1. Consider two identical bodies of heat capacity C_p and with negligible thermal expansion coefficients. The two bodies are placed in thermal contact in an adiabatic enclosure and have initial temperature T_1 and T_2, respectively.

(a) What is the final temperature? (6%)

Now consider these two bodies being brought into thermal equilibrium by a Carnot engine operating between them (the bodies are still in an adiabatic enclosure). The size of the engine is small so that the temperatures of the bodies behave as reservoirs during the cycle.

(b) What is the entropy change of the universe for this second process? (7%)

(c) What is the final temperature after this process? (7%)

2. A cylinder contains one liter of air at room temperature (300 K) and atmospheric pressure (10^5 N/m^2). At one end of the cylinder is a massless piston, whose surface area is $0.02\,\mathrm{m}^2$. Suppose that you push the piston in very suddenly, exerting a force of 1000 N. The piston moves only one millimeter. Before it is stopped by an immovable barrier of some sort.

(a) How much work have you done on this system? (5%)

(b) How much heat has been added to the gas? (5%)

(c) Assuming that all the energy added goes into the gas (not the piston or cylinder walls), by how much does the internal energy of the gas increase? (5%)

(d) Use the thermodynamic identity to calculate the change in the entropy of the gas (once it has again reached equilibrium). (5%)

3. A heat pump is an electrical device that heats a building by pumping heat in from the cold outside. In other words, it's the same as a refrigerator, but its purpose is to warm the hot reservoir rather than to cool the cold reservoir (even though it does both). Let us define the following standard symbols, all taken to be positive by convention:

T_h = temperature inside building
T_c = temperature outside
Q_h = heat pumped into building in 1 day
Q_c = heat taken from outdoors in 1 day
W = electrical energy used by heat pump in 1 day

(a) Explain why the "coefficient of performance" (COP) for a heat pump should be defined as Q_h/W. (6%)

(b) What relation among Q_h, Q_c and W is implied by energy conservation alone? Will energy conservation permit the COP to be greater than 1? (6%)

(c) Use the second law of thermodynamics to derive an upper limit on the COP, in terms of the temperatures T_h and T_c alone. (6%)

(d) Explain why a heat pump is better than an electric furnace, which simply converts electrical work directly into heat. (Include some numerical estimates.) (7%)

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4. A coal-fired power plant operates with a steam engine under Rankine cycle. The associated PV diagram is shown in Figure 1. The cycle operates between a minimum pressure of 0.023 bar (where the boiling temperature is at 20°C) and a maximum pressure of 300 bars, with superheated steam temperature of 600 °C. The properties of working fluids can be found in Table 1. and Table 2.
(a) Calculate the efficiency of this power plant. (10%)
(b) If the power plant is to deliver 1 GW (10^9 watts) of power. Estimate the amount of steam (in kilograms) that must pass through the turbine each second. (10%)

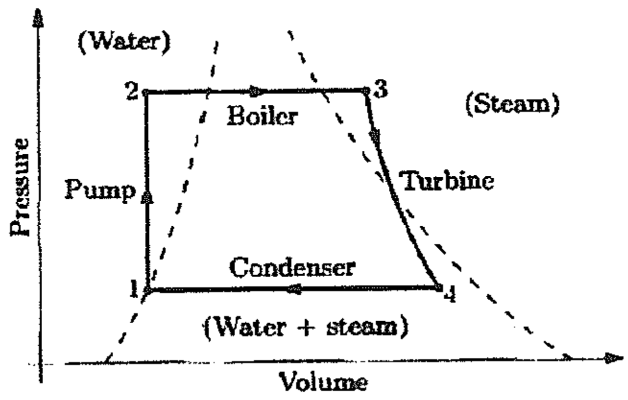

Figure 1. The Rankine cycle associated with the steam engine. The dashed lines show where the fluid is liquid water, steam, and part water part steam.

T (°C)	P (bar)	H_{water} (kJ)	H_{steam} (kJ)	S_{water} (kJ/K)	S_{steam} (kJ/K)
0	0.006	0	2501	0	9.156
10	0.012	42	2520	0.151	8.901
20	0.023	84	2538	0.297	8.667
30	0.042	126	2556	0.437	8.453
50	0.123	209	2592	0.704	8.076
100	1.013	419	2676	1.307	7.355

Table 1. Properties of saturated water/steam. Pressures are given in bars. All values are for 1 kg of fluid, and are measured relative to liquid water at the triple point.

		Temperature (°C)				
P (bar)		200	300	400	500	600
1.0	H (kJ)	2875	3074	3278	3488	3705
	S (kJ/K)	7.834	8.216	8.544	8.834	9.098
3.0	H (kJ)	2866	3069	3275	3486	3703
	S (kJ/K)	7.312	7.702	8.033	8.325	8.589
10	H (kJ)	2828	3051	3264	3479	3698
	S (kJ/K)	6.694	7.123	7.465	7.762	8.029
30	H (kJ)		2994	3231	3457	3682
	S (kJ/K)		6.539	6.921	7.234	7.509
100	H (kJ)			3097	3374	3625
	S (kJ/K)			6.212	6.597	6.903
300	H (kJ)			2151	3081	3444
	S (kJ/K)			4.473	5.791	6.233

Table 2. Properties of superheated steam. All values are for 1 kg of fluid, and are measured relative to liquid water at the triple point.

5. Consider a completely miscible two-component system whose overall composition is x, at a temperature where liquid and gas phases coexist. The composition of the gas phase at this temperature is x_a and the composition of the liquid phase is x_b. Prove the lever rule, which says that the proportion of liquid to gas is $(x-x_a)/(x_b-x)$. Interpret this rule graphically on a hypothesized phase diagram. (15%)