INTRODUCTION TO BASIC LAB INSTRUMENTS: THEIR USAGE, LEAST COUNT, ERROR ANALYSIS AND GRAPH PLOTTING

"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."

Richard P. Feynman

Introduction: Conducting experimental work involves far more than just recording a set of observations. An experimenter must first possess a deep understanding of the physical principles that form the foundation of the experiment. It is essential to clearly grasp the aim or objective of the experiment and the methods by which it should be executed. Furthermore, a solid theoretical background regarding the entity or parameter being investigated is crucial. Without this knowledge, the experimenter's efforts may yield little meaningful insight. Therefore, a comprehensive understanding of the underlying physical principles is the foremost prerequisite for any successful experimental endeavor.

First Step to Physics Laboratory: Physics governs every event around us, making it essential for students to keenly observe and understand the cause-and-effect relationships that manifest as phenomena. Each phenomenon in physics is governed by specific laws, which are verified through experiments. These experiments, using precise instruments, form the foundation of physics. The success of any experiment depends on the accuracy and reliability of measurements.

In physics practicals, experiments are designed to achieve specific quantitative results: determining physical constants like gravity (g), measuring quantities such as the focal length of a lens, comparing values like the EMFs of two cells, and verifying laws like Ohm's law and Newton's law of cooling.

While these laws and constants have already been accurately established, the purpose of student laboratory work is to familiarize them with the instruments they study in theory and to develop the habit of taking careful readings, aiming to achieve results that closely match standard values with minimal error.

Getting Ready For an Experiment:

1. **Study the Theory:** Read the experiment's theory multiple times until you fully understand the procedure and purpose.
2. **Visualize Measurements:** Clearly picture the measurements and observations, focusing on those that require extra precision.
3. **Gather Apparatus:** List and collect all necessary equipment before starting.
4. **Prepare Observation Tables:** Create a table to record observations in sequence to avoid missing data.
5. **Check Instruments:** Verify the accuracy and constants of tools like screw gauges, callipers, and spherometers.

6. **Test Time Devices:** Ensure stopwatches or clocks are accurate and thermometers are unbroken.
7. **Inspect Optical Instruments:** Confirm telescopes and microscopes have clear cross-wires and are properly focused.
8. **Examine Electrical Instruments:** Ensure batteries are charged, and galvanometers, ammeters, and voltmeters are correctly calibrated.
9. **Check Electrical Connections:** Ensure wires are tightly stretched, clean, and properly soldered.
10. **Sketch Circuit Diagrams:** Draw and get circuit diagrams checked by a teacher before making connections.
11. **Draw Graphs:** Use large graphs with suitable scales, and express results in proper units with justified significant figures.
12. **Use Accurate Methods:** Prefer methods that balance two effects for greater accuracy.
13. **Comprehensive Observations:** Make observations over a wide range, and extrapolate graphs with broken lines if needed.

- **BASIC INSTRUMENTS AND THEIR USES, LEAST COUNT.**

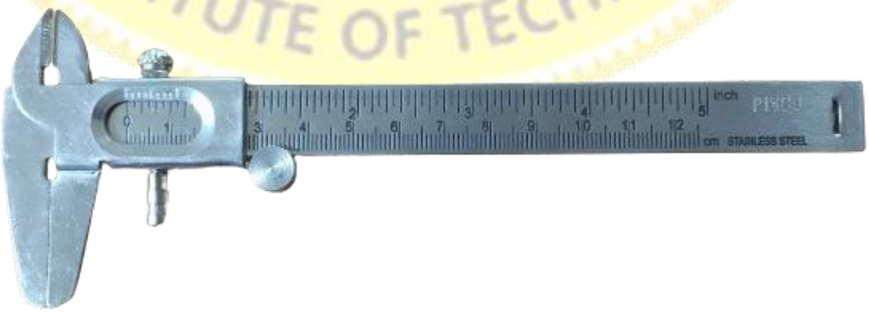
  In our physics laboratory we use some basic instruments to measure fundamentals quantities like length, mass, time, temperature etc. It is very much important to us to know up to what accuracy the instruments can measure a quantity. ***The minimum value that an instrument can measure is known as the least count of the instrument.***

  In our laboratory we use instruments like meter scale, Vernier Callipers, Screw Gauge, Spherometer, Thermometer, Ammeter and Voltmeter etc.

  In order to measure radius, thickness and curvature very accurately , we use Vernier calliper, screw gauge and spherometer respectively.

1. **VERNIER CALLIPERS:**

   To measure length, breadth, thickness, inner or outer radius we can use Vernier callipers.



The main scale is divided into millimetres. The Vernier scale has 10 divisions on it which together are equal to 9 scale divisions i.e. to 9 mm. ***The difference between***

one scale division and one Vernier division is called the Vernier constant of the instrument.

Now, 10 vernier division **(V.D) =** 9 main scale division **(S.D)**

$\therefore \mathbf{1\ V.D\ =\ \frac{9}{10}\ S.D = \frac{9}{10}\ mm\ =\ 0.9\ mm}$

$So, vernierconstant\ or\ leastcount = (1S.D - 1V.D) = (1\ - 0.9)\ mm\ =\ 0.1\ mm\ =\ 0.01\ cm$

So, the least count or Vernier constant of the Vernier Callipers is 0.01 cm.

This can also be alternatively calculated as :

Least Count (LC) = $\frac{\textit{Value of 1 main scale division}}{\textit{Total number of divisions on vernier scale}} = \frac{1\ mm}{10} = \mathbf{0.1\ mm = 0.01\ cm}$

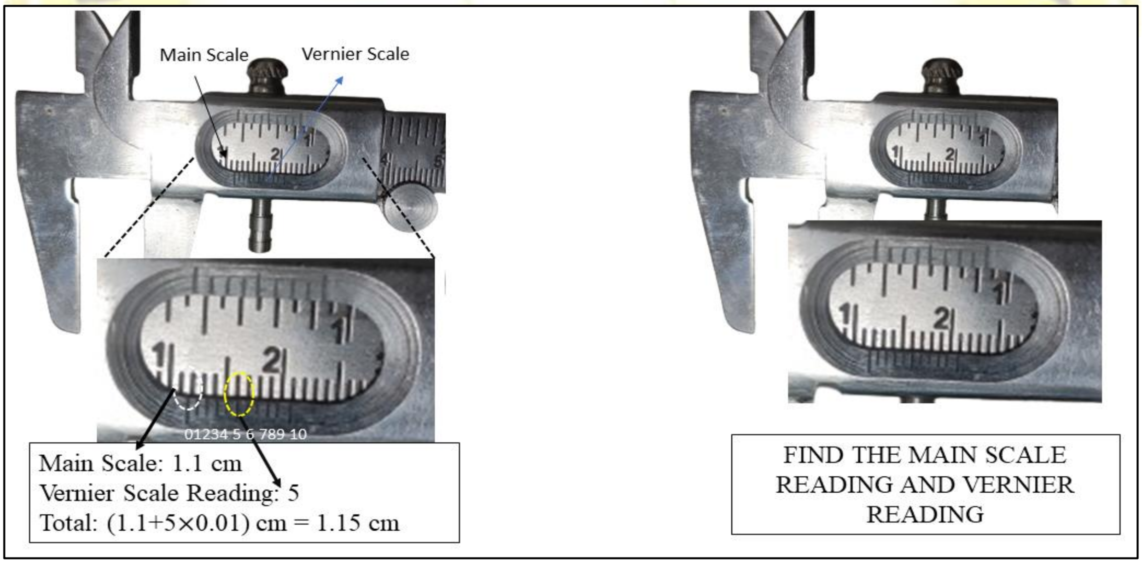
How to read Vernier:

The main scale reading in a Vernier callipers: The first division of Vernier will cross certain value in main scale. Then the value in the main scale shows the main scale reading.

Vernier scale Reading: The div in the Vernier scale which exactly coincides with one of the main scale division is the Vernier scale reading.

Total Reading: If the main scale reading in slide calliper is M and Vernier scale reading (V.S.R) is X, then your total reading is T= M+(V.S.R)*LC (write in cm).

<u>**Below are some examples:**</u>



2. **SCREW GAUGE:**

It is a device for measuring with considerable accuracy, the diameters of wires. It consists essentially of a screw, with a uniform pitch, which moves in a nut. The wire is held between the jaws A and B which should then be pressed just tight. The screw gauge is provided with two scales a linear scale called as pitch scale usually graduated in millimetres and a circular scale

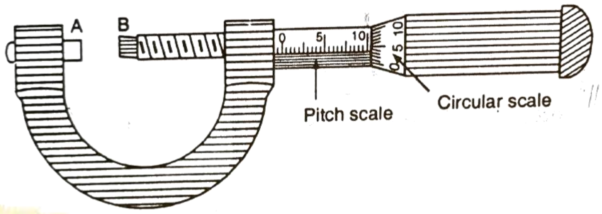


Fig. 1.3. Screw gauge.

divided into 100 equal parts. When the s––crew is given one complete rotation, it advances or recedes by one millimetre. This distance is called the **pitch** of the screw.

∴ **Least Count of the screw gauge =** $\frac{pitch}{Total\ number\ of\ divisions\ on\ circular\ scale} = \frac{1\ mm}{100} = \mathbf{0.01}\ mm.$

It means that the instrument can measure up to 0.01 mm. The accuracy of a screw gauge is more than that of a Vernier callipers.

Note: *The crew must always be turned either forwards only (or backwards only) to avoid the* ***back-lash error****, which is produced by the slipping of the screw in the nut.*

3. SPHEROMETER:

It is a device for measuring the thicknesses of thin plates and the radii of curvature of spherical surfaces. In our lab we various types of spherometers with which we can measure the bending of a beam in Young's modulus experiment or we can also measure the elongation of a wire in case of Searle's Apparatus. It carries a small vertical scale usually divided into millimetres. A screw, whose pitch is usually one mm and which carries a circular disc (having a circular scale divided into 100 equal parts, engraved on it) at its top.

The least count of this instrument can be calculated in same ways as that of a screw gauge.

∴ **Least Count of the spherometer:**

$$= \frac{pitch}{Total\ number\ of\ divisions\ on\ circular\ scale}$$

$$= \frac{1\ mm}{100}$$

$$= 0.01\ mm.$$

Below are the different types of spherometers

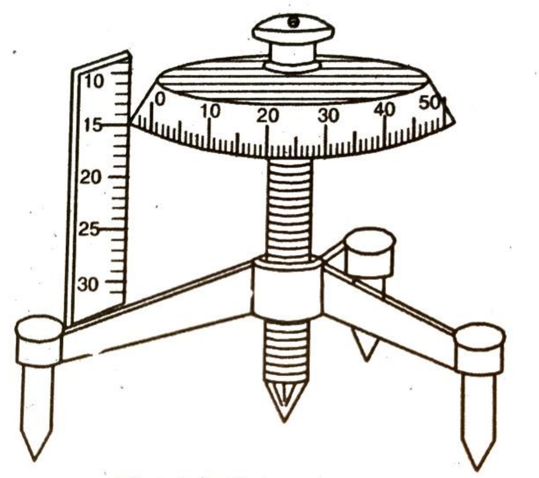


Fig. 1.4. Spherometer.

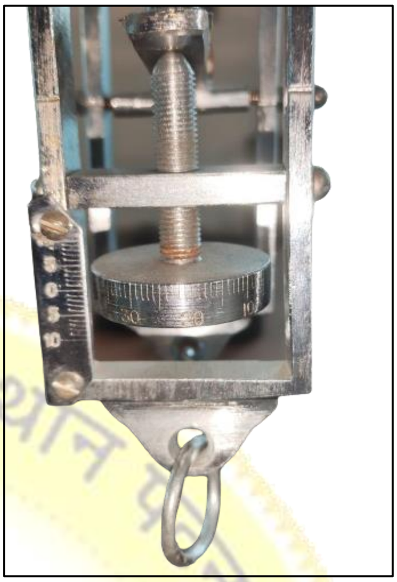


Fig. 2: Spherometer used in Searle's Apparatus

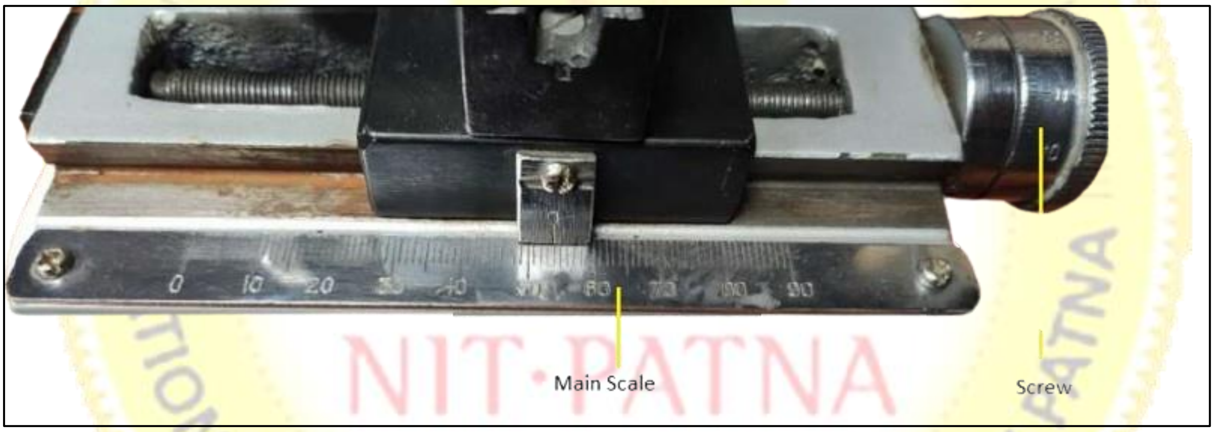


Fig. 3 Spherometer attached to a travelling microscope

4. **STOP WATCH**
   In our lab we use stop watch, which can measure time in steps of 0.01 seconds. So, the least count of the stop watch is 0.01 sec.

s

Stop watch 1: reading is 1 min 15.21 (60+15.21) s $= 75.21$ s.

While in stop watch 2: the reading is 14.31= (14+31× 0.01) s = 14.31 s

- ***Apart from these we use thermometer, Ammeter, Voltmeter whose least count is easily found by looking at the instrument. Just see the smallest div in the scale of the instruments.***

Introduction to error analysis:

2.1. INTRODUCTION

When students report their final results, there's often a misconception that these results must perfectly match the standard value. This can sometimes lead to unhealthy practices aimed at achieving artificially accurate results. However, it's crucial for students to understand that exact matches with standard values are often a matter of chance. Deviations from the standard value should not be discouraging. The key is to conduct the experiment with care, sincerity, and honesty in collecting data.

The result should be (i) presented with the correct numerical figures and units, and (ii) reflect the reliability of the findings. The accuracy of the result is conveyed through 'Significant Figures,' while the reliability is indicated by accounting for 'Experimental Errors.' Finally, we will explore the use of different types of graph papers, such as linear, semi-log, and log-log, and their specific applications.

2.2. SIGNIFICANT FIGURES

The number of significant figures in the final result of an experiment depends on the precision of the measurements made during the experiment.

2.3. PERCENTAGE ERROR IN EXPERIMENTS

In experiments, we measure physical quantities using tools like vernier callipers, screw gauges, spherometers, stopwatches, thermometers, and balances. The errors in these measurements, denoted by ΔL, Δr, ΔT, ΔQ, etc., are typically taken as the least count of the instrument used. Examples include:

1. **Length Measurement:** When measuring length with a meter rod, the error ΔL is 1 mm (0.1 cm), which is the smallest graduation on the scale.
2. **Diameter/Length with Callipers:** The error ΔL is 0.1 mm (0.01 cm), the least count of the callipers.
3. **Diameter/Thickness with Screw Gauge:** The error ΔL is 0.01 mm (0.001 cm), corresponding to the least count of the screw gauge.
4. **Mass Measurement:** Using a good balance, the error Δm in mass is typically 5 mg or 10 mg (0.005 g or 0.01 g), depending on the balance's accuracy. For larger masses, like in Searle's apparatus or a sonometer, the error Δm can be around 10 grams or more.

5. **Time Measurement:** With a stopwatch (that can measure milli-second) graduated to 0.001 seconds, the error Δt is 0.001 seconds, respectively. For a stop clock graduated in seconds, where each second is divided into three ticks, the error Δt is approximately 0.33 seconds.
6. **Temperature Measurement:** Using thermometers graduated in half or one-tenth degrees, the error $\Delta\theta$ is 0.5°C or 0.1°C, respectively, reflecting the smallest graduation on the thermometer.

Example of percentage calculation:

Let Y be a quantity defined by the equation

$$Y = \frac{C \cdot (a^3 \cdot b)}{L},$$

where C is a constant and a, b, and L are measurable quantities.

We want to determine the error in Y due to errors in a, b, and L.

First, take the natural logarithm of Y:

$$\ln(Y) = \ln(C) + 3\ln(a) + \ln(b) - \ln(L).$$

Differentiate this equation with respect to each variable:

$$d(\ln(Y)) = \frac{3 \cdot \Delta a}{a} + \frac{\Delta b}{b} - \frac{\Delta L}{L}.$$

Thus, the error in Y can be approximated by:

$$\Delta Y \approx Y \left(\frac{3 \cdot \Delta a}{a} + \frac{\Delta b}{b} - \frac{\Delta L}{L} \right).$$

So, the final value of Y including the error is:

$$Y_{\text{final}} = Y \pm \Delta Y.$$

❖ Note on Plotting Graphs

Plotting a graph involves several key steps:

1. **Define the Function**: Determine the mathematical function or data you want to plot.
2. **Choose the Range**: Decide the range of values for the x-axis and y-axis.
3. **Set Up the Plot**: Create a coordinate system, plot the points or function, and label the axes.

4. **Customize the Plot**: Add titles, legends, and adjust styles to make the graph clear and informative.

Example: Plotting a Simple Function

The independent variables should be plotted along X-axis and the dependent variable should be plotted along Y-axis.

Data Points without Fitting

In this example, we plot data points without fitting a line.

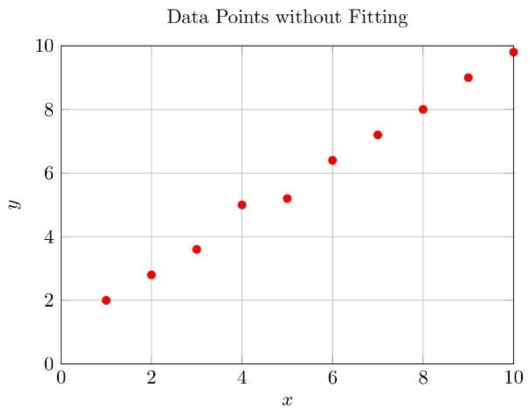


Figure 1: Plot of data points without fitting a line

Note on Least Squares Fitting

Least Squares Fitting is a statistical method used to find the best-fitting curve or line through a set of data points. The goal is to minimize the sum of the squared differences (errors) between the observed values and the values predicted by the model.

Steps for Least Squares Fitting:

1. **Define the Model**: Choose the type of model (e.g., linear, quadratic) that you believe fits the data.
2. **Formulate the Objective Function**: The objective is to minimize the sum of the squared residuals (errors):
3. **Solve for Parameters**: Use optimization techniques to find the model parameters that minimize the objective function.
4. **Plot the Data and Fit**: Visualize the data points and the fitted curve or line to evaluate the fitting.

Let's fit a linear model $y = mx + c$ (equation of straight line) to a set of data points using least squares fitting. Below is an

Least Squares Fitting Example

In this example, we perform linear least squares fitting to a set of data points.

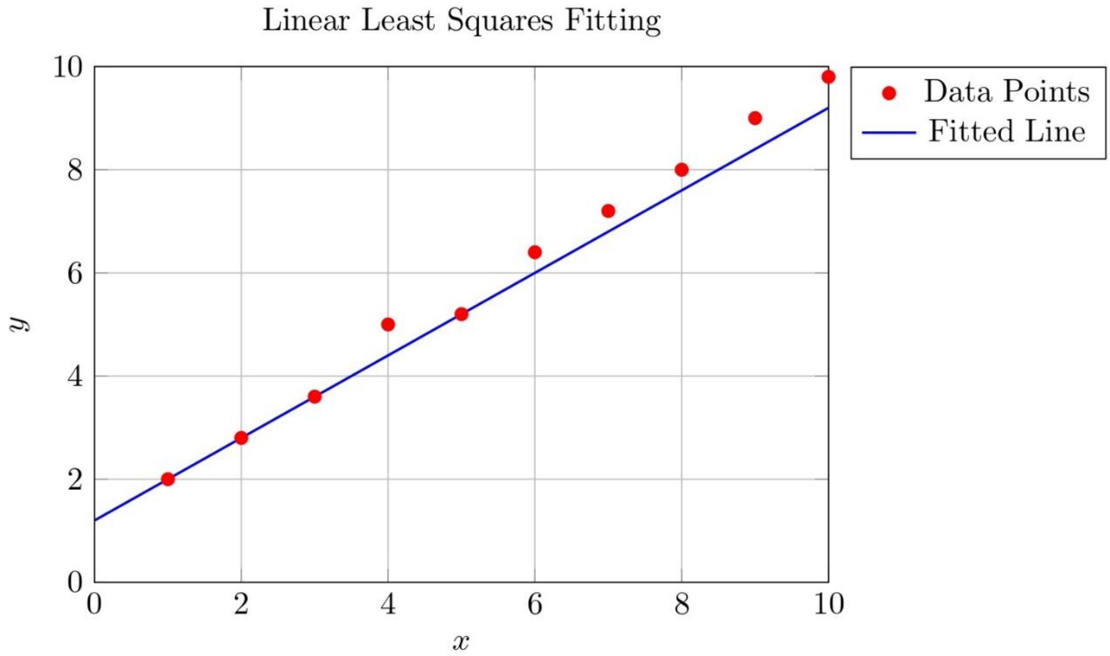


Figure 1: Linear least squares fitting of data points