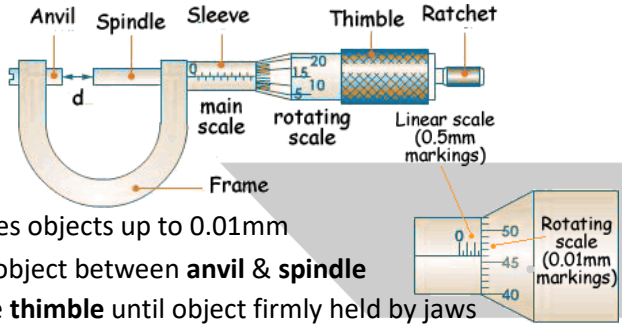
1 General Tips

- If range given e.g. 0 to 20, try to get measurement from a large spread of the range.
- Record all measurements needed to obtain final value including intermediary steps
- For example if a length *l* is derived from $l = l_2 - l_1$ then l_1 and l_2 should appear in the table.
- Column labelled with name of symbol and units

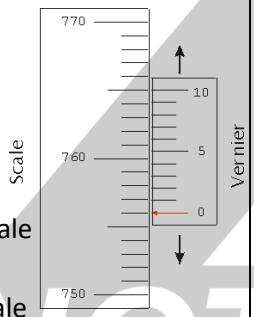
2 Micrometer Screw Gauge



Measures objects up to 0.01mm

- Place object between **anvil** & **spindle**
- Rotate **thimble** until object firmly held by jaws
- Add together value from main scale and rotating scale

3 Vernier Scale



Measures objects up to 0.1mm

- Place object on rule
- Push slide scale to edge of object.
- The sliding scale is 0.9mm long & is divided into 10 equal divisions.
- Check which line division on sliding scale matches with a line division on rule
- Subtract the value from the sliding scale ($0.09 \times Divisions$) by the value from the rule.

4 Systematic and Random Errors

- **Systematic error:**
  - Constant error in one direction; too big or too small
  - **Cannot** be eliminated by repeating or averaging
  - If systematic error small, measurement accurate
  - **Accuracy:** refers to degree of agreement between result of a measurement and true value of quantity.
- **Random error:**
  - Random fluctuations or scatter about a true value
  - **Can** be reduced by repeating and averaging
  - When random error small, measurement precise
  - **Precision:** refers to degree of agreement of repeated measurements of the same quantity (regardless of whether it is correct or not)

4 Uncertainties

For a quantity $x = (2.0 \pm 0.1)mm$

- **Absolute uncertainty** $= \Delta x = \pm 0.1mm$
- **Fractional uncertainty** $= \frac{\Delta x}{x} = 0.05$
- **Percentage uncertainty** $= \frac{\Delta x}{x} \times 100\% = 5\%$
- **Combining errors:**
  - When values **added or subtracted**, add absolute error
    If $p = \frac{2x+y}{3}$ or $p = \frac{2x-y}{3}$, then $\Delta p = \frac{2\Delta x + \Delta y}{3}$
  - When values **multiplied or divided**, add % errors
  - When values are **powered** (e.g. squared), multiply percentage error with power
    If $r = 2xy^3$ or $r = \frac{2x}{y^3}$, then $\frac{\Delta r}{r} = \frac{\Delta x}{x} + \frac{3\Delta y}{y}$

Instrument	Uncertainty
Ruler	0.1 cm
Protractor	2°
Stop watch	$\frac{\text{Max - Min}}{2}$
Ammeter	

5 Treatment of Significant Figures

- **Actual error:** recorded to only 1 significant figure
- Number of decimal places for a calculated quantity is equal to number of decimal places in actual error

Quantity	Justification
s.f. of calculated quantity	To s.f. of measure value
s.f. of measure value	To precision of instrument

- Always give calculated quantity s.f. equal or one less than measured value

6 Errors in Experiments

Error	Improvement
Water related experiment	
Hard to see surface due to refraction/meniscus effect	Use colored liquid
Labels get wet/ink runs	Use waterproof labels/ink
Ball related experiment	
Locating center of the ball when reading rule	Mark the center of the ball with marker
Inconsistent bounce	Use a flat surface
Fast-moving object experiment	
Difficult to judge when ball is at e.g. max displacement	Use sensor or record with camera frame by frame
Hard to see when object strikes floor	Use pressure sensor to stop timer
Difficult to judge end point	Mark distance with lines

Difficulty in deciding the toppling point	Move by increments/hold with newton-meter and tilt until F = 0
Releasing object from rest experiment	
Difficulty in releasing object due to e.g. force	Use a remote-controlled clamp/electromagnet
Rod falls sideways	Keep rod vertical/use guide
Oscillation experiment	
Time taken (T) too short or large uncertainty in T	Time object at max disp. with motion sensor/video & playback in slow motion /time more oscillations
Object doesn't swing freely/ friction between pivot and object	Make hole bigger/bush or bearing idea
Non-uniform osc.	Turn off fan (light object)
Oscillations die out quickly	Increase object thickness
Difficult to judge end/start/ complete swing	Use fiducial marker
Retort stand moves	Add weights/clamp
Electricity experiment	
Resistance/current fluctuating	Clean contacts
Voltmeter scale not sensitive enough	Use digital voltmeter
Wires not straight	Tape to ruler/hang weights off end/clamp wire
Force experiment	
Reach max force suddenly	Force sensor w/data logger
Weights move off path	Fix cotton loop to rule e.g. tape, glue
Pulley experiment	
Masses hit each other	Use larger pulley
Friction at pulley	Lubricate pulley
Uncertain starting position	Clamp / electromagnetic with steel
Moment experiment	
Rule hits bench	Project cylinder over bench / elevate apparatus
Ruler slips on support	Glue support to block
Magnetism experiment	
Effect of surrounding e.g. glass/magnetic materials	Use various materials to separate magnets & test if material affects results

Bench/ Ramp (Surface) related experiment	
Some parts of board rougher / surface uneven	Ensure same section of board used in each expt.
Board slips/unstable /supporting block topples	Clamp/fix to bench with tape/blu-tack
Difficult in pulling in line with board	use (long) piece of string to connect the newton-meter to the block
Heat loss experiment	
Heat lost through sides and /or Bottom	Lag/insulate/polystyrene container
Thermometer bulb not completely immersed	Use larger volume of water /use thermocouple/small temperature sensor
Resistor gives heat when switched off/temp. rises even after switching off	Wait until temp. reaches max before reading
Terminal velocity experiment	
May not have reached terminal velocity	Time over three markers constant
Light dependent experiment	
External light affects (LDR)	Conduct expt. in dark room
Length of tube changes when paper added	Make pre-slots in tube
Cylinders not aligned	Align on desk/rule
Difficult to hold together	Tape/clamp together

Errors in Apparatus

Error	Improvement
Meter rule	
Parallax error	Put colored paper behind/ eye-level perpendicular /extend mark to wood /shadow projection
Difficult to hold rule still	Mount ruler in stand
Difficult to measure because the ruler moves	Clamp rule / ensure rule is vertical using set square
Newton meter	
Difficult to pull Newton meter parallel to ruler/ bench	Ensure force parallel to ruler e.g. use a long string/pulley and weights
Difficult to judge reading on meter when detached: ruler moves suddenly/ force = 0 after detachment	Use Newton meter with a 'max hold' facility/video & playback or freeze frame/ use force sensor & logger
Difficult to zero Newton-meter when horizontal	Use system of pulley & weights/use force sensor with data-logger

Objects with unfixed diameter (Circular objects)	
Difficult to measure diameter because object flexible/not circular	Use Vernier calipers or micrometer screw gauge to measure average diameter
Difficult to form perfect sphere/diameter varied	Method to make uniform spheres/discs e.g. molds
Protractor	
Protractor "wobbles" / difficult to measure; container curved at the bottom/difficult to line up	Use protractor with horizontal line level to table top/freestanding or clamped protractor
Parallax error in θ	Use mirror scale

- **General:**
  - **Error:** two readings not enough
  - **Improvement:** take several readings and plot a graph