Ch 14 (5th ed)

CONCEPTUAL QUESTIONS

1. What does a heat engine do?

2. In a heat engine, 140 joules of energy are extracted from a hot region. According to the first law of thermodynamics, what is the maximum amount of work that can be done by this engine? Is this result consistent with the second law of thermodynamics? Explain.

3. Why is it not possible to run an ocean liner by taking in seawater at the bow of the ship, extracting internal energy from the water, and dropping ice cubes off the stern?

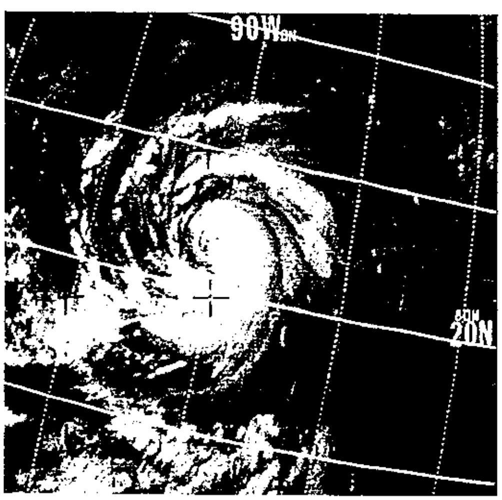
4. One possible end to the universe is for it to reach thermal equilibrium; that is, it would have a uniform temperature. Would this temperature be absolute zero? Explain.

5. In an ideal heat engine, 1000 joules of energy are extracted from the hot region at 800 K. One of the laws of thermodynamics requires that if the cold region is at 320 K, the engine must exhaust 400 joules of energy. Which law of thermodynamics requires this?

6. If the ideal heat engine used in Question 5 must exhaust 400 joules of energy, one of the laws of thermodynamics indicates that the engine can do no more than 600 joules of useful work. Which law of thermodynamics indicates this?

7. It is possible to float heat engines on the ocean and extract some of the internal energy of the water by extending a tube well beneath the ocean's surface. Why is it necessary for the heat engine to have this tube in order to satisfy the second law of thermodynamics?

8. A hurricane can be thought of as a heat engine that converts thermal energy from the ocean to the mechanical motion of its winds. Use this idea to explain why the wind speeds decrease as the hurricane moves away from the equator.



U.S. Environmental Science Services Administration

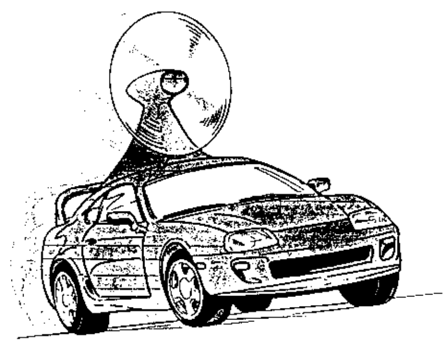
9. Many people have tried to build perpetual motion machines. What restrictions does the first law of thermodynamics place on the possibility of building a perpetual motion machine?

10. What restrictions does the second law of thermodynamics place on the possibility of building a perpetual motion machine?

11. Explain how the following simplified statements of the first and second laws of thermodynamics are consistent with the versions given in this chapter.

First: You cannot get ahead.
Second: You cannot even break even.

12. A student proposes to run an automobile without using any fuel. He says that he will build a windmill on top of the car. The car's motion will cause the windmill to rotate and generate electricity. The electricity will run a motor, maintaining the car's motion, which in turn causes the windmill to rotate. Can you see anything wrong with his proposal?



13. What happens to the efficiency of an ideal heat engine as its input temperature is increased while its exhaust temperature is held fixed?

14. If the input temperature of an ideal heat engine is fixed, what happens to its efficiency as its exhaust temperature is increased?

15. Heat engine A operates between 20°C and 300°C, whereas heat engine B operates between 80°C and 300°C. Which engine has the greater possible theoretical efficiency? Explain.

16. You are building a heat engine in which the temperature difference between the hot and cold regions is 100 K. Will it be more efficient to have your cold region as cold as possible or as hot as possible? Why?

17. An engineer claims that she could build a more efficient automobile engine if the materials science division could develop piston materials that could withstand higher operating temperatures. Why would this help?

18. A car company has just designed an ultra-fuel-efficient car, and they wish to advertise the best possible miles per gallon. If the engine can be thought of as a heat engine with a constant operating temperature, would it be better to run the trial on a hot day or a cold day? Why?

19. How is the following statement equivalent to the heat-engine form of the second law of thermodynamics? The efficiency of a heat engine must be less than 1.

*20. With his paddle-wheel apparatus, Joule determined that 4.2 joules of mechanical work were equivalent to 1 calorie of heat. Imagine that he had mistakenly used a heat engine instead and had measured the heat flowing into the engine and the work done by the engine to determine the conversion factor. Would this have produced a conversion factor for 1 calorie that was greater than, equal to, or less than 4.2 joules? Why?

21. You are installing a central air-conditioning system in which the main unit sits outside your home. For maximum cooling, should you locate the unit on the sunny or the shady side of the house? Why?

22. Bob moves into a new home that is heated with an electric heat pump. He decides that because no heat pump can be perfectly efficient, he will disconnect the heat pump and use the electricity to run a baseboard heater instead. Will Bob's energy bill increase, remain the same, or decrease? Why?

23. Would it be possible to keep a room cool by leaving the door of the refrigerator open? Why or why not?

24. An air-conditioner mechanic is testing a unit by running it on the workbench in an isolated room. What happens to the temperature of the room?

25. A salesperson tries to sell you a "new and improved" air conditioner that does not need a window opening. The unit just sits in the corner of the room and keeps it cool. Use the second law of thermodynamics to convince the salesperson that this will not work.

26. Imagine you are heating your home with a heat pump that uses a small amount of work to transfer heat from the cold outside air to the warm inside air. Your friend suggests that you set up a second heat engine using the air inside the house as the hot region and the outside air as the cold region to provide the necessary work to drive the heat pump. Which law or laws of thermodynamics does this money-saving scheme violate?

27. In what way is the following statement equivalent to the refrigerator form of the second law of thermodynamics? The natural direction for the flow of heat is from hotter objects to colder objects.

28. Is the following statement equivalent to the refrigerator form of the second law of thermodynamics? In moving energy from a cold region to a hot region, the energy delivered to the hot region must be the sum of the work performed plus the energy extracted from the cold region. Explain your reasoning.

29. The coefficient of performance for a refrigerator is defined as the ratio of the heat extracted from the colder system to the work required. Will this number be greater than, equal to, or less than one for a good refrigerator? Explain.

30. Why is the efficiency of a heat engine always less than 1, whereas the coefficient of performance for a heat pump is not so constrained?

31. You have two friends who always play the state lottery. Janice's strategy is to always select last week's winning number for this week's draw. In contrast, Jeremy has researched the winning number combinations for the last ten years and always selects a combination that has not yet won. Which strategy, if either, is more likely to be a winner? Explain.

32. You watch a friend flipping coins and notice that heads has come up four times in a row. Does this mean that it is more likely that tails will come up on the next throw? Explain.

*33. What sums of two dice have the highest and lowest order?

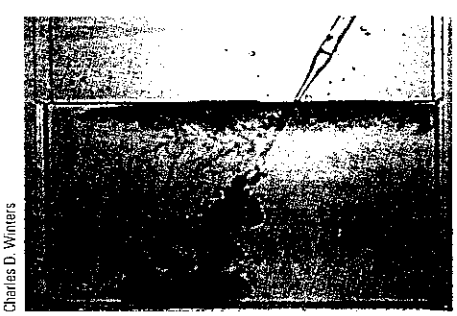
*34. What sums of three dice have the highest order?

35. Your friend challenges that, given 25 chances to roll two dice, you cannot roll a sum of 7 at least three times. Should you accept the challenge? Why or why not?

36. On average, how many times would you expect to roll "boxcars" (a pair of sixes) with two dice if you rolled the dice a total of 180 times?

37. One end of a steel bar is held over a flame until it is red hot. We know from Chapter 13 that when the bar is removed from the flame, the thermal energy will diffuse along the bar until the entire bar has the same equilibrium temperature. Use a microscopic model to explain why the bar's entropy (that is, its disorder) is increasing during this equilibration process.

38. What happens to the entropy of the universe as the orange liquid diffuses into the clear liquid?



Charles D. Winters

39. What happens to the entropy of the universe as an ice cube melts in water?

40. A cold piece of metal is dropped into an insulated container of hot water. After the system has reached an equilibrium temperature, has the entropy of the universe increased or decreased? Explain.

*41. Describe a system in which the entropy is decreasing. Is this system isolated from its surroundings?

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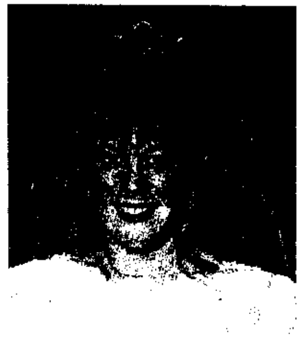
Pearl Levi



Courtesy of Anne Sherman

42. What happens to the entropy of a human as it grows from childhood to adulthood? Is this consistent with the second law of thermodynamics? Explain.

43. When water freezes to ice, does the order of the water molecules increase or decrease? What does this imply about the change in entropy in the rest of the universe?

44. A ringing bell is inserted into a large glass of water. The bell and the water are initially at the same temperature and are insulated from their surroundings. Eventually, the bell stops vibrating, and the water comes to rest.
   a. What happens to the mechanical energy of the bell?
   b. What happens to the temperature of the system?
   c. What happens to the entropy of the system?

45. If you slide a crate across the floor, kinetic energy is converted to thermal energy as it comes to rest. Why will adding thermal energy to a stationary crate not cause it to move?

*46. Are Mexican jumping beans a violation of the second law of thermodynamics? Explain.

47. Imagine that you could film the motion of the gas molecules in the room. Would you be able to tell whether the film was running forward or backward? Would it make a difference if air were being released from a balloon? Explain.

48. You have an aquarium with a divider down the middle. One side is filled with hot water, and the other is filled with cold water. Imagine that as the divider is removed you can film the individual collisions between water molecules. When watching the film, how could you tell whether it was running forward or backward?

49. Which of the following statements explains why we are currently experiencing a worldwide energy crisis?
   a. The amount of energy in the world is decreasing rapidly.
   b. The entropy of the world is increasing rapidly.
   c. The entropy of the world is decreasing rapidly.

50. How does slowing the increase in entropy help solve the world's energy crisis?

51. Which results in the larger increase in the entropy of the universe: heating a liter of room-temperature water to boiling using natural gas or using electricity? Why?

52. Why is heating water on a gas stove more efficient than heating it on an electric stove?

53. It is the middle of winter, and you live in a house with electric baseboard heating. Your friend chides you for being wasteful for turning on the oven to 400°F for 45 minutes just to cook a single baked potato. How do you respond?

54. Since childhood we've been told to turn out the lights when we leave a room. Does this really reduce the electric bill during the winter for a house with electric heating? Why?

EXERCISES

1. What input energy is required if an engine performs 300 kJ of work and exhausts 400 kJ of heat?

2. How much work is performed by a heat engine that takes in 2000 J of heat and exhausts 800 J?

3. An engine takes in 9000 cal of heat and exhausts 4000 cal of heat each minute it is running. How much work does the engine perform each minute?

4. A heat engine requires an input of 10 kJ per minute to produce 3 kJ of work per minute. How much heat must the engine exhaust per minute?

5. What is the efficiency of a heat engine that does 50 J of work for every 200 J of heat it takes in?

6. An engine exhausts 1200 J of energy for every 3600 J of energy it takes in. What is its efficiency?

7. An engine has an efficiency of 40%. How much energy must be extracted to do 900 J of work?

*8. An engine operates with an efficiency of 25%. If the engine does 600 J of work every minute, how many joules per minute are exhausted to the cold region?

9. An engineer has designed a machine to produce electricity by using the difference in the temperature of ocean water at different depths. If the surface temperature is 20°C and the temperature at 50 m below the surface is 12°C, what is the maximum efficiency of this machine?

10. A heat engine takes in 1000 J of energy at 1000 K and exhausts 600 J at 500 K. What are the actual and maximum theoretical efficiencies of this heat engine?

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11. An ideal heat engine has a theoretical efficiency of 60% and an exhaust temperature of 27°C. What is its input temperature?

12. What is the exhaust temperature of an ideal heat engine that has an efficiency of 50% and an input temperature of 400°C?

13. How much work is required by a refrigerator that takes in 1000 J from the cold region and exhausts 1800 J to the hot region?

14. A refrigerator uses 600 J of work to remove 1800 J of heat from a room. How much heat does it exhaust?

15. How much work per second (power) is required by a refrigerator that takes 800 J of thermal energy from a cold region each second and exhausts 1500 J to a hot region?

16. A heat pump requires 500 W of electrical power to deliver heat to your house at a rate of 2400 J per second. How many joules of energy are extracted from the cold air outside each second?

17. The coefficient of performance for a heat pump is defined as the ratio of the heat extracted from the colder system to the work required. If a heat pump requires an input of 400 W of electrical energy and has a coefficient of performance of 3, how much energy is delivered to the inside of the house each second?

18. If a refrigerator requires an input of 200 J of electrical energy each second and has a coefficient of performance of 5, how much heat energy is extracted from the refrigerator each second?

19. Show that four coins can be arranged in 16 different ways.

20. Show that the combination of four coins with the lowest order (two heads and two tails) is the one with the largest number of arrangements.

21. What is the probability of rolling a total of 6 with two dice?

22. What is the probability of rolling a sum of 10 with two dice?

23. The total number of possible states for three dice is $6 \times 6 \times 6 = 216$. What is the probability of throwing a sum equal to 5?

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