Measurement

Objectives

• Make measurements with accuracy and precision.
• Identify and quantify causes and effects of uncertainties in measured data.
• Record data using International System (SI) units and scientific notation.

Assessment

1. You are asked to measure a small quantity (less than 5 ml) of an unknown liquid. Two graduated cylinders are available: 100 ml and 10 ml.
   a) Which cylinder should you choose and why?
   b) What possible operator error(s) could affect the uncertainty of your measurement?

2. You are planning to knit yourself some mittens. You measure the width of your hand to be 7.3 cm.
   a) Identify possible causes of uncertainty in your measurement.
   b) What effects might that uncertainty have in your mittens?

3. Using a caliper, you measure the width of your pencil lead to be 0.0345 cm.
   a) Write this value using scientific notation.
   b) How many significant figures are there in your measurement?

Physics terms

• accuracy
• precision
• decimal places
• significant figures
Physics is based on measurement. ALL measurements have some uncertainty.

Uncertainty can be expressed in this way:

\[ l = 2.067 \pm 0.001 \, \text{m} \]

**Measurement**  **Uncertainty**

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The measuring system might be inadequate.

Example: a ruler with gradations that are too large.

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The measuring procedure might have shortcomings.

Example: trying to measure a wiggling child.

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The environment causes problems.

Example: a ruler that heats up and expands.

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The operator could make an error.

Example: due to poor eyesight or lack of skill.

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For some measurements, uncertainty is relatively unimportant.

- An exact mass value doesn’t matter much when riding a see-saw.
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- An exact mass value doesn't matter much when riding a see-saw.

For some measurements, knowing the uncertainty is very important.

- Calculating the load accurately on a space shuttle mission is critical.

**The effects of uncertainty**

Engineers design products to fit certain requirements or tolerances.

Example:

Metal parts may be required to fit together within 0.1 mm or less.

Engineering tolerances specify the allowable uncertainty. If exceeded, the product may fail to function.

**Engineering tolerances**

**Accuracy**

Accuracy indicates how closely the measurement corresponds to the standard or true value of that quantity.

A meter stick would be inaccurate if it were accidentally manufactured to be 1.0 yards long rather than 1.0 meters long.

**Precision**

Precision is an indicator of the exactness of a measuring tool and measurement.

Some measuring tools have finer gradations that allow for making more precise measurements.
Accuracy vs. precision

- Accurate, not precise
- Precise, not accurate
- Accurate and precise

Significant figures

Significant figures are digits used to write a measured value. The number of significant figures tells you the level of certainty (and uncertainty) of the measurement.

- Zero’s in FRONT of a number are not significant digits. These zeros are simply placeholders.
  - Example: 5 meters = 0.005 kilometers
  - Both numbers have just a single significant digit.
  - Changing units never changes the number of significant digits. That’s because converting units doesn’t make the original measurement any more or less uncertain.

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- For example, here are two measured values written in correct scientific notation:
  - 1.965 m/s  This measurement has 4 significant figures.
  - $2.4 \times 10^4$ m/s  This measurement has 2 significant figures.

Significant figures

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- Both numbers have just a single significant digit.
- Changing units never changes the number of significant digits. That’s because converting units doesn’t make the original measurement any more or less uncertain.

Significant figures

- Count the number of significant figures in these numbers.
  - DO NOT include leading zeros to the left.
  - DO include all other zeros.

- 0.0736  This measurement has ___ significant figures.
- 1.9030  This measurement has ___ significant figures.
Count the number of significant figures in these numbers.

- DO NOT include leading zeros to the left.
- DO include all other zeros.

0.0736  This measurement has 3 significant figures.

1.9030  This measurement has 5 significant figures.

When making a measurement, you may estimate to one more subdivision than the smallest marking on the measuring instrument. The estimated digit is a significant figure.

This measurement of 23.5 mm has three significant figures.

The significant digits include every digit you are sure of AND the final digit you are estimating.

The result of a calculation can never be more accurate than the individual measurements that went into it.

Example: A bystander reports that it took about 3 seconds for a car to race down a 100.0 meter track. What is the speed of the car?

What's wrong with this answer? What is the correct answer?

speed = \frac{\text{distance}}{\text{time}} = \frac{100.0 \text{ m}}{3 \text{ sec}} = 33.333333 \text{ m/s}

A better idea is to use scientific notation:

2.1650 \times 10^5 \text{ m} has 5 significant figures
Scientific notation

How many significant figures is 216,500 m?

When written this way, the number of significant figures is ambiguous.

A better idea is to use scientific notation:

\[ 2.1650 \times 10^5 \text{ m} \] has 5 significant figures

When a number is written in proper scientific notation, every digit that appears will be a significant digit.

“Sig figs” and multiplication

When multiplying or dividing, round the final value to the least number of significant figures among the individual measurements.

\[ \frac{4.37 \text{ m}}{0.49 \text{ m}} = 2.1413 \text{ m}^2 \]

Measurement with fewest significant figures (2)

Round final answer to two significant figures

2.1 m²

“Sig figs” and addition

When adding or subtracting, the measurement with the fewest decimal places determines the final answer. Do you see why?

<table>
<thead>
<tr>
<th>Decimal places and addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement with fewest number of decimal places (1)</td>
</tr>
<tr>
<td>1.072 m + 0.19 m = 24.862 m</td>
</tr>
</tbody>
</table>

Round final answer to one decimal place

24.9 m

Direct and indirect measurement

Direct measurement:
You can easily count the number of buttons on your coat.

Indirect measurement:
An astronomer says there are 200 billion stars in our Milky Way galaxy.

Did he actually count them?

Investigation

Investigation 2A on direct and indirect measurement appears on page 54.
Investigation

Part 1: Indirect measurement

Make the following indirect measurements and describe your methodology.

a. What is the mass of a single grain of rice?
b. What is the thickness of a single piece of paper?
c. What is the height of a tree on the school grounds?

Record your answers on the assignment sheet.

Where did you obtain the sheet(s) of paper for your investigation?

What are the comparative advantages of using different kinds of resources for this activity?

Investigation

Part 2: Atoms, size and scale

The density of gold is 19,300 kg/m$^3$. The periodic table lists the mass of gold as 0.197 kg per $6.02 \times 10^{23}$ atoms.

a. What is the mass of a single gold atom?
b. Estimate how many gold atoms are in a 1-meter cube.
c. Assume gold atoms pack together as shown. What is the diameter (in m) of a single gold atom?

Record your answers on the assignment sheet.

Safety guidelines

Stay safe at school and at home. Be sure to follow all safety procedures in instruction manuals.

For example:

You might buy a new appliance.

Even if it is installed by a licensed professional, you should still read all safety guidelines in the manual before using it.

Safety during investigations

When you conduct investigations, safety should be a top priority. Anticipate potential safety hazards in every investigation and master these safety procedures:

- Wear goggles or approved eye protection when conducting investigations.
- Wear laboratory coats and disposable gloves to protect your skin from harmful substances.
- Know the location and operation of the fire extinguisher, eye wash, and safety shower in your lab space.
- Never conduct an investigation by yourself.
Disposal of materials

After you have completed measurements for rice and paper, what should you do with the materials?

- Throw them in a pile on the ground behind your school?
- Throw them away in the garbage?
- Put them in the recycling?
- Flush them down the drain?
- Store them back in the container for the next class?

Proper disposal or recycling of materials is an important part of physics class! Which option did you choose? What informed you in your choice?

Did you use more rice or paper than you needed, or did you conserve your resources?

Assessment

1. You are asked to measure a small quantity (less than 5 ml) of an unknown liquid. Two graduated cylinders are available: 100 ml and 10 ml.
   a) Which cylinder should you choose and why?

   You should choose the 10 ml cylinder. It will have finer gradations and allow for a more precise measurement.
   b) What possible operator error(s) could affect the uncertainty of your measurement?

   Possible example: not reading the measured value at eye level could cause uncertainty in the measurement.

2. You are planning to knit yourself some mittens. You measure the width of your hand to be 7.3 cm.
   a) Identify possible causes of uncertainty in your measurement.

   The width of your hand is not the same everywhere.
   b) What effects might that uncertainty have in your mittens?

   Your mittens might be too tight or too loose.

3. Using a caliper, you measure the width of your pencil lead to be 0.0345 cm.
   a) Write this value using scientific notation.

   b) How many significant figures are there in your measurement?
Assessment

3. Using a caliper, you measure the width of your pencil lead to be 0.0345 cm.
   a) Write this value using scientific notation.
      \[ 3.45 \times 10^{-2} \text{ cm} \]
   b) How many significant figures are there in your measurement?
      three