UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

LABORATORY REPORT PHYSICS 1 PNAP0123 SEM 1 2024/2025

Title of Experiment	MEASUREMENT AND UNCERTAINTY	
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EXPERIMENT 1: MEASUREMENT AND UNCERTAINTIES

OBJECTIVES:

1. To know and understand the utilization of apparatus to quantify the magnitude of a physical property.
2. To perform measurements using various measurement devices
3. Apply the ideas of accuracy and precision to a measured value.

APPARATUS:

1. Meter ruler
2. Vernier caliper
3. Micrometer screw gauge
4. Triple Beam Balance
5. Beaker
6. Wooden plane
7. Wooden wood

THEORY:

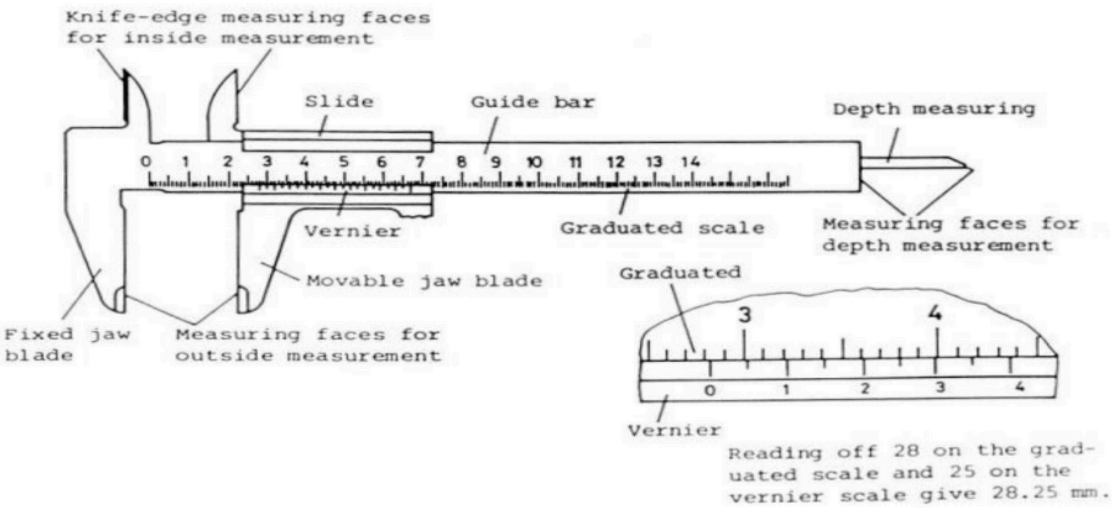
Physics is a qualitative science based on measurement of physical quantities. The comparison of any physical quantity with its standard unit is called Measurement. In the physics lab, there are many instruments that are used to measure different physical quantities.

(i) Meter ruler

A meter ruler, sometimes called a rule or line gauge, is an instrument used in geometry, technical drawing, printing, engineering and building to measure distances or to rule straight lines. It is a device which is used to measure length of different objects. A meter rule of length 1m is equal to 100 centimeters (cm). On meter rule each cm is divided further in to 10 divisions which are called millimeters (mm). So, a meter rule can measure up to 1 mm as smallest reading

(ii) Vernier caliper

The Vernier caliper was invented by a French mathematician called Pierre Vernier hence bearing his name Vernier. It is used for measuring the outside dimensions of small objects, inner diameters of tubes and holes and depth of the hollow object.The Vernier consists of a rule with an engraved main scale (MS) and a movable jaw with an engraved Vernier scale (VS). The span of the lower jaw is used to measure length and is particularly convenient for measuring the diameter of a cylindrical object. The span of the upper jaw is used to measure distances between two surfaces, such as the inside diameter of a hollow cylindrical object. The main scale is calibrated in centimetres with a millimetre least count, and the movable Vernier scale has 10 divisions that cover 9 divisions on the main scale. The left most mark on the Vernier scale is the zero mark (lower scale for metric reading and upper scale for inches). With the callipers closed, the zero mark of the Vernier scale coincides with the zero mark on the main scale for an error-free instrument.

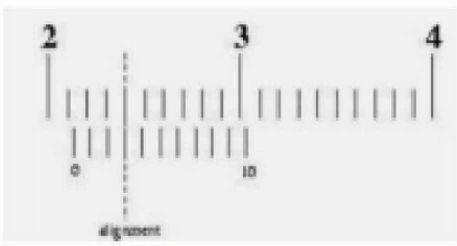


The concept of the least count is used to interpret a measurement made with the Vernier callipers. The least count (LC) of an instrument is the smallest measurement that can be taken accurately with it. The least count is given by:

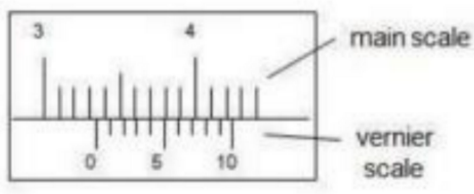
$$\text{Least count} = \frac{\text{Value of the smallest division on the main scale}}{\text{Total numbers of divisions on the vernier scale}}$$

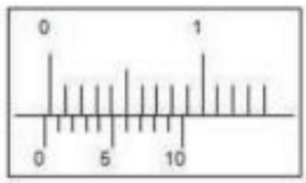
The length of an object is given as: Length = [MS + (VS x LC)].
MS is the main scale reading, and VS is the number of divisions of the Vernier scale coinciding with a main scale division.

If the Vernier calliper outputs a measurement reading of 2.13cm, this means that: The main scale contributes the main numbers and one decimal place to the reading. For example, 2.1cm whereby 2 is the main number and 0.1 is the one decimal place number. The Vernier scale contributes the second decimal place to the reading like 0.03cm. To obtain the main scale readings: look at the image below, 2.1cm is to the immediate left of the zero on the Vernier Scale, hence the main scale reading is 2.1cm. To obtain the Vernier scale reading: Look closely for an alignment of the scale lines of the main scale and Vernier scale. In the image below, the aligned line corresponds to 3. Hence, the Vernier scale reading 3 cm. considering the least count being 0. 01cm. Then this will read 2.1cm + (3cm x 0.01cm) = 2.13cm.



After making the measurement, one should check the zero of the Vernier callipers with the jaws completely closed. It is possible that through misuse the calliper is no longer zeroed and thus gives erroneous readings (systematic error). If this is the case, zero correction should be made for each reading.



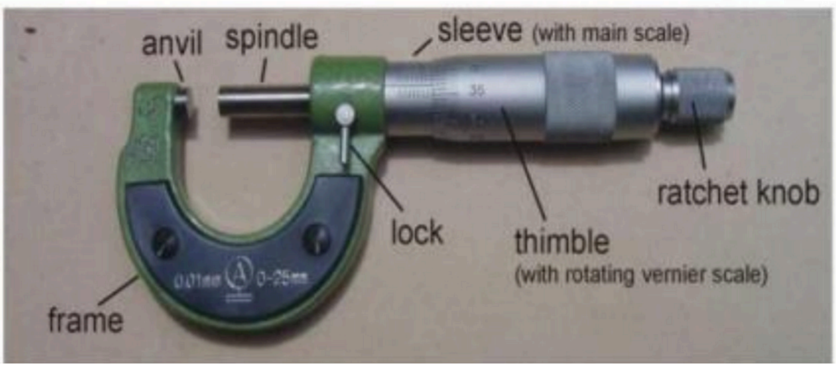


On the figure above, the reading on the top is the measurement obtained by reading at the bottom is the zero error. Find the actual measurement (get rid of the zero error in the measurement or take into account the zero error).

Measurement without zero error: 3.34 - (-0.04) = 3.38cm
Since the zero error is -0.04cm, this means that all measurements taken by the Vernier calipers will be smaller by 0.04cm. Hence, add 0.04 cm to all measurement. This means that once you have determined the nature of zero error (positive or negative) you can just subtract the zero error and be sure that your final answer is correct.

(iii) The Micrometer screw gauge

The Micrometer provides for accurate measurements of small lengths. It is used to measure even the smaller dimensions than the Vernier caliper. Particularly, it is convenient in measuring the diameters of thin wires and the thicknesses of thin sheets. The principle of the micrometer is that as a screw is turned by one revolution it advances a distance equal to the pitch of the screw. The Micrometer screw gauge uses an auxiliary scale (measuring hundreds of millimeter) which is marked on the rotary thimble. It consists of a movable spindle (jaw) that is advanced toward another, parallel-faced jaw (called an anvil) by rotating the thimble. The thimble rotates over an engraved sleeve (or "barrel") mounted on a solid frame. Most Micrometer screw gauges are equipped with a ratchet (ratchet handle is to the far right in the figure) that allows slippage of the screw mechanism when a small and constant force is exerted on the jaw. This permits the jaw to be tightened on an object with the same amount of force each time. Care should be taken not to force the screw (particularly if the Micrometer does not have a ratchet mechanism), so as not to damage the measured object and/or the Micrometer.



The axial main scale on the sleeve is calibrated in millimeters, and the thimble scale is calibrated in 0.01 *mm* (hundredths of a millimeter). The movement mechanism of the micrometer is a carefully machined screw with a pitch of 0.5 *mm*. The pitch of a screw, or the distance between screw threads, is the lateral linear distance the screw moves when turned through one rotation. The axial line on the sleeve main scale serves as a reading line. Since the pitch of the screw is 0.5 mm and there are 50 divisions on the thimble, when the thimble is turned through one of its divisions, the thimble moves (and the jaws open or close) 1/50 of 0.5 mm, or 0.01 *mm* ($1/50\ x 0.5mm = 0.01\ mm$).

One complete rotation of the thimble (50 divisions) moves it through 0.5 *mm*, and a second rotation moves it through another 0.5 *mm*, for a total of 1.0*mm*, or one scale division along the main scale. That is, the first rotation moves the thimble from 0.00 through 0.50 *mm*, and the second rotation moves the thimble from 0.50 *mm* through1.00*mm*.

The Least count of a screw gauge is the smallest distance moved by the tip of the screw when the screw turns through one division. Least count is equal to Pitch by Number of divisions on the circular scale.

$Least\ count = 1/100 = 0.01mm$

A micrometer reading contains two parts: The first part is contributed by the main scale on the sleeve and the second part is contributed by the rotating Vernier scale on the thimble

To obtain the first part of the measurement: look at the image above, you will see a number 5 to the immediate left of the thimble, his means 5.0mm. Notice that there is an extra line below the datum line, this represents an additional 0.5mm. So, the first part of the measurement is

$5.0 + 0.5 = 5.5mm$

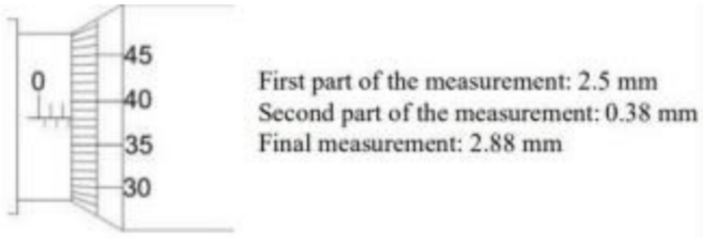
To obtain the second part of the measurement: look at the image above, the number 28 on the rotating Vernier scale coincides with the datum line on the sleeve. Hence, 0.28mm is the second part of the measurement.You just have to add the first part and second part of the measurement to obtain the micrometer reading:

5.5 + 0.28 = 5.78 mm

To ensure that you understand the steps above, here is one more example:

Experimental Errors

All measurements have uncertainties called experimental errors associated with them. Uncertainties in measurements arise due to the limited accuracy of every measuring instrument and the inability to read an instrument beyond some fraction of the smallest division thus the need to state the estimated uncertainty in a measurement.



If N independent measurements are made of the same quantity x and these are designated x_1 .... x_i .... x_N:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

The best estimate of the quantity x is given by the MEAN of the N measurements:

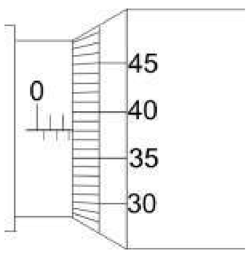
The deviation of any one of the readings, xi , is the difference between it and the mean value, $\bar{x}$:
(deviation)i = (δxi) = ($x_i - \bar{x}$). This is also known as the residual.
A good estimate of the uncertainty or experimental error in the mean is given by the mean deviation which is the mean of the moduli of N deviations, or by the standard error

mean deviation $\overline{\delta x} = \sum \left| \left(x_i - \bar{x} \right) \right| / N$

standard deviation $\sigma = \sqrt{\sum \left(x_i - \bar{x} \right)^2 / (N-1)}$

standard error $\Delta x = \sqrt{\sum \left(x_i - \bar{x} \right)^2 / N(N-1)}$

$= \sigma/\sqrt{N}$



The result is then expressed as: $x \pm \Delta x$

PROCEDURE:

1. The initial reading of the Vernier caliper is checked and recorded as the zero reading. If a zero correction is required, it is determined whether it is a positive or negative error.
2. The micrometer's initial reading is checked, and its zero reading is recorded. If necessary, it is indicated whether the error is positive or negative.
3. The longer dimension of the wooden plane is measured using a meter stick, Vernier caliper, and micrometer. The data is recorded in Table L1-2. The measured values are discussed in terms of accuracy and precision, with comparisons made between the different devices.
4. The thickness of the wooden plane is measured using a meter stick, Vernier caliper, and micrometer, and the data is recorded in Table L1-3. The accuracy and precision of the measurements are discussed, and the devices are compared.
5. The inner diameter (ID), outer diameter (OD), and depth of a beaker are measured in centimeters using a Vernier caliper, and the results are recorded in Table L1-4. The measurements are discussed in terms of accuracy and precision.
6. The mass of a wooden block is measured in grams using a triple-beam balance, and the data is recorded in Table L1-5. The accuracy and precision of the results are evaluated.

RESULTS:

Table L1-1

Zero correction	**Vernier Caliper**	**Micrometer**
	+ 0.004	- 0.05

Table L1-2

	Meter Ruler (±0.05cm)		Vernier Caliper (±0.002cm)		Micrometer (±0.001cm)	
	Measurement	Deviation	Measurement	Deviation	Measurement	deviation
1.	10.10	0.07	10.022	0.001	-	-
2.	10.00	0.03	10.024	0.001	-	-
3.	10.00	0.03	10.022	0.001	-	-
Average	10.03± 0.04cm		10.023±0.001 cm		-	

Table L1-3

	Meter Ruler (±0.05cm)		Vernier Caliper (±0.002cm)		Micrometer (±0.001cm)	
	Measurement	Deviation	Measurement	Deviation	Measurement	deviation
1.	1.20	0.03	1.146	0.008	11.99	0.00
2.	1.30	0.07	1.148	0.006	12.02	0.03
3.	1.20	0.03	1.168	0.014	11.95	0.04
Average	1.23±0.04 cm		1.154±0.009 cm		11.99±0.023cm	

Table L1-4: Measurement using Vernier Caliper

	ID		OD		Depth	
	Measurement	Deviation	Measurement	Deviation	Measurement	deviation
1.	4.524	0.066	5.410	0.119	7.446	0.107
2.	4.406	0.052	5.572	0.043	7.264	0.075
3.	4.444	0.014	5.604	0.075	7.308	0.031
Average	4.458±0.044 cm		5.529±0.079 cm		7.339±0.071 cm	

Table L1-5: Measurement using Triple- Beam Balance

	Mass (±0.05g)	
	Measurement	Deviation
1.	16.0	0.0
2.	15.9	0.1
3.	16.1	0.1
Average	16.0±0.7 g	

DISCUSSION:

Table L1-2

The Vernier caliper has more precise measurements (±0.001cm) compared to meter rule (±0.04cm), making it the best measurement device for small and accurate measurements. There is no reading for micrometer as it is too small to be measured.

Table L1-3

The micrometer has the highest level of precision, making it the most accurate tool for small-scale measurements in this experiment.. It is followed by Vernier Caliper, which suggests it provides higher precision than the meter ruler but may still be influenced by user handling or positioning. Meter ruler has the least deviation and is only appropriate for measurements of larger dimensions.

Table L1-4

The Vernier caliper is best suited for measuring the beakers inner and outer diameters as well as its depth. The internal diameter (ID) showed deviations of ±0.0044 cm, indicating some variation in the measurements. The outer diameter (OD) had a lower deviation of ±0.079 cm, demonstrating greater precision. Depth measurements had the smallest deviation at ±0.071 cm, reflecting high precision for this dimension.

Table L1-5

The triple-beam balance has a deviation of ±0.07 g, which suggests that the balance provides precise results within the specified tolerance.

This experiment shows that measurement of various lengths can be performed using a meter ruler, vernier caliper and micrometer. Based on the accuracy and precision due to the different devices on your measured quantities, and the uncertainty of each device, there are different suitability and practicality of employing each device depending on the kind of measurement to be performed.

meter ruler: The meter ruler is best suited for measuring larger objects where high precision and accuracy are not critical. Its practicality lies in its ease of use for general measurements, and it provides decent accuracy with a deviation of 0.04 cm. This makes it sufficient for tasks where slight variations in length are acceptable.

vernier caliper: The Vernier caliper is more suitable for tasks requiring higher accuracy and precision, particularly for smaller dimensions or when measuring features like thickness and internal diameters. It produced a minimal deviation of 0.001 cm, indicating its versatility and relatively high precision, making it ideal for more detailed measurements.

micrometer: The micrometer offers the highest level of precision (±0.005 cm). Its ability to provide very fine measurements makes it essential for measuring very small objects or dimensions where even the smallest variations are significant. It is best employed when extremely high precision is required, though it is less practical for larger objects due to its limited range.

DATA ANALYSIS:

1. By using one of the measured values above, show how you can find the percentage uncertainty of the measurement. State clearly your selected measurement.

The selected measurement is triple beam balance.

$$\text{Percentage uncertainty} = \frac{0.1}{16} \times 100\% = 0.625\%$$

2. Compute the surface area of the wooden plane confined by the length and thickness which you have measured using vernier caliper. Express your answer together with its uncertainty in correct number of significant figures.

$$\text{Area} = 10.023 \times 1.154 = 11.57$$

$$\begin{aligned}\frac{\Delta S}{11.57} &= \frac{0.001}{10.023} + \frac{0.009}{1.154} \\ &= 0.01\% + 0.78\% \\ &= 0.79\% \\ \Delta S &= 11.57 \times 0.79\% \\ &= 0.091\end{aligned}$$

$$Area = (11.57 \pm 0.09)cm^2$$

PRECAUTIONARY STEPS:

Identify two possible sources of errors in this experiment. Suggest ways to overcome these errors.

Parallax Error: Ensure that the eyes are aligned directly and perpendicular to the scale
Zero Error: Carefully verify the zero point before each measurement

CONCLUSION:

In conclusion, this experiment provided valuable insights into various measurement instruments and their principles of operation, leading to reliable results. The meter ruler proved to be suitable for measuring larger objects where high precision is not required, while the Vernier caliper and micrometer were more appropriate for smaller objects demanding higher accuracy. The micrometer, in particular, delivered the most precise readings due to its minimal uncertainty. The use of the triple-beam balance demonstrated its reliability for precise mass measurements, reinforcing its suitability for accurate determinations in future laboratory experiments.

Through hands-on practice with these devices, we gained a deeper understanding of measurement principles and uncertainties, enabling us to effectively evaluate our measured values and identify potential sources of error. This experience emphasized the importance of meticulous measurement techniques and highlighted how uncertainties affect scientific data collection.

EXPERIMENT 1: MEASUREMENT AND UNCERTAINTIES

Pre-Lab Exercise
Please answer the following questions and show your work.

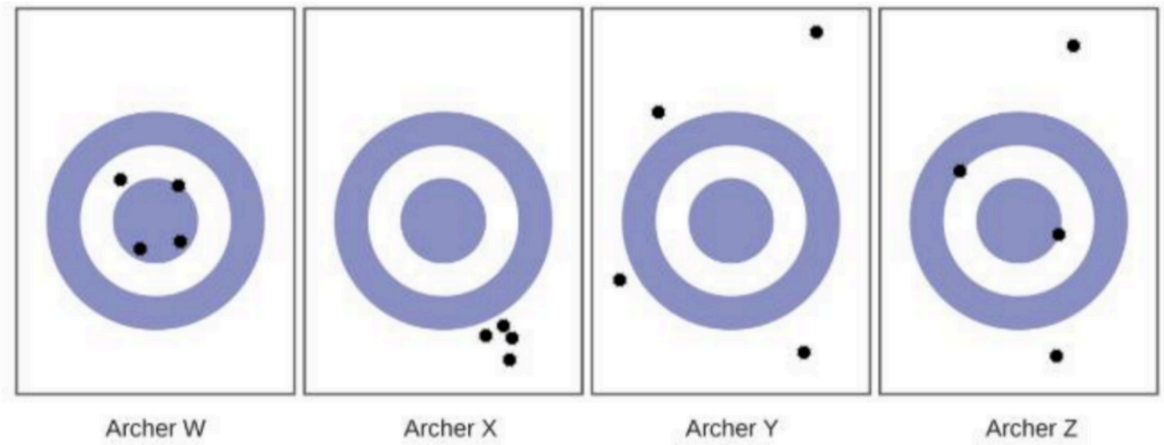


Figure L1-1

1. Consider the results of the archery contest shown in this Figure L1-1.

(a) Which archer is most precise? [1]

Archer X

(b) Which archer is most accurate? [1]

Archer W

(c) Who is both least precise and least accurate? [1]

Archer Y

2. A metal rod has known a length of 1.23 cm and you measure its length using three different measuring devices (A, B, and C), you obtain the following data:

Data Table: Measured Lengths of Device A, B, and C

	Device A (cm)	Device B (cm)	Device C (cm)
Trial 1	1.43	1.24	1.19
Trial 2	1.43	1.23	1.23
Trial 3	1.43	1.25	1.22
Trial 4	1.42	1.22	1.26

(a) Calculate the mean value of each device. Give your final answer in correct number of significant figure [6]

Device A

$$\tilde{X} = \frac{1.43 + 1.43 + 1.43 + 1.42}{4} = 1.4275cm \approx 1.43cm$$

Device B

$$\tilde{X} = \frac{1.24 + 1.23 + 1.25 + 1.22}{4} = 1.23 \approx 1.24cm$$

Device C

$$\tilde{X} = \frac{1.19 + 1.23 + 1.22 + 1.26}{4} = 1.225 \approx 1.23cm$$

(b) Determine quantitively the accuracy for each device [6]

Device A

$$\frac{1.43 - 1.23}{1.23} \times 100\% = 16.26\%$$

Device B

$$\frac{1.24 - 1.23}{1.23} \times 100\% = 0.81\%$$

Device C

$$\frac{1.23 - 1.23}{1.23} \times 100\% = 0\%$$

(c) Determine quantitively the precision of each device [6]

Device A

$$\sqrt{\frac{(1.43 - 1.43)^2 + (1.43 - 1.43)^2 + (1.43 - 1.43)^2 + (1.43 - 1.43)^2}{4 - 1}} = 0.0058$$

Device B

$$\sqrt{\frac{(1.24 - 1.24)^2 + (1.23 - 1.24)^2 + (1.25 - 1.24)^2 + (1.22 - 1.24)^2}{4 - 1}} = 0.0141$$

Device C

$$\sqrt{\frac{(1.19 - 1.23)^2 + (1.23 - 1.23)^2 + (1.22 - 1.23)^2 + (1.25 - 1.23)^2}{4 - 1}} = 0.0294$$

(d) Based on the answers in question (b) and (c), which measuring device is “best” to used? [1]

Device B; It has a balance of both good accuracy and precision.

3. The radius of a spherical ball is measured to be r= 2.89 ± 0.09 m. The volume of this ball is to be determined.

(a) Calculate the volume of this ball [2]

$$
\begin{aligned}
V &= \frac{4}{3}\pi(2.89)^3 \\
&= 101.11 \\
&\approx 101\text{m}^3
\end{aligned}
$$

(b) Determine the uncertainty in the volume. Express the volume of the ball along with its uncertainty. [3]

$$V_{min} = \frac{4}{3}\pi(2.89 - 0.09)^3 = 91.952$$
$$V_{max} = \frac{4}{3}\pi(2.89 + 0.09)^3 = 110.850$$
$$\frac{1}{2}(110.850 - 91.952) = 9.45$$
$$\therefore (101.11 \pm 9.45)m^3$$

(c) Determine the percentage uncertainty of the volume of the ball [2]

$$\frac{9.45}{101.11} \times 100\% = 9.35\%$$

Total Marks [29]