UNIVERSITY OF SWAZILAND

BACHELOR OF SCIENCE

FINAL EXAMINATION 2012

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|---|---|---|
| TITLE OF PAPER | : | INTRODUCTORY PHYSICAL CHEMISTRY |
| COURSE NUMBER | : | C202 |
| TIME | : | 3 HOURS |
| INSTRUCTIONS | : | THERE ARE SIX QUESTIONS |
| | : | ANSWER ANY FOUR QUESTIONS |
| | : | BEGIN THE ANSWER TO EACH QUESTION ON A SEPARATE SHEET OF PAPER |
| | : | DATA SHEETS ARE PROVIDED WITH THIS EXAMINATION PAPER |

DO NOT OPEN THIS PAPER UNTIL THE INVIGILATOR INSTRUCTS YOU TO DO SO.

**Question 1[25 marks]**

a) Define the variable, compressibility factor, z. With the aid of Lennard-Jones potential plot and compressibility or isotherm plots, compare and contrast real and ideal gases. Your account should make mention of interactions, equations and any necessary theories to help clarify your discussion. [10]

b) A real gas equation of state for a gas is given by:

$$P = \frac{RT}{Vm} - \frac{B}{Vm^2} + \frac{C}{Vm^3} \quad (1)$$

(i) Derive an expression for $V_{m,c}$, $T_c$ and $P_c$ using equation (1). [9]

(ii) Estimate the radii of real gas molecules using the critical molar volume, $V_{m,c}$, expression obtained using equation (1) in (i) and given that the critical molar volume is also three times the repulsive gas constant ***b***. B=21.7 $cm^3\ mol^{-1}$ and C=1200 $cm^6\ mol^{-2}$. [6]

**<u>QUESTION</u> 2 [25 marks]**

a) Write short notes on **<u>Any Two</u>** of the following concepts:

| | | |
|---|---|---|
| i) | Statistical view of entropy | [8] |
| ii) | Clausius inequality | [8] |
| iii) | Second law of thermodynamics | [8] |
| iv) | Third law of thermodynamics | [8] |

For each concept include the origin or a short derivation showing its origin, an example where applicable and the role or implication of each of the concepts in thermodynamics.

b) Calculate the change entropy of the system, surroundings and the total change in entropy when 1.0 mol of oxygen gas at 27 °C is expanded from an initial pressure of 3.00 atm to a final pressure of 1 atm

i) Isothermal reversible expansion [2]

ii) Isothermally against a constant external pressure of 1.0 atm [2]

iii) Adiabatic reversible expansion [2]

c) Calculate the change in entropy when 20 g $H_2O$ at 40 °C is poured into 40 g $H_2O$ at 5 °C in an insulated vessel given that the heat capacity, $C_{p,m}$ is 75.5 J/K/mol. [3]

**Question 3 [25 Marks]**

a) Using an example of your choice differentiate between enthalpy and internal energy change [10].

b) Find $\Delta_r H^\theta$ for the following reactions from standard enthalpies of formation:

i) $2NO_2(g) \rightarrow N_2O_4(g)$ [2]

ii) $NH_3(g) + HCl(g) \rightarrow NH_4Cl$ (s) [2]

iii) Calculate the enthalpy of hydrogenation and the internal energy change of hydrogenation of ethyne (acetylene) to ethene (ethylene) from the enthalpy of combustion data given below: [2]

| | $\Delta_C H^\theta$/kJmol$^{-1}$ |
|---|---|
| $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ | -285.83 |
| $C_2H_4(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2CO_2(g)$ | -1411 ethene |
| $C_2H_2(g) + \frac{5}{2}O_2(g) \rightarrow 2H_2O(l) + 2CO_2(g)$ | -1300 ethyne |

<u>*use table attached*</u>

c) The standard enthalpy of reaction of $NH_3SO_2$ (g) $\rightarrow NH_3(g) + SO_2(g)$ is -40 kJ/mol.
Calculate

i) the standard enthalpy of formation of $NH_3SO_2$ (g). [2]

ii) Calculate the internal energy of formation of $NH_3SO_2$ (g). [3]

***Use data for enthalpy of formation of $NH_3(g)$ and $SO_2(g)$ in the attached table***

d) Derive Kirrchoff's equation [2]

$$\Delta_r H(T_2) = \Delta_r H(T_1) + \Delta_r C_{p,m} \Delta T$$

Using the data in the table below calculate $\Delta_r H^\theta$ and $\Delta_r U^\theta$ for the reaction:

$$C(graphite) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

At

i) 298 K [1,1]

ii) 348 K [1,1]

| | C(graphite) | $H_2O(g)$ | CO(g) | $H_2(g)$ |
|---|---|---|---|---|
| Cp,m Jmol$^{-1}$K$^{-1}$ | 8.53 | 33.58 | 29.14 | 28.82 |
| $\Delta_f H$/kJ/mol | 0 | -241.8 | -110.5 | 0 |

**<u>Question 4</u> [25 Marks]**

a) Using examples and/or diagrams compare and contrast the following terms

i) reversible and irreversible expansion [10]

ii) path and state functions [5]

b) A sample of 4.50 g of methane, $CH_4$, occupies 12.7 L at 310 K.

(i) Calculate the work done when the gas expands isothermally against a constant external pressure of 200 Torr until its volume has increased by 3.3L. [5]

(ii) Calculate the efficiency of the system in 1 (b(i)) above. [5]

[R.A.W C=12 g/mol H=1.008 g/mol]

**Question 5 [25 Marks]**

a) Derive the integrated Gibbs-Helmholtz equation [3]

$$\frac{\Delta G_2}{T_2} - \frac{\Delta G_1}{T_1} = \Delta H\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

from the fundamental thermodynamic equation $dG = VdP - SdT$

b) Given the reaction:

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

Calculate the change in Gibbs free energy $\Delta G^\theta$

i) at 298K [5]

ii) at 500K [5]

iii) Comment on the significance of the values obtained in (i) and (ii). [2]

c) The Gibbs equation is given by G=H-TS.

(i) Prove that the Gibbs function is maximum nonexpansion work, $dW_{e,max}$. [4]

(ii) Oxidation of beta-D-glucose at 25°C is given by:

$$C_6H_{12}O_6(s) + 6O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(l)$$

Using the appropriate thermodynamic data find the maximum work done and maximum nonexpansion work done. [6]

**QUESTION 6 [25 MARKS]**

a) Write short notes on any Two of the following: [10]

i) Eutectic temperature and Congruent melting point

ii) Zeotrope and Azeotrope

iii) Lower consulate and upper consulate temperature

b) Draw a sketch of the phase diagram of water and explain briefly the slopes and curvature of the liquid-solid and the liquid-gas boundaries, respectively. [5]

c) i) Derive the Clausius-Clapeyron equation for evaporation [5]

ii) The triple point of benzene is at 5.5$^{O}$C and 36 mm Hg. Predict the boiling point of benzene at 0.2 atm pressure. [5]

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END OF EXAM

# THE PERIODIC TABLE OF ELEMENTS

NON-METALS

METALLOIDS

METALS

| Group | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IA | IIA | IIIB | IVB | VB | VIB | VIIB | VIIIB | | | IB | IIB | IIIA | IVA | VA | VIA | VIIA | VIIIA |
| Period 1 | 1 **H** 1.008 | | | | | | | | | | | | | | | | | 2 **He** 4.003 |
| 2 | 3 **Li** 6.94 | 4 **Be** 9.01 | | | | | | | | | | | 5 **B** 10.81 | 6 **C** 12.01 | 7 **N** 14.01 | 8 **O** 16.00 | 9 **F** 19.00 | 10 **Ne** 20.18 |
| 3 | 11 **Na** 22.99 | 12 **Mg** 24.31 | | | | | | | | | | | 13 **Al** 26.9 | 14 **Si** 28.09 | 15 **P** 30.97 | 16 **S** 32.06 | 17 **Cl** 35.45 | 18 **Ar** 39.95 |
| 4 | 19 **K** 39.10 | 20 **Ca** 40.08 | 21 **Sc** 44.96 | 22 **Ti** 47.90 | 23 **V** 50.94 | 24 **Cr** 52.01 | 25 **Mn** 54.9 | 26 **Fe** 55.85 | 27 **Co** 58.71 | 28 **Ni** 58.71 | 29 **Cu** 63.54 | 30 **Zn** 65.37 | 31 **Ga** 69.7 | 32 **Ge** 72.59 | 33 **As** 74.92 | 34 **Se** 78.96 | 35 **Br** 79.91 | 36 **Kr** 83.80 |
| 5 | 37 **Rb** 85.47 | 38 **Sr** 87.62 | 39 **Y** 88.91 | 40 **Zr** 91.22 | 41 **Nb** 91.22 | 42 **Mo** 95.94 | 43 **Tc** 98.9 | 44 **Ru** 101.1 | 45 **Rh** 102.9 | 46 **Pd** 106.4 | 47 **Ag** 107.9 | 48 **Cd** 112.4 | 49 **In** 114.8 | 50 **Sn** 118.7 | 51 **Sb** 121.8 | 52 **Te** 127.6 | 53 **I** 126.9 | 54 **Xe** 131.3 |
| 6 | 55 **Cs** 132.9 | 56 **Ba** 137.3 | 71 **Lu** 174.9 | 72 **Hf** 178.5 | 73 **Ta** 180.9 | 74 **W** 183.8 | 75 **Re** 186.2 | 76 **Os** 190.2 | 77 **Ir** 192.2 | 78 **Pt** 195.1 | 79 **Au** 196.9 | 80 **Hg** 200.6 | 81 **Tl** 204.4 | 82 **Pb** 207.2 | 83 **Bi** 208.9 | 84 **Po** 210 | 85 **At** 210 | 86 **Rn** 222 |
| 7 | 87 **Fr** 223 | 88 **Ra** 226.0 | 103 **Lr** 257 | 104 **Unq** | 105 **Unp** | 106 **Unh** | 107 **Uns** | 108 **Uno** | 109 **Une** | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 57 **La** 138.9 | 58 **Ce** 140.1 | 59 **Pr** 140.9 | 60 **Nd** 144.2 | 61 **Pm** 146.9 | 62 **Sm** 150.9 | 63 **Eu** 151.3 | 64 **Gd** 157.3 | 65 **Tb** 158.9 | 66 **Dy** 162.5 | 67 **Ho** 164.9 | 68 **Er** 167.3 | 69 **Tm** 168.9 | 70 **Yb** 173.0 |
| Actinides | 89 **Ac** 227.0 | 90 **Th** 232.0 | 91 **Pa** 231.0 | 92 **U** 238.0 | 93 **Np** 237.1 | 94 **Pu** 239.1 | 95 **Am** 241.1 | 96 **Cm** 247.1 | 97 **Bk** 249.1 | 98 **Cf** 251.1 | 99 **Es** 254.1 | 100 **Fm** 257.1 | 101 **Md** 258.1 | 102 **No** 255 |

*Numbers **below** the symbol indicates the **atomic masses**; and the numbers above the symbol indicates the atomic numbers.*

*SOURCE: International Union of Pure and Applied Chemistry, I mills, ed., Quantities, Units, and symbols in Physical Chemistry, Blackwell Scientific publications, Boston,*

## Useful Relations

$(RT)_{298.15K}$=2.4789 kJ/mol

$(RT/F)_{298.15K}$=0.025 693 V

| | | | | |
|---|---|---|---|---|
| T/K: | 100.15 | 298.15 | 500.15 | 1000.15 |
| T/Cm$^{-1}$: | 69.61 | 207.22 | 347.62 | 695.13 |

1mmHg=133.222 N m$^{-2}$

hc/k=1.438 78x10$^{-2}$ m K

| **1atm** | 1 cal | 1 eV | 1cm$^{-1}$ |
|---|---|---|---|
| **=1.01325x10$^{5}$ Nm$^{-2}$** | =4.184 J | =1.602 189x10$^{-19}$ J | =0.124x10$^{-3}$ eV |
| **=760torr** | | =96.485 kJ/mol | =1.9864x10$^{-23}$J |
| **=1 bar** | | = 8065.5 cm$^{-1}$ | |

**SI-units:**

***1 L = 1000 ml = 1000cm$^{3}$ = 1 dm$^{3}$***

1 dm = 0.1 m

1 cal (thermochemical) = 4.184 J

dipole moment: 1 Debye = 3.335 64x10$^{-30}$ C m

force: ***1N=1J m$^{-1}$= 1kgms$^{-2}$***=10$^{5}$ dyne pressure: ***1Pa=1Nm$^{-2}$***=1Jm$^{-3}$

***1J = 1 Nm***

power: 1W = 1J s$^{-1}$ potential: 1V =1 J C$^{-1}$

magnetic flux: 1T=1Vsm$^{-2}$=1JCsm$^{-2}$ current: 1A=1Cs$^{-1}$

**Prefixes:**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| p | n | m | m | c | d | k | M | G |
| pico | nano | micro | milli | centi | deci | kilo | mega | giga |
| 10$^{-12}$ | 10$^{-9}$ | 10$^{-6}$ | 10$^{-3}$ | 10$^{-2}$ | 10$^{-1}$ | 10$^{3}$ | 10$^{6}$ | 10$^{9}$ |

## General Data

| | | |
|---|---|---|
| **speed of light** | **c** | **2.997 925x10$^{8}$ ms$^{-1}$** |
| charge of proton | *e* | 1.602 19x10$^{-19}$ C |
| Faraday constant | F=L*e* | 9.648 46x10$^{4}$ C mol$^{-1}$ |
| **Boltzmann constant** | **k** | **1.380 66x10$^{-23}$ J K$^{-1}$** |
| **Gas constant** | **R=Lk** | **8.314 41 J K$^{-1}$ mol$^{-1}$** |
| | | **8.205 75x10$^{-2}$ dm$^{3}$ atm K$^{-1}$ mol$^{-1}$** |
| **Planck constant** | **h** | **6.626 18x10$^{-34}$ Js** |
| | $\hbar = \frac{h}{2\pi}$ | 1.054 59x10$^{-34}$ Js |
| **Avogadro constant** | **L or N$_{av}$** | **6.022 14x10$^{23}$ mol$^{-1}$** |
| Atomis mass unit | u | 1.660 54x10$^{-27}$ kg |
| **Electron mass** | **$m_e$** | **9.109 39x10$^{-31}$ kg** |
| Proton mass | $m_p$ | 1.672 62x10$^{-27}$ kg |
| Neutron mass | $m_n$ | 1.674 93x10$^{-27}$ kg |
| Vacuum permittivity | $\varepsilon_o = \mu_o^{-1}c^{-2}$ | 8.854 188x10$^{-12}$ J$^{-1}$ C$^{2}$ m$^{-1}$ |
| Vacuum permeability | $\mu_o$ | 4πx10$^{-7}$ Js$^{2}$C$^{-2}$ m$^{-1}$ |
| Bohr magneton | $\mu_B = e\hbar/2m_e$ | 9.274 02x10$^{-24}$ JT$^{-1}$ |
| Nuclear magneton | $\mu_N = e\hbar/2m_p$ | 5.05079x10$^{-27}$ JT$^{-1}$ |
| Gravitational constant | G | 6.67259x10$^{-11}$ Nm$^{2}$kg$^{-2}$ |
| **Gravitational acceleration** | **g** | **9.80665 ms$^{-2}$** |
| Bohr radius | $a_o$ | 5.291 77x10$^{-11}$ m |

Standard molar enthalpies of formation at 298.15 K

| | $M_r$ | $\Delta H_f^\theta$/KJ/mol | | $M_r$ | $\Delta H_f^\theta$/KJ/mol |
|---|---|---|---|---|---|
| $H_2O(g)$ | 18.015 | -241.8 | $O_3(g)$ | 47.998 | +142.7 |
| $H_2O(l)$ | 18.015 | -285.8 | $NO(g)$ | 30.006 | +90.2 |
| $H_2O_2(l)$ | 34.015 | -187.8 | $NO_2(g)$ | 46.006 | +33.2 |
| $NH_3(g)$ | 17.031 | -46.1 | $N_2O_4(g)$ | 92.012 | +9.2 |
| $N_2H_4(l)$ | 32.045 | +50.6 | $SO_2(g)$ | 64.063 | -296.8 |
| $N_3H(l)$ | 43.028 | +264.1 | $H_2S(g)$ | 34.080 | -20.6 |
| $N_3H(g)$ | 43.028 | +294.1 | $SF_6(g)$ | 146.054 | -1209 |
| $HNO_3(l)$ | 63.013 | -174.1 | $HF(g)$ | 20.006 | -271.1 |
| $NH_2OH(s)$ | 33.030 | -114.2 | $HCl(g)$ | 36.461 | -92.3 |
| $NH_4Cl(s)$ | 53.492 | -314.4 | $HCl(aq)$ | 36.461 | -167.2 |
| $HgCl_2(s)$ | 271.50 | -224.3 | $HBr(g)$ | 80.917 | +36.4 |
| $H_2SO_4(l)$ ) | 98.078 | -814.0 | $HI(g)$ | 127.912 | +26.5 |
| $H_2SO_4(aq)$ | 98.078 | -909.3 | $CO_2(g)$ | 44.010 | -393.5 |
| $NaCl(s)$ | 58.443 | -411.0 | $CO(g)$ | 28.011 | -110.5 |
| $NaOH(s)$ | 39.997 | -426.7 | $Al_2O_3(\alpha,s)$ | 101.945 | -1675.7 |
| $KCl(s)$ | 74.555 | -435.9 | SiO2(s) | 60.085 | -910.9 |
| $KBr(s)$ | 119.011 | -392.2 | $FeS(s)$ | 87.91 | -100.0 |
| $KI(s)$ | 166.006 | -327.6 | $FeS_2(s)$ | 119.975 | -178.2 |
| **DIATOMICS** | **Eg. $N_2$, $O_2$, $H_2$** | 0 | $AgCl(s)$ | 143.323 | -127.1 |

Temperature dependence of heat capacities, $C_{p,m} = a+bT+cT^{-2}$

| | a/J $K^{-1}mol^{-1}$ | b/$10^{-3}$J $K^{-2}mol^{-1}$ | c/$10^5$J $Kmol^{-1}$ |
|---|---|---|---|
| Gases (298-2000K) | | | |
| He, Ne, Ar, Kr, Xe | 20.78 | 0 | 0 |
| $H_2$ | 27.28 | 3.26 | 0.50 |
| $O_2$ | 29.96 | 4.18 | -1.67 |
| $N_2$ | 28.58 | 3.77 | -0.50 |
| $Cl_2$ | 37.03 | 0.67 | -2.85 |
| $CO_2$ | 44.23 | 8.79 | -8.62 |
| $H_2O$ | 30.54 | 10.29 | 0 |
| $NH_3$ | 29.75 | 25.10 | -1.55 |
| $CH_4$ | 23.64 | 47.86 | -1.92 |
| C(S) | 16.86 | 4.77 | -8.54 |

Enthalpies of fusion and evaporation $\Delta H_m$/KJ/mol at the transition temperature

| | $T_f$/K | Fusion[a] | $T_b$/K | Evaporation[b] | |
|---|---|---|---|---|---|
| He | 3.5 | 0.021 | 4.22 | 0 084 | |
| Ar | 83.81 | 1.188 | 87.29 | 6.506 | |
| $H_2$ | 13.96 | 0.117 | 20.38 | 0.9163 | |
| $N_2$ | 63.15 | 0.719 | 77.35 | 5.586 | |
| $O_2$ | 54.36 | 0.444 | 90.18 | 6.820 | |
| $Cl_2$ | 172.12 | 6.406 | 239.05 | 20.410 | |
| $Br_2$ | 265.90 | 10.573 | 332.35 | 29.45 | |
| $I_2$ | 386.75 | 15.52 | 458.39 | 41.80 | |
| Hg | 234.29 | 2.292 | 629.73 | 59.296 | |
| Ag | 1234 | 11.30 | 2436 | 250.63 | |
| Na | 370.95 | 2.601 | 1156 | 98.01 | |
| $CO_2$ | 217.0 | 8.33 | 194.64 | 25.23┴ | |
| $H_2O$ | 273.15 | 6.008 | 373.15 | 40.656 | (44.016 at 298.15 K) |
| $NH_3$ | 195.40 | 5.652 | 239.73 | 23.351 | |
| $H_2S$ | 187.61 | 2.377 | 212.80 | 18.673 | |
| $CH_4$ | 90.68 | 0.941 | 111.66 | 8.18 | |
| $C_2H_6$ | 89.85 | 2.86 | 184.55 | 14.7 | |
| $C_6H_6$ | 278.65 | 10.59 | 353.25 | 30.8 | |
| $CH_3OH$ | 175.25 | 3.159 | 337.22 | 35.27 | (37.99 at 298.15K) |

Standard molar enthalpies of formation and combustion at 298.15 K.

| | $M_r$ | $\Delta H_f^\theta$/KJ/mol | $\Delta H_c^\theta$/KJ/mol |
|---|---|---|---|
| $CH_4(g)$ | 16.043 | -74.81 | |
| $C_2H_2(g)$ | 26.038 | +226.8 | -1300 |
| $C_2H_4(g)$ | 28.054 | +52.30 | -1411 |
| $C_2H_6(g)$ | 30.070 | -84.64 | -1560 |
| $C_3H_6$ cyclopropane(g) | 42.081 | 53.35 | -2091 |
| $C_3H_6$ (propene(g) | 42.081 | 20.5 | -2058 |
| $C_4H_{10}$ n-butane (g) | 58.124 | -126.11 | -2877 |
| $C_5H_{12}$ n-pentane(g) | 72.151 | -146.4 | -3536 |
| $C_6H_{12}$ cyclohexane (l) | 84.163 | -156.2 | -3920 |
| $C_6H_{14}$ n-hexane (l) | 86.178 | -198.7 | -4163 |
| $C_6H_6$ benzene (l) | 78.115 | +48.99 | -3268 |
| $C_8H_{18}$ n-octane (l) | 114.233 | -249.8 | -5471 |
| $C_{10}H_8$ naphthalene (l) | 128.175 | +78.53 | -5157 |
| $CH_3OH$ (l) | 32.042 | -239.0 | -726.1 |
| $CH_3CHO$ (g) | 44.054 | -166.0 | -1193 |
| $CH_3CH_2OH$ (l) | 46.070 | -277.0 | -1368 |
| $CH_3COOH$ (l) | 60.053 | -484.2 | -874.5 |
| $CH_3COOC_2H_5$ (l) | 88.107 | -486.6 | -2231 |
| $C_6H_5OH$ (s) | 94.114 | -165.0 | -3054 |
| $C_6H_5NH_2$ (l) | 93.129 | -31.1 | -3393 |
| $NH_2CO.NH$, urea(s) | 60.056 | -333.0 | -632.2 |
| $CH_2(NH_2)CO_2H$, glycine (s) | 75.068 | -537.2 | -964.4 |
| $C_6H_{12}O_6$, $\alpha$-D-glucose (s) | 180.159 | -1274 | -2802 |
| $C_6H_{22}O_6$, $\beta$-D-glucose (s) | 180.159 | -1268 | -2808 |
| $C_{12}H_{22}O_{11}$, sucrose (s) | 342.303 | -2222 | -5645 |
| $CH_3CH(OH)COOH$ lactic acid (s) | 90.079 | -694.0 | -1344 |

┴ Sublimation: [a]various pressures: [b]at 1atm

Source: American Institute of Physics handbook, McGraw-Hill.

Heat capacities at 25°C

| | $C_{v,m}$ JK$^{-1}$ mol$^{-1}$ | $C_{p,m}$ JK$^{-1}$ mol$^{-1}$ |
|---|---|---|
| He, Ne, Ar, Kr, Xe | 12.47 | 20.78 |
| $H_2$ | 20.50 | 28.81 |
| $O_2$ | 21.01 | 29.33 |
| $N_2$ | 20.83 | 29.14 |
| $CO_2$ | 28.83 | 37.14 |
| $NH_3$ | 27.17 | 35.48 |
| $CH_4$ | 27.43 | 35.74 |
| $N_2O_4$ | | 77.28 |
| $NO_2$ | | 37.20 |

F.P Depression, B.P. Elevation

| Solvent | F.P °C | $K_f$ °C kg mol$^{-1}$ | B.P (°C, 101kNm$^{-2}$) | $K_b$ °C kg mol$^{-1}$ |
|---|---|---|---|---|
| Water | 0 | 1.86 | 100.0 | 0.52 |
| Benzene | 5.51 | 5.10 | 80.1 | 2.60 |
| Acetic Acid | 16.6 | 3.90 | 118.1 | 3.10 |
| Cyclohexane | 6.5 | 20.2 | 81.4 | 2.79 |
| Camphor | 177.7 | 40.0 | 205 | - |
| Nitrobenzene | 5.7 | 6.9 | 210.9 | 5.24 |
| Ethanol | -177 | | 78.5 | 1.22 |
| Chloroform | -64 | | 61.3 | 3.63 |

Third Law entropies at 25°C, $S_m^\theta$/J K$^{-1}$ mol$^{-1}$

| Solids | | Liquids | | Gases | |
|---|---|---|---|---|---|
| Ag | 42.68 | Hg | 76.02 | $H_2$ | 130.6 |
| C(gr) | 5.77 | $Br_2$ | 152.3 | $N_2$ | 192.1 |
| C(d) | 2.44 | | | $O_2$ | 205.1 |
| Cu | 33.4 | | | $Cl_2$ | 223.0 |
| Zn | 41.6 | $H_2O$ | 70.0 | | |
| $I_2$ | 116.7 | | | $CO_2$ | 213.7 |
| S(Rh) | 31.9 | $HNO_3$ | 155.6 | HCl | 186.8 |
| | | | | $H_2S$ | 205.6 |
| AgCl | 96.2 | $C_2H_5OH$ | 161.0 | $NH_3$ | 192.5 |
| AgBr | 104.6 | $CH_3OH$ | 126.7 | $CH_4$ | 186.1 |
| $CuSO_45H_2O$ | 305.4 | $C_6H_6$ | 49.03 | $C_2H_6$ | 229.4 |
| $HgCl_2$ | 144 | $CH_3COOH$ | 159.8 | $CH_3CHO$ | 265.7 |
| Sucrose | 360.2 | $C_6H_{12}$ | 298.2 | | |

# Standard molar Gibbs free energy and molar entropy of formation at 298.15 K

| | $M_r$ | $\Delta G_f^\theta$/KJ/mol | $S^\theta$/J $K^{-1}$ $mol^{-1}$ | | $M_r$ | $\Delta G_f^\theta$/KJ/mol | $S^\theta$/J $K^{-1}$ $mol^{-1}$ |
|---|---|---|---|---|---|---|---|
| $H_2O$(g) | 18.015 | -228.57 | 188.83 | $O_3$(g) | 47.998 | 163.2 | 238.93 |
| $H_2O$(l) | 18.015 | -120.35 | 109.6 | NO(g) | 30.006 | 86.55 | 210.76 |
| $H_2O_2$(l) | 34.015 | -120.35 | 109.6 | $NO_2$(g) | 46.006 | 51.31 | 240.06 |
| $NH_3$(g) | 17.031 | -16.45 | 192.45 | $N_2O_4$(g) | 92.012 | 97.89 | 304.29 |
| $N_2H_4$(l) | 32.045 | 149.43 | 121.21 | $SO_2$(g) | 64.063 | -300.19 | 248.22 |
| $N_3H$(l) | 43.028 | 327.3 | 140.6 | $H_2S$(g) | 34.080 | -33.56 | 205.79 |
| $N_3H$(g) | 43.028 | 328.1 | 238.97 | $SF_6$(g) | 146.054 | -1105.3 | 291.82 |
| $HNO_3$(l) | 63.013 | -80.71 | 155.60 | HF(g) | 20.006 | -273.2 | 173.78 |
| $NH_2OH$(s) | 33.030 | | | HCl(g) | 36.461 | -95.30 | 186.91 |
| $NH_4Cl$(s) | 53.492 | -202.87 | 94.6 | HCl(aq) | 36.461 | -131.23 | 56.5 |
| $HgCl_2$(s) | 271.50 | -178.6 | 146.0 | HBr(g) | 80.917 | -53.45 | 198.70 |
| $H_2SO_4$(l) ) | 98.078 | -690.00 | 156.90 | HI(g) | 127.912 | 1.70 | 206.59 |
| $H_2SO_4$(aq) | 98.078 | -744.53 | 20.1 | $CO_2$(g) | 44.010 | -394.36 | 213.74 |
| NaCl(s) | 58.443 | -384.14 | 72.13 | CO(g) | 28.011 | -137.17 | 197.67 |
| NaOH(s) | 39.997 | -379.49 | 64.46 | $AL_2O_3$(□,s) | 101.945 | -1582.3 | 50.92 |
| KCl(s) | 74.555 | -409.14 | 82.59 | SiO2 | 60.09 | -856.64 | 41.84 |
| KBr(s) | 119.011 | -380.66 | 95.90 | FeS(s) | 87.91 | -100.4 | 60.29 |
| KI(s) | 166.006 | -324.89 | 106.32 | $FeS_2$(s) | 119.975 | -166.9 | 52.93 |
| | | | | AgCl(s) | 143.323 | -109.79 | 96.2 |
| | | | | | | | |
| He(g) | 4.003 | 0 | 126.15 | Hg(g) | 200.59 | 31.82 | 174.96 |
| Ar(g) | 39.95 | 0 | 154.84 | Hg(l) | 200.59 | 0 | 76.02 |
| $H_2$(g) | 2.016 | 0 | 130.684 | Ag(g) | 107.87 | 245.65 | 173.00 |
| $N_2$(g) | 28.013 | 0 | 191.61 | Ag(s) | 107.87 | 0 | 42.55 |
| $O_2$(g) | 31.999 | 0 | 205.138 | Na(g) | 370.95 | 76.76 | 153.71 |
| $O_3$(g) | 47.998 | 163.2 | 238.93 | Na(s) | 22.99 | 0 | 51.21 |
| $Cl_2$(g) | 70.91 | 0 | 223.07 | | | | |
| $Br_2$(g) | 159.82 | 3.110 | 245.46 | | | | |
| $Br_2$(l) | 159.82 | 0 | 152.23 | | | | |
| $I_2$(g) | 253.81 | 19.33 | 260.69 | | | | |
| $I_2$(s) | 253.81 | 0 | 116.135 | | | | |
| | | | | | | | |

| | $M_r$ | $\Delta G_f^\theta$/KJ/mol | $S^\theta$/J $K^{-1}$ $mol^{-1}$ |
|---|---|---|---|
| organic compounds | | | |
| $CH_4$(g) methane | 16.043 | -50.72 | 186.26 |
| $C_2H_2$(g) ethyne | 26.038 | 209.20 | 200.94 |
| $C_2H_4$(g) ethene | 28.05 | 68.15 | 219.56 |
| $C_2H_6$(g) ethane | 30.070 | -32.82 | 229.60 |
| $C_3H_6$ cyclopropane(g) | 42.081 | 104.45 | 237.55 |
| $C_3H_6$ propene(g) | 42.081 | 62.78 | 267.05 |
| $C_4H_{10}$ n-butane (g) | 58.124 | -17.03 | 310.23 |
| $C_5H_{12}$ n-pentane(g) | 72.151 | -8.20 | 348.40 |
| $C_6H_{12}$ cyclohexane (l) | 84.163 | 26.8 | |
| $C_6H_{14}$ n-hexane (l) | 86.178 | | 204.3 |
| $C_6H_6$ benzene (l) | 78.115 | 124.3 | 173.3 |
| $C_6H_6$ benzene (g) | 78.115 | 129.72 | 269.31 |
| $C_8H_{18}$ n-octane (l) | 114.233 | 6.4 | 361.1 |
| $C_{10}H_8$ naphthalene (l) | 128.175 | | |
| $CH_3OH$ (g) | 32.042 | -161.96 | 239.81 |
| $CH_3OH$ (l) | 32.042 | -166.27 | 126.8 |
| $CH_3CHO$ (g) | 44.054 | -128.86 | 250.3 |
| $CH_3CH_2OH$ (l) | 46.07 | -174.78 | 160.7 |
| $CH_3COOH$ (l) | 60.053 | -389.9 | 159.8 |
| $CH_3COOC_2H_5$ (l) | 88.107 | -332.7 | 259.4 |
| $C_6H_5OH$ (s) | 94.114 | -50.9 | 146.0 |
| $C_6H_5NH_2$ (l) | 93.129 | | |
| $CH_2(NH_2)CO_2H$, glycine (s) | 75.068 | -373.4 | 103.5 |
| $C_6H_{12}O_6$, α-D-glucose (s) | 180.159 | | |
| $C_6H_{22}O_6$, β-D-glucose (s) | 180.159 | -910 | 212 |
| $C_{12}H_{22}O_{11}$, sucrose (s) | 342.303 | -1543 | 360.2 |
| $CH_3CH(OH)COOH$ | 90.079 | | |
| lactic acid (s) | | | |
| | | | |
| | | | |
| | | | |

Source: American Institute of Physics handbook, McGraw-Hill.