Chemistry Example Problems

Chemistry I (Inorganic chemistry, Analytical chemistry),
Chemistry II (Chemical reaction engineering, Radiochemistry)

If you intend to choose Chemistry, please contact the department head of “Quantum Science and Energy Engineering” in advance of submitting your application.

Applicants who are graduated or to be graduated from “Department of Mechanical and Aerospace Engineering at School of Engineering, Tohoku University” may make a request to the department head of “Quantum Science and Energy Engineering” for choosing Chemistry I as a specialized subject.

The other applicants may make a request to the department head for choosing Chemistry I and/or Chemistry II as one or two of their specialized subjects. The students who choose Chemistry I or Chemistry II need to choose another specialized subject.

Chemistry I

[1] Answer the following questions.
(1) Show which metal complex is more stable, with using the sign of inequality. In addition, describe the reason.

i) Cu (en)^{2+}, Cu(NH_3)^{2+} (en: ethylene diamine)

ii) Eu(EDTA)^-, La(EDTA)^- (EDTA: ethylene diamine tetra-acetic acid)

iii) Co(en)^{2+}, Ni(en)^{2+}

iv) Cu(CH_3CO_2)^+, Cu(CH_2ClO)^+

v) YF^{2+}, ThF^{3+}

(2) Describe the definition of Brønsted-Lowry acid-base theory. In addition, classify the following ions or molecules as Brønsted acid, Brønsted base or amphoteric substance.

\[ \text{C}_6\text{H}_2\text{NH}_2, \text{CN}^-, \text{HS}^-, \text{H}_3\text{O}^+, \text{H}_2\text{CO}_3, \text{HSO}_4^-, \text{NH}_3, (\text{CH}_3)_3\text{N}, \text{NH}_4^+, \text{HOCN} \]
Consider a weak acid, HA, with an acidity constant in water, $K_a$, of $10^{-5.10}$. The distribution coefficient of HA between hexane (o) and water (a) is

$$K_p = \frac{[HA]_o}{[HA]_a} = 30$$

and the distribution ratio of A is

$$D = \frac{[HA]_a}{[HA]_a + [A^-]_a}.$$

Answer the following questions.

(1) Obtain the respective percentages of A extracted from water at pH=1.0 to hexane when the volume ratios of hexane to water are $V_o/V_a=1.0$ and $V_o/V_a=0.1$, assuming that the phases are shaken enough.

(2) Obtain the distribution ratio of A when the volume ratio of hexane to water at pH=5.1 is $V_o/V_a=1.0$, assuming that the phases are shaken enough.
Consider a bimolecular reaction as follows:

\[ \text{A} + \text{B} \rightarrow \text{C} \]

(1) \([A]\) and \([B]\) mean the concentrations of A and B, respectively. Show the rate equation describing the time-change of \([A]\).

(2) Explain how the order of reaction is, when \([B] \gg [A]\).

(3) The rate constants are 0.01 L/(mol\cdot s) at 400 K, and 0.80 L/(mol\cdot s) at 600 K in temperature, respectively. Find the time (seconds) at which A halves at each temperature under a condition with a large excess of B, i.e., \([B]=0.1\ \text{mol}/\text{L}\).

(4) Calculate the activation energy, when Arrhenius equation describes the rate constants of (3). Here, gas constant \(R\) is 8.314 J/(K\cdot mol).
[2] Answer the following questions.

(1) Answer the following questions by referring to uranium decay series (4n + 2 series) given in the attached paper.* (*The attached paper is omitted in this example question.)

a) Obtain the Q value of alpha decay of $^{238}\text{U}$.
   In addition, obtain the energy of the alpha ray emitted at the transition from $^{238}\text{U}$ to $^{234}\text{Th}$ (ground state). Here, $^{238}\text{U} = 238.0508$ u, $^{234}\text{Th} = 234.0436$ u, and $^4\text{He} = 4.0026$ u.

b) Consider a uranium mineral in radioactive equilibrium state. The measured activity of this mineral is $3.5 \times 10^4$ Bq. Obtain the activity (Bq) of Ra in this mineral.
   
   Next, chemically pure U is separated from this mineral, and then converted to $\text{UO}_2$ to measure its weight. The weight of the $\text{UO}_2$ is 200 mg. Now, obtain the yield (= recovery percentage) and activity (Bq) of the separated U. Here, the nuclides of thorium decay series and actinium decay series in the mineral are negligible.

   c) Obtain the total half-life of $^{234m}\text{Pa}$ and partial half-life of $^{234m}\text{Pa}$ for nuclear isomer transition.

(2) Explain the following technical terms.

   a) hold-back carrier
   b) specific activity
   c) neutron activation analysis
   d) isotope dilution analysis

-End of the questions-