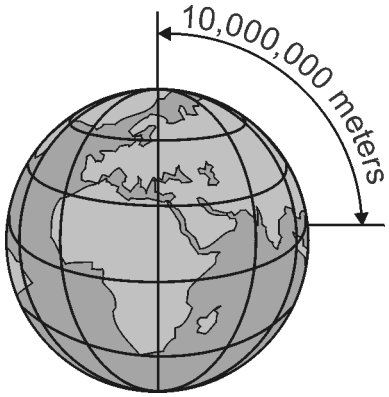
Name:

Skill Sheet 2.1 International System of Units

In ancient times, as trade developed between cities and nations, units of measurement were developed to measure the size of purchases and transactions. Greeks and Egyptians based their measurements of length on the human foot. Usually, it was based on the king's foot size. The volume of baskets was measured by how much goatskin they could hold. Can you see how this could lead to disputes among merchants and their customers? The International System of Units resolves this problem and others by providing a standard, interrelated, and reproducible system of measurement.

1. A short history of measurement

The eighteenth century was a time of great beginnings in science. However, by century's end, scientists found that their system of measures was increasingly burdensome. Measurements such as the foot were not well standardized and made it hard to communicate observations. A system that allowed scientists to reproduce and verify each other's data was needed.



The metric system was developed to fulfill this need. The system's basic unit for measuring length was called the *meter,* after the Greek word metron meaning "measure." But the metric system was not created in a single development. For example, there were two ideas for the meter—one that used the length of a pendulum and another that used a fraction of the distance between Earth's equator and the north pole. The north pole-to-equator line was chosen in one of a series of decisions that shaped the metric system. Today, the General Conference on Weights and Measures, or CGPM (Conférence Générale des Poids et Mesures), has responsibility for these decisions.

The United States began to incorporate the use of the metric system the late 1800's. However, most Americans still use the US Customary System (inherited from the British Imperial System) of feet, inches, and pounds. Not only scientists but most countries—even England—use what was named the International System of Units. In all these countries, your car's speed is measured in kilometers per hour, its gasoline in liters, the cheese you buy in grams, and the temperature in degrees Celsius.

2. Today's International System of Units

The 11th General Conference on Weights and Measures in 1960 made some of the most important recent revisions to the universal measurement system. A meter was defined as the distance light travels in a small fraction of a second. A kilogram was reaffirmed as the mass of platinum-iridium kept in Paris. The International System of Units was renamed Système International d'Unités and the new "modernized" metric system given the official symbol SI.

Most students regard "metrics" as a set of memorized prefixes that increase a measurement by tens. This is certainly true, but it overlooks one of the most important characteristics of SI units. The SI unit for volume, the liter, is derived from the meter. A liter is that volume contained in a cube that measures 10 centimeters on each side. The SI unit for weight, the kilogram, was originally the weight of one liter of pure water at standard temperature and pressure. Although today a kilogram is defined by the prototype platinum-iridium kilogram kept in Paris, both definitions are close enough to be interchangeable except in the most precise work. This interrelated characteristic makes SI measurements very easy for scientists and non-scientists.

Consider the carpenter who is installing a hot tub. He needs to know the weight of the tub filled with water to determine whether to strengthen the supports:

Using English units	Using SI units
The carpenter measures a tub interior and finds that it is 6 feet long, 2 feet deep, and 3 feet wide. He calculates the tub's volume to be 36 cubic feet. There are 7.48 gallons per cubic foot. Therefore, he multiplies the volume by 7.48 gallons/cubic foot and finds that the tub holds 269.3 gallons of water when filled. He multiplies gallons by 8.36 pounds/gallon and finds the water weight will be 2251.3 pounds.	The carpenter measures the interior of a tub and finds that it is 2 meters long, 60 centimeters (0.6 m) deep, and 1 meter wide. He calculates the tub's volume to be 1.2 cubic meters. He knows that a cubic meter is equivalent to 1,000 liters, so he shifts the decimal and the volume becomes 1,200 liters. He also knows that a liter of water weighs 1 kilogram, so in shifting the decimal he arrived at the weight directly–1,200 kilograms. He did all of the above in his head.

3. SI prefixes

Prefixes in the SI system indicate the multiplication factor to be used with the measurement unit. For example, the prefix *kilo* multiplies the unit by 1,000. A kilometer is equal to 1,000 meters. A kilogram equals 1,000 grams.

Prefix	Symbol	Multiplication factor	
pico–	p	0.000000000001	$= 10^{-12}$
nano–	n	0.000000001	$= 10^{-9}$
micro–	µ	0.000001	$= 10^{-6}$
milli–	m	0.001	$= 10^{-3}$
centi–	c	0.01	$= 10^{-2}$
deci–	d	0.1	$= 10^{-1}$
No prefix		1	$= 100$
deka–	da	10	$= 10^{1}$
hecto–	h	100	$= 10^{2}$
kilo–	k	1,000	$= 10^{3}$
mega–	M	1,000,000	$= 10^{6}$
giga–	G	1,000,000,000	$= 10^{9}$
tera–	T	1, 000, 000, 000, 000	$= 10^{12}$

4. Practical units of SI measurement

In practice, many of the possible prefix and unit measurements are seldom used. In the table below, the most commonly used SI units of length, volume, and weight are provided.

	The most commonly used SI units		
Prefix	**Length**	**Volume**	**Weight**
milli-	millimeter	milliliter	milligram
centi-	centimeter		
deci-			
(unit)	meter	liter	gram
deca-			
hecto-			
kilo-	kilometer	($meter^3$)	kilogram

Consider this progression:	millimeter –––>	centimeter –––>	meter –––>	kilometer –––>
Now the prefix multipliers:	0.001	0.01	1	1,000

Finally, consider the magnitude of change between each of these steps:

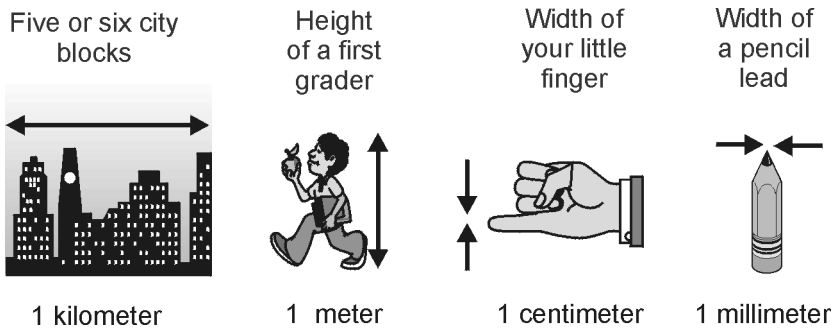
millimeter to centimeter = 10

centimeter to meter = 100

meter to kilometer = 1,000

This progression explains why there are gaps in the table and illustrates the practical side of measurement. As the quantity to be measured increases, the size of the most practical unit increases geometrically. If a meter is too small for a measurement, the next largest prefix-unit, hectometers, will probably not be large enough either.

Here is another example of SI units in practice. The prefix *kilo* can be joined with the unit liter to form kiloliter, but you will never see it written and here's why. Small laboratory ware and kitchenware are calibrated in milliliters and liters. Remember that a liter of water weighs one kilogram (2.2 pounds), which is easy enough to pick up. But a kiloliter is 1,000 times heavier! How would you measure and handle that amount of water? Easy—you would measure its container in meters as the carpenter did in the hot tub example above.



5. Comparing SI units

1. Is a cubic meter equivalent to another measure?

   Large volumes are determined by measuring the length, width, and height of their containers. The result is expressed as the cube of the unit of length used. Because large containers are measured in meters, the result is expressed in cubic meters. Can you determine another SI unit that is equal to a cubic meter?

   - Remember that a liter is a cube that measures 10 centimeters on each side.
   - Now visualize a cubic meter. How many liter-cubes would line one side? (10 liter-cubes)
   - How many liter-cubes would fit into your virtual cubic meter? (1,000 liter-cubes)
   - How many liters are in a kiloliter? Use the prefix table to answer this question. (1,000 liters)
   - What is the relationship between a cubic meter and a kiloliter? (They are equivalent.)

   Now you realize that in the practical world of measurement, large volumes are always measured in cubic meters. That is why the table in Part 4 shows meters^3 in parentheses where kiloliters would have appeared. Lake volumes are measured from maps in cubic meters, natural gas is delivered to homes in cubic meters, and topsoil lost to erosion is measured in cubic meters

2. What is the relationship between a cubic centimeter and a milliliter?

   - What is the length of one side of a liter-cube in centimeters? Use the information found in Practical units of SI measurement, above. (10 cm)
   - What is the volume of a liter in cubic centimeters? (Use the volume formula, $l \times w \times h$. (1,000 cm^3)
   - How many milliliters are in a liter? Use the prefix table to answer this question. (1,000 mL)
   - What is the relationship between a cubic centimeter and a milliliter? (They are equivalent.)

3. What is the relationship between a milliliter of water and a gram?

   A milliliter of salt water weights more than a milliliter of fresh water. Therefore, to discover the relationship between a milliliter of water and a gram, we must define the nature of the water. We will use pure water at standard temperature and pressure.

   - How much does a liter of pure water at standard temperature and pressure weigh? (1 kg; see Part 2)
   - How many grams are in a kilogram? Use the prefix table to answer this question. (1,000 g)
   - How many milliliters are in a liter? Use the prefix table to answer this question. (1,000 mL)
   - What is the relationship between a milliliter of pure water at standard temperature and pressure and a gram? (One milliliter weighs one gram.)

It's important to note that the results of the first two SI challenges were equivalent; you can exchange one for the other. Although the result of this challenge is numerically equivalent, volume and weight are completely different concepts. *That is why you must state that a milliliter of water WEIGHS one gram, not that a milliliter of water equals one gram.*

6. Applying the results of the SI challenges

European kitchens always include a tare scale. A tare scale weighs just like any other scale except that it has a button that returns the weight to zero even if there is something on it. Cooking with a tare scale and SI units is easy. Here is how it's done:

Many recipes like brownies and flavored noodles require an amount of water and milk to be added to a mix. How might a tare scale allow you to prepare flavored noodles using only a tare balance, a pot, and a mixing spoon?

- Place the pot with the dry noodles on the balance. Press tare to zero the scale.
- Run water into the pot until the balance reads in grams the amount of water needed in milliliters.
- Press tare again to zero the balance. Pour milk from the container until the scale reads in grams the amount of milk needed in milliliters. Then, heat and stir the noodle, water, and milk mixture. Bon appétit!

7. Converting between two SI Units

Here is how you convert one SI unit to another.

1. Ask yourself whether the new unit is larger or smaller than the old unit. For example, in converting from meters to centimeters, the new unit is smaller than the old unit.
2. If the new unit is smaller, the new quantity must be larger to maintain equality. If the new unit is larger, the new quantity must be smaller. To make this idea clear, think about a mother and a small child walking across the room. The mother takes a few large steps, but the child must take many small steps.
3. If the quantity of the new unit must be larger, the decimal is moved to the right. If the quantity of the new unit must be smaller, the decimal is moved to the left.
4. Find the multiplication factor for the old and new units in the SI prefixes table in Part 3. Subtract the exponents algebraically. Disregard the sign of the result.
5. Move the decimal in the old quantity in the direction found in Step 2. Move the number of places found in Step 4. Add zeros if necessary. Write this number as the new quantity.

Example:

How many centimeters equal 2.35 meters?

1. The new unit (centimeters) is smaller than meters. Therefore, the new quantity must be larger.
2. The decimal must move right.
3. The multiplication factor exponent for meter = 0, multiplication factor exponent for centimeter = -2. Difference without regarding sign = 2.
4. Therefore, the decimal moves right two places. The new quantity = 235 centimeters.

Practice:

1. 3.45 milligrams = _____ grams
2. 3.004 meters = _____ centimeters
3. 112.3 grams = _____ kilograms
4. 6567.09 millimeters = _____ centimeters
5. 5.2 liters = _____ milliliters
6. How many centimeters are in a kilometer? _____ centimeters