Phys 340

Assignments # 6 and 7

Answer the following questions:

6-1

a. Does satisfying the first law of thermodynamics ensure that the process can actually take place? Explain.

b. Describe an imaginary process that satisfies the first law but violates the second law of thermodynamics.

c. Describe an imaginary process that satisfies the second law but violates the first law of thermodynamics.

6-2. Consider the process of baking potatoes in a conventional oven. How would you define the efficiency of the oven for this baking process?

6-3. Are the efficiencies of all the work-producing devices, including the hydroelectric power plants, limited by the Kelvin-Planck statement of the second law? Explain.

6-4. A steam power plant with a power output of 150 MW consumes coal at a rate of 60 tons/h. If the energy content of the coal is 30,000 kJ /kg, determine the thermal efficiency of this plant (1 ton = 1000 kg).
Answer: 30.0 percent

6-5. A household refrigerator with a COP of 1.8 removes heat from the refrigerated space at a rate of 90 kJ/min. Determine *(a)* the electric power consumed by the refrigerator and *(b)* the rate of heat transfer to the kitchen air.
Answers: (a) 0.83kW. *(b)* 140kJ/min

6-6. An air conditioner removes heat steadily from a house at a rate of 750 kJ/min while drawing electric power at a rate of 6 kW. Determine (a) the COP of this air conditioner and (b) the rate of heat discharge to the outside air.
Answers: (a) 2.08, (b) 1110kJ/min

6-7. When a man returns to his well-sealed house on a summer day, he finds that the house is at 32°C. He turns on the air conditioner, which cools the entire house to 20°C in 15 min. If the COP of the air conditioning system is 2.5, determine the power drawn by the air conditioner. Assume the entire mass within the house is equivalent to *800* kg of air for which C_v = 0.72 kJ / (kg.°C) and C_p = 1.0 kJ / (kg.°C).

6-8. A heat pump is used to maintain a house a constant temperature of 23°C. The house is losing heat to the outside air through the walls and the windows at a rate of 60,000 kJ /h while the energy generated within the house from people, lights, and appliances amounts to 4000 kJ /h. For a COP of 2.5, determine the required power input to the heat pump.
Answer: 6.22 kW

6-9. Air is compressed from 20^{o}C and 100 kPa to 300^{o}C and 800 kPa first in a reversible manner and then in an irreversible manner. Which case do you think will require more work input?

6-10. Consider two actual power plants operating with solar energy. Energy is supplied to one plant from a solar pond at 80°C and to the other from concentrating collectors that raise the water temperature to 600°C. Which of these power plants will have a higher efficiency and why?

6-11. A Carnot heat engine receives 500 kJ of heat from a source of unknown temperature and rejects 200 kJ of it to a sink at 17°C. Determine *(a)* the temperature of the source and *(b)* the thermal efficiency of the heat engine.

6-12. A heat engine is operating on Carnot cycle and has a thermal efficiency of 55 percent. The waste heat from this engine is rejected to a nearby lake at 15°C at a rate of 800 kJ/min. Determine *(a)* the power output of the engine and *(b)* the temperature of the source.
Answers: (a) 16.3kW, *(b)* 640K

6-13. An innovative way of power generation involves the utilization of geothermal energy-the energy of hot water that exists naturally underground-as the heat source. If a supply of hot water at 140°C is discovered at a location where the environmental temperature is 20°C, determine the maximum thermal efficiency a geothermal power plant built at that location can have.
Answer: 29.1 percent

6.14. It is well established that the thermal efficiency of a heat engine increases as the temperature at which heat is rejected from the heat engine T_L decreases. In an effort to increase the efficiency of a power plant, somebody suggests refrigerating the cooling water before it enters the condenser, where heat rejection takes place. Would you be in favor of this idea? Why?

6-15. A Carnot refrigerator operates in a room in which the temperature is 25°C. The refrigerator consumes 500 W of power when operating and had a COP of 4.5. Determine *(a)* the rate of heat removal from the refrigerated space and *(b)* the temperature of the refrigerated space.
Answers: (a) 135kJ/min, *(b)* 29.2°C

6-16. A Carnot heat pump is to be used for heating a house and maintaining it at 20°C during the winter. On a day when the average outdoor temperature remains at about 2°C, the house is estimated to lose heat at a steady rate of 82,000 kJ/h. If the heat pump consumes 8 kW of power while operating, determine *(a)* how long-the heat pump ran on that day; *(b)* the total heating costs, assuming an average price of 8.5¢/kWh for electricity; and *(c)* the heating cost for the same day if resistance heating is used instead of a heat pump.
Answers: (a) 4.19h, *(b)* $2.85, *(c)* $46.47

6-17. An air conditioning system is used to maintain a house at a constant temperature of 20°C. The house is gaining heat from outdoors at a rate of 20,000 kJ /h, and the heat generated in the house from the people, lights, and appliances amounts *to* 8000 kJ/h. For a COP *of* 2.5, determine the required power input to this air conditioning system.
Answer: 3.11 kW

6-18. Consider two Carnot heat engines operating in series. The first engine receives heat from the reservoir at 1200 K and rejects the waste heat to another reservoir at temperature *T*. The second engine receives this energy rejected by the first one, converts some of it to work, and rejects the rest to a reservoir at 300 K. If the thermal efficiencies of both engines are the same, determine the temperature *T*.
Answer: 600 K

6-19. A heat engine operates between two reservoirs at 800 and 20°C. One-half of the work output of the heat engine is used to drive a Carnot heat pump that removes heat from the cold surroundings at 2°C and transfers it to a house maintained at 22°C. If the house is losing heat at a rate of 95,000 kJ/h, determine the minimum rate of heat supply to the heat engine required to keep the house at 22°C.

6-20. Do internal combustion engines operate on a closed or an open cycle? Why?

6-21. An air-standard cycle is executed in a closed system and is composed of the following four processes:
1-2 Isentropic compression from 100 kPa and 27^{o}C to 800 kPa
2-3 *V* = constant heat addition to 1800 K
3-4 Isentropic expansion to 100 kPa
4-1 *P* = constant heat rejection to initial state

(a) Show the cycle on *P-V* diagram.
(b) Calculate the net work output per unit mass.
(c) Determine the thermal efficiency.

6-22. An air-standard cycle is executed in a closed system and is composed of the following four processes:

1-2 V = constant heat addition from 100 kPa in the amount of 701.5 kJ /kg
2-3 P = constant heat addition to 2000 K
3-4 Isentropic expansion to 100 kPa
4-1 P = constant heat rejection to initial state

(a) Show the cycle on *P-V* diagrams.
(b) Calculated the total heat input per unit mass.
(c) Determine the thermal efficiency. Account for the variation of specific heats with temperature.

6-23. An air-standard Carnot cycle is executed in a closed system between the temperature limits of 350 and 1200 K. The pressures before and after the isothermal compression are 150 and 300 kPa, respectively. If the net work output per cycle is 0.5 kJ, determine *(a)* the maximum pressure in the cycle, *(b)* the heat transfer to air, and *(c)* the mass of air. Assume variable specific heats for air.
Answers: (a) 32.4 MPa, *(b)* 0.706kJ, *(c)* 0.00296 kg

6-24. An ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process, air is at 95 kPa and 27°C, and 750 kJ/kg of heat is transferred to air during the constant-volume heat addition process. Using constant specific heats at room temperature, determine *(a)* the pressure and temperature at the end of the heat addition process, *(b)* the net work output, *(c)* the thermal efficiency, and *(d)* the mean effective pressure for the cycle.
Answers: (a) 4392kPa, 1734K; *(b)* 423.5kJ/kg; *(c)* 56.5 percent; *(d)* 534 kPa

6-25. The compression ratio of an air-standard Otto cycle is 9.5. Prior to the isentropic compression process, the air is at 100 kPa, 17°C, and 600 cm^3. The temperature at the end of the isentropic expansion process is 800 K. Using specific heat values at room temperature, determine *(a)* the highest temperature and pressure in the cycle, *(b)* the amount of heat transferred during heat addition, in kJ, *(c)* the thermal efficiency, and *(d)* the mean effective pressure.
Answers: (a) 1969K, 6449kPa; *(b)* 0.65 kJ; *(c)* 59.4 percent; *(d)* 719kPa

6-26. An air-standard Diesel cycle has a compression ratio of 16 and a cutoff ratio of 2. At the beginning of the compression process, air is at 95 kPa and 27°C. Using constant specific heats at room temperature, determine *(a)* the temperature after the heat addition process, *(b)* the thermal efficiency, and *(c)* the mean effective pressure.
Answers: (a) 1819K, *(b)* 61.4 percent, *(c)* 660.5kPa

6-27. An ideal diesel engine has a compression ratio of 20 and uses air as the working fluid. The state of air at the beginning of the compression process is 95 kPa and 20°C. If the maximum temperature in the cycle is not to exceed 2200 K, determine *(a)* the thermal efficiency and *(b)* the mean effective pressure. Assume constant specific heats for air at room temperature.
Answers: (a) 63.5 percent, *(b)* 933 kPa

6-28; The coefficient β of thermal expansion is defined by the equation

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$$

Obtain an expression for β for a gas which obeys the van der Waals equation.

6-29. Derive the following identities:

a $$C_V = -\left(\frac{\partial U}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_U$$

b $$\left(\frac{\partial U}{\partial V}\right)_P = C_P\left(\frac{\partial T}{\partial V}\right)_P - P$$

Hence, show that, for 1 mol of an ideal gas,

$$\left(\frac{\partial U}{\partial V}\right)_P = \frac{PC_V}{R}$$

c $$\left(\frac{\partial U}{\partial T}\right)_P = C_P - P\left(\frac{\partial V}{\partial T}\right)_P$$

6-30. Show that for an ideal gas,

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$$

Hence, show that for 1 mol of a van der Waals gas,

$$\left(\frac{\partial U}{\partial V}\right)_T = \frac{a}{V^2}$$