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Skills Worksheet

Problem Solving

Significant Figures

A lever balance used to weigh a truckload of stone may be accurate to the nearest 100 kg, giving a reading of 15 200 kg, for instance. The measurement should be written in such a way that a person looking at it will understand that it represents the mass of the truck to the nearest 100 kg, that is, that the mass is somewhere between 15 100 kg and 15 300 kg.

Some laboratory balances are sensitive to differences of 0.001 g. Suppose you use such a balance to weigh 0.206 g of aluminum foil. A person looking at your data table should be able to see that the measurement was made on a balance that measures mass to the nearest 0.001 g. You should not state the measurement from the laboratory balance as 0.2060 g instead of 0.206 g because the balance was not sensitive enough to measure 0.0001 g.

To convey the accuracy of measurements, all people working in science use significant figures. *A significant figure is a digit that represents an actual measurement.* The mass of the truck was stated as 15 200 kg. The 1, 5, and 2 are significant figures because the balance was able to measure ten-thousands, thousands, and hundreds of kilograms. The truck balance was not sensitive enough to measure tens of kilograms or single kilograms. Therefore, the two zeros are not significant and the measurement has three significant figures. The mass of the foil was correctly stated as 0.206 g. There are three decimal places in this measurement that are known with some certainty. Therefore, this measurement has three significant figures. Had the mass been stated as 0.2060 g, a fourth significant figure would have been incorrectly implied.

Rules for Determining Significant Figures

A. All digits that are not zeros are significant.

All are nonzero digits.

↓↓↓

3 2 5 mL of ethanol

The measurement has three significant figures.

All are nonzero digits.

↓↓↓↓

1.3 2 5 g of zinc

The measurement has four significant figures.

B. Zeros may or may not be significant. To determine whether a zero is significant, use the following rules:

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Problem Solving *continued*

1. Zeros appearing between nonzero digits are significant.

Nonzero digits

↓ ↓

4 0. 7 L of ammonia

↑

Zero between nonzero digits

The measurement has three significant figures.

Nonzero digits

↓ ↓ ↓

3 2 0 0 6 m of wire

↑ ↑

Zero between nonzero digits

The measurement has five significant figures.

2. Zeros appearing in front of nonzero digits are not significant.

Nonzero digits

↓ ↓ ↓

0.0 5 7 2 m^2 of foil

The measurement has three significant figures.

Nonzero digits

↓

0.000 2 g of RNA

The measurement has one significant figure.

3. Zeros at the end of a number and to the right of a decimal are significant figures. Zeros between nonzero digits and significant zeros are also significant. This is a restatement of Rule 1.

Nonzero digits

↓ ↓

9 7. 0 0 kg of tungsten

↑ ↑

Zeros to the right of a number and after a decimal point

The measurement has four significant figures.

Nonzero digits

↓ ↓

1 2 0 0.0 0 cm^3 of lead

↑ ↑ ↑ ↑

Zeros to the right of a number and after a decimal point

The measurement has six significant figures.

4. Zeros at the end of a number but to the left of a decimal may or may not be significant. If such a zero has been measured or is the first estimated digit, it is significant. On the other hand, if the zero has not been measured or estimated but is just a place holder, it is not significant. A decimal placed after the zeros indicates that they are significant.

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Problem Solving *continued*

Nonzero digits

↓ ↓

3 4 0 0 g of sulfur

The measurement has two significant figures.

Nonzero digits

↓ ↓

4 0 0 0. mL of oxygen

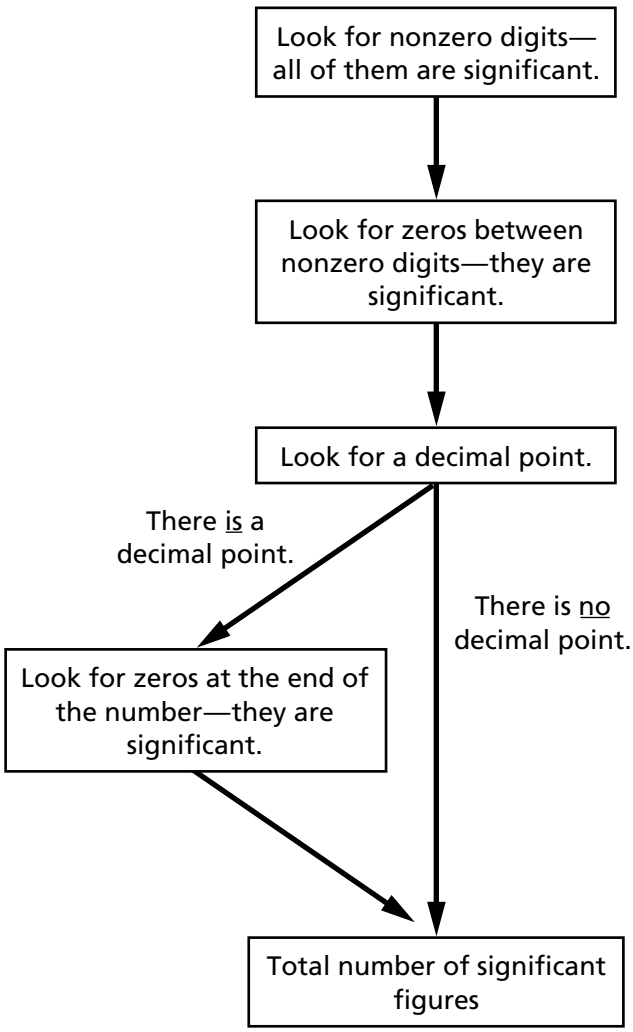
↑ ↑

Decimal point is present, so these zeros are significant.

The measurement has four significant figures.

The rules are summarized in the following flowchart:

General Plan for Determining Significant Figures



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Sample Problem 1

Determine the number of significant figures in the following measurements:

a. 30 040 g
b. 0.663 kg
c. 20.05 mL
d. 1500. mg
e. 0.0008 m

Solution

ANALYZE

What is given in the problem? **five measurements**

What are you asked to find? **the number of significant figures in each measurement**

Items	Data				
	a	b	c	d	e
Measured quantity	30 040 g	0.663 kg	20.05 L	1500. mg	0.0008 g

PLAN

What steps are needed to determine the number of significant figures in each measurement?

Apply the steps in the flowchart to determine the number of significant figures.

Apply the following steps from the flowchart. Eliminate the steps that are not applicable to the measurement in question.

How many nonzero digits are there?	?
How many zeros are there between nonzero digits?	?
Is there a decimal point?	?
How many significant zeros are at the end of the number?	?
Total number of significant figures	?

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SOLVE

a. 30 040 g

How many nonzero digits are there?	2
How many zeros are there between nonzero digits?	2
Is there a decimal point?	no
How many significant zeros are at the end of the number?	NA
Total number of significant figures	4

The final zero is not significant.

b. 0.663 kg

How many nonzero digits are there?	3
How many zeros are there between nonzero digits?	NA
Is there a decimal point?	yes
How many significant zeros are at the end of the number?	NA
Total number of significant figures	3

The zero only locates the decimal point and is not significant.

c. 20.05 L

How many nonzero digits are there?	2
How many zeros are there between nonzero digits?	2
Is there a decimal point?	yes
How many significant zeros are at the end of the number?	NA
Total number of significant figures	4

d. 1500. mg

How many nonzero digits are there?	2
How many zeros are there between nonzero digits?	NA
Is there a decimal point?	yes
How many significant zeros are at the end of the number?	2
Total number of significant figures	4

There is a decimal following the final two zeros, so all digits are significant.

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e. 0.0008 g

How many nonzero digits are there?	1
How many zeros are there between nonzero digits?	NA
Is there a decimal point?	yes
How many significant zeros are at the end of the number?	NA
Total number of significant figures	1

The zeros are only place holders. They are not significant.

EVALUATE

Are the answers reasonable?

Yes; all answers are in agreement with the rules for determining significant figures.

Practice

1. Determine the number of significant figures in the following measurements:

a. 640 cm^3 **ans: 2**

b. 200.0 mL **ans: 4**

c. 0.5200 g **ans: 4**

d. 1.005 kg **ans: 4**

e. 10 000 L **ans: 1**

f. 20.900 cm **ans: 5**

g. 0.000 000 56 g/L **ans: 2**

h. 0.040 02 kg/m^3 **ans: 4**

i. 790 001 cm^2 **ans: 6**

j. 665.000 $kg \cdot m/s^2$ **ans: 6**

DETERMINING SIGNIFICANT FIGURES IN CALCULATIONS

Suppose you want to determine the density of an ethanol-water solution. You first measure the volume in a graduated cylinder that is accurate to the nearest 0.1 mL. You then determine the mass of the solution on a balance that can measure mass to the nearest 0.001 g. You have read each measuring device as accurately as you can, and you record the following data:

Measurement	Data
Mass of solution, m	11.079 g
Volume of solution, V	12.7 mL
Density of solution in g/mL, D	?

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Problem Solving *continued*

You can determine density on your calculator and get the following result:

$$D = \frac{m}{V} = \frac{11.079\ \text{g}}{12.7\ \text{mL}} = 0.872\ 362\ 204\ \text{g/mL}$$

Although the numbers divide out to give the result shown, it is not correct to say that this quantity is the density of the solution. Remember that you are dealing with measurements, not just numbers. Consider the fact that you measured the mass of the solution with a balance that gave a reading with five significant figures: 11.079 g. In addition, you measured the volume of the solution with a graduated cylinder that was readable only to three significant figures: 12.7 mL. It seems odd to claim that you now know the density with an accuracy of nine significant figures.

You can calculate the density—or any measurement—*only as accurately as the least accurate measurement* that was used in the calculation. In this case the least accurate measurement was the volume because the measuring device you used was capable of giving you a measurement with only three significant figures. Therefore, you can state the density to only three significant figures.

Rules for Calculating with Measured Quantities

Operation	Rule
Multiplication and division	• Round off the calculated result to the same number of significant figures as the measurement having the fewest significant figures.
Addition and subtraction	• Round off the calculated result to the same number of decimal places as the measurement with the fewest decimal places. If there is no decimal point, round the result back to the digit that is in the same position as the leftmost uncertain digit in the quantities being added or subtracted.

In the example given above, you must round off your calculator reading to a value that contains three significant figures. In this case, you would say:

$$D = \frac{m}{V} = \frac{11.079\ \text{g}}{12.7\ \text{mL}} = 0.872\ \cancel{362\ 204}\ \text{g/mL} = 0.872\ \text{g/mL}$$

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Sample Problem 2

In an experiment to identify an unknown gas, it is found that 1.82 L of the gas has a mass of 5.430 g. What is the density of the gas in g/L?

Solution

ANALYZE

What is given in the problem? **the measured mass and volume of the gas**

What are you asked to find? **the density of the gas**

Items	Data
Mass of the gas, m_{gas}	5.430 g
Volume of the gas, V_{gas}	1.82 L
Density of the gas, D_{gas} (numerical result)	? g/L
Least number of significant figures in measurements	3 (in 1.82 L)
Density of the gas, D_{gas} (rounded)	? g/L

PLAN

What step is needed to calculate the density of the gas?

Divide the mass measurement by the volume measurement.

What steps are necessary to round the calculated value to the correct number of significant figures?

Determine which measurement has the fewest significant figures. Round the calculated result to that number of significant figures.

$$D_{gas} = \frac{m_{gas}}{V_{gas}} = \text{numerical result} \xrightarrow[\text{significant figures}]{\text{round to correct}} \text{rounded result}$$

COMPUTE

$$D_{gas} = \frac{m_{gas}}{V_{gas}} = \frac{\overset{\text{four significant figures}}{5.430\text{ g}}}{\underset{\text{three significant figures}}{1.82\text{ L}}} = \overset{\text{round to three significant figures}}{2.983\cancel{516\,484}} = 2.98\text{ g/L}$$

the digit following the 8 is less than 5, so the 8 remains unchanged

EVALUATE

Are the units correct?

Yes; density is given in units of mass per unit volume.

Are the significant figures correct?

Yes; the mass had only three significant figures, so the answer was rounded to three significant figures.

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Is the answer reasonable?

Yes; the mass/volume ratio is roughly 3/1, so the density is approximately 3 g/L.

Practice

1. Perform the following calculations, and express the result in the correct units and number of significant figures.

a. 47.0 ÷ 2.2 s **ans: 21 m/s**

b. 140 cm × 35 cm **ans: 4900 cm^2**

c. 5.88 kg ÷ 200 m^3 **ans: 0.03 kg/m^3**

d. 0.00 50 m^2 × 0.042 m **ans: 0.000 21 m^3**

e. 300.3 L ÷ 180. s **ans: 1.67 L/s**

f. 33.00 cm^2 × 2.70 cm **ans: 89.1 cm^3**

g. 35 000 kJ ÷ 0.250 min **ans: 140 000 kJ/min**

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Sample Problem 3

Three students measure volumes of water with three different devices. They report the following volumes:

Device	Volume measured
Large graduated cylinder	164 mL
Small graduated cylinder	39.7 mL
Calibrated buret	18.16 mL

If the students pour all of the water into a single container, what is the total volume of water in the container?

Solution

ANALYZE

What is given in the problem? **three measured volumes of water**

What are you asked to find? **the total volume of water**

Items	Data
First volume of water	164 mL
Second volume of water	39.7 mL
Third volume of water	18.16 mL
Total volume of water	?

PLAN

What step is needed to calculate the total volume of the water?

Add the separate volumes.

What steps are necessary to round the calculated value to the correct number of significant figures?

Determine which measurement has the fewest decimal places. Round the calculated result to that number of decimal places.

COMPUTE

$$V_{total} = V_1 + V_2 + V_3 = 164 \text{ mL} + 39.7 \text{ mL} + 18.16 \text{ mL}$$

$$\begin{array}{r} 164 \text{ mL} \\ +\ 39.7 \text{ mL} \\ +\ 18.16 \text{ mL} \\ \hline 221.86 \text{ mL} \end{array}$$

Round the sum to the same number of decimal places as the measurement with the fewest decimal places (164 mL).

$$V_{total} = 221.\cancel{86} \text{ mL} = 222 \text{ mL}$$

the digit following the 1 is greater than 5, so the 1 is rounded up to 2

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EVALUATE

Are the units correct?

Yes; the given values have units of mL.

Are the significant figures correct?

Yes; three significant figures is correct.

Is the answer reasonable?

Yes; estimating the values as 160, 40, and 20 gives a sum of 220, which is very near the answer.

Practice

1. Perform the following calculations and express the results in the correct units and number of significant figures:

a. 22.0 m + 5.28 m + 15.5 m **ans: 42.8 m**

b. 0.042 kg + 1.229 kg + 0.502 kg **ans: 1.773 kg**

c. 170 cm^2 + 3.5 cm^2 − 28 cm^2 **ans: 150 cm^2**

d. 0.003 L + 0.0048 L + 0.100 L **ans: 0.108 L**

e. 24.50 dL + 4.30 dL + 10.2 dL **ans: 39.0 dL**

f. 3200 mg + 325 mg − 688 mg **ans: 2800 mg**

g. 14 000 kg + 8000 kg + 590 kg **ans: 23 000 kg**