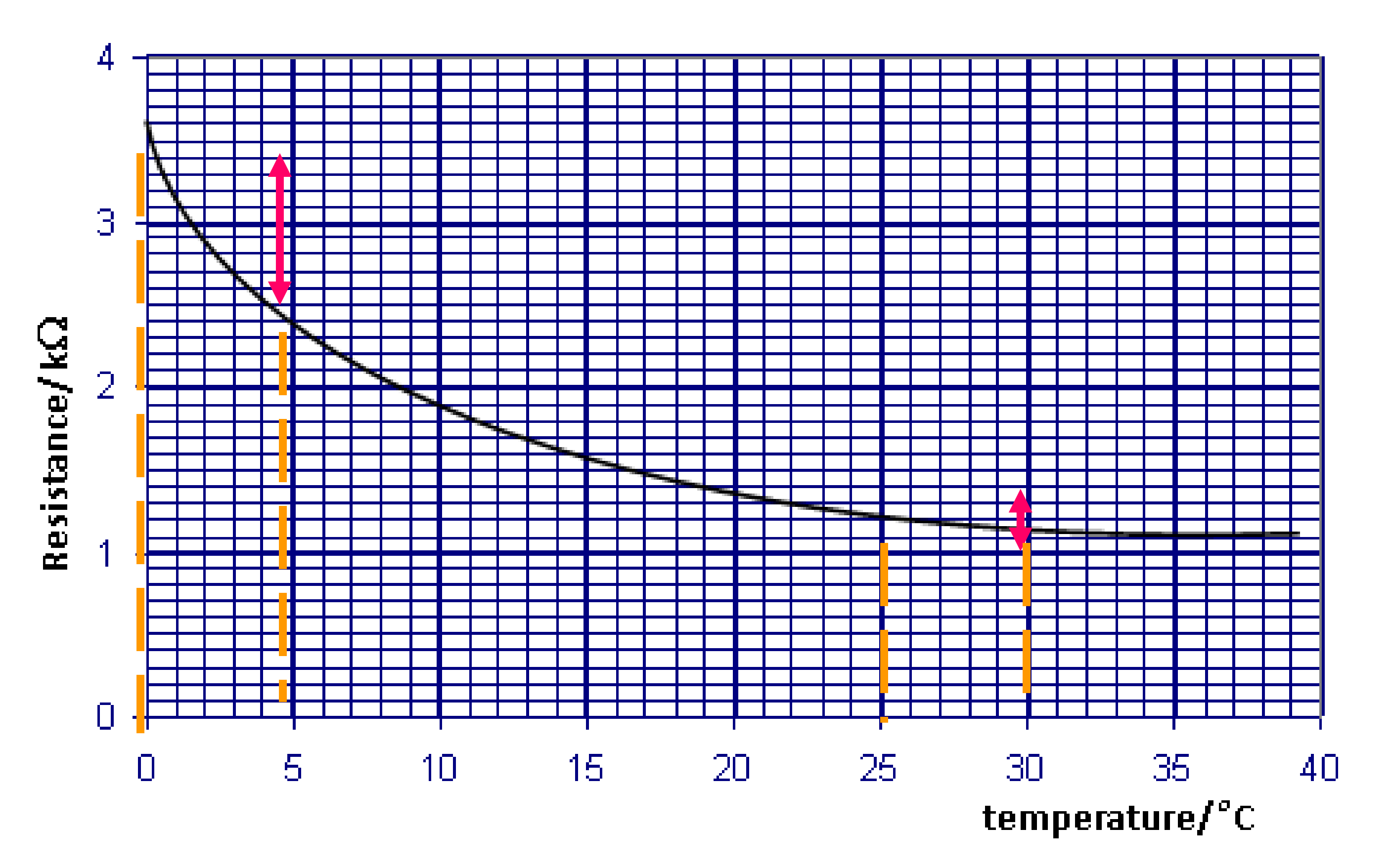
(3) 9.88 ms^{-2}; 9.81 ms^{-2}; 9.79 ms^{-2}; 9.87 ms^{-2}; 9.89 ms^{-2}

Precise and accurate

Sensitivity & calibration curve

A measuring device is said to be sensitive if it shows a large deflection over a small change in the quantity to be measured.

Thermistor
T ↑ R ↓
Sensitive for low temperature



Uncertainty / error of measurement

- Uncertainty of **measured** quantities => determined from instruments

  Length – metre rule - ± 0.1 cm

- Uncertainty of **calculated** quantities => determined from the equations

  Area – length & width

Uncertainty

- **Absolute uncertainty (from instrument), e.g. Δd**
- **Fractional uncertainty, e.g. $\Delta d/d$**
- **Percentage of uncertainty, e.g. $\Delta d/d \times 100\%$**

ONE S.F

Accepted up to **two** S.F

$y = a \pm b$

Quantities *a* and *b* are measured.

uncertainty of y, that is Δy, is calculated by:

$$\Delta y = \Delta a + \Delta b$$

Example:

initial temperature *b* = $(34.5 \pm 0.1)^o$ C

final temperature , *a* = $(18.0 \pm 0.1)^o$ C

Determine the magnitude of change in temperature with its uncertainty ΔT.

Solution

initial temperature *b* = $(34.5 \pm 0.1)^o$ C

final temperature , *a* = $(18.0 \pm 0.1)^o$ C

Change in temperature T = $|a - b|$ = 16.5

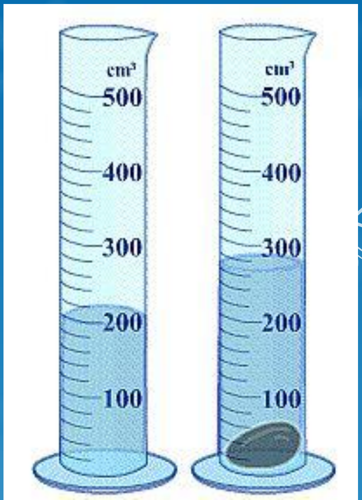
$\Delta T = \Delta a + \Delta b = 0.1 + 0.1 = 0.2$ (not 0.20)

Thus, T = $(16.5 \pm 0.2)^o$ C

Consistent in decimal places

Uncertainty - One sig. fig.

Try this !



Example: the volume of a sphere is determined by water displacement method.

initial volume *b* = (50.0 ± 0.5) cm ^{3}

final volume, *a* = (72.5 ± 0.5) cm ^{3}

Determine the volume of the sphere with its uncertainty ΔV.

Answer : (23 ± 1) cm ^{3}

No decimal places

Uncertainty - One sig. fig.

$y = ab$ or $y = a/b$

Quantities *a* and *b* are measured.

uncertainty of y, that is Δy, is calculated by:

$$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$$

Example: mass and volume of a sphere are measured as follows:

Mass $m = (29.2 \pm 0.1)$ g

volume, $V = (23 \pm 1)$ cm ^{3}

Determine the density of the sphere its uncertainty $\Delta\rho$.

Solution

Mass *m* = (29.2 ± 0.1) g

volume, *V* = (23 ± 1) cm ^{3}

Density ρ = m/V = 29.2/23 = 1.2695

$$\frac{\Delta\rho}{\rho} = \frac{\Delta m}{m} + \frac{\Delta V}{V} = \frac{0.1}{29.2} + \frac{1}{23}$$

$\Delta\rho$ = 0.06

Thus, ρ = (1.27 ± 0.06) g cm^{-3}

$y = k\,a^{n}$; k & n are constants

Constant k is not measured and hence, it does not have an error.

If n =3, then y = k x a x a x a

$$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta a}{a} + \frac{\Delta a}{a} + \ldots$$

$$\frac{\Delta y}{y} = |n| \frac{\Delta a}{a}$$

Example:

Length of a cube *L* = (5.0 ± 0.1) cm

Volume V = L^3

$$\frac{\Delta V}{V} = 3\frac{0.1}{5.0}$$

ΔV = 8

Thus, V = (125 ± 8) cm^3

Rounding off to the nearest tens or hundreds

- **(125 ± 10) -> (130 ± 10)**
- **(12596 ± 100) -> (12600 ± 100)**

Try this!

The length of a piece paper is measured as (297 ± 1) mm, its width (209 ± 1) mm.

Calculate:

i. fractional uncertainty in its length

ii. percentage of uncertainty in its length

iii. area with its uncertainty

Answer A = (62100 ± 500) mm^2

Any questions ?