End-of-Chapter Exercises

Exercises 1 – 12 are conceptual questions that are designed to see if you have understood the main concepts of the chapter.

1. Two cylinders of ideal gas are initially identical (same pressure, volume, number of moles, and temperature) except that, in cylinder 1, the piston is free to move up or down without friction while, in cylinder 2, the piston is fixed in place so the volume occupied by the gas is constant. The same amount of heat is then added to both cylinders. Rank the cylinders based on (a) the final temperature of the gas, (b) the change in internal energy for the gas, and (c) the final pressure of the gas.

2. A system of ideal gas can be taken from state 3 to state 4 by three different paths labeled A, B, and C on the P-V diagram in Figure 15.22. Rank these paths based on (a) the work done by the gas; (b) the change in internal energy of the gas; (c) the heat transferred to the gas.
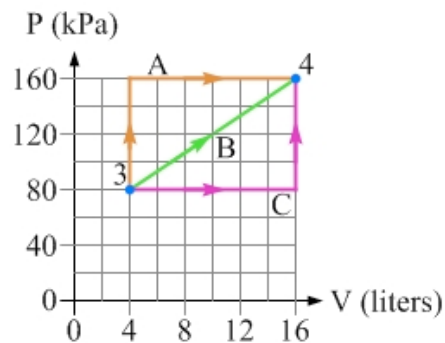
3. Consider two systems, each containing the same number of moles of ideal gas at the same initial pressure, volume, and temperature. In system A, the temperature is then doubled by adding heat at constant volume. In system B, the temperature is doubled by adding heat at constant pressure. (a) Under these conditions, which system would you expect to need more heat to be transferred to it, to achieve the doubling of the temperature? Why? (b) It turns out that exactly the same amount of heat is added to each system to double the temperature. Upon closer inspection, you find that the gases are different in the two systems. In what way are they different?

P (kPa)

Figure 15.22: A system is taken from state 3 to state 4 by one of three possible paths. For Exercise 2.

4. A system of monatomic ideal gas is in a particular initial state. You now have a choice between three different processes, each of which double the volume occupied by the gas. Process A is an isothermal (constant temperature) expansion, process B is an adiabatic expansion, and process C is an isobaric (constant pressure) expansion. Rank these three processes, from most positive to most negative, based on (a) the work done by the gas, (b) the change in internal energy of the gas, and (c) the heat transferred to the gas during the process.

5. Is it possible to accomplish any of the following with a sample of ideal gas? If so, explain how you would do it. If not, explain why not. (a) Add heat to a system without changing the system's temperature. (b) Increase the temperature of a system without adding heat. (c) Add heat to a system while decreasing the temperature. (d) Change the temperature of a system that is so well-insulated that no heat is transferred between the system and its surroundings.

6. A system of ideal gas is in a particular initial state, and you will add a particular amount of heat Q to the system.
   Process A: Add the heat at constant temperature.
   Process B: Add the heat at constant volume.
   Process C: Add the heat at constant pressure.
   Which process should you use if you want the system to end up (a) doing the most work? (b) with the maximum possible final temperature? (c) with the maximum possible final volume? (d) with the maximum possible final pressure?

7. Return to the situation described in Exercise 6. Rank the three processes based on (a) the work done by the gas in the process. (b) the final temperature of the system. (c) the final volume of the system. (d) the final pressure of the system.

8. A system of ideal gas is in a particular initial state, and you want the system to do a particular amount of work, *W*. You have three different processes to choose from. Process A is a constant pressure process; process B is done at constant temperature; while process C is an adiabatic process. (a) Sketch a P-V diagram showing the three different processes. Which process should you use if you want the system to end up (b) using the smallest amount of heat? (c) with the maximum possible final temperature? (d) with the maximum possible final volume? (e) with the minimum possible final pressure?

9. Return to the situation described in Exercise 8. Rank the three processes based on (a) the heat required by the process. (b) the final temperature of the system. (c) the final volume of the system. (d) the final pressure of the system.

10. A system of ideal gas is in a particular initial state, and you want to double the absolute temperature of the system. You have three different processes to choose from. Process A is a constant pressure process; process B is done at constant volume; while process C is an adiabatic process. (a) Sketch a P-V diagram showing the three different processes. Which process should you use if you want the system to end up (b) with the maximum possible final volume? (c) with the minimum possible final pressure?

11. Return to the situation described in Exercise 10. Rank the three processes based on (a) the heat required by the process. (b) the final temperature of the system. (c) the final volume of the system. (d) the final pressure of the system.

12. On a hot day, you decide to open your fridge door to be cooled by the cold air inside the fridge. In the short term, this is effective for cooling you down. If you left the fridge door open for a long time, however, with the refrigerator running, would the room end up warmer, cooler, or the same temperature as it was when you first opened the door? Explain.

Exercises 13 – 16 deal with heat, change in internal energy, and work, the three parameters that are connected by the first law of thermodynamics.

13. Two cylinders of ideal gas are initially identical (same pressure, volume, number of moles, and temperature) except that in cylinder 1 the piston is free to move up or down without friction, while in cylinder 2 the piston is fixed in place so the volume occupied by the gas is constant. The temperature in each cylinder is initially 50°C. Each cylinder is then placed in a container of ice water that is maintained at 0°C, and allowed to come to equilibrium. (a) Which cylinder has more heat removed from it in this process? (b) Which cylinder experiences the larger change in internal energy in this process? Justify your answers.

14. (a) How much work is done by the gas in the process shown in Figure 15.23? (b) If the gas is monatomic, what is the change in internal energy associated with the process? (c) How much heat is involved in this process? (d) Is heat transferred into the gas or transferred out of the gas?
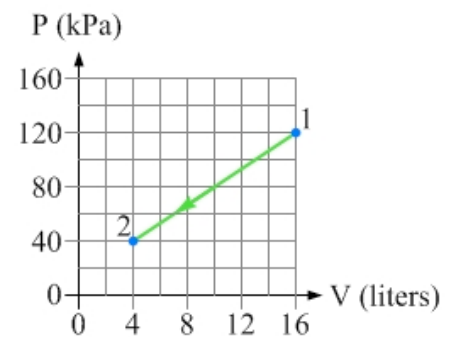
Figure 15.23: A system is taken from state 1 to state 2 by the process shown. For Exercise 14.

P (kPa)

15. A system of ideal gas can be taken from state 3 to state 4 by three different paths labeled A, B, and C on the P-V diagram in Figure 15.24. Assume the gas is diatomic. For each of the three paths, calculate (a) the work done by the gas; (b) the change in internal energy of the gas; (c) the heat transferred to the gas.
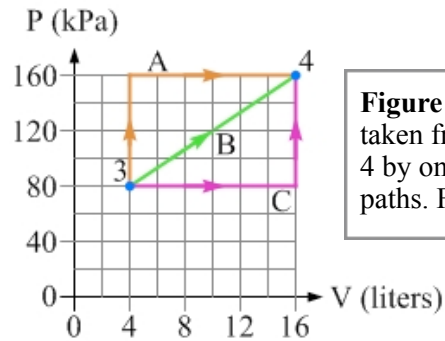
Figure 15.24: A system is taken from state 3 to state 4 by one of three possible paths. For Exercise 15.

16. A system of monatomic ideal gas contains a certain number of moles of gas so that $nR = 0.200$ J/K . The system is taken from state 5 to state 6 (see Figure 15.25) by an unknown sequence of processes. (a) What is the temperature of the system in state 6? (b) What is the work done by the gas as the system moves from state 5 to state 6? (c) What is the change in internal energy of the gas as it moves from state 5 to state 6?
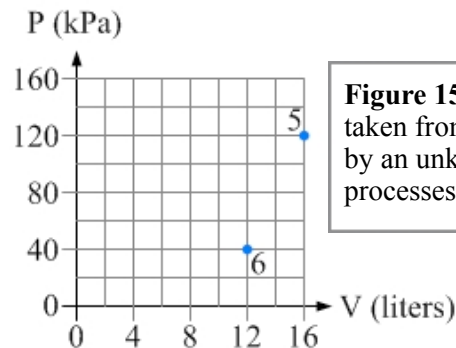

Figure 15.25: A system is taken from state 5 to state 6 by an unknown sequence of processes. For Exercise 16.

Exercises 17 – 21 deal with constant volume and constant pressure processes.

17. A cylinder of diatomic ideal gas is sealed in a cylinder by a piston that is fixed in place so the gas occupies a constant volume of 2.0 L. The pressure is initially 100 kPa, and the temperature is 400 K. The temperature is then decreased to 200 K by means of a constant volume process. (a) Sketch this process on a P-V diagram, and mark the final state of the system accurately on the diagram. (b) Find the work done by the gas in this process. (c) Find the change in internal energy of the gas in this process. (d) Find the amount of heat removed from the gas in this process. (e) Find the final internal energy of the gas.

18. Repeat Exercise 17, but this time the gas is monatomic instead of diatomic.

19. Repeat Exercise 17, but this time the piston is free to move without friction, and the decrease in temperature from 400 K to 200 K is done via a process in which the pressure remains constant at 100 kPa.

20. Four different processes are shown on the P-V diagram in Figure 15.26. The processes are carried out on a system of diatomic ideal gas. Rank these processes, from most positive to most negative, based on (a) the work done by the gas during the process, and (b) the change in internal energy of the gas during the process. Express your rankings in a form like 2>1=3>4.
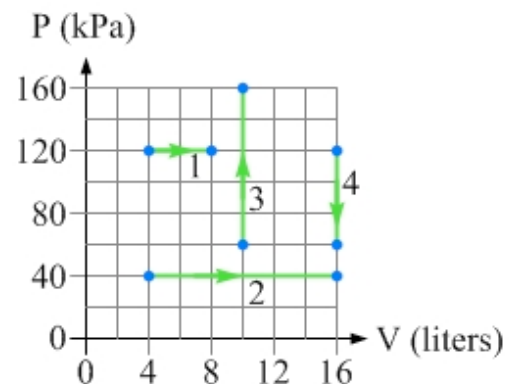

21. Return to the situation described in Exercise 20 and shown in Figure 15.26. (a) For the process in which the work done by the gas is most positive, calculate the work. (b) For the process in which the internal energy of the gas increases by the largest amount, calculate that change in internal energy.

Figure 15.26: A P-V diagram showing four different processes, for Exercises 20 and 21.

Exercises 22 – 27 deal with constant temperature and adiabatic processes.

22. A cylinder of monatomic ideal gas is sealed in a cylinder by a piston. The gas occupies a volume of 2.0 L. The pressure is initially 100 kPa, and cylinder is placed in an oven that maintains the temperature at 400 K. 100 J of work is then done on the piston, compressing the gas (in other words, the gas does –100 J of work). The work is done very slowly so that the gas maintains a constant temperature. (a) Sketch this process on a P-V diagram, shading in the region corresponding to the work done by the gas. (b) Find the change in internal energy of the gas in this process. (c) Find the final volume occupied by the gas. (d) Find the final pressure of the gas.

23. Repeat Exercise 22, but now the compression of the system is done very quickly so there is no time for heat to be transferred between the system and its surroundings. In other words, the process is adiabatic.

24. A system of diatomic ideal gas is in an initial state such that the pressure is 80 kPa and the volume occupied by the gas is 6.0 L. The system then experiences a compression at constant temperature that raises the pressure to 150 kPa. (a) Find the final volume occupied by the gas. (b) Find the work done by the gas in this process. (c) Find the ratio of the final temperature to the initial temperature.

25. Repeat Exercise 24, but now the compression that raises the pressure of the system to 150 kPa is an adiabatic process.

26. A system of monatomic ideal gas is in an initial state such that the pressure is 120 kPa and the volume occupied by the gas is 3.0 L. The system then experiences an expansion at constant temperature that increases the volume occupied by the gas to 8.0 L. (a) Find the final pressure of the gas. (b) Find the work done by the gas in this process. (c) Find the ratio of the final temperature to the initial temperature.

27. Repeat Exercise 26, but now the expansion that increases the volume to 8.0 L is an adiabatic process.

Exercises 28 – 31 deal with thermodynamic processes in general. Make use of the various tools for solving thermodynamic problems, outlined in section 15-5.

28. A system of diatomic ideal gas with an initial temperature of 500K is taken from an initial state i to a final state f by the process shown on the P-V diagram in Figure 15.27. Determine (a) the work done by the gas in the process. (b) the final temperature of the system. (c) the change in internal energy of the gas. (d) the heat associated with the process.

29. A system of monatomic ideal gas has an initial pressure of 100 kPa, a temperature of 400K, and a number of moles such that the product $nR = 2.0$ J/K . 1000 J of heat is then added to the system, while the pressure remains constant. Determine (a) the work done by the gas in the process, and (b) the final temperature of the gas. (c) Sketch an accurate P-V diagram for this process.
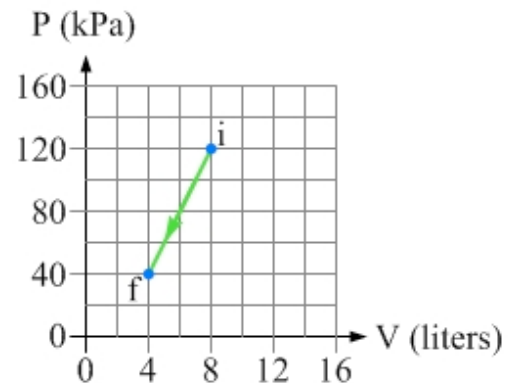

Figure 15.27: A process carried out on a system of diatomic ideal gas, for Exercise 28.

P (kPa)

30. A system of monatomic ideal gas has an initial volume of 12 liters, a temperature of 600K, and a number of moles such that the product $nR = 0.50$ J/K. 200 J of heat is then removed from the system at constant temperature. Determine (a) the work done by the gas in the process, and (b) the final volume occupied by the gas. (c) Sketch an accurate P-V diagram for this process.

31. A system of diatomic ideal gas is taken through the process shown in Figure 15.28. The process has the shape of a ¼-circle on the P-V diagram. For this process, find (a) the work done by the gas, (b) the change in internal energy, and (c) the heat added to the gas.
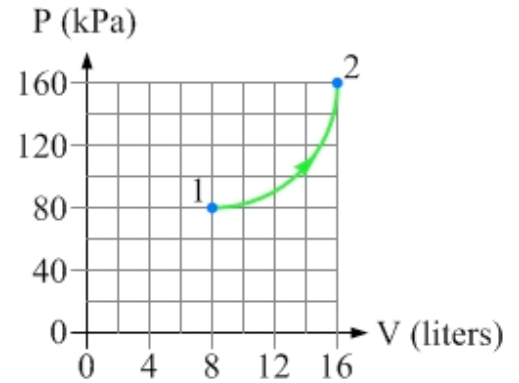
Figure 15.28: P-V diagram for a process taking a diatomic ideal gas from state 1 to state 2, for Exercise 31.

Exercises 32 – 38 deal with thermodynamic cycles.

32. Complete Table 15.6, where the process taking the system from state 2 to state 3 is isothermal.

Process	Q (J)	W (J)	ΔE_{int} (J)
1 → 2			-300
2 → 3	+200		
3 → 1		+100	
Entire Cycle	+500		

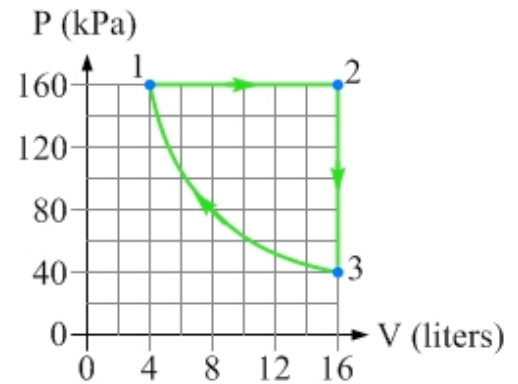**Table 15.6**: A table for a three-process cycle, for Exercise 32.

Figure 15.29: A three-process cycle, for Exercises 33 and 34.

33. Consider the P-V diagram for a three-process cycle in Figure 15.29. The cycle consists of a constant pressure process, a constant volume process, and an isothermal process at a temperature of 500 K. The system consists of a particular amount of a diatomic ideal gas. For this cycle, construct a table like that shown in Table 15.6.

34. Consider again the situation described in Exercise 33, and shown in Figure 15.29. What happens to all the values in the table when the cycle is carried out in the direction opposite to that shown in the P-V diagram, going from state 1 to 3 to 2 to 1?

35. Consider the following four-process cycle that is carried out on a system of monatomic ideal gas, starting from state 1 in which the pressure is 120 kPa and the volume is 4.0 liters. Process A is a constant-pressure process that doubles the volume; process B is an isothermal process, doubling the volume from the previous state; process C is a constant volume process that returns the system to its initial temperature; and process D is an isothermal process that returns the system to state 1. (a) Sketch a P-V diagram for this cycle. (b) Calculate the net work done by the gas in this cycle.

36. Consider the following four-process cycle that is carried out on a system of monatomic ideal gas, starting from state 1 in which the pressure is 80 kPa and the volume is 4.0 liters. Process A is an isothermal process that triples the volume; process B is a constant volume process that returns the system to a pressure of 80 kPa; process C is an isothermal process that returns the system to a volume of 4.0 liters; and process D is a constant volume process that returns the system to state 1. (a) Sketch a P-V diagram for this cycle. (b) For this cycle, construct a table like that shown in Table 15.6.

37. Consider the four-process cycle shown in the P-V diagram in Figure 15.30. (a) What does the area of the enclosed region, shown in red, represent? (b) What is the area of one of the boxes on the P-V diagram? (c) Estimate how many such boxes it would take to equal the area of the enclosed region. (d) Estimate the work done by the gas in one cycle.

38. Consider the four-process cycle shown in the P-V diagram in Figure 15.30. Find the work done by the gas in the process taking the system from (a) state 1 to state 2, (b) state 2 to state 3, (c) state 3 to state 4, (d) state 4 to state 1. For the entire cycle determine (e) the net work done by the gas, (f) the net change in internal energy of the gas, and (g) the net heat added to the gas.
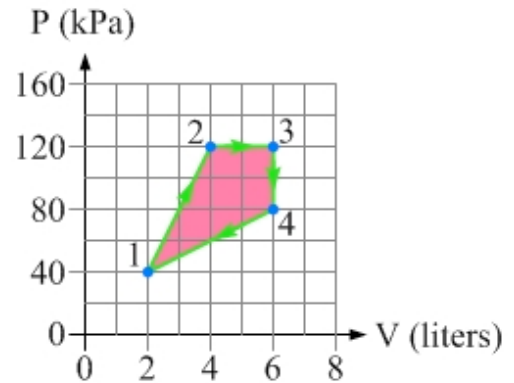

Figure 15.30: The P-V diagram for a four-process cycle, for Exercises 37 and 38.

Exercises 39 – 42 deal with entropy, the second law of thermodynamics, and heat engines.

39. You have two containers of water. In one container there is 1.0 kg of water at 7.0°C, while in the second container there is 5.0 kg of water at 27°C. You then pour the water in the first container into the second container and allow the system to come to equilibrium. Assuming no heat is transferred from the water to the container or the surroundings, determine the change in entropy for (a) the water that is initially cooler, (b) the water that is initially warmer, and (c) the system.

40. You have two containers of water. In one container there is 5.0 kg of water at 7.0°C, while in the second container there is 1.0 kg of water at 27°C. You then pour the water in the first container into the second container and allow the system to come to equilibrium. Assuming no heat is transferred from the water to the container or the surroundings, determine the change in entropy for (a) the water that is initially cooler, (b) the water that is initially warmer, and (c) the system.

41. In Section 15-8, we discussed the Carnot cycle, the cycle for a Carnot engine. Let's now examine the Stirling cycle, the cycle for a Stirling engine. The four processes are:
    Process A: Expansion at constant temperature T_H.
    Process B: Removing heat at a constant volume V_2.
    Process C: Contraction at constant temperature T_L (say $T_H = 2T_L$).
    Process D: Adding heat at constant volume V_1 (say $V_2 = 2V_1$).

Process D returns the system to its initial state. (a) Sketch a P-V diagram for this cycle. (b) Create a table to show, for each process and the entire cycle, whether the heat, work, change in internal energy, and change in entropy, is positive, negative, or zero.

42. Return to the situation described in Exercise 41. Let's say the system uses monatomic ideal gas, that $V_1 = 8.0\,\text{L}$, $T_L = 300\,\text{K}$, and the pressure in the initial state is $P_1 = 150\,\text{kPa}$. (a) Determine the net work done by the engine in one cycle. (b) Calculate the efficiency of the engine by dividing the net work done by the total amount of heat added to the system during processes A and D. (c) Compare your answer in part (b) to the ideal efficiency of an engine operating between temperatures of T_L and T_H.

43. A particular car engine operates between temperatures of $T_H = 400°\text{C}$ (inside the cylinders of the engine) and $T_L = 20°\text{C}$ (the temperature of the surroundings). (a) Given these two temperatures, what is the maximum possible efficiency the car can have? (b) With this maximum efficiency, determine how much heat must be obtained by burning fuel in the car's engine to accelerate a 1500 kg car from rest to a speed of 100 km/h (neglect resistive forces).

44. A refrigerator is characterized by a number called the coefficient of performance (COP), which is defined as the heat removed from the cool place (inside the fridge) divided by the work required to remove that heat: $COP = Q_L / W$. (a) If you are buying a new fridge is it better to buy one with a higher COP or a lower COP? Let's say that a fridge operates between temperatures of $T_L = 4°\text{C}$ and $T_H = 30°\text{C}$. A particular fridge has a COP of 6.0.
(b) If 500 J of work is done by the compressor in the fridge to extract heat from inside the fridge, how much heat is removed from inside the fridge? (c) How much heat is dumped by the fridge into the surroundings, in this case? (d) What is the maximum possible COP that would be achieved by an ideal fridge operating between the two temperatures specified above?

45. An air conditioner and a refrigerator operate on the same principles, so the definition of coefficient of performance given in the previous exercise applies to air conditioners as well as refrigerators. Let's say a particular air conditioner has a COP of 7.5 when operating between temperatures of $T_L = 20°\text{C}$ (inside your house) and $T_H = 30°\text{C}$ (outside your house). (a) Is this an ideal device? Explain. (b) If the outside temperature increased to 35°C, would you expect this to change the coefficient of performance? Explain.

General problems and conceptual questions

46. In Section 15-2, we calculated the work done by the gas, and the change in internal energy of the gas, for a system of diatomic ideal gas that went from state 1 to state 2 and then to state 3 (see Figure 15.6). Determine the heat Q associated with the process that takes the system from (a) state 1 to state 2 (b) state 2 to state 3.

47. In section 15-2, we examined a system of diatomic ideal gas that was moved from state 1 to state 3 via state 2. Let's now bring the same system from state 1 to state 3 via state 4, as shown in Figure 15.31. Draw your own version of the P-V diagram, and then shade in the region that corresponds to the work done in moving the system from (a) state 1 to state 4 (b) state 4 to state 3. (c) Calculate the work done by the gas in these two processes.

P (kPa)

48. Consider the system of diatomic ideal gas described in Exercise 47, and the processes shown on the P-V diagram in Figure 15.31. For the two processes shown, calculate (a) the change in internal energy of the gas, and (b) the heat added to the gas.
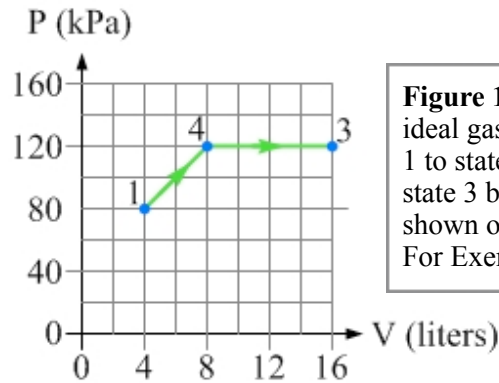
Figure 15.31: A system of ideal gas is moved from state 1 to state 4 and then on to state 3 by the processes shown on the P-V diagram. For Exercises 47 – 49.

49. Re-do Exercise 48. This time, the gas is monatomic instead of diatomic.

50. A system of monatomic ideal gas is moved from state 1 to state 2 by the process shown in Figure 15.32. (a) Determine the work done by the gas in this process. (b) Determine the change in internal energy for this process. (c) Determine the amount of heat associated with this process, and state whether heat was transferred into the gas or out of the gas.
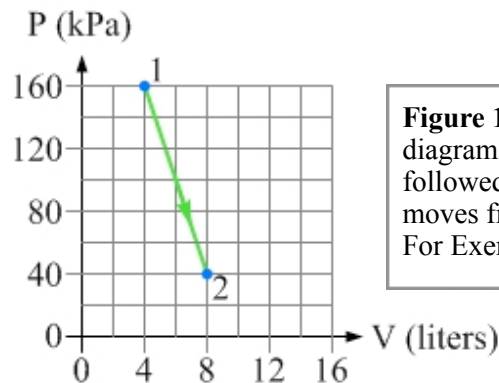
Figure 15.32: The P-V diagram shows the process followed by a system as it moves from state 1 to state 2. For Exercise 50.

51. A system of monatomic ideal gas is initially in state i, as shown in Figure 15.33. Compare the following situations, in which the system starts in the initial state i in each case. In case 1, the system's volume is increased by 4.0 L in a constant-pressure process. In case 2, the volume is decreased by 4.0 L in a constant-pressure process. (a) Sketch these two cases on a P-V diagram. (b) In which case is the magnitude of the work done by the gas larger? Explain your answer. (c) Calculate the work done by the gas in case 2.
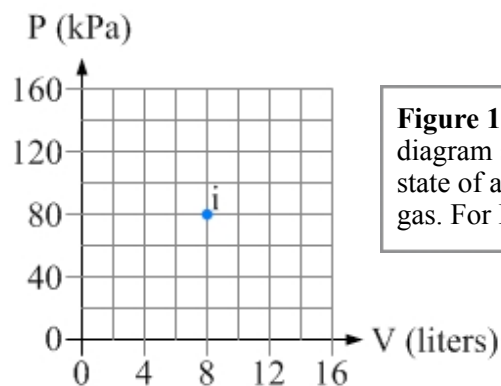
Figure 15.33: The P-V diagram shows the initial state of a system of ideal gas. For Exercises 51 – 53.

52. Repeat Exercise 51, but this time the changes in volume occur at constant temperature instead of at constant pressure.

53. Repeat Exercise 51 but, this time, the changes in volume have magnitudes of 2.0 L and occur during adiabatic processes.

54. (a) Why does a bicycle pump get hot as you pump it? (b) The pump is first filled with air, which we can approximate as a diatomic ideal gas, at room temperature and atmospheric pressure. You then quickly compress the gas, increasing the pressure by a factor of 5. Estimate the final temperature of the gas in this process.

55. A system of ideal gas has an initial pressure of 100 kPa and occupies a volume of 8.0 liters. Doubling the system's absolute temperature by means of a constant pressure process would require an amount of work W. Instead, you decide to double the absolute temperature by carrying out two processes in sequence, a constant volume process followed by a constant pressure process. Find the final pressure and volume of the system if the total work done in the sequence of processes is (a) $W/2$, or (b) 1.5 W.

56. Repeat Exercise 55 but, this time, the sequence of processes used to double the temperature is done in reverse order. First, you do a constant pressure process, and then you do a constant volume process.

57. Consider what happens to entropy when a house is built. The construction involves taking a large number of bricks, pieces of wood, nails, cans of paint, wires, pipes, etc., and putting them together into a well-ordered system. Does this process violate the second law of thermodynamics? Explain.

58. Return to the description of the Carnot cycle in Section 15-8. The P-V diagram for the Carnot cycle can be hard to follow, because none of the processes is a straight line. Let's consider the T-S (temperature-entropy) diagram for the Carnot cycle instead, shown in Figure 15.34. For the Carnot cycle, the T-S diagram is a rectangle. (a) The area under the curve on a P-V diagram represents the work done by the gas. What does the area under the curve represent on the T-S diagram? (b) The area of the region enclosed by a cycle on a P-V diagram represents the net work done by the gas in one cycle. What does the area of the region enclosed by a cycle on the T-S diagram represent?
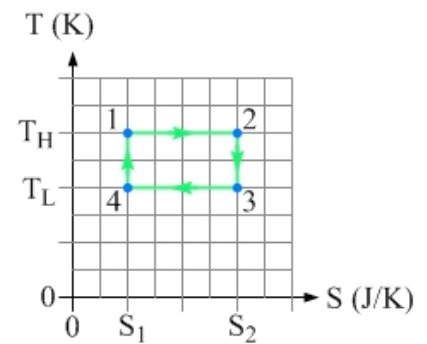

Figure 15.34: T-S (temperature-entropy) diagram for the Carnot cycle.

59. Ocean Thermal Energy Conversion (OTEC) generates electricity using the difference between the temperatures at the surface of the ocean, where the water is warm, and far below the surface, where the water is cool. A test system off Hawaii operated between temperatures of 80°F (the water temperature at the surface) and 40°F (the temperature far below the surface), and operated with an efficiency of about 2.3%. (a) What is the maximum efficiency we could expect from this system? (b) At the maximum efficiency, let's say the plant generates electricity at the rate of 100 MW. At what rate is energy being removed from the warm surface water? (c) At what rate is energy being deposited into the cooler sub-surface water?

60. Do some research on the Ocean Thermal Energy Conversion process described in Exercise 59, and write a paragraph or two describing how it works. Comment, in particular, on whether this idea is feasible for generating electricity, as well as on the environmental impact of such a system.

61. Comment on each statement in the following conversation between two students.

Jesse: This question talks about a thermodynamic system that is so well insulated that no heat is transferred between the system and the surrounding environment. That must mean that the temperature of the system stays constant, right?

Scott: I think so. That's the way it works in your house - the more insulation you have, the more constant the temperature of your house is.

Jesse: So, because the temperature is constant, there is no change in internal energy, and with no heat transferred there must also be no work done, right?