Heat engines and the second law of thermodynamics

$$\Delta U = 0 = |Q_h| - |Q_c| - W \Rightarrow W = |Q_h| - |Q_c|$$

$$e = \frac{W}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$$

1. (1) A heat engine takes in 360J of energy from a hot reservoir and performs 25.0 J of work in each cycle. Find a) the efficiency of the engine, and b) the energy expelled to the cold reservoir in each cycle. (7%; 335J)
2. (3) A particular heat engine has a useful power output of 5.00kW and an efficiency of 25.0%. The engine expels 8,000J of exhaust energy in each cycle. Find a) the energy taken in during each cycle and b) the time interval for each cycle. (a) 10.7kJ; b) 0.54s

Heat pumps and refrigerators:

$$\Delta U = 0 = |Q_c| - |Q_h| + W \Rightarrow$$

$$W = |Q_h| - |Q_c|$$

$$COP(\text{in cooling mode}) = \frac{|Q_c|}{W}$$

3. (6) A refrigerator has a COP of 5.00. It takes in 120J of energy from a cold reservoir in each cycle. Find (a) the work (electricity) required in each cycle, and b) the energy expelled to the hot reservoir. (W=24.0J, Q_h=144J)
4. A certain refrigerator runs at 0.50 kW and has a COP of 5.00. 3.0 liters of water at 20 degree Celsius are placed into the freezing department. How long does it take until the water has obtained a temperature of 10 degree Celsius below freezing? (8.8 minutes)

Reversible and irreversible processes, the Carnot engine

5. (9) A steam turbine in the Ohio valley operates between 430°C and 1,870 °C fired by coal from West Virginia. a) What is its maximum theoretical efficiency? b)The actual efficiency is 42.0%. How much useful power does the engine deliver if it takes in 1.40E5J of energy each second from its hot reservoir? (a) 67% b)58.8kW.
6. (13) An ideal gas is taken through a Carnot cycle. The isothermal expansion occurs at 250°C, and the isothermal compression takes place at 50.0°C. The gas takes in 1.20kJ of energy from the hot reservoir during the isothermal expansion. Draw a PV diagram and indicate the heat entering and leaving the engine. Find (a) the energy expelled to the cold reservoir in each cycle, and b) the net work done by the engine in each cycle. a) 741J b)459J.
7. A Diesel engine runs between pressures of 1.00 and 18.0 atm during the adiabatic compression from C to D. Calculate a) the compression ratio (the ratio between the highest and lowest volume) and the highest possible efficiency for this engine. If 500 J of heat is taken in during the intake cycle, calculate the work done by the engine during each cycle. A) 7.88 b) 56% c)281J.
8. A Carnot engine runs between a high temperature of 500°C and a low temperature of 50°C. The isothermal expansion (upper branch) occurs between a volume of 0.500 liters and 1.00 liters. The isothermal contraction (lower branch) occurs

between 2.00 l and 1.00 l. There are 2 mols of a gas involved. Calculate the work done by the engine, the heat taken in, and the heat ejected. Calculate the efficiency of the cyle. Draw a PV diagram and show the area corresponding to the total work being done. Show the beginning and end points of the isothermal and adiabatic curves. Show during which branch of the cycle heat enters and leaves the engine. (Note that we defined work W as the work done on the system. In your calculations here you will find negative work for the path from A to B to C to D. The negative of this value is the work done by the engine.)

$W = 5.07kJ, Q_h = 8.91kJ; Q_c = 3.84kJ; e = 0.57$

Entropy:

$$dS \geq \frac{dQ_{reversible}}{T}; \Delta S_{AB} \geq \int_A^B \frac{dQ_{reversible}}{T}$$

9. (30) An ice tray contains 500g of liquid water at 0°C. Calculate the change in entropy of the water as it freezes slowly and completely at 0°C. (-147cal/K=-612J/K)
10. (33) Calculate the change in entropy of 250g of water heated slowly from 20°C to 80°C. Note: dQ= mcdT; (195J/K)

Entropy changes in irreversible processes:

$\Delta U = Q + W \Rightarrow \delta Q = dU - \delta W = nC_V dT + P\ dV =$ $\frac{nRT}{V}$

11. (35) A 1,500 kg car is moving at 20.0m/s. The driver brakes to stop. The brakes cool off to the temperature of the surrounding air, which is constant at 20.0°C. What is the total entropy change? (1.02kJ/K)
12. (39) A 1.00 mol sample of H_2 gas is contained in the left hand side of an insulated container separated into two equal halves, and connected by a valve. The right hand side is evacuated. When the valve is opened, the gas streams into the right hand side. What is the final entropy change of the gas? Does the temperature of the gas change? Rln2=5.76J/K
13. A 1.00 mol sample of an ideal mono-atomic gas, initially at a pressure of 1.00atm and a volume of 0.0250m^3, is heated to a final state with a pressure of 2.00atm and a volume of 0.0400m^3. Determine the change in entropy of the gas in this process. 18.4J/K
14. 50 g of aluminum (c=0.215cal/gC^o) at 100^{o}C are immersed into 100g of water at 20^{o}Celsius. Find the entropy change for the combination of aluminum plus water. 0.39 cal/K

15. 100g of ice at 0˚C are immersed into 200g of water at 60˚C. Calculate the entropy change of the mixture after thermodynamic equilibrium has been established. 3.84cal/K.