ENV-413: Thermodynamics of the Earth systems

Midterm Exam (max: 80 points)

Closed books & notes. 2 hours

NAME: SCIPER:

1. (5 points) Consider a thermodynamic system that initially is in equilibrium. The system is *adiabatically compressed*. State whether the following variables increase, decrease, or remain the same. Justify your answer based on the laws of thermodynamics.

Temperature _________________
Specific volume _______________
Entropy ________________
Enthalpy _________________
Gibbs Free Energy_________________

2. (10 points) Heat flowing from a cold substance to a warmer substance would violate
a) 1st law of thermodynamics
b) 2nd law of thermodynamics
c) neither the 1st or 2nd law

Justify your answer using equations, applied to as system where heat is flowing reversibly from a cold tank (with temperature Tc) to a warm tank (with temperature Tw); assume that during the heat transfer, the tank temperatures do not change.

3. (15 points) Clouds and cloud systems can be thought as "heat engines" that convert solar radiation into the work that drives atmospheric circulation. Assuming that the "cold" and "hot" reservoirs of cloud heat engines are cloud top and ground level, respectively, calculate the maximum efficiency of clouds as a function of their vertical extent. Calculate the efficiency for marine boundary layer (height ~ 1km) and deep convection (height ~ 10km) clouds. Do you think that these differences are important?

4. (5 points) Circle the following statements that are true about heat engines:
a) they receive heat from a high-temperature source
b) they convert part of this heat to work
c) they reject the remaining waste heat to a low-temperature sink
d) they operate on a cycle

5. (15 points) Which of the following has a higher chemical potential (if neither species has a higher potential, answer "same")? Briefly explain.

a) H_2O (s), H_2O (l) or H_2O(v) at water's triple point (where all 3 phases can coexist).

b) H_2O (v) at 200 C and 1 bar or H_2O (l) at 200 C and 1 bar.

c) Pure water or water with some NaCl dissolved in it. In both cases T=25 C and P=1 bar.

6. (10 points) For a closed system doing non-pV work, changes in the Gibbs free energy is equal to dG=Vdp-SdT. Calculate the change in Gibbs Free energy for an incompressible liquid of specific volume v as it is compressed from a pressure P1 to P2. Assume that the compression is reversible, and that the temperature remains constant. State any assumptions.

7. (10 points) Repeat question 6, but for a reversible compression of an ideal gas.

8. (10 points) You have a system that contains, liquid water, ice, dissolved NaCl and solid NaCl in equilibrium (no water vapor).

a. How many properties of this system you need to measure to completely characterize it? Please justify

b. If pressure is kept constant in this system, how many variables do you need to measure now to characterize the system? Please justify.

c. solid NaCl can be found in two forms: NaCl and $NaCl.2H_2O$. Under the conditions of (b), can you have both phases of NaCl co-exist with ice and liquid water? Please explain.

Formula Sheet
$R^* = 8.3144$ J/°K mol, 1 bar = 1 atm = 10^5 Pa, 1 atm = 1.013×10^5 Pa,
1 Pa= 1 N m^{-2}, 1 N = 1 J/m, Molar mass of Air = 29 x 10^{-3} kg mol^{-1},
$L_{lv} = 2.47\times10^6$ J kg^{-1}

$g = -\frac{1}{\rho}\frac{\partial p}{\partial z}$, where ρ is density.
$dw = - pdv$
$du = dq + dw$

For an ideal gas:
$du = c_V\, dT$
$dh = c_p\, dT$
$c_p - c_v = R$

1 cm^3 = 0.1 J/bar
R^* = 8.3144 J/K mol
1 atm = 10^5 Pa
1 bar = 1 atm.
1 Pa = N/m^2
1 N = J/m
g = 9.81 m/s^2

Molar mass of Air = 29 x 10^{-3} kg/mol
K = °C + 273.15

$pv = RT$, R is the specific gas constant = R^*/M, where M is the molar mass of the gas.

For an ideal gas: $du = c_V\, dT$, $dh = c_p\, dT$, $c_p - c_v = R$

Combined 1st+2nd law: $du = dq - pdv = Tds - pdv$
$h = u + pv$; $g = u + pv - sT$
Gibbs Free Energy $dg = -sdT + vdP$

Gibbs Phase Rule: F = C - P + 2
Carnot Heat Engine is $\eta = 1 - \frac{T_{cold}}{T_{hot}}$.