SAMPLE PROBLEM 12-1

How much heat energy is absorbed when 47.0 g of ice melts at STP? How much heat energy is absorbed when this same mass of liquid water boils?

SOLUTION

1 ANALYZE

Given: mass of H₂O(s) = 47.0 g
mass of H₂O(l) = 47.0 g
molar heat of fusion of ice = 6.009 kJ/mol (given on page 385)
molar heat of vaporization = 40.79 kJ/mol (given on page 385)

Unknown: heat energy absorbed when ice melts
heat energy absorbed when liquid water boils

2 PLAN

First, convert the mass of water in grams to moles.

\[ \text{g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = \text{ mol H}_2\text{O} \]

Then, use the molar heat of fusion of a solid to calculate the amount of heat absorbed when the solid melts. Multiply the number of moles by the amount of energy needed to melt one mole of ice at its melting point (the molar heat of fusion of ice). Using the same method, calculate the amount of heat absorbed when water boils by using the molar heat of vaporization.

amount of substance (mol) \times \text{ molar heat of fusion or vaporization (kJ/mol)} = \text{ heat energy (kJ)}

3 COMPUTE

\[ 47.0 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 2.61 \text{ mol H}_2\text{O} \]

2.61 mol \times 6.009 kJ/mol = 15.7 kJ (on melting)
2.61 mol \times 40.79 kJ/mol = 106 kJ (on vaporizing or boiling)

4 EVALUATE

Units have canceled correctly. The answers have the proper number of significant digits and are reasonably close to estimated values of 18 (3 x 6) and 120 (3 x 40), respectively.

PRACTICE

1. What quantity of heat energy is released when 506 g of liquid water freezes? Answer: 169 kJ
2. What mass of steam is required to release 4.97 \times 10^3 kJ of heat energy on condensation? Answer: 2.19 \times 10^3 g

SECTION REVIEW

1. Why is a water molecule polar?
2. How is the structure of water responsible for some of water’s unique characteristics?
3. Describe the arrangement of molecules in liquid water and in ice.
4. Why does ice float? Why is this phenomenon important?
12.4 Water is a polar-covalent compound. A water molecule has a bent shape and a partial negative charge near its oxygen atom and a partial positive charge near each hydrogen atom.

- The structure and the types of bonds water is able to form are responsible for its relatively high melting point, molar heat of fusion, boiling point, and molar heat of vaporization.

- The structure and bonding of water also explain why water expands upon freezing and why ice is able to float in liquid water.

### REVIEWING CONCEPTS

1. What is a fluid? (12.1)
2. What is surface tension? (12.1)
3. Give two reasons why evaporation is a crucial process in nature. (12.1)
4. List seven properties of solids, and explain each in terms of the kinetic-molecular theory of solids. (12.2)
5. a. List four common examples of amorphous solids.
b. Why is glass sometimes classified as a supercooled liquid?
c. Name some uses of glass. (12.2)
6. Distinguish between a crystal structure, a lattice, and a unit cell. (12.2)
7. a. List and describe the four types of crystals in terms of the nature of their component particles and the type of bonding between them.b. What physical properties are associated with each type of crystal? (12.2)
8. Using Figure 12-12, estimate the approximate equilibrium vapor pressure of each of the following at the specified temperature.
a. water at 40°C
b. water at 80°C
c. diethyl ether at 20°C
d. ethanol at 60°C (12.3)
9. a. What is sublimation?
b. Give two examples of common substances that sublime at ordinary temperatures. (12.3)
10. What is meant by the normal freezing point of a substance? (12.3)
11. Explain why the vapor pressure of a liquid increases with increasing temperature. (12.3)

### PROBLEMS

#### Molar Heat

18. a. The molar heat of vaporization for water is 40.79 kJ/mol. Express this heat of vaporization in joules per gram.
b. The molar heat of fusion for water is 6.009 kJ/mol. Express this heat of fusion in joules per gram.

19. The standard molar heat of vaporization for water is 40.79 kJ/mol. How much energy would be required to vaporize each of the following?
   a. 5.00 mol H₂O
   b. 45.9 g H₂O
   c. 8.45 × 10¹⁰ molecules H₂O

20. The molar heat of fusion for water is 6.009 kJ/mol. How much energy would be required to melt each of the following?
   a. 12.75 mol ice
   b. 6.48 × 10⁵ kg ice

21. Calculate the molar heat of vaporization of a substance given that 0.435 mol of the substance absorbs 36.5 kJ of energy when it is vaporized.

22. Given that a substance has a molar mass of 259.0 g/mol and a 71.8 g sample of the substance absorbs 4.307 kJ when it melts, a. calculate the number of moles in the sample.
b. calculate the molar heat of fusion.

23. a. Calculate the number of moles in a liquid sample of a substance that has a molar heat of fusion of 3.811 kJ/mol, given that the sample contains 85.2 kJ when it freezes.
b. Calculate the molar mass of this substance if the mass of the sample is 5519 g.

#### Water

24. Which contains more molecules of water: 5.00 cm³ of ice at 0°C or 5.00 cm³ of liquid water at 0°C?

25. Which contains more molecules of water (density = 1.27 g/cm³), 5.00 cm³ of liquid water at 0°C or 5.00 cm³ of water vapor at 50°C?

26. a. What volume and mass of steam at 100°C and 1.00 atm would, during condensation, release the same amount of heat as 100.0 cm³ of liquid water during freezing?
b. What do you note, qualitatively, about the relative volumes and masses of steam and liquid water required to release the same amount of heat? (Hint: See Sample Problem 12-1)

#### MIXED REVIEW

27. Find the molar heat of vaporization for a substance, given that 3.21 mol of the substance absorbs 28.4 kJ of energy when it changes from a liquid to a gas.

28. Water’s molar heat of fusion is 6.009 kJ/mol. Calculate the amount of energy required to melt 7.95 × 10³ g of ice.

29. A certain substance has a molar heat of vaporization of 31.6 kJ/mol. How much of the substance is in a sample that requires 57.0 kJ to vaporize?

30. Given that water has a molar heat of vaporization of 40.79 kJ/mol, how many grams of water could be vaporized by 0.545 kJ?

31. Calculate the amount of energy released by the freezing of 13.3 g of a liquid substance, given that the substance has a molar mass of 82.9 g/mol and a molar heat of fusion of 4.60 kJ/mol.

32. What volume and mass of steam at 100°C and 760 torr would release the same amount of heat due to condensation as 65.3 cm³ of liquid water would release during freezing?

33. A substance has a molar heat of fusion of 3.43 kJ/mol. Calculate the molar mass of the substance, given that a 64.2 g sample of it absorbs 2.77 kJ on melting.

34. The following liquid-vapor system is at equilibrium at a given temperature in a closed system.

   liquid + heat energy ————> vapor

   Suppose the temperature is increased and equilibrium is established at the higher temperature. How does the final value of each of the following compare with its initial value? (In each case, answer either higher, lower, or the same.)
   a. the rate of evaporation
   b. the rate of condensation
   c. the final concentration of vapor molecules
d. the final number of liquid molecules

35. Decide whether the temperature of a liquid-vapor equilibrium system should be increased or decreased to make each of the following changes in the system.
   a. increased final rate of evaporation
   b. increased final concentration of vapor
   c. increased final rate of condensation
d. increased final number of liquid molecules

36. Given a sample of water at any point on curve AB in Figure 12-14, what effect would each of the following changes have on that sample?
   a. adding heat energy at constant pressure
   b. decreasing the volume at constant temperature
   c. removing heat energy at constant pressure
   d. increasing the volume at constant temperature
37. Using the phase diagram for CO₂, describe all the phase changes that would occur when CO₂ is heated from −100°C to −20°C at a constant pressure of 6 atm.

38. Applying Ideas Explain the role of humidity of the air in determining relative comfort on a hot day.

39. Interpreting Concepts During the freezing of a substance, energy is being removed from that substance. Yet the temperature of the liquid-solid system remains constant. Explain this phenomenon.

40. Applying Models At normal atmospheric pressure, the temperature of an ice-water system remains at 0°C as long as both ice and liquid water are present, regardless of the surrounding temperature. Explain this in terms of Le Chatelier’s principle.

41. Describe the forces that must be overcome to explain why the heat of vaporization of a substance is always greater than its heat of fusion.

42. Predicting Outcomes Given a sample of water at any point on curve AD in Figure 12-14, how could more of the liquid water in that sample be converted into a solid without changing the temperature? Explain your reasoning.

43. Interpreting Diagrams Refer to the phase diagram in question 37.
   a. Explain what happens when solid CO₂ (“dry ice”) warms up to room temperature at normal atmospheric pressure.
   b. Is there a pressure below which liquid CO₂ cannot exist? Estimate that pressure from the graph.

44. Interpreting Concepts Methane, CH₄, which is similar to water in molecular size and mass, is a gas at room temperature. However, water is a liquid at that temperature. Explain why.

45. Three simple unit cells found in metals are shown below. The dimensions of each unit cell can be described mathematically using the following information.

   s = length of the edge
   r = atomic radius

   ![Simple cubic cell](image)
   ![Body-centered cubic cell](image)
   ![Face-centered cubic cell](image)

Which of the following relationships applies to the simple cubic cell?
   a. 2r = s
   b. 8r = 2s
   c. r = s
   d. 2s = r

Which of the following relationships applies to the face-centered cubic cell?
   a. 2r = 4r
   b. 2r = s
   c. 4r = s\(\sqrt{2}\)
   d. 3r = s

46. How would the model of an electron in a face-centered cubic lattice differ from the compound shown in Figure 12-7?
   a. The body-centered cubic lattice is the least-efficient packing structure of the metals.
   b. What elements in Groups 1 and 2 show this arrangement?

47. Graphing Calculator Calculating Vapor Pressure Using a Table

   The graphing calculator can run a program that calculates a table for the vapor pressure in atmospheres at different temperatures (K) given the number of moles of a gas and its volume (V). Given a 0.50 mol gas sample with a volume of 10 L, you can calculate the pressure at 290 K, using a table. Use this program to create the table. Next, use the table to perform the calculations.

   Go to Appendix C. If you are using a TI-83 Plus, you can download the program and data and run the application as directed. If you are using another calculator, your teacher will provide you with keystrokes and data sets to use. Remember that you will need to name the program and check the display, as explained in Appendix C. You will then be ready to run the program. After you have graphed the data, answer these questions.

   Note: All answers show five significant digits.
   a. What is the pressure for a gas with a mass of 1.3 mol, volume of 8.0 L, and temperature of 320° K?
   b. What is the pressure for a gas with a mass of 1.5 mol, volume of 10.0 L, and temperature of 340° K?
   c. Two gases are measured at 300° K. One has a mass of 1.3 mol and has a volume of 7.5 L, and the other has a mass of 0.5 mol and a volume of 10.0 L. Which gas has the lesser pressure?

**HANDBOOK SEARCH**

48. The Elements Handbook contains a table of properties for each group that includes information on the crystal structures of the elements. Most metals crystallize in one of three lattice arrangements: body-centered cubic, face-centered cubic, or hexagonal close-packed. Figure 12-7 shows a model of the face-centered cubic lattice for sodium chloride. Use this figure and the information in the Elements Handbook to answer the following.

   a. What elements in Group 2 have the same lattice structure as sodium chloride?

**TECHNOLOGY & LEARNING**

44. How would the model of an electron in a face-centered cubic lattice differ from the compound shown in Figure 12-7?
   a. The body-centered cubic lattice is the least-efficient packing structure of the metals.
   b. What elements in Groups 1 and 2 show this arrangement?

**RESEARCH & WRITING**

49. Ceramics are formed from silicates found in the soil. Artists use them to create pottery, but engineers and scientists have created ceramics with superconductive properties. Investigate the growing field of superconductive ceramics.

50. Liquid crystals are substances that possess the combined properties of both liquids and crystals. Write a report on these substances and the various uses we are finding for them.

51. Consult reference materials at the library, and prepare a report on the process of freeze-drying, describing its history and applications.

52. Prepare a report about the adjustments that must be made when cooking and baking at high elevations. Collect instructions for high-elevation adjustments from packages of prepared food mixes. Explain why changes must be made in recipes that will be prepared at high elevations. Check your library for cookbooks containing information about food preparation at high elevations.

**ALTERNATIVE ASSESSMENT**

53. Compile separate lists of crystalline and amorphous solids found in your home. Compare your lists with those of your classmates.

54. Design an experiment to grow crystals of various safe, common household materials. Record the conditions under which each type of crystal is best grown.