CHEM 1515
Exam IV
John IV. Gelder

Name________________________

TA's Name________________________

Section _______

INSTRUCTIONS:

1. This examination consists of a total of 10 different pages. The last three pages include a periodic table, a solubility table, a table of standard reduction potentials and a table of equilibrium values. All work should be done in this booklet.

2. PRINT your name, TA's name and your lab section number now in the space at the top of this sheet. DO NOT SEPARATE THESE PAGES.

3. Answer all questions that you can and whenever called for show your work clearly. Your method of solving problems should pattern the approach used in lecture. You do not have to show your work for the multiple choice or short answer questions.

4. No credit will be awarded if your work is not shown in 3, 4, and 5aii.

5. Point values are shown next to the problem number.

6. Budget your time for each of the questions. Some problems may have a low point value yet be very challenging. If you do not recognize the solution to a question quickly, skip it, and return to the question after completing the easier problems.

7. Look through the exam before beginning; plan your work; then begin.

8. Relax and do well.

	Page 2	Page 3	Page 4	Page 5	Page 6	TOTAL
SCORES	______ (32)	______ (22)	______ (17)	______ (14)	______ (15)	______ (100)

(9) 1. Write the chemical formula(s) of the product(s) and balance the following reactions. Identify all products phases as either (g)as, (l)iquid, (s)olid or (aq)ueous. Soluble ionic compounds should be written in the form of their component ions. If no reaction occurs write NR.

a) $HClO_4(aq)$ + $NH_3(aq)$ →

b) $Al(s)$ + $Mg(NO_3)_2(aq)$ →

c) $Cu(s)$ + $HNO_3(aq)$ →

(2) 2. Write the ionic and net ionic chemical equations for reactions 1a.

1a) Ionic equation:

1a) Net Ionic equation:

(21) 3. Calculate the E˚ for the reaction in 1b and the value of ΔG˚ and K for the reaction.

(14) 4.Balance the following oxidation-reduction reaction using the half-reaction method in acidic solution.

a) $KMnO_4(aq) + H_2SO_4(aq) + NaCl(aq) \rightarrow Cl_2(aq) + NaHSO_4(aq) + K_2SO_4(aq) + MnSO_4(aq)$

identify the species oxidized ______ identify the species reduced _____

(16) 5. Given the electrochemical cell shown in Figure I.

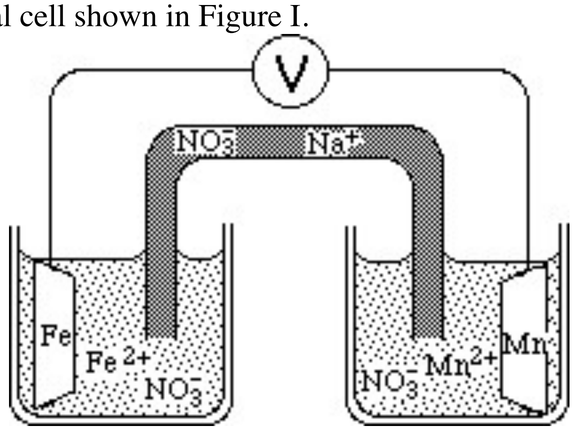


Figure I

(2) a) Write the balanced net ionic equation for the thermodynamically favored reaction that occurs as the cell operates.

b) Determine the standard cell voltage, E°.

c) Describe (use a diagram if you like) what is happening at the submicroscopic/atomic level on the surface of the anode in the cell.

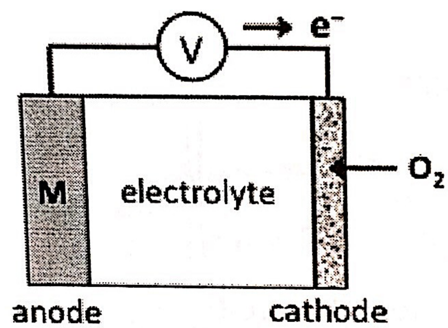
d) Indicate the direction of flow of the ions in the salt bridge. (Be sure the anode and cathode compartments are identified.)

(9) 6. Short answer.

a) The standard reduction potential for the reduction of RuO_4^- to RuO_4^{2-} is +0.59 volts. Which of the following substances can oxidize RuO_4^{2-} to RuO_4^- under standard condition?

H_2SO_4*(aq)*, Pb^{2+}*(aq)*, $Cr_2O_7^{2-}$ (in acidic solution)

Write the balanced chemical equation to support your choice.



7. Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an electrolyte that is an alkaline (OH^-) paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is show above. Reduction potential for the cathode and possible reduction potentials for the metal anodes are given in the table below.

Reduction potential at pH 11 and 298K	***E*** **(V)**
$O_2 + 2H_2O + 4e^- \rightarrow 4\ OH^-$	+ 0.34
$ZnO + H_2O + 2e^- \rightarrow Zn + 2\ OH^-$	- 1.31
$Na_2O + H_2O + 2e^- \rightarrow 2\ Na + 2\ OH^-$	- 1.60
$CaO + H_2O + 2e^- \rightarrow Ca + 2\ OH^-$	- 2.78

a) Early forms of metal-air cells used zinc as the anode.

i) Write a balanced net ionic chemical equation for the reaction that occurs in the cell as it operates. (6 pt)

ii) Using the data in the table above, calculate the cell potential for the zinc metal-air cell. (6 pt)

iii) The electrolyte paste contains OH^- ions. On the diagram of the cell above, draw an arrow to indicate the direction of OH^- ion migration through the electrolyte as the cell operates. (2 pt)

b) A fresh zinc-air cell is weighed on an analytical balance before being placed in a hearing aid for use. As the cell operates, does the mass of the cell increase, decrease, or remain the same? Justify your answer in terms of the net equation for the reaction. (6 pt)

c) If the metal-air cell is operating on top of a mountain where air pressure is lower, will the cell potential be higher, lower, or the same? Justify your answer based on the net ionic equation for the reaction and the information above. (6 pt)

(19) 8. The table below gives data for a reaction rate study of the following reaction;

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

Experiment #	$[H_2]$ (M)	$[Cl_2]$ (M)	Initial Rate of Disappearance of Cl_2 ($M\ s^{-1}$)
1	0.00100	0.00500	1.82×10^{-12}
2	0.00200	0.00500	3.64×10^{-12}
3	0.00400	0.00125	1.82×10^{-12}

(a) Determine the order of the reaction with respect to H_2 and justify your answer. (4 pts)

(b) Determine the order of the reaction with respect to Cl_2 and justify your answer. (4 pts)

(c) Write the overall rate law for the reaction. (5 pts)

(d) Determine the magnitude and the units for the rate constant. (6 pts)

9. The following data is for the decomposition of NOBr to Br_2 and NO at a particular temperature.

Time (seconds)	0	2.0	4.0	6	8	10
[NOBr] M	0.0100	0.0071	0.0055	0.0045	0.0038	0.0033

Describe a graphical method that could be used to determine the order of the reaction and the rate constant for the reaction.

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 **H** 1.008																	2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	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** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.0	89 **Ac** 227.0	104 (261)	105 (262)	106 (263)												

Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.2	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
Actinides	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.0	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Useful Information

$pH = -\log[H^+]$ $pOH = -\log[OH^-]$ $pH + pOH = 14$

$K_w = 1.0 \times 10^{-14}$

$E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$

$\Delta G^\circ = -nFE^\circ$ $F = 96{,}500 \frac{J}{mol\ volt} = 96{,}500 \frac{Coulombs}{mol\ e^-}$ $R = 8.314 \frac{J}{mol\ K}$

$\Delta G^\circ = -RT \ln K$ $\Delta G^\circ = -2.303RT \log K$

$E_{cell} = E^\circ - \frac{0.0287}{n} \ln Q$ $E_{cell} = E^\circ - \frac{0.0592}{n} \log Q$

Name	Formula	K_{a1}	K_{a2}	K_{a3}
Acetic	$HC_2H_3O_2$	1.8×10^{-5}		
Ascorbic	$HC_6H_7O_6$	8.0×10^{-3}		
Arsenic	H_3AsO_4	5.6×10^{-3}	1.0×10^{-7}	3.0×10^{-12}
Arsenous	H_3AsO_3	6.0×10^{-10}		
Benzoic	$HC_7H_5O_2$	6.5×10^{-5}		
Butyric acid	$HC_4H_7O_2$	1.5×10^{-5}		
Carbonic	H_2CO_3	4.3×10^{-7}	5.6×10^{-11}	
Cyanic	HCNO	3.5×10^{-4}		
Citric	$H_3C_6H_5O_7$	7.4×10^{-4}	1.7×10^{-5}	4.0×10^{-7}
Formic	$HCHO_2$	1.8×10^{-4}		
Hydroazoic	HN_3	1.9×10^{-5}		
Hydrocyanic	HCN	4.9×10^{-10}		
Hydrofluoric	HF	7.2×10^{-4}		
Hydrogen chromate ion	$HCrO_4^-$	3.0×10^{-7}		
Hydrogen peroxide	H_2O_2	2.4×10^{-12}		
Hydrogen selenate ion	$HSeO_4^-$	2.2×10^{-2}		
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}		
Hydrogen sulfide	H_2S	5.7×10^{-8}	1.3×10^{-13}	
Hypobromous	HBrO	2.0×10^{-9}		
Hypochlorous	HClO	3.0×10^{-8}		
Hypoiodus	HIO	2.0×10^{-11}		
Iodic	HIO_3	1.7×10^{-1}		
Lactic	$HC_3H_5O_3$	1.4×10^{-4}		
Malonic	$H_2C_3H_2O_4$	1.5×10^{-3}	2.0×10^{-6}	
Oxalic	$H_2C_2O_4$	5.9×10^{-2}	6.4×10^{-5}	
Nitrous	HNO_2	4.5×10^{-4}		
Phenol	HC_6H_5O	1.3×10^{-10}		
Phosphoric	H_3PO_4	7.5×10^{-3}	6.2×10^{-8}	4.2×10^{-13}
Paraperiodic	H_5IO_6	2.8×10^{-2}	5.3×10^{-9}	
Propionic	$HC_3H_5O_2$	1.3×10^{-5}		
Pyrophosphoric	H_4P_2O	3.0×10^{-2}	4.4×10^{-3}	
Selenous	H_2SeO_3	2.3×10^{-3}	5.3×10^{-9}	
Sulfuric	H_2SO_4	strong acid	1.2×10^{-2}	
Sulfurous	H_2SO_3	1.7×10^{-2}	6.4×10^{-8}	
Tartaric	$H_2C_4H_4O_6$	1.0×10^{-3}	4.6×10^{-5}	

E.2 DISSOCIATION CONSTANTS FOR BASES AT 25˚C

Name	Formula	K_b	Name	Formula	K_b
Ammonia	NH_3	1.8×10^{-5}	Hydroxylamine	$HONH_2$	1.1×10^{-8}
Aniline	$C_6H_5NH_2$	4.3×10^{-10}	Methylamine	CH_3NH_2	4.4×10^{-4}
Dimethylamine	$(CH_3)_2NH$	5.4×10^{-4}	Pyridine	C_5H_5N	1.7×10^{-9}
Ethylamine	$C_2H_5NH_2$	6.4×10^{-4}			
Hydrazine	H_2NNH_2	1.3×10^{-6}			

Solubility Table

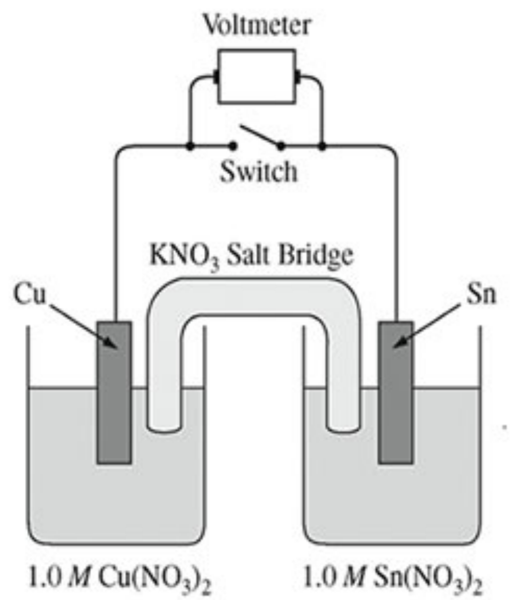
Ion	Solubility	Exceptions
NO_3^-	soluble	none
ClO_4^-	soluble	none
Cl^-	soluble	except Ag^+, Hg_2^{2+}, *Pb^{2+}
I^-	soluble	except Ag^+, Hg_2^{2+}, Pb^{2+}
SO_4^{2-}	soluble	except Ca^{2+}, Ba^{2+}, Sr^{2+}, Hg^{2+}, Pb^{2+}, Ag^+
CO_3^{2-}	insoluble	except Group IA and NH_4^+
PO_4^{3-}	insoluble	except Group IA and NH_4^+
^-OH	insoluble	except Group IA, *Ca^{2+}, Ba^{2+}, Sr^{2+}
S^{2-}	insoluble	except Group IA, IIA and NH_4^+
Na^+	soluble	none
NH_4^+	soluble	none
K^+	soluble	none

*slightly soluble

Standard Reduction Potentials at 25 ˚C

Reaction	E^o(V)
$F_2(g) + 2H^+ + 2e^- \rightarrow 2HF(aq)$	3.06
$F_2(g) + 2e^- \rightarrow 2F^-$	2.87
$O_3(g) + 2H^+ + 2e^- \rightarrow O_2(g) + H_2O(l)$	2.07
$S_2O_8{}^{2-} + 2e^- \rightarrow 2SO_4{}^{2-}$	2.00
$H_2O_2(aq) + 2H^+ + 2e^- \rightarrow 2H_2O(l)$	1.776
$HClO_2(aq) + 2H^+ + 2e^- \rightarrow HClO(aq) + H_2O(l)$	1.645
$2HClO(aq) + 2H^+ + 2e^- \rightarrow Cl_2(g) + 2H_2O(l)$	1.63
$MnO_4{}^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O(l)$	1.51
$Au^{3+} + 3e^- \rightarrow Au(s)$	1.498
$PbO_2(s) + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O(l)$	1.455
$Cl_2(g) + 2e^- \rightarrow 2Cl^-$	1.360
$Cr_2O_7{}^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O(l)$	1.33
$2HNO_2(aq) + 4H^+ + 4e^- \rightarrow N_2O(g) + 3H_2O(l)$	1.29
$MnO_2(s) + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O(l)$	1.23
$O_2(g) + 4H^+ + 4e^- \rightarrow 2H_2O(l)$	1.229
$ClO_3{}^- + 3H^+ + 2e^- \rightarrow HClO_2(aq) + H_2O(l)$	1.21
$Pt^{2+} + 2e^- \rightarrow Pt(s)$	~1.2
$2IO_3{}^- + 12H^+ + 10e^- \rightarrow I_2(s) + 6H_2O(l)$	1.195
$ClO_4{}^- + 2H^+ + 2e^- \rightarrow ClO_3{}^- + H_2O(l)$	1.19
$Br_2(aq) + 2e^- \rightarrow 2Br^-$	1.087
$Pd^{2+} + 2e^- \rightarrow Pd(s)$	0.987
$NO_3{}^- + 4H^+ + 3e^- \rightarrow NO(g) + 2H_2O(l)$	0.96
$2Hg^{2+} + 2e^- \rightarrow Hg_2{}^{2+}$	0.920
$Ag^+ + e^- \rightarrow Ag(s)$	0.799
$Hg^{2+} + 2e^- \rightarrow Hg(l)$	0.788
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.771
$O_2(g) + 2H^+ + 2e^- \rightarrow H_2O_2(aq)$	0.682
$MnO_4{}^- + e^- \rightarrow MnO_4{}^{2-}$	0.564
$I_2(s) + 2e^- \rightarrow 2I^-$	0.536
$H_2SO_3(aq) + 4H^+ + 4e^- \rightarrow S(s) + 3H_2O(l)$	0.450
$SO_4{}^{2-} + 8H^+ + 6e^- \rightarrow S(s) + 4H_2O(l)$	0.357
$Cu^{2+} + 2e^- \rightarrow Cu(s)$	0.337
$AgCl(s) + e^- \rightarrow Ag(s) + Cl^-$	0.222
$SO_4{}^{2-} + 4H^+ + 2e^- \rightarrow H_2SO_3(aq) + H_2O(l)$	0.172
$Cu^{2+} + e^- \rightarrow Cu^+$	0.153
$Sb_2O_3(s) + 6H^+ + 6e^- \rightarrow 2Sb(s) + 3H_2O(l)$	0.152
$Sn^{4+} + 2e^- \rightarrow Sn^{2+}$	0.15
$S(s) + 2H^+ + 2e^- \rightarrow H_2S(aq)$	0.142
$2H^+ + 2e^- \rightarrow H_2(g)$	0.000
$Pb^{2+} + 2e^- \rightarrow Pb(s)$	–0.126
$Sn^{2+} + 2e^- \rightarrow Sn(s)$	–0.140
$Ni^{2+} + 2e^- \rightarrow Ni(s)$	–0.250
$PbCl_2(s) + 2e^- \rightarrow Pb(s) + 2Cl^-$	–0.268
$PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4{}^{2-}$	–0.359
$Cd^{2+} + 2e^- \rightarrow Cd(s)$	–0.403
$Cr^{3+} + e^- \rightarrow Cr^{2+}$	–0.408
$Fe^{2+} + 2e^- \rightarrow Fe(s)$	–0.440
$Cr^{3+} + 3e^- \rightarrow Cr(s)$	–0.744
$Zn^{2+} + 2e^- \rightarrow Zn(s)$	–0.763
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-$	–0.828
$Mn^{2+} + 2e^- \rightarrow Mn(s)$	–1.185
$Al^{3+} + 3e^- \rightarrow Al(s)$	–1.662
$H_2(g) + 2e^- \rightarrow 2H^-$	–2.25
$Mg^{2+} + 2e^- \rightarrow Mg(s)$	–2.363
$Na^+ + e^- \rightarrow Na(s)$	–2.714
$Ca^{2+} + 2e^- \rightarrow Ca(s)$	–2.866
$Sr^{2+} + 2e^- \rightarrow Sr(s)$	–2.888
$Ba^{2+} + 2e^- \rightarrow Ba(s)$	–2.906
$K^+ + e^- \rightarrow K(s)$	–2.925
$Li^+ + e^- \rightarrow Li(s)$	–3.045

6. In the electrochemical cell below one half-cell has an electrode made of Sn metal immersed in 1.00 M $SnSO_4$. The other half-cell has an electrode made of Cu metal immersed in 1.00 M $Cu(NO_3)_2$. The salt-bridge connecting the half-cells contains a saturated solution of $NaNO_3$.



(a) Write the balanced net-ionic equation for the overall cell reaction. (3)

(b) Use the table of standard reduction potentials to determine the cell voltage, E□, for the cell. (4)

(c) Predict what would be observed in the copper/copper nitrate half-cell after the cell has operated for several hours. Explain the basis of your prediction. (4)

(d) Calculate ΔG° for the reaction in the electrochemical cell. (5)

(e) Calculate E_{cell} under the following conditions $[Sn^{2+}]$ = 0.0250 M and $[Cu^{2+}]$ = 0.750 M. Assume the temperature does not change during the reaction. (6)