

NAME: _____ Section: _____ Student Number: _____

Spring 2017

Chemistry 2000 Midterm #2A

____/ 50 marks

- INSTRUCTIONS:
- 1) Please read over the test carefully before beginning. You should have 5 pages of questions, a blank “overflow” page and two pages of data sheets with periodic table.
 - 2) If your work is not legible, it will be given a mark of zero.
 - 3) Marks will be deducted for incorrect information added to an otherwise correct answer.
 - 4) Marks will be deducted for improper use of significant figures and for missing or incorrect units.
 - 5) Show your work for all calculations. Numerical answers without supporting calculations will not be given full credit.
 - 6) You may use a calculator but only for the purposes of calculation. No text-capable calculators are allowed.
 - 7) You have 90 minutes to complete this test.
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Confidentiality Agreement:

I agree not to discuss (or in any other way divulge) the contents of this exam until after 8:00 pm Mountain Time on Thursday, March 23rd, 2017. I understand that breaking this agreement would constitute academic misconduct, a serious offense with serious consequences. The minimum punishment would be a mark of 0/50 on this exam and removal of the “overwrite midterm mark with final exam mark” option for my grade in this course; the maximum punishment would include expulsion from this university.

Signature: _____

Date: _____

Course: CHEM 2000 (General Chemistry II)

Semester: Spring 2017

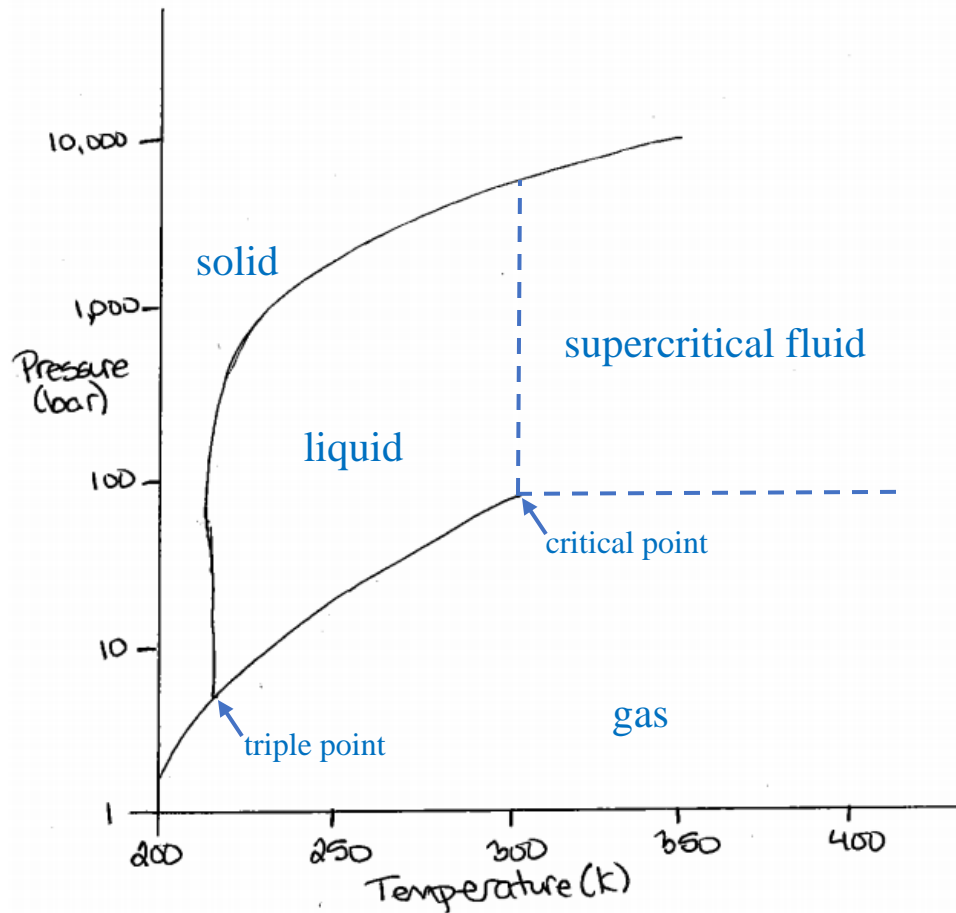
The University of Lethbridge

Question Breakdown

Q1	/ 5
Q2	/ 11
Q3	/ 9
Q4	/ 5
Q5	/ 8
Q6	/ 12

Total	/ 50
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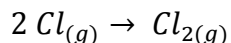
1. Consider the unlabeled phase diagram below. [5 marks]



- (a) On the diagram, label: [3 marks]
- the critical point
 - the triple point
 - regions corresponding to the four states of matter discussed in class
- (b) A sample of this substance is initially at 200 K and 10 bar. The temperature is raised to 300 K while the pressure is maintained at 10 bar. What phase change(s) will occur? [1 mark]
- solid → liquid → gas (solid melts to give liquid; liquid vaporizes to give gas)
- (c) A sample of this substance is initially at 200 K and 1 bar. The pressure is raised to 10 bar. What phase change(s) will occur? [1 mark]
- gas → solid (“deposition” or “desublimation”)

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2. Two chlorine atoms react to form a chlorine molecule under standard conditions: **[11 marks]**



(a) What information does the phrase “standard conditions” give you about the conditions under which this reaction is being studied? **[2 marks]**

temperature is 25 °C (298.15 K)

partial pressures of all gases are 1 bar

(b) Is $\Delta_r G^\circ$ positive, negative or zero for this reaction? Briefly, justify your answer. **[2 marks]**

$\Delta_r G^\circ$ must be negative

For a reaction to proceed in the forward direction, $\Delta_r G$ must be negative for those conditions. Since this reaction proceeds in the forward direction under standard conditions, $\Delta_r G^\circ$ must be negative.

(c) Is $\Delta_r S^\circ$ positive, negative or zero for this reaction? Briefly, justify your answer. **[2 marks]**

$\Delta_r S^\circ$ should be negative

Gases have larger entropy values than other states of matter. Since this reaction consumes two moles of gas but only generates one mole of gas, the entropy of the system is expected to decrease.

(d) Is $\Delta_r H^\circ$ positive, negative or zero for this reaction? Briefly, justify your answer. **[2 marks]**

$\Delta_r H^\circ$ should be negative

either: In this reaction, no bonds are broken while one bond is formed. Heat is released when bonds are formed. Therefore, this reaction is exothermic (negative $\Delta_r H$).

or: In order for a reaction to proceed, it must be favoured by enthalpy and/or entropy. This reaction proceeds but is not favoured by entropy. Therefore, it must be favoured by enthalpy (exothermic therefore negative $\Delta_r H$).

(e) Will there be any temperature at which this reaction is not favoured in the forward direction? If ‘yes’, will it be high or low temperatures (and why)? If ‘no’, why not? **[3 marks]**

This reaction will not be favoured at sufficiently high temperatures.

$$\Delta_r G = \Delta_r H - T\Delta_r S$$

$\Delta_r H$ and $T\Delta_r S$ are both negative.

At high temperatures, the $T\Delta_r S$ term will dominate: a larger negative number will be subtracted from a smaller negative number. This will give a positive number for $\Delta_r G$, and reactions with positive $\Delta_r G$ are not favoured in the forward direction.

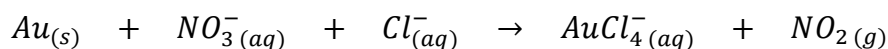
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3. Fill in each blank with the word or short phrase that best completes the sentence. [9 marks]

- (a) The term for “heat at constant pressure” is enthalpy.
- (b) The only time that $Q = K$ is when the system is at equilibrium.
- (c) If $Q > K$, we can expect that the reaction will proceed in the reverse direction.
- (d) The entropy of the universe increases in every thermodynamically allowed process.
- (e) The reduction half reaction occurs at the cathode of an electrochemical cell.
- (f) The activity of a pure solid is 1.
- (g) The activity of $Cl_{(aq)}^-$ in an ideal 0.1 M solution of $MgCl_{2(aq)}$ is $\frac{0.2 \frac{mol}{L}}{1 \frac{mol}{L}} = 0.2$.
- (h) Henry’s law states that the concentration of dissolved gas in a solution is directly proportional to partial pressure of the gas above the solution.
- (i) The third law of thermodynamics states that entropy of a perfect crystal at 0 K is 0.

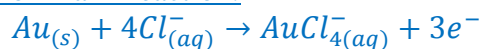
4. In the qualitative analysis lab, you used aqua regia, a mixture of concentrated $HNO_{3(aq)}$ and $HCl_{(aq)}$ to isolate for certain Group II/III cations. The use of aqua regia was originally developed by alchemists to “dissolve” gold but, in reality, this is just a redox reaction under acidic conditions.

The incomplete and unbalanced equation is shown below: [5 marks]

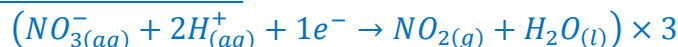


- (a) Balance the equation using either the half reaction method or the oxidation method. [3 marks]
Show your work.

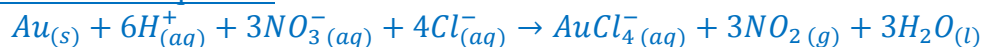
Oxidation Half-Reaction:



Reduction Half-Reaction:



Overall Balanced Equation:



- (b) Identify the oxidizing agent. [1 mark]

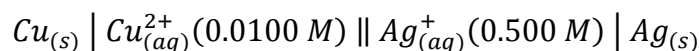
$NO_{3(aq)}^-$ is the oxidizing agent. It is reduced from +5 to +4.

- (c) Identify the reducing agent. [1 mark]

$Au_{(s)}$ is the reducing agent. It is oxidized from 0 to +3.

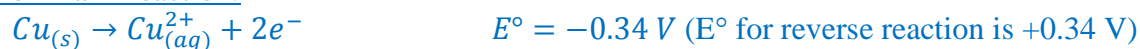
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5. Consider the following electrochemical cell, run at 25.00°C: [8 marks]

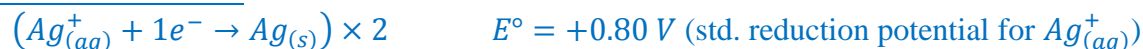


- (a) Write a balanced chemical equation for the reaction that proceeds in this electrochemical cell. [1 mark]

Oxidation Half-Reaction:



Reduction Half-Reaction:



Overall Balanced Equation:



- (b) Calculate the cell potential for this electrochemical cell. [7 marks]

Step 1: Calculate cell potential under standard conditions.

$$E^{\circ} = (+0.80 \text{ V}) + (-0.34 \text{ V}) = +0.46 \text{ V}$$

Step 2: Convert temperature into Kelvin.

$$T = 25.00 + 273.15 = 298.15 \text{ K}$$

Step 3: Find ν_e .

2 electrons were cancelled when the half-reactions were added, so $\nu_e = 2$.

Step 4: Find activities and calculate the reaction quotient (Q).

Activities of both solids are 1. Activities of both cations are $\frac{\text{concentration}}{1 \text{ M}}$.

$$Q = \frac{(a_{\text{Cu}_{(aq)}^{2+}})(a_{\text{Ag}_{(s)}})^2}{(a_{\text{Cu}_{(s)}})(a_{\text{Ag}_{(aq)}^{+}})^2} = \frac{\left(\frac{0.0100 \text{ M}}{1 \text{ M}}\right)(1)^2}{(1)\left(\frac{0.500 \text{ M}}{1 \text{ M}}\right)^2} = \frac{(0.0100)(1)^2}{(1)(0.500)^2} = 0.0400$$

3 sig. fig.

Step 5: Use Nernst equation to calculate cell potential under actual conditions.

$$E = E^{\circ} - \frac{RT}{\nu_e F} \ln Q$$

$$E = (+0.46 \text{ V}) - \left[\frac{\left(8.314462 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(298.15 \text{ K})}{(2)\left(96485 \frac{\text{C}}{\text{mol}}\right)} \ln(0.0400) \right] \times \frac{1 \text{ V}}{1 \text{ C}}$$

$$E = (+0.46 \text{ V}) - (-0.04135 \text{ V})$$

$$E = +0.50 \text{ V}$$

2 decimal places therefore 2 sig. fig.

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6. The K_a value for $HF_{(aq)}$ at $25.00\text{ }^\circ\text{C}$ is 6.8×10^{-4} . [12 marks]



- (a) Calculate $\Delta_r G^\circ$ for the reaction above. [2 marks]

$$\Delta_r G^\circ = -RT \ln K = -\left(8.314462 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right) (298.15 \text{ K}) \ln(6.8 \times 10^{-4}) = +18080 \frac{\text{J}}{\text{mol}}$$

$$\Delta_r G^\circ = +18080 \frac{\text{J}}{\text{mol}} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = +18.1 \frac{\text{kJ}}{\text{mol}}$$

$\ln(6.8 \times 10^{-4}) = -7.29$ therefore the answer has 3 sig. fig.

(2 sig. fig. in 6.8×10^{-4} therefore 2 decimal places in -7.29)

- (b) Calculate $\Delta_f G^\circ$ for $HF_{(aq)}$. [3 marks]

$$\Delta_r G^\circ = \sum \Delta_f G^\circ(\text{products}) - \sum \Delta_f G^\circ(\text{reactants})$$

$$\Delta_r G^\circ = \Delta_f G^\circ(H_{(aq)}^+) + \Delta_f G^\circ(F_{(aq)}^-) - \Delta_f G^\circ(HF_{(aq)})$$

$$\Delta_f G^\circ(HF_{(aq)}) = \Delta_f G^\circ(H_{(aq)}^+) + \Delta_f G^\circ(F_{(aq)}^-) - \Delta_r G^\circ$$

$$\Delta_f G^\circ(HF_{(aq)}) = \left(0 \frac{\text{kJ}}{\text{mol}}\right) + \left(-278.79 \frac{\text{kJ}}{\text{mol}}\right) - \left(+18.1 \frac{\text{kJ}}{\text{mol}}\right)$$

$$\Delta_f G^\circ(HF_{(aq)}) = -296.9 \frac{\text{kJ}}{\text{mol}}$$

1 decimal place therefore 4 sig. fig.

- (c) Calculate the K_a value for $HF_{(aq)}$ at $50.00\text{ }^\circ\text{C}$. [6 marks]

Step 1: Get organized

This question compares K values at different temperatures, so it must involve:

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta_r H^\circ}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad \text{“integrated van’t Hoff equation”}$$

Assign one temperature to each number: $K_1 = 6.8 \times 10^{-4}$ and $T_1 = 298.15 \text{ K}$.

$K_2 = ???$ and $T_2 = 50.00 + 273.15 = 323.15 \text{ K}$

Then you just need $\Delta_r H^\circ$ and you can use the integrated van’t Hoff equation to solve for K_2 .

Step 2: Solve for Standard Enthalpy Change for the Reaction

$$\Delta_r H^\circ = \sum \Delta_f H^\circ(\text{products}) - \sum \Delta_f H^\circ(\text{reactants})$$

$$\Delta_r H^\circ = \Delta_f H^\circ(H_{(aq)}^+) + \Delta_f H^\circ(F_{(aq)}^-) - \Delta_f H^\circ(HF_{(aq)})$$

$$\Delta_r H^\circ = \left(0 \frac{\text{kJ}}{\text{mol}}\right) + \left(-332.63 \frac{\text{kJ}}{\text{mol}}\right) - \left(-320.08 \frac{\text{kJ}}{\text{mol}}\right) = -12.55 \frac{\text{kJ}}{\text{mol}} = -1.255 \times 10^4 \frac{\text{J}}{\text{mol}}$$

Step 3: Solve for K_2

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{(-1.255 \times 10^4 \frac{\text{J}}{\text{mol}})}{\left(8.314462 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)} \left(\frac{1}{298.15 \text{ K}} - \frac{1}{323.15 \text{ K}}\right)$$

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{(-1.255 \times 10^4 \frac{\text{J}}{\text{mol}})}{\left(8.314462 \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)} (2.5948 \times 10^{-4})$$

$$\ln\left(\frac{K_2}{K_1}\right) = -0.3917$$

$$\frac{K_2}{K_1} = e^{-0.3917} = 0.6759$$

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$$K_2 = 0.6759 \cdot K_1$$

$$K_2 = (0.6759)(6.8 \times 10^{-4}) = 4.6 \times 10^{-4}$$

2 sig. fig. (because K_1 had 2 sig. fig.)

- (d) Is $\text{HF}_{(aq)}$ a stronger acid at 50.00 °C or at 25.00 °C? How do you know? *[1 mark]*
In other words, at which temperature is the reaction more product-favoured?

$K_1 > K_2$ therefore the reaction is more product-favoured at 25.00 °C.

Therefore, HF is a stronger acid at 25.00 °C.

Some Useful Constants and Formulae

Fundamental Constants and Conversion Factors

Atomic mass unit (u)	$1.660\,539 \times 10^{-27} \text{ kg}$	Kelvin temperature scale	$0 \text{ K} = -273.15 \text{ }^\circ\text{C}$
Avogadro's number (N_A)	$6.022\,141 \times 10^{23} \text{ mol}^{-1}$	K_w (at $25 \text{ }^\circ\text{C}$)	10^{-14}
Boltzmann constant (k_B)	$1.380\,649 \times 10^{-23} \text{ J}\cdot\text{K}^{-1}$	Planck's constant (h)	$6.626\,070 \times 10^{-34} \text{ J}\cdot\text{Hz}^{-1}$
Charge of electron	$-1.602\,176 \times 10^{-19} \text{ C}$	Speed of light in vacuum (c)	$2.997\,925 \times 10^8 \text{ m}\cdot\text{s}^{-1}$
Faraday's constant (F)	$96\,485 \text{ C}\cdot\text{mol}^{-1}$	Volume conversion	$1000 \text{ L} = 1 \text{ m}^3$
Ideal gas constant (R)	$8.314\,462 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$	Pressure conversions	$1 \text{ bar} = 100 \text{ kPa}$
	$8.314\,462 \text{ m}^3\cdot\text{Pa}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$		$1 \text{ atm} = 1.01325 \text{ bar}$

Formulae

$$\bar{K} = \frac{1}{2} m \overline{v^2} = \frac{3}{2} RT \quad v_{rms} = \sqrt{\overline{v^2}} = \sqrt{\frac{3RT}{M}} \quad PV = nRT$$

$$S = k_B \ln \Omega \quad \Delta S = \frac{q_{rev}}{T} \quad \Delta_r G = \Delta_r H - T \Delta_r S \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\Delta_r G = \Delta_r G^\circ + RT \ln Q \quad \Delta_r G^\circ = -RT \ln K \quad \ln \left(\frac{K_2}{K_1} \right) = \frac{\Delta_r H^\circ}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right)$$

$$P_A = X_A P_A^* \quad [A] = k_H P_A \quad X = \frac{n}{\sum n} \quad \Delta_r G = -\nu_e F E \quad E = E^\circ - \frac{RT}{\nu_e F} \ln Q$$

$$pH = -\log a_{H^+} \quad pK_a = -\log K_a \quad pK_b = -\log K_b \quad K_w = K_a \cdot K_b \quad pH = pK_a + \log \left(\frac{a_{A^-}}{a_{HA}} \right)$$

$$\Delta H_{rxn}^0 = \sum (\Delta H_f^0(\text{products})) - \sum (\Delta H_f^0(\text{reactants}))$$

$$\Delta S_{rxn}^0 = \sum (S^0(\text{products})) - \sum (S^0(\text{reactants}))$$

$$\Delta G_{rxn}^0 = \sum (\Delta G_f^0(\text{products})) - \sum (\Delta G_f^0(\text{reactants}))$$

Activities

Solid	$a = 1$
Pure liquid	$a = 1$
Ideal Solvent	$a = X$
Ideal Solute	$a = \frac{c}{c^\circ}$
Ideal Gas	$a = \frac{P}{P^\circ}$

CHEM 2000 Standard Periodic Table

1																	18	
1.0079 H 1												13	14	15	16	17	4.0026 He 2	
6.941 Li 3	9.0122 Be 4												10.811 B 5	12.011 C 6	14.0067 N 7	15.9994 O 8	18.9984 F 9	20.1797 Ne 10
22.9898 Na 11	24.3050 Mg 12	3	4	5	6	7	8	9	10	11	12	26.9815 Al 13	28.0855 Si 14	30.9738 P 15	32.066 S 16	35.4527 Cl 17	39.948 Ar 18	
39.0983 K 19	40.078 Ca 20	44.9559 Sc 21	47.88 Ti 22	50.9415 V 23	51.9961 Cr 24	54.9380 Mn 25	55.847 Fe 26	58.9332 Co 27	58.693 Ni 28	63.546 Cu 29	65.39 Zn 30	69.723 Ga 31	72.61 Ge 32	74.9216 As 33	78.96 Se 34	79.904 Br 35	83.80 Kr 36	
85.4678 Rb 37	87.62 Sr 38	88.9059 Y 39	91.224 Zr 40	92.9064 Nb 41	95.94 Mo 42	(98) Tc 43	101.07 Ru 44	102.906 Rh 45	106.42 Pd 46	107.868 Ag 47	112.411 Cd 48	114.82 In 49	118.710 Sn 50	121.757 Sb 51	127.60 Te 52	126.905 I 53	131.29 Xe 54	
132.905 Cs 55	137.327 Ba 56	La-Lu	178.49 Hf 72	180.948 Ta 73	183.85 W 74	186.207 Re 75	190.2 Os 76	192.22 Ir 77	195.08 Pt 78	196.967 Au 79	200.59 Hg 80	204.383 Tl 81	207.19 Pb 82	208.980 Bi 83	(210) Po 84	(210) At 85	(222) Rn 86	
(223) Fr 87	226.025 Ra 88	Ac-Lr	(265) Rf 104	(268) Db 105	(271) Sg 106	(270) Bh 107	(277) Hs 108	(276) Mt 109	(281) Ds 110	(280) Rg 111	(285) Cn 112	(284) Nh 113	(289) Fl 114	(288) Mc 115	(293) Lv 116	(294) Ts 117	(294) Og 118	

138.906 La 57	140.115 Ce 58	140.908 Pr 59	144.24 Nd 60	(145) Pm 61	150.36 Sm 62	151.965 Eu 63	157.25 Gd 64	158.925 Tb 65	162.50 Dy 66	164.930 Ho 67	167.26 Er 68	168.934 Tm 69	173.04 Yb 70	174.967 Lu 71
227.028 Ac 89	232.038 Th 90	231.036 Pa 91	238.029 U 92	237.048 Np 93	(240) Pu 94	(243) Am 95	(247) Cm 96	(247) Bk 97	(251) Cf 98	(252) Es 99	(257) Fm 100	(258) Md 101	(259) No 102	(262) Lr 103

Developed by Prof. R. T. Boéré (updated 2016)

Some Useful Thermodynamic Properties

Substance	$\Delta_f H^\circ \left(\frac{kJ}{mol} \right)$	$\Delta_f G^\circ \left(\frac{kJ}{mol} \right)$	$S^\circ \left(\frac{J}{mol \cdot K} \right)$
$F_{(aq)}^-$	-332.63	-278.79	-13.8
$HF_{(aq)}$	-320.08	<i>see question 6</i>	88.7

Half Reaction	$E^\circ(V)$
$Ag_{(aq)}^+ + e^- \rightarrow Ag_{(s)}$	+0.80
$Cu_{(aq)}^{2+} + 2 e^- \rightarrow Cu_{(s)}$	+0.34
$Cu_{(aq)}^{2+} + e^- \rightarrow Cu_{(aq)}^+$	+0.15
$2 H_{(aq)}^+ + 2 e^- \rightarrow H_{2(g)}$	0