1.5 Reporting Values from Measurements

All measurements are uncertain to some degree. Scientists are very careful to report the values of measurements in a way that not only shows the measurement's magnitude but also reflects its degree of uncertainty. Because the uncertainty of a measurement is related to both the *precision* and the *accuracy* of the measurement, we need to begin by explaining these terms.

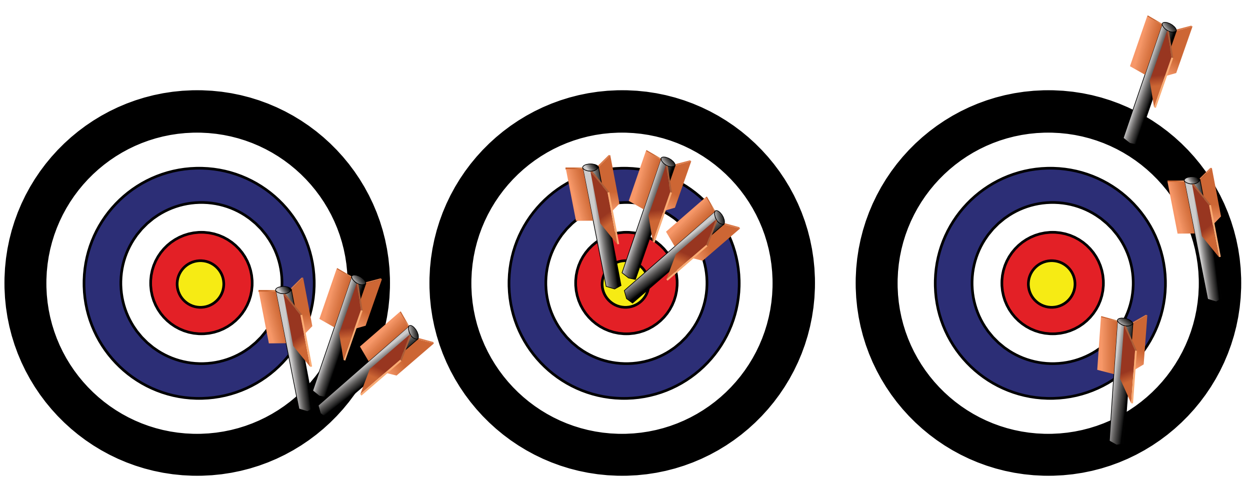
Accuracy and Precision

Precision describes how closely a series of measurements of the same object resemble each other. The closer the measurements are to each other, the more precise they are. The precision of a measurement is not necessarily equal to its accuracy. **Accuracy** describes how closely a measured value approaches the true value of the property.

Objective 17

To get a better understanding of these terms, let's imagine a penny that has a true mass of 2.525 g. If the penny is weighed by five different students, each using the same balance, the masses they report are likely to be slightly different. For example, the reported masses might be 2.680 g, 2.681 g, 2.680 g, 2.679 g, and 2.680 g. Because the range of values is ±0.001 g of 2.680 g, the precision of the balance used to weigh them is said to be ±0.001 g, but notice that none of the measured values is very accurate. Although the precision of our measurement is ±0.001 g, our measurement is inaccurate by 0.155 g (2.680 − 2.525 = 0.155). Scientists recognize that even very precise measurements are not necessarily accurate. Figure 1.12 provides another example of the difference between accuracy and precision.

Figure 1.12
Precision and Accuracy



This archer is precise but not accurate.

This archer is precise and accurate.

This archer is imprecise and inaccurate.

Describing Measurements

Certain standard practices and conventions make the taking and reporting of measurements more consistent. One of the conventions that scientists use for reporting measurements is to report all of the certain digits and one estimated (and thus uncertain) digit.

Objective 18

Consider, for example, how you might measure the volume of water shown in the graduated cylinder in Figure 1.13. (Liquids often climb a short distance up the walls of a glass container, so the surface of a liquid in a graduated cylinder is usually slightly curved. If you look from the side of the cylinder, this concave surface looks like a bubble. The surface is called a meniscus. Scientists follow the convention of using the bottom of the meniscus for their reading.) The graduated cylinder in Figure 1.13 has rings corresponding to milliliter values and smaller divisions corresponding to increments of 0.1 mL. When using these marks to read the volume of the liquid shown in Figure 1.13, we are certain that the volume is between 8.7 mL and 8.8 mL. By imagining that the smallest divisions are divided into 10 equal parts, we can estimate the hundredth position. Because the bottom of the meniscus seems to be about four-tenths of the distance between 8.7 mL and 8.8 mL, we report the value as 8.74 mL. Because we are somewhat uncertain about our estimation of the hundredth position, our value of 8.74 mL represents all of the certain digits and one uncertain digit.

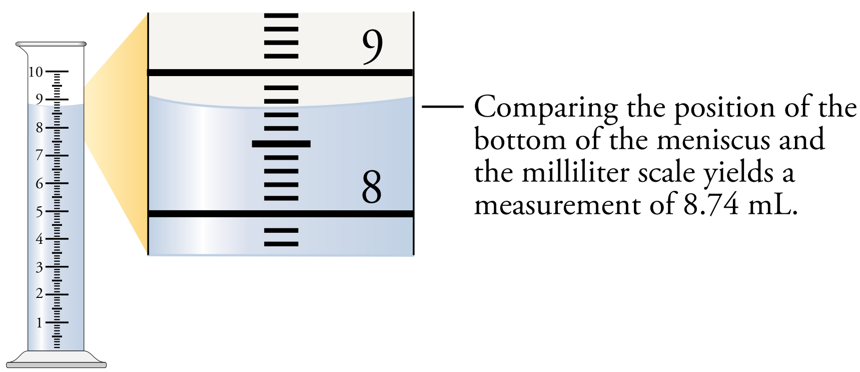


Figure 1.13
Measuring Volume with a Graduated Cylinder

Scientists agree to assume that the number in the last reported decimal place has an uncertainty of ±1 unless stated otherwise. Example 1.2 shows how this assumption is applied.

Objective 19

Example 1.2 – Uncertainty

Objective 19

If you are given the following values that are derived from measurements, what will you assume is the range of possible values that they represent?

a. 5.4 mL c. 2.34×10^3 kg
b. 64 cm

Solution

We assume an uncertainty of ±1 in the last decimal place reported.

a. 5.4 mL means **5.4 ± 0.1 mL** or **5.3 to 5.5 mL.**
b. 64 cm means **64 ± 1 cm** or **63 to 65 cm.**
c. 2.34×10^3 kg means **$(2.34 \pm 0.01) \times 10^3$ kg** or **2.33×10^3 kg to 2.35×10^3 kg.**

Exercise 1.2 – Uncertainty

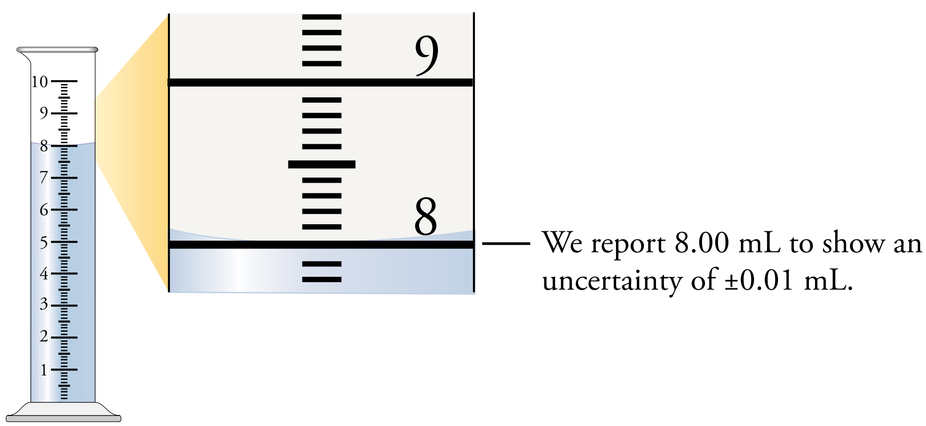
Objective 19

If you are given the following values that are derived from measurements, what will you assume is the range of possible values that they represent?

a. 72 mL
b. 8.23 m
c. 4.55×10^{-5} g

Sometimes it is necessary to use trailing zeros to show the uncertainty of a measurement. If the top of the liquid in the graduated cylinder shown in Figure 1.14 is right at the 8-mL mark, you would report the measurement as 8.00 mL to indicate that the uncertainty is in the second decimal place. Someone reading 8.00 mL would recognize that the measured amount was between 7.99 mL and 8.01 mL. Reporting 8 mL would suggest an uncertainty of ±1 mL, in which case the amount would be assumed to lie anywhere between 7 mL and 9 mL.

Figure 1.14
Reporting Values with Trailing Zeros



Objective 18

There are other ways to decide how to report values from measurements. For example, the manufacturer of the graduated cylinder in Figure 1.14 might inform you that the lines have been drawn with an accuracy of ±0.1 mL. Therefore, your uncertainty when measuring with this graduated cylinder will always be at least ±0.1 mL, and your values reported should be to the tenth position. In this case, the volumes in Figure 1.13 and 1.14 would be reported as 8.7 mL and 8.0 mL.

Objective 18

In general, though, unless you are told to do otherwise, the conventional practice in using instruments such as a graduated cylinder is to report all of your certain digits and one estimated digit. For example, if you were asked to measure the volumes shown in Figures 1.13 and 1.14, you would report 8.74 mL and 8.00 mL unless you were told to report your answer to the tenth place.

Example 1.3 - Uncertainty in Measurement

Objective 18

Consider a laboratory situation where five students are asked to measure the length of a piece of tape on a lab bench with a meter stick. The values reported are 61.94 cm, 62.01 cm, 62.12 cm, 61.98 cm, and 62.10 cm. The average of these values is 62.03 cm. How would you report the average measurement so as to communicate the uncertainty of the value?

Solution

If we compare the original measured values, we see that they vary in both the tenth and hundredth decimal places. Because we only report one uncertain decimal place, we report our answer as **62.0 cm**. The final zero must be reported to show that we are uncertain by ±0.1 cm. (When we also consider the uncertainties that arise from the difficulty in aligning the meter stick with the end of the tape and the difficulty estimating between the lines for the very tiny 0.1 cm divisions, it is reasonable to assume that our uncertainty is no better than ±0.1 cm.)

Exercise 1.3 - Uncertainty in Measurement

Objective 18

Let's assume that four members of your class are asked to measure the mass of a dime. The reported values are 2.302 g, 2.294 g, 2.312 g, and 2.296 g. The average of these values is 2.301 g. Considering the values reported and the level of care you expect beginning chemistry students to take with their measurements, how would you report the mass so as to communicate the uncertainty of the measurement?

Digital Readouts

The electronic balances found in most scientific laboratories have a digital readout that reports the mass of objects to many decimal positions. For example, Figure 1.15 shows the display of a typical electronic balance that reports values to the ten-thousandth of a gram, or to a tenth of a milligram. As you become more experienced, you will realize that you are not always justified in reporting a measurement to the number of positions shown on a digital readout. For the purposes of this course, however, if you are asked to make a measurement using an instrument that has a digital readout, you should report all of the digits on the display unless told to do otherwise.

Figure 1.15
The Display of a Typical Electronic Balance

Objective 18