Laboratory Procedure 101

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September 19, 2025

1 Good Laboratory Practices

- Be punctual and attentive during laboratory sessions.
- **Handle all instruments and apparatus with care.**
- Record observations neatly, with correct units and significant figures.
- Use scientific notation where appropriate for very large or very small numbers.
- **Always mention the scale** in the legend while plotting graphs.
- **Ensure safety protocols are followed at all times**.

2 Scientific Notation

In laboratory work, measured quantities often span a wide range of magnitudes. To express such values clearly and concisely, we use **scientific notation**. In this system, a number is written in the form:

$$N = a \times 10^n$$

where a is a real number such that $1 \leq |a| < 10$, and n is an integer representing the order of magnitude.

Advantages of Scientific Notation

- It provides a compact and standardized way of expressing very large or very small numbers.
- It makes comparison of orders of magnitude straightforward.
- It reduces errors in recording and interpreting experimental data.
- It simplifies calculations involving multiplication and division.

Rules for Usage

1. Always express the coefficient a with the appropriate number of **significant figures** reflecting the precision of the measurement. For example:

$$0.000\,345 \quad \rightarrow \quad 3.45 \times 10^{-4}$$

2. Use scientific notation consistently in data tables, graphs, and calculations.
3. Units must always be retained when expressing values. Example:

$$6.022 \times 10^{23}\ \mathrm{mol}^{-1}$$

4. When reporting results, match the power of ten in both numerator and denominator if possible, to minimize confusion.

Examples

- The radius of an electron: 2.82×10^{-15} m
- Avogadro's number: 6.022×10^{23} mol^{-1}
- Speed of light: 2.998×10^{8} m/s

3 Procedure to Plot a Good Graph

1. **Choose axes:** Put the independent variable on the x-axis and the dependent variable on the y-axis. Use SI units.
2. **Select a suitable scale:** Use simple, evenly spaced tick increments (1, 2, 5, 10, ...). Make full use of the graph area so the data spread occupies most of the plotting region.
3. **Label axes:** Always show the quantity and unit, e.g. V (V) or I (A).
4. **Plot points accurately:** Mark each data point clearly (dot or small cross). Avoid large symbols that obscure accuracy.
5. **Best-fit line or curve:** For linear relationships, draw a best-fit straight line (not a line joining the points). For nonlinear data, draw a smooth curve that follows the trend.
6. **Show uncertainties:** Where applicable, draw error bars representing measurement uncertainty.
7. **Extract quantities:** Determine slope, intercept, and uncertainties from the graph. Use slope $= \Delta y/\Delta x$ for linear fits.
8. **Neat presentation:** Use a ruler for axes and lines, include a title, and keep the graph free of unnecessary clutter.

Ohm's Law Example

Ohm's law states that $V = IR$, where V is the potential difference across a conductor, I is the current through it, and R is the resistance (assumed constant for an ohmic conductor). In a graph of current (I) versus voltage (V), the slope gives $\frac{\Delta I}{\Delta V} = 1/R$.

Sample measurements

The following set of measurements for voltage and current are recorded for a resistor:

Voltage V (V)	Current I (A)
0.5	0.11
1.0	0.18
1.5	0.27
2.0	0.38
2.5	0.53

Table 1: Measured voltage and current for a resistor.

These data lie on a straight line passing through the origin. A linear fit gives:

$$I = m\,V + c,$$

where for this data $m = 0.20\ \mathrm{A\,V^{-1}}$ and $c \approx 0$. Therefore the resistance is

$$R = \frac{1}{m} = \frac{1}{0.20\ \mathrm{A\,V^{-1}}} = 5\ \Omega.$$

Plot

The plot in Figure. 1 shows the data points and the best-fit line $I = 0.2\,V$.

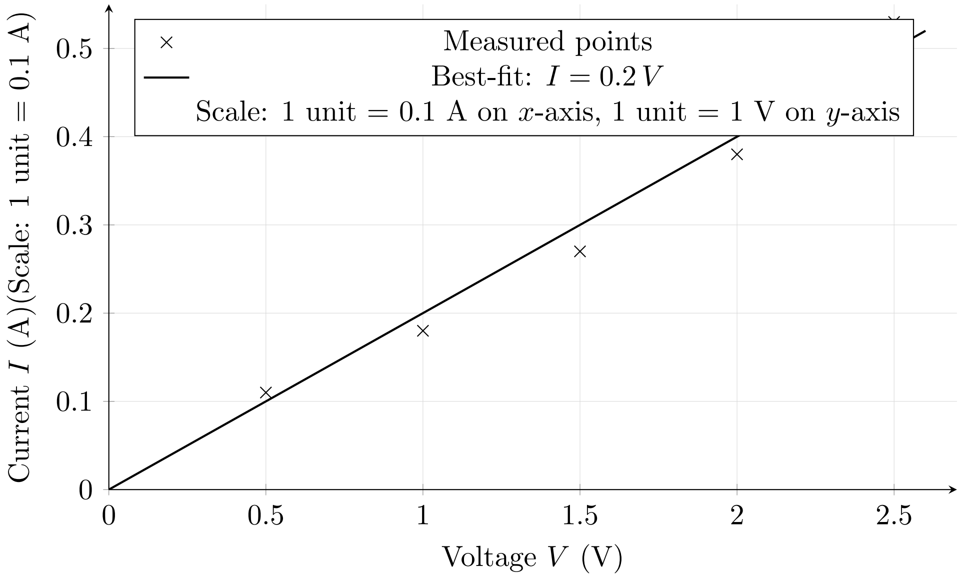

Figure 1: Graph of current vs voltage for the resistor. Slope = $0.2\ \mathrm{A\,V^{-1}}$, so $R = 5\ \Omega$.

4 Finding Constants of a Straight Line Using Error Analysis

When two physical quantities are related linearly, their relation can be expressed as:

$$y = mx + c$$

where

- m is the slope (constant of proportionality),
- c is the intercept on the y-axis,
- x and y are the measured variables.

4.1 Experimental Data

During the experiment, pairs of values (x_i, y_i) are recorded. Each measurement has an associated error:

- Δx_i: least count or uncertainty in measurement of x,
- Δy_i: least count or uncertainty in measurement of y.

4.2 Best-Fit Straight Line

A graph of y vs. x is plotted. The slope m and intercept c can be determined using the **method of least squares**:

$$m = \frac{N \sum x_i y_i - \sum x_i \sum y_i}{N \sum x_i^2 - \left(\sum x_i\right)^2}$$

$$c = \frac{\sum y_i \sum x_i^2 - \sum x_i \sum x_i y_i}{N \sum x_i^2 - \left(\sum x_i\right)^2}$$

where N is the number of data points.

Expressions in Terms of Averages

Let

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i, \qquad \bar{y} = \frac{1}{N} \sum_{i=1}^{N} y_i$$

be the mean values of the data. Then, the slope m and intercept c are given by:

$$m = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2}, \qquad c = \bar{y} - m\bar{x}.$$

4.3 Error in Slope and Intercept

The deviations of observed points from the line are:

$$d_i = y_i - (m x_i + c)$$

The sum of squared deviations is used to estimate the uncertainty in slope and intercept. The standard error of estimate is:

$$\sigma = \sqrt{\frac{\sum d_i^2}{N - 2}}$$

The error in slope is given by:

$$\Delta m = \sigma \sqrt{\frac{N}{N \sum x_i^2 - (\sum x_i)^2}}$$

The error in intercept is:

$$\Delta c = \sigma \sqrt{\frac{\sum x_i^2}{N \sum x_i^2 - (\sum x_i)^2}}$$

5 Significant Figures

In experimental physics, every measured quantity has an associated **uncertainty**. The number of **significant figures** used in reporting results must reflect this uncertainty.

1. **Definition:** Significant figures are the digits in a number that carry meaningful information about its precision. This includes all certain digits and the first uncertain digit.

2. **Rules for Use:**

   - All non-zero digits are significant.
   - Zeros between non-zero digits are significant.

   - Leading zeros are not significant; they only indicate the position of the decimal point.
   - Trailing zeros after a decimal point are significant.

3. **In Calculations:**
   - For multiplication or division: the result should have as many significant figures as the measured value with the *least number* of significant figures.
   - For addition or subtraction: the result should be rounded off to the *least precise decimal place* among the quantities involved.

4. **In Reporting Final Results:**
   - The uncertainty (error) should be quoted to *one significant figure* (occasionally two if the first digit is 1 or 2).
   - The measured value should be reported up to the same decimal place as the uncertainty.

Example: Counting Significant Figures

- $1234 \quad \rightarrow \quad 4$ significant figures (all non-zero digits).
- $0.00456 \quad \rightarrow \quad 3$ significant figures (leading zeros are not significant).
- $2.300 \quad \rightarrow \quad 4$ significant figures (trailing zeros after the decimal point are significant).
- $7.0890 \quad \rightarrow \quad 5$ significant figures (zeros between non-zero digits and the final zero are significant).
- $1.20 \times 10^3 \quad \rightarrow \quad 3$ significant figures (scientific notation helps to clearly indicate them).

Example:
If resistance is found to be

$$R = 12.36\,\Omega \pm 0.07\,\Omega,$$

the correct way to report is

$$R = 12.36 \pm 0.07\,\Omega$$

and not 12.360 ± 0.07, since extra digits suggest unwarranted precision.

5.1 Final Result

The constants of the line are written with their uncertainties as:

$$m \pm \Delta m, \qquad c \pm \Delta c$$

This ensures the linear relation is reported within the limits of experimental accuracy.

Note: This method is commonly applied in laboratory experiments such as verification of Ohm's law, Hooke's law, and determination of refractive index, where linear relations are analyzed.

Notes and Tips

- Always record data in scientific notation when the number is too large or too small for convenient decimal representation.
- Always include units and report final values with **appropriate significant figures** and uncertainty.