The SI System of Measurement

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CONCEPT 1

The SI System of Measurement

Lesson Objectives

The student will:

- explain the difference between mass and weight.
- identify SI units of mass, distance (length), volume, temperature, and time.
- define derived unit.
- describe absolute zero.

Vocabulary

absolute zero the temperature at which molecules stop moving and therefore have zero kinetic energy

cubic meter the SI unit of volume

derived units units that are defined in terms of other SI base units

heat the flow of thermal energy from a warmer object to a cooler object

International System of Units the internationally agreed upon standard metric system, also abbreviated as the SI system (derived from the French name)

Kelvin temperature scale a temperature scale which has its zero at absolute zero

kilogram the SI unit of mass

length the measurement of anything from end to end

mass a measure of the amount of matter in an object

meter the SI unit of length

second the SI unit for time

temperature the average kinetic energy of the particles that make up a material

volume the amount of space an object occupies

weight the force of attraction between the object and the earth (or whatever large, gravity-producing body the object is located on)

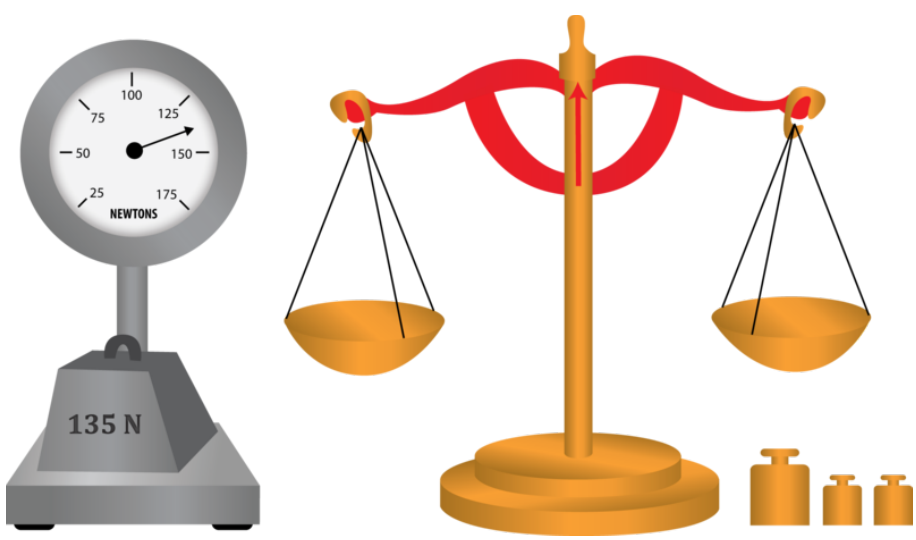
Introduction

The **International System of Units**, abbreviated SI from the French *Le Système International d' Unites*, is the main system of measurement units used in science. Since the 1960s, the International System of Units has been agreed upon internationally as the standard metric system. The SI base units are based on physical standards. The definitions of the SI base units have been and continue to be modified, and new base units are added as advancements in science are made. Each SI base unit, except the kilogram, is described by stable properties of the universe.

Mass and Its SI Unit

Mass and weight are not the same thing. Although we often use these terms interchangeably, each one has a specific definition and usage. The **mass** of an object is a measure of the amount of matter in it and remains the same regardless of where the object is placed. For example, moving a brick to the moon does not cause matter in the brick to disappear or to be removed. The **weight** of an object is the force of attraction between the object and the Earth (or whatever large, gravity-producing body the object is located on). This attraction is due to the force of gravity. Since the force of gravity is not the same at every point on the Earth's surface, the weight of an object is not constant. The gravitational pull on the object varies and depends on where the object is with respect to the Earth or other gravity-producing object. For example, a man who weighs 180 pounds on Earth would weigh only 45 pounds if he were in a stationary position 4,000 miles above the Earth's surface. This same man would weigh only 30 pounds on the moon, because the moon's gravitational pull is one-sixth that of Earth's. The mass of this man, however, would be the same in each situation because the amount of matter in the man is constant.

We measure weight with a scale, which contains a spring that compresses when an object is placed on it. An illustration of a scale is depicted on the left in the diagram below. If the gravitational pull is less, the spring compresses less and the scale shows less weight. We measure mass with a balance, depicted on the right in the diagram below. A balance compares the unknown mass to known masses by balancing them on a lever. If we take our balance and known masses to the moon, an object will have the same measured mass that it had on the Earth. The weight, of course, would be different on the moon. Consistency requires that scientists use mass and not weight when measuring the amount of matter.



The basic unit of mass in the International System of Units is the kilogram. A **kilogram** is equal to 1,000 grams. A gram is a relatively small amount of mass, so larger masses are often expressed in kilograms. When very tiny amounts of matter are measured, we often use milligrams, with one milligram equal to 0.001 gram. Other larger, smaller, or intermediate mass units may also be appropriate.

At the end of the 18th century, a kilogram was the mass of a cubic decimeter of water. In 1889, a new international prototype of the kilogram was made from a platinum-iridium alloy. The kilogram is equal to the mass of this international prototype, which is held in Paris, France. A copy of the standard kilogram is shown in **Figure** 1.1.

FIGURE 1.1
This image shows a copy of the standard kilogram stored and used in Denmark.

Length and Its SI Unit

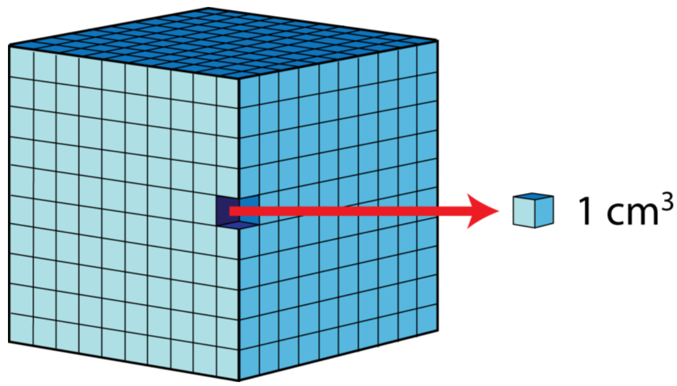
Length is the measurement of anything from end to end. In science, length usually refers to how long an object is. There are many units and sets of standards used in the world for measuring length. The ones familiar to you are probably inches, feet, yards, and miles. Most of the world, however, measure distances in meters and kilometers for longer distances, and in centimeters and millimeters for shorter distances. For consistency and ease of communication, scientists around the world have agreed to use the SI standards, regardless of the length standards used by the general public.

FIGURE 1.2
This image shows the standard meter used in France in the 18th century.

The SI unit of length is the **meter**. In 1889, the definition of the meter was the length of a bar made of platinum-iridium alloy stored under conditions specified by the International Bureau of Standards. In 1960, this definition of the standard meter was replaced by a definition based on a wavelength of krypton-86 radiation. In 1983, that definition was replaced by the following: the meter is the length of the path traveled by light in a vacuum during a time interval of $\frac{1}{299,792,458}$ of a second.

Volume: A Derived Unit

The **volume** of an object is the amount of space it takes up. In the International System of Units, volume is a **derived unit**, meaning that it is based on another SI unit. Consider a cube with each side measuring 1.00 meter. The volume of this cube is $1.00 \text{ m} \times 1.00 \text{ m} \times 1.00 \text{ m} = 1.00 \text{ m}^3$, or one cubic meter. The **cubic meter** is the SI unit of volume and is based on the meter, the SI unit of length. The cubic meter is a very large unit and is not very convenient for most measurements in chemistry. A more common unit is the liter (L), which is $\frac{1}{1,000}$ of a cubic meter. One liter is slightly larger than one quart: 1.000 liter = 1.057 quart. Another commonly used volume measurement is the milliliter, which is equal to $\frac{1}{1,000}$ of a liter. Since $\frac{1}{1,000}$ of a liter is also equal to 1.00 cubic centimeter, then $1.00 \text{ mL} = 1.00 \text{ cm}^3$.



As seen in the illustration above, the volume of 1,000 blocks, each with a volume of 1 cubic centimeter, is equivalent to 1 liter.

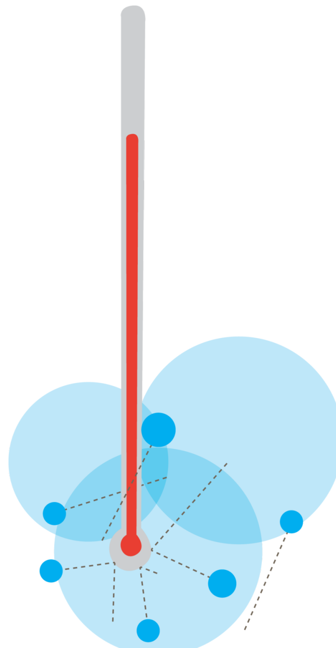
Measuring Temperature

When used in a scientific context, the words heat and temperature do *not* mean the same thing. **Temperature** represents the average kinetic energy of the particles making up a material. Increasing the temperature of a material increases its thermal energy; objects contain thermal energy, not "heat." **Heat** is the movement of thermal energy from a warmer object to a cooler object. When thermal energy moves from one object to another, the temperature of both objects change. These different types of energies will be re-examined in more detail in later chapters, but the key concept to remember here is that temperature reflects the thermal energy *contained* in an object, while heat is the *movement* of thermal energy between two objects.

Consider a small beaker of boiling water (100°C) and a bathtub of water at a temperature of 50°C. The amount of thermal energy contained in the bathtub is 40,000,000 joules (a measure of energy), while the amount of thermal energy in the beaker is 4,000 joules. Although the temperature of the beaker of water is only twice the temperature of the bathtub of water, the amount of thermal energy contained in the bathtub is many times greater than that in the beaker of water. The important thing to note here is that the amount of thermal energy contained in an object increases greatly with an increase in temperature.

A thermometer is a device that measures temperature. The name is made up of *thermo*, which means heat, and *meter*, which means to measure. One of the earliest inventors of a thermometer was Galileo. He is said to have used a device called a thermoscope around the year 1600. The thermometers we typically use today, however, are different from the one Galileo used.

The type of thermometers most people are familiar with operates on the principle that the volume of most liquids increases when heated and decreases when cooled. If a liquid is trapped inside an evacuated tube with an attached bulb reservoir, like that shown in the diagram below, the liquid in the tube will move higher in the tube when the liquid is heated and lower when the liquid is cooled. After a short period of time, the temperature of the liquid in the bulb will be the same temperature as the surrounding material. The liquid in the tube reflects the temperature of the surrounding because the molecules of material surrounding the bulb will collide with the tube and transfer heat during the process. If heat is transferred to the liquid in the bulb, the liquid will rise and indicate an increase in temperature. If heat is transferred to the surrounding material, the height of the liquid in the tube will fall and indicate a decrease in temperature.



Each thermometer is calibrated by placing it in a liquid whose exact temperature is known. Most thermometers are calibrated using consistent known temperatures that are easy to reproduce. At normal sea level and atmospheric pressure, a stable mixture of ice and water will be at the freezing point of water, and a container of boiling water will be at the boiling point of water. When the height of the liquid inside the thermometer reflects the temperature of the surrounding liquid, a mark (scratch) is made on the tube to indicate that temperature. Once the freezing and boiling temperatures have been marked on the thermometer, the distance between the marks can be marked up into equal divisions called degrees.

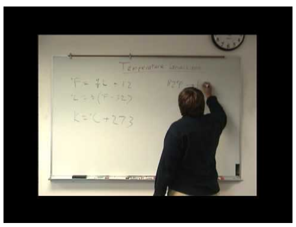
Daniel Fahrenheit established the Fahrenheit scale. On his temperature scale, Fahrenheit designated the freezing point of water as 32°F and the boiling point of water as 212°F. Therefore, the distance between these two points would be divided into 180 degrees. The Fahrenheit temperature scale is used in the United States for most daily expressions of temperature. In another temperature scale established by Anders Celsius, Celsius designated the freezing point of water as 0°C and the boiling point of water as 100°C. Therefore, the temperatures between these two points on the Celsius scale are divided into 100 degrees. Clearly, the size of a Celsius degree and the size of a Fahrenheit degree are not the same.

Earlier in the lesson, the temperature of a substance is defined to be directly proportional to the average kinetic energy it contains. In order for the average kinetic energy and temperature of a substance to be directly proportional, it is necessary for the average kinetic energy to be zero when the temperature is zero. This is not true with either the Fahrenheit or Celsius temperature scales. Most of us are familiar with temperatures that are below the freezing point of water. It should be apparent that even though the air temperature may be -5°C, the molecules of air are still moving. Substances like oxygen and nitrogen have already become vapor at temperatures below -150°C, indicating that molecules are still in motion at over a hundred degrees below zero.

A third temperature scale was established to address this issue. This temperature scale was designed by Lord Kelvin. Lord Kelvin stated that there is no upper limit to how hot things can get, but there is a limit as to how cold things can get. Kelvin developed the idea of **absolute zero**, which is the temperature that molecules stop moving and have zero kinetic energy. The **Kelvin temperature scale** has its zero at absolute zero (determined to be $-273.15°C$) and uses the same degree size as a degree on the Celsius scale. As a result, the mathematical relationship between the Celsius scale and the Kelvin scale is: $K = °C + 273.15$. On the Kelvin scale, water freezes at 273.15 K and boils at 373.15 K. In the case of the Kelvin scale, the degree sign is not used. Temperatures are expressed, for example, simply as 450 K.

It should be noted that many mathematical calculations in chemistry involve the difference between two temperatures, symbolized by ΔT (pronounced *delta T*). Since the size of a degree is the same in Celsius and in Kelvin, the ΔT will be the same for either scale. For example, $20°C = 293$ K and $50°C = 323$ K; the difference between the Celsius temperatures is 30°C, and the difference between the Kelvin temperatures is 30 K. When the calculations involve ΔT, it is not necessary to convert Celsius to Kelvin, but when the temperature is used directly in an equation, it *is* necessary to convert Celsius to Kelvin.

This video is an explanation of how to convert among the Celsius, Kelvin, and Fahrenheit temperature scales and includes a sample problem **(4e)**: http://www.youtube.com/watch?v=SASnMMGp5mo (4:37).



MEDIA
Click image to the left for more content.

This video is an explanation of particle temperature, average temperature, heat flow, pressure, and volume **(7a)**: http://www.youtube.com/watch?v=tfE2y_7LqA4 (4:00).

MEDIA
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Time and Its SI Unit

The SI unit for time is the second. The second was originally defined as a tiny fraction of the time required for the Earth to orbit the Sun. It has since been redefined several times. The definition of a **second** (established in 1967 and reaffirmed in 1997) is: the duration of 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

Lesson Summary

- The International System of Units, abbreviated SI from the French *Le Système International d' Unites*, is internationally agreed upon since the 1960s as the standard metric system.
- Mass and weight:
  - The mass of an object is a measure of the amount of matter in it.

- The mass of an object remains the same regardless of where the object is placed.
- The basic unit of mass in the International System of Units is the kilogram.
- The weight of an object is the force of attraction between the object and the earth (or whatever large, gravity-producing body the object is located on).

- Length:
  - Length is the measurement of anything from end to end.
  - The SI unit of length is the meter.
- Volume:
  - The volume of an object is the amount of space it takes up.
  - The cubic meter is the SI unit of volume.
- Temperature and heat:
  - Temperature represents the average kinetic energy of the particles that make up a material.
  - Increasing the temperature of a material increases its thermal energy.
  - Heat is the movement of thermal energy from a warmer object to a cooler object.
  - When thermal energy moves from one object to another, the temperature of both objects change.
  - Absolute zero is the temperature at which molecules stop moving and therefore have zero kinetic energy.
  - The Kelvin temperature scale has its zero at absolute zero (determined to be $-273.15°C$) and uses the same degree size as the Celsius scale.
  - The mathematical relationship between the Celsius scale and the Kelvin scale is $K = °C + 273.15$.
- Time:
  - The SI unit for time is the second.

Further Reading / Supplemental Links

This website has lessons, worksheets, and quizzes on various high school chemistry topics. Lesson 1-3 is on measuring matter, lesson 1-7 is on temperature conversion, and lesson 2-1 is on the International System of measurements.

- http://www.fordhamprep.org/gcurran/sho/sho/lessons/lessindex.htm

Review Questions

1. What is the basic unit of measurement in the metric system for length?
2. What is the basic unit of measurement in the metric system for mass?
3. What unit is used in the metric system to measure volume? How is this unit related to the measurement of length?
4. Give the temperatures in Celsius for the freezing and boiling points of water.
5. Give the temperatures in Kelvin for the freezing and boiling points of water.
6. Would it be comfortable to swim in a swimming pool whose water temperature was 275 K? Why or why not?