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

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

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

FIGURE 15–25 Problem 22.

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

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

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

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

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

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

15–6 Refrigerators, Air Conditioners, Heat Pumps

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

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

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

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

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

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

15–7 Entropy

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

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

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

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

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

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

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

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

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

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