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

Chemistry for Students of Mechanical Engineering, Studiengang Bachelor

Thursday, 2nd October 2014, 9:00-12:00

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 understood by atomic number, and what are isotopes? (2 P)

b) Give the number of electrons, protons and neutrons in atoms of uranium with atomic weights 235 and 238. (2 P)

c) Name the four quantum numbers that describe the energy levels of electrons in atoms. Explain briefly (keywords are enough) the significance of each quantum number. (4 P)

d) How many electrons must atoms of the elements strontium and bromine either lose or gain, when they form ionic compounds? (2 P)

e) What do (i) the Pauli Principle and (ii) Hund's Rules tell us? (2 P)

f) Give the electron configuration of the oxygen (O) atom (1 P)

g) Arrange the elements Na, Al, Cl and F in order of increasing electronegativity. (2 P)

Question 2:

a) What is understood by (i) enthalpy of reaction and (ii) entropy of reaction? (2 P)

b) Modern power stations often use natural gas as fuel. Give the reaction equation for the complete combustion of methane (CH_4).

Use the values given below to calculate the enthalpy (ΔH), entropy (ΔS) and Gibbs free energy (ΔG) of reaction for the complete combustion of methane at 1500 ºC. (*n.b*. these values are appropriate for 1500 ºC, you do not need to take any temperature dependence into account). (4 P)

Substance	ΔH_f^o [kJ/mol]	ΔS_f^o [J/mol·K]
CH_4	30	300
O_2	49	260
CO_2	-312	300
H_2O	-179.5	259.5

c) Using the Gibbs free energy of reaction ΔG, state the criterion for a spontaneous process.

Give the reaction equation for the formation of ethene by elimination of H_2 from ethane. Use the above criterion to explain why this reaction can take place at high temperature, even though the reaction is endothermic. (3 P)

d) For a reaction aA + bB ⇆ cC + dD, give the equation that relates the equilibrium constant K to the concentrations of the substances taking part in the reaction, and also an equation that relates K to a thermodynamic quantity. (2 P)

e) The formation of sulphur trioxide (SO_3) from sulphur dioxide (SO_2) and oxygen (O_2) is an equilibrium reaction. Give the reaction equation, and decide whether the entropy increases or decreases when SO_3 is formed.

In which direction does the equilibrium position shift, when:

- the temperature is increased?
- an excess of oxygen is added to the starting gas mixture?

Explain your answers, noting that the formation of SO_3 is exothermic (ΔH^o = -99 kJ/mol).

The reaction takes place with the help of a catalyst.

How does a catalyst affect a chemical reaction? Does it change the equilibrium position of the reaction? What is the important chemical substance in the catalyst usually used for the formation of SO_3? (6 P)

f) What is understood by oxidation and reduction? For the formation of sodium chloride (NaCl) from the elements (Na und Cl_2), give the equations for the reduction and oxidation half-reactions. (3 P)

g) What is the potential produced by a Ag/Sn Daniell cell, in which 1 molar solutions of $AgNO_3$ and $Sn(NO_3)_2$ are used (see table of standard electrode potentials at end of this exam script). What half-reactions take place at the electrodes? (3 P)

h) Two glass beakers each contain a piece of iron (Fe) metal. A 1 molar solution of $CuSO_4$ is poured into one beaker; a 1 molar solution of $MnSO_4$ is poured into the other. For each beaker, do you expect a chemical reaction to take place, and if so, what will happen? (2 P)

Question 3:

a) Give the reaction equation for the **partial** oxidation of hexane to hydrogen and carbon monoxide. (1 P)

b) What is understood by the term “greenhouse effect”, and what property of the carbon dioxide (CO2) molecule makes it an efficient greenhouse gas? (1 P)

c) Name the two allotropes of the element oxygen that are found in the atmosphere. For each one, give both the sum formula and the Lewis structure. Which of these forms is the more common, and why is it attracted into a magnetic field? (4 P)

d) How is ammonium nitrate (NH_4NO_3) produced from ammonia? Give equations for the the four reactions involved in the process. (4 P)

e) For each of the metals aluminium (Al), iron (Fe) and copper (Cu), state one property that is made use of industrially.

For each of these metals, give a raw material from which they can be obtained, the most important production method, and an important industrial application. (6 P)

f) Why is limestone ($CaCO_3$) added to the mixture of iron ore and coke in a Blast Furnace? (1 P)

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

h) Apart from platinum itself, name two further members of the “platinum group” of metals. What is the main industrial significance of the platinum metals? (2 P)

i) What is understood by corrosion, and what is a “local element” (bimetallic corrosion)? (2 P)

Question 4:

a) There are two organic compounds with the sum formula C_2H_6O. Give Lewis structures for both compounds. To which classes of organic compounds do they belong? Give their correct names. (3 P)

b) Give the Lewis structure for the compound 2,2,4-trimethylpentane. (3 P)

c) Explain with the help of sketches the different covalent bonding in ethane, ethane and ethyne, giving the hybridisations of the carbon atoms, the orbital structures and the bond angles. (6 P)

d) Describe the mechanism of a radical chain reaction, using the formation of CH_3Br from CH_4 and Br_2 as an example. (3 P)

e) Draw the Lewis structures of the functional groups characteristic of the compound classes alkenes, ketones and carboxylic acids. (3 P)

f) Give the structures of the characteristic repeating units in polyethene and polystyrene. From which monomers are these two polymers produced? (2 P)

Question 5:

a) What pollutants can be formed during the combustion of hydrocarbon fuels in a combustion motor? (2 P)

b) What catalyst system is used to remove toxic substances from the exhaust gas of a petrol engine? (1 P)

c) Describe with the help of a diagram how the amounts of the pollutants formed depends on the fuel:air ratio used in the engine. (2 P)

d) Why is it only sensible to use an exhaust catalyst for a petrol engine, when it is being run with a stoichiometric ($\lambda = 1$) fuel:air ratio? (1 P)

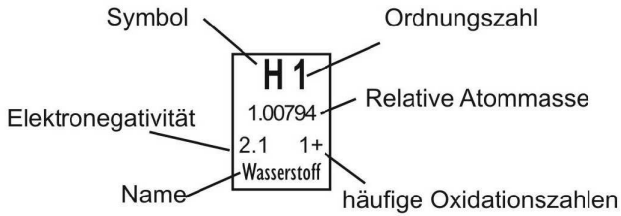
e) What is understood by “knocking” in a petrol engine? What number is used to describe the knock-resistance of a petrol, and how is it defined? (2 P)

f) Why are more nitrogen oxides (NO_x) formed during the running of a Diesel motor than for a petrol motor? What process is used to treat the exhaust gases to minimise the amount of pollutants released? In Diesel vehicles, what substance is added to the exhaust gases, and what compound is formed from this *in situ* that acts as a reducing agent in this process? (2 P)

g) How much CO_2 is emitted by a car with a petrol engine that consumes 5,7 litre per 100km? You may assume for the calculation that the fuel is 100 % isooctane with a density $\rho = 0,7$ g/ml, and that it is completely combusted in the engine. (3 P)

h) State an important function of lubricants. (1 P)

i) Name one solid lubricant, and one application of solid lubricants. (1 P)



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