Unit 1 Measurement

Scientific Methods

The scientific method refers to a *systematic* approach to scientific investigation. There is *more than* one process known as the scientific method.

A. *Observation/Research Question*

1. Use existing *knowledge* and *data*
2. Qualitative data relates to the *five senses*; describes *characteristics*
   - Examples: *color, shape, odor, texture*
3. Quantitative data involves *measurements* – numbers with *units*
   - Examples: *30 g, 27 mL, 42.5 cm, 22 s*

In chemistry, every number has a unit.

B. *Hypothesis*

1. Tentative *explanation* or *prediction* based upon observations
2. Includes *prediction* of results and *explanation/reason*
3. Two possible formats:
   - If/then statement
     - If: *states tentative relationship between the dependent and independent variables*
     - Then: *gives the prediction of what will happen to the dependent variable when the independent variable is manipulated*
     - May also include a *reason* to support prediction (*because*)
   - Conditional statement
     - Suggests *a causal relationship between the independent and dependent variables*
     - Reason *adds detail to support prediction (because)*

C. *Experiment*

1. An experiment is a set of controlled *observations* to test the hypothesis.

2. Only *one* variable can be changed or manipulated at a time.

3. *Independent* or manipulated variable is changed by the researcher. It may be the treatment applied or the *cause* and is graphed on the *x-axis*.

4. *Dependent* or responding variable changes in response. The value depends on the *independent* variable. It represents the *effect* and is graphed on the *y-axis*.

5. A *control* is a factor that is not changed and that provides a basis or standard for *comparison*. An experiment may have control *groups* or *controlled variables*.

   - Control groups *have similar characteristics but receive not treatment*.
   - Controlled variables *are those characteristics or conditions which are kept constant*.
   - If an experiment is testing the effectiveness of a new fertilizer, what would be held constant? *Soil, water, sunlight, number of plants, age of plants, strain of plants, etc.*

Example

Melissa believes that turtles eating Tasty Turtle Tidbits food will become smarter and will be able to navigate a maze faster than turtles eating regular Turtle Chow. She decides to perform an experiment to test her hypothesis. She has ten turtles navigate a maze and records the time it takes for each one to make it to the end. She feeds Tasty Turtle Tidbits to five turtles and Turtle Chow to five other turtles. After one week, she puts the turtles through the maze again and records the times for each.

1) What was Melissa's hypothesis? *Turtles who eat Tasty Turtle Tidbits will be smarter and able to navigate a maze faster than turtles who eat Turtle Chow because Tasty Turtle Tidbits are more nutritious.*
2) Which fish are in the control group? *Turtles eating Turtle Chow form the control group.*
3) What is the independent variable? *The independent variable is the type of food given.*
4) What is the dependent variable? *The dependent variable is the time it takes the turtles to navigate the maze.*

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Writing Activity: *A medical research team is investigating how taking aspirin will affect the number of heart attacks in men over 50 years of age.*

The control group takes a *placebo* instead of aspirin. Why? *The researcher will compare results of experimental group with the control group to see if the treatment caused differences.*

What are the manipulated and responding variables? *The manipulated variable is the aspirin, whether aspirin or the placebo was given. The responding variable is the number of heart attacks in the subjects.*

What other factors would need to be controlled? Age, sex, exercise level, family history, current health conditions, diet, life stressors, amount of aspirin given, etc.

Write a possible hypothesis for this investigation. If men over age 50 take aspirin, then the number of heart attacks they will experience will be reduced because aspirin thins the blood and reduces the pressure in the heart.

In a line graph for this investigation, how would the x- and y-axes be labeled? The independent variable, the administration of aspirin, will be graphed on x-axis and would be labeled with the amount of aspirin given. The dependent variable is graphed on the y-axis and would be labeled as number of heart attacks.

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D. Data Analysis

1. Raw data must be placed into meaningful context.
2. Involves performing calculations and summarizing data from multiple trials.
3. Review, interpret, and make sense of collected data.
4. Allows comparison of experimental results to the hypothesis.

E. Conclusion

1. A judgment based on information obtained through experimentation
2. Data/results will support or fail to support the hypothesis.
3. A written conclusion communicates the results of the scientific process.

Hypotheses, Theories, and Laws

A. Hypothesis: supported by many experiments

B. Theory: states a broad principle of nature supported by many experiments over time. A theory is considered successful if it can be used to make predictions that are true. Example: Theory of Relativity

C. Scientific Law: describes a relationship in nature that is supported by multiple experiments with no exceptions. Example: Law of Gravity

Measurement

Mars Climate Orbiter: What would happen if measurements were expressed one way but interpreted in another? Differences in expressing measurements lead to misunderstandings and costly mistakes.

Reliability of Measurements

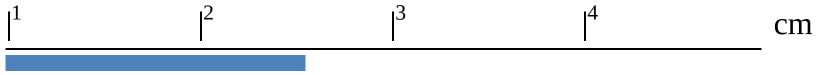
A. Every measurement consists of two parts: 1) a number followed by 2) a unit from the measuring tool.
   - A measurement can only be as precise as the measuring tool used.
   - The more digits in a measurement, the more precise it is.
     - Example: 3.02 cm is more precise than 3.0 cm.

B. All measurements possess a certain degree of uncertainty or error.

C. Types of Error
   1. Erratic or human error (blunder/mistake) are due to mistakes in procedure by experimenter or instrument and can be avoided.
   2. Random error is expected, has an equal chance of being high or being low, and is addressed by averaging results.
   3. Systematic error or bias occurs in the same direction (always high or always low) and is usually due to bad equipment or poor technique.

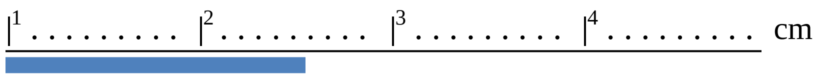
D. Propagation of error: errors are transmitted from one step or calculation through every subsequent step or calculation
   - Process begins with the experimenter making the measurement with a specific tool or instrument.
     - Known digits are indicated by markings on measuring tool.
     - Space between markings gives one estimated digit.
   - Error is inherent in making measurements due to estimating digits, and these errors subsequently affect calculation results.

E. The maximum possible precision for a measuring tool is defined as 1/10 or 0.1 times the smallest division marked on the tool. The uncertainty in the final digit of the measurement is assumed to be ±1 (known as the plus-or-minus amount), unless otherwise noted.
   - For rulers marked only by centimeters, the uncertainty in the last digit (estimated) is 0.1 x 1 cm. Therefore, the plus-or-minus amount is ±0.1 cm.
   - For rulers with markings for millimeters in addition to centimeters, the plus-or-minus amount is 0.1 x 0.1 cm = 0.01 cm or ±0.01 cm. This ruler is more precise than the first.



Ruler A:
Marked by Centimeters

- The length of the line is *more than 2cm but less than 3 cm*; therefore, a known digit in the measurement is "*2*".
- The second digit must be *estimated* because of the absence of markings.
- The length of the line can be measured as *2.5 cm* with an uncertainty of *±0.1 cm*, meaning the length measurement ranges from *2.4 cm to 2.6 cm*.



Ruler B:
Marked by Millimeters

- The length of the line is *more than 2 cm but less than 3 cm*; therefore, a known digit in the measurement is "*2*".
- The second digit is between *2.5 cm and 2.6 cm*; due to the millimeter markings, a second known digit in the measurement is "*5*".
- The third digit must be *estimated*.
- The length of the line can be measured as *2.57 cm* with an uncertainty of *±0.01 cm*, meaning the length measurement ranges from *2.56 cm to 2.58 cm*.

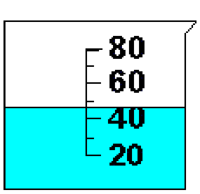
Reading Graduated Cylinders

A. To measure *liquid volume*, use a graduated cylinder

- Make volume readings at *eye level* with the graduated cylinder on a flat surface.
- View the curve or *meniscus*.
- Read the volume at the lowest point or *center of the meniscus*.

B. Typically, the smaller the graduated cylinder, the greater the *precision*.

- The markings on the cylinder give the *certain* digits in the volume reading.
- Digits between markings are *estimated* and will be *1/10th* the size of the smallest division.



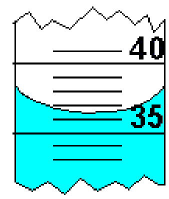
Cylinder A

Cylinder A is marked every *10 mL*. Numbers only appear every 20 mL but the *short lines between numbers* divide the space evenly. The error or uncertainty is 1/10 of the 10-mL increment, making it *±1 mL*.

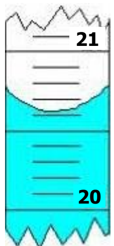
The liquid level in this cylinder could be measured as *47 ± 1 mL*, giving it a range of *46 mL to 48 mL*.

Cylinder B is marked every 1 mL. The error or uncertainty is 1/10 of this increment, making it ±0.1 mL.

The liquid level in this cylinder could be measured as 36.4 ± 0.1 mL, giving it a range of 36.3 mL to 36.5 mL.



Cylinder B



Cylinder C

For Cylinder C, there are ten spaces between 20 mL and 21 mL; it is marked every 0.1 mL. The error or uncertainty is 1/10 of this increment, making it ±0.01 mL.

The liquid level in this cylinder could be measured as 20.62 ±0.01 mL, giving it a range of 20.61 mL to 20.63 mL.

Reading Balances

A. Different types of balances differ in the precision of their readings.

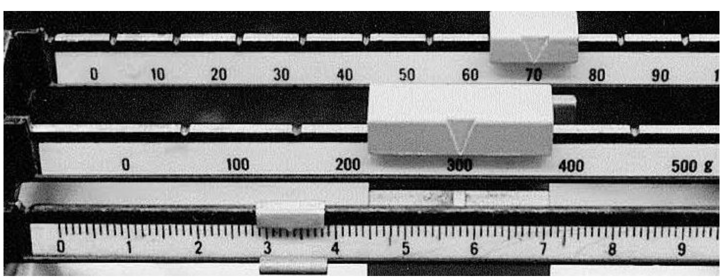
B. Electronic balances display all known digits and one estimated digit on the read-out.

C. Triple beam balances have beams numbered for three place values: hundreds, tens, and ones.

Four beam balances have an additional beam marked for the tenths place value (one decimal place).

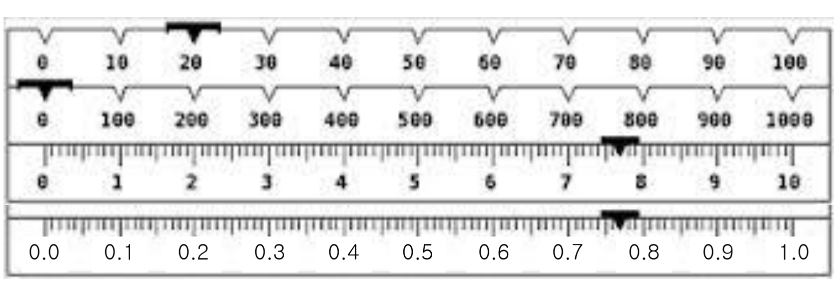
In beam balances, the values for all beams are added together to attain the total mass.

D. Estimating a final digit gives measurements written to two decimal places for triple beam balances and three decimal places for four beam balances.



The hundreds digit is certain.
The tens digit is certain.
The ones digit is certain.
The tenths digit is certain.
The hundredths digit is estimated.

3 7 3 . 3 4 g



The hundreds digit is certain.
The tens digit is certain.
The ones digit is certain.
The tenths digit is certain.
The hundredths digit is certain.
The thousandths digit is estimated.

0 2 7 . 7 7 0 g

Standards of Measurement

A. Measurement involves using a *measuring tool* to compare a specific dimension of an object to a *standard*.

   1. Ancient Egyptians used the length of *Pharaoh's arm* as the standard of measure.

   2. What are some problems with this standard? *The Pharaoh's arm would not be available to everyone needing to make a measurement; the standard would change as the Pharaoh grows or is replaced.*

B. In the 1790s, during the French revolution, the *metric system* was instituted as a standard system of measurement. A revision of this system began in 1948 and culminated in the publication of the *International System of Units* (or SI system) in 1960.

C. The building blocks of SI are the standard *base units* for seven quantities, which are defined in terms of objects or events in the physical world, while *derived units* are defined by combinations of the seven base units.

   1. Time: *second* (*s*)

   2. Length: *meter* (*m*)

   3. Mass: *kilogram* (*kg*)

   4. Temperature: *kelvin* (*K*)

   5. Amount of a substance: *mole* (*mol*)

      a. 6.02×10^{23} items makes up one mole of that item

      b. AKA *Avogadro's* Number

   6. Electric current: *ampere* (*A*)

   7. Luminous intensity: *candela* (*cd*)

Prefixes for SI Units

A. Prefixes are used to produce a *multiple* of the original unit.

   1. All multiples are *integer powers of 10*.

   2. Prefixes are used with the SI *base units* but are never combined. Prefixes may also be used with certain *non-SI units*, which are considered acceptable for use with SI.

   3. Multiples for mass are named as if the *gram* is the base unit.

B. Memory aid: King Henry Died By Drinking Chocolate Milk

			base unit			
1,000 or 10^3	100 or 10^2	10 or 10^1	1 or 10^0	.01 or 10^{-1}	.001 or 10^{-2}	.0001 or 10^{-3}

C. Conversions can be made between different prefixes, using the mathematical relationships between them.

1. Dimensional analysis: problem-solving strategy to convert measurements in one unit to an equivalent quantity in another unit

2. Conversion factors express the relationships between two units for the same quantity.

1 kg = 1000 g

1 hg = 100 g

1 dag = 10 g

1 g = 10 dg

1 g = 100 cg

1 g = 1000 mg

3. Short-cut conversions only work when the base unit is the same.

Smaller → Larger	**Larger → Smaller**
Divide by 10 for each increment	Multiply by 10 for each increment
Move the decimal point one place to the left for each increment	Move the decimal point one place to the right for each increment

Short-Cut Conversion Practice

1) 10 m = __________ mm

2) 500 g = __________ kg

3) 75 cs = __________ s

4) 450 mg = __________ g

5) 25 dm = __________ dam

6) 750 hs = __________ks

7) 0.50 kg = __________ mg

8) 17.5 dm = __________ hm

9) 32.5 dag = __________ g

10) 25 ms = __________ s

Dimensional Analysis

A. Dimensional analysis must be used when base units are different.

B. Dimensional analysis uses *conversion factors*, which identify the relationship between two values with different units that express the same quantity. These factors provide *step-by-step directions* to go from the starting point to the ending point.

- Examples: *1 min = 60 s; 1 hr = 60 min; 1 g = 1000 mg; 1 kg = 2.2 lbs; 1 cal = 4.184 J*

C. Conversion factors are *ratios* and can be expressed as *fractions*. Each fraction can be written in *two ways* and always equals a value of *one*.

- Example: If you have one dozen eggs, how many eggs do you have? *Twelve eggs*. Therefore, *1 dz = 12 eggs*. Written as fractions — $\frac{1 \text{ dz}}{12 \text{ eggs}}$ $\frac{12 \text{ eggs}}{1 \text{ dz}}$

D. Dimensional analysis is a problem-solving method consisting of specific steps.

1. *Know where you are going*: identify (underline) the unknown in problem statement.
2. *Know where you start*: identify (circle) the given in the problem statement.
3. *Draw the bridge*: provides framework to get from start to finish.
4. *Step-by-step directions*: determined by applicable conversion factors.

Dimensional Analysis Practice

How many kilograms are in 150 lbs? What conversion factor(s) apply to this problem? *1 kg = 2.2 lbs.*

This conversion factor can be expressed as a fraction in two forms: $\frac{1 \text{ kg}}{2.2 \text{ lbs.}}$ $\frac{2.2 \text{ lbs.}}{1 \text{ kg}}$

Write the *unknown*, start with the *given*, and then draw the *bridge* to connect the two quantities.

$$\text{Kg} = \frac{150 \text{ lbs.}}{} \left| \frac{1 \text{ kg}}{2.2 \text{ lbs.}} \right. = 68.18181818 \text{ kg} = \mathbf{68\ kg}$$

Use dimensional analysis to solve the following problems.

1) How many seconds are in 22 days?

2) How many inches are in 127 miles?

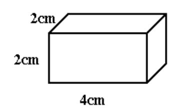
3) How many calories are in 42 joules?

Volume

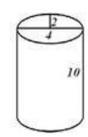
A. Volume: the amount of space occupied by a sample of matter

1. Derived unit for volume: cubic meter (m^3); cubic centimeter (cm^3 or cc) is more useful in chemistry
   - 1 m^3 = 100 cm^3
2. Some non-SI units are accepted for use with SI units; for example, the liter (L) is still an accepted unit for liquid volume.
   - 1 L = 1 dm^3
3. For smaller quantities of liquids, volume is measured in milliliters (mL).
   - 1 cm^3 = 1 cc = 1 mL
   - 1 dm^3 = 1 L = 1000 mL

C. Volume of Regular Objects: solid objects with regular dimensions



1. For square/rectangular objects, V = (length)(width)(height)
   - Calculate the volume of the cube:



2. For cylinders, V = π(height)(radius), where π = 3.14
   - Calculate the volume of the cylinder:

D. Volume of Irregular Objects: solid objects with irregular shapes

1. Use the method called water displacement.

① Add water to a graduated cylinder. Measure and record the volume.

② Add the irregular object to the cylinder. Measure and record the new volume.

③ Use the initial and final volume readings to calculate the volume of the object.

- $V_{object} = V_{final} - V_{initial}$
- A toy dinosaur placed in a graduated cylinder causes the water to rise from 4.80 mL to 5.60 mL. What is the volume of the rock? 5.60 mL - 4.80 mL = 0.80 mL

Density

A. Density (D): ratio comparing the mass of an object to its volume

B. Formula

D = mass / volume = m / V

$$D = \frac{mass}{volume} = \frac{m}{V}$$

C. Using the Density Formula

1. Find the density of aluminum if a 13.5 g sample has a volume of 5.0 cm^3.

$$D = \frac{m}{V} = \frac{13.5\ g}{5.0\ cm^3} = \mathbf{2.7\ g/cm^3}$$

2. Find the mass of a liquid if 10. mL have a density of 2.1 g/mL.

$m = DV = (2.1\ g/mL)(10.\ mL) = \mathbf{21\ g}$

D. The density of water (H_2O) is *1 g/cm^3* or *1 g/mL*. Therefore, 1 mL of water has a mass of *1* g, meaning, for water, *1 g = 1 mL* (conversion factor).

- Given that the density of water can be expressed as 1 g/cm^3 or 1 g/mL, what can you say about the relationship between cm^3 and mL? *The units - cubic centimeter and milliliter - must express the same amount of space or volume.*

Temperature

A. Temperature defined: a measure of the average *kinetic energy* of particles of a substance

B. Used to compare the relative *warmth or coldness* of objects or substances

C. Measure with a *thermometer*

D. The Celsius scale is a *relative* temperature scale based upon the freezing point (*0°C*) and boiling point (*100°C*) of water. The distance between these two points was divided into 100 equal units known as *degrees Celsius*.

E. The kelvin scale is an *absolute* temperature scale devised by Lord Kelvin and based upon the temperature known as *absolute zero* (the lowest possible temperature where all molecular motion stops). There are no *negative* temperature values on the kelvin scale.

F. Formula for conversion: *K = °C + 273*

Conversion Practice

1) 100°C = __________ K
2) 0°C = __________ K
3) 25°C = __________ K
4) 27°C = __________ K

4) 293 K = __________°C
5) 333 K = __________°C
6) 303 K = __________°C
7) 223 K = __________°C

Representing Data

A. *Graph*: a visual display of data that helps to reveal *patterns or trends*

B. A *circle* graph shows parts, often as percentages, of a fixed whole (100%).

C. A *bar* graph shows how a quantity varies with specific factors.

D. A *line* graph, the most useful in chemistry, consists of points representing the intersection of data for two variables: the independent on the *x*-axis and the dependent on the *y*-axis.

1. *Scatter* plot: points are plotted based upon the values for the independent and dependent variables
2. *Best-fit* line: does not have to touch all data points; drawn with as many points above the line as below it
3. Straight line indicates a *linear* relationship.
   - A *positive* slope (line rises to the right) indicates that the dependent variable *increases* with an increase in the independent variable. *(direct relationship)*
   - A *negative* slope (line sinks to the right) indicates that the dependent variable *decreases* with an increase in the independent variable. *(inverse relationship)*

E. Creating a line graph requires specific steps.

1. General guidelines: *use full graph paper (at least ¾ of page) draw in pencil, and write name on the back of the graph paper*.
2. Calculate the *range* for both the independent and dependent variables by taking the *difference* between the highest and lowest value for each. The *variable with the greatest range* is graphed on the longest side of the graph paper, determining whether to use the paper in the *portrait or landscape orientation*.
3. Data collected for the independent variable usually appears in the *lefthand* column of the data table and is graphed on the *x-axis*. Data for the *dependent* variable is in the righthand column of the data table and is graphed on the *y-axis*. Both axes should be labeled with the *variable name* followed by the appropriate *unit* in parentheses.
4. The *scale* is the value represented by one box on the graph paper and can vary for each graph. The scale should be set as *small* as possible based upon the size of the graph paper, but it usually equals *0.1, 0.2, 0.5, 1, 2, 5, or 10*. Scales for the x- and y-axes do not have to be the same.

5. Mark the *increments* on each axis evenly, such as every line or every other line. Both axes do not have to be marked the same, but each should be marked *consistently*. Increments are usually marked by *0.1s, 0.2s, 0.5s, 1s, 2s, 5s, or 10s* and must make sense in terms of the *data*.

6. Only one *quadrant* (upper right) of a graph is used and should be drawn to take up as much space on the graph paper as possible. Do not extend axes below or to the left of the origin and do not draw *arrows on axes lines*. The intersection of axes (*origin*) is the starting point for both axes, but it does not have to be *zero* and does not have to be the *same* for both axes.

7. Draw a *dot* representing the intersection of the x- and y-axes for each data value in the data table. The points must remain *visible* once the line is drawn but are only labeled with their *coordinates* if the labeling does not clutter the graph.

8. Unless otherwise instructed, all lines should be drawn as *best-fit lines*, which may be *straight or curved*. Do not draw *arrows* on the ends of lines.

9. The *title* of the graph should be written toward the top of the graph in any available space; do not allow the title to obscure the lines in any way. The title should use the *labels or names* for the x- and y-axes in the format *"label for y-axis vs. label for x-axis"* to show the dependence of the dependent variable on the independent variable.

Graphing Practice

A sample of gas was collected at 100°C and then cooled. Changes in volume were recorded in the following data table. Graph the data shown on the graph paper provided on the next page.

Temperature (°C)	**Volume (mL)**
100	315
80	300
60	290
40	280
30	250
20	245
10	240
0	235

Reliability of Measurements

A. Accuracy: *the degree of closeness of a measurement to the actual or true value*

Was the target achieved? Is the answer correct?

B. Precision: *the degree to which repeated measurements under unchanged conditions show the same results; AKA reproducibility or repeatability*

C. The *accuracy* of experimental data must be evaluated. An *error* is the difference between an experimental value and an *accepted* value.

Error = *|experimental value - accepted value|*

D. Percent error is a *ratio* of an error to an accepted value.

$$\text{Percent Error} = \frac{\text{Error}}{\text{Accepted Value}} \times 100 = \frac{|\text{experimental value} - \text{accepted value}|}{\text{accepted value}} \times 100$$

Practice: *Using the data in the table below, calculate the average percent error (use average data, not trial data) for the three groups if the accepted value for density is 1.60 g/cm^3.*

Density Data	Group A (g/cm^3)	Group B (g/cm^3)	Group C (g/cm^3)
Trial 1	1.54	1.40	1.70
Trial 2	1.60	1.68	1.69
Trial 3	1.57	1.45	1.71
Average	**1.57**	**1.51**	**1.70**

$$\text{\% error for Group A} = \frac{|1.57\ g/cm^3 - 1.60\ g/cm^3|}{1.60\ g/cm^3} \times 100 = 1.88\%$$

$$\text{\% error for Group B} = \frac{|1.51\ g/cm^3 - 1.60\ g/cm^3|}{1.60\ g/cm^3} \times 100 = 5.63\%$$

$$\text{\% error for Group C} = \frac{|1.70\ g/cm^3 - 1.60\ g/cm^3|}{1.60\ g/cm^3} \times 100 = 6.25\%$$

Which group's data was most accurate (using averages)? *Group A had the most accurate data.*
Which group's data was most precise (using trial data)? *Group C had the most precise data.*

Significant Figures or Digits

A. The precision of measurements is limited by the *measuring tool* and is indicated by the *number* of digits reported; these digits are known as *significant* figures.

B. Significant figures include all *known or certain* digits plus one *estimated* digit.

C. Rules for determining significant figures

1. Non-zero numbers are *always* significant.
2. Zeros between non-zero numbers are *always* significant. *(trapped zeros)*
3. All final zeros to the right of the decimal place *are* significant. *(trailing zeros)*
4. Zeros that act as placeholders are *not* significant.
5. Counting numbers and defined constants have an *infinite* number of significant figures.

Practice How many significant figures are in each of the following measurements?

38.15 cm	__________	0.008 mm	__________	50.8 mm	__________
72.050 kg	__________	25,000 m	__________	200. yr	__________

Calculations with Significant Figures

A. Recall: propagation of uncertainty means *errors made in measuring carry through any calculations made with those measurements*

B. A calculated answer cannot be more *precise* than the measuring tool.

C. A calculated answer must match the *least* precise measurement.

D. Addition and Subtraction

- The answer has the same number of decimal places as the measurement with the *fewest* decimal places. For example, 2.51 + 3.064 = *5.574 = 5.57*.

E. Multiplication and Division

- Round result or add zeros to the calculated answer until it has the same number of significant figures as the measurement with the *fewest* significant figures. For example, 3.50/2 = *1.75 = 2*.
- Rounding is reserved for the *final answer*; do not *round or truncate digits* for intermediate answers.