Chemistry 11

Measurement 3:
Significant Figures & Density

Significant Figures

0.00003400

All nonzero numbers are significant

Zeros after nonzero numbers in a decimal are significant

Zeros are not significant after decimal before non-zero numbers

Name:__________________ Block:____
Significant Figures

When determining the correct value indicated by a measuring device, you should always record all of the significant figures (sometimes called “sig figs”).

The number of significant figures in a measurement includes...

When COUNTING a small number of objects it is not difficult to find the EXACT number of objects. On the other hand, when a property such as mass, time, volume or length is MEASURED you can never find the exact value. It is possible to find a mass, say, very precisely but it is impossible to find an object’s exact mass.

All measurements have a certain amount of “uncertainty” associated with them. The purpose of this section is to show you how to correctly report and use the results of the experimental measurements you will be making in Chemistry 11.

You will need to learn (a) how to find and report the uncertainty associated with each measurement, and (b) the number of digits which can be claimed when reporting results and carrying out calculations with the results.

A significant figure is a measured or meaningful digit

Example: if a stopwatch is used to time an event and the elapsed time is 35.2 s, then the measurement has ____ significant figures (____, ____ and ____). If the stopwatch can only be read to 0.1 s then it is silly to claim that the time according to the stopwatch is 35.2168497 s. Since the stopwatch cannot measure the time to 7 decimal places, the last digits (____________) have ________________...in other words they are “fictional” or “imagined”.

Example: if a balance gives a reading of 97.53 g when a beaker is placed on it. This first reading has ___ sig. figs. The beaker is then put on a different balance, giving a reading of 97.5295 g. In this second case there are now ____ sig. figs. because the measurement tool used, and the measurement taken has less uncertainty and likely, more precision.

Say the scale on a measuring device reads as shown in Figure 1.3.3. (Note that scale may refer to the numerical increments on any measuring device.)

The measured value has ________________ certain figures (__________________) and __________ uncertain figure (__________________).

Hence the measurement has ________________ significant figures.

The following _________ can be applied to determine how many figures are significant in any measurement.

Counting Significant Figures in a Measured Value

1. All ___________________________ digits are significant.

2. All __________________ non-zero digits ______________________. Such zeros may be called sandwiched or captive zeros.

3. __________________________ zeros (zeros to the ________________ of a non-zero digit) are never significant.

4. __________________________ zeros (zeros to the ________________ of a non-zero digit) are ________ significant if there is a________________________ in the number.

Another way to determine the number of significant figures in a measured value is to simply express the number in _____________________________ and count the digits.

This method nicely ______________________ the non-significant leading zeros.

However, it is only successful if you recognize when to include the trailing (right side) zeros.

Remember that trailing zeros are only significant if there is__________________________ in the number.

If the trailing zeros are significant, they need to be ___________________________ when the number is written in
### Sample Problems — Counting Significant Figures in a Measured Value

Determine the number of significant figures in each example.

1. 0.09204 g
2. 87.050 L

<table>
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<th>What to Think about</th>
<th>How to Do It</th>
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</thead>
<tbody>
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<td><strong>Question 1</strong></td>
<td></td>
</tr>
<tr>
<td>1. To begin with, apply rule 3: leading zeros are never significant. Note that the position of the zero relative to the decimal is irrelevant. These are sometimes referred to as place holding zeros. The underlined leading zeros are not significant.</td>
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<tr>
<td>2. Apply rule 1 next: all non-zero digits are significant. The underlined digits are significant.</td>
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<tr>
<td>3. Finally, apply rule 2: the captive zero is significant. The underlined zero is sandwiched between two non-zero digits so it is significant.</td>
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<tr>
<td>4. A check of the number in scientific notation, 9.204 × 10⁻² g, also shows four significant figures.</td>
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<tr>
<td><strong>Question 2</strong></td>
<td></td>
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<tr>
<td>1. Apply rule 1: all non-zero digits are significant. All of the underlined digits are significant.</td>
<td></td>
</tr>
<tr>
<td>2. Apply rule 2: the captive zero is significant. The underlined zero is between two non-zero digits so it is significant.</td>
<td></td>
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<tr>
<td>3. Finally, consider the trailing or right-side zero. Rule four states that such zeros are only significant if a decimal is present in the number. Note that the position of the zero relative to the decimal is irrelevant. As this number does contain a decimal, the underlined trailing zero is significant.</td>
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<tr>
<td>4. Check: 8.7050 × 10¹ L has five sig figs (note that the right-side zero is retained).</td>
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</tbody>
</table>

**EXERCISE:** Show FULL WORKING OUT on THIS PAGE in the space provided below.

42. How many significant figures do each of the following measurements have?

<table>
<thead>
<tr>
<th>Option</th>
<th>Measurement</th>
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<tbody>
<tr>
<td>a)</td>
<td>1.25 kg</td>
</tr>
<tr>
<td>b)</td>
<td>1255 kg</td>
</tr>
<tr>
<td>c)</td>
<td>11 s</td>
</tr>
<tr>
<td>d)</td>
<td>150 m</td>
</tr>
<tr>
<td>e)</td>
<td>1.283 cm</td>
</tr>
<tr>
<td>f)</td>
<td>365,249 days</td>
</tr>
<tr>
<td>g)</td>
<td>2,000,000 years</td>
</tr>
<tr>
<td>h)</td>
<td>17.25 L</td>
</tr>
</tbody>
</table>
Practice Problems — Counting Significant Figures in a Measured Value

1. How many significant figures are in each of the following measured values?
   (a) 425 mL _________
   (b) 590.50 g _________
   (c) 0.00750 s _________
   (d) $1.50 \times 10^4$ L _________
   (e) 3400 m _________

2. Round the following measurements to the stated number of significant figures.
   (a) 30.54 s (3 sig figs) ______________
   (b) 0.2895 g (3 sig figs) ______________
   (c) 4.49 m (2 sig figs) ______________
   (d) 100.4°C (2 sig figs) ______________

Remember!

An **ACCURATE** measurement is a measurement that is close to the CORRECT or ACCEPTED value. (The closer to the correct/accepted value, the more accurate the measurement.)

A **PRECISE** measurement is a reproducible measurement. In general, the more precise a measurement, the more **SIGNIFICANT DIGITS** it has.

**Example:** Assume that the correct width of the room is 5.32000m
- A measurement of 5.3m is ______________ but not very ______________. The value is close to the true value, but there are **not many significant figures** so the value is **not** very precise.

- If several measurements with some device consistently give the width as 5.45217m the measurements are ______________ but not ______________. (none of the sig figs are correct, so lacks accuracy)

- If several measurements are given at 5.32001m, it is ______________ and ____________________.
EXERCISES: Show FULL WORKING OUT on THIS PAGE in the space provided below.

44. A "calibration weight" has a mass of exactly 1.000 000 g. A student uses 4 different balances to check the mass of the weight. The results of the weighings are shown below.

mass using balance A = 0.999 999 g  
mass using balance B = 1.00 g  
mass using balance C = 3.0 g  
mass using balance D = 0.811 592 g

(a) Which of the balances give accurate weighings?
(b) Which of the balances give precise weighings?
(c) Which balance is both accurate and precise?

45. An atomic clock is used to measure a time interval of 121.315 591 s. Assume you have to measure the same time interval. Give an example of a time interval you might actually measure if your measurement is:

(a) not accurate, but is precise.  
(b) not precise, but is accurate.  
(c) both inaccurate and imprecise.  
(d) both accurate and precise.

The number of significant figures is equal to all the certain digits PLUS the first uncertain digit.

EXAMPLE: In the figure at the right, the liquid level is somewhere between □□ mL. You know that it is at least 42 mL, so you are "certain" about the first two digits. As a guess, the volume is about 42.6 mL; it could be 42.5 or 42.7 but 42.6 seems reasonable. There is some to this last, guessed digit. It is somewhat uncertain, but not completely so. For example, the reading is □□ 42.1 or 42.9. As a result, there are two CERTAIN digits (4 and 2) and one uncertain—but–still—significant digit (6) for a total of THREE significant figures.

NOTE: If you are given a measurement without being told something about the device used to obtain the measurement, assume that the LAST DIGIT GIVEN IS ____________________________

EXERCISE: Show FULL WORKING OUT on THIS PAGE in the space provided below.

46. How many "certain" digits are contained in each of the following measurements?

(a) 45.3 s  
(b) 125.70 g  
(c) 1.85 L  
(d) 2.12138 g
"Defined" numbers and "counting" numbers are assumed to be PERFECT so that they are ______ from the rules applying to significant figures.

Defined or counted values involve things which cannot realistically be subdivided and must be taken on an ________

EXAMPLES: When "1 book" or "4 students" is written, it means exactly "1 book" and "4 students", not 1.06 books and 4.22 students.

The conversion factor 1 kg = 1000 g is used to define an _______ between grams and kilograms, so that the numbers involved are assumed to be perfect.

EXERCISE: Show FULL WORKING OUT on THIS PAGE in the space provided below.

47. In the space following each value below put "M" if the value was likely obtained by a Measurement, or "C" if the value was probably determined by Counting.

(a) 4 comets    (b) 45 seconds  (c) 6.5 litres  (d) 12 TV sets  (e) 12 grams

Leading zeroes are not significant.

EXAMPLE: The mass "25 g" has__significant figures. Using a unit conversion to express 25 g in kilograms gives

A more precise measurement was not performed so the measurement must still have two significant figures, the 2 and 5. The leading zeroes (in bold) in 0.025 kg are ______ Notice that re-expressing 25 g in megagrams increases the number of leading zeroes — 0.000 025 Mg — but the leading zeroes are not significant.

The number of leading zeroes depends on the size of the unit used to express the measured value, and is not related to the precision, accuracy or number of significant figures.

Trailing zeroes are all assumed to be significant and must be justified by the precision of the measuring equipment.

EXAMPLE: The zeroes at the end of the following 2 numbers are called ________

25.00 g represents the precision of a common lab balance (significant figures in this case)

25.000 000 g represents a highly precise microbalance (significant figures)

A balance precise to at least 0.000 001 g is required in order to ensure that the trailing zeroes in 25.000 000 g are zeroes and not some other digits.

(If a balance capable of making a measurement to ± 0.01 g is used and the result is written as "35.6 g", it is not correct to say "Oh, I forgot to record the second decimal place, it must have been a zero." In fact, any reading from "35.60 g" to "35.69 g" was equally possible. Write "35.60 g" only when the balance actually shows "0" in the second decimal place.)

EXERCISE: Show FULL WORKING OUT on THIS PAGE in the space provided below.

55. State the number of significant figures in each of the following.

(a) 3570    (c) 41.400   (e) 0.000 572    (g) 4.150 x 10^4    (i) 1.234 00 x 10^8
(b) 17.505  (d) 0.511   (f) 0.009 00    (h) 0.007 160 x 10^5    (j) 0.000 410 0 x 10^7

A)____    C)____    E)____    G)____    I)____
B)____    D)____    F)____    H)____    J)____
After **multiplying** or **dividing** numbers, round off the answer to the **least number of significant figures** contained in the calculation.

**Example:**

\[
\begin{align*}
2.00 \times 3.0000 &= 6.00 \\
\uparrow &\quad \uparrow &\quad \uparrow
\end{align*}
\]

Since the calculation involves a lower precision number (3 significant figures) and a higher precision number (6 significant figures), the precision of the result is limited by

The answer has only 3 significant figures.

**Significant Figures and Arithmetic — Multiplication and Division**
The answer to a multiplication or division problem should have only as many figures as the number having the__________ significant digits in the problem.

**Sample Problems — Significant Figures in Multiplication and Division Calculations**

Give the answer to each of the following problems with the correct number of significant figures:

1. \(8.2 \text{ m} \times 9.47 \text{ m} = \)
2. \(12970.0 \text{ g} \div 530.8 \text{ mL} = \)

**What to Think about**

**Question 1**
1. Begin by applying rules 1 to 4 to determine the number of significant figures contained in each number in the problem.
2. Express the answer should be expressed to two significant figures.

**Question 2**
1. The second example involves more difficult numbers. Apply rules 1 to 4 to quickly determine the number of sig figs in each value.
2. Express the answer to four significant figures.

**How to Do It**

**Important:** You must **always** perform calculations to the maximum number of significant figures allowed by your calculator and only your final answer should be rounded off to the correct number of significant figures. Rounding off **intermediate** answers often produces incorrect results.

If you cannot keep all your calculated values in your calculator (or its memory), then always round off intermediate results so as to keep at least one “significant figure” more than you will eventually use in your final result.
EXAMPLE: \[
\frac{15.55 \times 0.012}{24.6}
\]

EXAMPLE: \[
\frac{2.4000}{8.000}
\]

EXAMPLE: \[
\frac{2.56 \times 10^5}{8.1 \times 10^8}
\]

EXERCISE: Show FULL WORKING OUT on THIS PAGE in the space provided below.

56. Perform the indicated operations and give the answer to the correct number of significant figures.
   (a) \[12.5 \times 0.50\]  
   (b) \[0.15 \times 0.0016\]  
   (c) \[40.0 / 30.0000\]  
   (d) \[2.5 \times 7.500 / 0.150\]  
   (e) \[(6.40 \times 10^8) \times (5 \times 10^5)\]  
   (f) \[4.37 \times 10^9 / 0.0085600\]  
   (g) \[51.3 \times 3.940\]  
   (h) \[0.51 \times 10^{-4} / 6 \times 10^{-7}\]  
   (i) \[4.75 \times 5\]  
   (j) \[0.00001 / 0.1000\]  
   (k) \[7.4 / 3\]  
   (l) \[0.0043 \times 0.00501\]

Quick Check

Give the answer to each of the following problems with the appropriate unit and the correct number of significant figures:

1. \[0.14 \text{ m} \times 14.0 \text{ m} = \text{__________________________}\]
2. \[940 \text{ g} \div 0.850 \text{ mL} = \text{__________________________}\]
3. \[0.054 \text{ g} \div 1.10 \text{ s} = \text{__________________________}\]
Sample Problems — Significant Figures in Addition and Subtraction Calculations

Give the answer to each of the following problems with the correct number of significant figures:

1. \(246.812 \text{ cm} + 1.3 \text{ cm} = \)

2. \(25\,510 \text{ km} - 7\,000 \text{ km} = \)

What to Think about

**Question 1**

1. In addition and subtraction problems, the most important thing is to determine the place value of the last significant figure in each number.
   
   246.812 contains non-zero digits only, so the last significant figure is the last 2, which occupies the thousandths place.
   
   The 3 in 1.3 is the last significant figure and occupies the tenths place.

2. When these two place values are compared, the tenths is less precise; that is, it is less exact than the thousandths place.
   
   Round the final answer to the tenths place, resulting in a number with four significant figures.

   Notice that this rounded to one decimal place.

**How to Do It**

Significant Figures and Arithmetic – Addition and Subtraction

The answer to an addition or subtraction problem should have only as many figures as the (least exact) number in the problem.

The number of significant figures in the answer is determined by considering the place value of the last significant figure in each number in the problem.

*(If both measurements include numbers to the right of a decimal, this means you simply round to the smallest number of decimal places.)*

---

**EXAMPLE:**

\[
\begin{array}{c}
12.56 \text{ cm} \\
+ 125.8 \text{ cm} \\
\hline
138.36 \text{ cm}
\end{array}
\]

\[
\begin{array}{c}
41.037 \text{ g} \\
- 41.037 \text{ g} \\
\hline
0 \text{ g}
\end{array}
\]

---

**Sample Problems — Significant Figures in Addition and Subtraction Calculations**

Give the answer to each of the following problems with the correct number of significant figures:

1. \(246.812 \text{ cm} + 1.3 \text{ cm} = \)

2. \(25\,510 \text{ km} - 7\,000 \text{ km} = \)
Practice Problems—Significant Figures in Addition and Subtraction Calculations

**EXERCISES:** Show FULL WORKING OUT on THIS PAGE in the space provided below.

57. Perform the indicated operations and give the answer to the correct number of significant figures.
   (a) $15.1 + 75.32$
   (b) $178.90456 - 125.8055$
   (c) $4.55 \times 10^{-5} + 3.1 \times 10^{-5}$
   (d) $0.000159 + 4.0074$
   (e) $1.805 \times 10^4 + 5.89 \times 10^2$
   (f) $0.0000481 - 0.000817$
   (g) $7.819 \times 10^5 - 8.166 \times 10^4$
   (h) $45.128 + 8.50187 - 89.18$
   (i) $0.0589 \times 10^{-6} + 7.785 \times 10^{-8}$
   (j) $89.75 \times 10^{-12} + 6.1157 \times 10^{-6}$

**IN SUMMARY**

When **or** two numbers, the result is rounded to the least number of significant figures used in the calculation.

When **or** two numbers, the result is rounded to the least number of decimal places used in the calculation.

**EXERCISES:** Show FULL WORKING OUT on THIS PAGE in the space provided below.

58. Perform the indicated operations and give the answer to the correct number of significant figures.
   (a) $7.95 + 0.583$
   (b) $1.99 / 3.1$
   (c) $4.15 + 1.582 + 0.0588 - 35.5$
   (d) $1200.0 / 3.0$
   (e) $5.31 \times 10^{-4} / 3.187 \times 10^{-8}$
   (f) $45.9 - 15.0025$
   (g) $375.59 \times 1.5$
   (h) $5.1076 \times 10^{-3} - 1.584 \times 10^{-2} + 2.008 \times 10^{-3}$
   (i) $1252.7 - 9.4 \times 10^2$
   (j) $0.02400 / 6.000$
Density

The ________________, or more precisely, the volumetric mass density, of a substance is its _____________________.

The symbol most often used for density is ___ (the lower case Greek letter rho), although the Latin letter ____ can also be used.

Mass =
Volume =

In other words, density is ______________ divided by ______________.

If mass "m" is measured in ______________, and volume "V" is measured in ______________, what are the units for density?

EXAMPLE: An iron bar has a mass of 19 600 g and a volume of 2.50 L. What is the iron's density?

EXAMPLE: If mercury has a density of 13 600 g/L, what volume (in millilitres) is occupied by 425g of mercury?

IMPORTANT FACT: For water at 40°C —

\[ d = 1000.0 \text{ g/L} \]

or \[ d = 1.0000 \text{ g/mL} \]

Measuring the volume of a sample of water allows you to immediately know its mass, and vice versa.

Density can be translated into a conversion statement:

IMPORTANT FACT:

liquids and objects ____________________ on liquids having a ____________________ density.
EXERCISES: Show FULL WORKING OUT on THIS PAGE in the space provided below.

31. A 3.50 mL chunk of boron has a mass of 8.19 g. What is the density of the boron?

32. An iron bar has a mass of 125 g. If iron’s density is 7.86 \times 10^3 \text{ g/L}, what volume does the bar occupy?

33. A block of beeswax has a volume of 200.0 mL and a density of 961 g/L. What is the mass of the block?

34. Alcohol has a density of 789 g/L. What volume of alcohol is required in order to have 46 g of alcohol?

35. A gas called neon is contained in a glass bulb having a volume of 22.4 L. If the density of the neon is 0.900 g/L, what is the mass of the neon in the bulb?

36. A 70.0 g sphere of manganese (density = 7.20 \times 10^3 \text{ g/L}) is dropped into a graduated cylinder containing 54.0 mL of water. What will be the water level indicated after the sphere is inserted?

37. A 25.0 mL portion of each of W, X, Y and Z is poured into a 100 mL graduated cylinder. Each of the 4 compounds is a liquid and will not dissolve in the others. If 55.0 mL of W have a mass of 107.3 g, 12.0 mL of X have a mass of 51.8 g, 42.5 mL of Y have a mass of 46.8 g and 115.0 mL of Z have a mass of 74.8 g, list the layers in the cylinder from top to bottom.
Review Questions

10. Determine the number of significant figures in each of the following measurements:
   (a) 0.1407 m ________________
   (b) 21.05 mg ________________
   (c) 570.00 km ________________
   (d) 0.0030 cm ________________
   (e) 250 m ________________
   (f) 10 035.00 cm³ ________________
   (g) 2800 g ________________
   (h) 5000°C ________________
   (i) $1.1 \times 10^2$ kPa ________________
   (j) $5.35 \times 10^{-2}$ m/h ________________

11. Express the following in proper form scientific notation. Then indicate the correct number of significant figures in the value.
   (a) 4907 L ___________________________
   (b) 0.000 052 m ___________________________
   (c) 7900 g ___________________________
   (d) 0.060 30 ft ___________________________
   (e) 790.0 lb ___________________________

12. Carry out the following operations and give the answers with the correct number of significant figures. Pay close attention to the units.
   (a) $14.6 \text{ cm} \times 12.2 \text{ cm} \times 9.3 \text{ cm}$
   (b) $28.0 \text{ m} \times 16.0 \text{ m} \times 7.0 \text{ m}$

13. A chunk of nickel has a mass of 9.0 g and a volume of 1.01 mL. What is its density?

14. The density of copper is 8.9 g/mL. What is the mass of a 10.8 mL piece of copper?

15. Carry out the following operations and give the answer with the correct number of significant figures.
   (a) $608 \text{ g} + 7 \text{ g} + 0.05 \text{ g}$
   (b) $481.33 \text{ mL} - 37.1 \text{ mL}$
   (c) $6620 \text{ s} + 35.7 \text{ s} + 1.00 \text{ s}$
   (d) $0.007 \text{ m} + 0.100 \text{ m} + 0.020 \text{ m}$

16. Determine the answer with the correct number of significant figures:
   \[
   \frac{1.415 \text{ g}}{1.6 \text{ mL}} + \frac{0.240 \text{ g}}{0.311 \text{ mL}} + \frac{40.304 \text{ g}}{0.2113 \text{ mL}}
   \]

17. Determine the answer to each the following with the correct number of significant figures:
   (a) $\frac{8.4 \text{ g} + 3.0 \text{ g} + 4.175 \text{ g}}{3}$
   (b) \[
   \frac{9.00 \times 10^{-23} \text{ units} \times 2.9900 \times 10^{-25} \text{ units}}{2.9 \times 10^{-9} \text{ units}}
   \]
   (c) \[
   \frac{(5.9 \times 10^{-12} \text{ u} + 7.80 \times 10^{-13} \text{ u})}{(4 \times 10^{12} \text{ u} + 6.700 \times 10^{13} \text{ u})}
   \]