CHEM-E1130 Catalysis
Exam
February 18, 2020, 14:00, time reserved: 4 h

Five questions; answer each question. Each question (1-5) is worth 9 points. Maximum: 45 points.

No materials allowed.
Students are not allowed to take the exam paper with them.

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1. **Definition of a catalyst**. Give the definition of a catalyst. On the basis of the definition, how does the catalyst affect a chemical process? What kinds of requirements are there for industrial catalysts?

2. **Explain briefly** the following terms and concepts related to catalysis (1.5 pt each):
   a. Micropore
   b. Dispersion
   c. Distribution
   d. Langmuir adsorption isotherm
   e. Tamman temperature
   f. 18-electron rule

3. **Preparation of supported solid heterogeneous catalysts.** What are the three fundamental stages of catalyst preparation [according to the International Union of Pure and Applied Chemistry (IUPAC)]? Describe the principle of the pore volume impregnation method (also known as "dry impregnation") and how can one control the obtained metal loading with it. What are the expected benefits and limitations of this method for catalyst preparation?

4. **Catalyst deactivation.** Describe the phenomenon of catalyst deactivation by coking. Give example(s) of when it takes place and how it may affect the activity/selectivity/lifetime of the catalyst. Which measures can be taken to avoid catalyst deactivation by coking?

5. **Catalyst characterization**. An enthusiastic Master's thesis student prepared two supported rhodium (Rh) catalysts on titania (TiO_2) for testing in the reverse water gas shift reaction. The specific surface area of the titania support was 100 m^2/g. The targeted metal contents were 0.1 and 10 wt-%; achieving these metal contents was verified with x-ray fluorescence (XRF) analysis.

   But: poor student! After the XRF analysis, it was no longer clear, which sample was which; the samples had been mixed up! (The student will remember to label samples better next time.)

   Luckily, the student has participated in the CHEM-E1130 Catalysis course and is familiar with several catalyst characterization methods. Which characterization methods could the student use to find out, which sample is which? Describe the principles of at least two different catalyst characterization methods and what you expect the student could find out with these methods related to solving the case. If you make assumptions related to the samples of pretreatments/metal particle size etc., please explain your assumptions clearly.

IUPAC Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen [1.0078, 1.0082]																	2 **He** helium 4.0026
3 **Li** lithium [6.938, 6.997]	4 **Be** beryllium 9.0122											5 **B** boron [10.803, 10.821]	6 **C** carbon [12.009, 12.012]	7 **N** nitrogen [14.006, 14.008]	8 **O** oxygen [15.999, 16.000]	9 **F** fluorine 18.998	10 **Ne** neon 20.180
11 **Na** sodium 22.990	12 **Mg** magnesium [24.304, 24.307]	3	4	5	6	7	8	9	10	11	12	13 **Al** aluminium 26.982	14 **Si** silicon [28.084, 28.086]	15 **P** phosphorus 30.974	16 **S** sulfur [32.059, 32.076]	17 **Cl** chlorine [35.446, 35.457]	18 **Ar** argon [39.792, 39.963]
19 **K** potassium 39.098	20 **Ca** calcium 40.078(4)	21 **Sc** scandium 44.956	22 **Ti** titanium 47.867	23 **V** vanadium 50.942	24 **Cr** chromium 51.996	25 **Mn** manganese 54.938	26 **Fe** iron 55.845(2)	27 **Co** cobalt 58.933	28 **Ni** nickel 58.693	29 **Cu** copper 63.546(3)	30 **Zn** zinc 65.38(2)	31 **Ga** gallium 69.723	32 **Ge** germanium 72.630(8)	33 **As** arsenic 74.922	34 **Se** selenium 78.971(8)	35 **Br** bromine [79.901, 79.907]	36 **Kr** krypton 83.798(2)
37 **Rb** rubidium 85.468	38 **Sr** strontium 87.62	39 **Y** yttrium 88.906	40 **Zr** zirconium 91.224(2)	41 **Nb** niobium 92.906	42 **Mo** molybdenum 95.95	43 **Tc** technetium	44 **Ru** ruthenium 101.07(2)	45 **Rh** rhodium 102.91	46 **Pd** palladium 106.42	47 **Ag** silver 107.87	48 **Cd** cadmium 112.41	49 **In** indium 114.82	50 **Sn** tin 118.71	51 **Sb** antimony 121.76	52 **Te** tellurium 127.60(3)	53 **I** iodine 126.90	54 **Xe** xenon 131.29
55 **Cs** caesium 132.91	56 **Ba** barium 137.33	57–71 lanthanoids	72 **Hf** hafnium 178.49(2)	73 **Ta** tantalum 180.95	74 **W** tungsten 183.84	75 **Re** rhenium 186.21	76 **Os** osmium 190.23(3)	77 **Ir** iridium 192.22	78 **Pt** platinum 195.08	79 **Au** gold 196.97	80 **Hg** mercury 200.59	81 **Tl** thallium [204.38, 204.39]	82 **Pb** lead 207.2	83 **Bi** bismuth 208.98	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
87 **Fr** francium	88 **Ra** radium	89–103 actinoids	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Nh** nihonium	114 **Fl** flerovium	115 **Mc** moscovium	116 **Lv** livermorium	117 **Ts** tennessine	118 **Og** oganesson

Key:

atomic number
Symbol
name
conventional atomic weight
standard atomic weight

57 **La** lanthanum 138.91	58 **Ce** cerium 140.12	59 **Pr** praseodymium 140.91	60 **Nd** neodymium 144.24	61 **Pm** promethium	62 **Sm** samarium 150.36(2)	63 **Eu** europium 151.96	64 **Gd** gadolinium 157.25(3)	65 **Tb** terbium 158.93	66 **Dy** dysprosium 162.50	67 **Ho** holmium 164.93	68 **Er** erbium 167.26	69 **Tm** thulium 168.93	70 **Yb** ytterbium 173.05	71 **Lu** lutetium 174.97
89 **Ac** actinium	90 **Th** thorium 232.04	91 **Pa** protactinium 231.04	92 **U** uranium 238.03	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.

United Nations Educational, Scientific and Cultural Organization

2019 IYPT International Year of the Periodic Table of Chemical Elements

100 IUPAC