Heat Energy and Changes of State

Matter may exist in the solid, liquid, or gaseous states, or phases. An increase or decrease in energy and temperature of matter can cause the matter to go from one state to another.

Types of Change of State

The following are some changes of state.

- Melting is the changing of a solid to a liquid.
- **Solidification,** or freezing, is the changing of a liquid to a solid. If solidification results in a solid with an ordered pattern of atoms, the process is **crystallization.**
- Evaporation, or **vaporization** is the changing of a liquid to a gas, or vapor.
- **Condensation** is the changing of a gas, or vapor, to a liquid.
- Sublimation is the changing of a gas directly to a solid (also called deposition), or from a solid directly to a gas—without going through a liquid state.

The changes in state of water are shown in Figure 5-6. When water changes state from a solid to a liquid to a gas, it absorbs heat, molecular movement speeds up, and the tightly bound water molecules become less and less tightly bound. When water changes state from a gas to a liquid to a solid, water releases stored heat, molecular movements slow down, and molecules become more tightly bound.

Stored Heat and Changes of State

When a material is in one of the three states, its temperature rises as heat is added to it. If, however, the material is in the process of changing state,

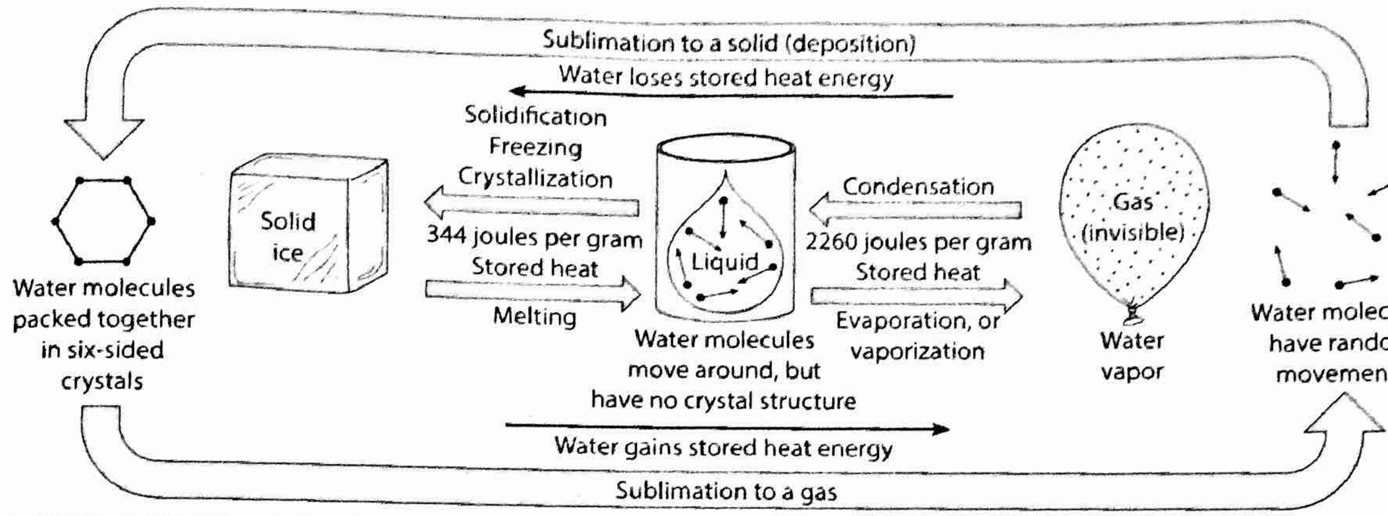


Figure 5-6. Changes in state of water: When water changes phase from a solid to a liquid to a gas, it absorbs heat and changes tightly bound water molecules of a solid to less tightly bound molecules of liquid water and gaseous water. To go from a gas to a liquid to a solid, water releases stored heat and the molecular movements slow down.

its temperature remains the same as it is heated. During the change of state, the added heat energy is not increasing the kinetic energy of the atoms or molecules, and therefore, the temperature does not change. The added heat energy is being converted to a kind of potential energy, or stored heat.

In order for a change of state from a solid to a liquid, or from a liquid to a gas to occur, the substance must gain heat. When the change of state is from a gas to a liquid, or from a liquid to a solid, the substance must lose stored heat. The amount of stored heat, gained or lost, varies with the particular substance and type of change of state.

Stored Heat and Changes of State of Water

Figure 5-7 shows how the temperature of a fixed amount of water changes as it is heated at a constant rate from ice—solid water—at –100°C to gaseous water—water vapor—at 200°C. The temperature is plotted against time in minutes (upper scale of the graph) and the corresponding amount of added heat (lower scale of the graph). You can see that the temperature remains constant at 0°C for almost 2 minutes while the water is changing from the solid state to the liquid state. There is another constant-temperature interval, of more than 10 minutes, at 100°C while the water is changing from the liquid state to the gaseous phase. The reason for these intervals of constant temperature is that the heat being added at those times is being changed to stored heat (potential energy). To find the amount of energy gained or released by water as it changes state, refer to Figure 5-6 or to Properties of Water in the *Earth Science Reference Tables.*

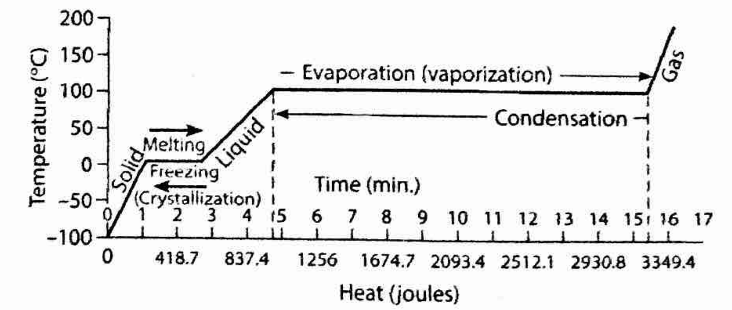


Figure 5-7. Heating or cooling of water: When read from left to right, the graph shows the temperature change of one gram of water as heat is added at a constant rate—209.3 joules per minute. When read from right to left, the graph shows the temperature change if 209.3 joules per gram is released from the water. The flat portion of the graph shows data as water absorbs or releases stored heat associated with a change of state. The steeply sloped portions of the graph show data as water is increasing or decreasing in temperature, but not experiencing a change of state.

Earth's Energy Supply

The energy for some of Earth's processes comes from Earth's interior. However, most of the energy Earth needs comes from the sun's electromagnetic radiation.

Solar Energy

The sun radiates, or gives off, and Earth receives a wide range of electromagnetic energy of various wavelengths. This solar electromagnetic spectrum includes X-rays, ultraviolet rays, visible light, and infrared rays. Of all the types of electromagnetic radiation from the sun, the one with the greatest intensity is visible light.

Solar energy is produced by nuclear fusion—a process in which the nuclei (centers) of atoms are combined to form larger atomic nuclei—releasing great amounts of energy in the process. Nuclear fusion can only occur under the conditions of very high temperature and pressure, for example, in the interior of a star. Figure 5-8 illustrates the type of fusion believed to be most common in the sun. A small fraction of the energy produced by nuclear fusion is radiated as electromagnetic energy and received by Earth—thus "fueling" most Earth processes.

Earth's Own Energy

Heat energy from Earth's interior is converted into mechanical energy for mountain building, volcanic eruptions, plate movements, and other internal movements. Some of this heat remains from when Earth formed, and some is produced as the result of materials being pulled by gravity towards Earth's center. Probably most of Earth's interior energy comes from the nuclear decay of radioactive materials within Earth. **Nuclear decay,** also called nuclear fission or radioactive decay, is the process by which unstable or radioactive atomic nuclei of elements, such as uranium and radium, split to form lighter elements. In the process, large amounts of

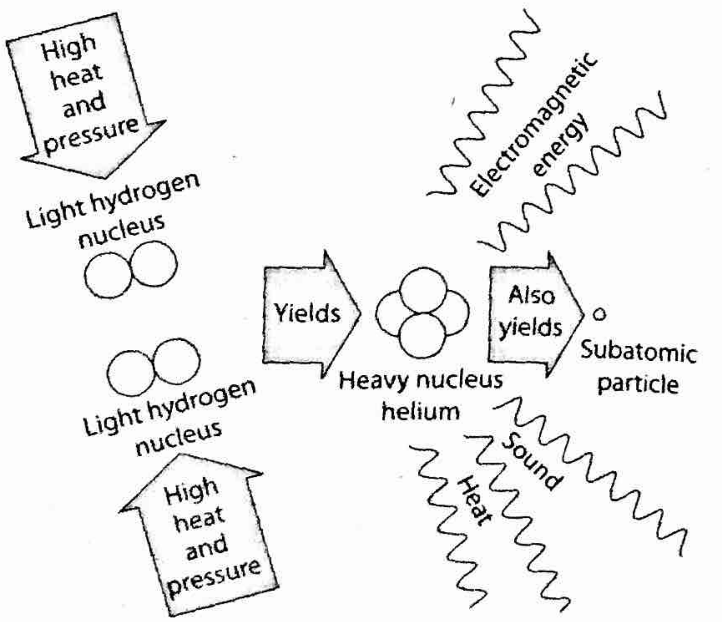


Figure 5-8. A simple model of nuclear fusion in our sun: The high heat and pressure of our sun combine the nuclei of hydrogen to produce helium, energy, and subatomic particles.

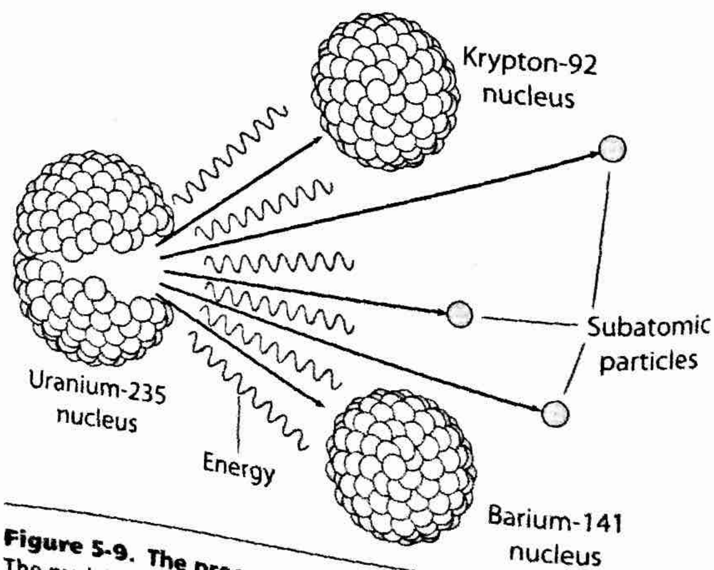


Figure 5-9. The process of nuclear decay (of uranium-235): The nuclei of radioactive elements are unstable, and they can split to form elements with smaller nuclei, subatomic particles, and large amounts of energy.

energy are released. Nuclear decay is the process employed in the atomic reactors used to produce a portion of the nation's electric supply. Figure 5-9 illustrates the process of nuclear decay.

Another source of Earth's energy is the energy created by the impact of meteoroids, asteroids, and comets with Earth's atmosphere and Earth's surface. These impacts continue today although they are likely not as frequent as in ancient Earth history. There are many other minor sources of Earth energy, including the gravitational energy of the Sun and Moon creating the tidal energy of the oceans and many sources of friction.

Review Questions

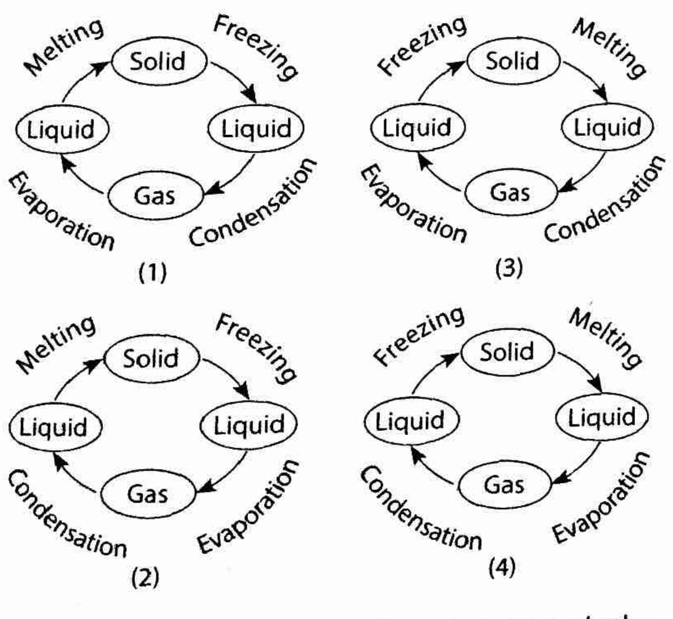
31. At which temperature will ice melt under normal conditions?

(1) 0 K (2) 32 K (3) 212 K (4) 273 K

32. The change from the gas, or vapor phase, to the liquid phase is called

(1) evaporation
(2) condensation
(3) precipitation
(4) transpiration

33. Which diagram correctly shows the processes that change the phases of matter?



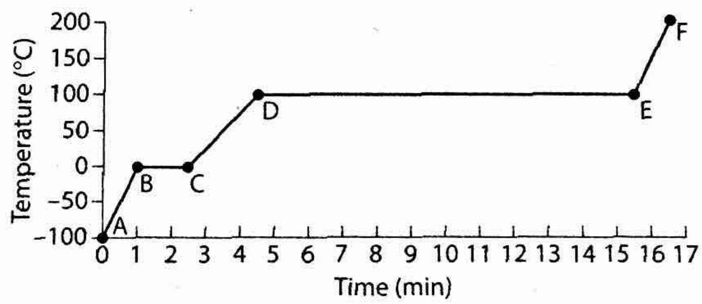
34. Two identical towels are hanging on a clothesline in the sun. One towel is wet; the other is dry. The wet towel feels much cooler than the dry towel because the

(1) dry towel receives more heat energy from the sun
(2) dry towel has more room for heat storage than the wet towel
(3) presence of water in the wet towel requires an additional amount of heat energy to bring about a temperature change
(4) water in the wet towel prevents absorption of heat energy

35. Water loses energy when it changes phase from

(1) liquid to solid
(2) solid to liquid
(3) liquid to gas
(4) solid to gas

Base your answers to questions 36 through 42 on the following graph. The graph shows the temperatures recorded when a sample of water was heated from –100°C to 200°C. The water received the same amount of heat every minute.



36. For the time on the graph represented by the line from point B to point C, the water was

(1) freezing
(2) melting
(3) condensing
(4) boiling

37. At which point in time would most of the water be in the liquid phase?

(1) 1 minute
(2) 14 minutes
(3) 16 minutes
(4) 4 minutes

38. What is the rate of temperature change between points C and D?

(1) 10°C/min
(2) 25°C/min
(3) 50°C/min
(4) 150°C/min

39. The greatest amount of energy was absorbed by the water between points

(1) A and B
(2) B and C
(3) C and D
(4) D and E

40. During which time interval was the rate of temperature change the greatest?

(1) A to B
(2) B to C
(3) C to D
(4) D to E

41. What is the most probable explanation for the constant temperature between points D and E on the graph?

(1) The added heat was radiated as fast as it was absorbed.
(2) The added heat was lost to the surroundings.
(3) The added heat changed liquid water to water vapor.
(4) The added heat changed water vapor to liquid water.

42. Which change occurred between point A and point B?

(1) Ice melted.
(2) Ice warmed.
(3) Water froze.
(4) Water condensed.

43. What is the major source of energy for Earth's surface?

(1) convective motion within the mantle
(2) energy released during the collision of tectonic plates
(3) interaction of major air masses as Earth rotates on its axis
(4) electromagnetic energy from the sun

44. The sun's energy is most likely the result of

(1) the burning of fossil fuels
(2) gravitational contraction of the sun
(3) a nuclear reaction involving the combination of atoms
(4) a nuclear reaction involving a radioactive decay

45. A source of energy for the high temperatures found deep within Earth is

(1) tidal friction
(2) incoming solar radiation
(3) nuclear decay of radioactive materials
(4) meteorite bombardment of Earth

46. As the lake surface freezes in the winter, how many joules of heat are released by each gram of water?

47. Which process requires water to gain 2260 joules of energy per gram?

(1) vaporization
(2) condensation
(3) melting
(4) freezing

48. Describe two sources of Earth's energy that are not produced in Earth's interior or produced by the sun.