AoPS CHEM WOOT
Art of Problem Solving

2022–2023 Syllabus

1. Steady State Kinetics

This class introduces students to chemical reaction kinetics and covers the use of the steady-state approximation to find rate laws for complex reaction systems.

Example Problem: For the reaction $\mathrm{A} \longrightarrow \mathrm{B}$, the rate law is rate = $k[\mathrm{A}]$. If the reaction is 40.0% complete after 50.0 minutes, what is the value of the rate constant, k?

Example Problem: What is the rate law for the hypothetical reaction with the mechanism shown? (I_1 and I_2 indicate intermediates, not molecular formulae.)

$$2\,\mathrm{A} \rightleftharpoons \mathrm{I}_1 \text{ (fast equilibrium)}$$

$$\mathrm{I}_1 + \mathrm{B} \longrightarrow \mathrm{I}_2 \text{ (slow)}$$

$$\mathrm{I}_2 + \mathrm{B} \longrightarrow \mathrm{A}_2\mathrm{B}_2 \text{ (fast)}$$

2. Equilibrium I: Single-Reaction Equilibria
3. Equilibrium II: Multiple Simultaneous Equilibria

These two classes cover chemical equilibria, with a particular focus on how to determine equilibrium concentrations of different species in mixed solutions.

Example Problem: The pH of a saturated solution of $\mathrm{Fe(OH)_2}$ is 8.67. What is the K_{sp} for $\mathrm{Fe(OH)_2}$?

Example Problem: Solution X contains 0.10 M acetic acid and 0.02 M formic acid. Calculate the pH of this solution.

4. Inorganic Reaction Schemes

This class explores techniques for identifying unknown substances in chemical reactions, with a focus on qualitative properties like color and solubility. Determination of oxidation states and balancing of oxidation states in reactions are also covered.

Example Problem: An aqueous solution contains the ions $\mathrm{Ag^+}$, $\mathrm{Ba^{2+}}$, and $\mathrm{Ni^{2+}}$. Dilute aqueous solutions of NaCl, $\mathrm{Na_2S}$, and $\mathrm{Na_2SO_4}$ are available. In what order should these solutions be added if the goal is to precipitate each of the three cations separately?

Example Problem: When equal volumes of 0.2 M solutions of the following compounds are mixed, which combination forms a red precipitate?

(A) $\mathrm{AgNO_3 + Na_2S}$ (B) $\mathrm{AgNO_3 + K_2CrO_4}$ (C) $\mathrm{NiCl_2 + NaOH}$ (D) $\mathrm{CuSO_4 + NH_3}$

5. Unit Cells

In this class, students learn about the quantitative aspects of solid structures. Different types of structures are described, and the geometries are related to macroscopic properties like density.

Example Problem: Barium metal crystallizes in a body-centered cubic lattice with barium atoms only at the lattice points. If the density of barium metal is 3.50 g/cm^3, what is the length of the unit cell?

6. Metallurgy

This class examines reactions that are used to isolate metals from contaminated ores and other metal-containing minerals. In addition to the multiple types of reactions that are used in these processes, students learn how to identify intermediate complexes in reactions with metals.

Example Problem: $\mathrm{Fe_2O_3}$ reacts with excess CO at a high temperature according to the equation

$$\mathrm{Fe_2O_3} + 3\,\mathrm{CO} \longrightarrow 2\,\mathrm{Fe} + 3\,\mathrm{CO_2}$$

If 6.50 g of $\mathrm{Fe_2O_3}$ yields 3.85 g of Fe, what is the percentage yield of the reaction?

Example Problem: Electrolysis of 10.00 g of a binary metal chloride deposits 6.207 g of the pure metal. What is the metal?

7. Thermodynamics I
8. Thermodynamics II
9. Thermodynamics III

These classes provide students with a thorough foundation of core thermodynamic principles and techniques to apply these principles to determine quantitative properties of chemical reaction systems. The first two classes focus on enthalpy, entropy, Gibbs free energy, and the relationship between these quantities and reaction equilibrium states. The third class describes the thermodynamics of phase transitions of pure substances.

Example Problem: The reaction

$$\mathrm{N_2O_4(g)} \rightleftharpoons 2\,\mathrm{NO_2(g)}$$

is endothermic as written. Which change will increase the amount of $\mathrm{NO_2}$ at equilibrium?

(A) adding a catalyst

(B) decreasing the temperature

(C) increasing the volume of the container

(D) adding an inert gas to increase the pressure

Example Problem: An ice cube at an unknown temperature is added to 25.0 g of liquid $\mathrm{H_2O}$ at 40.0 °C. The final temperature of the 29.3 g equilibrated mixture is 21.5 °C. What was the original temperature of the ice cube? [C_p of water is 4.184 J/g·°C; $\Delta H^\circ_{fusion} = 333$ J/g]

10. Electrochemistry

This class covers electrochemical reactions, in particular how chemical oxidations and reductions can be used to create electrical potentials and how those potentials relate to the thermodynamic properties of the chemical reactions.

Example Problem: The $\mathrm{Zn(s)|Zn^{2+}(aq)||H^+(aq)|H_2(g)}$ cell has a standard potential of $E^\circ = 0.76$ V. If $[\mathrm{Zn_2}^+] = 1$ M, $P_{\mathrm{H_2}} = 1$ atm and $T = 25$ °C, what must be the pH in the hydrogen compartment of the cell if the measured cell voltage is 0.70 V?

Example Problem: When it is connected to a Standard Hydrogen Electrode (SHE), electrons flow from an unknown half cell to the SHE. Which statement is correct?

(A) The unknown half cell is the anode

(B) Oxidation occurs at the SHE

(C) E°_{red} for the unkown half cell is positive

(D) E°_{cell} is negative

11. Carbonyls as Electrophiles: Carboxylic Acid Derivatives
12. Carbonyls as Electrophiles: Aldehydes and Ketones

These two classes introduce basic principles of organic chemistry with a focus on the C=O functional group and reactions in which it acts as an electrophile.

Example Problem: Esters are easily formed by acid-catalyzed reactions between alcohols and carboxylic acids. However, the reactions are slow and do not go to completion unless water is constantly removed. What type of carbonyl could you use in place of the carboxylic acid to make the reaction go more quickly and with higher yield?

(A) amide (B) acid chloride (C) aldehyde (D) ketone

13. Carbonyls as Nucleophiles: Enols and Enolates

The focus on the organic chemistry of the C=O group continues with this look at reactions in which molecules containing this functional group act as nucleophiles.

Example Problem: Draw the product of the reaction of ethyl acetate with ethyl benzoate in the presence of a strong base.

14. Biochemistry

This class describes the structure and chemistry of the most important classes of biological molecules – lipids, proteins, and carbohydrates.

Example Problem: Which functional group present in simple sugars is responsible for their high solubility in water?

15. Polymers

This final class covers the synthesis and properties of polymers, an important class of materials that are produced in large quantities by the chemical industry.

Example Problem: You perform a polymerization of propylene which yields a product with an average degree of polymerization of 10,000 and a dispersity of 0.5. What is the average number of double bonds in a single product molecule?

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