Lab 01: Using Numbers

Objectives

- Practice expressing numbers using scientific notation
- Learn how to multiply and divide large or small numbers using scientific notation
- Understand the difference between precision and accuracy in terms of measurement
- Learn to make reliable and repeatable measurements
- Present data and results graphically

Scientific Notation

Scientists routinely have to contend with numbers that are very large (like the distances between planets or to another star entirely), or numbers that are very small (like the mass of an electron, or the radius of a single atom). Scientific notation is used to make dealing with these numbers easier and quicker.

Scientific notation uses shorthand for powers of ten. For example, $10 \times 10 = 10^2$, where the exponent (2) tells you how many times the ten is multiplied by itself. Very large numbers can then be expressed compactly: one million $= 1,000,000 = 1 \times 10^6$. Two million, then, would be $2,000,000 = 2 \times 10^6$.

Small numbers (less than 1) can be written as fractions or decimals. But very small numbers make inconvenient decimals: for example, $0.000000001$ seconds is one nanosecond. That many zeros is just cumbersome to keep track of. When scientific notation is used for numbers smaller than one, the exponents are written as negative. The negative means that you are dividing by 10 instead of multiplying: $(1/10) = 0.1 = 10^{-1}$, and $(1/10)/10 = 1/100 = 0.01 = 10^{-2}$. And the nanosecond? That’s $1 \times 10^{-9}$ seconds.

Activity 1: Writing Scientific Notation

Rewrite each of the following numbers using scientific notation. Be careful with your positive and negative exponents, and leave only a single digit before the decimal point. You may round your values to three significant digits (in this case, two decimal places).

1. The mass of an electron: $0.0000000000000000000000000000091$ kilograms
2. The average distance from the sun to Alpha Centauri: $19,386,146,750,000$ miles
3. The charge on a proton: $0.000000000000000000160218$ Coulombs
4. The speed of light in a vacuum: $299,792,500$ m/s
5. The universal gravitational constant: $0.0000000000667$ N·m$^2$/kg$^2$

Activity 2: Multiplying and Dividing Large Numbers

Multiply or divide each of the following numbers. Practice using the “EE” key to enter in your values quickly and accurately. Remember to leave only a single digit before the decimal point, and retain a single decimal in your final answer.

6. $(5.9 \times 10^3) \times (7.1 \times 10^{-9})$
7. $(3.3 \times 10^{-7}) \times (4.2 \times 10^9)$
8. $(6.2 \times 10^{-8}) \times (8.1 \times 10^{-10})$
9. $(5.9 \times 10^5) \div (7.1 \times 10^{-9})$
10. $(3.3 \times 10^{-7}) \div (4.2 \times 10^9)$
11. $(6.2 \times 10^{-8}) \div (8.1 \times 10^{-10})$

Activity 3: Accuracy, Precision, and Estimation

Typically, we tend to think that precision and accuracy mean the same thing, and we probably use the words interchangeably. However, they do represent separate and distinct concepts, so we need to have a clear definition for each.

A carpenter building a house needs to be precise to 1/8, or maybe 1/16 of an inch. So a tape measure or T-square marked in inches, subdivided down to an eighth or sixteenth of an inch is an adequate enough tool for him to use. But a machinist milling parts for a jet engine will need a more precise measuring tool—something that can measure much smaller increments, down to a thousandth or even a ten-thousandth of an inch. For these types of measurements, a micrometer would be an adequate enough tool for him to use.
thousandth of an inch. The carpenter’s ruler simply isn’t going to be useful to him. However, just because the carpenter’s ruler is less precise than the machinist’s micrometer does not automatically mean that the machinist is more accurate!

While **precision** is an inherent property of a measuring instrument, **accuracy** is related to the use of that tool. A machinist with a very precise micrometer can still make an inaccurate measurement—what if he has aligned the tool improperly, or read the dial incorrectly, or has done something otherwise careless or inconsistent? The carpenter, using a less precise tool may be more accurate, if he is using his instrument properly and making his measurements carefully.

- Select three common items from among your workgroup (pencils, combs, keys, coins, calculators, credit cards, lip balm...endless options).
- Independently (without your lab partners), estimate the length (longest dimension) of each item in both inches and centimeters, and record these estimates in your lab notebook. Make a neat table for clarity.
- Compare and discuss your estimates in centimeters with those of your partners. Note any trends or patterns in how you or your partners make estimates.
- Using a ruler or meter stick, measure each item (again, in both inches and centimeters) and record.
- If you have not already, organize a neat and logical table of your estimates and measurements.

**Questions**

12. Find the one estimate that you made (in either inches or cm) that is closest to the actual measured length. Calculate the percent error using:

\[
\% \text{error} = \frac{(\text{true value} - \text{your value})}{(\text{true value})} \times 100
\]

Do you tend to consistently over- or under-estimate, or is there randomness (some over-, some under-estimates)?

13. Look at your data and note if there is a pattern in your estimates: Do you tend to consistently over- or under-estimate, or is there randomness (some over-, some under-estimates)?

14. In general, were your estimates in one set of units consistently more accurate than your estimates in the other? If so, which set was more accurate? Why do you think that the units might make a difference in your estimates?

15. Examine the ruler and determine the numerical precision of your measurements in both inches and centimeters. Which set of units (inches or centimeters) is more precise? Why?

16. If two people measure the same object using the same tools, will their measurements have the same precision? The same accuracy? Explain briefly.

17. Think of (and record in your notebook) at least three examples in your daily life where you make numerical estimates fairly routinely. Comment on the relative importance of both accuracy and precision when you make those estimates.

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### Activity 4: Measurements & Analysis

- Measure and record the mass of the empty graduated cylinder.
- Fill the cylinder with 20ml of water.
- Measure and record the mass of the cylinder + water. **Remember to subtract the mass of the cylinder to obtain the mass of the water.**
- Repeat, increasing the volume of water in 20 ml increments until the cylinder is full.
- If you have not already, use the example shown below to record your data in a neat table in your lab notebook.

<table>
<thead>
<tr>
<th>Volume (ml)</th>
<th>Mass (g)</th>
<th>Density (g/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
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<tr>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
slope = \frac{m_2 - m_1}{V_2 - V_1}
\]

\[
density = \frac{mass}{volume}
\]

**Questions**

18. Prepare a graph of mass as a function of volume. This means that **mass** belongs on the **y-axis** and **volume** belongs on the **x-axis**. Scale your axes appropriately and apply the scale consistently. When the data are plotted, use a ruler to draw the best-fit line for the data.

19. Find the slope of the line that you have drawn. What are the units on your slope?

20. Calculate the density of the water for each trial, using the formula above.

21. Compare the values for the density to the slope of the line. Related? (Hint: The general equation of a line is \( y = mx \), where \( m \) is the slope. According to our definition of density above, we could also write \( \text{mass} = (\text{density}) \cdot (\text{volume}) \). Hmmmm...)

22. Why are the individual values for the density not all identical? Does the density of the water change when you change the amount of water in the cylinder? Explain, using the concepts of both precision and accuracy.