Section 3: Measurements

The following maps the videos in this section to the Texas Essential Knowledge and Skills for Science TAC §112.35(c).

3.01 Math Skills
- Chemistry (2)(G)

3.02 Graph Interpretation
- Chemistry (2)(H)

3.03 Recording Measurements
- Chemistry (2)(F)

3.04 Temperature
- This video contains information about temperature scales that is necessary for the understanding of heat transfer, gas laws, and calorimetry in later sections.

3.05 Scientific Notation and Significant Figures
- Chemistry (2)(G)

3.06 Decimal Prefixes and Equalities
- Chemistry (2)(G)

3.07 Dimensional Analysis
- Chemistry (2)(G)

3.08 Lab Reports
- Chemistry (2)(I)
- Chemistry (2)(H)

Note: Unless stated otherwise, any sample data is fictitious and used solely for the purpose of instruction.

3.01

Math Skills

Many problems in chemistry involve numerical calculations, so it is important to be comfortable with some basic math skills.

Place Values

In the number below, each numeral has a corresponding ***place value*** (as shown in the following table) that signifies what multiple of 10 that numeral represents. The place values to the right of the decimal point are called ***decimal places***.

2,134.382

Numeral	2	1	3	4	3	8	2
Place Value	thousands	hundreds	tens	ones	tenths	hundredths	thousandths

Positive and Negative Numbers

Arithmetic with positive and negative numbers can be tricky, so remember the following rules:

- The addition of two positive numbers yields a positive number.
- The addition of two negative numbers yields a negative number.
- The addition of a positive number and a negative number may yield a positive or negative result, depending on the values of the numbers.

$$2 + (-4) =$$

$$5 + (-3) =$$

- The multiplication or division of two positive numbers yields a positive number.
- The multiplication or division of two negative numbers yields a positive number.
- The multiplication or division of a negative number and a positive number yields a negative number.

$$-20 \div 5 =$$

Percentages

A ***percentage*** represents a portion of a total value. A percentage can be expressed as an equivalent decimal number if you move the decimal point two spaces to the left. For example, 25% can also be written as 0.25.

STUDY EDGE TIP

$$\text{Percentage} = \frac{\text{the parts}}{\text{the total}} \times 100$$

1. Suppose that a 25-gram candy bar contains 12 grams of sugar, 3 grams of protein, and 10 grams of fat. What percentage of the candy bar is fat?

   A. 25%
   B. 40%
   C. 15%
   D. 60%

2. Solve the following expression for x:

$$H = -k^2T\left(\frac{1}{x} - \frac{1}{z}\right)$$

3.02

Graph Interpretation

A ***graph*** is a visual representation of the relationship between two variables, which are plotted on the horizontal axis (***x-axis***) and the vertical axis (***y-axis***). The ***points*** on the graph show the correlation of the two variables as individual ordered pairs.

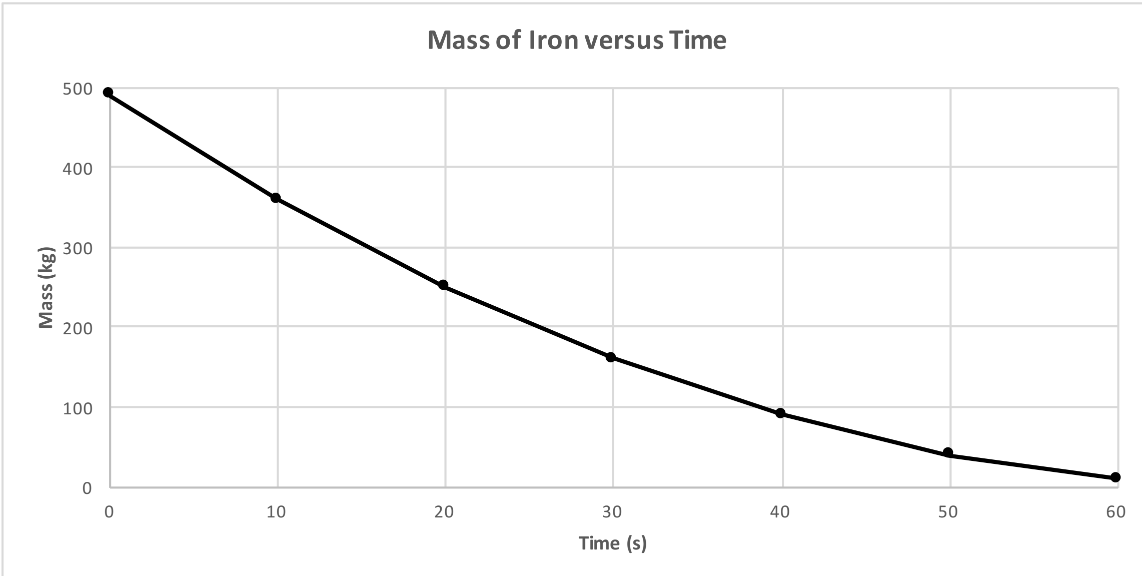
The variables can be described as having a ***direct relationship*** if both variables follow the same behavior (i.e., they both increase or they both decrease).

The variables can be described as having an ***indirect relationship*** if the variables behave in opposite manners (i.e., when one increases, the other decreases).

STUDY EDGE TIP

$$\text{Percentage change} = \frac{\text{final} - \text{initial}}{\text{initial}} \times 100$$

1. In a laboratory experiment, iron readily reacts with pure oxygen to form an oxide of iron. The graph below shows the mass of iron (in kilograms) remaining in the sample, plotted against the amount of time elapsed (in seconds).

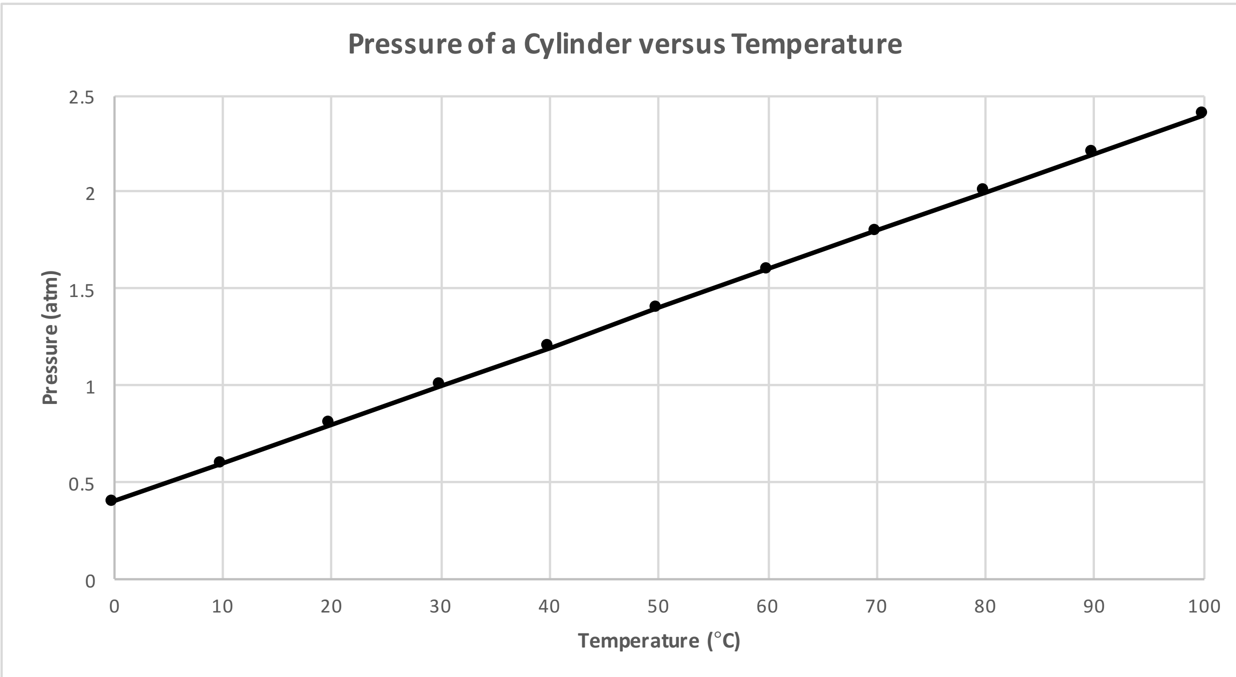


i. Classify the relationship above as either direct or indirect.

ii. Provide a possible explanation for the relationship shown in the graph above.

iii. Approximately how many more kilograms of iron are present at 20 seconds than at 40 seconds?

2. The graph below shows the internal pressure of a cylinder (in atmospheres) plotted against the temperature of the cylinder (in degrees Celsius).



i. Classify the relationship above as either direct or indirect.

ii. What is the approximate percentage change in the pressure of the cylinder when the temperature is increased from 30 °C to 60 °C?

3.03

Recording Measurements

In order for members of the scientific community to communicate clearly across different languages, a standard set of measurements is needed. In the 19th century, a German mathematician named ***Carl Friedrich Gauss*** advocated for such a system.

His work, and the work of others, led to what would eventually be called the ***International System of Units (SI)***: a set of units recognized as the worldwide standard for measuring specific properties and dimensions. These SI units provide a base for all experimental measurements.

SI Base Units

Quantity (Dimension)	Unit Name	Abbreviation
Mass	kilogram	kg
Length	meter	m
Time	second	s
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Electric current	ampere	A

When describing measurements recorded in an experiment, we use the following terms:

- ***Precision*** – A measure of how close your recorded values are to each other (or, alternatively, a measure of how easily the results can be reproduced)
- ***Accuracy*** – A measure of how close your recorded values are to the actual value

1. Suppose Kelsey and her dad go to watch a stock car race at Texas Motor Speedway, an oval-shaped racetrack in Fort Worth, Texas. After the race, she uses a measuring wheel to determine the length of the track. Kelsey recorded the following five measurements, in miles, for the length of the track:

   1.21, 1.23, 1.22, 1.21, 1.20

   i. If the known length of the track is 1.50 miles, describe the accuracy and precision of Kelsey's measurements.

   ii. Provide a possible explanation for the results above.

3.04

Temperature

Temperature is a measure of the average amount of energy of the particles within a substance. We use temperature to predict the direction of heat transfer. There are a number of different scales commonly used to express temperature.

- ***Fahrenheit (°F)*** – The scale we are most familiar with in the United States, although it is rarely used in the scientific community
- ***Celsius (°C)*** – A scale based on the freezing point and boiling point of water
- ***Kelvin (K)*** – An absolute temperature scale, based on the idea that zero kelvin is the point where no thermal energy in a substance remains. This point is referred to as ***absolute zero***.

To convert between the Kelvin, Celsius, and Fahrenheit scales, use the following formulas:

$$T(in\ K) = T(in\ {}^{\circ}C) + 273.15$$

$$T(in\ {}^{\circ}C) = \frac{5}{9} \times (T(in\ {}^{\circ}F) - 32)$$

1. Suppose that while watching a Houston Astros game, Aaron notices that the scoreboard in right field displays the temperature as 95 °F.

   i. Convert this temperature into degrees Celsius.

   ii. Convert the temperature from degrees Celsius into kelvin.

3.05

Scientific Notation and Significant Figures

Scientific notation is a way to express very large or very small numbers in manageable terms. There are three components in scientific notation: a coefficient, a power of 10, and a unit of measurement.

- For numbers larger than 10:
  - The coefficient is obtained by moving the decimal place to the left until you reach a number greater than 1 but less than 10.
  - The power of 10 is the number of decimal places you moved and will be a positive value.

4,200 ft

- For numbers smaller than 1:
  - The coefficient is obtained by moving the decimal place to the right until you reach a number greater than 1 but less than 10.
  - The power of 10 is the number of decimal places you moved and will be a negative value.

0.00039 g

1. Express the numbers below in scientific notation.

   i. 35,413

   ii. 0.0453

   iii. 34.7268

A ***measured number*** is a number obtained when you measure a quantity using a measuring tool (e.g., the length of a piece of paper or the weight of a penny).

The ***significant figures*** in a measurement are all the digits in the reported value that are known, including one estimated digit. Significant figures allow us to express a reported value with a specified degree of certainty. There are a few rules for determining significant figures in a reported value:

- All nonzero digits are significant.

  7.185 inches

- Zeros between two nonzero digits are significant.

  204.2 pounds

- The zero(s) to the left of the first nonzero digit is/are not significant.

  0034.12 seconds

- Zeros to the right of the last nonzero digit are significant if there is a decimal place present.

  6.300 liters

- Zeros to the right of the last nonzero digit are not significant if there is no decimal place present.

  2040 grams

Exact numbers are the numbers you obtain from counting or the numbers in a known conversion factor. Exact numbers do not affect the number of significant figures in a calculated answer. For example, there are 60 seconds in 1 minute. In this case, both the 60 and the 1 are exact numbers.

2. How many significant figures does each of the values reported below have?

   i. 203.10 inches

   ii. 003.430 seconds

   iii. 250.0 grams

When determining the number of significant figures in the result of an arithmetic operation, we must use the following rules:

- For multiplication and division, the reported answer must contain as many *significant figures* as the given value with the *fewest* significant figures.

$$1.39 \times 2.7 =$$

- For addition and subtraction, the reported answer must contain as many *decimal places* as the given value with the *fewest* decimal places.

$$2.42 + 14.2 =$$

When doing long calculations with several steps, do not round the answer after each step. In general, you should leave extra significant figures in your intermediate values, for accuracy, until you are ready to report the final answer.

3. What is the result of the following calculation, reported with the correct number of significant figures?

$$\frac{137.8\ g + 32.23\ g}{1.23\ cm^3}$$

A. 138.24 g/cm^3
B. 138.2 g/cm^3
C. 138 g/cm^3
D. 140 g/cm^3

3.06

Decimal Prefixes and Equalities

When dealing with quantities that are much smaller or larger than the common SI units, we use prefixes to express the units in manageable terms. The table below shows a set of standardized prefixes, based on powers of ten.

Prefix	Abbreviation	Meaning	Example		
peta-	P	10^{15}	1 m = 1 × 10^{-15} Pm	Or	1 Pm = 1 × 10^{15} m
tera-	T	10^{12}	1 g = 1 × 10^{-12} Tg		1 Tg = 1 × 10^{12} g
giga-	G	10^{9}	1 s = 1 × 10^{-9} Gs		1 Gs = 1 × 10^{9} s
mega-	M	10^{6}	1 L = 1 × 10^{-6} ML		1 ML = 1 × 10^{6} L
kilo-	k	10^{3}	1 m = 1 × 10^{-3} km		1 km = 1 × 10^{3} m
hecto-	h	10^{2}	1 g = 1 × 10^{-2} hg		1 hg = 1 × 10^{2} g
deca-	da	10^{1}	1 s = 1 × 10^{-1} das		1 das = 1 × 10^{1} s
Base Unit	m, g, s, L, etc.	10^{0}	1 m, 1 g, 1 s, 1 L		
deci-	d	10^{-1}	1 dL = 1 × 10^{-1} L	Or	1 L = 1 × 10^{1} dL
centi-	c	10^{-2}	1 cm = 1 × 10^{-2} m		1 m = 1 × 10^{2} cm
milli-	m	10^{-3}	1 mg = 1 × 10^{-3} g		1 g = 1 × 10^{3} mg
micro-	μ	10^{-6}	1 μs = 1 × 10^{-6} s		1 s = 1 × 10^{6} μs
nano-	n	10^{-9}	1 nL = 1 × 10^{-9} L		1 L = 1 × 10^{9} nL
pico-	p	10^{-12}	1 pm = 1 × 10^{-12} m		1 m = 1 × 10^{12} pm
femto-	f	10^{-15}	1 fg = 1 × 10^{-15} g		1 g = 1 × 10^{15} fg

The unit prefixes in the table above can also be thought of as ***conversion factors***: a way to go from one unit to another unit, based on the idea of equivalent units.

$$1 \text{ kilometer} = 1 \times 10^3 \text{ meters}$$

1. Suppose that during a laboratory experiment, Sean records the mass of a sample of water as 240.5 grams.
   i. Express Sean's measurement in milligrams.

   ii. Express Sean's measurement in kilograms.

3.07

Dimensional Analysis

In chemistry calculations, ***dimensional analysis*** is a tool used to convert a measurement into a more useful, or appropriate, form. In dimensional analysis, one or more conversion factors, written as fractions, are used to get from the initial unit to some desired unit.

$$35 \text{ minutes} \times \frac{60 \text{ seconds}}{1 \text{ minute}} = 2100 \text{ seconds}$$

1. Suppose that the average adult male in the United States weighs 200 pounds. Using the fact that 1 pound equals 453.59 grams, convert this weight to kilograms.

2. A space shuttle launching from the Lyndon B. Johnson Space Center in Houston, Texas, must reach a speed of 28,000 kilometers per hour to escape the gravitational force of the earth and reach orbit. Convert this speed into miles per second, using the fact that 1 mile is equivalent to 1.609 kilometers.

3.08

Lab Reports

Accurately and clearly reporting the findings of a laboratory experiment is one of the most important steps of a scientific investigation. Whether the results support your hypothesis or not is immaterial.

A ***lab report*** is a summary of a lab experiment, and it is used to communicate all the necessary details of that experiment. A typical lab report has many different parts, which may include the following:

- ***Purpose*** – Describes the problem statement of the experiment and the question that the experiment is trying to answer
- ***Materials*** – Lists the equipment and substances needed to carry out the experiment
- ***Procedure*** – Outlines the necessary steps to complete the experiment
- ***Results*** – Presents the data collected and observations made during the experiment
- ***Conclusion*** – Summarizes the findings of the experiment and offers potential explanations or theories about the results

1. Suppose Chris, Omar, Gabby, and Morgan are performing a lab experiment to analyze the flow of water. In the experiment, Omar and Gabby pour 100 liters of water into a 120-liter tank that has a plugged hole at the bottom. The tank has markings down the side at 10-liter intervals.

    i. Sketch and label a diagram to show the setup for this experiment.

ii. Chris removes the plug, and Morgan uses her stopwatch to record the amount of time that passes until the water level reaches each of the markings down the side. She stops taking measurements once the water level reaches 10 liters. The data is shown in the chart below.

Water Level (liters)	Time Elapsed (seconds)
100	0
90	1.40
80	3.36
70	6.10
60	9.95
50	15.32
40	22.85
30	33.39
20	48.15
10	68.81

iii. Create a line graph that reflects the data from the table above.

iv. Summarize the data and propose a possible explanation for the observed behavior.