# Problems -Physical Chemistry I

NOTE: If the heat capacity (c) is dependent on the temperature:

Q=∫ c(T)*dT ( if molar heat capacity is given: Q=∫ c(T)*n*dT )

ΔS=∫ [ c(T)/T ]*dT

**2.** Using the ideal gas law calculate

a) The mass of the air in a room of 110 $m^3$ volume. The pressure is 1.013 bar, the temperature is 23 °C. The average molar mass of air is 29 g/mol.

b) The volume of one mol ideal gas at 0 °C and 1.013 bar.

c) The pressure in a cylinder, which is of 10 $dm^3$ volume and contains 0.5 kg nitrogen at 15 °C.

**3.** 1.0 mol $N_2$ and 3.0 mol $H_2$ are in a container of volume 10.0 $dm^3$ at 298 K. Calculate the partial pressures and the total pressure.

**4.** A perfect gas at 35 °C is heated at constant pressure until its volume has increased by 18%. What is the final temperature of the gas?

**5.** The density of aluminium at 20 °C is 2.70 $gcm^{-3}$ and that of the liquid at 660 °C is 2.38 $gcm^{-3}$. Calculate the work done on surroundings when 1 kg aluminium is heated under p = 100 kPa from 20 °C to 660 °C.

**6.** Calculate the heat needed for heating two moles of $O_2$ (ideal gas) from 25 °C to 90 °C

a) at 100 kPa constant pressure

b) at constant volume

$C_{mp} = 25.72 + 12.98\cdot 10^{-3}\ T - 38.6\cdot 10^{-6}\ T^2$ (J/molK)

**7.** 1 mol liquid benzene is vaporized at its boiling point and the vapor (ideal gas) is heated to 427 °C at 0.1 MPa constant pressure. Calculate ΔH, ΔU, W, and Q.

Boiling point: 80 °C. Density of liquid benzene: 0,85 $gcm^{-3}$,heat of vaporization: 30,8 kJ/mol.

Vapor $C_{mp} = -1.195 + 21.51 \cdot 10^{-3}\, T$ (J/molK)

**8.** A vessel containing 200 g water is heated for 5 minutes with a 10.0 W (W=J/s) heater. The temperature increases by 1.5 °C. Calculate the heat capacity of the empty vessel. The specific heat capacity of water is 4.18 J/(gK)

**9.** 2 mol ideal gas is compressed from 50 kPa to 200 kPa at a constant temperature of 200 K. Calculate the work, the heat and $\Delta U$ if the process is reversible.

**10.** Calculate the work if 5 mol ideal gas is heated from 0 °C to 500 °C at a constant pressure of $10^5$ Pa.

**11.** 1 mol argon (one atomic ideal gas, $C_{mv} = 3/2R$) of 25 °C and $10^5$ Pa is heated to 100 °C and the pressure is increased to $5 \cdot 10^5$ Pa in three different ways. Calculate W, Q, $\Delta H$ and $\Delta U$ in each case.

a) First it is heated up from 25 °C to 100 °C at constant volume, then the pressure is increased to $5 \cdot 10^5$ Pa at constant temperature.

b) First it is heated up from 25 °C to 100 °C at constant pressure, then the pressure is increased from $10^5$ Pa to $5 \cdot 10^5$ at constant temperature.

c) First it is compressed from $10^5$ Pa to $5 \cdot 10^5$ Pa at constant temperature, then the temperature is increased from 25 °C to 100 °C at constant pressure.

**12.** The following cyclic process is performed on 1 mol argon.

a) It is heated from 25 °C to 100 °C at 5 bar constant pressure,

b) it is expanded from 5 bar to 1 bar at 100 °C,

c) it is cooled to 25 °C at one bar

d) finally it is compressed at 25 °C to 5 bar.

Calculate the heat, the work, the change of internal energy and the change of enthalpy in each step and in the whole cyclic process.

**13.** 4 mol nitrogen of 25 $^{o}$C and 1 bar pressure is compressed adiabatically (and reversibly) to 5 bar and then it is cooled down to 25 $^{o}$C at 5 bar constant pressure. Calculate W, Q, $\Delta$U, $\Delta$H in each step. (Ideal gas, reversible processes, $C_{mp}$ = 31.1 J/(molK), const.)

**14.** There is 1 dm$^3$ ideal gas in a cylinder with piston at 1.2*10$^5$ Pa and 298 K. It is expanded adiabatically (and reversibly) to 10$^5$ Pa, then the piston is fixed in its position and the gas is heated to its original temperature. After the second step the pressure of the gas is 1.076*10$^5$ Pa. Calculate $\kappa$.

( Help: logarithm change of base rule: $\log_b x = [\log_k x]/[\log_k b]$ )

**15.** 1 mol nitrogen (ideal gas) of 373 K is adiabatically (and reversibly) expanded until its temperature decreases to 273 K. Calculate the work if the initial pressure is

a) 10$^6$ Pa

b) 5*10$^5$ Pa.

$C_{mp}$ = 30.418 +2.544*10$^{-3}$ * T - 0.238*10$^6$T$^{-2}$

**16.** The pressure of a one atomic ideal gas ($C_{mv}$ = 3/2R) is increased by a factor of five in an adiabatic reversible process. Calculate the final temperature if the initial temperature is 298 K.

**17**. Calculate the change of internal energy of 100 g nitrogen of 273 K temperature and p$^0$ pressure if

a) the pressure is inreased to 151.95 kPa by heating at constant volume,

b) the temperature is increased to 100 $^{o}$C at constant pressure.

(Ideal gas, $C_{mp}$ = 30.418 +2.544*10$^{-3}$ * T - 0.238*10$^6$T$^{-2}$)

**18.** Calculate the change of molar internal energy of ethyl ether (M = 74 g/mol) if it is evaporated at 1.013*10$^5$ Pa. The boiling point at this pressure is 34.5 $^{o}$C, the density of the liquid is 0.697 kgdm$^{-3}$, that of the vapor is 3.16*10$^{-3}$ kgdm$^{-3}$ at the boiling point. The molar heat of vaporization is 26.7 kJ/mol.

**19.** One mol nitrogen is expanded from 0.01 $m^3$ to 0.02 $m^3$ at a constant temperature of 125 °C. Calculate the heat, the work and the change of internal energy. (Ideal gas)

**20.** One mol nitrogen (ideal gas) is cooled at constant volume from 125 °C to 28.6 °C. How much heat has to be extracted? How much is the change of internal energy? (Ideal gas, $C_{mp} = 30.418 + 2.544*10^{-3} * T - 0.238*10^{6}T^{-2}$.)

**21.** One mol nitrogen (ideal gas) is compressed adiabatically (and reversibly) from 0.02 $m^3$ to 0.01 $m^3$. The final temperature is 125 °C. Calculate the initial temperature. Calculate the work and the change of internal energy. $\kappa = 1.40$. Assume that $C_{mp}$ and $C_{mv}$ are constants.

**22.** The steps of the previous three problems are parts of a cyclic process. Plot it in a p -V diagram. Calculate the heat and work in the overall cyclic process.

**29.** 1 mol solid tin of 450 K temperature is added adiabatically to 10 mol liquid tin of 600 K. Calculate the change of entropy if equilibrium is attained. The average molar heat capacity of solid tin is 30.7 J/(molK), that of liquid tin is 29.0 J/(molK), the melting point is 505 K, the enthalpy of fusion is 7.01 kJ/mol.

**30.** Calculate $\Delta S$ when 90 g ice at 0 K is mixed with 18 g steam at 100 °C and 1 bar pressure and the system comes to equilibrium in an adiabatic enclosure. The heat of vaporization of water at 100 °C is 41.4 kJ/mol, the heat of fusion of ice at 0 °C is 6.02 kJ/mol, the average molar heat capacity of water is 75.312 J/(molK).

**31.** Calculate the change of entropy if 2 mol nitrogen is heated from 27 °C to 127 °C at constant pressure. $C_{mp} = 27.3 + 5.23 \cdot 10^{-3}T - 0.04 \cdot 10^{-7}T^2$

**32.** Calculate $\Delta S$ when 1 mol $H_2O$ is heated from 263 K to 283 K at 100 kPa. $C_{mp}(ice) = 2.09 + 0.126\ T$ ($JK^{-1}mol^{-1}$) $C_{mp}(water) = 75.3\ JK^{-1}mol^{-1}$ $\Delta H_f = 6000\ Jmol^{-1}$.

**33.** 3 mol nitrogen (ideal gas) is compressed from 1.2 bar to 4.1 bar at 300 K constant temperature. Calculate the change of entropy.

**34.** The following cyclic process is performed on 160 g oxygen

1. From 20 °C and 0.1 MPa it is compressed adiabatically (and reversibly) to 2 MPa,
2. It is heated in an isochor process to 500 °C,
3. It is expanded in an isothermal process to 0.1 MPa,
4. Finally it is cooled down in an isobaric process to 20 °C.

Calculate W, Q, $\Delta U$, $\Delta H$, $\Delta S$ in each step and in the whole cycle.

$\kappa = 1.4$. The molar heat capacity can be taken independent of temperature.

**37.** 2 kg saturated steam of 200 °C temperature is expanded isothermally to 50 kPa. Calculate $\Delta U$, $\Delta H$, and $\Delta S$.

**38.** Saturated steam of 2 Ma pressure is expanded adiabatically through a throttle to a pressure of 0.15 MPa. What is the temperature of the expanded gas and how much is the change of enthalpy?

**39.** 600 dm$^3$ saturated steam of 3 MPa is is expanded adiabatically through a throttle to a pressure of 200 kPa and then it is used for heating in an isobaric process until 30 per cent of the steam condenses. Calculate the heat.

**40.** 1 kg saturated steam of 2 MPa is closed in a cylinder with a piston and then it is compressed adiabatically and reversibly to 8 MPa. Relate this work to that of of an ideal adiabatic compressor.

**41.** 30 kg damp steam containing 40 per cent water at 0.5 MPa is heated to 300 °C at constant volume. Calculate the heat.

**42.** Steam overheated (compared to the saturation temperature) by 20 K at 1 MPa pressure is first expanded adiabatically and reversibly to 0.1 MPa then it is used for heating at constant pressure until its water content reaches 60 per cent. How many m$^3$ steam of initial state has to be used if we need 60 000 kJ for heating?

**43.** 4.5 $m^3$ steam overheated (compared to the saturation temperature) by 50 K at 0.1 MPa is first compressed adiabatically and reversibly to 0.5 MPa, then it is cooled at constant pressure until its 5 per cent consdenses, finally it is expanded through a throttle to 0.1 MPa. Calculate the compression work and the heat of cooling. Determine the final temperature and water content.

**44.** 10 kg saturated steam at 250 °C is expanded isothermally. Calculate the work if the heat is 9 MJ.

**45.** For the operation of a steady state chemical reactor, 10 kJ/s heat is needed. For the production of heat, steam overheated (compared to the saturation temperature) by 20 K at 1 MPa pressure is available. First the steam is adiabatically expanded through a throttle so that in the second step the heat exchange takes place in an isobaric process by the end of which 120 °C damp steam of 75 % water content leaves the system. Calculate how many $m^3$ initial (overheated) steam has to be used in an hour.

**46.** Calculate the heat of evaporation of benzene. The boiling point at 101.3 kPa is 80.1 $^{o}$C . dt/dp = 0.320 K/kPa, $\rho_l = 0.8144 \cdot 10^3$ kg/$m^3$, $\rho_V = 0.002741 \cdot 10^3$ kg/$m^3$ at 80.1 $^{o}$C .

**50.** The vapour pressure of n-octane is 26660 Pa at 83.52 $^{o}$C and 39990 Pa at 95.16 $^{o}$C. Calculate the vapour pressure at 90 $^{o}$C.

**51.** The normal boiling point of diethyl ether is 307.6 K. Ether is to be stored in aluminium drums that can withstand a pressure of $10^3$ kPa. What is the maximum temperature to which the drums of ether could be exposed?

**57.** At 140 $^{o}$C the vapour pressure of chlorobenzene is 125.24 kPa, that of bromobenzene is 66.1 kPa. What is the composition of a solution which has a boiling point of 140 $^{o}$C at 100 kPa? What is the composition of the vapour?

**58.** 65 mol benzene and 35 mol toluene are in a vessel. The temperature is 70 $^{o}C$ and the pressure is 53.3 kPa. How many moles are altogether in the vapour phase? Calculate the volume of the vapour phase (ideal gases). $p_B^*$= 72.0 kPa, $p_T^*$=27.5 kPa

**60.** A vessel of 40 $dm^3$ volume contains a vapour mixture of hexane and octane, in which the mole fraction of hexane is 0.700. The temperature is 150 $^{o}C$., the pressure is 200 kPa. The system is cooled down to 80 $^{o}C$ while some of the vapour is condensed and an equilibrium pressure of 94.25 kPa sets in. How many moles of hexane are there in the liquid phase? At 80 $^{o}C$ the vapour pressure of hexane is 141.55 kPa, that of octane is 23.29 kPa.