ACTIVITY 3

AIM

To plot a graph for a given set of data choosing proper scale and show error bars due to the precision of the instruments.

APPARATUS AND MATERIAL REQUIRED

Graph paper, a pencil, a scale and a set of data

PRINCIPLE

Graphical representation of experimentally obtained data helps in interpreting, communicating and understanding the interdependence between the variable parameters of a given phenomena. Measured values of variables have some error or expected uncertainty. For this reason each data point on the graph cannot have a unique position. That means depending upon the errors, the x-axis coordinate and y-axis coordinate of every point plotted on the graph will lie in a range known as an error bar.

Any measurement using a device has an uncertainty in its value depending on the precision of the device used. For example, in the measurement of diameter of a spherical bob, the correct way is to represent it $d \pm \Delta d$, where Δd is the uncertainty in measurement of d given by the least count of the vernier/screw gauze used. Representation of $d \pm \Delta d$ in a graph is shown as a line having a length of $\pm \Delta d$ about point 'd'. This is known as the error bar of d.

We take an example where the diameters of objects, circular in shape, are measured using a vernier calipers of least count 0.01 cm. These measured values are given in Table 1. From the measured values of diameters, it is required to calculate the radius of each object and to round off the digits in the radius to the value consistent with the least count of the measuring instrument, in this case, the vernier calipers. We also estimate the maximum possible fractional uncertainty (or error) in the values of radius. Next, the area A of each object is then calculated using the formula.

Area, $A = \dfrac{\pi d^2}{4}$

where π is the well-known constant.

Graphical representation of experimental data provides a convenient way to look for interdependence or patterns between various parameters associated with a given experiment or phenomenon or an event. Graphs also provide a useful tool to communicate a given data in pictorial form. We are often required to graphically represent the data collected during an experiment in the laboratory, to verify a given relation or to infer inter-relationships between the variables. It is, therefore, imperative that we must know the method for representing a given set of data on a graph, develop skill to draw most appropriate curve to represent the plotted data and learn as to how to interpret a given graph to infer relevant information.

Basic ideas about the steps involved in plotting a line graph for a given data and finding the slope of the curve have already been discussed in Chapter I. The steps involved in plotting a graph include choice of axes (independent variable versus dependent variable), choice of scale, marking the points on the graph for each pair of data and drawing a smooth curve/line by joining maximum number of points corresponding to the given data. Interpretation of the graph usually involves finding the slope of the curve/line, inferring nature of dependence between variables/parameters, interpolating/ extrapolating the graph to find desired value of the dependable variable corresponding to a given value of independent variable or vice versa. However, so far you have learnt to graphically represent the data for which uncertainty or error is either ignored or is presumed not to exist. As you know every data has some uncertainty/error due lack of precision in measurement or some other factors inherent in the process/method of data collection. It is possible to plot a graph that depicts the extent of uncertainty/error in the given data. Such a depiction in the graph is called an **error bar**. In general error bars allow us to graphically illustrate actual errors, the statistical probability of errors in the measurement or typical data points in comparison to the rest of the data.

You have learnt to show uncertainty in measurement of a physical quantity like length, mass, temperature and time on the basis of the least count of the measuring instruments used. For example, the diameter of a wire measured with a screw gauge having least count 0.001cm is expressed as 0.181 cm ± 0.001 cm. The figure ± 0.001 cm in the measurement indicates that the actual value of diameter of the wire may lie between 0.180 and 0.182 cm. However, the error in measurement may also be due to many other factors, such as personal error, experimental error etc. In some cases the error in data may be due to factors other than those associated with measurement. For example, angles of scattering of charge particles in an experiment on scattering of α–particles or opinion collected from a section of a population on a social issue. The uncertainty due to such errors is estimated through a variety of statistical methods about which you will learn in higher classes. Here we shall consider uncertainty in measurements only due to the least count of the measuring instrument so as to learn how uncertainty for a given data is shown in a line graph.

Let us take the example of the graph between time period, *T*, and the length, *l*, of a simple pendulum. The uncertainty in measurement of time period will depend on the least count of the stop watch/clock while that in measurement of length of the pendulum will depend on the least count of the device(s) used to measure length. Table A 3.1 gives the data for the time period of simple pendulum measured in an experiment along with the uncertainty in measurement of the length and time period of the pendulum.

Table A 3.1 Time period of simple pendulums of different lengths

S. No.	Length of the pendulum		Time period		
	Length as measured with metre scale, *L* (cm)	Length with uncertainty in *L* (least count of scale 0.1 cm) (cm)	Average time period as measured with stop watch, *T* (s)	Time period with uncertainty in *T* (least count of stop watch 0.1 s) (s)	Square of time period T^2 with uncertainty
1	80.0	80±0.1	1.8	1.8±0.1	3.24±0.2
2	90.0	90±0.1	1.9	1.9±0.1	3.61±0.2
3	100.0	100±0.1	2.0	2.0±0.1	4.0±0.2
4	110.0	110±0.1	2.1	2.1±0.1	4.41±0.2
5	120.0	120±0.1	2.2	2.2±0.1	4.84±0.2
6	130.0	130±0.1	2.3	2.3±0.1	5.29±0.2
7	140.0	140±0.1	2.4	2.4±0.1	5.76±0.2
8	150.0	150±0.1	2.4	2.4±0.1	5.76±0.2

PLOTTING OF A GRAPH WITH ERROR BARS

Steps involved in drawing a graph with error bars on it are as follows:

1. Draw x- and y- axes on a graph sheet and select an appropriate scale for plotting of the graph. In order to show uncertainty/error in given data, it is advisable that the scale chosen should be such that the lowest value of uncertainty/error on either axes could be shown by at least the smallest division on the graph sheet.

2. Mark the points on the graph for each pair of data without taking into account the given uncertainty/error.

3. Each point marked on the graph in Step 2 has an uncertainty in the value shown on either the x-axis or the y-axis or both. For example, let us consider the case for the point corresponding to (80, 1.8) marked on the graph. If we take into account the uncertainty in measurement for this case, the actual length of the pendulum may lie between 79.9 cm and 80.1 cm. This uncertainty in the data is shown in the graph by a line of length 0.2 cm drawn parallel to x-axis with its midpoint at 80.0 cm, in accordance with the scale chosen. The line of length 0.2 cm parallel to x-axis shows the error bar for the pendulum of length 80.0 cm. One can similarly draw error bar for each length of the pendulum.

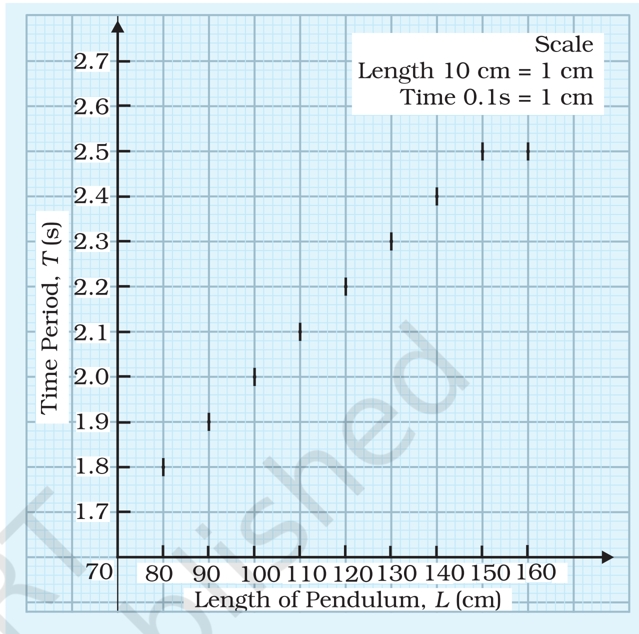

***Fig. A 3.1:** Error bars corresponding to uncertainty in time period of the given pendulum (uncertainty in length is not shown due to limitation of scale)*

4. Repeat the procedure explained in Step 3 to draw error bars for uncertainty in measurement of time period. However, the error bars in this case will be parallel to the y-axis.

5. Once the error bars showing the uncertainty for data in both the axes of the graph have been marked, each pair of data on the graph will be marked with a + or <% or <% sign, depending on the extent of uncertainty and the scale chosen for each axis, instead of a point usually marked for drawing line graph (Fig. A 3.1).

6. A smooth curve drawn passing as close as possible through all the + marks marked on the graph, instead of points, gives us the plot between the two given variables (Fig. A 3.2).

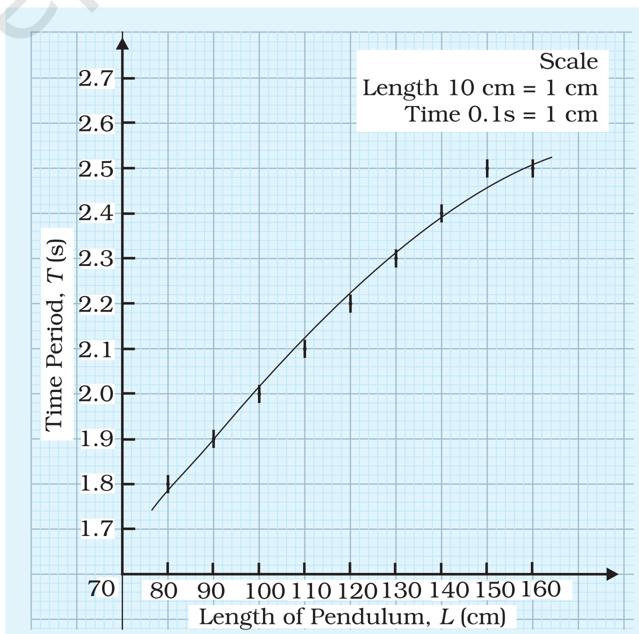

***Fig. A 3.2:** Graph showing variation in time period of a simple pendulum with its length along with error bars*

RESULT

A given set of data gives unique points. However, when plotted, a curve representing that data may not physically pass through these points. It must, however, pass through the area enclosed by the error bars around each point.

PRECAUTIONS

1. In this particular case the point of intersection of the two x-axis and y-axis represent the origin of O at (0, 0). However, this is not always necessary to take the values of physical quantities being plotted as zero at the intersection of the x-axis and y-axis. For a given set of data, try to maximize the use of the graph paper area.

2. While deciding on scale for plotting the graph, efforts should be made to choose a scale which would enable to depict uncertainty by at least one smallest division on the graph sheet.

3. While joining the data points on the graph sheet, enough care should be taken to join them smoothly. The curve or line should be thin.

4. Every graph must be given a suitable heading, which should be written on top of the graph.

SOURCES OF ERROR

1. Improper choice of origin and the scale.

2. Improper marking of observation points.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

how error bars in the graphs plotted for the data obtained while doing Experiment Nos. 6, 9, 10, 11, 14 and 15.

Note:

As the aim of the Activity is to choose proper scale while plotting a graph alongwith uncertainty only due to the measuring devices, the calculation in the activity should be avoided.

Suggested alternate Activity for plotting cooling curve with error bars (Experiment No. 14) where temperature and time are measured using a thermometer and a stop-clock (stop-watch) with complete set of data / observations with LC of the measuring devices and $\frac{\Delta\theta}{\theta}$ and $\frac{\Delta T}{T}$ values be given.

Additionally the same curve along with error bar be asked to be drawn using two different scales and the discussion may be done using them.

20/04/2018