

NAME: _____

COURSE 3.20: THERMODYNAMICS OF MATERIALS

90 minute EXAM, Oct 11, 2002

PROBLEM 1 (20 POINTS) _____

PROBLEM 2 (20 POINTS) _____

PROBLEM 3 (20 POINTS) _____

PROBLEM 4 (20 POINTS) _____

PROBLEM 5 (20 POINTS) _____

TOTAL (100 POINTS) _____

You can either write your answer on the question sheets or use separate pages. In each case make sure your answer is clearly marked.

A neat answer is the sign of a clear mind

Question 1

A beaker of water (100g) at 20 C (1 atm) is heated to a temperature of 100 C by placing it on a reservoir at 100 C. The reservoir is at constant temperature.

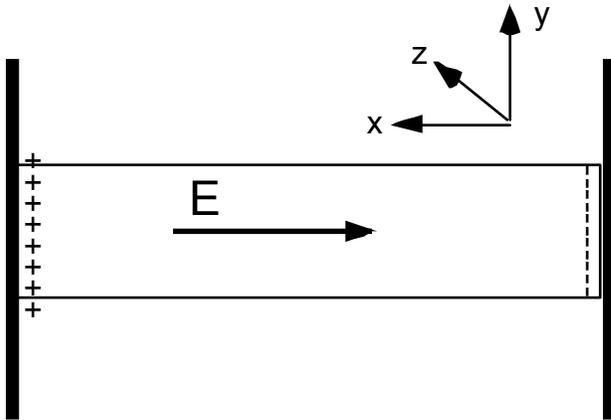
- a) Calculate the entropy change of the beaker of water
- b) What is the entropy change of the universe ?

c) Assume now that an ideal Carnot engine is inserted between the reservoir and the beaker of water. Calculate the entropy change of the universe in this case.

DATA: Heat capacity for water: 4.184J/g
Enthalpy of evaporation for water: 41kJ/mole
Molar mass for water: 18g/mole

Question 2

An insulating (non-conducting) cylinder is clamped between two rigid and charged walls. The charge produces a constant electrical field in the material equal to E , which produces a polarization P in the material. The contribution of this polarization to the internal energy is EdP . The whole assembly is at constant temperature.



a) Write down the relevant thermodynamic potential that is minimal for these boundary conditions as a Legendre transform of the energy.

b) Write down the equations of state derived from this potential. Clearly indicate what the variables are in these equations of state.

Question 3

The objective of this question is to quantify the difference between the isothermal elastic stretching of a material and the isentropic stretching.

Consider a material of length l and surface area A to which a force is being applied as shown in Figure 1. This force causes only *elastic deformation*. Poisson effects can be neglected.

Note: The Young's modulus E of a material can be defined as $l \left(\frac{\partial \sigma}{\partial l} \right)$. The stress σ is the force per unit area (A)

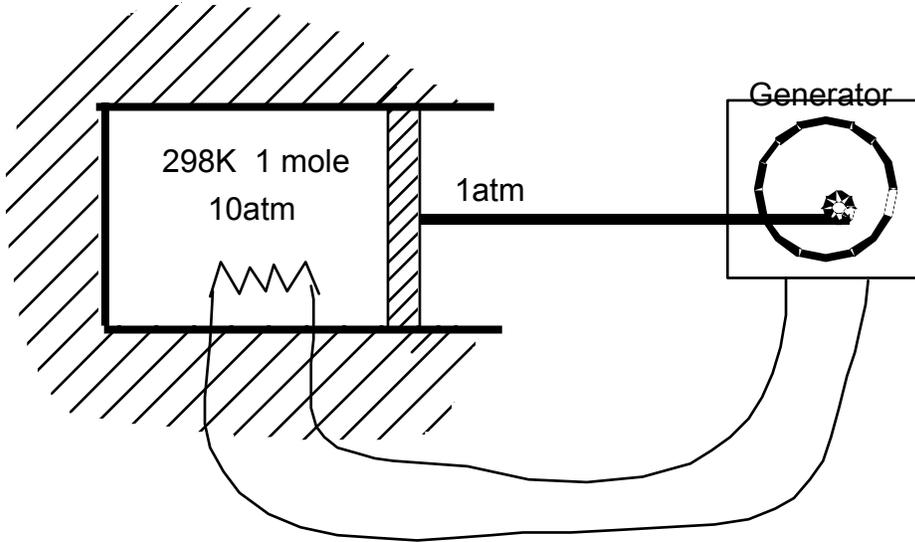


a) Derive a relation between the isentropic Young's modulus and the isothermal Young's modulus in terms of well known properties of the material (Note: "well known properties" are second derivatives of G : thermal expansion, compressibilities, heat capacities).

b) Estimate the *relative* difference between the isentropic Young's modulus and the isothermal Young's modulus for a typical metal (e.g. Al, Fe, Cu etc.). (Note: show clearly what estimates you use for the properties). Answer should be as % difference between isentropic and isothermal modulus.

Question 4

One mole of ideal gas, initially at 10 atm pressure and 298K in a thermally insulated cylinder, is expanded by displacing a piston. The final pressure of the gas is 1 atm. The pressure in the environment is 1 atm. The piston is connected to an electrical generator which converts the work performed by the piston into electrical energy (with no losses). This electrical energy is used to heat the gas in the piston through a resistance heater.



- What is the final temperature in the gas ?
- What is the change in entropy of the surroundings (universe – system) ?
- Is this a reversible process ?

DATA: The gas can be treated as ideal with heat capacities $C_v = 5/2 R$ and $C_p = 7/2 R$

Problem 5

Titanium forms an hcp (ϵ) phase at low temperature but transforms at 1155K to a bcc (β) phase. At 1943 K this β -phase melts.

Estimate the metastable melting point of the ϵ phase.

DATA: for β : $\Delta S_m = 9.6 \text{ J/mol-K}$
for the $\epsilon - \beta$ transition $\Delta S = 3.43 \text{ J/mol-K}$