Grundlagen der Chemie für Studierende des Maschinenbaus, Prof. Grunwaldt und Prof. Heske

Chemistry for Students of Mechanical Engineering
Studiengang Bachelor

Thursday, 13th March 2014, 14:00-17:00

No unauthorised resources (*e.g.* lecture notes, textbooks etc.) may be used during the examination. Any attempt to use such unauthorised resources will be considered as cheating, and will lead to immediate exclusion from the examination and a mark of 5,0.

Foreign students may use a dictionary (mother tongue – English) but this may not contain any handwritten notes. The use of a calculator is not permitted.

Numerical answers that are given without showing any working or explanation will receive no marks.

In general, short answers with keywords will be sufficient; long essays are not necessary! To illustrate or explain a point, a clear sketch is often sufficient!

The maximum number of points for each question is given in parentheses.

Conversion from % to mark:

0-49,5	50-54	55-59	60-64	65-70	71-75	76-80	81-85	86-90	91-95	96-100
5,0	4,0	3,7	3,3	3,0	2,7	2,3	2,0	1,7	1,3	1,0

Question 1:

a) What is the difference between an element and a chemical compound? What is the difference between isotopes of the same element? (3P)

b) What do the numbers in the nuclide $^{7}_{3}\mathrm{Li}$ tell us?

Give the electronic configurations of sodium (Na) and nitrogen (N), showing clearly how electrons are distributed between orbitals of the same energy.

Explain why compounds of the formulae Na_2O and NH_3 form from their respective constituent elements. Give reasons for your answer. (4P)

c) In the analytical method Atomic Absorption Spectroscopy, the substance to be analysed is first atomised, the atoms are then introduced into a beam of polychromatic light, and the intensity of the transmitted light is measured as a function of wavelength.

What results does one obtain from this? Why can it be used as an analytical method?

This method is based on a principle that is important for the description of the electronic structure of atoms. What is this principle? (2P)

d) Name the four Quantum Numbers, that determine the energy levels of electrons in an atom. State briefly the significance of each Quantum Number. (4P)

e) On which physical principle is the separation process Solvent Extraction based?(1P)

Question 2:

a) What are the oxidation states of the nitrogen atoms in the following compounds: N_2O, N_2, NH_3, NO_2? (2P)

b) The formation of ammonia (NH_3) from the elements is an exothermic equilibrium reaction. Give the equation for the reaction, and explain why entropy decreases as the reaction proceeds. Why was it such a great challenge to develop an efficient industrial synthesis of ammonia, for which Carl Bosch obtained the Nobel Prize?

In which direction is the equilibrium position shifted, if:

(i) the temperature is increased?
(ii) the pressure is increased?

Explain your answer, noting that the reaction is exothermic (ΔH = -46 kJ/mol). (6P)

c) Fritz Haber, who taught in Karlsruhe, discovered in 1909 that the synthesis of ammonia from the elements required the use of a catalyst, and at first used metallic osmium for this.

Why must a catalyst be used? Does this alter the equilibrium position?

Osmium is very expensive. What catalyst is now used industrially? (3P)

d) Ammonia, or alternatively urea, can be used to remove polluting substances from waste gases.

Which toxic gases are formed in internal combustion motors?

What group of toxic waste gases can be removed using ammonia? Give the reaction equations.

Why is urea used instead of ammonia in mobile systems such as car engines? (6P)

e) The use of gas-powered motors is being encouraged. What volume (in m^3) of CO_2 is produced by the combustion of 2.24 m^3 of methane (in both cases at 273K und 1 bar)? What is the mass of this CO_2 in kg? (C: 12 g mol^{-1}, H: 1 g mol^{-1}) (2P)

f) What is understood by the "Greenhouse Effect"? Which property of the CO_2 molecule makes it a significant greenhouse gas? (2P)

Question 3:

a) According to Brønsted and Lowry, what is understood by acids and bases? Give the reaction equation for the protolysis equlibrium of ethanoic acid (H_3CCOOH) in water. State which of the four species involved are acting as acids, and which as bases. (3P)

b) At room temperature, the solubility product of $PbCl_2$ $L_{PbCl2} = 3.2 \times 10^{-5}$ $(mol/l)^3$. What is the concentration of Pb^{2+} (In mol/l) in a saturated solution of $PbCl_2$ in pure water, and what would the concentration of Pb^{2+} be if the water contains 0.1 mol/l chloride? Use these Pb^{2+} concentrations to calculate the solubility of $PbCl_2$ (in g/l) in the two solutions. M($PbCl_2$) = 278.2 g/mol (4P)

c) Determine the stoichiometric coefficients for the "Thermite" redox reaction:

[ ] Fe_2O_3 + [ ] Al → [ ] Fe + [ ] Al_2O_3

Which substance is acting as a reducing agent, and which as an oxidising agent? (3P)

d) What is the potential (in volts) of a Co/Zn Daniell cell, if 1 molar solutions of cobalt(II) sulphate and zinc(II) sulphate are used? What are the redox half-reactions? (n.b. standard reduction potentials are listed on the last page of the Klausur).

Will the potential of this Galvanic cell increase or decrease, if the concentration of Co^{2+} is decreased? What is the equation that can be used to calculate this (give either the equation itself or its name)? (5P)

e) Two glass beakers each contain a piece of tin metal (Sn). One beaker is then filled with a 1 mol/l solution of $CuSO_4$, the other with a 1 mol/l solution of $FeSO_4$. In each case, use the table of Standard Reduction Potentials on the last page to explain whether you expect a chemical reaction to take place. (2P)

f) Give the equations for the two redox half-reactions that take place when a lead accumulator (car battery) is discharged. What happens when the accumulator is recharged? (3P)

Aufgabe 4:

a) Give the name of an industrial method for the production of hydrogen from hydrocarbons. Give the corresponding reaction equation(s). (2P)

b) Draw the Lewis-structure for the ozone (O_3) molecule, and give the reaction equation for the formation of ozone. (2P)

c) State three industrially-important properties of metals. (3P)

d) What is understood by Passivation? (1P)

e) State a property of aluminium that makes it an important industrial material.

The main raw material for the production of aluminium is the ore bauxite, which is a mixture of Al_2O_3 and Fe_2O_3.

What are the four principal steps in the production of aluminium from bauxite? Give the equations for the reactions that take place in each stage. (6P)

f) Most of the sulphur that is needed for the production of sulphuric acid is obtained from the processing of mineral oil or natural gas.

Which sulphur-containing compound is obtained in this way? Which process is used to obtain sulphur from this compound? Give the reaction equations.

Give the equations of the reactions that take plave during the industrial production of sulphuric acid from sulphur. (5P)

g) In a Blast Furnace, partial oxidation of coke results in formation of the reducing agent CO. This is also involved in the Boudouard equilibrium, by which finely-divided carbon is formed which dissolves in the liquid iron.

Give the reaction equation for the Boudouard equilibrium.

What disadvantageous effect does this dissolved carbon have on the “pig iron”?

Give the name of a process that is used to reduce this carbon content during the production of steel. (3P)

h) What is understood by corrosion, and what is a local element? (2P)

i) Give two methods for protecting metals from corrosion. (2P)

j) Give the equations of the reactions that take place when iron rusts in moist air. (4P)

Question 5:

a) What is the hybridisation of carbon atoms involved in single, double and triple bonds, respectively? In each case, what is the three-dimensional geometry of the bonds to the central carbon atom? (3P)

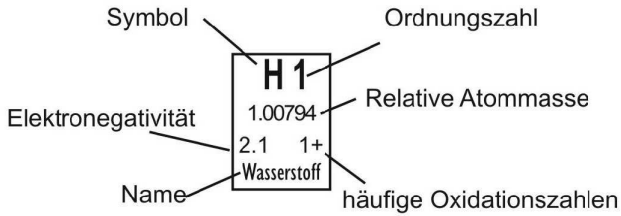
b) Give three structural characteristics of the benzene molecule, and draw the Lewis-structures of the two mesomeric structures. What is the hybridisation of the carbon atoms? (3P)

c) Give the Lewis-structure of the 3,3-dimethylpentan-1-ol molecule. (2P)

d) Draw the Lewis-structures of the characteristic functional groups of ketones, alcohols and carboxylic acids. (3P)

e) Explain why an alcohol has a much higher boiling point than the corresponding alkane with the same number of carbon atoms. Why is ethane hydrophobic, whereas ethanol is hydrophilic? (2P)

f) Describe using a simple sketch the difference between a simple distillation and distillation using a fractionating column. (2P)



	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	H 1 1.00794 2.1 1+ Wasserstoff																	He 2 4.002602 - - Helium
2	Li 3 6.941 1.0 1+ Lithium	Be 4 9.012182 1.5 2+ Beryllium											B 5 10.811 2.0 3+ Bor	C 6 12.0107 2.5 4+,4- Kohlenstoff	N 7 14.0067 3.0 3+,3- Stickstoff	O 8 15.9994 3.5 2- Sauerstoff	F 9 18.998403 4.0 1- Fluor	Ne 10 20.1797 - - Neon
3	Na 11 22.989769 0.9 1+ Natrium	Mg 12 24.3050 1.2 2+ Magnesium											Al 13 26.981539 1.5 3+ Aluminium	Si 14 28.0855 1.8 4+ Silicium	P 15 30.973762 2.1 5+ Phosphor	S 16 32.065 1.8 4+ Schwefel	Cl 17 35.453 3.0 1- Chlor	Ar 18 39.948 - - Argon
4	K 19 39.0983 0.8 1+ Kalium	Ca 20 40.078 1.0 2+ Calcium	Sc 21 44.95592 1.3 3+ Scandium	Ti 22 47.867 1.5 4+ Titan	V 23 50.9415 1.6 5+ Vanadium	Cr 24 51.9961 1.6 3+ 2+ Chrom	Mn 25 54.938045 1.5 2+ 3+ Mangan	Fe 26 55.845 1.8 2+ 3+ Eisen	Co 27 58.933195 1.8 2+ 3+ Cobalt	Ni 28 58.6934 1.8 2+ Nickel	Cu 29 63.546 1.9 2+ 1+ Kupfer	Zn 30 65.409 1.6 2+ Zink	Ga 31 69.723 1.6 3+ Gallium	Ge 32 72.64 1.6 4+ Germanium	As 33 74.92160 2.0 3+ 3- Arsen	Se 34 78.96 2.4 4+ Selen	Br 35 79.904 2.8 1- Brom	Kr 36 83.798 - - Krypton
5	Rb 37 85.4678 0.8 1+ Rubidium	Sr 38 87.62 1.0 2+ Strontium	Y 39 88.90585 1.3 3+ Yttrium	Zr 40 91.224 1.4 4+ Zirconium	Nb 41 92.90638 1.6 5+ Niob	Mo 42 95.94 1.8 6+ Molybdän	Tc 43 98.9062 1.9 7+ Technetium	Ru 44 101.07 2.2 3+ 4+ Ruthenium	Rh 45 102.90550 2.2 3+ Rhodium	Pd 46 106.42 2.2 2+ Palladium	Ag 47 107.8682 1.9 1+ Silber	Cd 48 112.411 1.7 2+ Cadmium	In 49 114.818 1.7 3+ Indium	Sn 50 118.710 1.8 4+ 2+ Zinn	Sb 51 121.760 1.9 3+ 3- Antimon	Te 52 127.60 2.1 4+ Tellur	I 53 126.90447 2.5 1- Iod	Xe 54 131.293 - - Xenon
6	Cs 55 132.90545 0.7 1+ Cäsium	Ba 56 137.327 0.9 2+ Barium	La 57 138.90547 1.1 3+ Lanthan	Hf 72 178.49 1.3 4+ Hafnium	Ta 73 180.94788 1.5 5+ Tantal	W 74 183.84 1.7 6+ Wolfram	Re 75 186.207 1.9 7+ Rhenium	Os 76 190.23 2.2 4+ Osmium	Ir 77 192.22 2.2 4+ Iridium	Pt 78 195.084 2.2 4+ Platin	Au 79 196.96657 2.4 3+ Gold	Hg 80 200.59 1.9 2+ 1+ Quecksilber	Tl 81 204.3833 1.8 1+ Thallium	Pb 82 207.2 1.8 4+ 2+ Blei	Bi 83 208.98040 1.9 3+ Bismut	Po 84 208.9824 2.0 2+ Polonium	At 85 209.9871 2.2 1- Astat	Rn 86 222.0176 - - Radon
7	Fr 87 223.0197 0.7 1+ Francium	Ra 88 226.0254 0.9 2+ Radium	Ac 89 227.0278 1.1 3+ Actinium	Rf 104 261.11 - - Rutherfordium	Db 105 262.11 - - Dubnium	Sg 106 263.12 - - Seaborgium	Bh 107 262.12 - - Bohrium	Hs 108 264 - - Hassium	Mt 109 266.1378 - - Meitnerium	Ds 110 269 - - Darmstadtium	Rg 111 272 - - Roentgenium	Uub 112 277 - - Ununbium	Uut113 - - - Ununtrium	Uuq 114 289 - - Ununquadium	Uup 115 - - - Ununpentium	Uuh 116 292 - - Ununhexium	Uus 117 - - - Ununseptium	Uuo 118 - - - Ununoctium

		Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
Lanthaniden	6	140.116 1.1 3+ Cer	140.90765 1.1 3+ Praseodym	144.242 1.1 3+ Neodym	144.9127 1.1 3+ Promethium	150.36 1.2 3+ Samarium	151.964 1.2 3+ Europium	157.25 1.2 3+ Gadolinium	158.92535 1.2 3+ Terbium	162.500 1.2 3+ Dysprosium	164.93032 1.2 3+ Holmium	167.259 1.2 3+ Erbium	168.93421 1.2 3+ Thulium	173.04 1.1 3+ Ytterbium	174.967 1.2 3+ Lutetium
		Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103
Actiniden	7	232.03806 1.3 4+ Thorium	231.03588 1.5 5+ Protactinium	238.02891 1.4 6+ Uran	237.0482 1.3 5+ Neptunium	244.0642 1.3 4+ Plutonium	243.0614 1.3 3+ Americium	247 1.3 3+ Curium	247.0703 1.3 3+ Berkelium	251.0796 1.3 3+ Californium	252.03 1.3 - Einsteinium	257.0951 1.3 - Fermium	258.01 1.3 - Mendelevium	259.1009 1.3 - Nobelium	260.1053 - - Lawrencium

Reduzierte Form	⇌ Oxidierte Form	$+z\,e^-$	Standardpotential $E°$ in V
Li	$\rightleftharpoons Li^+$	$+ e^-$	−3,04
K	$\rightleftharpoons K^+$	$+ e^-$	−2,92
Ba	$\rightleftharpoons Ba^{2+}$	$+2e^-$	−2,90
Ca	$\rightleftharpoons Ca^{2+}$	$+2e^-$	−2,87
Na	$\rightleftharpoons Na^+$	$+ e^-$	−2,71
Mg	$\rightleftharpoons Mg^{2+}$	$+2e^-$	−2,36
Al	$\rightleftharpoons Al^{3+}$	$+3e^-$	−1,68
Mn	$\rightleftharpoons Mn^{2+}$	$+2e^-$	−1,19
Zn	$\rightleftharpoons Zn^{2+}$	$+2e^-$	−0,76
Cr	$\rightleftharpoons Cr^{3+}$	$+3e^-$	−0,74
S^{2-}	$\rightleftharpoons S$	$+2e^-$	−0,48
Fe	$\rightleftharpoons Fe^{2+}$	$+2e^-$	−0,41
Cd	$\rightleftharpoons Cd^{2+}$	$+2e^-$	−0,40
Co	$\rightleftharpoons Co^{2+}$	$+2e^-$	−0,28
Sn	$\rightleftharpoons Sn^{2+}$	$+2e^-$	−0,14
Pb	$\rightleftharpoons Pb^{2+}$	$+2e^-$	−0,13
Fe	$\rightleftharpoons Fe^{3+}$	$+3e^-$	−0,036
$H_2 + 2H_2O$	$\rightleftharpoons 2H_3O^+$	$+2e^-$	0
Sn^{2+}	$\rightleftharpoons Sn^{4+}$	$+2e^-$	+0,15
Cu^+	$\rightleftharpoons Cu^{2+}$	$+ e^-$	+0,15
$SO_2 + 6H_2O$	$\rightleftharpoons SO_4^{2-} + 4H_3O^+$	$+2e^-$	+0,17
Cu	$\rightleftharpoons Cu^{2+}$	$+2e^-$	+0,34
Cu	$\rightleftharpoons Cu^+$	$+ e^-$	+0,52
$2I^-$	$\rightleftharpoons I_2$	$+2e^-$	+0,54
$H_2O_2 + 2H_2O$	$\rightleftharpoons O_2 + 2H_3O^+$	$+2e^-$	+0,68
Fe^{2+}	$\rightleftharpoons Fe^{3+}$	$+ e^-$	+0,77
Ag	$\rightleftharpoons Ag^+$	$+ e^-$	+0,80
Hg	$\rightleftharpoons Hg^{2+}$	$+2e^-$	+0,85
$NO + 6H_2O$	$\rightleftharpoons NO_3^- + 4H_3O^+$	$+3e^-$	+0,96
$2Br^-$	$\rightleftharpoons Br_2$	$+2e^-$	+1,07
$6H_2O$	$\rightleftharpoons O_2 + 4H_3O^+$	$+4e^-$	+1,23
$2Cr^{3+} + 21H_2O$	$\rightleftharpoons Cr_2O_7^{2-} + 14H_3O^+$	$+6e^-$	+1,33
$2Cl^-$	$\rightleftharpoons Cl_2$	$+2e^-$	+1,36
$Pb^{2+} + 6H_2O$	$\rightleftharpoons PbO_2 + 4H_3O^+$	$+2e^-$	+1,46
Au	$\rightleftharpoons Au^{3+}$	$+3e^-$	+1,50
$Mn^{2+} + 12H_2O$	$\rightleftharpoons MnO_4^- + 8H_3O^+$	$+5e^-$	+1,51
$3H_2O + O_2$	$\rightleftharpoons O_3 + 2H_3O^+$	$+2e^-$	+2,07
$2F^-$	$\rightleftharpoons F_2$	$+2e^-$	+2,87