## PROBLEM SOLVING Thermodynamics

1. Define the **system** you are dealing with; distinguish the system under study from its surroundings.
2. When applying the first law of thermodynamics, be careful of **signs** associated with **work** and **heat**. In the first law, work done *by* the system is positive; work done *on* the system is negative. Heat *added* to the system is positive, but heat *removed* from it is negative. With heat engines, we usually consider the heat intake, the heat exhausted, and the work done as positive.
3. Watch the **units** used for work and heat; work is most often expressed in joules, and heat can be in calories, kilocalories, or joules. Be consistent: choose only one unit for use throughout a given problem.
4. **Temperatures** must generally be expressed in kelvins; temperature *differences* may be expressed in C° or K.
5. **Efficiency** (or coefficient of performance) is a ratio of two energy transfers: useful output divided by required input. Efficiency (but *not* coefficient of performance) is always less than 1 in value, and hence is often stated as a percentage.
6. The **entropy** of a system increases when heat is added to the system, and decreases when heat is removed. If heat is transferred from system A to system B, the change in entropy of A is negative and the change in entropy of B is positive.

# Summary


The **first law of thermodynamics** states that the change in internal energy $\Delta U$ of a system is equal to the heat *added* to the system, $Q$, minus the work done *by* the system, $W$:

$$\Delta U = Q - W. \tag{15–1}$$

This is a statement of the conservation of energy, and is found to hold for all types of processes.

An **isothermal** process is a process carried out at constant temperature.

In an **adiabatic** process, no heat is exchanged ($Q = 0$).

The work $W$ done by a gas at constant pressure $P$ is given by

$$W = P\,\Delta V, \tag{15–3}$$

where $\Delta V$ is the change in volume of the gas.

A **heat engine** is a device for changing thermal energy, by means of heat flow between two temperatures, into useful work.

The **efficiency** $e$ of a heat engine is defined as the ratio of the work $W$ done by the engine to the heat input $Q_H$. Because of conservation of energy, the work output equals $Q_H - Q_L$, where $Q_L$ is the heat exhausted at low temperature to the environment; hence

$$e = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}. \tag{15–4}$$

The *upper limit* on the efficiency (the *Carnot efficiency*) can be written in terms of the higher and lower operating temperatures (in kelvins) of the engine, $T_H$ and $T_L$, as

$$e_{ideal} = 1 - \frac{T_L}{T_H}. \tag{15–5}$$

The operation of **refrigerators** and **air conditioners** is the reverse of that of a heat engine: work is done to extract heat from a cool region and exhaust it to a region at a higher temperature. The coefficient of performance (COP) for either is

$$\text{COP} = \frac{Q_L}{W}, \qquad \begin{bmatrix}\text{refrigerator or}\\ \text{air conditioner}\end{bmatrix} \tag{15–6a}$$

where $W$ is the work needed to remove heat $Q_L$ from the area with the low temperature.

A **heat pump** does work $W$ to bring heat $Q_L$ from the cold outside and deliver heat $Q_H$ to warm the interior. The coefficient of performance of a heat pump is

$$\text{COP} = \frac{Q_H}{W}. \qquad \text{[heat pump]} \tag{15–7}$$

The **second law of thermodynamics** can be stated in several equivalent ways:

(a) heat flows spontaneously from a hot object to a cold one, but not the reverse;

(b) there can be no 100% efficient heat engine—that is, one that can change a given amount of heat completely into work;

(c) natural processes tend to move toward a state of greater disorder or greater **entropy**.

Statement (*c*) is the most general statement of the second law of thermodynamics, and can be restated as: the total entropy, $S$, of any system plus that of its environment increases as a result of any natural process:

$$\Delta S > 0. \tag{15–9}$$

The change in entropy in a process that transfers heat $Q$ at a constant temperature $T$ is

$$\Delta S = \frac{Q}{T}. \tag{15–8}$$

Entropy is a quantitative measure of the disorder of a system.

As time goes on, energy is degraded to less useful forms—that is, it is less available to do useful work.

[*The second law of thermodynamics tells us in which direction processes tend to go, so entropy is called "time's arrow."]

[*All heat engines give rise to **thermal pollution** because they exhaust heat to the environment.]

## Questions

1. What happens to the internal energy of water vapor in the air that condenses on the outside of a cold glass of water? Is work done or heat exchanged? Explain.
2. Use the conservation of energy to explain why the temperature of a gas increases when it is quickly compressed, whereas the temperature decreases when the gas expands.
3. In an isothermal process, 3700 J of work is done by an ideal gas. Is this enough information to tell how much heat has been added to the system? If so, how much?
4. Is it possible for the temperature of a system to remain constant even though heat flows into or out of it? If so, give one or two examples.
5. Explain why the temperature of a gas increases when it is adiabatically compressed.
6. Can mechanical energy ever be transformed completely into heat or internal energy? Can the reverse happen? In each case, if your answer is no, explain why not; if yes, give one or two examples.
7. Can you warm a kitchen in winter by leaving the oven door open? Can you cool the kitchen on a hot summer day by leaving the refrigerator door open? Explain.
8. Would a definition of heat engine efficiency as $e = W/Q_L$ be useful? Explain.
9. What plays the role of high-temperature and low-temperature areas in (*a*) an internal combustion engine, and (*b*) a steam engine?
10. Which will give the greater improvement in the efficiency of a Carnot engine, a 10 C° increase in the high-temperature reservoir, or a 10 C° decrease in the low-temperature reservoir? Explain.
11. The oceans contain a tremendous amount of thermal (internal) energy. Why, in general, is it not possible to put this energy to useful work?
12. A gas is allowed to expand (*a*) adiabatically and (*b*) isothermally. In each process, does the entropy increase, decrease, or stay the same? Explain.
13. A gas can expand to twice its original volume either adiabatically or isothermally. Which process would result in a greater change in entropy? Explain.
14. Give three examples, other than those mentioned in this Chapter, of naturally occurring processes in which order goes to disorder. Discuss the observability of the reverse process.
15. Which do you think has the greater entropy, 1 kg of solid iron or 1 kg of liquid iron? Why?
16. (*a*) What happens if you remove the lid of a bottle containing chlorine gas? (*b*) Does the reverse process ever happen? Why or why not? (*c*) Can you think of two other examples of irreversibility?
17. You are asked to test a machine that the inventor calls an "in-room air conditioner": a big box, standing in the middle of the room, with a cable that plugs into a power outlet. When the machine is switched on, you feel a stream of cold air coming out of it. How do you know that this machine cannot cool the room?
18. Think up several processes (other than those already mentioned) that would obey the first law of thermodynamics, but, if they actually occurred, would violate the second law.
19. Suppose a lot of papers are strewn all over the floor; then you stack them neatly. Does this violate the second law of thermodynamics? Explain.
20. The first law of thermodynamics is sometimes whimsically stated as, "You can't get something for nothing," and the second law as, "You can't even break even." Explain how these statements could be equivalent to the formal statements.

* 21. Entropy is often called "time's arrow" because it tells us in which direction natural processes occur. If a movie were run backward, name some processes that you might see that would tell you that time was "running backward."

* 22. Living organisms, as they grow, convert relatively simple food molecules into a complex structure. Is this a violation of the second law of thermodynamics?

## Problems

### 15–1 and 15–2 First Law of Thermodynamics

1. (I) An ideal gas expands isothermally, performing $3.40 \times 10^3$ J of work in the process. Calculate (*a*) the change in internal energy of the gas, and (*b*) the heat absorbed during this expansion.
2. (I) A gas is enclosed in a cylinder fitted with a light frictionless piston and maintained at atmospheric pressure. When 1400 kcal of heat is added to the gas, the volume is observed to increase slowly from $12.0\,\text{m}^3$ to $18.2\,\text{m}^3$. Calculate (*a*) the work done by the gas and (*b*) the change in internal energy of the gas.
3. (I) One liter of air is cooled at constant pressure until its volume is halved, and then it is allowed to expand isothermally back to its original volume. Draw the process on a *PV* diagram.
4. (I) Sketch a *PV* diagram of the following process: 2.0 L of ideal gas at atmospheric pressure are cooled at constant pressure to a volume of 1.0 L, and then expanded isothermally back to 2.0 L, whereupon the pressure is increased at constant volume until the original pressure is reached.
5. (II) A 1.0-L volume of air initially at 4.5 atm of (absolute) pressure is allowed to expand isothermally until the pressure is 1.0 atm. It is then compressed at constant pressure to its initial volume, and lastly is brought back to its original pressure by heating at constant volume. Draw the process on a *PV* diagram, including numbers and labels for the axes.
6. (II) The pressure in an ideal gas is cut in half slowly, while being kept in a container with rigid walls. In the process, 265 kJ of heat left the gas. (*a*) How much work was done during this process? (*b*) What was the change in internal energy of the gas during this process?

7. (II) In an engine, an almost ideal gas is compressed adiabatically to half its volume. In doing so, 1850 J of work is done on the gas. (a) How much heat flows into or out of the gas? (b) What is the change in internal energy of the gas? (c) Does its temperature rise or fall?

8. (II) An ideal gas expands at a constant total pressure of 3.0 atm from 400 mL to 660 mL. Heat then flows out of the gas at constant volume, and the pressure and temperature are allowed to drop until the temperature reaches its original value. Calculate (a) the total work done by the gas in the process, and (b) the total heat flow into the gas.

9. (II) One and one-half moles of an ideal monatomic gas expand adiabatically, performing 7500 J of work in the process. What is the change in temperature of the gas during this expansion?

10. (II) Consider the following two-step process. Heat is allowed to flow out of an ideal gas at constant volume so that its pressure drops from 2.2 atm to 1.4 atm. Then the gas expands at constant pressure, from a volume of 6.8 L to 9.3 L, where the temperature reaches its original value. See Fig. 15–22. Calculate (a) the total work done by the gas in the process, (b) the change in internal energy of the gas in the process, and (c) the total heat flow into or out of the gas.

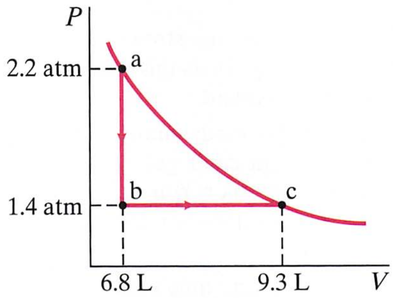


**FIGURE 15–22** Problem 10.

11. (II) The *PV* diagram in Fig. 15–23 shows two possible states of a system containing 1.35 moles of a monatomic ideal gas. ($P_1 = P_2 = 455\ \text{N/m}^2$, $V_1 = 2.00\ \text{m}^3$, $V_2 = 8.00\ \text{m}^3$.) (a) Draw the process which depicts an isobaric expansion from state 1 to state 2, and label this process A. (b) Find the work done by the gas and the change in internal energy of the gas in process A. (c) Draw the two-step process which depicts an isothermal expansion from state 1 to the volume $V_2$, followed by an isovolumetric increase in temperature to state 2, and label this process B. (d) Find the change in internal energy of the gas for the two-step process B.

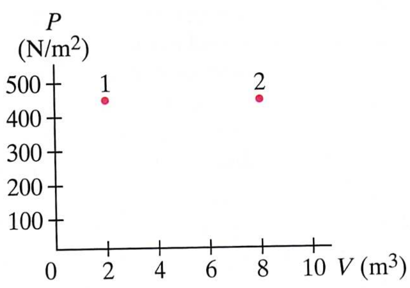


**FIGURE 15–23** Problem 11.

12. (III) When a gas is taken from a to c along the curved path in Fig. 15–24, the work done by the gas is $W = -35\ \text{J}$ and the heat added to the gas is $Q = -63\ \text{J}$. Along path abc, the work done is $W = -48\ \text{J}$. (a) What is $Q$ for path abc? (b) If $P_c = \frac{1}{2}P_b$, what is $W$ for path cda? (c) What is $Q$ for path cda? (d) What is $U_a - U_c$? (e) If $U_d - U_c = 5\ \text{J}$, what is $Q$ for path da?

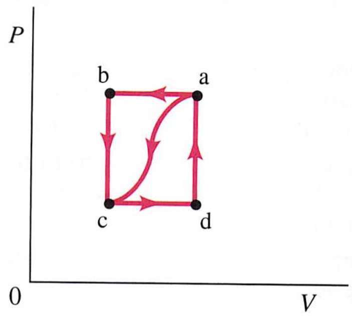


**FIGURE 15–24** Problems 12 and 13.

13. (III) In the process of taking a gas from state a to state c along the curved path shown in Fig. 15–24, 80 J of heat leaves the system and 55 J of work is done *on* the system. (a) Determine the change in internal energy, $U_a - U_c$. (b) When the gas is taken along the path cda, the work done by the gas is $W = 38\ \text{J}$. How much heat $Q$ is added to the gas in the process cda? (c) If $P_a = 2.5P_d$, how much work is done by the gas in the process abc? (d) What is $Q$ for path abc? (e) If $U_a - U_b = 10\ \text{J}$, what is $Q$ for the process bc? Here is a summary of what is given:

$$Q_{a\to c} = -80\ \text{J}$$
$$W_{a\to c} = -55\ \text{J}$$
$$W_{cda} = 38\ \text{J}$$
$$U_a - U_b = 10\ \text{J}$$
$$P_a = 2.5P_d.$$

## * 15–3 Human Metabolism

* 14. (I) How much energy would the person of Example 15–8 transform if instead of working 11.0 h she took a noontime break and ran for 1.0 h?

* 15. (I) Calculate the average metabolic rate of a person who sleeps 8.0 h, sits at a desk 8.0 h, engages in light activity 4.0 h, watches television 2.0 h, plays tennis 1.5 h, and runs 0.5 h daily.

* 16. (II) A person decides to lose weight by sleeping one hour less per day, using the time for light activity. How much weight (or mass) can this person expect to lose in 1 year, assuming no change in food intake? Assume that 1 kg of fat stores about 40,000 kJ of energy.

## 15–5 Heat Engines

17. (I) A heat engine exhausts 8200 J of heat while performing 3200 J of useful work. What is the efficiency of this engine?

18. (I) A heat engine does 9200 J of work per cycle while absorbing 22.0 kcal of heat from a high-temperature reservoir. What is the efficiency of this engine?

19. (I) What is the maximum efficiency of a heat engine whose operating temperatures are 580°C and 380°C?

20. (I) The exhaust temperature of a heat engine is 230°C. What must be the high temperature if the Carnot efficiency is to be 28%?

21. (II) A nuclear power plant operates at 75% of its maximum theoretical (Carnot) efficiency between temperatures of 625°C and 350°C. If the plant produces electric energy at the rate of 1.3 GW, how much exhaust heat is discharged per hour?

22. (II) It is not necessary that a heat engine's hot environment be hotter than ambient temperature. Liquid nitrogen (77 K) is about as cheap as bottled water. What would be the efficiency of an engine that made use of heat transferred from air at room temperature (293 K) to the liquid nitrogen "fuel" (Fig. 15–25)?


**FIGURE 15–25** Problem 22.

23. (II) A Carnot engine performs work at the rate of 440 kW while using 680 kcal of heat per second. If the temperature of the heat source is 570°C, at what temperature is the waste heat exhausted?

24. (II) A Carnot engine's operating temperatures are 210°C and 45°C. The engine's power output is 950 W. Calculate the rate of heat output.

25. (II) A certain power plant puts out 550 MW of electric power. Estimate the heat discharged per second, assuming that the plant has an efficiency of 38%.

26. (II) A heat engine utilizes a heat source at 550°C and has an ideal (Carnot) efficiency of 28%. To increase the ideal efficiency to 35%, what must be the temperature of the heat source?

27. (II) A heat engine exhausts its heat at 350°C and has a Carnot efficiency of 39%. What exhaust temperature would enable it to achieve a Carnot efficiency of 49%?

28. (III) At a steam power plant, steam engines work in pairs, the output of heat from one being the approximate heat input of the second. The operating temperatures of the first are 670°C and 440°C, and of the second 430°C and 290°C. If the heat of combustion of coal is $2.8 \times 10^7$ J/kg, at what rate must coal be burned if the plant is to put out 1100 MW of power? Assume the efficiency of the engines is 60% of the ideal (Carnot) efficiency.

## 15–6 Refrigerators, Air Conditioners, Heat Pumps

29. (I) The low temperature of a freezer cooling coil is −15°C, and the discharge temperature is 30°C. What is the maximum theoretical coefficient of performance?

30. (II) An ideal refrigerator-freezer operates with a COP = 7.0 in a 24°C room. What is the temperature inside the freezer?

31. (II) A restaurant refrigerator has a coefficient of performance of 5.0. If the temperature in the kitchen outside the refrigerator is 29°C, what is the lowest temperature that could be obtained inside the refrigerator if it were ideal?

32. (II) A heat pump is used to keep a house warm at 22°C. How much work is required of the pump to deliver 2800 J of heat into the house if the outdoor temperature is (*a*) 0°C, (*b*) −15°C? Assume ideal (Carnot) behavior.

33. (II) What volume of water at 0°C can a freezer make into ice cubes in 1.0 hour, if the coefficient of performance of the cooling unit is 7.0 and the power input is 1.0 kilowatt?

34. (II) An ideal (Carnot) engine has an efficiency of 35%. If it were possible to run it backward as a heat pump, what would be its coefficient of performance?

## 15–7 Entropy

35. (I) What is the change in entropy of 250 g of steam at 100°C when it is condensed to water at 100°C?

36. (I) One kilogram of water is heated from 0°C to 100°C. Estimate the change in entropy of the water.

37. (I) What is the change in entropy of 1.00 $m^3$ of water at 0°C when it is frozen to ice at 0°C?

38. (II) If 1.00 $m^3$ of water at 0°C is frozen and cooled to −10°C by being in contact with a great deal of ice at −10°C, what would be the total change in entropy of the process?

39. (II) A 10.0-kg box having an initial speed of 3.0 m/s slides along a rough table and comes to rest. Estimate the total change in entropy of the universe. Assume all objects are at room temperature (293 K).

40. (II) A falling rock has kinetic energy KE just before striking the ground and coming to rest. What is the total change in entropy of the rock plus environment as a result of this collision?

41. (II) An aluminum rod conducts 7.50 cal/s from a heat source maintained at 240°C to a large body of water at 27°C. Calculate the rate entropy increases per unit time in this process.

42. (II) 1.0 kg of water at 30°C is mixed with 1.0 kg of water at 60°C in a well-insulated container. Estimate the net change in entropy of the system.

43. (II) A 3.8-kg piece of aluminum at 30°C is placed in 1.0 kg of water in a Styrofoam container at room temperature (20°C). Calculate the approximate net change in entropy of the system.

44. (III) A real heat engine working between heat reservoirs at 970 K and 650 K produces 550 J of work per cycle for a heat input of 2200 J. (*a*) Compare the efficiency of this real engine to that of an ideal (Carnot) engine. (*b*) Calculate the total entropy change of the universe per cycle of the real engine. (*c*) Calculate the total entropy change of the universe per cycle of a Carnot engine operating between the same two temperatures.

## * 15–11 Statistical Interpretation

* **45.** (II) Calculate the probabilities, when you throw two dice, of obtaining (*a*) a 5, and (*b*) an 11.

* **46.** (II) Rank the following five-card hands in order of increasing probability: (*a*) four aces and a king; (*b*) six of hearts, eight of diamonds, queen of clubs, three of hearts, jack of spades; (*c*) two jacks, two queens, and an ace; and (*d*) any hand having no two equal-value cards. Discuss your ranking in terms of microstates and macrostates.

* **47.** (II) Suppose that you repeatedly shake six coins in your hand and drop them on the floor. Construct a table showing the number of microstates that correspond to each macrostate. What is the probability of obtaining (*a*) three heads and three tails, and (*b*) six heads?

## * 15–12 Energy Resources

* **48.** (I) Solar cells (Fig. 15–26) can produce about 40 W of electricity per square meter of surface area if directly facing the Sun. How large an area is required to supply the needs of a house that requires 22 kWh/day? Would this fit on the roof of an average house? (Assume the Sun shines about 9 h/day.)

**FIGURE 15–26** Problem 48.

* **49.** (II) Energy may be stored for use during peak demand by pumping water to a high reservoir when demand is low and then releasing it to drive turbines when needed. Suppose water is pumped to a lake 135 m above the turbines at a rate of $1.00 \times 10^5$ kg/s for 10.0 h at night. (*a*) How much energy (kWh) is needed to do this each night? (*b*) If all this energy is released during a 14-h day, at 75% efficiency, what is the average power output?

* **50.** (II) Water is stored in an artificial lake created by a dam (Fig. 15–27). The water depth is 45 m at the dam, and a steady flow rate of 35 $m^3/s$ is maintained through hydroelectric turbines installed near the base of the dam. How much electrical power can be produced?

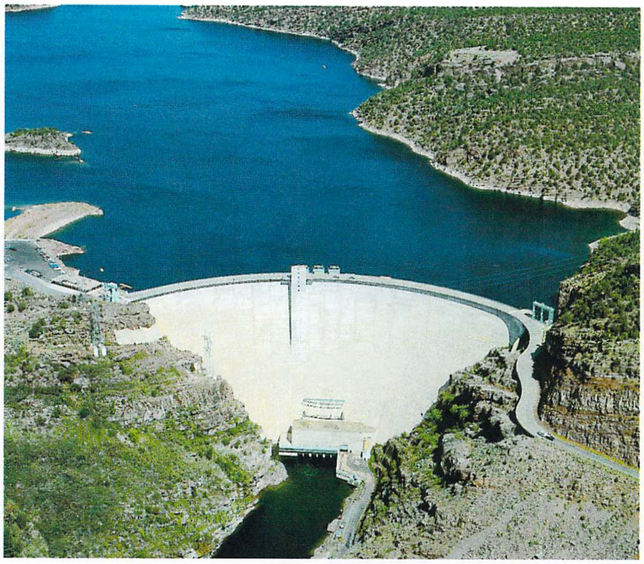

**FIGURE 15–27** Problem 50.

## General Problems

**51.** An inventor claims to have designed and built an engine that produces 1.50 MW of usable work while taking in 3.00 MW of thermal energy at 425 K, and rejecting 1.50 MW of thermal energy at 215 K. Is there anything fishy about his claim? Explain.

**52.** When $5.30 \times 10^5$ J of heat is added to a gas enclosed in a cylinder fitted with a light frictionless piston maintained at atmospheric pressure, the volume is observed to increase from 1.9 $m^3$ to 4.1 $m^3$. Calculate (*a*) the work done by the gas, and (*b*) the change in internal energy of the gas. (*c*) Graph this process on a *PV* diagram.

**53.** A 4-cylinder gasoline engine has an efficiency of 0.25 and delivers 220 J of work per cycle per cylinder. When the engine fires at 45 cycles per second, (*a*) what is the work done per second? (*b*) What is the total heat input per second from the fuel? (*c*) If the energy content of gasoline is 35 MJ per liter, how long does one liter last?

**54.** A "Carnot" refrigerator (the reverse of a Carnot engine) absorbs heat from the freezer compartment at a temperature of −17°C and exhausts it into the room at 25°C. (*a*) How much work must be done by the refrigerator to change 0.50 kg of water at 25°C into ice at −17°C? (*b*) If the compressor output is 210 W, what minimum time is needed to accomplish this?

**55.** It has been suggested that a heat engine could be developed that made use of the temperature difference between water at the surface of the ocean and that several hundred meters deep. In the tropics, the temperatures may be 27°C and 4°C, respectively. (*a*) What is the maximum efficiency such an engine could have? (*b*) Why might such an engine be feasible in spite of the low efficiency? (*c*) Can you imagine any adverse environmental effects that might occur?

56. Two 1100-kg cars are traveling 95 km/h in opposite directions when they collide and are brought to rest. Estimate the change in entropy of the universe as a result of this collision. Assume $T = 20°C$.

57. A 120-g insulated aluminum cup at 15°C is filled with 140 g of water at 50°C. After a few minutes, equilibrium is reached. (*a*) Determine the final temperature, and (*b*) estimate the total change in entropy.

* 58. (*a*) What is the coefficient of performance of an ideal heat pump that extracts heat from 6°C air outside and deposits heat inside your house at 24°C? (*b*) If this heat pump operates on 1200 W of electrical power, what is the maximum heat it can deliver into your house each hour?

59. The burning of gasoline in a car releases about $3.0 \times 10^4$ kcal/gal. If a car averages 41 km/gal when driving 90 km/h, which requires 25 hp, what is the efficiency of the engine under those conditions?

60. A Carnot engine has a lower operating temperature $T_L = 20°C$ and an efficiency of 30%. By how many kelvins should the high operating temperature $T_H$ be increased to achieve an efficiency of 40%?

61. Calculate the work done by an ideal gas in going from state A to state C in Fig. 15–28 for each of the following processes: (*a*) ADC, (*b*) ABC, and (*c*) AC directly.

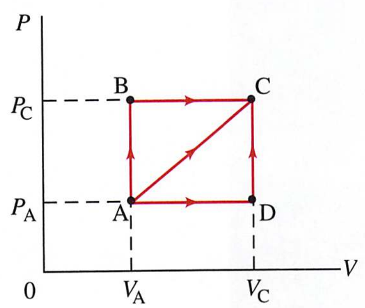


**FIGURE 15–28** Problem 61.

62. A 33% efficient power plant puts out 850 MW of electrical power. Cooling towers are used to take away the exhaust heat. (*a*) If the air temperature is allowed to rise 7.0 C°, estimate what volume of air ($km^3$) is heated per day. Will the local climate be heated significantly? (*b*) If the heated air were to form a layer 200 m thick, estimate how large an area it would cover for 24 h of operation. Assume the air has density 1.2 kg/m$^3$ and that its specific heat is about 1.0 kJ/kg·C° at constant pressure.

63. Suppose a power plant delivers energy at 980 MW using steam turbines. The steam goes into the turbines superheated at 625 K and deposits its unused heat in river water at 285 K. Assume that the turbine operates as an ideal Carnot engine. (*a*) If the river flow rate is 37 m$^3$/s, estimate the average temperature increase of the river water immediately downstream from the power plant. (*b*) What is the entropy increase per kilogram of the downstream river water in J/kg·K?

64. A 100-hp car engine operates at about 15% efficiency. Assume the engine's water temperature of 85°C is its cold-temperature (exhaust) reservoir and 495°C is its thermal "intake" temperature (the temperature of the exploding gas–air mixture). (*a*) What is the ratio of its efficiency relative to its maximum possible (Carnot) efficiency? (*b*) Estimate how much power (in watts) goes into moving the car, and how much heat, in joules and in kcal, is exhausted to the air in 1.0 h.

65. An ideal gas is placed in a tall cylindrical jar of cross-sectional area 0.080 m$^2$. A frictionless 0.10-kg movable piston is placed vertically into the jar such that the piston's weight is supported by the gas pressure in the jar. When the gas is heated (at constant pressure) from 25°C to 55°C, the piston rises 1.0 cm. How much heat was required for this process? Assume atmospheric pressure outside.

66. Metabolizing 1.0 kg of fat results in about $3.7 \times 10^7$ J of internal energy in the body. (*a*) In one day, how much fat does the body burn to maintain the body temperature of a person staying in bed and metabolizing at an average rate of 95 W? (*b*) How long would it take to burn 1.0-kg of fat this way assuming there is no food intake?

67. An ideal air conditioner keeps the temperature inside a room at 21°C when the outside temperature is 32°C. If 5.3 kW of power enters a room through the windows in the form of direct radiation from the Sun, how much electrical power would be saved if the windows were shaded so that the amount of radiation were reduced to 500 W?

68. A dehumidifier is essentially a "refrigerator with an open door." The humid air is pulled in by a fan and guided to a cold coil, where the temperature is less than the dew point, and some of the air's water condenses. After this water is extracted, the air is warmed back to its original temperature and sent into the room. In a well-designed dehumidifier, the heat is exchanged between the incoming and outgoing air. This way the heat that is removed by the refrigerator coil mostly comes from the condensation of water vapor to liquid. Estimate how much water is removed in 1.0 h by an ideal dehumidifier, if the temperature of the room is 25°C, the water condenses at 8°C, and the dehumidifier does work at the rate of 600 W of electrical power.

## Answers to Exercises

**A:** 700 J.
**B:** Less.
**C:** $-6.8 \times 10^3$ J.
**D:** Equation 14–1 applies only to an ideal monatomic gas, not to liquid water.