Part I

1. The interactions between atoms, ions, and molecules determine chemical properties. The important aspects of each type of interaction are its relative strength, how rapidly it decreases with increasing distance, and whether it is directional or not. Please (a) illustrate the various types of interactions acting on chemical species, (b) arrange the interactions in order of decreasing strength, and (c) write the mathematical relationship between potential energy and distance for each type of interaction if possible. (20%)
2. The reaction *cis*-2-butene to *trans*-2-butene is first order in both directions. At 25°C, the equilibrium constant is 0.406 and the forward rate constant is $4.21\times10^{-4}\ s^{-1}$. Starting with a sample of the pure *cis* isomer with $[cis]_o = 0.115\ mol\cdot dm^{-3}$, how long would it take for half the equilibrium amount of the *trans* isomer to form? (20%)

Part II

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Choose the one that is best in each case.

Questions (each 2%)

1. The equilibrium constant for the autoprotolysis of water is 1.00×10^{-14} at 25 °C. The pH of a 1.00×10^{-9}-molar HCl solution at 25 °C is closest to which of the following?
   (a) 12 (b) 9 (c) 7 (d) 6 (e) 5
2. Which of the following samples contains the smallest number of atoms?
   (a) 1 g of $CO_2(g)$
   (b) 1 g of $C_8H_{18}(liq)$
   (c) 1 g of $C_2H_6(g)$
   (d) 1 g of $LiF(s)$
   (e) 1 g of $B_4H_{10}(g)$
3. An ore contains 1.34 % of the mineral argentite, Ag_2S, by weight. How many grams of this ore would have to be processed in order to obtain 1.00 g of pure solid silver, Ag?
   (a)74.6 g (b) 85.7 g (c) 107.9 g (d) 134.0 g (e) 171.4 g
4. Methyl benzoate is prepared by the reaction between benzoic acid and methanol, according to the equation

$$\underset{\text{Benzoic acid}}{C_6H_5COOH} + \underset{\text{Methanol}}{CH_3OH} \rightarrow \underset{\text{Methyl benzoate}}{C_6H_5COOCH_3} + H_2O$$

   In an experiment 24.4 g of benzoic acid were reacted with 70.0 mL of CH_3OH. The density of CH_3OH is $0.791\ g\cdot mL^{-1}$. The methyl benzoate produced in this reaction had a mass of 21.6 g. What was the percentage yield of product?
   (a) 91.7 % (b) 79.3 % (c) 71.5 % (d) 21.7 % (e) 9.17%
5. When cerium (III) carbonate pentahydrate is heated strongly it decomposes to yield carbon dioxide, cerium (III) oxide, and water vapor. How many moles of carbon dioxide can be obtained by completely decomposing 1.50 mol of cerium (III) carbonate pentahydrate?
   (a) 1.50 (b) 3.00 (c) 4.50 (d) 6.00 (e) 7.50

6. At room temperature mercury has a density of 13.6 $g \cdot cm^{-3}$, while liquid bromoform, $CHBr_3$, has a density of 2.89 $g \cdot cm^{-3}$. How high a column of bromoform will be supported by a pressure that supports a column of mercury 200-mm high?
   (a) 94.1 mm (b) 272.0 mm (c) 42.5 cm (d) 94.1 cm (e) 272.0 cm
7. A certain solid has a density of 4.0 g/cm^3. An educated guess of the value of the density of the liquid form of this substance would be
   (a) 4.0 g/cm^3 (b) 3.6 g/cm^3 (c) 1.8 g/cm^3 (d) 0.4 g/cm^3 (e) 4.0 g/L
8. An aqueous solution of ethanol, CH_3CH_2OH, that is 12.00 % ethanol by weight, has a density of 0.9808 $g \cdot mL^{-1}$ at 20 °C. What is the molality of ethanol in this solution?
   (a) 0.05063 (b) 0.1200 (c) 2.555 (d) 2.960 (e) 12.00
9. Insoluble hydroxides can generally be dissolved in strong acids. Suppose you have solid samples of $Pb(OH)_2$, $Al(OH)_3$, $Sr(OH)_2$, and $Zn(OH)_2$. In which of the following strong acids could you dissolve all four solids to produce solely a clear solution?
   (a) HCl (b) HNO_3 (c) HBr (d) H_2SO_4 (e) HI
10. Which of the following insoluble electrolytes will NOT be significantly more soluble in 1.0 *M* HNO_3 than it is in pure water?
   (a) FeS (b) $SrCO_3$ (c) AgCN (d) $BaSO_3$ (e) AgI
11. Which of the following statements about Millikan's oil drop experiment is TRUE?
   (a) When the electric field is turned on, all the oil drops move toward the positively charged plate.
   (b) The charge on each drop is the electronic charge.
   (c) In the absence of the electric field, the speed with which the drop falls depends only upon the acceleration of gravity.
   (d) Oil drops, rather than water drops, were used because oil is easier to see.
   (e) Some oil drops become positively charged and some become negatively charged after colliding with gaseous ions.
12. Of the quantum state designations listed below, which does NOT describe an allowed state for an electron in an atom?
   I. $n = 3, l = 2, m_l = -2$
   II. $n = 3, l = 1, m_l = 0$
   III. $n = 3, l = 0, m_l = -1$
   IV. $n = 3, l = 2, m_l = 0$
   V. $n = 3, l = 3, m_l = -2$
   (a) I and V (b) II and III (c) III and IV (d) I and IVJ (e) III and V
13. In which of the following molecules does the central atom use sp^2 hybrid atomic orbitals in forming bonds?
   (a) H_2S (b) CS_2 (c) Cl_2O (d) NH_3 (e) SO_2
14. Which of the following best describes the hybrids used by S in the sulfite ion, SO_3^{2-}?
   (a) *sp* (b) sp^2 (c) sp^3 (d) dsp^2 (e) d^2sp^3

15. When thiosulfate ion, $S_2O_3^{2-}$, reacts with I_2, the products are I^- and tetrathionate ion, $S_4O_6^{2-}$. In a titration of a solution of I_2, 32.78 mL of 0.100 *M* $Na_2S_2O_3$ were required to react completely with the I_2 How many millimoles of I_2 were in this solution?
(a) 1.639 (b) 3.278 (c) 4.917 (d) 6.556 (e) 9.834

16. During the electrolysis of aqueous zinc nitrate,
(a) Zinc plates out at the cathode.
(b) Zinc plates out at the anode.
(c) Nitrogen gas, N_2, is evolved at the cathode.
(d) Hydrogen gas, H_2, is evolved at the anode.
(e) Oxygen gas, O_2, is evolved at the anode.

17. If a steady current of 15.0 A is passed through an aqueous solution of $CuSO_4$, how long will it take to deposit 0.250 mol of Cu at the cathode, assuming 100% efficiency?
(a) 3.22×10^3 min (b) 1.61×10^3 min (c) 53.6 min (d) 26.8 min (e) 0.893 min

18. If $\Delta G_f°(HI, g) = +1.7$ kJ, what is the equilibrium constant at 25 °C for

$$2\ HI(g) \rightleftharpoons H_2(g) + I_2(s)$$

(a) 24 (b) 3.9 (c) 2.0 (d) 0.50 (e) 0.25

19. If a process is both endothermic and spontaneous then
(a) $\Delta S > 0$ (b) $\Delta S < 0$ (c) $\Delta H < 0$ (d) $\Delta G > 0$ (e) $\Delta U = 0$

20. Which of the following statements about the spontaneous reaction occurring in a galvanic cell is always true?
(a) $\Delta E_{cell}° > 0$, $\Delta G° < 0$, and $Q < K$ (b) $\Delta E_{cell}° > 0$, $\Delta G° > 0$, and $Q < K$
(c) $\Delta E_{cell}° > 0$, $\Delta G° > 0$, and $Q > K$ (d) $\Delta E_{cell} > 0$, $\Delta G < 0$, and $Q > K$
(e) $\Delta E_{cell} > 0$, $\Delta G < 0$, and $Q < K$

21. Concentrated ammonia solution is added to an aqueous solution of each of the following salts. In which one does a precipitate form?
(a) $Ni(NO_3)_2$ (b) $CuSO_4$ (c) $Mg(NO_3)_2$ (d) $CoSO_4$ (e) $ZnCl_2$

22. A compound contains two types of atoms, X and Y. It crystallizes in a cubic lattice with X atoms at the corners of the unit cells and Y atoms at the body centers. The simplest formula of this compound is
(a) X_8Y (b) X_2Y (c) XY (d) XY_2 (e) XY_8

23. The activity of ^{14}C in living bones is 15.3 dpm/g of carbon. The half-life of ^{14}C is 5730 yr. A fossil animal bone found in Hsinchu county has an activity of 3.83 dpm/g of carbon. How many years ago did the animal die?
(a) 5730 (b) 8600 (c) 11400 (d) 14300 (e) 17200

24. Of the following, the element which in solution will form a white precipitate with chloride ion which will turn black on the addition of aqueous ammonia is
(a) lead (b) silver (c) tin (d) sodium (e) mercury

25. Which of the following reactions when heated quickly produces small amounts of chlorine gas?
(a) $NaCl + HNO_3$ (b) $NaCl + KMnO_4$ (c) $NaCl + H_2SO_4$
(d) $HCl + Br_2$ (e) $HCl + KMnO_4$

26. Which of the following is the most abundant element in limestones?
(a) Si (b) Al (c) Fe (d) Mg (e) Ca

27. For the nonaqueous titration of a weak acid, the desirable properties of a solvent include all of the following EXCEPT
(a)a moderate dielectric constant
(b)good proton-accepting ability
(c)adequate solubility of the acid
(d)a low autoprotolysis constant
(e)low vapor pressure

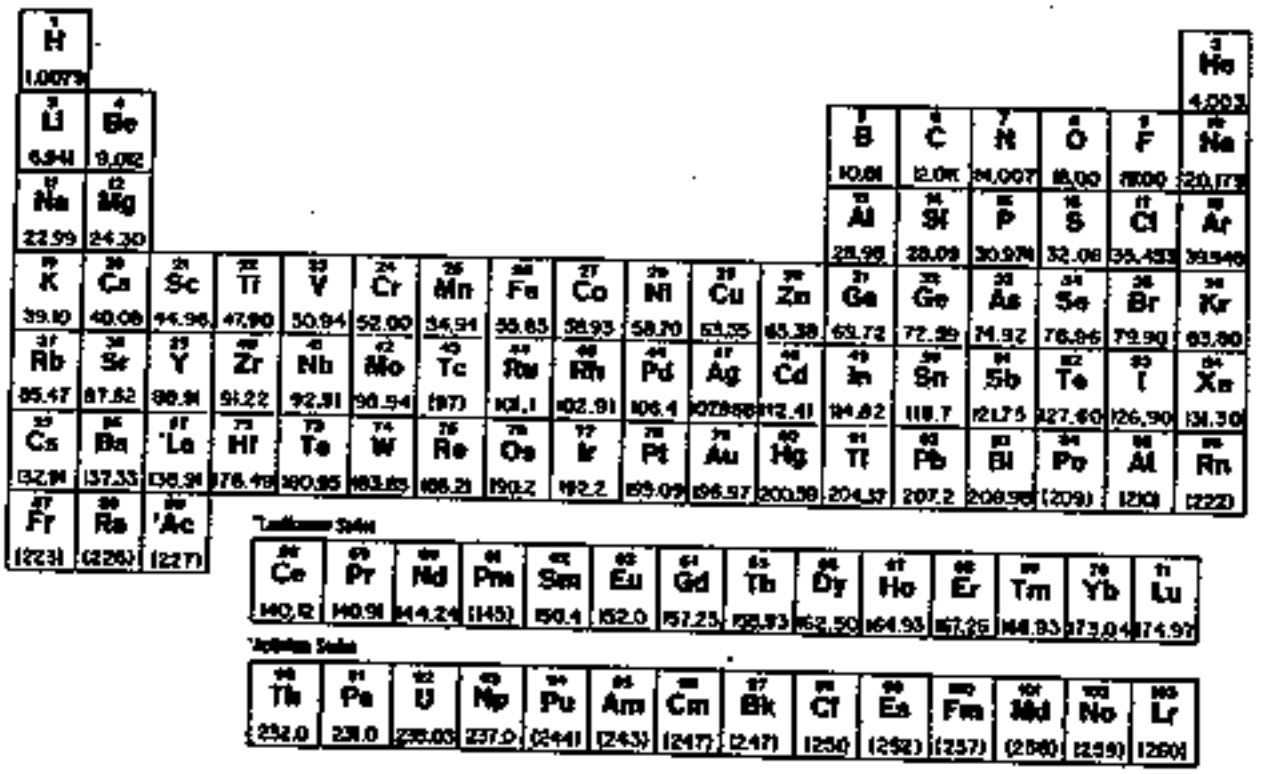
28. Which of the following samples of reducing agents is chemically equivalent to 25 mL of 0.20-normal $KMnO_4$ to be reduced to Mn^{2+} and H_2O?
(a) 50 mL of 0.10 *M* H_3AsO_3 to be oxidized to H_3AsO_4
(b) 25 mL of 0.20 *M* H_2O_2 to be oxidized to H^+ and O_2
(c) 25 mL of 0.10 *M* $SnCl_2$ to be oxidized to Sn^{4+}
(d) 25 mL of 0.10 *M* $FeSO_4 \cdot 7H_2O$ to be oxidized to Fe^{3+}
(e) 100 mL of 0.10 *M* $H_2C_2O_4 \cdot 2H_2O$ to be oxidized to CO_2 and H_2O

29. Two reactions that may occur at the cathode during the electrolysis of aqueous NaCl are indicated below
(1) $Na^+ + e^- \rightarrow Na$ E° reduction = –2.71 V
(2) $2\ H_2O + 2\ e^- \rightarrow H_2(g) + 2\ OH^-$ E° reduction = –0.83 V
The first reaction occurs if the cathode is mercury; the second reaction occurs if the cathode is iron. Part of the accepted explanation for these observations includes the fact that
(a) sodium and iron form a liquid alloy
(b) iron catalyzes the reaction of sodium with water
(c) sodium dissolves in iron and is removed before it has time to react
(d) the reduction potential indicates the second reaction is more probable
(e) the overvoltage for hydrogen evolution on mercury can be in excess of 1.5 volts

30. The freezing point of water is lowered by the addition of a soluble substance such as sodium chloride. This lowering is considered to be a consequence of the fact that
(a) the partial molal volume of ice is greater than the partial molal volume of liquid water at the freezing point of the solution
(b) the vapor pressure of pure ice is less than that of the water in solution at the normal freezing point of pure ice
(c) the chemical potential of water in the solution at the normal freezing point of water is less than that of pure ice
(d) sodium chloride dissociates into ions when it dissolves in water
(e) the dissolving of sodium chloride in water is an exothermic process

Ⅱ. Information

PERIODIC CHART OF THE ELEMENTS



Values of Some Physical Constants

Constant	Symbol	Value
Atomic mass constant	m_u	$1.660\,5402 \times 10^{-27}$ kg
Avogadro constant	N_A	$6.022\,1367 \times 10^{23}$ mol^{-1}
Bohr magneton	$\mu_B = e\hbar/2m_e$	$9.274\,0154 \times 10^{-24}$ J · T^{-1}
Bohr radius	$a_0 = 4\pi\epsilon_0\hbar^2/m_e e^2$	$5.291\,772\,49 \times 10^{-11}$ m
Boltzmann constant	k_B	$1.380\,658 \times 10^{-23}$ J · K^{-1}
		0.695 038 cm^{-1}
Electron rest mass	m_e	$9.109\,3897 \times 10^{-31}$ kg
Gravitational constant	G	$6.672\,59 \times 10^{-11}$ m^3 · kg^{-1} · s^{-2}
Molar gas constant	R	8.314 510 J · K^{-1} · mol^{-1}
		0.083 1451 dm^3 · bar · K^{-1} · mol^{-1}
		0.082 0578 dm^3 · atm · K^{-1} · mol^{-1}
Molar volume, ideal gas		
(one bar, 0°C)		22.711 08 L · mol^{-1}
(one atm, 0°C)		22.414 09 L · mol^{-1}
Nuclear magneton	$\mu_N = e\hbar/2m_p$	$5.050\,7866 \times 10^{-27}$ J · T^{-1}
Permittivity of vacuum	ϵ_0	$8.854\,187\,816 \times 10^{-12}$ C^2 · J^{-1} · m^{-1}
	$4\pi\epsilon_0$	$1.112\,650\,056 \times 10^{-10}$ C^2 · J^{-1} · m^{-1}
Planck constant	h	$6.626\,0755 \times 10^{-34}$ J · s
	$\hbar$	$1.054\,572\,66 \times 10^{-34}$ J · s
Proton charge	e	$1.602\,177\,33 \times 10^{-19}$ C
Proton magnetogyric ratio	γ_p	$2.675\,221\,28 \times 10^{8}$ s^{-1} · T^{-1}
Proton rest mass	m_p	$1.672\,6231 \times 10^{-27}$ kg
Rydberg constant (Bohr)	$R_\infty = m_e e^4/8\epsilon_0^2 h^2$	$2.179\,8736 \times 10^{-18}$ J
		109 737.31534 cm^{-1}
Rydberg constant (expt)	R_H	109 677.581 cm^{-1}
Speed of light in vacuum	c	299 792 458 m · s^{-1} (defined)
Stefan–Boltzmann constant	$\sigma = 2\pi^5 k_B^4/15h^3c^2$	$5.670\,51 \times 10^{-8}$ J · m^{-2} · K^{-4} · s^{-1}

Conversion Factors for Energy Units

	joule	kJ · mol^{-1}	eV
1 joule	1	$6.022\,137 \times 10^{20}$	$6.241\,506 \times 10^{18}$
1 kJ · mol^{-1}	$1.660\,540 \times 10^{-21}$	1	$1.036\,427 \times 10^{-2}$
1 eV	$1.602\,177 \times 10^{-19}$	96.4853	1
1 E_h	$4.359\,748 \times 10^{-18}$	2625.500	27.2114
1 cm^{-1}	$1.986\,447 \times 10^{-23}$	$1.196\,266 \times 10^{-2}$	$1.239\,842 \times 10^{-4}$
1 Hz	$6.626\,076 \times 10^{-34}$	$3.990\,313 \times 10^{-13}$	$4.135\,669 \times 10^{-15}$