Foundations of Chemistry for Students of Mechanical Engineering, Prof. Dr. Meier

Prüfung in Chemie
für Studierende des Maschinenbaus und des Lehramts an Gymnasien

Friday, 22nd February 2013, 15:00-18:00

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.

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

Part 1:

a) What is the significance of the two numbers in the nuclide $^{37}_{20}\mathrm{Cl}$? (1P)

b) What is observed when the light emitted by an energetically-excited atom is passed through a prism and separated into its constituent wavelengths? Why was this observation important for the understanding of atomic structure? (2P)

c) Give the electron configuration of the element zirconium (Zr). (1P)

d) How do the radii of atoms change on going from left to right across a Row in the Periodic Table, and how do they change on going down a Group? Give reasons for your answers. (3P)

e) Use the VSEPR model to give the three-dimensional structures of the $BeCl_2$, BF_3, $SiCl_4$ und NH_3 molecules. (4P)

f) Which of the molecules in question e) have a dipole moment? (2P)

g) What is understood by permanent dipoles and induced dipoles? (2P)

h) What are the characteristics of the structures of crystals? (1P)

i) Which simple rule tells us that elements of Group 6 tend to form dianions X^{2-}? (1P)

j) How does an osmotic pressure arise? (1P)

k) Give two important properties of metals. (2P)

Part 2:

a) What does Hess's Law tell us? (1P)

b) Give the equations that are used to calculate the changes in enthalpy, entropy and free energy for a reaction. (3P)

c) A mixture of CO and H_2 ("Water Gas" or "Synthesis Gas") is formed when water vapour reacts with glowing coke (C). Give the equation for this reaction.
Calculate the changes in enthalpy ($\Delta H°$), in entropy ($\Delta S°$) and in free energy ($\Delta G°$) for the reaction, using the following values:
$\Delta H^o_f(CO) = -111$ kJ mol^{-1}, $^{\Delta}H^o_f(H_2O) = -241.8$ kJ mol^{-1}
$S^o(CO) = 198$ J mol^{-1} K^{-1}, $S^o(H_2O) = 188.8$ J mol^{-1} K^{-1},
$S^o(H_2) = 130.7$ J mol^{-1} K^{-1}, $S^o(C) = 5.7$ J mol^{-1} K^{-1} (4P)

d) How is the change in Free Energy ($\Delta G°$) the criterion for whether a reaction takes place spontaneously?
Use this criterion to explain why the formation of ethene from ethane (with elimination of H_2) is spontaneous at high temperatures, even though the reaction is endothermic. (2P)

e) The formation of ammonia (NH_3) from its elements is an equilibrium reaction. Give the equation for the reaction, and explain why entropy decreases when the reaction takes place.
In which direction does the equilibrium position shift, when
● the temperature is (i) increased or (ii) decreased
● the pressure is (i) increased or (ii) decreased?
Explain your answers.
n.b. the reaction is exothermic: $\Delta H°_f(NH_3) = -46$ kJ mol^{-1}. (6P)

f) For a reaction aA + bB ⇆ cC + dD, give the equation that relates the equilibrium constant K to the concentrations of the substances involved, and also the equation that relates K to a thermodynamic quantity. (1P)

g) At room temperature, the solubility product of CaF_2 is 4×10^{-12} mol^3 l^{-3}.
What is the concentration of Ca^{2+} in a saturated solution of CaF_2 in pure water, and what is [Ca^{2+}] in a saturated solution of CaF_2 in water in which the concentration of F^- is 0.1 mol l^{-1}? (2P)

h) What is understood by (i) the rate, and (ii) the order of a chemical reaction? (1P)

i) Give the equation that describes the influence of temperature on the rate of a chemical reaction. (1P)

j) Determine the stoichiometric coefficients for the substances in the following redoxreactions, and give their oxidation numbers: (6P)
[ ] Fe + [ ] NO_3^- + [ ] H^+ → [ ] Fe^{2+} + [ ] NO + [ ] H_2O
[ ] $NaNO_2$ + [ ] $KMnO_4$ + [ ] H_2SO_4 → [ ] $NaNO_3$ + [ ] $MnSO_4$ + [ ] K_2SO_4 + [ ] H_2O
[ ] MnO_2 + [ ] HBr → [ ] $MnBr_2$ + [ ] Br_2 + [ ] H_2O

k) Calculate the potential E_{cell} of a Galvanic cell in which a Zn electrode is immersed in a 1 molar solution of $ZnSO_4$, and a Cu electrode is immersed in a 1 molar solution of $CuSO_4$? What are the redox half-reactions at each electrode? (3P)
$E°(Cu^{2+}/Cu) = +0.34$ V; $E°(Zn^{2+}/Zn) = -0.76$ V

Part 3:

a) Give the equation for the acid-base reaction between ethanoic acid and ammonia. How are acids and bases defined according to the theory of Lowry and Brønsted? (2P)

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

c) What are the oxidation numbers of the nitrogen atoms in N_2O, N_2, NH_3 and NO_2? (2P)

d) Give one property of iron that is important in the industrial use of the metal. (1P)

e) Name two raw materials from which iron can be obtained. (1P)

f) What is the reducing agent in a Blast Furnace? Give the equation for the reaction in which Fe is formed in a Blast Furnace. (The equation for the overall reaction of a raw material to give metallic Fe is sufficient). (2P)

g) In a Blast Furnace, finely-divided carbon is formed via the Boudouard equilibrium and dissolves into the newly-formed iron. Give the equation for the Boudouard equilibrium. What negative effect does this dissolved carbon have on the properties of Pig Iron? Give the name of a process from steel production, by which this carbon content can be reduced. (3P)

h) The reduction of copper ores results in impure copper metal. What method is used to convert this crude product into high-purity copper? Give the equations for the reactions that take place. What solid substances are obtained from this process in addition to the pure copper? (3P)

i) Give the equations for the reactions that take place when iron rusts in damp air. (2P)

j) Name two important methods that can prevent the rusting of iron described in question (i) above. (2P)

k) Draw the Lewis structures for SO_3 and the sulphate anion $(SO_4)^{2-}$. What are the oxidation states of S and O in each case? (4P)

l) Name two modifications (allotropes) of carbon and describe the structure of each. (2P)

Part 4:

a) There are five organic compounds with the sum formula C_4H_6. Choose two of these, and give their Lewis structures, together with their correct names. What class does each of these molecules belong to? (3P)

b) Give the Lewis structure for the molecule 4-ethyl-5-hydroxy-hept-3-one-1,7-dicarboxylic acid. (4P)

c) Give the Lewis structures of the characteristic functional groups of ethers, aldehydes and primary amides. (3P)

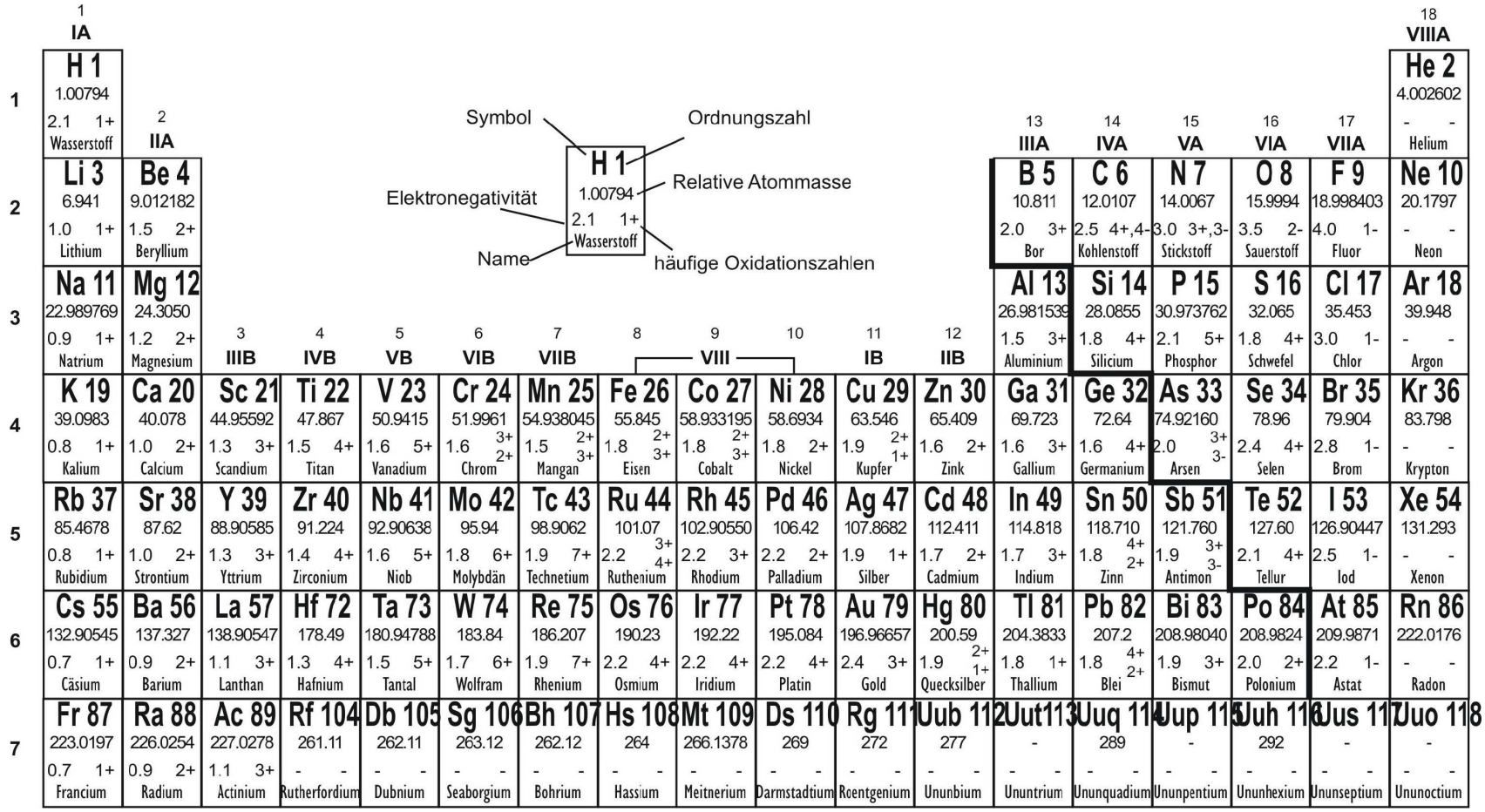
d) Explain why alcohols have higher boiling points that the corresponding alkanes with the same number of carbon atoms. Why is ethane hydrophobic, whereas ethanol is hydrophilic?
Give the equation and the reaction conditions for the industrial synthesis of methanol. Give the reaction equation for the synthesis of ethanoic acid from methanol. (5P)

e) Give three characteristics of the structure of the benzene molecule, Draw the Lewis structures of the two mesomeric structures for benzene. (2P)

f) Describe with the help of reaction equations the radical chlorination of ethane to chloroethane. (3P)

g) What are the two principal types of mechanisms for polymerisation reactions? (1P)

h) Give the structures of the repeating units in polypropene, polystyrene und polyvinylchloride. (3P)



	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

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