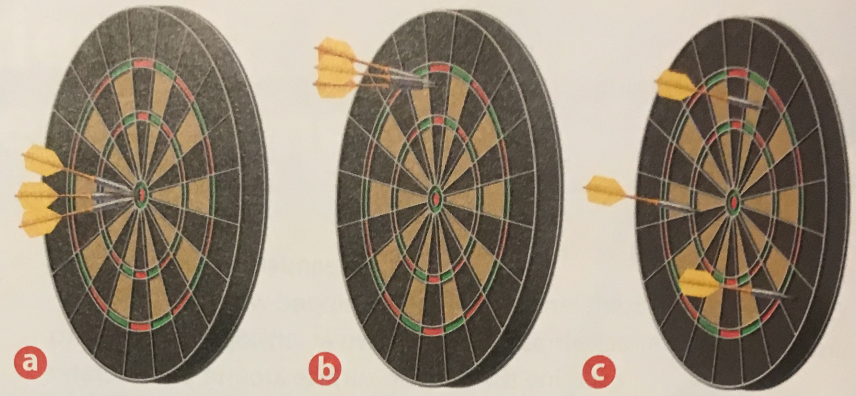
Figure 3.2 The distribution of darts illustrates the difference between accuracy and precision. **a** Good accuracy and good precision: The darts are close to the bull's-eye and to one another. **b** Poor accuracy and good precision: The darts are far from the bull's-eye but close to one another. **c** Poor accuracy and poor precision: The darts are far from the bull's-eye and from one another.



Accuracy, Precision, and Error

Your success in the chemistry lab and in many of your daily activities depends on your ability to make reliable measurements. Ideally, measurements should be both correct and reproducible.

Accuracy and Precision Correctness and reproducibility relate to the concepts of accuracy and precision, two words that mean the same thing to many people. In chemistry, however, their meanings are quite different. **Accuracy** is a measure of how close a measurement comes to the actual or true value of whatever is measured. **Precision** is a measure of how close a series of measurements are to one another. **To evaluate the accuracy of a measurement, the measured value must be compared to the correct value. To evaluate the precision of a measurement, you must compare the values of two or more repeated measurements.**

Darts on a dartboard illustrate accuracy and precision in measurement. Let the bull's-eye of the dartboard represent the true, or correct, value of what you are measuring. The closeness of a dart to the bull's-eye corresponds to the degree of accuracy. The closer it comes to the bull's-eye, the more accurately the dart was thrown. The closeness of several darts to one another corresponds to the degree of precision. The closer together the darts are, the greater the precision and the reproducibility.

Look at Figure 3.2 as you consider the following outcomes.

a. All of the darts land close to the bull's-eye and to one another. Closeness to the bull's-eye means that the degree of accuracy is great. Each dart in the bull's-eye corresponds to an accurate measurement of a value. Closeness of the darts to one another indicates high precision.

b. All of the darts land close to one another but far from the bull's-eye. The precision is high because of the closeness of grouping and thus the high level of reproducibility. The results are inaccurate, however, because of the distance of the darts from the bull's-eye.

c. The darts land far from one another and from the bull's-eye. The results are both inaccurate and imprecise.

Checkpoint ***How does accuracy differ from precision?***

Determining Error Note that an individual measurement may be accurate or inaccurate. Suppose you use a thermometer to measure the boiling point of pure water at standard pressure. The thermometer reads 99.1°C. You probably know that the true or accepted value of the boiling point of pure water under these conditions is actually 100.0°C. There is a difference between the **accepted value,** which is the correct value based on reliable references, and the **experimental value,** the value measured in the lab. The difference between the experimental value and the accepted value is called the **error.**

$$\text{Error} = \text{experimental value} - \text{accepted value}$$

Error can be positive or negative depending on whether the experimental value is greater than or less than the accepted value.

For the boiling-point measurement, the error is 99.1°C − 100.0°C, or −0.9° C. The magnitude of the error shows the amount by which the experimental value differs from the accepted value. Often, it is useful to calculate the relative error, or percent error. The **percent error** is the absolute value of the error divided by the accepted value, multiplied by 100%.

$$\text{Percent error} = \frac{|\text{error}|}{\text{accepted value}} \times 100\%$$

Using the absolute value of the error means that the percent error will always be a positive value. For the boiling-point measurement, the percent error is calculated as follows.

$$\text{Percent error} = \frac{|99.1^\circ\text{C} - 100.0^\circ\text{C}|}{100.0^\circ\text{C}} \times 100\%$$

$$= \frac{0.9\cancel{^\circ\text{C}}}{100.0\cancel{^\circ\text{C}}} \times 100\%$$

$$= 0.009 \times 100\%$$

$$= 0.9\%$$

Just because a measuring device works doesn't necessarily mean that it is accurate. As Figure 3.3 shows, a weighing scale that does not read zero when nothing is on it is bound to yield error. In order to weigh yourself accurately, you must first make sure that the scale is zeroed.

Word *Origins*

Percent comes from the Latin words *per,* meaning "by" or "through," and *centum,* meaning "100." **What do you think the phrase *per annum* means?**

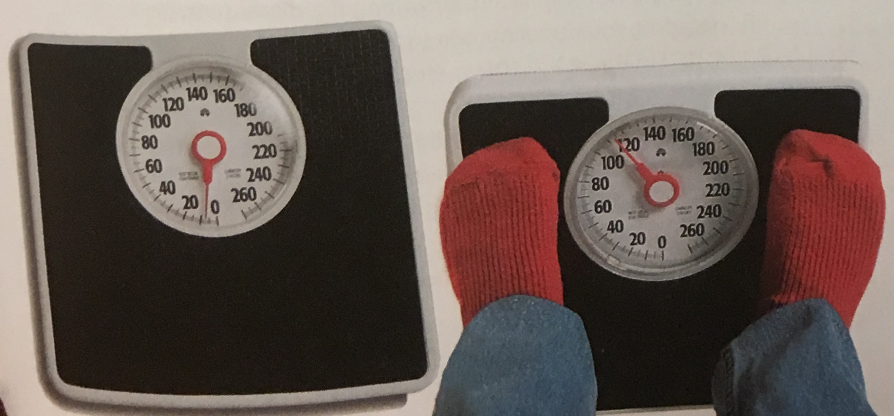


Figure 3.3 The scale below has not been properly zeroed, so the reading obtained for the person's weight is inaccurate. There is a difference between the person's correct weight and the measured value. **Calculating** ***What is the percent error of a measured value of 114 lb if the person's actual weight is 107 lb?***