**Uncertainty in measured values:**
Every measurement made in a laboratory comes with some uncertainty. The uncertain digit in any measurement is always the rightmost (estimated) digit, the last digit written. Unless stated otherwise, the precision (uncertainty) in a number is taken to be ± one unit in the estimated digit. For example, a reported value of 95.4 mL indicates a precision of ± 0.1 mL (95.4 ± 0.1 mL). If the precision of the value is not ±1 in the estimated digit, then the recorder has a responsibility to report the actual precision. For example, if the uncertainty is ± 0.5 mL then the recorder should report 95.4 ± 0.5 mL. You must be able to determine the uncertainty in measurements and record measured values to the proper number of significant digits. Sometimes precision is recorded as a percentage value instead as an absolute value. For example, 50 mL ± 4% instead of 50 mL ± 2 mL where 2 mL is 4% of 50 mL.

**In measured values, or values calculated using measured values, the significant figures must be correct in order to indicate the correct precision.**

**Counting Significant Figures:**
**Inexact Numbers**
All digits of a measured quantity to the left of the uncertain digit plus the uncertain digit are called significant figures.
Consider the following example: The mass of a penny is measured to be 2.5 g (2 significant figures) on one balance and 2.502 g (4 significant figures) on a different balance. What is the implied absolute error (±x) for each of these values? Which one is more precise?

Can you determine which is more accurate with the information given?

When multiple measurements are made of a quantity, the results can be averaged, and the precision of the average estimated through various methods (sig fig rounding “rules” and range are the simplest, standard deviation more sophisticated).

**Rules for Counting Significant Figures in an Inexact Number**
1. All nonzero digits are significant.
2. All leading zeros are not significant.
3. Zeros that end a number are significant whether they occur before or after the decimal point as long as a decimal point is present.
4. Zeros that end a number are NOT significant if no decimal point is present.

Examples:
- 0.0045 has 2 significant figures
- 1.030 mL has 4 significant figures
- 5300. L has 4 significant figures
- 5300 L has only 2 significant figures
5. It is best to use scientific notation to unambiguously reflect the number of significant figures in cases like the last two examples:

\[ 5300. \text{ L} = 5.300 \times 10^3 \text{ L} \]
\[ 5300 \text{ L} = 5.3 \times 10^3 \text{ L} \]

**Exact Numbers**

These numbers have no uncertainty and are taken to be exact (“unlimited” sig. figs.). Examples are 1 dozen=12, 1 liter = 1000 mL, etc. As a rule, numeric definitions and whole numbers used for counting are taken to be exact. Some metric to English conversion factors are also exact, such as 1 inch = 2.54 cm. Since exact numbers are considered to have an unlimited number of significant figures, they do not need to be considered when determining how many significant figures the result of a calculation has.

Silly Example: Dr. Larson has 2 eyes. This is exact, not 2±1!

**Significant Digits in Calculated Numbers**

When we do a calculation involving inexact numbers the result of the calculation will have some uncertainty. It is your responsibility to determine the uncertain digit in the resultant calculation and to round the result to the correct digit. To do this we apply the rules below to EACH STEP of a calculation.

1. *A Multiplication or Division Step:* The result of the calculation contains the same number of significant figures as there are in the measurement with the fewest significant figures. Find the uncertain digit by counting significant digits from left to right in the result. Underline this digit.

2. *An Addition or Subtraction Step:* The answer has an absolute error at least as big as the greatest absolute error found in the numbers added and/or subtracted. Locate and underline the digit in the calculation result corresponding to this absolute error.

3. **Rules for Rounding the UNCERTAIN DIGIT:** *(This is simpler than the textbook instructions and it is consistent with how your calculator will round off.)*

   3.1. If the digit to be removed after the uncertain digit is 5 or greater then round the uncertain digit up.

   3.2. If the digit to be removed after the uncertain digit is 4 or less then leave the uncertain digit unchanged.

   3.3. When there are 2 or more steps in a calculation, accumulated rounding-off errors may skew the value of the final result (cause it to be too low or too high). Therefore, when a calculation involves two or more steps you should retain at least one additional digit—past the uncertain digit—for the intermediate answers. This procedure helps to ensure that small errors from rounding at each step do not combine to skew the final result. When using a calculator, you may enter the numbers one after another, rounding only the final answer, but you need to keep track of where the result of each step should be rounded!
Practice:
1. How many significant figures are in the following numbers?
   (a) 1.608  
   (b) 0.0910  
   (c) 1.30\times10^{-3}

2. Round each of the following to 3 significant figures.
   (a) 6.167  
   (b) 0.002245  
   (c) 3136

3. Indicate which of the following are exact numbers:
   (a) the mass of a paper clip  
   (b) your height in cm  
   (c) the number of microseconds in a week  
   (d) the number of pages in this worksheet

4. Carry out the following operations, and express the answer with the appropriate number of significant figures:
   (a) 6.19 \times 2.8  
   (b) 213 + 0.01

   (c) 320.55 - (6104.5/2.3)  
   (d) (4.10 \times 302 - 1.1\times10^3)/1.56\times10^{-4}

   (e) (0.0045 \times 20,000.0) + (2.813 \times 12)