Chapter 15: Thermodynamics

# 15.1 The First Law of Thermodynamics

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| 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* *. All other factors, such as the car’s temperature, are constant.* |
| Solution | Using the energy content of a gallon of gasoline, the energy stored in 12.0 gallons of gasoline is  Therefore, the internal energy of the car increases by this energy, so that |
| 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?* |
| Solution | Thus, 120 J was lost in the heat. |
| 3. | *A system does*  *of work while*  *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)?* |
| Solution |  |
| 4. | *What is the change in internal energy of a system which does*  *of work while*  *of heat transfer occurs into the system, and*  *of heat transfer occurs to the environment?* |
| Solution |  |
| 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?* |
| Solution | (a)  (b) |
| 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 found in Problem-Solving Strategies for Thermodynamics.* |
| Solution | (a)  (b) |
| 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.* |
| Solution | (a)  (b)  , so  (c) Work done by the motor is  Then, . Thus the motor produces 7.67 times the work done by the man. |
| 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?* |
| Solution | (a)  (b) Since eating an extra 350 kcal cup of yogurt takes a half an hour to burn off, just one candy bar takes about that same amount of time to work off, so it is definitely easy to consume more food calories than you can expect to work off with exercise! That is why it is so important to watch your calorie intake when you are trying to lose weight. |
| 9. | *(a) A woman climbing the Washington Monument metabolizes  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?* |
| Solution | (a)  (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. |

# 15.2 The First Law of Thermodynamics and Some Simple Processes

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| 10. | *A car tire contains*  *of nitrogen at a pressure of*  *(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)?* |
| Solution | Assume , where state 1 is that at 32 psi and state 2 is that at gauge pressure  (1 atm). |
| 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?* |
| Solution | The volume remains constant, so that , and  , and .  For a monatomic gas:      and so: |
| 12. | *Steam to drive an old-fashioned steam locomotive is supplied at a constant gauge pressure of*  *(about 250 psi) to a piston with a 0.200-m radius. (a) By calculating , 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)?* |
| Solution | (a)  (b) . Yes, the answer is the same. |
| 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*  *(about 35 psi)? (b) What average force do you exert on the piston, neglecting friction and gravitational force?* |
| Solution | (a)  (b) |
| 14. | *Calculate the net work output of a heat engine following path ABCDA in the figure below.* |
| Solution |  |
| 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.* |
| Solution | The work done for path ABDA is less than for ABCDA because the environment does more work on the system in BD than in BCD. We see this diagrammatically because the area enclosed by ABDA is less than that enclosed by ABCDA. |
| 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?* |
| Solution | For a cyclical engine,  must equal . is not equal to the difference between the heat input and heat output. |
| 17. | *(a) A cyclical heat engine, operating between temperatures of  and  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?* |
| Solution | (a)  (b)  It is unreasonable that .  (c) It is unreasonable that the engine does that much work for the given heat input for the given hot and cold temperatures. |

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

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| 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?* |
| Solution | (a)  (b) |
| 21. | *With*  *of heat transfer into this engine, a given cyclical heat engine can do only*  *of work. (a) What is the engine’s efficiency? (b) How much heat transfer to the environment takes place?* |
| Solution | (a) The efficiency is the work out divided by the heat in:    (b) The work output is the difference between the heat input and the wasted heat, so from the first law of thermodynamics: |
| 22. | *(a) What is the work output of a cyclical heat engine having a 22.0% efficiency and*  *of heat transfer into the engine? (b) How much heat transfer occurs to the environment?* |
| Solution | (a)  (b) |
| 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?* |
| Solution | (a)  (b) |
| 24. | *The engine of a large ship does*  *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*  *of heat transfer when burned?* |
| Solution | (a)  (b) Let equal the number of barrels of fuel consumed. |
| 25. | *(a) How much heat transfer occurs to the environment by an electrical power station that uses*  *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?* |
| Solution | (a)  (b)  (c) |
| 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* *. (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?* |
| Solution | (a) Efficiency increased to . Additional output will be  .  (b) Heat transfer to the environment will be where the negative sign indicates a reduction in heat transfer to the environment. |
| 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,* *. (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.)* |
| Solution | (a)  (b) |

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

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| 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 ?* |
| Solution |  |
| 29. | *A gas-cooled nuclear reactor operates between hot and cold reservoir temperatures of  and . (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.)* |
| Solution | (a)  (b) |
| 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 ? (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 )? (c) Does your answer imply practical limits to the efficiency of car gasoline engines?* |
| Solution | (a)  (b)  (c) Yes, since automobiles engines cannot get too hot without overheating, their efficiency is limited. |
| 31. | *Steam locomotives have an efficiency of 17.0% and operate with a hot steam temperature of . (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 ?* |
| Solution | (a)  (b) |
| 32. | *Practical steam engines utilize  steam, which is later exhausted at . (a) What is the maximum efficiency that such a heat engine can have? (b) Since  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 ? (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  and . Explicitly show how you follow the steps in the Problem-Solving Strategies for Thermodynamics.* |
| Solution | (a)  (b)  (c)  (d) |
| 33. | *A coal-fired electrical power station has an efficiency of 38%. The temperature of the steam leaving the boiler is . What percentage of the maximum efficiency does this station obtain? (Assume the temperature of the environment is .)* |
| Solution | Carnot efficiency  So the power plant achieves  of the maximum efficiency. |
| 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.* |
| Solution | The heat transfer to the cold reservoir is  so the efficiency is .  The Carnot efficiency is .  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. |
| 35. | ***Unreasonable Results*** *(a) Suppose you want to design a steam engine that has heat transfer to the environment at  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?* |
| Solution | (a)  (b) The temperature is too high. (Iron melts at 1809 K.)  (c) The exhaust temperature  is too high, as is the assumed efficiency. |
| 36. | ***Unreasonable Results*** *Calculate the cold reservoir temperature of a steam engine that uses hot steam at  and has a Carnot efficiency of 0.700. (b) What is unreasonable about the temperature? (c) Which premise is unreasonable?* |
| Solution | (a)  (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. |

# 15.5 Applications of Thermodynamics: Heat Pumps and Refrigerators

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| 37. | *What is the coefficient of performance of an ideal heat pump that has heat transfer from a cold temperature of  to a hot temperature of ?* |
| Solution |  |
| 38. | *Suppose you have an ideal refrigerator that cools an environment at  and has heat transfer to another environment at . What is its coefficient of performance?* |
| Solution |  |
| 39. | *What is the best coefficient of performance possible for a hypothetical refrigerator that could make liquid nitrogen at  and has heat transfer to the environment at ?* |
| Solution |  |
| 40. | *In a very mild winter climate, a heat pump has heat transfer from an environment at  to one at . What is the best possible coefficient of performance for these temperatures? Explicitly show how you follow the steps in Problem-Solving Strategies for Thermodynamics.* |
| Solution |  |
| 41. | *(a) What is the best coefficient of performance for a heat pump that has a hot reservoir temperature of  and a cold reservoir temperature of ? (b) How much heat transfer occurs into the warm environment if*  *of work () is put into it? (c) If the cost of this work input is , 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* *.)* |
| Solution | (a)  (b)  (c) For the heat pump:  To transfer the same amount of heat using natural gas:    To transfer , the heat pump costs $1.00, natural gas costs $1.34. |
| 42. | *(a) What is the best coefficient of performance for a refrigerator that cools an environment at  and has heat transfer to another environment at ? (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*  *(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.* |
| Solution | (a)  (b)  (c)  (d)  (e) The inside of this refrigerator (actually freezer) is at so this probably is a commercial meat packing freezer. The exhaust is generally vented to the outside, so as to not heat the building too much. |
| 43. | *Suppose you want to operate an ideal refrigerator with a cold temperature of , and you would like it to have a coefficient of performance of 7.00. What is the hot reservoir temperature for such a refrigerator?* |
| Solution |  |
| 44. | *An ideal heat pump is being considered for use in heating an environment with a temperature of . What is the cold reservoir temperature if the pump is to have a coefficient of performance of 12.0?* |
| Solution |  |
| 45. | *A 4-ton air conditioner removes*  *(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 () of 12.0? (b) What is the cost of doing this if the work costs 10.0 cents per*  *(one kilowatt-hour)? (c) Discuss whether this cost seems realistic. Note that the energy efficiency rating () 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.* |
| Solution | (a)  (b)  (c) This cost seems quite realistic, since it says that running an air conditioner all day would cost $9.59 (if it ran continuously). |
| 46. | *Show that the coefficients of performance of refrigerators and heat pumps are related by . Start with the definitions of the  and the conservation of energy relationship between , , and .* |
| Solution |  |

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

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| 47. | *(a) On a winter day, a certain house loses*  *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  and an average outdoor temperature of ? (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?* |
| Solution | (a) Use  to calculate the change in entropy, remembering to use temperatures in Kelvin:    (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. |
| 48. | *On a hot summer day,* *of heat transfer into a parked car takes place, increasing its temperature from  to . What is the increase in entropy of the car due to this heat transfer alone?* |
| Solution |  |
| 49. | *A hot rock ejected from a volcano’s lava fountain cools from  to , and its entropy decreases by 950 J/K. How much heat transfer occurs from the rock?* |
| Solution |  |
| 50. | *When*  *of heat transfer occurs into a meat pie initially at , its entropy increases by 480 J/K. What is its final temperature?* |
| Solution |  |
| 51. | *The Sun radiates energy at the rate of*  *from its  surface into dark empty space (a negligible fraction radiates onto Earth and the other planets). The effective temperature of deep space is . (a) What is the increase in entropy in one day due to this heat transfer? (b) How much work is made unavailable?* |
| Solution | (a)  (b) |
| 52. | *(a) In reaching equilibrium, how much heat transfer occurs from 1.00 kg of water at  when it is placed in contact with 1.00 kg of  water? (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 ? Explicitly show how you follow the steps in the Problem-Solving Strategies for Entropy.* |
| Solution | (a)  since there are equal masses of water in the  reservoirs.    (b) For the hot water:  For the cold water:  so the total change in entropy is  (c) |
| 53. | *What is the decrease in entropy of 25.0 g of water that condenses on a bathroom mirror at a temperature of , assuming no change in temperature and given the latent heat of vaporization to be 2450 kJ/kg?* |
| Solution | The entropy of the water decreases by 199 J/K when it condenses. |
| 54. | *Find the increase in entropy of 1.00 kg of liquid nitrogen that starts at its boiling temperature, boils, and warms to  at constant pressure.* |
| Solution |  |
| 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, , in one day. (b) How much heat transfer*  *occurs to the environment in one day? (c) If the heat transfer in the cooling towers is from  water into the local air mass, which increases in temperature from  to , 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  lowest temperature? (Part of  could be utilized to operate heat engines or for simply heating the surroundings, but it rarely is.)* |
| Solution | (a)  (b)  (c)  (d) |
| 56. | *(a) How much heat transfer occurs from 20.0 kg of  water placed in contact with 20.0 kg of  water, producing a final temperature of ? (b) How much work could a Carnot engine do with this heat transfer, assuming it operates between two reservoirs at constant temperatures of  and ? (c) What increase in entropy is produced by mixing 20.0 kg of  water with 20.0 kg of  water? (d) Calculate the amount of work made unavailable by this mixing using a low temperature of , 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.* |
| Solution | (a)  (b)  (c)  (d)  (e) This problem says that 79.3% of the work done by the engine is unavailable, so in everyday processes, even more energy would be unavailable to do work, since everyday processes are not as efficient as Carnot systems. |

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

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| 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*  *years; calculate the time to two-digit accuracy.* |
| Solution | It should happen twice in every  or once in every |
| 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* *. (Consult Table 15.4.)* |
| Solution |  |
| 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.)* |
| Solution | |  |  |  | | --- | --- | --- | | **H** | **T** | **No. of ways** | | 49 | 51 |  | | 50 | 50 |  | | 51 | 49 |  |   (a)  Total =  (b) |
| 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?* |
| Solution | (a)  (b)  (c)  (d) No, entropy decreases are possible, but unlikely. Also, in the second case,  is a small negative number, indicating that a spontaneous fluctuation in the system that decreases the entropy is not highly unlikely. |
| 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.* |
| Solution | (a)  (b)  (c) If you were betting on 2 heads and 8 tails, the odds of breaking even are 252 to 45, so on average you would break even. Therefore, no, you would not bet on odds of 252 to 45. |
| 62. | *(a) If you toss 10 coins, what percent of the time will you get the three most likely macrostates (6 heads and 4 tails, 5 heads and 5 tails, 4 heads and 6 tails)? (b) You can realistically toss 10 coins and count the number of heads and tails about twice a minute. At that rate, how long will it take on average to get either 10 heads and 0 tails or 0 heads and 10 tails?* |
| Solution | (a)  (b) The probability of 10H, 0T or 0H, 10T is  Thus, on average it will take 512 trials or, at a rate of 2 trials/min, 256 min. In hours, 256 min = 4.27 h |
| 63. | *(a) Construct a table showing the macrostates and all of the individual microstates for tossing 6 coins. (Use Table 15.5 as a guide.) (b) How many macrostates are there? (c) What is the total number of microstates? (d) What percent chance is there of tossing 5 heads and 1 tail? (e) How much more likely are you to toss 3 heads and 3 tails than 5 heads and 1 tail? (Take the ratio of the number of microstates to find out.)* |
| Solution | (a) 6 coin toss   | **Macrostate** | | **Individual Microstates** | **Number of Microstates** | | --- | --- | --- | --- | | **H** | **T** |  | | | 6 | 0 | HHHHHH | 1 | | 5 | 1 | HHHHHT HHHHTH HHHTHH HHTHHH HTHHHH THHHHH | 6 | | 4 | 2 | TTHHHH THTHHH THHTHH THHHTH THHHHT HTTHHH HTHTHH HTHHTH HTHHHT HHTTHH HHTHTH HHTHHT HHHTTH HHHTHT HHHHTT | 15 | | 3 | 3 | TTTHHH TTHTHH TTHHTH TTHHHT THTTHH  THTHTH THTHHT THHTTH THHTHT THHHTT  HTTTHH HTTHTH HTTHHT HTHTTH HTHTHT  HTHHTT HHTTTH HHTTHT HHTHTT HHHTTT | 20 | | 2 | 4 | Entries opposite of 4-2 | 15 | | 1 | 5 | TTTTTH TTTTHT TTTHTT TTHTTT THTTTT HTTTTT | 6 | | 0 | 6 | TTTTTT | 1 | |  |  |  | **64** | |
|  | (b) 7  (c) 64  (d)  (e) |
| 64. | *In an air conditioner, 12.65 MJ of heat transfer occurs from a cold environment in 1.00 h. (a) What mass of ice melting would involve the same heat transfer? (b) How many hours of operation would be equivalent to melting 900 kg of ice? (c) If ice costs 20 cents per kg, do you think the air conditioner could be operated more cheaply than by simply using ice? Describe in detail how you evaluate the relative costs.* |
| Solution | (a)  (b)  (c) For ice: cost/day =  From Problem 15.45b, we can calculate the cost of running air conditioner:  Clearly, the air conditioner could be operated more cheaply. |

# Test Prep For AP® Courses

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| 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. |
| Solution | (d) |
| 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.* |
| Solution | The block with the balls shaking a lot is at a higher temperature. From conservation of momentum and energy, we know that when a moving mass hits a stationary (or slower) one, energy gets transferred to the ball with less kinetic energy. When the two blocks are in contact, the process transfers energy from the higher temperature one to the lower temperature one. |
| 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 |
| Solution | (a) |
| 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.* |
| Solution | A 350 kcal item would be 1470 kJ, which would take ~ 32 minutes. |
| 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 |
| Solution | (b) |
| 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.* |
| Solution | They ought to be able to hit the points that work is done on this system, to transfer even more heat out, for a net reduction in internal energy. |
| 7. | *In Figure 15.43, how much work is done by the system in process AB?*  (A) 4.5 × 103 J  (B) 6.0 × 103 J  (C) 6.9 × 103 J (D) 7.8 × 103 J |
| Solution | (c) |
| 8. | *Consider process CD in Figure 15.43. Does this represent work done by or on the system, and how much?* |
| Solution | This represents work done on the system, 2.4 × 103 J |
| 9. | *A thermodynamic process begins at 1.2 × 106 N/m2 and 5 L. The state then changes to 1.2 × 106 N/m2 and 2 L. Next it becomes 2.2 × 106 N/m2 and 2 L. The next change is 2.2 × 106 N/m2 and 5 L. Finally, the system ends at 1.0 × 106 N/m2 and 5 L.*  *Based on Figure 15.42, this process is best described by*  (A) EFCDB  (B) DEFCD  (C) CFABC (D) CFABD |
| Solution | (d) |
| 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.* |
| Solution | The sketch should have an upper right corner and a lower left curve on a P–V graph. The isothermal process curve is inside the adiabatic curve. Hence the cycle with the adiabatic process covers more area and does more work per cycle. |
| 11. | *In Figure 15.43, which of the following cycles has the greatest net work output?*  (A) ABDA  (B) BCDB  (C) (A) and (B) are equal (D) ADCBA |
| Solution | (a) |
| 12. | *Look at Figure 15.42, 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?* |
| Solution | Actual calculations should be straightforward given that we have two rectangles. Note that the result is ABCF – FCDE. The heat input should be equal to the net work. To maximize net work, increase AB, make FC=ED, and decrease ED. |
| 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 |
| Solution | (c) |
| 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?* |
| Solution | Entropy is calculated as heat per temperature. So while the amount of heat is the same in all cases, in the irreversible case we have the low temperature reservoir gaining more entropy than the high temperature one loses, and no way to reverse this, within just this system. |
| 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. |
| Solution | (b) |
| 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.* |
| Solution | Using a checkers set, place all of the black pieces onto the board. Stack all of the red pieces on one of the black pieces. All pieces move one space each turn. If they would bump into each other, they each move to the nearest open space. When this happens, if one has more red pieces than the other, give the piece with fewer red pieces one from the piece with more. |

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