Name: ______________________________________ Date: ________________________

Guided Learning: Units of Measurement

Learning goals
After completing this activity, you will be able to …

- Explain why the metric system was developed.
- List the base units and prefixes of the metric system.
- Convert from one metric unit to another.
- Rewrite a number using scientific notation.

Vocabulary: absolute zero, base unit, imperial units, International System of Units, metric system, prefix, scientific notation

Warm-up questions:

1. What units do you use to measure length, mass (or weight), volume, and temperature in everyday life? ____

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2. What units do you use to measure length, mass, volume, and temperature in science class?

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3. Why do you think different systems of units are used in these situations? _______________

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Systems of measurement
From the beginnings of civilization, humans have needed units of measurement to describe the goods they bartered and traded for. The earliest known systems of measurement were developed during the Bronze Age (3,000 BCE – 1,200 BCE) in Egypt, Mesopotamia, and India. Many early units of length were based on body parts. For example, the *cubit* was a length equal to the distance from the elbow to the fingertip. Other units were based on common materials such as seeds, stones, or gourds.

Many of the units that eventually became known as **imperial units** were developed by the ancient Greek and Roman civilizations. These include feet, inches, yards, and miles for measuring length and pounds for measuring mass or weight. (The pound is based on the Roman *libra*, which explains the abbreviation "lb" for pounds.) The exact quantities represented by these units varied from place to place and changed through time as well. By the 18th century, a dizzying variety of units were in common use. For example, imperial units for length included the inch, hand, foot, yard, mile, nautical mile, link, chain, furlong, league, fathom, cable, and rod.

The metric system was developed in response to this confusing profusion of units. In 1790, the government of France commissioned the French Academy of Sciences to develop a new system that was simple to use and based on unchanging physical quantities. The result was the **metric system**, a system that contains **base units** and **prefixes**. The modern version of the metric system is the **International System of Units**, or *Système Internationale* (SI) in French.

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1. Why do you think scientists and governments were unsatisfied with the imperial units used in the 18th century? Give at least two reasons.

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2. **Looking forward:** What attributes would you aim for if you designed a new system of units?

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***Système Internationale* base units**

Many of the base units of the metric system are based on attributes of Earth and water. For example, the *meter* (m) was originally defined as one ten-millionth of the distance from the equator to the North Pole. (Later it was discovered that the distance from the equator to the North Pole had been underestimated slightly.) A liter (L) is equal to a thousandth of a cubic meter. A gram (g) has a mass equal to the mass of one thousandth of a liter of water. The properties of water were also used to define the Celsius temperature scale. The freezing point of water at sea level has a temperature of 0 °C, while the boiling point of water at sea level is 100 °C.

The U.S. standard kilogram

The International System of Units was officially codified in 1960. The SI has seven base units:

Quantity	SI base unit	Symbol	Definition	Imperial equivalent
Length	meter	m	Distance traveled by light in a vacuum in 1/299,792,458 of a second	39.37 inches
Mass	kilogram	kg	Mass of 1 liter of water, or mass of 1/1,000 m^3 of water	2.20 pounds
Time	second	s	Duration equal to 1/86,400 of a day	second
Temperature	kelvin	K	Temperature unit equal to 1/100 of the difference between the freezing point and boiling point of water at 1 atmosphere of pressure	1.8 degrees Fahrenheit
Electrical current	ampere	A	Current of 6.241×10^{18} electrons passing a point in one second	none
Light intensity	candela	cd	Approximate amount of light emitted by a single candle	none
Amount of a chemical substance	mole	mol	6.022×10^{23} atoms or molecules of an element or compound	none

The SI base unit of temperature is the kelvin. A kelvin is equivalent to one degree Celsius, but is measured from **absolute zero**, the coldest possible temperature, which is equal to -273.16 °C. To convert from the Kelvin to the Celsius scale, subtract 273.16 from the kelvin temperature.

Other SI units are derived from the base units. Several common derived units are listed below:

Quantity	SI derived unit	Symbol	Definition
Area	square meter	m^2	A square the measures 1 meter on a side
Volume	cubic meter	m^3	Volume of a 1-meter cube
Speed	meter per second	m/s	Speed of one meter every second
Force	newton	N	Force required to accelerate a 1-kg mass at 1 m/s^2
Pressure	pascal	Pa	Pressure equal to a force of 1 newton on an area of 1 square meter.
Work, energy, or heat	joule	J	A force of 1 newton applied over a distance of 1 meter
Power	watt	W	One joule per second
Temperature	Celsius	°C	K – 273.16

Other common units are also acceptable in the SI. These include liters (L) for volume, hectares (ha) for area, minutes and hours for time, degrees for angles, decibels for sound, and others.

1. The air temperature is 22 °C. What is its Kelvin temperature? ________________________

2. **Challenge:** Why isn't there an SI base unit for area or volume? ______________________

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Metric prefixes

In the metric system, different units for the same quantity are related to one another by prefixes. Each prefix represents a multiple of 10: 10, 100, 1,000, 1/10, 1/100, etc. The table at right summarizes the metric prefixes. (Commonly-used prefixes are highlighted in red.)

One of the elegant aspects of the metric system is that all of the conversions are multiples of 10. Converting from one unit to another, such as from meters to centimeters, simply involves shifting the decimal point to the left or right. For example, 12.568 meters is equal to 1,256.8 centimeters or 0.012568 kilometers.

Prefix	Symbol	Meaning
giga-	G	1,000,000,000
mega-	M	1,000,000
kilo-	k	1,000
hecto-	h	100
deka-	da	10
deci-	d	1/10
centi-	c	1/100
milli-	m	1/1,000
micro-	μ	1/1,000,000
nano-	n	1/1,000,000,000

1. Which metric prefix means one billion? _______________ One billionth? _______________

2. How many centimeters are in 5.6 meters? _______________

3. How many liters are in 4,035 milliliters? _______________

4. How many milligrams are in 56,780 kilograms? _______________

Scientific notation

Often, scientists use very large or very small numbers to describe data. For example, the speed of light in a vacuum is 299,792,458 m/s. A *light year*, a unit used to measure the distances between stars, is approximately equal to 9,500,000,000,000,000 meters. At the other end of the spectrum is the mass of an atom, which is measured in *atomic mass units* (u). The mass of an atomic mass unit is 0.00000000000000000000000000166 kg.

Because it is inconvenient to write these long numbers, scientists use a type of shorthand called **scientific notation**, in which a long number is written as a shorter number multiplied by a power of 10. For example, 6,000 meters is equal to $6.0 \times 1{,}000$ m, or 6.0×10^3 m. A cell that has a width of 76 micrometers has a width of 0.0000076 meters, or 7.6×10^{-6} m.

To convert a number in standard form into scientific notation, first write the number as a product of a number between 1 and 10 and a power of 10. For example, 6,090 becomes $6.09 \times 1{,}000$. Next, convert the power of 10 to exponential form: $1{,}000 = 10^3$, so $6{,}090 = 6.09 \times 10^3$.

For numbers less than one, you will use negative powers of 10. For example, 10^{-1} is equal to 1/10, or 0.1. Similarly, 10^{-2} = 1/100 or 0.01, 10^{-3} = 1/1,000 or 0.001, and 10^{-4} = 1/10,000 or 0.0001. To convert 0.0006 to scientific notation, first write it as a product: 6.0×0.0001, then convert to a power of 10: 6.0×10^{-4}.

Written in scientific notation, a light year is about 9.5×10^{15} m, while the mass of an atomic mass unit has a mass of 1.66×10^{-27} kg. For these large numbers, scientific notation is very beneficial because it is compact and easy to work with. (In contrast, it can be very difficult to keep track of all the zeroes that appear in very large and small numbers.)

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1. Convert the following numbers to scientific notation. Include units in each answer.

4,500 mm	_______________	0.016 L	_______________
670,000 µg	_______________	0.0007 kg	_______________
90,100,000 s	_______________	0.0000109 N	_______________

2. Convert the following numbers to standard form. Include units in each answer.

5.8×10^2 g	_______________	9.7×10^{-2} cm	_______________
1.3×10^5 mL	_______________	3.8×10^{-5} cm^3	_______________
2.0×10^7 m	_______________	6.2×10^{-4} ms	_______________

3. **Critical thinking:** How is scientific notation useful? In what situations is scientific notation not very useful?

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