For homework assigned on MasteringPhysics, go to www.masteringphysics.com | BIO Biology and/or medical-related problems C Computer problems

For Thought and Discussion

1. Could you cool the kitchen by leaving the refrigerator open? Explain.
2. Could you heat the kitchen by leaving the oven open? Explain.
3. Should a car get better mileage in the summer or the winter? Explain.
4. Is there a limit to the maximum temperature that can be achieved by focusing sunlight with a lens? If so, what is it?
5. Name some irreversible processes that occur in a real engine.
6. Your power company claims that electric heat is 100% efficient. Discuss.
7. A hydroelectric power plant, using the energy of falling water, can operate with efficiency arbitrarily close to 100%. Why?
8. A heat-pump manufacturer claims the device will heat your home using only energy already available in the ground. Is this true?
9. Why do refrigerators and heat pumps have different definitions of COP?
10. The heat Q added during adiabatic free expansion is zero. Why can't we then argue from Equation 19.6 that the entropy change is zero?
11. Energy is conserved, so why can't we recycle it as we do materials?
12. Why doesn't the evolution of human civilization violate the second law of thermodynamics?

Exercises and Problems

Exercises

Sections 19.2 and 19.3 The Second Law of Thermodynamics and Its Applications

13. What are the efficiencies of reversible heat engines operating between (a) the normal freezing and boiling points of water, (b) the 25°C temperature at the surface of a tropical ocean and deep water at 4°C, and (c) a 1000°C flame and room temperature?
14. A cosmic heat engine might operate between the Sun's 5600 K surface and the 2.7 K temperature of intergalactic space. What would be its maximum efficiency?
15. A reversible Carnot engine operating between helium's melting point and its 4.25 K boiling point has an efficiency of 77.7%. What's the melting point?
16. A Carnot engine absorbs 900 J of heat each cycle and provides 350 J of work. (a) What's its efficiency? (b) How much heat is rejected each cycle? (c) If the engine rejects heat at 10°C, what's its maximum temperature?
17. Find the COP of a reversible refrigerator operating between 0°C and 30°C.
18. How much work does a refrigerator with COP = 4.2 require to freeze 670 g of water already at its freezing point?
19. BIO The human body can be 25% efficient at converting chemical energy of fuel to mechanical work. Can the body be considered a heat engine, operating on the temperature difference between body temperature and the environment?

Section 19.4 Entropy and Energy Quality

20. Calculate the entropy change associated with melting 1.0 kg of ice at 0°C.
21. BIO You metabolize a 650-kcal burger at your 37°C body temperature. What's the associated entropy increase?
22. You heat 250 g of water from 10°C to 95°C. By how much does the entropy of the water increase?
23. Melting a block of lead already at its melting point results in an entropy increase of 900 J/K. What's the mass of the lead? (*Hint:* Consult Table 17.1.)
24. How much energy becomes unavailable for work in an isothermal process at 440 K, if the entropy increase is 25 J/K?
25. For a gas of 6 molecules confined to a box, find the probability that (a) all the molecules will be found on one side of the box and (b) half the molecules will be found on each side.

Problems

26. A Carnot engine extracts 890 J from a 550 K reservoir during each cycle and rejects 470 J to a cooler reservoir. It operates at 22 cycles per second. Find (a) the work done during each cycle, (b) its efficiency, (c) the temperature of the cool reservoir, and (d) its mechanical power output.
27. The maximum steam temperature in a nuclear power plant is 570 K. The plant rejects heat to a river whose temperature is 0°C in the winter and 25°C in the summer. What are the maximum possible efficiencies for the plant during these seasons?
28. You're engineering an energy-efficient house that will require an average of 4.6 kW to heat on cold winter days. You've designed a photovoltaic system for electric power, which will supply on average 2.0 kW. You propose to heat the house with an electrically operated groundwater-based heat pump. What should you specify as the minimum acceptable COP for the pump if the photovoltaic system supplies its energy?
29. A power plant's electrical output is 750 MW. Cooling water at 15°C flows through the plant at 2.8×10^4 kg/s, and its temperature rises by 8.5°C. Assuming that the plant's only energy loss is to the cooling water, which serves as its low-temperature reservoir, find (a) the rate of energy extraction from the fuel, (b) the plant's efficiency, and (c) its highest temperature.
30. A power plant extracts energy from steam at 250°C and delivers 800 MW of electric power. It discharges waste heat to a river at 30°C. The plant's overall efficiency is 28%. (a) How does this efficiency compare with the maximum possible at these temperatures? (b) Find the rate of waste-heat discharge to the river. (c) How many houses, each requiring 18 kW of heating power, could be heated with the waste heat from this plant?
31. The electric power output of all the thermal electric power plants in the United States is about 2×10^{11} W, and these plants operate at an average efficiency of around 33%. Find the rate at which all these plants use cooling water, assuming an average 5°C rise in cooling-water temperature. Compare with the 1.8×10^7 kg/s average flow at the mouth of the Mississippi River.
32. Consider a Carnot engine operating between temperatures T_h and T_i, where T_i is intermediate between T_h and the ambient temperature T_c (Fig. 19.21). It should be possible to operate a second engine between T_i and T_c. Show that the maximum overall

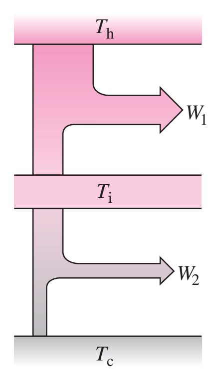

FIGURE 19.21 Problem 32

efficiency of such a two-stage engine is the same as that of a single engine operating between T_h and T_c (which is why combined-cycle power plants achieve high efficiencies).

33. An industrial freezer operates between 0°C and 32°C, consuming electrical energy at the rate of 12 kW. Assuming the freezer is perfectly reversible, (a) what's its COP? (b) How much water at 0°C can it freeze in 1 hour?

34. Use appropriate energy-flow diagrams to analyze the situation in Got It? 19.2; that is, show that using a refrigerator to cool the low-temperature reservoir can't increase the overall efficiency of a Carnot engine when the work input to the refrigerator is included.

35. It costs \$180 to heat a house with electricity in a typical winter month. (Electric heat simply converts all the incoming electrical energy to heat.) What would the monthly heating bill be after switching to an electrically powered heat-pump system with COP = 3.1?

36. A refrigerator maintains an interior temperature of 4°C while its exhaust temperature is 30°C. The refrigerator's insulation is imperfect, and heat leaks in at the rate of 340 W. Assuming the refrigerator is reversible, at what rate must it consume electrical energy to maintain a constant 4°C interior?

37. You operate a store that's heated by an oil furnace supplying 30 kWh of heat from each gallon of oil. You're considering switching to a heat-pump system. Oil costs \$1.75/gallon, and electricity costs 16.5¢/kWh. What's the minimum heat-pump COP that will reduce your heating costs?

38. Use energy-flow diagrams to show that the existence of a perfect heat engine would permit the construction of a perfect refrigerator, thus violating the Clausius statement of the second law.

39. A heat pump extracts energy from groundwater at 10°C and transfers it to water at 70°C to heat a building. Find (a) its COP and (b) its electric power consumption if it supplies heat at the rate of 20 kW. (c) Compare the pump's hourly operating cost with that of an oil furnace if electricity costs 15.5¢/kWh and oil costs \$2.60/gallon and releases about 30 kWh/gal when burned.

40. A reversible engine contains 0.20 mol of ideal monatomic gas, initially at 600 K and confined to 2.0 L. The gas undergoes the following cycle:

- Isothermal expansion to 4.0 L
- Isovolumic cooling to 300 K
- Isothermal compression to 2.0 L
- Isovolumic heating to 600 K

(a) Calculate the net heat added during the cycle and the net work done. (b) Determine the engine's efficiency, defined as the ratio of the work done to the heat *absorbed* during the cycle.

41. (a) Determine the efficiency for the cycle shown in Fig. 19.22, using the definition given in the preceding problem. (b) Compare with the efficiency of a Carnot engine operating between the same temperature extremes. Why are the two efficiencies different?

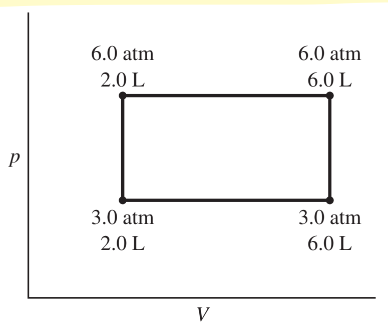

FIGURE 19.22 Problem 41

42. A 0.20-mol sample of an ideal gas goes through the Carnot cycle of Fig. 19.23. Calculate (a) the heat Q_h absorbed, (b) the heat Q_c rejected, and (c) the work done. (d) Use these quantities to determine the efficiency. (e) Find the maximum and minimum temperatures, and show explicitly that the efficiency as defined in Equation 19.1 is equal to the Carnot efficiency of Equation 19.3.

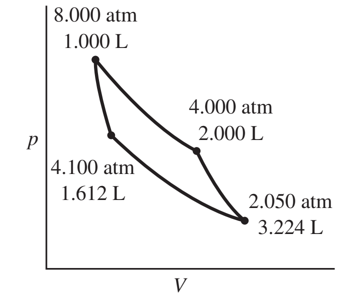

FIGURE 19.23 Problem 42

43. A shallow pond contains 94 Mg of water. In winter, it's entirely frozen. By how much does the entropy of the pond increase when the ice, already at 0°C, melts and then heats to its summer temperature of 15°C?

44. Estimate the rate of entropy increase associated with your body's
BIO normal metabolism.

45. The temperature of n moles of ideal gas is changed from T_1 to T_2 at constant volume. Show that the corresponding entropy change is $\Delta S = nC_V \ln(T_2/T_1)$.

46. The temperature of n moles of ideal gas is changed from T_1 to T_2 with pressure held constant. Show that the corresponding entropy change is $\Delta S = nC_p \ln(T_2/T_1)$.

47. A 5.0-mol sample of an ideal diatomic gas is at 1.0 atm pressure and 300 K. Find the entropy change if the gas is heated to 500 K (a) at constant volume, (b) at constant pressure, and (c) adiabatically.

48. A 250-g sample of water at 80°C is mixed with 250 g of water at 10°C. Find the entropy changes for (a) the hot water, (b) the cool water, and (c) the system.

49. An ideal gas undergoes a process that takes it from pressure p_1 and volume V_1 to p_2 and V_2, such that $p_1V_1^\gamma = p_2V_2^\gamma$, where γ is the specific heat ratio. Find the entropy change if the process consists of constant-pressure and constant-volume segments. Why does your result make sense?

50. In an adiabatic free expansion, 8.7 mol of ideal gas at 288 K expand 10-fold in volume. How much energy becomes unavailable to do work?

51. Find the entropy change when a 2.4-kg aluminum pan at 155°C is plunged into 3.5 kg of water at 15°C.

52. An engine with mechanical power output 8.5 kW extracts heat from a source at 420 K and rejects it to a 1000-kg block of ice at its melting point. (a) What's its efficiency? (b) How long can it maintain this efficiency if the ice isn't replenished?

53. Gasoline engines operate approximately on the Otto cycle, consisting of two adiabatic and two constant-volume segments. Figure 19.24 shows the Otto cycle for a particular engine. (a) If

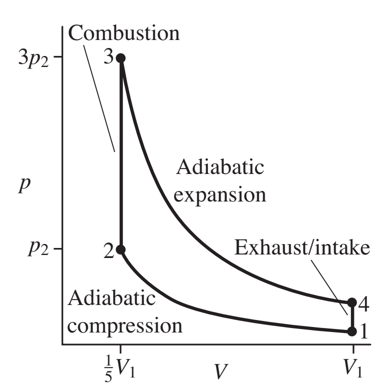

FIGURE 19.24 Problem 53

the gas in the engine has specific heat ratio γ, find the engine's efficiency, assuming all processes are reversible. (b) Find the maximum temperature in terms of the minimum temperature T_{min}. (c) How does the efficiency compare with that of a Carnot engine operating between the same temperature extremes?

54. The compression ratio r of an engine is the ratio of maximum to minimum gas volume. For the engine of the preceding problem, Fig. 19.24 shows that the compression ratio is 5. Find an expression for the engine's efficiency as a function of compression ratio, assuming that pressure continues to triple during the combustion phase.
55. The 54-MW wood-fired McNeil Generating Station in Burlington, Vermont, produces steam at 950°F to drive its turbines, and condensed steam returns to the boiler as 90°F water. (Note the temperatures in °F, used in U.S. engineering situations.) Find McNeil's maximum thermodynamic efficiency, and compare with its actual efficiency of 25%.
56. A 500-g copper block at 80°C is dropped into 1.0 kg of water at 10°C. Find (a) the final temperature and (b) the entropy change of the system.
57. An object's heat capacity is inversely proportional to its absolute temperature: $C = C_0(T_0/T)$, where C_0 and T_0 are constants. Find the entropy change when the object is heated from T_0 to T_1.
58. A Carnot engine extracts heat from a block of mass m and specific heat c initially at temperature T_{h0} but without a heat source to maintain that temperature. The engine rejects heat to a reservoir at constant temperature T_{c}. The engine is operated so its mechanical power output is proportional to the temperature difference $T_{\text{h}} - T_{\text{c}}$:
$$P = P_0\frac{T_{\text{h}} - T_{\text{c}}}{T_{\text{h0}} - T_{\text{c}}}$$
where T_{h} is the instantaneous temperature of the hot block and P_0 is the initial power. (a) Find an expression for T_{h} as a function of time, and (b) determine how long it takes for the engine's power output to reach zero.
59. In an alternative universe, you've got the impossible: an infinite heat reservoir, containing infinite energy at temperature T_{h}. But you've only got a finite cool reservoir, with initial temperature T_{c0} and heat capacity C. Find an expression for the maximum work you can extract if you operate an engine between these two reservoirs.
60. You're the environmental protection officer for a 35% efficient nuclear power plant that produces 750 MW of electric power, situated on a river whose minimum flow rate is 110 m^3/s. State environmental regulations limit the rise in river temperature from your plant's cooling system to 5°C. Can you achieve this standard if you use river water for all your cooling, or will you need to install cooling towers that transfer some of your waste heat to the atmosphere?
61. Find an expression for the entropy gain when hot and cold water are irreversibly mixed. A corresponding reversible process you can use to calculate this change is to bring each water sample slowly to their common final temperature T_{f} and then mix them. Express your answer in terms of the initial temperatures T_{h} and T_{c}. Assume equal masses of hot and cold water, with constant specific heat c. What's the sign of your answer?
62. Problem 74 of Chapter 16 provided an approximate expression for the specific heat of copper at low absolute temperatures: $c = 31(T/343\text{ K})^3$ J/kg·K. Use this to find the entropy change when 40 g of copper are cooled from 25 K to 10 K. Why is the change negative?
63. The molar specific heat at constant pressure for a certain gas is given by $C_p = a + bT + cT^2$, where $a = 33.6$ J/mol·K, $b = 2.93\times10^{-3}$ J/mol·K^2, and $c = 2.13\times10^{-5}$ J/mol·K^3. Find the entropy change when 2 moles of this gas are heated from 20°C to 200°C.
64. Consider a gas containing an even number N of molecules, distributed among the two halves of a closed box. Find expressions for (a) the total number of microstates and (b) the number of microstates with half the molecules on each side of the box. (You can either work out a formula, or explore the term "combinations" in a math reference source.) (c) Use these results to find the ratio of the probability that all the molecules will be found on one side of the box to the probability that there will be equal numbers on both sides. (d) Evaluate for $N = 4$ and $N = 100$.

Passage Problems

Refrigerators remain among the greatest consumers of electrical energy in most homes, although mandated efficiency standards have decreased their energy consumption by some 80% in the past four decades. In the course of a day, one kitchen refrigerator removes 30 MJ of energy from its contents, in the process consuming 10 MJ of electrical energy. The electricity comes from a 40% efficient coal-fired power plant.

65. The electrical energy
    a. is used to run the light bulb inside the refrigerator.
    b. wouldn't be necessary if the refrigerator had enough insulation.
    c. retains its high-quality status after the refrigerator has used it.
    d. ends up as waste heat rejected to the kitchen environment.
66. The refrigerator's COP is
    a. $\frac{1}{3}$.
    b. 2.
    c. 3.
    d. 4.
67. The fuel energy consumed at the power plant to run this refrigerator for the day is
    a. 12 MJ.
    b. 25 MJ.
    c. 40 MJ.
    d. 75 MJ.
68. The total energy rejected to the surrounding kitchen during the course of the day is
    a. 10 MJ.
    b. 30 MJ.
    c. 40 MJ.
    d. 75 MJ.

Answers to Chapter Questions

Answer to Chapter Opening Question

The second law of thermodynamics prevents us from converting thermal energy to mechanical energy with 100% efficiency, and practical limits on temperature make it hard to achieve 50% efficiency in conventional power plants.

Answers to GOT IT? Questions

19.1. (a), (c), and (f).
19.2. (c); see Problem 34 for a proof.
19.3. (a) increase; (b) decrease; (c) increase; (d) increase; (e) decrease; (f) increase; (g) increase.