



AP[®] Chemistry 2007 Free-Response Questions

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STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction	$E^\circ(\text{V})$
$\text{F}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{F}^-$	2.87
$\text{Co}^{3+} + \text{e}^- \rightarrow \text{Co}^{2+}$	1.82
$\text{Au}^{3+} + 3\text{e}^- \rightarrow \text{Au}(\text{s})$	1.50
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{Cl}^-$	1.36
$\text{O}_2(\text{g}) + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$	1.23
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightarrow 2\text{Br}^-$	1.07
$2\text{Hg}^{2+} + 2\text{e}^- \rightarrow \text{Hg}_2^{2+}$	0.92
$\text{Hg}^{2+} + 2\text{e}^- \rightarrow \text{Hg}(\text{l})$	0.85
$\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}(\text{s})$	0.80
$\text{Hg}_2^{2+} + 2\text{e}^- \rightarrow 2\text{Hg}(\text{l})$	0.79
$\text{Fe}^{3+} + \text{e}^- \rightarrow \text{Fe}^{2+}$	0.77
$\text{I}_2(\text{s}) + 2\text{e}^- \rightarrow 2\text{I}^-$	0.53
$\text{Cu}^+ + \text{e}^- \rightarrow \text{Cu}(\text{s})$	0.52
$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}(\text{s})$	0.34
$\text{Cu}^{2+} + \text{e}^- \rightarrow \text{Cu}^+$	0.15
$\text{Sn}^{4+} + 2\text{e}^- \rightarrow \text{Sn}^{2+}$	0.15
$\text{S}(\text{s}) + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{S}(\text{g})$	0.14
$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+} + 2\text{e}^- \rightarrow \text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+} + 2\text{e}^- \rightarrow \text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+} + 2\text{e}^- \rightarrow \text{Ni}(\text{s})$	-0.25
$\text{Co}^{2+} + 2\text{e}^- \rightarrow \text{Co}(\text{s})$	-0.28
$\text{Cd}^{2+} + 2\text{e}^- \rightarrow \text{Cd}(\text{s})$	-0.40
$\text{Cr}^{3+} + \text{e}^- \rightarrow \text{Cr}^{2+}$	-0.41
$\text{Fe}^{2+} + 2\text{e}^- \rightarrow \text{Fe}(\text{s})$	-0.44
$\text{Cr}^{3+} + 3\text{e}^- \rightarrow \text{Cr}(\text{s})$	-0.74
$\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-$	-0.83
$\text{Mn}^{2+} + 2\text{e}^- \rightarrow \text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}(\text{s})$	-1.66
$\text{Be}^{2+} + 2\text{e}^- \rightarrow \text{Be}(\text{s})$	-1.70
$\text{Mg}^{2+} + 2\text{e}^- \rightarrow \text{Mg}(\text{s})$	-2.37
$\text{Na}^+ + \text{e}^- \rightarrow \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+} + 2\text{e}^- \rightarrow \text{Ca}(\text{s})$	-2.87
$\text{Sr}^{2+} + 2\text{e}^- \rightarrow \text{Sr}(\text{s})$	-2.89
$\text{Ba}^{2+} + 2\text{e}^- \rightarrow \text{Ba}(\text{s})$	-2.90
$\text{Rb}^+ + \text{e}^- \rightarrow \text{Rb}(\text{s})$	-2.92
$\text{K}^+ + \text{e}^- \rightarrow \text{K}(\text{s})$	-2.92
$\text{Cs}^+ + \text{e}^- \rightarrow \text{Cs}(\text{s})$	-2.92
$\text{Li}^+ + \text{e}^- \rightarrow \text{Li}(\text{s})$	-3.05

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$$E = hv \quad c = \lambda\nu$$

$$\lambda = \frac{h}{m\nu} \quad p = mv$$

$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

EQUILIBRIUM

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

$$K_b = \frac{[\text{OH}^-][\text{HB}^+]}{[\text{B}]}$$

$$K_w = [\text{OH}^-][\text{H}^+] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\text{C}$$

$$= K_a \times K_b$$

$$\text{pH} = -\log[\text{H}^+], \text{pOH} = -\log[\text{OH}^-]$$

$$14 = \text{pH} + \text{pOH}$$

$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

$$\text{pOH} = \text{p}K_b + \log \frac{[\text{HB}^+]}{[\text{B}]}$$

$$\text{p}K_a = -\log K_a, \text{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where Δn = moles product gas – moles reactant gas

THERMOCHEMISTRY/KINETICS

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K = -2.303 RT \log K$$

$$= -n\mathcal{F}E^\circ$$

$$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303 RT \log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[A]_t - \ln[A]_0 = -kt$$

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$$

$$\ln k = \frac{-E_a}{R} \left(\frac{1}{T} \right) + \ln A$$

$$E = \text{energy} \quad \nu = \text{velocity}$$

$$\nu = \text{frequency} \quad n = \text{principal quantum number}$$

$$\lambda = \text{wavelength} \quad m = \text{mass}$$

$$p = \text{momentum}$$

$$\text{Speed of light, } c = 3.0 \times 10^8 \text{ m s}^{-1}$$

$$\text{Planck's constant, } h = 6.63 \times 10^{-34} \text{ J s}$$

$$\text{Boltzmann's constant, } k = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

$$\text{Avogadro's number} = 6.022 \times 10^{23} \text{ mol}^{-1}$$

$$\text{Electron charge, } e = -1.602 \times 10^{-19} \text{ coulomb}$$

$$1 \text{ electron volt per atom} = 96.5 \text{ kJ mol}^{-1}$$

Equilibrium Constants

K_a (weak acid)
 K_b (weak base)
 K_w (water)
 K_p (gas pressure)
 K_c (molar concentrations)

S° = standard entropy

H° = standard enthalpy

G° = standard free energy

E° = standard reduction potential

T = temperature

n = moles

m = mass

q = heat

c = specific heat capacity

C_p = molar heat capacity at constant pressure

E_a = activation energy

k = rate constant

A = frequency factor

Faraday's constant, $\mathcal{F} = 96,500$ coulombs per mole of electrons

Gas constant, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
 $= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$
 $= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \dots$$

$$n = \frac{m}{M}$$

$$K = ^\circ\text{C} + 273$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

$$KE \text{ per mole} = \frac{3}{2}RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

P = pressure

V = volume

T = temperature

n = number of moles

D = density

m = mass

v = velocity

u_{rms} = root-mean-square speed

KE = kinetic energy

r = rate of effusion

M = molar mass

π = osmotic pressure

i = van't Hoff factor

K_f = molal freezing-point depression constant

K_b = molal boiling-point elevation constant

A = absorbance

a = molar absorptivity

b = path length

c = concentration

Q = reaction quotient

I = current (amperes)

q = charge (coulombs)

t = time (seconds)

E° = standard reduction potential

K = equilibrium constant

OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}, \text{ where } aA + bB \rightarrow cC + dD$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E_{\text{cell}}^\circ - \frac{RT}{n\mathcal{F}} \ln Q = E_{\text{cell}}^\circ - \frac{0.0592}{n} \log Q \text{ @ } 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

$$\text{Gas constant, } R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$$

$$= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$$

$$\text{Boltzmann's constant, } k = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

$$K_f \text{ for H}_2\text{O} = 1.86 \text{ K kg mol}^{-1}$$

$$K_b \text{ for H}_2\text{O} = 0.512 \text{ K kg mol}^{-1}$$

$$1 \text{ atm} = 760 \text{ mm Hg}$$

$$= 760 \text{ torr}$$

$$\text{STP} = 0.00^\circ\text{C and } 1.0 \text{ atm}$$

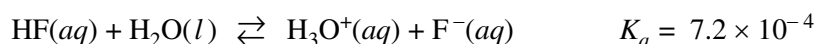
Faraday's constant, \mathcal{F} = 96,500 coulombs per mole of electrons

2007 AP[®] CHEMISTRY FREE-RESPONSE QUESTIONS**CHEMISTRY****Section II****(Total time—95 minutes)****Part A****Time—55 minutes****YOU MAY USE YOUR CALCULATOR FOR PART A.**

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the pink cover. Do NOT write your answers on the green insert.

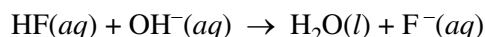
Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.



1. Hydrofluoric acid, $\text{HF}(aq)$, dissociates in water as represented by the equation above.

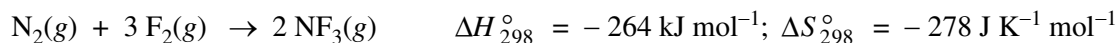
- Write the equilibrium-constant expression for the dissociation of $\text{HF}(aq)$ in water.
- Calculate the molar concentration of H_3O^+ in a $0.40 M$ $\text{HF}(aq)$ solution.

$\text{HF}(aq)$ reacts with $\text{NaOH}(aq)$ according to the reaction represented below.



A volume of 15 mL of $0.40 M$ $\text{NaOH}(aq)$ is added to 25 mL of $0.40 M$ $\text{HF}(aq)$ solution. Assume that volumes are additive.

- Calculate the number of moles of $\text{HF}(aq)$ remaining in the solution.
- Calculate the molar concentration of $\text{F}^-(aq)$ in the solution.
- Calculate the pH of the solution.

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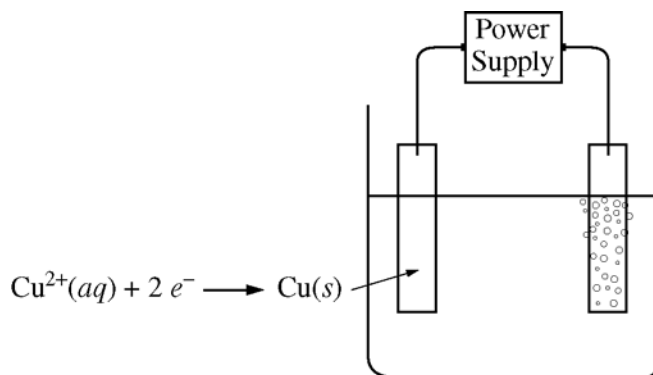
2. The following questions relate to the synthesis reaction represented by the chemical equation in the box above.
- Calculate the value of the standard free energy change, ΔG_{298}° , for the reaction.
 - Determine the temperature at which the equilibrium constant, K_{eq} , for the reaction is equal to 1.00. (Assume that ΔH° and ΔS° are independent of temperature.)
 - Calculate the standard enthalpy change, ΔH° , that occurs when a 0.256 mol sample of $\text{NF}_3(\text{g})$ is formed from $\text{N}_2(\text{g})$ and $\text{F}_2(\text{g})$ at 1.00 atm and 298 K.

The enthalpy change in a chemical reaction is the difference between energy absorbed in breaking bonds in the reactants and energy released by bond formation in the products.

- How many bonds are formed when two molecules of NF_3 are produced according to the equation in the box above?
- Use both the information in the box above and the table of average bond enthalpies below to calculate the average enthalpy of the F–F bond.

Bond	Average Bond Enthalpy (kJ mol ⁻¹)
N≡N	946
N–F	272
F–F	?

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3. An external direct-current power supply is connected to two platinum electrodes immersed in a beaker containing $1.0\text{ M CuSO}_4(\text{aq})$ at 25°C , as shown in the diagram above. As the cell operates, copper metal is deposited onto one electrode and $\text{O}_2(\text{g})$ is produced at the other electrode. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

Half-Reaction	$E^{\circ}(\text{V})$
$\text{O}_2(\text{g}) + 4 \text{H}^+(\text{aq}) + 4 e^{-} \rightarrow 2 \text{H}_2\text{O}(\text{l})$	+1.23
$\text{Cu}^{2+}(\text{aq}) + 2 e^{-} \rightarrow \text{Cu}(\text{s})$	+0.34

- (a) On the diagram, indicate the direction of electron flow in the wire.
- (b) Write a balanced net ionic equation for the electrolysis reaction that occurs in the cell.
- (c) Predict the algebraic sign of ΔG° for the reaction. Justify your prediction.
- (d) Calculate the value of ΔG° for the reaction.

An electric current of 1.50 amps passes through the cell for 40.0 minutes.

- (e) Calculate the mass, in grams, of the $\text{Cu}(\text{s})$ that is deposited on the electrode.
- (f) Calculate the dry volume, in liters measured at 25°C and 1.16 atm, of the $\text{O}_2(\text{g})$ that is produced.

S T O P

**If you finish before time is called, you may check your work on this part only.
Do not turn to the other part of the test until you are told to do so.**

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CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:



(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

- (a) A solution of sodium hydroxide is added to a solution of lead(II) nitrate.

(i) Balanced equation:

- (ii) If 1.0 L volumes of 1.0 M solutions of sodium hydroxide and lead(II) nitrate are mixed together, how many moles of product(s) will be produced? Assume the reaction goes to completion.

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(b) Excess nitric acid is added to solid calcium carbonate.

(i) Balanced equation:

(ii) Briefly explain why statues made of marble (calcium carbonate) displayed outdoors in urban areas are deteriorating.

(c) A solution containing silver(I) ion (an oxidizing agent) is mixed with a solution containing iron(II) ion (a reducing agent).

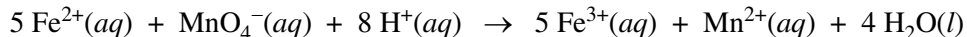
(i) Balanced equation:

(ii) If the contents of the reaction mixture described above are filtered, what substance(s), if any, would remain on the filter paper?

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Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.



5. The mass percent of iron in a soluble iron(II) compound is measured using a titration based on the balanced equation above.

- (a) What is the oxidation number of manganese in the permanganate ion, $\text{MnO}_4^{-}(\text{aq})$?
- (b) Identify the reducing agent in the reaction represented above.

The mass of a sample of the iron(II) compound is carefully measured before the sample is dissolved in distilled water. The resulting solution is acidified with $\text{H}_2\text{SO}_4(\text{aq})$. The solution is then titrated with $\text{MnO}_4^{-}(\text{aq})$ until the end point is reached.

- (c) Describe the color change that occurs in the flask when the end point of the titration has been reached. Explain why the color of the solution changes at the end point.
- (d) Let the variables g , M , and V be defined as follows:

g = the mass, in grams, of the sample of the iron(II) compound

M = the molarity of the $\text{MnO}_4^{-}(\text{aq})$ used as the titrant

V = the volume, in liters, of $\text{MnO}_4^{-}(\text{aq})$ added to reach the end point

In terms of these variables, the number of moles of $\text{MnO}_4^{-}(\text{aq})$ added to reach the end point of the titration is expressed as $M \times V$. Using the variables defined above, the molar mass of iron (55.85 g mol^{-1}), and the coefficients in the balanced chemical equation, write the expression for each of the following quantities.

- (i) The number of moles of iron in the sample
 - (ii) The mass of iron in the sample, in grams
 - (iii) The mass percent of iron in the compound
- (e) What effect will adding too much titrant have on the experimentally determined value of the mass percent of iron in the compound? Justify your answer.

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6. Answer the following questions, which pertain to binary compounds.

(a) In the box provided below, draw a complete Lewis electron-dot diagram for the IF_3 molecule.



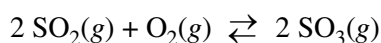
(b) On the basis of the Lewis electron-dot diagram that you drew in part (a), predict the molecular geometry of the IF_3 molecule.

(c) In the SO_2 molecule, both of the bonds between sulfur and oxygen have the same length. Explain this observation, supporting your explanation by drawing in the box below a Lewis electron-dot diagram (or diagrams) for the SO_2 molecule.



(d) On the basis of your Lewis electron-dot diagram(s) in part (c), identify the hybridization of the sulfur atom in the SO_2 molecule.

The reaction between $\text{SO}_2(g)$ and $\text{O}_2(g)$ to form $\text{SO}_3(g)$ is represented below.



The reaction is exothermic. The reaction is slow at 25°C ; however, a catalyst will cause the reaction to proceed faster.

(e) Using the axes provided on the next page, draw the complete potential-energy diagram for both the catalyzed and uncatalyzed reactions. Clearly label the curve that represents the catalyzed reaction.

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- (f) Predict how the ratio of the equilibrium pressures, $\frac{P_{\text{SO}_2}}{P_{\text{SO}_3}}$, would change when the temperature of the uncatalyzed reaction mixture is increased. Justify your prediction.
- (g) How would the presence of a catalyst affect the change in the ratio described in part (f)? Explain.

STOP

END OF EXAM