4200:225 EQUILIBRIUM THERMODYNAMICS SPRING 90

TEST 1 SSN________

1. Short Answer

a) Estimate the change in entropy when one mole of nitrogen is compressed by a piston in a cylinder from 300K and 23 liters/gmol to 400K and 460 liters/gmol.(Cp=7 cal/gmol)

b) Draw a sketch of the square well potential and indicate the position(s) where the force between two atoms is zero.

c) Write the simplest possible form of the energy balance for application to the following process and system: water drips slowly out of a hole in the bottom of an enclosed tank; system: the tank and its contents.

d) Write the simplest possible form of the energy balance for application to the following process and system: a rubber balloon being inflated; system: the balloon and its contents.

2. Estimate the density (g/cc) of liquid butane at 300 K and 38 psia. Assuming that a disposable lighter costs $1.00 and contains 2 g of butane, what is the value of the butane? ($/gal)

3. Saturated steam at 660°F is adiabatically throttled to atmospheric pressure. Estimate the final condition of the steam.

4. A mixture of 1CO:2H2 is adiabatically continuously compressed from 5 atm and 100°F to 100 atm and 1100°F. Estimate the work of compressing 1 ton of the gas.(Cp=7Btu/lbmol-R)

5. Determine the efficiency of the compressor in problem 4.

6. An insulated cylinder is fitted with a freely floating piston and contains 1 lbm of steam at 120 psia and 90% quality. The space above the piston, initially 1 ft^3, contains air at 300 K to maintain the pressure on the steam. Additional air is forced into the upper chamber, forcing the piston down and increasing the steam pressure until the steam has 100% quality. The final steam pressure is 428 psia and the work done on the steam is 91 Btu, but the air above the steam has not had time to exchange heat with the piston, cylinder or surroundings. The air supply line is at 700 psia and 300 K. What is the final temperature of the air in the upper chamber?

1a)7.4cal/mol-K (c)HdM=d(MU) (d)HdM+W=d(MU) 2).6 g/cc 3) 0.96 4) 1.3E6 5) 76% 6)360K

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TEST 1 SSN________

1. Short Answer

a) 15 molecules are distributed as 9:4:2 between boxes A:B:C respectively. The partitions between the boxes are removed and the molecules distribute themselves evenly between the boxes. Compute ΔS.

b) Explain in words how the pressure of a fluid against the walls of its container is related to the velocity of the molecules.

c) What is it about molecules that requires us to add heat to convert liquids to gases?

d) A rigid cylinder of gaseous hydrogen is heated from 300K and 1 bar to 400K. How much heat is added to the gas?

2. Steam is produced at 30 bar and some unknown temperature. A small amount of steam is bled off and goes through an adiabatic throttling valve to 1 bar. The temperature of the steam exiting the throttling valve is 110°C. What is the value of the specific entropy of the steam before entering the throttle?

3) An adiabatic compressor is used to continuously compress nitrogen (Cp/R=7/2) from 2 bar and 300K to 15 bar. The compressed air is found to have an outlet temperature of 722K. How much work is required?

4) What is the efficiency of the compressor in the previous problem?

5) As part of a supercritical extraction of coal, an initially evacuated cylinder is fed with steam from a line available at 20 MPa and 400°C. What is the temperature in the cylinder immediately after filling?

Answers: 1.a)2.31k 1.b)change of direction due to wall collision gives change in velocity per unit time providing the acceleration in the force per unit area that is pressure. 1.c)potential energy causes them to stick together when close to each other. 1.d)2079 J/mol. 2)5.9736kJ/kg-K 3)436J/g 4)53%5)454°C

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TEST 1 SSN________

1. Short Answer

a) How does heat get from the flame of a gas oven into a pizza inside the oven?

b) Nitrogen (Cp/R=7/2) is adiabatically and reversibly compressed from 300K and 5 bar to 25 bar. Compute the temperature coming out of the compressor.

c) Estimate the S of liquid freon-12 at -40°F.(Hint: use chart)

d) In a large refrigeration plant it is necessary to compress a fluid which we will assume to be an ideal gas with constant heat capacity, from a low pressure P1 to a much higher pressure P2. If the compression is to be done in two stages, first compressing the gas from P1 to P*, then cooling the gas at constant pressure down to the compressor inlet temperature T1, and then compressing the gas to P2, what should the value of the intermediate pressure be to accomplish the compression with minimum work? (Hint: don't derive the whole formula. If you know the answer, just write it down.)

2. An adiabatic compressor is used to continuously compress low pressure steam from 0.8 MPa and 200°C to 4.0 MPa and 500°C in a steady state process. What is the work required per kg of steam through this compressor?

3) Compute the efficiency of the compressor in the previous problem.

4) An ordinary vapor compression cycle is to operate a refrigerator on F-12 between -40°F and 120°F (coil temperatures). Compute the coefficient of performance and the heat removed from the refrigerator per day if the power used by the refrigerator is 9000 J per day.

5) Airplanes are launched from aircraft carriers by means of a steam catapult. The catapult is a well-insulated cylinder that contains steam and is fitted with a frictionless piston. The piston is connected to the airplane by a cable. As the steam expands, the movement of the piston causes movement of the plane. A catapult design calls for 270 kg of steam at 15 MPa and 450°C to be expanded to 0.4 MPa. How much work can this catapult generate during a single stroke? Compare this to the energy required to accelerate a 30,000 kg aircraft from rest to 350 km per hour.

Answers:1.a)air collisions b)475K c).0024 d)$\sqrt{P_1P_2}$ 2)606kJ/kg 3)67% 4)1.55,-14,000J/day 5)165224 kJ vs. 141782

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TEST 1 SSN________

1. Short Answer

a) 20 molecules are contained in a piston+cylinder at low pressure. The piston moves such that the volume is expanded by a factor of 4 with no work produced of any kind. Compute ΔS/k.

b) A tank of N2 (Cp=7R/2) at 300K and 25 bars leaks adiabatically until the pressure drops to 5 bar. What is the final temperature?.

c) A Carnot cycle is to operate with coil temperatures from -160°F to -280°F. Compute the coefficient of performance.

d) As part of the air standard Otto cycle, air (Cp=7R/2) in a cylinder at 400K is compressed adiabatically and reversibly with a volumetric compression ratio of 8:1. Develop an expression relating the work required for a given compression ratio in terms of the temperatures T1 and T2 (ie. the temperatures before and after).(Hint: No numbers are necessary in your "expression".)

e) A tank of air (Cp=7R/2) drives an adiabatic, reversible turbine exhausting to the atmosphere. Derive an overall entropy balance between the specific entropy of air exiting the turbine vs. the specific entropy in the tank.

2. An adiabatic turbine is supplied with steam at 2.0 MPa and 600°C and it exhausts at 98% quality and 24°C. Compute the work output per kg of steam.(15)

3. Compute the efficiency of the turbine in problem 2.(20)

4. An ordinary vapor compression cycle is to be operated on methane to cool a chamber to -260°F. Heat will be rejected to liquid ethylene at -165°F. The temperatures in the coils are -160°F and -280°F. Compute the coefficient of performance. (Hint: Use Chart)(20)

5. A well-insulated cylinder, fitted with a frictionless piston, initially contained 9 kg of liquid water and .4 kg of water vapor at a pressure of 1.4 MPa. 2 kg of steam at 1.6 MPa was admitted to the cylinder while the pressure was held constant by allowing the piston to expand.

a) Write the energy balance for this process. (10)

b) If the final volume of the contents of the cylinder was six times the initial volume, determine the temperature of the superheated steam that was admitted to the cylinder.(10).

1a)23.2(b)189(c)1.5(d)CvΔT(e) ΔS =0(2)-1194J(3)85%(4).86(5) ΔMU=W+HΔM,557°C

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TEST 1 SSN________

1. Short Answer

a) Rolling two dice (six sided cubes with numbers between 1 and 6 on each side) is like putting two particles in six boxes. Compute ΔS/k for going from double sixes to a four and three.0.693

b) Air (Cp/R=3.5) is isothermally compressed in a piston+cylinder from 100°C and 1 bar to 100 bar. Estimate the work requirement in J/mole.14000

c) Air (Cp/R=3.5) is adiabatically and reversibly compressed in a piston+cylinder from 100°C and 1 bar to 100 bar. Estimate the work requirement in J/mole.21000

d) Suppose a particular charge of gunpowder resulted in a high pressure gas at 100 bar and 3000K in a 10 cm dia X 20 cm length chamber. This chamber is connected to 480cm barrel of the same diameter angled at 45°. Assuming that the mass of the cannonball is 1 kg and the expansion of the gas is adiabatic and reversible, write the energy balance for the travel of the cannonball from its initial position to the end of the gun barrel. (You do not need to substitute any numbers.)

Wdt=d[M(U+v^2/2+gZ)]

e) A series of three adiabatic, reversible compressors with interstage cooling to the initial inlet temperature is to compress air (assume ideal gas) from 300K and 1 bar to 100 bar. Estimate the pressure after the first compression stage assuming the series has been designed to minimize the overall work requirement. 4.6bar

2. An adiabatic compressor has been designed to continuously compress 1 kg/s of saturated vapor steam from 1 bar to 100 bar and 1100 C. Estimate the power requirement of this compressor in horsepower. (15)3000

3. Determine the efficiency of the compressor described above. (20)60

4. A cold storage room is to be maintained at 10°F and the available cooling water is 70°F. Assume that the cold-room coils and the condenser are of sufficient size that a 10°F approach can be realized in each. The refrigerant capacity is to be 126,500 kJ/hr. Freon-***22*** (!!!) will be used for the vapor compression cycles. Calculate the COP for the following cases:

a) Carnot cycle (5)5.75

b) Ordinary vapor compression cycle for which compressor is 100% efficient.(10)4.3

c) Ordinary vapor compression cycle for which compressor is 80% efficient.(5)3.4

(Note: This is Freon-***22***. Minimal credit will be awarded for Freon-12.

5. A 1 m^3 tank is to be filled using N_2 at 300K and 20 MPa. Instead of throttling the N2 into the tank, a reversible turbine is put in line to get some work out of the pressure drop. If the pressure in the tank is initially zero and the final pressure is 20 MPa, what will be the final temperature in the tank? How much work will be accomplished over the course of the entire process? (Hint: consider the entropy balance carefully.)(20)300K,20E6J

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TEST 1 SSN________

1. Short Answer (20)

a) Two moles of oxygen are mixed with an equal volume of nitrogen at 300K and 1 bar. Estimate (assuming ideal gas) the change in entropy (J/mole-K) for the **oxygen**.

b) Saturated liquid water at 25°C is steadily pumped to a pressure of 70 bars. Estimate the work requirement in J/g.

c) An initially evacuated cylinder of hydrogen is to be filled from a supply line available at 400K and 50 bars. Estimate the final temperature (K) of the hydrogen in the cylinder after filling.

d) Write the most compact but applicable energy balance for the following: A surge tank is mounted at the side of an air supply line to damp out fluctuations in the air pressure. As the pressure in the supply line begins to drop, air leaks out of the surge tank into the supply line. System: the surge tank and its contents.

2) Freon-**22** is adiabatically compressed in a steady state process from saturated vapor at 240K to 15 bars and 400K. Compute the specific work required (kJ/kg).(20)

3) Estimate the efficiency of the compressor from the above problem.(20)

4) A heat engine is to operate on steam. Cooling water is available such that the condenser operates at a temperature of 50°C. The manufacturer of the boiler specifies that the temperature of the steam exiting the boiler may not exceed 400°C. The manufacturer of the turbine requires that the quality of steam exiting the turbine must be at least 89.5%.

a) Estimate the maximum thermal efficiency of a Carnot cycle operating between these upper and lower temperatures.(5)

b) Estimate the maximum thermal efficiency of a single stage Rankine cycle operating between these upper and lower temperatures.(20)

5) Suppose the fluid in the fix-a-flat can was Freon-22 (MW=85.5) at 50wt% liquid and 100kg/m^3. Let the can be 500 cm^3 and the tire be 40,000 cm^3 at 300K and 1 bar.

a) write the mass balance for the overall process (2).

b) write the energy balance for the overall process (2).

c) write the entropy balance for the can of Freon-22 (2).

d) Approximating that the tire was originally filled with Freon-22, that the contents of the tire are at such a low pressure that they can be treated as an ideal gas, and that the change in the temperature of the tire is negligible, solve for the tire pressure (bars) when the pressure in the can has dropped to 4 bars. Is it enough to inflate the tire? (9)

Answers: (1)a. 11.5J/mole-K, b.7J/g, c.560K, d.$H^{out}dn=d(nU)$ (2) 100J/g (3)64 (4)52%,30% (5) a.$m_{Cf} + m_{Tf} = m_{Ci} + m_{Ti}$ b. $m_{Cf} U_{Cf} + m_{Tf} U_{Tf} = m_{Ci} U_{Ci} + m_{Ti} U_{Ti}$ c.ΔS=0 d.1.25bars

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TEST 1 SSN________

1. Short Answer (15)

a) The specific volume of steam at 4 MPa and 1200°C in m^3/kg is ______ m^3/kg

b) A 2000 kg automobile traveling at 25 m/s strikes a plunger in 10,000 cm^3 of water, bringing the auto to a stop. What is the maximum temperature rise, in °C, of the water?

c) Find the work, in kJ/kg needed to compress air isentropically from 20°C and 100 kPa to 6 MPa (in a piston+cylinder).

2. Consider the case of 8 particles distributed between two boxes. What is the fraction of microstates with 4 particles in the first box and 4 particles in the second box? (10)

3. As part of a refrigeration cycle, Freon 134a is adiabatically compressed from the saturated vapor at -60°C (note the negative sign on temperature) to 1017kPa and 100°C. How much work is required in kJ/kg?(15)

4. Estimate the efficiency of the compressor in problem 3.(20)

5. A Rankine cycle is to be operated on steam entering the turbine at 500°C and 5MPa and expanding isentropically to 10kPa.

a) Estimate the maximum work output in kJ/kg.(10)

b) Estimate the maximum thermodynamic efficiency for this cycle. (10)

6. We have an isothermal 100% efficient, continuous compressor to raise steam from 0.5 MPa to 5 MPa. The process of interest involves a fluidized bed reactor that requires a volumetric flow rate of 0.1 m^3/sec to maintain the fluidization. The stoichiometry for the reaction of interest requires that 1.73 kg/sec of steam be fed to the reactor.

a) Write the appropriate reduced energy and entropy balances for the compressor.(6)

b) Determine the temperature at which the compressor should operate. (4)

c) Determine the work requirement in **horsepower** of the compressor. (10)

Answers: (1)0.17,15°C,466,(2).27(3)121(4)75%(5)1224,38%(6)$\Delta S=\Delta Q/T$,400°C,1616hp

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TEST 1 SSN________

1. Short Answer (35)

   Sketch the force between two molecules vs. dimensionless distance, r/σ, according to the Lennard-Jones potential. Is the value of r/σ when the force is equal to zero greater, equal, or less than unity?(5)

   Estimate the change in entropy (J/mole-K) when 0.5 moles of helium are mixed with 0.5 moles of hydrogen at 300K.(5)

   Estimate the "lost work" of the process in part c above.(5)

   Estimate the work required (J/mole) to adiabatically and reversibly compress argon from 1 bar and 300 K to 20 bars in a steady state process. (10)

   Ten particles distributed between two boxes go from 9 in box A to 6 in box A. Compute the change in entropy (dimensionless $\Delta \underline{S}/k$ will suffice).(10)

2. Steam expands through an adiabatic turbine from 200 bars and 700°C to 1 bar saturated vapor. Compute the work output of the turbine in kJ/kg. (15)
3. Compute the efficiency of the turbine in problem 3.(15)
4. Freon 134a is used in an OVC heat pump providing cooling to a building during the summer. The air inside the building is to be maintained at 25°C with a 5°C approach temperature (cf. Index for definition of approach temperature) and the heat is to be rejected to the outside air at 35°C with a 25°C approach. The compressor is 80% efficient. Compute the coefficient of performance for this cycle and compare it to the value for a Carnot cycle.(20)

5. It is desired to determine the volume of an initially evacuated tank by filling it from an 80 liter cylinder of air at 300 bars and 300K. The final pressure of both tanks is 5 bars. Estimate the volume in liters.(15)

Answers: 1(a) greater (b) 5.763J/mol-K (c) 1729J/mol (d) 14432 J/mol, 2. 3.04*k_B 3. 1133kJ/kg 4. 83% 5. 4.24vs.7.3 6. 4720L

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TEST 1 SSN________

1. Short Answer (25)

a) Derive the expression for the force between two molecules characterized by the Yukawa potential (given below)(5)

$$u(r) = \begin{cases} \infty & r < \sigma \\ -\varepsilon \dfrac{\exp\{-B[(r/\sigma)-1]\}}{(r/\sigma)} & r \geq \sigma \end{cases}$$

b) Estimate the change in entropy (J/mole-K) when 0.25 moles of helium are mixed with 0.75 moles of hydrogen at 300K. (5)
c) Estimate the "lost work" of the process in part b above.(5)
d) Nitrogen is adiabatically and reversibly expanded from 300 Kelvin and 1 bar to 1 Kelvin. Estimate the downstream pressure.(10)

2. Twenty particles are distributed between two boxes with 13 in box A. Compute the number of microstates for this macrostate and the fraction of all microstates associated with this macrostate.(10)
3. Freon 134a expands through an adiabatic turbine from saturated vapor at 70°C to -30°C saturated vapor. Compute the work output of the turbine in kJ/kg. (15)
4. Compute the efficiency of the turbine in problem 3.(15)
5. Steam is used in an OVC heat pump providing cooling to a space station on Mars. The saturated liquid water exits the condenser at 295°C. The saturated vapor exits the evaporator at 30°C. The adiabatic compressor is 80% efficient. Compute the coefficient of performance for this cycle and compare it to the value for a Carnot cycle.(20)
6. Saturated liquid Freon 134a at 296K is used in a fix-a-flat can starting filled with 300 g of saturated liquid and dropping to 2.42 bars.

(a) What is the quality of the Freon in the can at the end of the process (10)
(b) How many moles of Freon 134a (MW=102) are left the can? (5)

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TEST 1 SSN________

1. Short Answer (20)

a. Write the simplified energy balance for the following: A pot of water brought to a boil from initially cold water in a pressure cooker on the oven with the pressure relief valve operating perfectly. System: the pot and its contents.(5)
b. Molecules *A* and *B* can be represented by the square-well potential. For molecule *A*, σ = 0.3 nm and ε = 10e-22 J. For molecule *B*, σ = 0.5 nm and ε = 30e-22 J. Which molecule would you expect to have the higher boiling temperature?(5)
c. Molecules *A* and *B* can be represented by the square-well potential. For molecule *A*, σ = 0.3 nm and ε = 10e-22 J. For molecule *B*, σ = 0.5 nm and ε = 30e-22 J. Sketch the potential models for the two molecules on the same pair of axes clearly indicating σ's and ε's of each specie. Make molecule *A* a solid line and *B* a dashed line.(5)
d. Argon in a rigid cylinder at 300 K and 100 bars leaks adiabatically to a pressure of 25 bars. Estimate the temperature of the argon remaining the tank. (5)

2. A Rankine cycle operates on steam exiting the boiler at 7 MPa and 550°C and dropping to 60°C and 98% quality.
   (a) Compute the efficiency of the turbine.(10)
   (b) Estimate the pump work (kJ/kg).(5)
   (c) Compute the thermal efficiency of the Rankine cycle.(5)
   (d) Compute the thermal efficiency of a Carnot cycle operating between 550 and 60°C.(5)

3. 200 moles per hour of natural gas is to be adiabatically and reversibly compressed from 300K and 1 bar to 100 bars in a continuous two-stage process with inter-cooling to 300K. Natural gas may be approximated by pure ideal gas methane.
   (a) What pressure do you recommend between stages? (5)
   (b) Estimate the final temperature exiting the second stage. (5)
   (c) Estimate the work requirement (kJ/mole) (6)
   (d) Estimate the average power requirement for the compressor (hp). (4)

4. Freon 134a is to be adiabatically and reversibly compressed from saturated vapor at -25°C to 3MPa.
   (a) Compute the work requirement (kJ/kg) using the chart. (5)
   (b) Compute the heat removed in a condenser(Q_H) that drops the outlet of the above compressor to saturated liquid. (5)
   (c) Compute the Coefficient of Performance (Q_L/W) for an OVC cycle based on this compressor and condenser. (5)

5. Steam originally exists in a piston +cylinder at 0.4 MPa and 350°C. The piston is forced down adiabatically and reversibly till the volume is 38% of the original volume.
   (a) Write the energy and entropy balances for this process (6).
   (b) Estimate the final pressure and temperature. (6)
   (c) Compute the work for this process (kJ/kg) (8).

6. A rigid insulated cylinder is initially divided into two compartments by a frictionless piston that does not conduct heat. Initially, the piston separates two ideal gases (Cv/R=2 for both gases). The entire system is initially at 300K. One gas is at 200 bars and occupies 10% of the total fixed volume and the other is at 20 bars. The piston is attached to a rod such that work is adiabatically and reversibly removed as the two sides of the piston equilibrate.
   (a) What is the relationship between volume and pressure on each side of the piston? (5)
   (b) What is the ratio of the final volumes and what are the final temperatures for each gas at equilibrium? (15)
   (c) If the piston were able to conduct heat, but the process was conducted irreversibly, such that no work was removed, what would be the final states (P, V, T) of both sides of the piston at equilibrium? (10)