Chapter 1 – Measurement

1.1 What is Physics?

Physics: study of natural world

- Major topics:
  1. General Physics
  2. Thermal Physics
  3. Light
  4. Waves and Sound
  5. Electricity and Magnetism
- Related to 2 main ideas
  1. Matter
  2. Energy

1.2 Physical Quantities and SI Units

Physical quantity consists of:

1. **Numerical magnitude**
2. **Unit**

7 base quantities

SI units: from International System of Units

Base quantity	SI unit	Symbol
Length	metre	**m**
Mass	kilogram	**kg**
Time	second	**S**
Electric current	ampere	**A**
Thermodynamic temperature	kelvin	**K**
Luminous intensity	candela	**cd**
Amount of substance	mole	**mol**

Derived quantities

- physical quantities derived from base quantities
- Examples
  (a) Speed (m/s)
  (b) Area (m^2)
  (c) Volume (m^3)
  (d) Density (kg/m^3)
  (e) Force (N/m^2)

Prefixes – more convenient, less risk of miscounting

Factor	Prefix	Symbol
10^{9}	**giga**	G
10^{6}	**mega**	M
10^{3}	**kilo**	k
10^{-1}	**deci**	d
10^{-2}	**centi**	c
10^{-3}	**mili**	m
10^{-6}	**micro**	μ
10^{-9}	**nano**	n

Standard form:
a × 10^{n} where 1 ≤ a < 10

1.3 Measurement of Length

Magnitudes of sizes of common objects

Common objects	Magnitude in size (m)
Planet Earth (diameter)	10^{7}
Moon (diameter)	10^{6}
Height of tall mountain	10^{3}
Length of football field	10^{2}
Height of chair	10^{-1}
Width of paper	10^{-4}
Size of human cell	10^{-6}
Size of large molecule	10^{-9}
Size of an atom	10^{-10}

Measuring instruments

Instrument	Range	Precision (cm)
1. **Measuring tape**	0 – 5 m	0.1
2. **Metre rule**	0 – 1 m	0.1
3. **Vernier calipers**	0 – 15 cm	0.01
4. **Micrometer screw gauge**	0 – 2.5 cm	0.001

Metre rule and tape measure

Precision: smallest unit an instrument can measure

Avoid measurement errors:

1. **Parallax errors**: line of sight perpendicular to rule
2. Wear and tear: zero mark unsuitable for measuring purposes
   → measure from another point, subtract from final reading
3. Take several readings, calculate average

Measurement errors

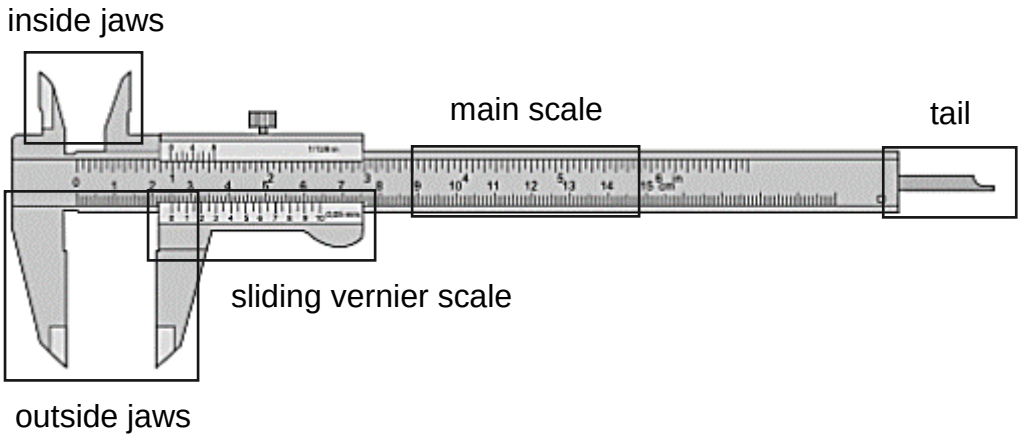
Types

Random error	**Systematic error**
Unpredictable	Predictable
Minimised by taking average of multiple readings	Eliminated by mitigating against sources of error
1) Parallax error 2) Estimate last digit of instrument reading	1) Parallax error 2) Zero error

Explanation

Type of error	Explanation	Causes
1. **Random error**	• Occur in all measurements • Unpredictable • Reduced by repeating measurements, obtain average	1) **Estimation of last figure** of reading (inadequate/low precision) 2) Limitation in **experimental techniques** • human reaction error – stopwatch • improper alignment of optical pin with image formed by glass block 3) **Unpredictable conditions** / changes in experiment → Manufacturing inconsistency – thickness of test tube vary along length
2. **Systematic error**	Consistent of underestimation / overestimation of reading	1) Error / **imperfection of equipment** → Zero error of instrument • check before & after measuring • account it when calculating actual length 2) **Wrong method** / technique • Wrong meniscus level when obtaining burette readings • Parallax error – reading instrument at angle (consistently high / low reading)

Vernier calipers



Parts

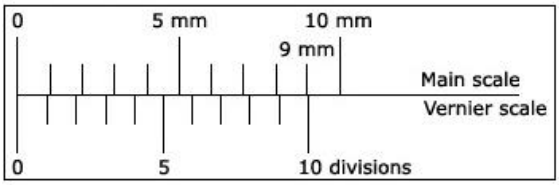
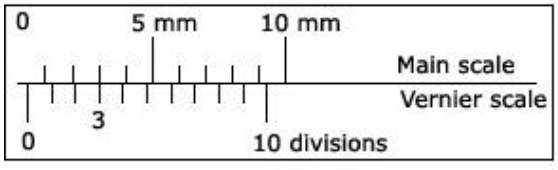
Part	Usage
1. **Main scale**	Read measurement
2. **Sliding vernier scale**	Read fraction of smallest interval
3. **Inside jaws**	Measure internal diameter of object
4. **Outside jaws**	Measure external diameter of object
5. **Tail**	Measure depth of object

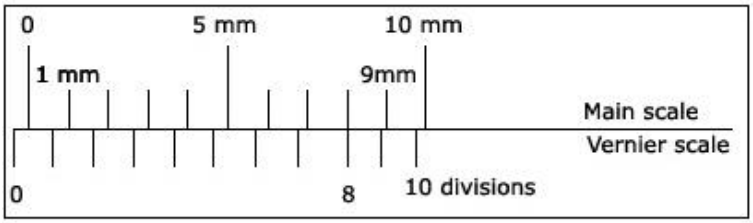
How to use:

1. Read main scale which is immediate left of zero mark on vernier scale
   → reading: x cm
2. Find the y^{th} vernier mark which coincides with marking on main scale
   → reading: 0.0y cm
3. Diameter = (x + 0.0y) cm

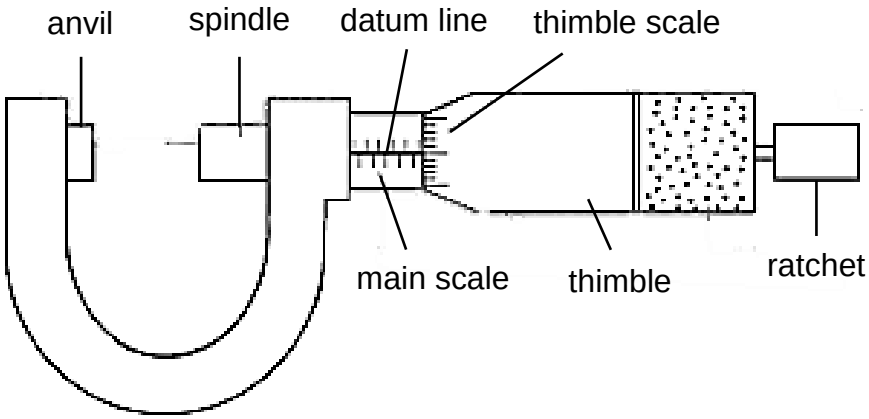
Check and correct zero errors

→ corrected reading = observed reading – zero error

Type	Observation
1. No zero error	
2. Positive zero error	

3. Negative zero error	

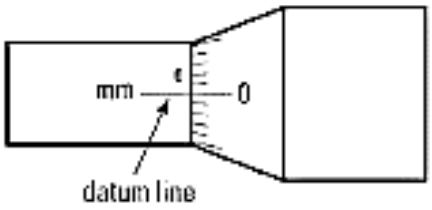
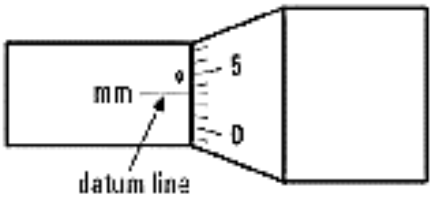
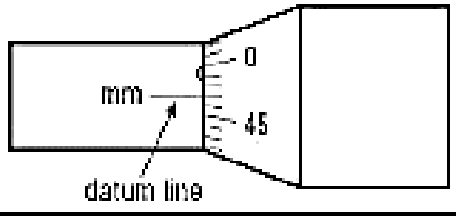
Micrometer screw gauge



How to use:

1. Read main scale reading to the immediate left of thimble edge
   → reading: x mm
2. Find thimble reading y in line with datum line
   → reading: 0.y mm
3. Length = (x + 0.y) mm

Check and correct zero errors
→ corrected reading = observed reading – zero error

Type	Observation
1. No zero error	
2. Positive zero error	
3. Negative zero error	

1.4 Measurement of Time

How to measure time

Observation of natural events – repeat at regular intervals

Observation	Period	Explanation
1. **Seasons**	year	1) Spring 2) Summer 3) Autumn 4) Winter
2. **Phases of the Moon**	month	Full moon → crescent → full moon
3. **Sunsets**	day	Sun sets each day
4. **Position of the Sun**	time of day	**Sundial**: position of shadow cast by Sun differs according to time of day • Noon: Sun high in sky • Evening: Sun low in western sky

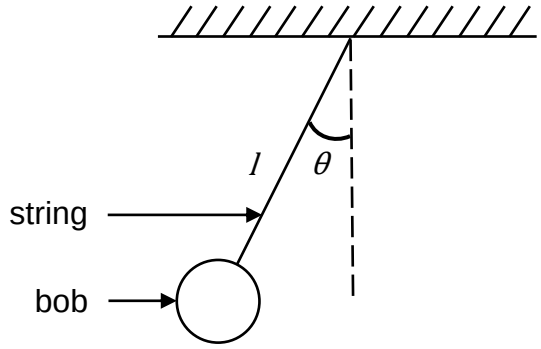
Pendulum

Pendulum swings freely → move back and forth at regular intervals

- **oscillation**: complete to-and-fro motion
- **period**: time taken for 1 complete oscillation

Formula for period of pendulum

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



T = period
π = pi
l = length of pendulum
g = gravitational field strength

Factors affecting period

1. length of pendulum
2. gravitational field strength

[mass does not affect period]

Procedure to measure period of pendulum

1. Set the pendulum into oscillation – displace pendulum bob to one side by angle θ, release it
2. Start recording time when the pendulum passes the equilibrium
3. Measure the time taken twice, t_1 and t_2 for the pendulum to make 20 oscillations
4. Determine the average time, t for 20 oscillations

$$t = \frac{t_1 + t_2}{2}$$

5. Determine period of pendulum, T

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

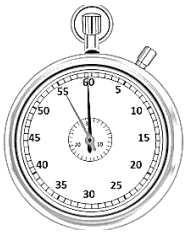
Atomic clock: precise timekeeping device which modern timepieces are calibrated using

Instruments to measure time

Instruments

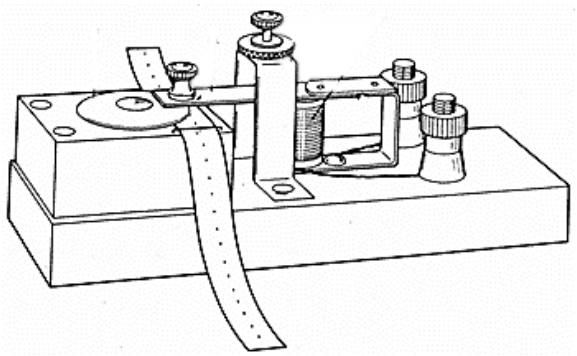
Instrument	Explanation
1. **Pendulum clock**	Keep time using pendulum's periodic swing
2. **Clocks**	Use **quartz crystals** 1) Small 2) Accurate 3) Little electrical energy
3. **Stopwatches**	

Human reaction time



- Take stopwatch reading to 1 d.p.
  - Stopwatch precision: 0.01s
  - Stopwatch started & stopped by hand
- 0.3 – 0.5 s

Ticker tape timer: study motion of moving object



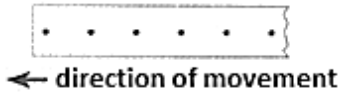
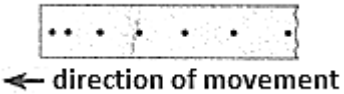
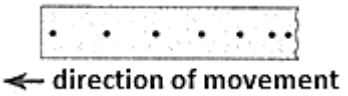
- Constant interval: 50 dots / second
- Speed measurement
  1. Calculate total distance travelled, d
  2. Calculate number of intervals, n and thus the total time interval, t

     $t = 0.02\,n$

  3. Calculate average speed, v

     $v = \frac{d}{t}$

- Determine tape pattern of trolley

Tape pattern	Motion of trolley	
	Distance per unit interval	Speed
 ← direction of movement	same	constant
 ← direction of movement	increasing	increasing (accelerating)
 ← direction of movement	decreasing	decreasing (decelerating)