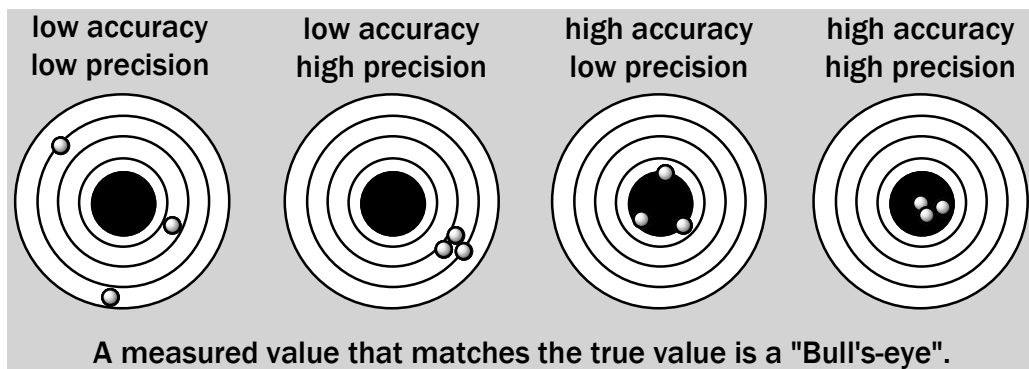Name _____

POGIL ACTIVITY **3**

All Targets Near and Far: Accuracy, Precision and Significant Figures

Accuracy and Precision

All measurements are estimates of some true value. The validity of any measurement is primarily due to the nature of the device used to make the measurement and partly due to the manner in which data is collected.

Model 1
Accuracy and Precision

| low accuracy low precision | low accuracy high precision | high accuracy low precision | high accuracy high precision |

A measured value that matches the true value is a "Bull's-eye".

Name _____

Critical Thinking Questions

CTQ 1
Using Model 1, define accuracy using a grammatically correct sentence.

CTQ 2
Define precision using a grammatically correct sentence.

CTQ 3
High precision implies high accuracy, true or false?

CTQ 4
High accuracy implies high precision, true or false?

According to the U.S. Mint, the mass of a U.S. quarter ($0.25) is **5.670 g**. Four students measured the same coin (**Table 1**).

Table 1. Mass of U.S. Quarter			
I	**II**	**III**	**IV**
5.010 g	5.670 g	5.673 g	5.669 g
5.010 g	5.589 g	5.674 g	5.672 g
5.011 g	5.801 g	5.673 g	5.672 g
5.011 g	5.800 g	5.669 g	5.671 g
5.010 g	5.712 g	5.669 g	5.669 g

CTQ 5
Which data set is the most precise?   I   II   III   IV

CTQ 6
What information is required to determine the accuracy of any data set?

CTQ 7
Explain how you could determine (mathematically) which set is the most accurate?

CTQ 8
Which data set is the most accurate? I   II   III   IV

Name _____

B. Uncertainty (or Error)

Every measurement is an estimate of the actual value because every measurement contains a degree of **uncertainty** or **error**. In this context, error does not mean "mistake". Error (uncertainty) is a mathematically determined variance between individual measurements that arises when repeated measurements are made on the same sample or object. For example, four students weighed a U.S. dime ($0.10) multiple times using different types of balances (**Table 2**).

Table 2. Mass of U.S. Dime			
I	**II**	**III**	**IV**
2.2 g	2.29 g	2.268 g	2.2681 g
2.1 g	2.26 g	2.269 g	2.2689 g
2.2 g	2.21 g	2.260 g	2.2683 g
2.3 g	2.23 g	2.267 g	2.2682 g
2.3 g	2.27 g	2.268 g	2.2680 g

The measurements in Set I contain two digits. The first digit (the one's place) is called the **reproducible digit** and the second digit in the tenth's place (0.1) is called the **doubtful digit**.

CTQ 9
Formulate a definition for the term **reproducible digit**.

CTQ 10
Formulate a definition for the term **doubtful digit**.

CTQ 11
Identify the doubtful digit in each data set in **Table 2**.

The doubtful digit is:					
data set	the one's place	one-tenth's place	hundredth's place	thousandth's place	ten-thousandth's place
I					
II					
III					
IV					

Name _____

CTQ 12

What is the uncertainty in each data set from Table 2?

Data Set	+/- 0.1 g	+/- 0.01 g	+/- 0.001 g	+/- 0.0001 g
I				
II				
III				
IV				

CTQ 13

An increase in precision is:
      a. an increase in uncertainty
      b. a decrease in uncertainty

C. Significant Figures (significant digits, sig figs), Exact Numbers and Those Pesky Zeros

Significant figures are those digits in any number that designate the level of precision.
Sig figs include all reproducible digits plus the first doubtful digit.

Table 3. Mass of U.S. Nickel			
I	**II**	**III**	**IV**
5.0 g	5.01 g	5.001 g	5.0001 g
5.0 g	5.00 g	5.002 g	5.0009g
5.0 g	5.01 g	5.002 g	5.0002 g
5.1 g	5.01 g	5.000 g	5.0006 g
5.0 g	5.02 g	5.002 g	5.0003 g

CTQ 14

According to the definition above, indicate how many sig figs are in each measurement:

      a. Set I   _____

      b. Set II _____

      c. Set III _____

      d. Set IV _____

Name _____

Exact numbers contain no error (uncertainty) since these numbers are not measurements; in other words, an exact count is not an estimate. For example, the number of people in a family of four is an exact number (**Table 4**).

Table 4. Measurements versus Exact Numbers				
Measurements (estimates)			**Exact Numbers**	
0.00024 kg	U.S. population		24 students in classroom	5 fingers each hand
2 cups of milk	volume of a 1-L water bottle		17 one-liter water bottles	1 dozen = 12
18 mph	9.3×10^6 miles		2.54 cm = 1 inch	100 cm = 1 meter

Non-zero digits are always significant but zeros may or may not be significant. In fact, zeros cause the most confusion when dealing with significant digits. Examine **Table 5**.

Table 5. Zeros are not always significant				
1 sig fig	**2 sig fig**	**3 sig fig**	**4 sig fig**	**5 sig fig**
3 kg	2.9 kg	2.98 kg	2.982 kg	2.9824 kg
80 km	81 km	80.7 km	80.76 km	80.761 km
0.06 g	0.055 g	0.0550 g	0.05503 g	0.055039 g
200 L	2.0	20.0	200.0 L	200.00 L
3×10^8 m	3.0×10^8 m	3.00×10^8 m	3.008×10^8 m	3.0081×10^8 m

CTQ 15
Using **Table 5** and the examples shown here, answer true or false:

	examples	T	F
Zeros between non-zero digits are significant	80.7 3.008×10^8		
Zeros at the beginning of a number are significant:	0.06 0.055		
Zeros in the coefficient for scientific notation are significant	3.0×10^8 1.00×10^{-3}		
Trailing zeros in numbers written with a decimal point are significant	200.0 8.750		
Trailing zeros in numbers written without a decimal point are significant	80 200		

Name _____

D. Calculations Involving Sig Figs and Rounding Numbers

A calculation cannot change the level of uncertainty. There are two rules to observe, one for multiplication and one for addition:

Rule 1
When multiplying (or dividing) measurements, the answer must contain the same number of sig figs as the starting quantity with the fewest sig figs.

For example, calculate the mileage for an automobile based on the following data, 108.4 miles driven using 3.5 gallons of fuel:

$$\frac{108.4 \text{ mi}}{3.5 \text{ gal}} = 30.97142857 \text{ mpg} = 31 \text{ mpg}$$

Since the denominator has fewer sig figs than the numerator, the answer must be rounded to two sig figs.

Rule 2
When adding (or subtracting) measurements, the answer must contain the same number of decimal places as the starting quantity with the fewest decimal places.

Consider the addition of volume in this example:

7.6 mL + 125 mL = 132.6 mL = 133 mL   *count decimal places, not sig figs*

In this case, one measurement (125 mL) does not have any digits past the one's place and the answer must be rounded to the nearest one milliliter.

When calculations generate trailing zeros, conversion to scientific notation clarifies the number of sig figs allowed in the answer:

730 cm + 880 cm = 1610 cm = 1.610 x 10^3 cm
Trailing zero is allowed since precision is to the nearest one's place.

525 g x 4 = 2100 g = 2 x 10^3 g
Trailing zeros are not allowed because the precision is limited to one sig fig.

Name _____

Rounding Numbers: Calculations often generate non-significant digits, especially calculations done with an electronic calculator; these values must be rounded to the correct number of sig figs. Once it is determined how many sig figs are allowed, all remaining digits to the right must be dropped. However, if the first digit to be dropped is 5 or greater, then the preceding digit is rounded up by one, then the extra digits are dropped.

In these examples, two sig figs are allowed in the answer:

2.1 x 3.5 = 7.35 = 7.4 round up the doubtful digit by one then truncate extra digit

2.1 x 3.4 = 7.14 = 7.1 do not round up, truncate extra digit

In this example, three sig figs are allowed in the answer:

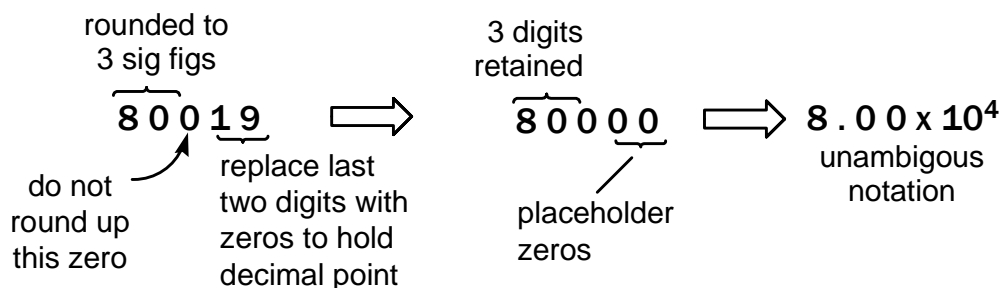**252 / 1.401 = 179.8715203 = 180 = 1.80 x 10²** round up and convert to sci.

notation

Notice the zero generated after rounding- this is the most ambiguous type of zero, a trailing zero with no decimal point. But inspection of the calculation reveals this to be a sig fig and should be included in the final answer. Conversion to scientific notation removes all doubt that this zero is significant and should be included in the final answer.

More about zeros. Frequently, rounding off numbers produces zeros which may or may not be significant. Scientific notation is the best method to remove all ambiguity and to eliminate placeholder zeros. Below are four more examples of how to deal with zeros.

1. Zeros generated to the left of the decimal point after rounding off become placeholder zeros (to hold the decimal point) but are not significant digits.
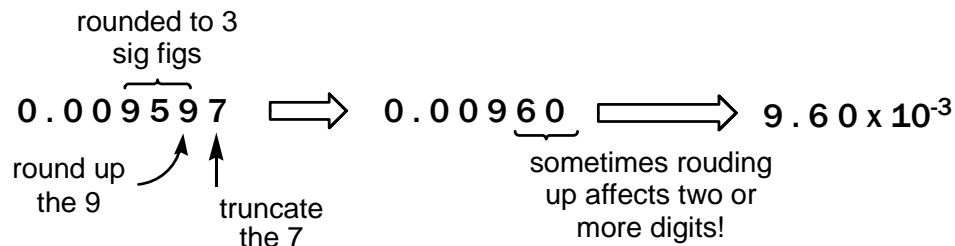
rounded to
3 sig figs

8 0 0 1 9 ⟹

do not
round up
this zero

replace last
two digits with
zeros to hold
decimal point

3 digits
retained

8 0 0 0 0 ⟹ 8 . 0 0 x 10⁴

placeholder
zeros

unambigous
notation

Name _____

2. Zeros generated to the right of the decimal point after rounding off may be significant depending on how many digits are allowed in the final answer.

rounded to 3
sig figs

$$0.009597 \implies 0.00960 \implies 9.60 \times 10^{-3}$$

round up
the 9

truncate
the 7

sometimes rouding
up affects two or
more digits!

3. Beware of Zeros that "disappear" from electronic calculators. Compare the addition problem below done by hand versus using a calculator.

Addition by pencil:
$87.72 + 2.28 = 90.00$ (keep 2 decimal places)

Addition by calculator:
$87.72 + 2.28 = 90$

4. Always include a "courtesy zero" for numbers that begin with a decimal point. <u>Your instructor will love you for this!</u>

Courtesy zeros are not significant digits.

Examples: (0.01 not .01) (0.005 not .005) (0.100 not .100 and not .1)

Exercises With Sig Figs and Rounding

1. Assume each number is a measured value. How many sig figs are in each number?

___ a. 93 million	___ g. 300	___ m. 1.81×10^{-5}
___ b. 93,000,000	___ h. 300.0	___ n. 6.0×10^{0}
___ c. 9.30×10^{7}	___ i. 0.607	___ o. 0.00023
___ d. 93,125,479	___ j. 1.277	___ p. 23,004
___ e. 0.677	___ k. 6089	___ q. 873.20
___ f. 0.0677	___ l. 6.700×10^{-2}	___ r. 0.00500

Name _____

2. Round each number to **3 sig figs**; write answers as decimal numbers and in scientific notation.

	decimal value	scientific notation
a. 30,010	_____	_____
b. 30.54	_____	_____
c. 609.7	_____	_____
d. 5.2377	_____	_____
e. 0.1278	_____	_____

3. Solve each calculation and round the answer to the correct number of sig figs. Use good judgment and convert to scientific notation where appropriate- to preserve zeros that are significant or to eliminate placeholder zeros. Include units where indicated.

a. 0.433 x 7.6889

b. 7.22 x 19.4

c. 989.17 / 23.1

d. 9.94 + 0.05

e. 6.94 - 0.072

f. 134.9 - 0.05

g. (2.21 + 0.09) x 12.75

h. (2.43 + 0.07) x 34.5

i. (2.5 cm x 0.65 cm)

j. Convert 65.4 g into kg

Name _____

NOTES