



## AP Chemistry 1999 Free-Response Questions

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The College Board  
Advanced Placement Examination  
CHEMISTRY  
SECTION II

MATERIAL IN THE FOLLOWING TABLE MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

<b>DO NOT DETACH FROM BOOK.</b>																													
<b>PERIODIC TABLE OF THE ELEMENTS</b>																													
1	H	1.0079	2	He	4.0026	3	Li	6.941	4	Be	9.012	5	B	10.811	6	C	12.011	7	N	14.007	8	O	16.00	9	F	19.00	10	Ne	20.179
11	Na	22.99	12	Mg	24.30	13	Al	26.98	14	Si	28.09	15	P	30.974	16	S	32.06	17	Cl	35.453	18	Ar	39.948	19	K	39.10	20	Ca	40.08
37	Rb	85.47	38	Sr	87.62	39	Y	88.91	40	Zr	91.22	41	Nb	92.91	42	Mo	95.94	43	Tc	(98)	44	Ru	101.1	45	Rh	102.91	46	Pd	106.42
55	Cs	132.91	56	Ba	137.33	57	*La	138.91	58	Ce	140.12	59	Pr	140.91	60	Nd	144.24	61	Pm	(145)	62	Sm	150.4	63	Eu	151.97	64	Gd	157.25
87	Fr	(223)	88	Ra	226.02	89	†Ac	227.03	90	Th	232.04	91	Pa	231.04	92	U	238.03	93	Np	237.05	94	Pu	244	95	Am	243	96	Cm	247
107	Uuh	(263)	108	Uuo	(265)	109	Uue	(266)	110	Uuh	(263)	111	Uuq	(261)	112	Uuq	(261)	113	Uup	(262)	114	Uunh	(263)	115	Uuns	(262)	116	Uuno	(265)
127	Hs	(261)	128	Ht	(262)	129	Hq	(263)	130	Hr	(264)	131	Hs	(265)	132	Ht	(266)	133	Hq	(267)	134	Hr	(268)	135	Hs	(269)	136	Ht	(270)
157	Ubu	(287)	158	Ubu	(288)	159	Ubu	(289)	160	Ubu	(290)	161	Ubu	(291)	162	Ubu	(292)	163	Ubu	(293)	164	Ubu	(294)	165	Ubu	(295)	166	Ubu	(296)
173	Uut	(288)	174	Uut	(289)	175	Uut	(290)	176	Uut	(291)	177	Uut	(292)	178	Uut	(293)	179	Uut	(294)	180	Uut	(295)	181	Uut	(296)	182	Uut	(297)
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737	Uuq	(289)	738	Uuq	(290)	739	Uuq	(291)	740	Uuq	(292)	741	Uuq	(293)	742	Uuq	(294)	743	Uuq	(295)	744	Uuq	(296)	745	Uuq	(297)	746	Uuq	(298)
765	Uuq	(289)	766	Uuq	(290)	767	Uuq	(291)	768	Uuq	(292)	769	Uuq	(293)	770	Uuq	(294)	771	Uuq	(295)	772	Uuq	(296)	773	Uuq	(297)	774	Uuq	(298)
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821	Uuq	(289)	822	Uuq	(290)	823	Uuq	(291)	824	Uuq	(292)	825	Uuq	(293)	826	Uuq	(294)	827	Uuq	(295)	828	Uuq	(296)	829	Uuq	(297)	830	Uuq	(298)
849	Uuq	(289)	850	Uuq	(290)	851	Uuq	(291)	852	Uuq	(292)	853	Uuq	(293)	854	Uuq	(294)	855	Uuq	(295)	856	Uuq	(296)	857	Uuq	(297)	858	Uuq	(298)
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905	Uuq	(289)	906	Uuq	(290)	907	Uuq	(291)	908	Uuq	(292)	909	Uuq	(293)	910	Uuq	(294)	911	Uuq	(295)	912	Uuq	(296)	913	Uuq	(297)	914	Uuq	(298)
933	Uuq	(289)	934	Uuq	(290)	935	Uuq	(291)	936	Uuq	(292)	937	Uuq	(293)	938	Uuq	(294)	939	Uuq	(295)	940	Uuq	(296)	941	Uuq	(297)	942	Uuq	(298)
961	Uuq	(289)	962	Uuq	(290)	963	Uuq	(291)	964	Uuq	(292)	965	Uuq	(293)	966	Uuq	(294)	967	Uuq	(295)	968	Uuq	(296)	969	Uuq	(297)	970	Uuq	(298)
989	Uuq	(289)	990	Uuq	(290)	991	Uuq	(291)	992	Uuq	(292)	993	Uuq	(293)	994	Uuq	(294)	995	Uuq	(295)	996	Uuq	(296)	997	Uuq	(297)	998	Uuq	(298)
1017	Uuq	(289)	1018	Uuq	(290)	1019	Uuq	(291)	1020	Uuq	(292)	1021	Uuq	(293)	1022	Uuq	(294)	1023	Uuq	(295)	1024	Uuq	(296)	1025	Uuq	(297)	1026	Uuq	(298)
1045	Uuq	(289)	1046	Uuq	(290)	1047	Uuq	(291)	1048	Uuq	(292)	1049	Uuq	(293)	1050	Uuq	(294)	1051	Uuq	(295)	1052	Uuq	(296)	1053	Uuq	(297)	1054	Uuq	(298)
1073	Uuq	(289)	1074	Uuq	(290)	1075	Uuq	(291)	1076	Uuq	(292)	1077	Uuq	(293)	1078	Uuq	(294)	1079	Uuq	(295)	1080	Uuq	(296)	1081	Uuq	(297)	1082	Uuq	(298)
1101	Uuq	(289)	1102	Uuq	(290)	1103	Uuq	(291)	1104	Uuq	(292)	1105	Uuq	(293)	1106	Uuq	(294)	1107	Uuq	(295)	1108	Uuq	(296)	1109	Uuq	(297)	1110	Uuq	(298)
1129	Uuq	(289)	1130	Uuq	(290)	1131	Uuq	(291)	1132	Uuq	(292)	1133	Uuq	(293)	1134	Uuq	(294)	1135	Uuq	(295)	1136	Uuq	(296)	1137	Uuq	(297)	1138	Uuq	(298)
1157	Uuq	(289)	1158	Uuq	(290)	1159	Uuq	(291)	1160	Uuq	(292)	1161	Uuq	(293)	1162	Uuq	(294)	1163	Uuq	(295)	1164	Uuq	(296)	1165	Uuq	(297)	1166	Uuq	(298)
1185	Uuq	(289)	1186	Uuq	(290)	1187	Uuq	(291)	1188	Uuq	(292)	1189	Uuq	(293)	1190	Uuq	(294)	1191	Uuq	(295)	1192	Uuq	(296)	1193	Uuq	(297)	1194	Uuq	(298)
1213	Uuq	(289)	1214	Uuq	(290)	1215	Uuq	(291)	1216	Uuq	(292)	1217	Uuq	(293)	1218	Uuq	(294)	1219	Uuq	(295)	1220	Uuq	(296)	1221	Uuq	(297)	1222	Uuq	(298)
1241	Uuq	(289)	1242	Uuq	(290)	1243	Uuq	(291)	1244	Uuq	(292)	1245	Uuq	(293)	1246	Uuq	(294)	1247	Uuq	(295)	1248	Uuq	(296)	1249	Uuq	(297)	1250		

## STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

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

## ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

## ATOMIC STRUCTURE

$$\Delta E = h\nu$$

$$c = \lambda\nu$$

$$\lambda = \frac{h}{m\nu}$$

$$p = m\nu$$

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

$E$  = energy

$\nu$  = frequency

$\lambda$  = wavelength

$p$  = momentum

$v$  = velocity

$n$  = principal quantum number

$m$  = mass

## 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  $\Delta n$  = moles product gas – moles reactant gas

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

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

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

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

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

1 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)

$S^\circ$  = standard entropy

$H^\circ$  = standard enthalpy

$G^\circ$  = standard free energy

$E^\circ$  = standard reduction potential

$T$  = temperature

$n$  = moles

$m$  = mass

$q$  = heat

$c$  = specific heat capacity

$C_p$  = molar heat capacity at constant pressure

1 faraday  $\mathcal{F}$  = 96,500 coulombs

## THERMOCHEMISTRY

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

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

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

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

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

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

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

$$q = mc\Delta T$$

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

## GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

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

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

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

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

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

molarity,  $M$  = moles solute per liter solution

molality = moles solute per kilogram solvent

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

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

$$\pi = \frac{nRT}{V} i$$

$P$  = 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

$\pi$  = osmotic pressure

$i$  = van't Hoff factor

$K_f$  = molal freezing-point depression constant

$K_b$  = molal boiling-point elevation constant

$Q$  = reaction quotient

$I$  = current (amperes)

$q$  = charge (coulombs)

$t$  = time (seconds)

$E^\circ$  = standard reduction potential

$K$  = equilibrium constant

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

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

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

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

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

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

STP =  $0.000^\circ\text{C}$  and  $1.000 \text{ atm}$

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

## OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

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CHEMISTRY

SECTION II

(Total time—90 minutes)

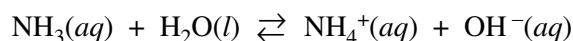
Part A

Time—40 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, because you may earn 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 this booklet.

Answer Question 1 below. The Section II score weighting for this question is 20 percent.



1. In aqueous solution, ammonia reacts as represented above. In  $0.0180\text{ M NH}_3(aq)$  at  $25^\circ\text{C}$ , the hydroxide ion concentration,  $[\text{OH}^-]$ , is  $5.60 \times 10^{-4}\text{ M}$ . In answering the following, assume that temperature is constant at  $25^\circ\text{C}$  and that volumes are additive.
  - (a) Write the equilibrium-constant expression for the reaction represented above.
  - (b) Determine the pH of  $0.0180\text{ M NH}_3(aq)$ .
  - (c) Determine the value of the base ionization constant,  $K_b$ , for  $\text{NH}_3(aq)$ .
  - (d) Determine the percent ionization of  $\text{NH}_3$  in  $0.0180\text{ M NH}_3(aq)$ .
  - (e) In an experiment, a  $20.0\text{ mL}$  sample of  $0.0180\text{ M NH}_3(aq)$  was placed in a flask and titrated to the equivalence point and beyond using  $0.0120\text{ M HCl}(aq)$ .
    - (i) Determine the volume of  $0.0120\text{ M HCl}(aq)$  that was added to reach the equivalence point.
    - (ii) Determine the pH of the solution in the flask after a total of  $15.0\text{ mL}$  of  $0.0120\text{ M HCl}(aq)$  was added.
    - (iii) Determine the pH of the solution in the flask after a total of  $40.0\text{ mL}$  of  $0.0120\text{ M HCl}(aq)$  was added.

GO ON TO THE NEXT PAGE 

Answer EITHER Question 2 below OR Question 3 printed on the next page. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.

2. Answer the following questions regarding light and its interactions with molecules, atoms, and ions.

(a) The longest wavelength of light with enough energy to break the Cl–Cl bond in  $\text{Cl}_2(g)$  is 495 nm.

(i) Calculate the frequency, in  $\text{s}^{-1}$ , of the light.

(ii) Calculate the energy, in J, of a photon of the light.

(iii) Calculate the minimum energy, in  $\text{kJ mol}^{-1}$ , of the Cl–Cl bond.

(b) A certain line in the spectrum of atomic hydrogen is associated with the electronic transition in the H atom from the sixth energy level ( $n = 6$ ) to the second energy level ( $n = 2$ ).

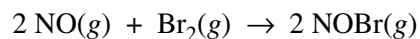
(i) Indicate whether the H atom emits energy or whether it absorbs energy during the transition. Justify your answer.

(ii) Calculate the wavelength, in nm, of the radiation associated with the spectral line.

(iii) Account for the observation that the amount of energy associated with the same electronic transition ( $n = 6$  to  $n = 2$ ) in the  $\text{He}^+$  ion is greater than that associated with the corresponding transition in the H atom.

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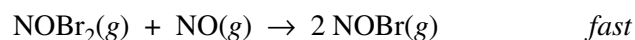
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3. A rate study of the reaction represented above was conducted at 25°C. The data that were obtained are shown in the table below.

Experiment	Initial [NO] (mol L <sup>-1</sup> )	Initial [Br <sub>2</sub> ] (mol L <sup>-1</sup> )	Initial Rate of Appearance of NOBr (mol L <sup>-1</sup> s <sup>-1</sup> )
1	0.0160	0.0120	$3.24 \times 10^{-4}$
2	0.0160	0.0240	$6.38 \times 10^{-4}$
3	0.0320	0.0060	$6.42 \times 10^{-4}$

- (a) Calculate the initial rate of disappearance of Br<sub>2</sub>(g) in experiment 1.
- (b) Determine the order of the reaction with respect to each reactant, Br<sub>2</sub>(g) and NO(g). In each case, explain your reasoning.
- (c) For the reaction,
- write the rate law that is consistent with the data, and
  - calculate the value of the specific rate constant, *k*, and specify units.
- (d) The following mechanism was proposed for the reaction:



Is this mechanism consistent with the given experimental observations? Justify your answer.

**STOP**

DO NOT GO ON TO PART B UNTIL YOU ARE TOLD TO DO SO.



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CHEMISTRY

Part B

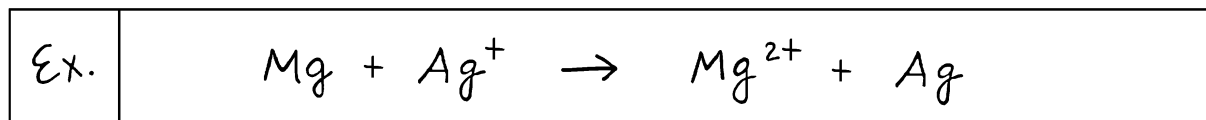
Time—50 minutes

**NO CALCULATORS MAY BE USED WITH PART B.**

Answer Question 4 below. The Section II score weighting for this question is 15 percent.

4. Write the formulas to show the reactants and the products for any FIVE of the laboratory situations described below. Answers to more than five choices will not be graded. In all cases a reaction occurs. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solution as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You need not balance the equations.

Example: A strip of magnesium is added to a solution of silver nitrate.

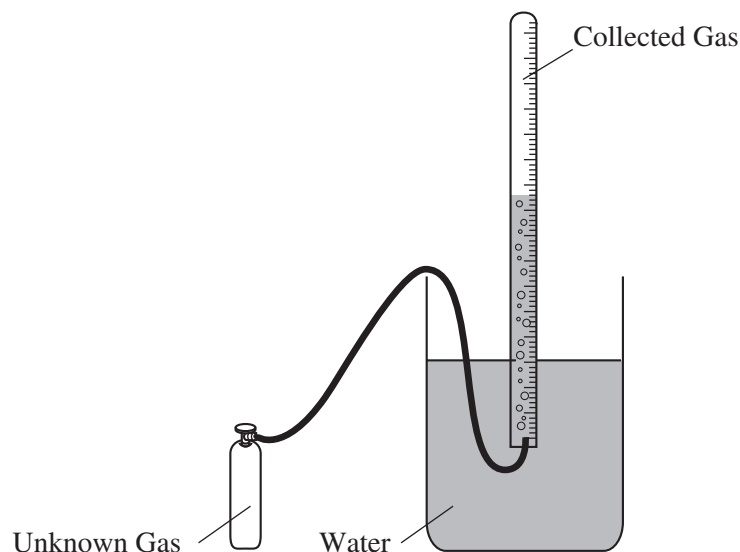


- (a) Calcium oxide powder is added to distilled water.
- (b) Solid ammonium nitrate is heated to temperatures above 300°C.
- (c) Liquid bromine is shaken with a 0.5 *M* sodium iodide solution.
- (d) Solid lead(II) carbonate is added to a 0.5 *M* sulfuric acid solution.
- (e) A mixture of powdered iron(III) oxide and powdered aluminum metal is heated strongly.
- (f) Methylamine gas is bubbled into distilled water.
- (g) Carbon dioxide gas is passed over hot, solid sodium oxide.
- (h) A 0.2 *M* barium nitrate solution is added to an alkaline 0.2 *M* potassium chromate solution.

**GO ON TO THE NEXT PAGE** 

Your responses to the rest of the questions in this part of the examination 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.

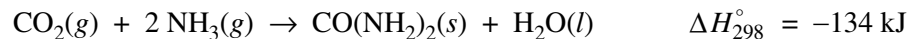
Answer BOTH Question 5 below AND Question 6 printed on the next page. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).



5. A student performs an experiment to determine the molar mass of an unknown gas. A small amount of the pure gas is released from a pressurized container and collected in a graduated tube over water at room temperature, as shown in the diagram above. The collection tube containing the gas is allowed to stand for several minutes, and its depth is adjusted until the water levels inside and outside the tube are the same. Assume that:
- the gas is not appreciably soluble in water
  - the gas collected in the graduated tube and the water are in thermal equilibrium
  - a barometer, a thermometer, an analytical balance, and a table of the equilibrium vapor pressure of water at various temperatures are also available.
- (a) Write the equation(s) needed to calculate the molar mass of the gas.
- (b) List the measurements that must be made in order to calculate the molar mass of the gas.
- (c) Explain the purpose of equalizing the water levels inside and outside the gas collection tube.
- (d) The student determines the molar mass of the gas to be  $64 \text{ g mol}^{-1}$ . Write the expression (set-up) for calculating the percent error in the experimental value, assuming that the unknown gas is butane (molar mass  $58 \text{ g mol}^{-1}$ ). Calculations are not required.
- (e) If the student fails to use information from the table of the equilibrium vapor pressures of water in the calculation, the calculated value for the molar mass of the unknown gas will be smaller than the actual value. Explain.

6. Answer the following questions in terms of thermodynamic principles and concepts of kinetic molecular theory.

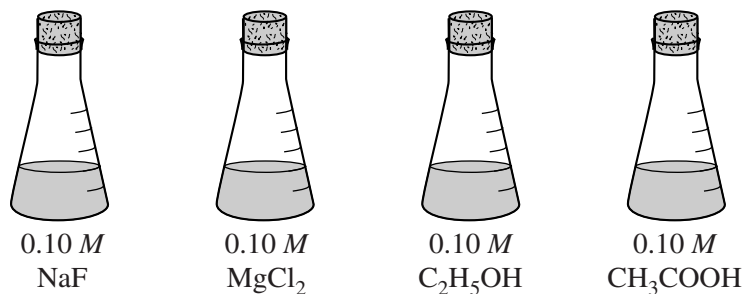
(a) Consider the reaction represented below, which is spontaneous at 298 K.



- (i) For the reaction, indicate whether the standard entropy change,  $\Delta S_{298}^\circ$ , is positive, or negative, or zero. Justify your answer.
- (ii) Which factor, the change in enthalpy,  $\Delta H_{298}^\circ$ , or the change in entropy,  $\Delta S_{298}^\circ$ , provides the principal driving force for the reaction at 298 K? Explain.
- (iii) For the reaction, how is the value of the standard free energy change,  $\Delta G^\circ$ , affected by an increase in temperature? Explain.
- (b) Some reactions that are predicted by their sign of  $\Delta G^\circ$  to be spontaneous at room temperature do not proceed at a measurable rate at room temperature.
- (i) Account for this apparent contradiction.
- (ii) A suitable catalyst increases the rate of such a reaction. What effect does the catalyst have on  $\Delta G^\circ$  for the reaction? Explain.

**GO ON TO THE NEXT PAGE** 

Answer EITHER Question 7 below OR Question 8 below. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 15 percent.



7. Answer the following questions, which refer to the 100 mL samples of aqueous solutions at 25°C in the stoppered flasks shown above.
- Which solution has the lowest electrical conductivity? Explain.
  - Which solution has the lowest freezing point? Explain.
  - Above which solution is the pressure of water vapor greatest? Explain.
  - Which solution has the highest pH? Explain.
8. Answer the following questions using principles of chemical bonding and molecular structure.
- Consider the carbon dioxide molecule,  $\text{CO}_2$ , and the carbonate ion,  $\text{CO}_3^{2-}$ .
    - Draw the complete Lewis electron-dot structure for each species.
    - Account for the fact that the carbon-oxygen bond length in  $\text{CO}_3^{2-}$  is greater than the carbon-oxygen bond length in  $\text{CO}_2$ .
  - Consider the molecules  $\text{CF}_4$  and  $\text{SF}_4$ .
    - Draw the complete Lewis electron-dot structure for each molecule.
    - In terms of molecular geometry, account for the fact that the  $\text{CF}_4$  molecule is nonpolar, whereas the  $\text{SF}_4$  molecule is polar.

**END OF EXAMINATION**