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. An American named Bill is visiting London, England. Listening to the weather forecast, Bill hears that the temperature will be 25°. Back home in New York, this would be a relatively cold day, so Bill puts on warm clothing. When Bill goes out of his hotel on his way to Trafalgar Square, however, he realizes that the temperature is much warmer than he thought. (a) What happened? (b) On the temperature scale that Bill is used to, what is the temperature?

2. A density ball is a ball that is weighted so its density is very similar to that of water. The ball floats in cold water but sinks in warm water. Explain why.

3. A solid iron disk is rotating without friction about an axle through its center. The Sun then comes out from behind a cloud and increases the temperature of the disk. You notice that the disk's angular velocity changes a little. What is responsible for the change, and does the disk speed up or slow down?

4. The graph in Figure 13.5 shows the temperature of a sample of an unknown material as a function of time. Heat is either being transferred into or out of this sample at a steady rate. (a) Is heat being transferred into or out of the sample? How do you know? (b) Does it look like the material undergoes a phase change? How can you tell? (c) If, over the period shown in the graph, the sample is in the solid phase for part of the time and is in the liquid phase for another part of the time, how do its two specific heat capacities compare? If possible, find the ratio of the specific heat capacity in the solid phase to the specific heat capacity in the liquid phase.

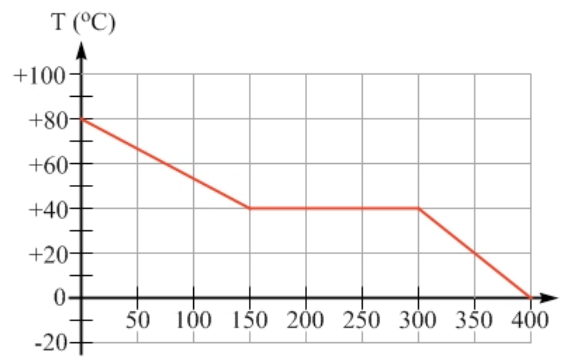

Figure 13.5: A graph of temperature as a function of time for a sample to which heat is being transferred at a constant rate, for Exercise 4.

5. A bimetallic strip is actually made from strips of two different metals that are bonded together back-to-back, as shown in Figure 13.6. The two strips have the same length at room temperature, 20°C. If the temperature changes, the two strips expand or contract different amounts, causing the bimetallic strip to bend into a circular arc, as shown in Figure 13.6, with the longer strip on the outside of the arc. (a) If the bimetallic strip in Figure 13.6 is composed of a strip of brass bonded to a strip of iron, which side is which? Why? (b) Bimetallic strips are often used as switches in thermostats, turning a furnace on if the temperature falls below a certain pre-set minimum value and turning the furnace off again when the temperature has risen sufficiently. Briefly explain how this process works.

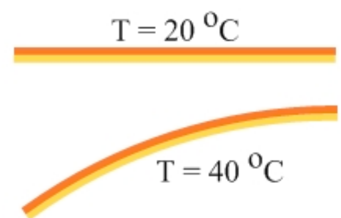

Figure 13.6: A bimetallic strip, for Exercise 5.

6. You have three blocks of equal mass. Block A is made of aluminum; block B is made of gold; and block C is made of copper. Each block starts at room temperature, 20°C. 100 J of energy is then added to each of the blocks. Rank the blocks based on their final temperatures, from largest to smallest.

7. You have three blocks. Block A is made of aluminum, block B is made of gold, and block C is made of copper. The blocks start at the same temperature. When 50 J of heat is added to each block, the blocks also have the same final temperature. Rank the blocks based on their masses, from largest to smallest.

8. You have three blocks of equal mass. Block A is made of aluminum; block B is made of gold; and block C is made of copper. Each block is initially at 80°C. You also have three identical Styrofoam cups, each containing the same amount of water at 10°C. You add one block to each of the cups and measure the final temperature. Assuming no heat is transferred to the cup or the surroundings, rank the final temperatures from highest to lowest.

9. You have three blocks. Block A is made of aluminum; block B is made of gold; and block C is made of copper. Each block is initially at 80°C. You also have three identical Styrofoam cups, each containing the same amount of water at 10°C. You add one block to each of the cups and measure the final temperature, which is exactly the same in each case. Assuming no heat is transferred to the cup or the surroundings, rank the blocks from largest to smallest based on their masses.

10. You decide to have spaghetti for dinner, so you fill a large pot with water and place it on the stove. While you are waiting for the water to boil, you decide to do an experiment, so you place a couple of drops of food coloring in the water to observe what the water is doing. You observe that the water is moving, with some water rising from the bottom of the pot to the top, moving sideways at the top, and then gradually falling back down to the bottom of the pot again. Which of the three heat transfer mechanisms are you observing here? Explain how it works.

11. You take two identical shiny metal cans and paint one black. You then place them out in the sun on a hot summer's day, and measure their temperatures as a function of time. (a) If the cans are initially at 20°C, which can reaches 30°C first? Why? (b) Later on, you take the cans inside and fill them both with hot water so both cans are initially at 95°C. Again you measure their temperatures as a function of time. Which can reaches 85°C first? Why?

12. Thin films of diamond are used on computer chips to ensure that the chips do not get too hot. Why is diamond such a good material for this application?

Exercises 13 – 16 deal with temperature scales and conversions between temperature scales.

13. What is the conversion equation to transform from (a) Fahrenheit to Kelvin? (b) Kelvin to Fahrenheit?

14. (a) What is the Rankine temperature scale? What is the equation for converting from the Rankine scale to (b) the Fahrenheit scale? (c) the Kelvin scale?

15. While visiting Toronto, Canada, James buys a cake mix at the grocery store. When James gets home to Los Angeles he tries baking the cake. He carefully follows the instructions on the package, including baking the cake at 250° for 45 minutes, but the cake is a disaster. (a) Explain what happened. (b) Did James burn the cake or was it underdone? (c) To what temperature should James have set his oven?

16. Liquid nitrogen boils at a temperature of 77K. What is this in (a) Celsius? (b) Fahrenheit?

Questions 17 – 21 deal with thermal expansion.

17. An iron ring has an inner radius of 2.5000 cm and an outer radius of 3.5000 cm, giving the ring a thickness of 1.0000 cm. If the temperature of the ring is increased from 20°C to 80°C, what is the thickness of the ring?

18. Do you think it is important for bridge designers to worry about thermal expansion when they design bridges? Why? Carry out the following two calculations to support your answer. At 10°C, a particular steel bridge has a length of precisely 500 m. Find the length of the bridge on a hot summer day when the temperature reaches 40°C. Then find the length in the middle of winter when the temperature drops to –30°C.

19. Liquid water has a linear thermal expansion coefficient of 70 x 10^{-6} /°C. You absent-mindedly fill an aluminum pot to the brim with water. Both the pot and the water are at 20°C. You then want to bring the water to a boil, so you put the pot on the stove to heat the water. (a) Assuming the temperature of the water and the pot are always equal, what happens as the temperature increases? Does the water spill out of the pot or does the water level fall relative to the top of the pot? Explain. Neglect any loss of water because of evaporation. (b) When the temperature reaches 80°C, determine either what fraction of the original water has overflowed the pot, or what fraction of the volume inside the pot is no longer occupied by water.

20. In section 13.2, we derived the following expression for the area A resulting from imposing a temperature change ΔT on an object of original area A_0 : $A = A_0\left[1 + 2\alpha\,\Delta T + (\alpha\,\Delta T)^2\right]$. We then argued that the $(\alpha\,\Delta T)^2$ inside the bracket is negligible in comparison to the $2\alpha\,\Delta T$ term. Let's check that to see the effect of neglecting the last term. Start with an aluminum cylinder with a cross-sectional area of 5.000000 cm². Compute the new cross-sectional area when the temperature is increased by 100°C by (a) using the complete area equation above; (b) using the approximation $A = A_0[1 + 2\alpha\,\Delta T]$. (c) What is the percentage difference between your two answers? (d) Based on this, do you think it is reasonable to neglect the $(\alpha\,\Delta T)^2$ term?

21. A solid iron disk is rotating without friction about an axle through its center. The Sun then comes out from behind a cloud and increases the temperature of the disk. You notice that the disk's angular velocity changes a little. When the temperature is 20°C, the disk's radius is 15.00 cm, and the angular speed of the disk is 20.00 rad/s. What is the disk's angular speed when its temperature is 60°C?

Exercises 22 – 27 are designed to give you practice applying the general method for solving a thermal equilibrium problem. For each of these exercises, begin with the following steps:

(a) Write out in words a brief description of the various heats involved.
(b) Apply $\sum Q = 0$ to obtain an equation of the form $Q_1 + Q_2 + \ldots = 0$. Each Q corresponds to one of the brief descriptions you wrote in part (a).
(c) For any temperature changes, apply the equation $Q = m\,c\,\Delta T$. Express each ΔT as $T_{final} - T_{initial}$. For any changes of phase, apply the equation $Q = m\,L_f$ or $Q = m\,L_v$. Use a positive sign if heat must be added to produce the phase change, and a negative sign if heat must be removed.

22. An aluminum block with a mass of 300 g and a temperature of 80°C is placed in a Styrofoam cup that contains 500 g of water at 10°C. Ignore any temperature change associated with the Styrofoam cup. Start by doing parts (a) – (c) as described above. (d) Find the equilibrium temperature.

23. Repeat Exercise 22, but now the water is in an aluminum container that has a mass of 200 g and is initially at the temperature of the water. The block, container, and water all come to the same final temperature.

24. A copper block with a mass of 500 g is cooled to 77K by being immersed in liquid nitrogen. The block is then placed in a Styrofoam cup containing some water that is initially at +50°C. Assume no heat is transferred to the cup or the surroundings. The goal of the exercise is to determine the mass of water in the cup, if the final temperature is +20°C. Start by doing parts (a) – (c) as described above. (d) Find the mass of the water.

25. Repeat Exercise 24, but this time the final temperature is –20°C.

26. Repeat Exercise 24, but this time the final temperature is 0°C. Start by doing parts (a) – (c) as described above. (d) Find the maximum mass of water in the cup. (e) Find the minimum mass of water in the cup.

27. Repeat Exercise 24, but this time the water is in an aluminum cup that has a mass of 300 g. Assume the temperature of the cup is equal to the temperature of the water at all times.

Exercises 28 – 32 are designed to give you practice solving problems in which heat (*q*) is added or removed from a system. Applying $\sum Q = q$ should help you answer these exercises.

28. A Styrofoam cup contains 200 g of water at 20°C. The cup is then placed in the freezer. The freezer can remove heat from the water at a steady rate of 50 W. (a) If we neglect any heat transfer involving the Styrofoam cup, how long does it take until the cup contains ice at –5°C? (b) Plot a graph of the temperature of the water as a function of time as the water cools from 20°C to –5°C.

29. Return to the situation described in Exercise 28, except now the water is placed in a 300 g aluminum container. The temperature of the container matches the water at all times and, because aluminum has a larger thermal conductivity than Styrofoam, the freezer removes heat from the aluminum-water system at a rate of 90 W. How long does it take the temperature of the system to drop from 20°C to –5°C now?

30. 500 g of water at 20°C is in a pot on the stove. An unknown mass of ice that is originally at –10°C is placed in an identical pot on the stove. Heat is then added to the two samples of water at precisely the same constant rate. You observe that both samples of water reach 80°C at the same time. (a) How does the mass of the ice in the second pot compare to the mass of the water in the first pot? (b) Which system reaches 90°C first? (c) Solve for the mass of the ice.

31. You have a 100 g block of lead that you intend to melt and then pour into a mold to form a bell. The lead is initially at room temperature, 20°C. You then add heat to the lead at a steady rate of 200 W. (a) How long does it take for the lead to reach its melting point? (b) How much additional time is required to completely melt the lead block? (c) Graph the temperature of the sample versus time, ending the graph when the lead is completely melted.

32. The graph in Figure 13.7 shows the temperature of a sample of an unknown material as a function of time. Heat is either being transferred into or out of this sample at a steady rate. Over the period shown in the graph, the sample is in the solid phase for part of the time and is in the liquid phase for another part of the time. (a) Is heat being transferred into or out of this sample? (b) What is the material's melting point? (c) What is the ratio of the material's specific heat when liquid to the specific heat when solid?

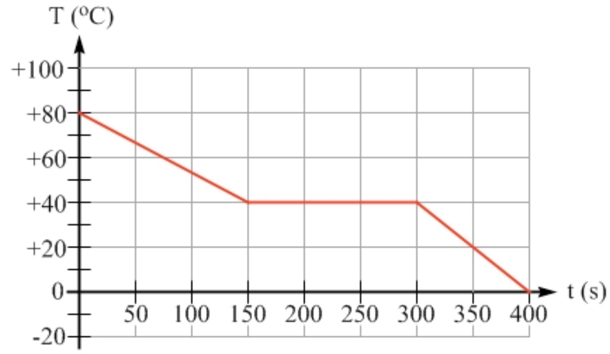

Figure 13.7: A graph of temperature as a function of time for a sample to which heat is being transferred at a constant rate, for Exercise 32.

Exercises 33 – 35 involve the energy-transfer mechanisms of convection, conduction, or radiation.

33. To keep yourself warm in the winter, you heat a solid metal ball and place it on a stand in the center of your room. The ball has a radius of 10.0 cm and an emissivity of 0.82. If your room has a temperature of 15°C, what is the net power radiated by the ball initially, when the ball's temperature is 200°C?

34. You have two rods that have the same dimensions but which are made from different materials. One rod is made of brass while the other is made of copper, and each rod is 1.00 m long. The rods are joined end-to-end, as shown in Figure 13.8. The far end of the brass rod is maintained at a temperature of 0°C, while the far end of the copper rod is maintained at a temperature of 90°C. The system is allowed to come to equilibrium (defined as each point on the rods reaching a constant temperature). What is the temperature at the point where the rods meet? Neglect thermal expansion.

Figure 13.8: A brass rod and a copper rod are joined together end-to-end. The other end of the brass rod is kept at 0°C, while the far end of the copper rod is maintained at 90°C. For Exercises 34 and 35.

35. Return to the situation described in Exercise 34. Plot a graph of the temperature as a function of position along the rods, taking the cooler end of the brass rod to be the origin and the hotter end of the copper rod to be x = +2.00 m.

General Exercises and Conceptual Questions

36. The Fahrenheit and Celsius temperature scales are named after particular individuals. Do a little research about these people and write a paragraph or two describing each one.

37. A photograph of a Galileo thermometer is shown in Figure 13.9. Explain how such a thermometer works. What property of the liquid inside the thermometer is being exploited in this thermometer?

38. The "Mpemba effect" is the name for an interesting phenomenon, namely that in some circumstances warmer water can end up freezing before cooler water. Do some research on the Mpemba effect and write two or three paragraphs describing how this might be possible.

39. To make a cup of tea, you put 1000 g of water at 15°C into a kettle and bring the water to a boil. However, you only need 300 g of hot water to make your cup of tea. How much energy did you waste bringing the extra water to the boiling point?

Figure 13.9: A photograph of a Galileo thermometer, for Exercise 37. Photo credit: Johanna Goodyear / iStockPhoto.

40. In the second paragraph of Section 13.3, we ask the following question: what is the equilibrium temperature when a 500-gram lead ball at 100°C is added to 400 g of water that is at room temperature, 20°C? What is the answer?

41. A 500-gram lead ball that is initially at 100°C is added to 500 g of water that is initially at room temperature, 20°C, in a Styrofoam cup. The system is allowed to come to thermal equilibrium. Note that 60°C is exactly halfway between the initial temperatures of the lead ball and the water. (a) Come up with a qualitative argument for whether the final temperature is more than 60°C, less than 60°C, or equal to 60°C. (b) Find the final temperature.

42. A lead bullet with a mass of 25 g is fired into a target. The bullet completely melts upon impact. Assuming all the kinetic energy of the bullet goes into raising the bullet's temperature and then melting it, what is the speed of the bullet when it strikes the target?

43. You have 2.00 liters of fruit punch at 20.0°C that you are trying to cool to get ready for a party. Assume that the relevant specific heat capacities and latent heats for water can also be used for the fruit punch, and that the freezing point is 0°C. To cool the fruit punch quickly, you pour it over a large bowl of ice that is initially at –15.0°C. The mixture comes to a final temperature of +5.0°C. Find the mass of ice that was originally in the bowl, assuming no energy is transferred between the ice-fruit punch system and the bowl or the surrounding environment.

44. Repeat Exercise 43, but now account for the bowl. Assume the bowl is made from 300 g of aluminum and that the bowl is also initially at –15.0°C.

45. In part (b) of Exploration 13.3, we found that when 0.447 kg of ice at –15.0°C is added to 2.00 liters of fruit punch at 20.0°C and allowed to come to thermal equilibrium, the result is that all the ice melts and the final temperature of the mixture is 0°C. There is a whole range of masses of ice, however, that could have been added to the punch to achieve that same final temperature. (a) Does 0.447 kg represent the minimum or the maximum amount of ice at –15.0°C we can add to the punch to produce a final temperature of 0°C? Explain. (b) Determine the other end of the range, the other extreme in the amount of ice we can add to the punch and yet still achieve a final temperature of 0°C.

46. A block of ice has an unknown initial temperature. Heat is transferred to the ice, first bringing the ice to 0°C, then melting it, and then bringing the resulting water to 50°C. The total heat required for the two changes in temperature is equal to the heat associated with the melting. What was the block's initial temperature?

47. A copper block, with a mass of 1500 g, is cooled to 77K by being immersed in liquid nitrogen. The block is then transferred to a Styrofoam cup containing 1.20 liters of water at 50°C. Assuming no energy is transferred to the cup, determine the final temperature of the system.

48. Repeat Exercise 47, but this time the block is aluminum instead of copper.

49. Repeat Exercise 47, but this time assume the water is in an aluminum container that has a mass of 400 g, and that the temperature of the container is equal to the temperature of the water at all times.

50. You have three blocks of equal mass. Block A is made of aluminum; block B is made of gold; and block C is made of copper. Each block is initially at 80°C. The blocks are added, one at a time, to a Styrofoam cup containing 500 g of water at 10°C. The final temperature is 40°C. Assuming no heat is transferred to the cup or the environment, what is the mass of each block?

51. You have three balls of equal mass. Ball A is made of aluminum; ball B is made of gold; and ball C is made of copper. Each ball is initially at –50°C. You also have three identical Styrofoam cups, each containing equal amounts of water at 10°C. You add one ball to each of the cups and measure the final temperature. Assuming no heat is transferred to the cup or the surroundings, is there enough information provided to rank the final temperatures from highest to lowest? If so, provide the ranking. If not, explain why not.

52. Return to the situation described in Exercise 51. Is it possible for the final temperature in one of the cups to be below 0°C, the final temperature in another to be 0°C, and the final temperature in the remaining cup to be above 0°C? If so, come up with an example specifying the mass of the balls and the mass of the water in the cup. If not, explain why not.

53. James Prescott Joule carried out an experiment known as the mechanical equivalent of heat. Write a few paragraphs about Joule and the experiment.

54. The water at Niagara Falls drops through a height of 52 m. (a) If the water's loss of gravitational potential energy shows up as an increase in temperature of the water, what is the temperature difference between the water at the top of the falls and the water at the bottom?

Figure 13.10: A photograph of Niagara Falls, for Exercise 54. Photo credit: Robert Glusic/ PhotoDisc/Getty Images.

55. As part of an experiment, you fill a cardboard tube that has a length of 1.2 m with 200 g of lead shot (small lead balls) and seal the ends of the tube. Aligning the axis of the tube vertically, you then invert the tube 100 times. Predict what you observe for the temperature difference of the lead balls at the end of the experiment compared to what it was at the beginning.

56. Return to Exercise 55. Doing the experiment with lead balls can be something of a health risk, because you can breathe in lead dust if you open the tube to measure the temperature. You try the experiment with small copper balls instead of lead. (a) In which case would you observe a larger temperature change, when you used the copper balls or when you used the lead balls? Explain your answer. (b) If you take the ratio of the two temperature changes, what would you expect to find?

57. The Sun has a radius of 6.96×10^5 km, and an average temperature at its surface of 5780 K. (a) Calculate the power radiated by the Sun. (b) The distance from the Sun to the Earth is about 150 million km. Estimate the power from the incident sunlight on a 1.0 m^2 solar cell that is part of an array being used to provide energy for a satellite in orbit around the Earth.

58. The base of a copper-bottomed pot has a radius of 15 cm and a thickness of 3.0 mm. Its bottom surface is maintained at a temperature of 250°C by being placed on a hot burner on the stove. (a) If the pot contains 2.00 liters of water that is initially at 20°C determine the initial rate at which energy is transferred through the base of the pot to the water. (b) As the water temperature increases, does the rate at which energy is transferred through the base of the pot increase, decrease, or stay the same? Explain. (c) Calculate the rate of energy transfer when the water temperature is 95°C.

59. Return to the situation described in Exercise 58. Let's say it takes a time T to raise the water temperature to the boiling point. The process is repeated with a second pot in which everything is the same except for the fact that the base of the second pot is aluminum instead of copper. (a) Is the time it takes to bring the water to the boiling point in the second pot greater than, less than, or the same as T? Justify your answer. (b) How much time, in terms of T, does the process take in the second pot?

60. On a chilly November day, you go out for a hike to the top of a local mountain with your friend. The two of you dress in layers, but for your inner-most layer you are wearing a high-tech fabric that wicks moisture away from your skin while your friend is wearing a long-sleeved cotton shirt that is damp with perspiration by the time you reach the top of the mountain. Coming back down, you are quite comfortable, while your friend is feeling colder with each passing minute. Fortunately, you reach the lodge at the base of the mountain before your friend becomes hypothermic, and your friend is able to warm up again in front of a roaring fire. Explain what happened, given that the fabric you were wearing has a thermal conductivity of 0.06 W/(m K), dry cotton has a thermal conductivity of 0.04 W/(m K), and water has a thermal conductivity of 0.6 W/(m K).

61. The outer walls of your house have an R-value of 5.0 K m^2 / W, and a total area of 2000 m^2. Let's assume that, from the beginning of December to the end of February, the temperature outside the house is 0°C while you set your thermostat to maintain a constant temperature of 22°C inside the house. (a) How much energy is conducted through the walls of your house in this three-month period? Assume it is not a leap year. (b) How much energy would be conducted through the walls if you lowered the thermostat so as to maintain a constant temperature of 20°? (c) Every kW-h of energy costs about 20 cents. First, convert a kW-h to joules, and then determine how much money you would save by keeping your thermostat at 20°C for the three months.

62. You have four square aluminum sheets, each with an area of 0.25 m^2 and a thickness of 5.0 mm, and four copper sheets, having exactly the same dimensions as the aluminum sheets. You plan to create a square piece of insulation, with an area of 1.00 m^2, by placing four of your sheets together in one layer, and layering the remaining four sheets on top of the first four. (a) To minimize the rate of energy transfer through your arrangement, should you place the four sheets of copper over the four sheets of aluminum, or should you stack sheets of aluminum together and stack the copper together? (b) Assuming a temperature difference of 20°C between the two faces of the arrangement, support your answer to part (a) by calculating the rate of energy transfer in the two cases.

63. What thickness of aluminum has the same R-value as 5.0 cm of Styrofoam?

64. You overhear two of your classmates discussing Essential Question 13.1. Comment on each of their statements.

Liam: Did you notice that we never got the answer to Essential Question 13.1? Does the space inside the glass thermometer increase or decrease when the temperature goes up? Well, the glass expands, so it must fill in some of that space – that would cause the alcohol level to go up even more than it would if the glass did not change size.

Sherry: Except, in Section 13.2 we looked at how holes expand when they're heated. Can't we apply that to the cavity inside the glass? That would mean the cavity volume increases when the temperature goes up, so the alcohol level is less than if the glass doesn't change size. Except, how do we know the level goes up at all when the temperature increases? Couldn't the level even go down, or stay the same? That doesn't sound like a very good thermometer!