3.1 Measurements and their errors

3.1.1 Use of SI units and their prefixes

- SI units

Quantity	Unit	Symbol
Mass	kilogram	kg
Length	metre	m
Time	second	s
Current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol

- Prefixes

Name	Symbol	Multiplier
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}
Femto	f	10^{-15}

3.1.2 Limitation of physical measurements

- Definitions

Term	Definition
Precision of a measurement	Precise measurements = very little spread about the mean value. Depends only on the extend of random error
Precision of an instrument / resolution	The smallest non-zero reading that can be measured
Repeatability	If the original experimenter can redo the experiment with the same equipment and method and get the same results it is repeatable
Reproducibility	If the experiment is redone by a different person or with different techniques and equipment and the same results are found, it is reproducible
Accuracy	How close a measurement or answer is to the true value

- Types of errors
  - Random errors
    - Affect precision, cause differences in measurements

        - Cannot get rid of all random errors
        - Reducing random errors
            - Take at least 3 repeats and calculate a mean
            - Use computers/data loggers/cameras to reduce human error and enable smaller intervals
            - Use appropriate equipment
    - Systematic errors
        - Affect accuracy
        - Occur due to the apparatus or faults in the experimental method
        - Causes all results to be too high or too low by the **same amount** each time
        - Types
            - Zero error: balance not zeroed correctly (all increase / decrease by the same amount)
            - Parallax error: reading the scale at a different angle than parallel
        - Reducing systematic errors
            - Calibrate the apparatus by measuring a known value
            - Correct for background radiation for radiation experiments
            - Read the meniscus at eye level
            - Use controls in experiments
- Uncertainty of measurements
    - The bounds in which the accurate value can be expected to lie
    - Absolute uncertainty: uncertainty given as a fixed quantity e.g. 7 ± 0.6 V
    - Fractional uncertainty: uncertainty as a fraction of the measurement e.g. $7 \pm \frac{3}{35}$ V
    - Percentage uncertainty: uncertainty as a percentage of the measurement e.g. $7 \pm 8.6\%$ V
    - To reduce percentage and fractional uncertainty: measure larger quantities
    - ★ Uncertainty can only be quoted to the **same precision** as the **measuring instrument / same number of decimal places as the data**
    - Work out uncertainty from the **number of decimal places** if not specified
- Reading
    - 1 value is found
    - Uncertainty in reading = $\pm$ smallest division
- Measurement
    - The difference between 2 values are found
    - Uncertainty in measurement = $\pm$ 2 × smallest division
- Uncertainty in different situations
    - Digital readings: uncertainty quoted or assumed to be $\pm$ the last significant digit
    - Repeated data: uncertainty = $\pm \frac{\text{range}}{2}$
- Uncertainty calculations
    - Adding / subtracting data = add absolute uncertainties
    - Multiplying / dividing data = add percentage uncertainties
    - Raising to a power = multiply percentage uncertainty by power
    - Uncertainties given to the same number of sig figs as the data
- Uncertainties on graphs
    - Uncertainties shown as error bars on graphs
    - A line of best fit on a graph should go through all error bars (excluding anomalous points)
- Uncertainty of gradient of line of best fit
    - Draw a steepest and shallowest line of worst fit (must go through all error bars)
    - Calculate the gradient of the line of best and worst fir
    - The uncertainty is the difference between the best gradient and the worst gradient (the one with the greatest difference in magnitude from the 'best' line of best fit)
    - $\text{percentage uncertainty} = \frac{|\text{best gradient} - \text{worst gradient}|}{\text{best gradient}} \times 100\%$
    $= \frac{\text{maximum gradient} - \text{minimum gradient}}{2} \times 100\%$
- Uncertainty of x and y-intercept

- $\text{percentage uncertainty} = \frac{|\text{best y intercept} - \text{worst y intercept}|}{\text{best y intercept}} \times 100\%$
  $= \frac{\text{maximum y intercept} - \text{minimum y intercept}}{2} \times 100\%$

3.1.3 Estimation of physical quantities

- Orders of magnitude
  - Powers of 10 which describe the size of an object
  - Give a value to the nearest order of magnitude = round to the nearest order of magnitude