Summary

- James Joule demonstrated the mechanical equivalent of heat (1 cal = 4.19 joules).
- Heat can be transferred by conduction, convection, or radiation.

Practice Exercises

In each case, select the choice that best answers the question or completes the statement.

1. Radiation is the chief method of energy transfer
   (A) from the Sun to an Earth satellite
   (B) from a gas flame to water in a teakettle
   (C) from a soldering iron to metals being soldered
   (D) from water to an ice cube floating in it
   (E) from a mammal to the surrounding air
2. Of the processes below, the one in which practically all the heat transfer is by conduction is
   (A) from the Sun to an Earth satellite
   (B) from a gas flame to the top layer of water in a teakettle
   (C) from a soldering iron to metals being soldered
   (D) from the bottom of a glass of water to an ice cube floating in it
   (E) from a mammal to the surrounding air
3. Two kilograms of water are heated by stirring. If this raises the temperature of the water from 15°C to 25°C, how much work, in joules, was done to the water by the stirring?
   (A) 20,000
   (B) 40,000
   (C) 60,000

(D) 80,000
(E) 100,000

4. In a certain steam engine, the average pressure on the piston during a stroke is 50 newtons per square meters. The length of each stroke is 12 centimeters, the area of the piston is 120 square centimeters, and the diameter of the flywheel is 5 meters. The amount of work done on the piston during each stroke is, in newton meters, approximately
(A) 250
(B) 0.072
(C) 0.54
(D) 1.63
(E) 12.62

5. The work done *to* a system is characterized as
(A) positive
(B) negative
(C) either positive or negative
(D) indeterminate
(E) of no consequence

6. Which of the following can actually lower the internal energy of ("cool") a room?
(A) a fan
(B) a refrigerator with its door open
(C) a refrigerator with its door closed
(D) an air conditioner in the middle of a room
(E) an air conditioner partially exposed to the outside

7. Thirty joules of heat flow into a system. The system in turn does 50 joules of work. The internal energy of the system has
(A) increased by 80 J
(B) decreased by 80 J
(C) increased by 20 J
(D) decreased by 20 J
(E) remained constant

8. Dark, rough objects are generally good for
(A) conduction
(B) radiation
(C) convection
(D) reflection
(E) refraction

9. Black plastic handles are often used on kitchen utensils because
(A) the black material is a good radiator
(B) the plastic is a good insulator
(C) the plastic is a good conductor
(D) the plastic softens gradually with excessive heat

(E) the material is thermoplastic

10. A person seated in front of a fire in a fireplace receives heat chiefly by
(A) convection of carbon dioxide
(B) convection of carbon monoxide
(C) convection of air
(D) conduction
(E) radiation

11. If friction is negligible, when a gas is compressed rapidly
(A) its temperature remains the same
(B) its temperature goes down
(C) its temperature rises
(D) it is liquefied
(E) work is done by the gas

Answer Key

1. **(A)**	5. **(B)**	9. **(B)**
2. **(C)**	6. **(E)**	10. **(E)**
3. **(D)**	7. **(D)**	11. **(C)**
4. **(B)**	8. **(B)**	

Answers Explained

1. **A** The space between the Sun and an Earth satellite is an almost perfect vacuum. Conduction and convection cannot take place through a vacuum. Although some particles are shot out of the Sun and thus carry kinetic energy with them to the satellite, this energy is small in comparison with the amount constantly conveyed by electromagnetic waves, that is, by radiation. (Also see answer to question 2.)
2. **C** The soldering iron is in good contact with the metal to be soldered and thus provides excellent opportunity for heat transfer by conduction. The tip of a soldering iron is often made of copper to provide better heat conduction. If a teakettle is made of metal, there is some heating, chiefly by convection, of the top layer of water in the kettle by conduction along the kettle; the bottom layer gets heated, rises toward the top, where it mixes with the colder water, and also pushes the top layer toward the bottom (B). Similar reasoning applies to choice (D). Mammals lose heat by the exhalation of warm air, evaporation of perspiration from the skin, convection, and other processes.
3. **D** 100% efficiency is implied.

$$\begin{aligned}\text{work done} &= \text{heat supplied}\\ &= \text{mass} \times \text{specific heat} \times \text{temperature change}\\ &= (2\ \text{kg})(4.19\ \text{kJ/kg}\cdot{}^\circ\text{C})(25^\circ - 15^\circ) = 80\ \text{kJ} = 80{,}000\ \text{J}.\end{aligned}$$

4. **B** pressure = force/area; force = **P***A*

$$\begin{aligned}\text{work} &= \text{force} \times \text{distance} = \text{pressure} \times \text{area} \times \text{distance}\\ &= 50\ \text{N/m}^2 \times 0.012\ \text{m}^2 \times 0.12\ \text{m} = 0.072\ \text{N}\cdot\text{m}\end{aligned}$$

Note that the diameter of the flywheel is irrelevant.

5. **B** By convention, the work done *by* a system is positive. Therefore, the work done *to* a system is negative.
6. **E** To cool a room, heat must be *removed*. In fact, *all* of the other choices result in an increase in room temperature, as the electric energy used to run the devices is dissipated as heat.
7. **D** $Q = \Delta U + W$

$$\begin{aligned}+30\ \text{J} &= \Delta U + 50\ \text{J}\\ -50\ \text{J} &\qquad -50\ \text{J}\\ \hline -20\ \text{J} &= \Delta U\end{aligned}$$

8. **B** This question involves mere recall of a fact mentioned in the chapter that everyone is expected to know.
9. **B** Although the black material is a good radiator, this is irrelevant (A). The important fact is that the plastic is a good insulator of heat. The term *thermoplastic* (E), which refers to the property of softening when heat is applied, is not essential for elementary physics. Such a plastic is usually not desirable in handles of kitchen utensils; choice (E) is essentially the same as choice (D).
10. **E** Convection of any kind would lead to the rising of the heated gases, in this case up the chimney, not to the person. Very little conduction to the person can take place, since the intervening air is a poor conductor.
11. **C** When a gas is compressed, work is done on the gas and tends to heat the gas even if friction is absent. If the compression takes place rapidly, the heat produced can't escape completely and the temperature of the gas rises. Similarly, if a gas is allowed to expand rapidly, its temperature falls.

Problems & Exercises

15.1 The First Law of Thermodynamics

1. What is the change in internal energy of a car if you put 12.0 gal of gasoline into its tank? The energy content of gasoline is $1.3\times10^8\ \text{J/gal}$. All other factors, such as the car's temperature, are constant.

2. How much heat transfer occurs from a system, if its internal energy decreased by 150 J while it was doing 30.0 J of work?

3. A system does $1.80\times10^8\ \text{J}$ of work while $7.50\times10^8\ \text{J}$ of heat transfer occurs to the environment. What is the change in internal energy of the system assuming no other changes (such as in temperature or by the addition of fuel)?

4. What is the change in internal energy of a system which does $4.50\times10^5\ \text{J}$ of work while $3.00\times10^6\ \text{J}$ of heat transfer occurs into the system, and $8.00\times10^6\ \text{J}$ of heat transfer occurs to the environment?

5. Suppose a woman does 500 J of work and 9500 J of heat transfer occurs into the environment in the process. (a) What is the decrease in her internal energy, assuming no change in temperature or consumption of food? (That is, there is no other energy transfer.) (b) What is her efficiency?

6. (a) How much food energy will a man metabolize in the process of doing 35.0 kJ of work with an efficiency of 5.00%? (b) How much heat transfer occurs to the environment to keep his temperature constant? Explicitly show how you follow the steps in the Problem-Solving Strategy for thermodynamics found in **Problem-Solving Strategies for Thermodynamics**.

7. (a) What is the average metabolic rate in watts of a man who metabolizes 10,500 kJ of food energy in one day? (b) What is the maximum amount of work in joules he can do without breaking down fat, assuming a maximum efficiency of 20.0%? (c) Compare his work output with the daily output of a 187-W (0.250-horsepower) motor.

8. (a) How long will the energy in a 1470-kJ (350-kcal) cup of yogurt last in a woman doing work at the rate of 150 W with an efficiency of 20.0% (such as in leisurely climbing stairs)? (b) Does the time found in part (a) imply that it is easy to consume more food energy than you can reasonably expect to work off with exercise?

9. (a) A woman climbing the Washington Monument metabolizes $6.00\times10^2\ \text{kJ}$ of food energy. If her efficiency is 18.0%, how much heat transfer occurs to the environment to keep her temperature constant? (b) Discuss the amount of heat transfer found in (a). Is it consistent with the fact that you quickly warm up when exercising?

15.2 The First Law of Thermodynamics and Some Simple Processes

10. A car tire contains $0.0380\ \text{m}^3$ of air at a pressure of $2.20\times10^5\ \text{N/m}^2$ (about 32 psi). How much more internal energy does this gas have than the same volume has at zero gauge pressure (which is equivalent to normal atmospheric pressure)?

11. A helium-filled toy balloon has a gauge pressure of 0.200 atm and a volume of 10.0 L. How much greater is the internal energy of the helium in the balloon than it would be at zero gauge pressure?

12. Steam to drive an old-fashioned steam locomotive is supplied at a constant gauge pressure of $1.75\times10^6\ \text{N/m}^2$ (about 250 psi) to a piston with a 0.200-m radius. (a) By calculating $P\Delta V$, find the work done by the steam when the piston moves 0.800 m. Note that this is the net work output, since gauge pressure is used. (b) Now find the amount of work by calculating the force exerted times the distance traveled. Is the answer the same as in part (a)?

13. A hand-driven tire pump has a piston with a 2.50-cm diameter and a maximum stroke of 30.0 cm. (a) How much work do you do in one stroke if the average gauge pressure is $2.40\times10^5\ \text{N/m}^2$ (about 35 psi)? (b) What average force do you exert on the piston, neglecting friction and gravitational force?

14. Calculate the net work output of a heat engine following path ABCDA in the figure below.

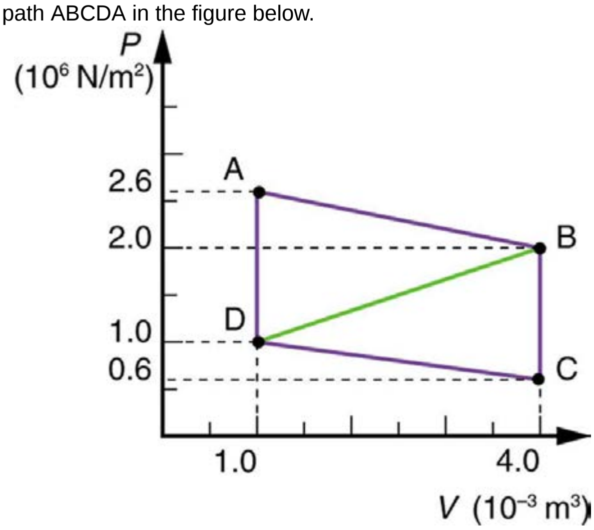

Figure 15.44

15. What is the net work output of a heat engine that follows path ABDA in the figure above, with a straight line from B to D? Why is the work output less than for path ABCDA? Explicitly show how you follow the steps in the **Problem-Solving Strategies for Thermodynamics**.

16. Unreasonable Results

What is wrong with the claim that a cyclical heat engine does 4.00 kJ of work on an input of 24.0 kJ of heat transfer while 16.0 kJ of heat transfers to the environment?

17. (a) A cyclical heat engine, operating between temperatures of $450^\circ\ \text{C}$ and $150^\circ\ \text{C}$ produces 4.00 MJ of work on a heat transfer of 5.00 MJ into the engine. How much heat transfer occurs to the environment? (b) What is unreasonable about the engine? (c) Which premise is unreasonable?

18. Construct Your Own Problem

Consider a car's gasoline engine. Construct a problem in which you calculate the maximum efficiency this engine can have. Among the things to consider are the effective hot and cold reservoir temperatures. Compare your calculated efficiency with the actual efficiency of car engines.

19. Construct Your Own Problem

Consider a car trip into the mountains. Construct a problem in which you calculate the overall efficiency of the car for the trip as a ratio of kinetic and potential energy gained to fuel consumed. Compare this efficiency to the thermodynamic efficiency quoted for gasoline engines and discuss why the thermodynamic efficiency is so much greater. Among the factors to be considered are the gain in altitude and speed, the mass of the car, the distance traveled, and typical fuel economy.

15.3 Introduction to the Second Law of Thermodynamics: Heat Engines and Their Efficiency

20. A certain heat engine does 10.0 kJ of work and 8.50 kJ of heat transfer occurs to the environment in a cyclical process. (a) What was the heat transfer into this engine? (b) What was the engine's efficiency?

21. With $2.56\times10^6\text{ J}$ of heat transfer into this engine, a given cyclical heat engine can do only $1.50\times10^5\text{ J}$ of work. (a) What is the engine's efficiency? (b) How much heat transfer to the environment takes place?

22. (a) What is the work output of a cyclical heat engine having a 22.0% efficiency and $6.00\times10^9\text{ J}$ of heat transfer into the engine? (b) How much heat transfer occurs to the environment?

23. (a) What is the efficiency of a cyclical heat engine in which 75.0 kJ of heat transfer occurs to the environment for every 95.0 kJ of heat transfer into the engine? (b) How much work does it produce for 100 kJ of heat transfer into the engine?

24. The engine of a large ship does $2.00\times10^8\text{ J}$ of work with an efficiency of 5.00%. (a) How much heat transfer occurs to the environment? (b) How many barrels of fuel are consumed, if each barrel produces $6.00\times10^9\text{ J}$ of heat transfer when burned?

25. (a) How much heat transfer occurs to the environment by an electrical power station that uses $1.25\times10^{14}\text{ J}$ of heat transfer into the engine with an efficiency of 42.0%? (b) What is the ratio of heat transfer to the environment to work output? (c) How much work is done?

26. Assume that the turbines at a coal-powered power plant were upgraded, resulting in an improvement in efficiency of 3.32%. Assume that prior to the upgrade the power station had an efficiency of 36% and that the heat transfer into the engine in one day is still the same at $2.50\times10^{14}\text{ J}$. (a) How much more electrical energy is produced due to the upgrade? (b) How much less heat transfer occurs to the environment due to the upgrade?

27. This problem compares the energy output and heat transfer to the environment by two different types of nuclear power stations—one with the normal efficiency of 34.0%, and another with an improved efficiency of 40.0%. Suppose both have the same heat transfer into the engine in one day, $2.50\times10^{14}\text{ J}$. (a) How much more electrical energy is produced by the more efficient power station? (b) How much less heat transfer occurs to the environment by the more efficient power station? (One type of more efficient nuclear power station, the gas-cooled reactor, has not been reliable enough to be economically feasible in spite of its greater efficiency.)

15.4 Carnot's Perfect Heat Engine: The Second Law of Thermodynamics Restated

28. A certain gasoline engine has an efficiency of 30.0%. What would the hot reservoir temperature be for a Carnot engine having that efficiency, if it operates with a cold reservoir temperature of 200°C?

29. A gas-cooled nuclear reactor operates between hot and cold reservoir temperatures of 700°C and 27.0°C. (a) What is the maximum efficiency of a heat engine operating between these temperatures? (b) Find the ratio of this efficiency to the Carnot efficiency of a standard nuclear reactor (found in **Example 15.4**).

30. (a) What is the hot reservoir temperature of a Carnot engine that has an efficiency of 42.0% and a cold reservoir temperature of 27.0°C? (b) What must the hot reservoir temperature be for a real heat engine that achieves 0.700 of the maximum efficiency, but still has an efficiency of 42.0% (and a cold reservoir at 27.0°C)? (c) Does your answer imply practical limits to the efficiency of car gasoline engines?

31. Steam locomotives have an efficiency of 17.0% and operate with a hot steam temperature of 425°C. (a) What would the cold reservoir temperature be if this were a Carnot engine? (b) What would the maximum efficiency of this steam engine be if its cold reservoir temperature were 150°C?

32. Practical steam engines utilize 450°C steam, which is later exhausted at 270°C. (a) What is the maximum efficiency that such a heat engine can have? (b) Since 270°C steam is still quite hot, a second steam engine is sometimes operated using the exhaust of the first. What is the maximum efficiency of the second engine if its exhaust has a temperature of 150°C? (c) What is the overall efficiency of the two engines? (d) Show that this is the same efficiency as a single Carnot engine operating between 450°C and 150°C. Explicitly show how you follow the steps in the **Problem-Solving Strategies for Thermodynamics**.

33. A coal-fired electrical power station has an efficiency of 38%. The temperature of the steam leaving the boiler is 550°C. What percentage of the maximum efficiency does this station obtain? (Assume the temperature of the environment is 20°C.)

34. Would you be willing to financially back an inventor who is marketing a device that she claims has 25 kJ of heat transfer at 600 K, has heat transfer to the environment at 300 K, and does 12 kJ of work? Explain your answer.

35. Unreasonable Results

(a) Suppose you want to design a steam engine that has heat transfer to the environment at $270^\circ C$ and has a Carnot efficiency of 0.800. What temperature of hot steam must you use? (b) What is unreasonable about the temperature? (c) Which premise is unreasonable?

36. Unreasonable Results

Calculate the cold reservoir temperature of a steam engine that uses hot steam at $450^\circ C$ and has a Carnot efficiency of 0.700. (b) What is unreasonable about the temperature? (c) Which premise is unreasonable?

15.5 Applications of Thermodynamics: Heat Pumps and Refrigerators

37. What is the coefficient of performance of an ideal heat pump that has heat transfer from a cold temperature of $-25.0^\circ C$ to a hot temperature of $40.0^\circ C$?

38. Suppose you have an ideal refrigerator that cools an environment at $-20.0^\circ C$ and has heat transfer to another environment at $50.0^\circ C$. What is its coefficient of performance?

39. What is the best coefficient of performance possible for a hypothetical refrigerator that could make liquid nitrogen at $-200^\circ C$ and has heat transfer to the environment at $35.0^\circ C$?

40. In a very mild winter climate, a heat pump has heat transfer from an environment at $5.00^\circ C$ to one at $35.0^\circ C$. What is the best possible coefficient of performance for these temperatures? Explicitly show how you follow the steps in the **Problem-Solving Strategies for Thermodynamics**.

41. (a) What is the best coefficient of performance for a heat pump that has a hot reservoir temperature of $50.0^\circ C$ and a cold reservoir temperature of $-20.0^\circ C$? (b) How much heat transfer occurs into the warm environment if $3.60\times10^7\ \text{J}$ of work ($10.0 \text{kW}\cdot\text{h}$) is put into it? (c) If the cost of this work input is $10.0\ \text{cents/kW}\cdot\text{h}$, how does its cost compare with the direct heat transfer achieved by burning natural gas at a cost of 85.0 cents per therm. (A therm is a common unit of energy for natural gas and equals $1.055\times10^8\ \text{J}$.)

42. (a) What is the best coefficient of performance for a refrigerator that cools an environment at $-30.0^\circ C$ and has heat transfer to another environment at $45.0^\circ C$? (b) How much work in joules must be done for a heat transfer of 4186 kJ from the cold environment? (c) What is the cost of doing this if the work costs 10.0 cents per $3.60\times10^6\ \text{J}$ (a kilowatt-hour)? (d) How many kJ of heat transfer occurs into the warm environment? (e) Discuss what type of refrigerator might operate between these temperatures.

43. Suppose you want to operate an ideal refrigerator with a cold temperature of $-10.0^\circ C$, and you would like it to have a coefficient of performance of 7.00. What is the hot reservoir temperature for such a refrigerator?

44. An ideal heat pump is being considered for use in heating an environment with a temperature of $22.0^\circ C$. What is the cold reservoir temperature if the pump is to have a coefficient of performance of 12.0?

45. A 4-ton air conditioner removes $5.06\times10^7\ \text{J}$ (48,000 British thermal units) from a cold environment in 1.00 h. (a) What energy input in joules is necessary to do this if the air conditioner has an energy efficiency rating (EER) of 12.0? (b) What is the cost of doing this if the work costs 10.0 cents per $3.60\times10^6\ \text{J}$ (one kilowatt-hour)? (c) Discuss whether this cost seems realistic. Note that the energy efficiency rating (EER) of an air conditioner or refrigerator is defined to be the number of British thermal units of heat transfer from a cold environment per hour divided by the watts of power input.

46. Show that the coefficients of performance of refrigerators and heat pumps are related by $COP_{\text{ref}} = COP_{\text{hp}} - 1$.

Start with the definitions of the COP s and the conservation of energy relationship between Q_h , Q_c , and W .

15.6 Entropy and the Second Law of Thermodynamics: Disorder and the Unavailability of Energy

47. (a) On a winter day, a certain house loses $5.00\times10^8\ \text{J}$ of heat to the outside (about 500,000 Btu). What is the total change in entropy due to this heat transfer alone, assuming an average indoor temperature of $21.0^\circ\ \text{C}$ and an average outdoor temperature of $5.00^\circ\ \text{C}$? (b) This large change in entropy implies a large amount of energy has become unavailable to do work. Where do we find more energy when such energy is lost to us?

48. On a hot summer day, $4.00\times10^6\ \text{J}$ of heat transfer into a parked car takes place, increasing its temperature from $35.0^\circ\ \text{C}$ to $45.0^\circ\ \text{C}$. What is the increase in entropy of the car due to this heat transfer alone?

49. A hot rock ejected from a volcano's lava fountain cools from $1100^\circ\ \text{C}$ to $40.0^\circ\ \text{C}$, and its entropy decreases by 950 J/K. How much heat transfer occurs from the rock?

50. When $1.60\times10^5\ \text{J}$ of heat transfer occurs into a meat pie initially at $20.0^\circ\ \text{C}$, its entropy increases by 480 J/K. What is its final temperature?

51. The Sun radiates energy at the rate of $3.80\times10^{26}\ \text{W}$ from its $5500^\circ\ \text{C}$ surface into dark empty space (a negligible fraction radiates onto Earth and the other planets). The effective temperature of deep space is $-270^\circ\ \text{C}$. (a) What is the increase in entropy in one day due to this heat transfer? (b) How much work is made unavailable?

52. (a) In reaching equilibrium, how much heat transfer occurs from 1.00 kg of water at 40.0°C when it is placed in contact with 1.00 kg of 20.0°C water in reaching equilibrium? (b) What is the change in entropy due to this heat transfer? (c) How much work is made unavailable, taking the lowest temperature to be 20.0°C? Explicitly show how you follow the steps in the **Problem-Solving Strategies for Entropy**.

53. What is the decrease in entropy of 25.0 g of water that condenses on a bathroom mirror at a temperature of 35.0°C, assuming no change in temperature and given the latent heat of vaporization to be 2450 kJ/kg?

54. Find the increase in entropy of 1.00 kg of liquid nitrogen that starts at its boiling temperature, boils, and warms to 20.0°C at constant pressure.

55. A large electrical power station generates 1000 MW of electricity with an efficiency of 35.0%. (a) Calculate the heat transfer to the power station, Q_h, in one day. (b) How much heat transfer Q_c occurs to the environment in one day? (c) If the heat transfer in the cooling towers is from 35.0°C water into the local air mass, which increases in temperature from 18.0°C to 20.0°C, what is the total increase in entropy due to this heat transfer? (d) How much energy becomes unavailable to do work because of this increase in entropy, assuming an 18.0°C lowest temperature? (Part of Q_c could be utilized to operate heat engines or for simply heating the surroundings, but it rarely is.)

56. (a) How much heat transfer occurs from 20.0 kg of 90.0°C water placed in contact with 20.0 kg of 10.0°C water, producing a final temperature of 50.0°C? (b) How much work could a Carnot engine do with this heat transfer, assuming it operates between two reservoirs at constant temperatures of 90.0°C and 10.0°C? (c) What increase in entropy is produced by mixing 20.0 kg of 90.0°C water with 20.0 kg of 10.0°C water? (d) Calculate the amount of work made unavailable by this mixing using a low temperature of 10.0°C, and compare it with the work done by the Carnot engine. Explicitly show how you follow the steps in the **Problem-Solving Strategies for Entropy**. (e) Discuss how everyday processes make increasingly more energy unavailable to do work, as implied by this problem.

15.7 Statistical Interpretation of Entropy and the Second Law of Thermodynamics: The Underlying Explanation

57. Using **Table 15.4**, verify the contention that if you toss 100 coins each second, you can expect to get 100 heads or 100 tails once in 2×10^{22} years; calculate the time to two-digit accuracy.

58. What percent of the time will you get something in the range from 60 heads and 40 tails through 40 heads and 60 tails when tossing 100 coins? The total number of microstates in that range is 1.22×10^{30}. (Consult **Table 15.4**.)

59. (a) If tossing 100 coins, how many ways (microstates) are there to get the three most likely macrostates of 49 heads and 51 tails, 50 heads and 50 tails, and 51 heads and 49 tails? (b) What percent of the total possibilities is this? (Consult **Table 15.4**.)

60. (a) What is the change in entropy if you start with 100 coins in the 45 heads and 55 tails macrostate, toss them, and get 51 heads and 49 tails? (b) What if you get 75 heads and 25 tails? (c) How much more likely is 51 heads and 49 tails than 75 heads and 25 tails? (d) Does either outcome violate the second law of thermodynamics?

61. (a) What is the change in entropy if you start with 10 coins in the 5 heads and 5 tails macrostate, toss them, and get 2 heads and 8 tails? (b) How much more likely is 5 heads and 5 tails than 2 heads and 8 tails? (Take the ratio of the number of microstates to find out.) (c) If you were betting on 2 heads and 8 tails would you accept odds of 252 to 45? Explain why or why not.

Table 15.5 10-Coin Toss

Macrostate		Number of Microstates (*W*)
Heads	Tails	
10	0	1
9	1	10
8	2	45
7	3	120
6	4	210
5	5	252
4	6	210
3	7	120
2	8	45
1	9	10
0	10	1
		Total: 1024

Test Prep for AP® Courses

15.1 The First Law of Thermodynamics

1. A cylinder is divided in half by a movable disk in the middle. Each half is filled with an equal number of gas molecules, but one half is at a higher temperature than the other. Which choice best describes what happens next?

a. Nothing.
b. The high temperature side expands, compressing the low temperature side.
c. Heat moves from hot to cold, so the low temperature side will gradually increase in temperature and expand
d. (b) happens quickly, but after that (c) happens more slowly.

2. Imagine a solid material at the molecular level as consisting of a bunch of billiard balls connected to each other by springs (this is actually a surprisingly useful approximation). If we have two blocks of the same material, but in one the billiard balls are shaking back and forth on their springs a great deal, and in the other they are barely moving, which block is at the higher temperature? Using what you know about conservation of momentum in collisions, describe which block will transfer energy to the other, and justify your answer.

3. A system has 300 J of work done on it, and has a heat transfer of -320 J. Compared to prior to these processes, the internal energy is:

a. 20 J less
b. 20 J more
c. 620 J more
d. 620 J less

4. Find a snack or drink item in the classroom, or at your next meal. Find the total Calories (kilocalories) in the item, and calculate how long it would take exercising at 150 W (moderately, climbing stairs) at 20% efficiency to burn off this energy.

5. A potato cannon has the fuel combusted, generating a lot of heat and pressure, which launch a potato. The combustion process _____ the internal energy, while launching the potato _____ the internal energy of the potato cannon.

a. increases, increases
b. increases, decreases
c. decreases, increases
d. decreases, decreases

6. Describe what happens to the system inside of a refrigerator or freezer in terms of heat transfer, work, and conservation of energy. Confine yourself to time periods in which the door is closed.

15.2 The First Law of Thermodynamics and Some Simple Processes

7. In **Figure 15.44**, how much work is done by the system in process AB?

a. 4.5×10^3 J
b. 6.0×10^3 J
c. 6.9×10^3 J
d. 7.8×10^3 J

8. Consider process CD in **Figure 15.44**. Does this represent work done by or on the system, and how much?

9. A thermodynamic process begins at 1.2×10^6 N/m^2 and 5 L. The state then changes to 1.2×10^6 N/m^2 and 2 L. Next it becomes 2.2×10^6 N/m^2 and 2 L. The next change is 2.2×10^6 N/m^2 and 5 L. Finally, the system ends at 1.0×10^6 N/m^2 and 5 L.

On **Figure 15.43**, this process is best described by

a. EFCDB
b. DEFCD
c. CFABC
d. CFABD

10. The first step of a thermodynamic cycle is an isobaric process with increasing volume. The second is an isochoric process, with decreasing pressure. The last step may be either an isothermal or adiabatic process, ending at the starting point of the isobaric process. Sketch a graph of these two possibilities, and comment on which will have greater net work per cycle.

11. In **Figure 15.44**, which of the following cycles has the greatest net work output?

a. ABDA
b. BCDB
c. (a) and (b) are equal
d. ADCBA

12. Look at **Figure 15.43**, and assign values to the three pressures and two volumes given in the graph. Then calculate the net work for the cycle ABCFEDCFA using those values. How does this work compare to the heat output or input of the system? Which value(s) would you change to maximize the net work per cycle?

15.6 Entropy and the Second Law of Thermodynamics: Disorder and the Unavailability of Energy

13. Equal masses of steam (100 degrees C) and ice (0 degrees C) are placed in contact with each other in an otherwise insulated container. They both end up as liquid water at a common temperature. The steam ___ entropy and ___ order, while the ice ___ entropy and ___ order.

a. gained, gained, lost, lost
b. gained, lost, lost, gained
c. lost, gained, gained, lost
d. lost, lost, gained, gained

14. A high temperature reservoir losing heat and hence entropy is a reversible process. A low temperature reservoir gaining a certain amount of heat and hence entropy is a reversible process. But a high temperature reservoir losing heat to a low temperature reservoir is irreversible. Why?

15.7 Statistical Interpretation of Entropy and the Second Law of Thermodynamics: The Underlying Explanation

15. A piston is resting halfway into a cylinder containing gas in thermal equilibrium. The layer of molecules next to the closed end of the cylinder is suddenly flash-heated to a very high temperature. Which best describes what happens next?

a. The high temperature molecules push out the piston until their energy is reduced enough that the system is in equilibrium.
b. The molecules with the highest temperature bounce off their neighbors, losing energy to them, and so on until the system is at a new equilibrium with the piston moved out.
c. The molecules with the highest temperature bounce off their neighbors, losing energy to them, and so on until the system is at a new equilibrium with the piston where it started.
d. The high temperature molecules push out the piston until their energy is reduced enough that the system is in equilibrium, and then the piston gets sucked back in.

16. Design a macroscopic simulation using reasonably common materials to represent one very high energy particle gradually transferring energy to a bunch of lower energy particles, and determine if you end up with some sort of equilibrium.

71
20.9 min
73

(a) 3.96×10^{-2} g

(b) 96.2 J

(c) 16.0 W

75

(a) 1.102

(b) 2.79×10^4 J

(c) 12.6 J. This will not cause a significant cooling of the air because it is much less than the energy found in part (b), which is the energy required to warm the air from $20.0^\circ C$ to $50.0^\circ C$.

76

(a) $36^\circ C$

(b) Any temperature increase greater than about $3^\circ C$ would be unreasonably large. In this case the final temperature of the person would rise to $73^\circ C\ (163^\circ F)$.

(c) The assumption of 95% heat retention is unreasonable.

78

(a) 1.46 kW

(b) Very high power loss through a window. An electric heater of this power can keep an entire room warm.

(c) The surface temperatures of the window do not differ by as great an amount as assumed. The inner surface will be warmer, and the outer surface will be cooler.

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1
(c)
3
(a)
5
(b)
7
(a)
9
(d)

Chapter 15

Problems & Exercises

1
1.6×10^9 J
3
-9.30×10^8 J
5

(a) -1.0×10^4 J, or -2.39 kcal

(b) 5.00%

7

(a) 122 W

(b) 2.10×10^6 J

(c) Work done by the motor is 1.61×10^7 J ;thus the motor produces 7.67 times the work done by the man

9

(a) 492 kJ

(b) This amount of heat is consistent with the fact that you warm quickly when exercising. Since the body is inefficient, the excess heat produced must be dissipated through sweating, breathing, etc.

10

$6.77\times10^3\ \text{J}$

12

(a) $W = P\Delta V = 1.76\times10^5\ \text{J}$

(b) $W = Fd = 1.76\times10^5\ \text{J}$. Yes, the answer is the same.

14

$W = 4.5\times10^3\ \text{J}$

16

W is not equal to the difference between the heat input and the heat output.

20

(a) $18.5\ \text{kJ}$

(b) 54.1%

22

(a) $1.32\times10^9\ \text{J}$

(b) $4.68\times10^9\ \text{J}$

24

(a) $3.80\times10^9\ \text{J}$

(b) 0.667 barrels

26

(a) $8.30\times10^{12}\ \text{J}$, which is 3.32% of $2.50\times10^{14}\ \text{J}$.

(b) $-8.30\times10^{12}\ \text{J}$, where the negative sign indicates a reduction in heat transfer to the environment.

28

403°C

30

(a) 244°C

(b) 477°C

(c)Yes, since automobiles engines cannot get too hot without overheating, their efficiency is limited.

32

(a) $Eff_1 = 1 - \frac{T_{\text{c},1}}{T_{\text{h},1}} = 1 - \frac{543\ \text{K}}{723\ \text{K}} = 0.249 \text{ or } 24.9\%$

(b) $Eff_2 = 1 - \frac{423\ \text{K}}{543\ \text{K}} = 0.221 \text{ or } 22.1\%$

(c) $Eff_1 = 1 - \frac{T_{\text{c},1}}{T_{\text{h},1}} \Rightarrow T_{\text{c},1} = T_{\text{h},1}(1, \ -, \ eff_1)$ similarly, $T_{\text{c},2} = T_{\text{h},2}(1 - Eff_2)$

using $T_{\text{h},2} = T_{\text{c},1}$ in above equation gives
$$\begin{aligned} &T_{\text{c},2} = T_{\text{h},1}(1 - Eff_1)(1 - Eff_2) \equiv T_{\text{h},1}(1 - Eff_{\text{overall}}) \\ &?(1 - Eff_{\text{overall}}) = (1 - Eff_1)(1 - Eff_2) \\ &Eff_{\text{overall}} = 1 - (1 - 0.249)(1 - 0.221) = 41.5\% \end{aligned}$$

(d) $Eff_{\text{overall}} = 1 - \frac{423\ \text{K}}{723\ \text{K}} = 0.415 \text{ or } 41.5\%$

34

The heat transfer to the cold reservoir is $Q_c = Q_h - W = 25\text{ kJ} - 12\text{ kJ} = 13\text{ kJ}$, so the efficiency is $Eff = 1 - \frac{Q_c}{Q_h} = 1 - \frac{13\text{ kJ}}{25\text{ kJ}} = 0.48$. The Carnot efficiency is $Eff_C = 1 - \frac{T_c}{T_h} = 1 - \frac{300\text{ K}}{600\text{ K}} = 0.50$. The actual efficiency is 96% of the Carnot efficiency, which is much higher than the best-ever achieved of about 70%, so her scheme is likely to be fraudulent.

36

(a) -56.3°C

(b) The temperature is too cold for the output of a steam engine (the local environment). It is below the freezing point of water.

(c) The assumed efficiency is too high.

37

4.82

39

0.311

41

(a) 4.61

(b) $1.66\times10^8\text{ J or }3.97\times10^4\text{ kcal}$

(c) To transfer $1.66\times10^8\text{ J}$, heat pump costs $1.00, natural gas costs $1.34.

43

27.6°C

45

(a) $1.44\times10^7\text{ J}$

(b) 40 cents

(c) This cost seems quite realistic; it says that running an air conditioner all day would cost $9.59 (if it ran continuously).

47

(a) $9.78\times10^4\text{ J/K}$

(b) In order to gain more energy, we must generate it from things within the house, like a heat pump, human bodies, and other appliances. As you know, we use a lot of energy to keep our houses warm in the winter because of the loss of heat to the outside.

49

$8.01\times10^5\text{ J}$

51

(a) $1.04\times10^{31}\text{ J/K}$

(b) $3.28\times10^{31}\text{ J}$

53

199 J/K

55

(a) $2.47\times10^{14}\text{ J}$

(b) $1.60\times10^{14}\text{ J}$

(c) $2.85\times10^{10}\text{ J/K}$

(d) $8.29\times10^{12}\text{ J}$

57

It should happen twice in every $1.27\times10^{30}\text{ s}$ or once in every $6.35\times10^{29}\text{ s}$

$$\left(6.35\times10^{29}\ \text{s}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)\left(\frac{1\ \text{d}}{24\ \text{h}}\right)\left(\frac{1\ \text{y}}{365.25\ \text{d}}\right)$$

$$= 2.0\times10^{22}\ \text{y}$$

59

(a) 3.0×10^{29}

(b) 24%

61

(a) $-2.38\times10^{-23}\ \text{J/K}$

(b) 5.6 times more likely

(c) If you were betting on two heads and 8 tails, the odds of breaking even are 252 to 45, so on average you would break even. So, no, you wouldn't bet on odds of 252 to 45.

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1
(d)
3
(a)
5
(b)
7
(c)
9
(d)
11
(a)
13
(c)
15
(b)

Chapter 16

Problems & Exercises

1

(a) $1.23\times10^{3}\ \text{N/m}$

(b) $6.88\ \text{kg}$

(c) $4.00\ \text{mm}$

3

(a) 889 N/m

(b) 133 N

5

(a) $6.53\times10^{3}\ \text{N/m}$

(b) Yes

7
16.7 ms
8
$0.400\ \text{s / beats}$
9
400 Hz
10
12,500 Hz
11

13)

Thermodynamics Problems solved

1/ $\Delta U = \cancel{Q}^{=0} + W_{\text{to system}} = 1.3\ 10^8 \cdot 12 = 1.6\ 10^9\ J$

3/ $\Delta U = -Q_{out} - W_{\text{by system}} = -3.3 \cdot 10^8\ J$

19/ a/ $W = P\Delta V = P h \Delta A = 1.76\ 10^5\ J.$

b/ $W = F h = P A \cdot h = 1.76\ 10^5\ J.$

20/ a/ cyclic process $\to \Delta U = 0 \to Q_t = W + Q_{ex} = 18.5$

b/ $e = \dfrac{W}{Q} = 0.52 \quad (52\%)$

22/ a/ $W = Q \cdot e = 1.32 \cdot 10^9\ J$

b/ $Q_{ex} = Q - W = 4.68\ 10^9\ J.$

28/ $e = 1 - \dfrac{Q_c}{Q_H} \to T_H = \dfrac{T_c}{1-e} = \dfrac{200+273}{0.7}$

$T_H = 676\ K = 403°C$

43/ for Refrigerators: $K_R = \frac{Q_c}{W} = \frac{Q_c}{Q_H - Q_c}$

for Pumps $K_P = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_c}$

$\rightarrow Q_H = \frac{Q_c + Q_c K_R}{K_R} = 300.6K = 27.6°C$

53/ $\Delta S = \frac{Q}{T} = \frac{m H_v}{T} = \frac{0.025 kg \cdot 2450 \ kJ/kg}{35 + 273 \ K}$

$\Delta S = 0.199 \ kJ/K = 199 \ J/K$