MATERIALS EXPLORERS™

THE MATERIALS THAT MOVE US: MEASUREMENT AND SCALE

From discussions of the weather to complex scientific applications, measurements help define the world around us. Explore the importance of accurate measurements through a simulation of hail damage on car hoods. Then, go even further by learning what gives units of measurement any meaning at all.

In this module students will be able to:

- Select the appropriate device for measuring impact impressions
- Apply significant figures to measurements
- Identify the limitations of measuring devices in relation to significant figures
- Discuss the importance of measurements using a specific example from industrial applications
- Understand the importance of standardizing measurements and their units

Class Activity

MEASURING UP

Background

Measurements are at the heart of our understanding of the world around us. The very act of describing qualities such as temperature, length, time or mass requires some basic measurement as we are comparing a physical quality to some known unit of reference. To illustrate this concept, try describing how tall you are without referencing any unit of measurement or explaining the temperature outside without using degrees.

While you can probably get by with generalizations such as “a warm summer day” or comparisons such as “slightly taller than the average girl my age,” these aren’t accurate enough for the types of measurements taken in industries such as farming, engineering, construction, manufacturing, and commerce.

Measurements are composed of three parts:

- A numerical value
- A unit of measurement that denotes the scale
- An estimate of the uncertainty of the measurement

The numerical value of a measurement should always be recorded with the proper number of **significant figures**. The number of significant figures depends on the instrument or measuring device used and is equal to the certain digits (obtained from the scale divisions marked on the instrument) plus one estimated digit. The estimated digit represents the uncertainty in the measurement and provides an indication of the minor scale markings on the instrument. For example, try measuring your pen using a standard ruler. If the ruler has millimeter markings, the millimeters are your certain digits and your result might be close to 108mm. However you can also add one further significant figure by estimating how far between two millimeter markings your pen tip ends. In this way, your measurement might now be 108.2mm instead (your one estimated digit has now been added).

Significant figures are important in measurement because they indicate how precise the measurement is or the level of uncertainty in the measurement. Applying significant figure rules to measurements prevents the measurement from appearing to be more accurate than the measuring device allows.

Accurate measurements are especially important when products are being developed or tested as they

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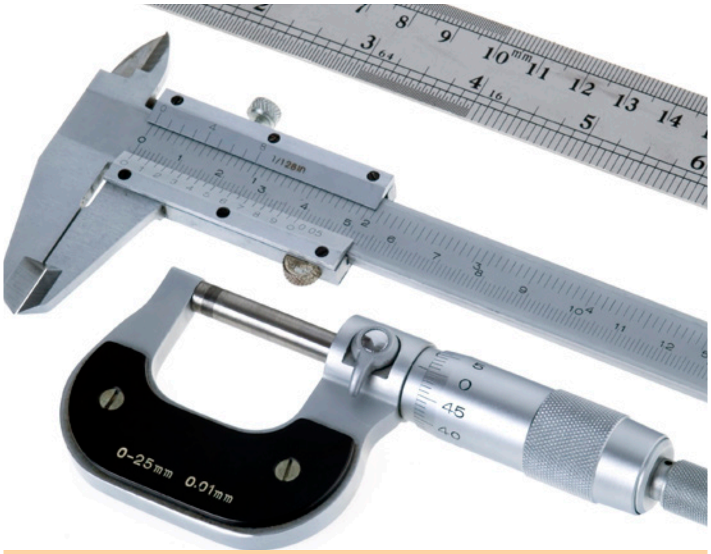
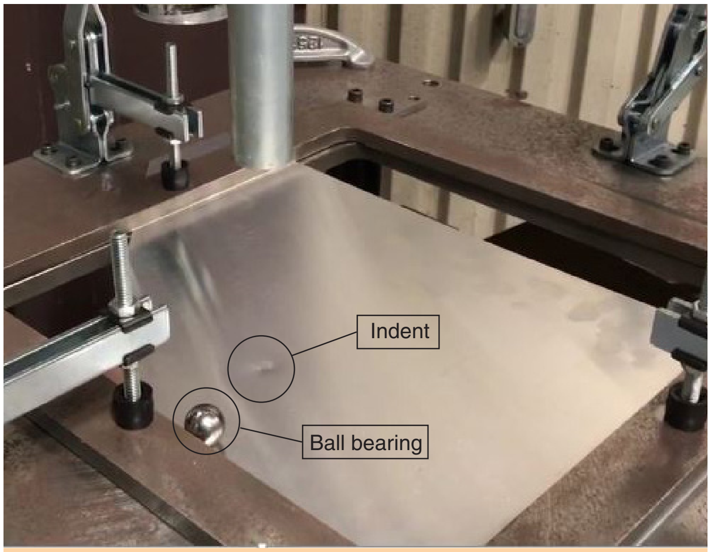


Measurements are only as accurate as the device used since the instrument determines how many significant figures you can obtain. A standard ruler cannot be read beyond 2 or 3 significant figures, but a micrometer might allow you to provide a more detailed measurement.



The experiment you are conducting is similar to how scientists test the extent to which car hoods can withstand hail damage. A large ball bearing is dropped onto a sheet of metal and the indentation is then measured and recorded. (Photo courtesy of Arconic.)

provide an objective, scientific method of comparing results. Scientists and engineers working in research and development labs often design accelerated tests that help simulate the conditions a product must operate in. For example, when scientists develop a sheet product for use on car hoods, they must test how it will perform when hit by hail. Instead of waiting for a hailstorm to occur, scientists and engineers create an experiment that simulates the effect of hail dropping on the sheet. The width and depth of the impacted areas are measured and the results are reported to the number of significant figures appropriate for the measurement device. The material is then given a pass/fail rating. This helps companies ensure that their products will meet the high standards customers expect.

Problem:

An insurance company has been receiving several claims regarding hail damage to vehicles. The company wants to cross-reference the damage recorded in these claims with the size of hailstones recorded in the day's weather reports. You have been asked to investigate these claims by determining the impact of different sized hailstones on aluminum.

Task:

You and your partner are tasked with developing a procedure to simulate the impact of hail on car hoods using the materials provided by your teacher. Your procedure must measure the size of the impact impressions and must be approved by the teacher before you begin. After you conclude your experiment, you must write a report for the insurance company detailing the extent of impact damage they can expect to see for different sizes of hail stones.

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Requirements:

1. Collect data by measuring the impact different sizes of hail have on the piece of aluminum. The width of the indent should be measured using a micrometer and the depth of the indent should be measured using water and a graduated cylinder. Be sure to apply significant figures when measuring!
2. Write up a report for the insurance agency detailing your experiment procedure and results.

Questions

1. **Identify the independent and dependent variables as well as any constants or controls in your experiment.**

2. **How would the data differ in terms of accuracy if you did not apply significant figures to your measurements?**

3. **Compose a report for the insurance agent including:**
    - **i. Procedure**
    - **ii. Data**
    - **iii. Summary of results (i.e. trends in the data)**

4. **Identify at least one source of experimental error and explain how this error could be mitigated in future experiments.**

5. **Ask a family member or friend who routinely uses measuring devices in their job to explain how they record measurements. Summarize their explanation and conclude whether or not they apply significant figures. If they do not apply significant figures, why not?**

Definitions

Significant Figures
These apply to measured quantities and are equal to the number of digits known with certainty plus an estimated digit.

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Extension Activity

The Kilogram Controversy

Here's something to think about: when you place an item on a scale or use a stopwatch to record a race, you're making an assumption that those devices are going to give you an accurate reading. For example, you expect that the scale will give you a numerical value, in a specified unit such as a kilogram. It's also likely that the manual for the scale references the degree of uncertainty caused by the limitations of the equipment. However at an even deeper level, you're assuming that the unit means something: that a kilogram is a universal standard. And it is—sort of.

The International prototype kilogram was once the primary standard kilogram for the entire scientific community but was replaced in 2019 with a new definition based on constants occurring in nature. (Photo courtesy of The National Institute of Standards.)

What's in a Kilogram?

A kilogram is one of the seven basic units of measurement within the **International System of Units**, or SI. You're probably already familiar with this system from your science classes because it is the international standard for science, but have you ever wondered how we determine exactly what counts as one kilogram? For 130 years, the value of a kilogram was based on a real object called the "**international prototype kilogram**" (IPK). The IPK is a closely guarded platinum-iridium alloy cylinder housed in a vault at the International Bureau of Weights and Measures near Paris, France. For something to count as a true kilogram, it had to exactly match the mass of the IPK. Therein lay the problem.

The kilogram was the only basic SI unit still defined by a physical artifact rather than a natural phenomenon. The meter, for example, is determined based on the speed that light travels in a vacuum over a specific period of time. By definition, this natural phenomenon is unchanging and can be measured anywhere (with the right tools). As durable as the IPK is, it could be damaged over time or even destroyed—not to mention

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that you have to get into a vault controlled by three independent keys in order to weigh it. That's why, in 2018, representatives from 60 countries came together to vote on a new definition for the kilogram. As of 2019, the kilogram will now be measured based on three fundamental constants (the Planck constant, the speed of light, and the cesium atom's natural microwave radiation) instead of a physical artifact.

Laboratory Standards

Regardless of how the kilogram is defined, it's important to understand why standardizing measurements are so critical to the everyday applications of science and engineering. Just like you, scientists are operating under the assumption that a measurement in their laboratory is exactly the same as a measurement their colleague makes somewhere else. They need to be able to trust that their equipment is giving them accurate results.

That's where **Certified Reference Materials**, or CRMs, come in. CRMs are samples that act as a standard to test against. To return to our earlier example of a scale: imagine measuring 100 objects of unknown weight. What would happen if you then added a one kilogram weight to the scale but received a readout of 1.5kg? You would be left questioning the accuracy of all 100 measurements you took before! Now imagine if the same problem was applied to a company testing the chemical makeup of an alloy being used on a bridge, a medical laboratory testing blood samples, or a food company testing the level of arsenic present. Suddenly accurate measurements seem much more important.

Many laboratory or industry-grade measuring devices need to either be checked periodically for accuracy, or **calibrated** against a sample of known value. CRMs act as that known standard that allows scientists and engineers to calibrate their equipment or to double-check that the measurements being taken are still accurate.

CRMs help ensure precise measurement and testing in everything from DNA, to greenhouse gas emissions, to the nutritional value of supposed "superfoods." Think about that the next time you read the nutritional label of a food package.

Extension Activity

Questions

1. The International System of Units has seven base units. Identify all seven and indicate what each is used to measure.

2. The International Prototype Kilogram needed to last a long time. Research the IPK to determine why it was made of a platinum iridium alloy.

3. The IPK has recently gained tens of micrograms of mass from surface contamination. Although tens of micrograms may seem insignificant, how could adding this mass to the standard unit of mass impact the accuracy of measurements?

4. List and describe the 5 types of reference materials.

Definitions

Calibrate
Correlate an instrument's readings with a standard to determine accuracy of the instrument.

Certified Reference Materials (CRM)
Control or standard used to validate analytical measurements.

International prototype kilogram (IPK)
An artifact that defines the current SI unit of mass.

International System of Units (SI)
A system of measurement based on seven base units: meter, kilogram, second, ampere, Kelvin, mole, and candela.

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ARCONIC FOUNDATION

Materials Explorers™ is a STEM educational outreach initiative of The Minerals, Metals & Materials Society (TMS). TMS is non-profit, international professional society with a mission to promote the global science and engineering professions concerned with minerals, metals, and materials.

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