Ch 13 (5th ed)

change from solids to liquids to gases. At higher temperatures, molecules, atoms, and even nuclei break apart.

There is a limit to how much internal energy can be removed from an object, and thus there is a lowest possible temperature—absolute zero, or −273°C—the same as the zero on the Kelvin scale. A substance at absolute zero has the lowest possible internal energy.

The temperature of a substance does not change while it undergoes a physical change of state. The energy that is released or gained per gram of material is known as the latent heat.

The natural flow of thermal energy is always from hotter objects to colder ones. In the process called conduction, thermal energy is transferred by collisions between particles; in convection the transfer occurs through the movement of the particles; and in radiation the energy is carried by electromagnetic waves.

KEY TERMS

absolute zero: The lowest possible temperature; 0 K, −273°C, or −459°F.

British thermal unit: The amount of heat required to raise the temperature of 1 pound of water by 1°F.

calorie: The amount of heat required to raise the temperature of 1 gram of water by 1°C.

change of state: The change in a substance between solid and liquid or liquid and gas.

conduction: The transfer of thermal energy by the collisions of the atoms or molecules within a substance.

conductor: A material that allows the easy flow of thermal energy. Metals are good conductors.

convection: The transfer of thermal energy in fluids by means of currents such as the rising of hot air and the sinking of cold air.

heat: Energy flowing due to a difference in temperature.

heat capacity: The amount of heat required to raise the temperature of an object by 1°C.

insulator: A material that is a poor conductor of thermal energy. Wood and stationary air are good thermal insulators.

internal energy: The total microscopic energy of an object, which includes its atomic and molecular translational and rotational kinetic energies, vibrational energy, and the energy stored in the molecular bonds.

latent heat: The amount of heat required to melt (or vaporize) 1 gram of a substance. The same amount of heat is released when 1 gram of the same substance freezes (or condenses).

radiation: The transport of energy via electromagnetic waves.

specific heat: The amount of heat required to raise the temperature of 1 gram of a substance by 1°C.

thermal energy: Internal energy.

thermal equilibrium: A condition in which there is no net flow of thermal energy between two objects. This occurs when the two objects obtain the same temperature.

thermal expansion: The expansion of a material when heated.

thermodynamics: The area of physics that deals with the connections between heat and other forms of energy.

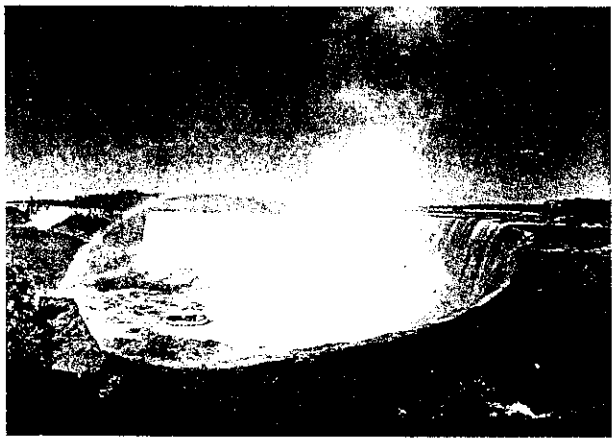
thermodynamics, first law of: The increase in the internal energy of a system is equal to the heat added plus the work done on the system.

thermodynamics, third law of: Absolute zero may be approached experimentally but can never be reached.

thermodynamics, zeroth law of: If objects A and B are each in thermodynamic equilibrium with object C, then A and B are in thermodynamic equilibrium with each other. All three objects are at the same temperature.

CONCEPTUAL QUESTIONS

1. In an avalanche, the snow and ice begin at rest at the top of the mountain and end up at rest at the bottom. What happens to the gravitational potential energy that is lost in this process?
2. What happens to the sound energy from your stereo speakers?
3. What evidence did Rumford have that heat was not a fluid?
4. Rumford concluded that heat cannot be a fluid. Does this imply that heat does not flow?
5. How are the concepts of work and heat the same? How are they different?



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6. What would you expect to find if you measure the temperature of the water at the top and bottom of Niagara Falls? Explain your reasoning.

7. It might be argued that the only time you measure the undisturbed temperature of a system is when the reading on the thermometer does not change when it is placed in thermal contact with the system. Use the zeroth law to explain why this is so.

8. Imagine a universe where the zeroth law of thermodynamics was not valid. Would the concept of temperature still make sense in this universe? Why or why not?

9. Could two objects be touching but not be in thermal equilibrium? Explain.

10. Is it possible for a bucket of water in Los Angeles and a bucket of water in New York City to be in thermal equilibrium? Explain.

11. Why is it incorrect to talk about the flow of temperature from a hot object to a colder object?

12. On the inside back cover of this textbook are conversion factors between different units. Why is there no conversion factor between joules and kelvin?

13. What is the difference between heat and temperature?

14. The same amount of heat flows into two different buckets of water, which are initially at the same temperature. Will both buckets necessarily end up at the same temperature? Explain.

15. Student 1 claims, "Two buckets of water must have the same heat if they are at the same temperature." Student 2 counters, "That's true only if both buckets contain the same amount of water." Which, if either, of these students do you agree with? Explain.

16. How do the internal energies of a cup of water and a gallon of water at the same temperature compare?

17. Under what conditions is the first law of thermodynamics valid?

18. Work is done on a system without changing the internal energy of the system. Which direction (into or out of the system) must heat flow during this process? Use the first law of thermodynamics to justify your answer.

19. How is specific heat defined?

20. Does it take more thermal energy to raise the temperature of 5 grams of water or 5 grams of ice by 6°C? Explain.

21. Liquid X and gas Y have identical specific heats. Would 100 calories of heat raise the temperature of 1 liter of liquid X by the same amount as 1 liter of gas Y? Explain your reasoning.

22. One kilogram of material A at 80°C is brought into thermal contact with 1 kilogram of material B at 40°C. When the materials reach thermal equilibrium, the temperature is 68°C. Which material, if either, has the greater specific heat? Explain.

23. A hot block of aluminum is dropped into 500 grams of water at room temperature in a thermally insulated container where it reaches thermal equilibrium. If 1000 grams of water had been used instead, would the amount of heat transferred to the water be greater than, equal to, or less than it was before? Why?

24. A hot block of aluminum is dropped into 500 grams of water at room temperature in a thermally insulated container where it reaches thermal equilibrium. If 1000 grams of water had been used instead, would the temperature change of the water be greater than, equal to, or less than it was before? Why?

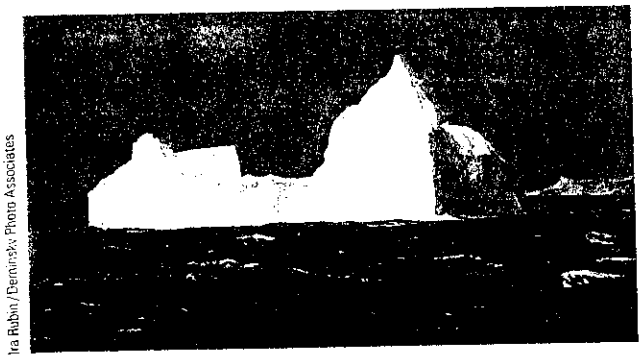
25. Why do climates near the coasts tend to be more moderate than those in the middle of the continent?

26. Why does the coldest part of winter occur during late January and February when the shortest day is near December 21?

27. Given that the melting and freezing temperatures of water are identical, what determines whether a mixture of ice and water will freeze or melt?

28. If you make the mistake of removing ice cubes from the freezer with wet hands, the ice cubes will stick to your hands. Why does the water on your hands freeze rather than the ice cubes melt?

George Semple



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29. Why can an iceberg survive for several weeks floating in seawater that's above freezing?

30. The boiling point for liquid nitrogen at atmospheric pressure is 77 K. Is the temperature of an open container of liquid nitrogen higher, lower, or equal to 77 K? Explain.

31. One hundred grams of ice at 0°C is added to 100 grams of water at 80°C. The system is kept thermally insulated from its environment. Will the equilibrium temperature of the mixture be greater than, equal to, or less than 40°C? Explain your reasoning.

32. An ice cube at 0°C is placed in a Styrofoam cup containing 200 grams of water at 60°C. When the system reaches thermal equilibrium, its temperature is 30°C. Was the mass of the ice cube greater than, equal to, or less than 200 grams? Explain your reasoning.

33. Why is steam at 100°C more dangerous than water at 100°C?

34. A new liquid is discovered that has the same boiling point and specific heat as water but a latent heat of vaporization of 10 calories per gram. Assuming that this new liquid is safe to drink, would it be more or less convenient than water for boiling eggs? Why?

35. A system is thermally insulated from its surroundings. Is it possible to do work on the system without changing its internal energy? Is it possible to do work on the system without changing its temperature? Explain.

36. In Washington, D.C., the weather report sometimes states that the temperature is 95°F and the humidity is 95%. Why does the high humidity make it so uncomfortable?

37. Use a microscopic model to explain how a metal rod transports thermal energy from the hot end to the cold end.

38. Why would putting a rug on a tiled bathroom floor make it feel less chilly to bare feet?

39. Rank the following materials in terms of their insulating capabilities: static air, glass, polyurethane foam, and concrete.

40. Which of the following is the best thermal conductor: fiberglass, stainless steel, wood, or silver?

41. If the temperature is 35°F and the wind is blowing at 20 mph, the equivalent wind chill temperature is 24°F. Will a glass of water freeze in this situation? Explain your reasoning.

42. You hear on the morning weather report that the outside temperature is −5°F with a wind-chill equivalent temperature of −40°F. You know that your old car, which is parked outside, will not start if the temperature of the battery drops below −15°F. Will your car start this morning? Why or why not?

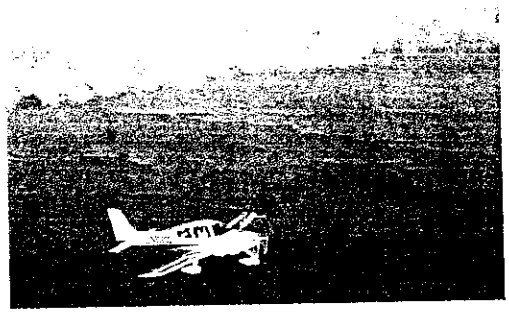
43. The respective thermal conductivities of iron and stainless steel are 79 W/m · °C and 14 W/m · °C. Use these data to explain why you need to use potholders for pots with iron handles but not for pots with stainless steel handles.

44. Why might a cook put large aluminum nails in potatoes before baking them?

45. In northern climates drivers often encounter signs that read "BRIDGE FREEZES BEFORE ROADWAY." Why does this occur?

46. You have just made yourself a hot cup of coffee and are about to add the cream, which is at room temperature. Suddenly the phone rings and you have to leave the room for a while. Is it better to add the cream to the coffee before you leave or after you get back if you want your coffee as hot as possible? Why?

47. When pilots fly under clouds, they often experience a downdraft. Why is this?



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48. It is midafternoon and you are canoeing down a river that empties into a large lake. You are having a hard time making progress because of a stiff wind in your face. Is this situation likely to get better or worse as the Sun sets? Explain.

49. A black car and a white car are parked next to each other on a sunny day. The surface of the black car gets much hotter than the surface of the white car. Which mode of energy transport is responsible for this difference?

50. Earth satellites orbit Earth in a very good vacuum. Would you expect these satellites to cool off when they enter Earth's shadow? Explain.

51. A Thermos bottle is usually constructed from two nested glass containers with a vacuum between them, as shown in the figure. The walls are usually silvered as well. How does this construction minimize the loss of thermal energy?

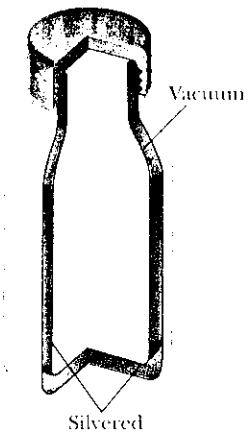
52. Will a Thermos bottle (shown in the figure) keep something cold as well as it keeps it hot? Explain.

53. The metal roof on a wooden shed makes noises when a cloud passes in front of the Sun. Why?

54. Why might a glass dish taken from the oven and put into cold water shatter?

***55.** Suppose the column in an alcohol-in-glass thermometer is not uniform. How would the spacing between the degrees on a wide portion of the thermometer compare with those on a narrow portion?

***56.** When a mercury thermometer is first put into hot water, the level of the mercury drops slightly before it begins to climb. Why?



Questions 51 and 52

EXERCISES

1. How much heat is required to raise the temperature of 500 g of water from 20°C to 30°C?

2. If the temperature of 600 g of water drops by 8°C, how much heat is released?

***3.** How much work is required to push a crate with a force of 200 N across a floor a distance of 4 m? How many calories of thermal energy does the friction produce?

***4.** How many calories are released to the surroundings when 100 g of lead shot falls from a height of 50 cm and doesn't bounce?

***5.** A physics student foolishly wants to lose weight by drinking cold water. If he drinks 1 L (1000 cm^3) of water at 10°C below body temperature, how many Calories will it take to warm the water?

6. A typical jogger burns up food energy at the rate of about 40 kJ per minute. How long would it take to run off a piece of cake if it contains 400 Calories?

7. During a process, 28 J of heat are transferred into a system, while the system itself does 12 J of work. What is the change in the internal energy of the system?

8. If the internal energy of an ideal gas increases by 150 J when 240 J of work are done to compress it, how much heat is released?

9. It takes 250 cal to raise the temperature of a metallic ring from 20°C to 30°C. If the ring has a mass of 90 g, what is the specific heat of the metal?

10. If it takes 3400 cal to raise the temperature of a 500-g statue by 44°C, what is the specific heat of the material used to make the statue?

11. How many calories will it take to raise the temperature of a 50-g gold chain from 20°C to 100°C?

12. How many calories would it take to raise the temperature of a 300-g aluminum pan from 293 K to 373 K?

13. Six grams of liquid X at 35°C are added to 3 grams of liquid Y at 20°C. The specific heat of liquid X is 2 cal/g · °C, and the specific heat of liquid Y is 1 cal/g · °C. If each gram of liquid X gives up two calories to liquid Y, find the change in temperature of each liquid.

14. In Exercise 13, imagine that liquid X continues to transfer energy to the other liquid 12 calories at a time. How many transfers would be required to reach a common temperature? What is this equilibrium temperature?

15. Eighty grams of water at 70°C are mixed with an equal amount of water at 30°C in a completely insulated container. The final temperature of the water is 50°C.
- **a.** How much heat is lost by the hot water?
- **b.** How much heat is gained by the cold water?
- **c.** What happens to the total amount of internal energy of the system?

***16.** If 200 g of water at 100°C are mixed with 300 g of water at 50°C in a completely insulated container, what is the final equilibrium temperature?

17. A kettle containing 3 kg of water has just reached its boiling point. How much energy, in joules, is required to boil the kettle dry?

18. How much heat would it take to melt a 1-kg block of ice?

19. You wish to melt a 3-kg block of aluminum, which is initially at 20°C. How much energy, in joules, is required to