SCHOOL NAME: ______________KEY______________ TEAM NUMBER: ________

Technical Problem Solving

2014 Eastern Long Island
Regional Examination

Instructions

Place the answers to each question in the space provided. With any calculations, **all work** must be shown. This includes substitution of values into the appropriate equations or dimensional analyses **with units**. Failure to include the correct units with the proper work and/or the final answer will result in point deduction from each question. Points will also be deducted for failing to report the collected data to the greatest degree of precision. Points will also be deducted for failing to report both the magnitude and algebraic sign of the calculated result, when appropriate.

In the event of a tie, tiebreaker questions have been designated with an asterisk (*).

SCORING GUIDELINES

PART I = 100 POINTS
PART II = 100 POINTS

TIEBREAKER #1 = TOTAL NUMBER OF TIEBREAKER POINTS
TIEBREAKER #2 = TOTAL POINTS ON SECTION I QUESTION 10
TIEBREAKER #3 = TOTAL POINTS ON SECTION I QUESTION 7
TIEBREAKER #4 = TOTAL POINTS ON SECTION II QUESTION 8
TIEBREAKER #5 = TOTAL POINTS FROM SECTION I

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Standard Reduction Potentials in Aqueous Solution at 25⁰C

Reduction Half-Reaction		$E°$ (V)
$F_2(g) + 2\ e^-$	$\rightarrow 2\ F^-(aq)$	+2.87
$H_2O_2(aq) + 2\ H_3O^+(aq) + 2\ e^-$	$\rightarrow 4\ H_2O(\ell)$	+1.77
$PbO_2(s) + SO_4^{2-}(aq) + 4\ H_3O^+(aq) + 2\ e^-$	$\rightarrow PbSO_4(s) + 6\ H_2O(\ell)$	+1.685
$MnO_4^-(aq) + 8\ H_3O^+(aq) + 5\ e^-$	$\rightarrow Mn^{2+}(aq) + 12\ H_2O(\ell)$	+1.52
$Au^{3+}(aq) + 3\ e^-$	$\rightarrow Au(s)$	+1.50
$Cl_2(g) + 2\ e^-$	$\rightarrow 2\ Cl^-(aq)$	+1.360
$Cr_2O_7^{2-}(aq) + 14\ H_3O^+(aq) + 6\ e^-$	$\rightarrow 2\ Cr^{3+}(aq) + 21\ H_2O(\ell)$	+1.33
$O_2(g) + 4\ H_3O^+(aq) + 4\ e^-$	$\rightarrow 6\ H_2O(\ell)$	+1.229
$Br_2(\ell) + 2\ e^-$	$\rightarrow 2\ Br^-(aq)$	+1.08
$NO_3^-(aq) + 4\ H_3O^+(aq) + 3\ e^-$	$\rightarrow NO(g) + 6\ H_2O(\ell)$	+0.96
$OCl^-(aq) + H_2O(\ell) + 2\ e^-$	$\rightarrow Cl^-(aq) + 2\ OH^-(aq)$	+0.89
$Hg^{2+}(aq) + 2\ e^-$	$\rightarrow Hg(\ell)$	+0.855
$Ag^+(aq) + e^-$	$\rightarrow Ag(s)$	+0.80
$Hg_2^{2+}(aq) + 2\ e^-$	$\rightarrow 2\ Hg(\ell)$	+0.789
$Fe^{3+}(aq) + e^-$	$\rightarrow Fe^{2+}(aq)$	+0.771
$I_2(s) + 2\ e^-$	$\rightarrow 2\ I^-(aq)$	+0.535
$O_2(g) + 2\ H_2O(\ell) + 4\ e^-$	$\rightarrow 4\ OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2\ e^-$	$\rightarrow Cu(s)$	+0.337
$Sn^{4+}(aq) + 2\ e^-$	$\rightarrow Sn^{2+}(aq)$	+0.15
$2\ H_3O^+(aq) + 2\ e^-$	$\rightarrow H_2(g) + 2\ H_2O(\ell)$	0.00
$Sn^{2+}(aq) + 2\ e^-$	$\rightarrow Sn(s)$	−0.14
$Ni^{2+}(aq) + 2\ e^-$	$\rightarrow Ni(s)$	−0.25
$V^{3+}(aq) + e^-$	$\rightarrow V^{2+}(aq)$	−0.255
$PbSO_4(s) + 2\ e^-$	$\rightarrow Pb(s) + SO_4^{2-}(aq)$	−0.356
$Cd^{2+}(aq) + 2\ e^-$	$\rightarrow Cd(s)$	−0.40
$Fe^{2+}(aq) + 2\ e^-$	$\rightarrow Fe(s)$	−0.44
$Zn^{2+}(aq) + 2\ e^-$	$\rightarrow Zn(s)$	−0.763
$2\ H_2O(\ell) + 2\ e^-$	$\rightarrow H_2(g) + 2\ OH^-(aq)$	−0.8277
$Al^{3+}(aq) + 3\ e^-$	$\rightarrow Al(s)$	−1.66
$Mg^{2+}(aq) + 2\ e^-$	$\rightarrow Mg(s)$	−2.37
$Na^+(aq) + e^-$	$\rightarrow Na(s)$	−2.714
$K^+(aq) + e^-$	$\rightarrow K(s)$	−2.925
$Li^+(aq) + e^-$	$\rightarrow Li(s)$	−3.045

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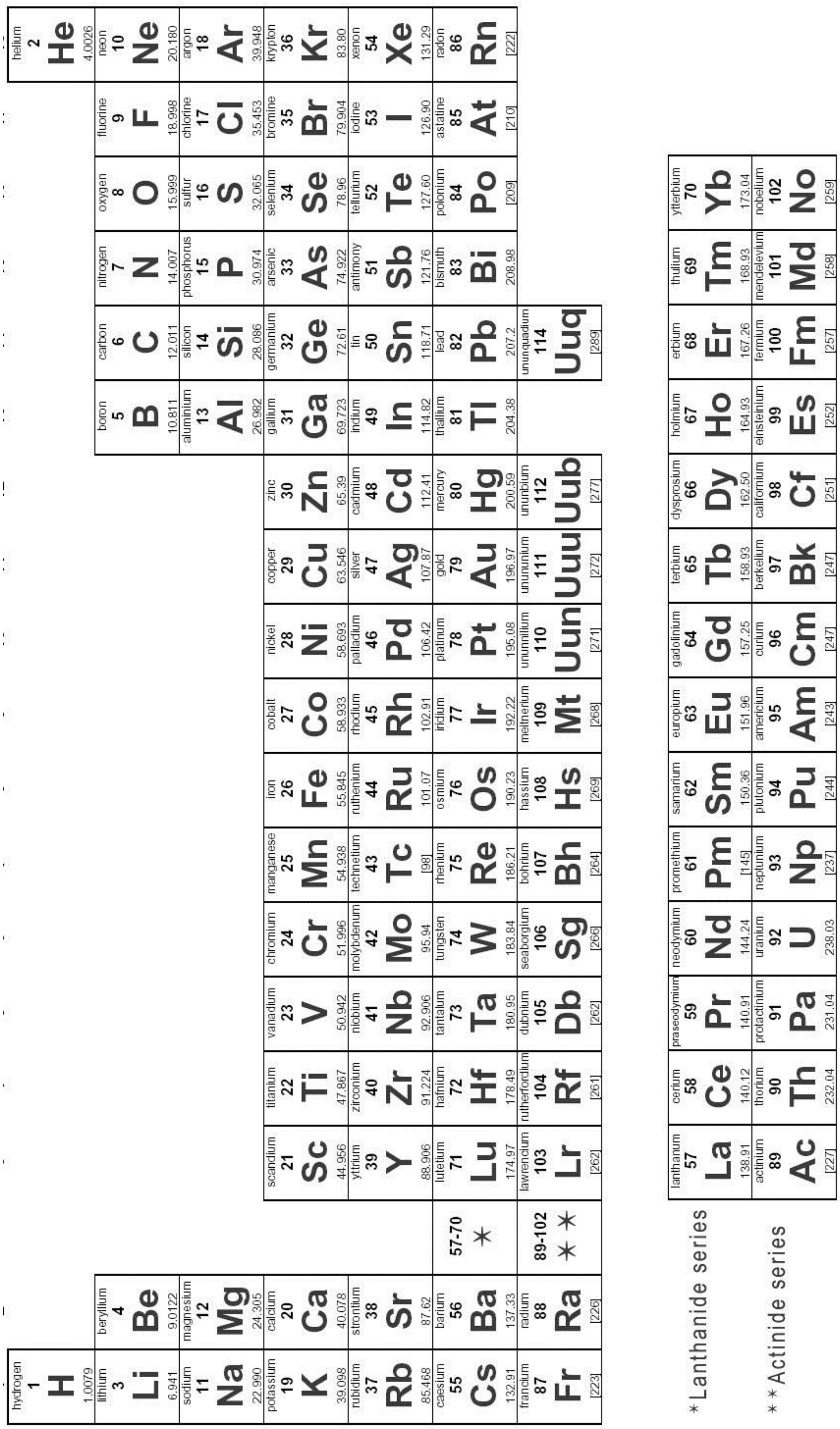

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Metal	Specific Heat Capacity(J/g·K)
Aluminum	0.91
Cast Iron	0.46
Copper	0.39
Gold	0.13
Iron	0.45
Lead	0.13
Magnesium	1.05
Manganese	0.48
Molybdenum	0.25
Nickel	0.44
Silicon	0.71
Silver	0.23
Sodium	1.21
Strontium	0.30
Tin	0.21
Titanium	0.54
Water	4.18
Zinc	0.39
Zirconium	0.27
Wrought Iron	0.50

Mass of an electron: 9.11×10^{-31} kilograms
Charge of an electron: 1.60×10^{-19} coulombs
Ideal Gas Constant: 8.314 J/K·mol

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Section I – Electrochemistry

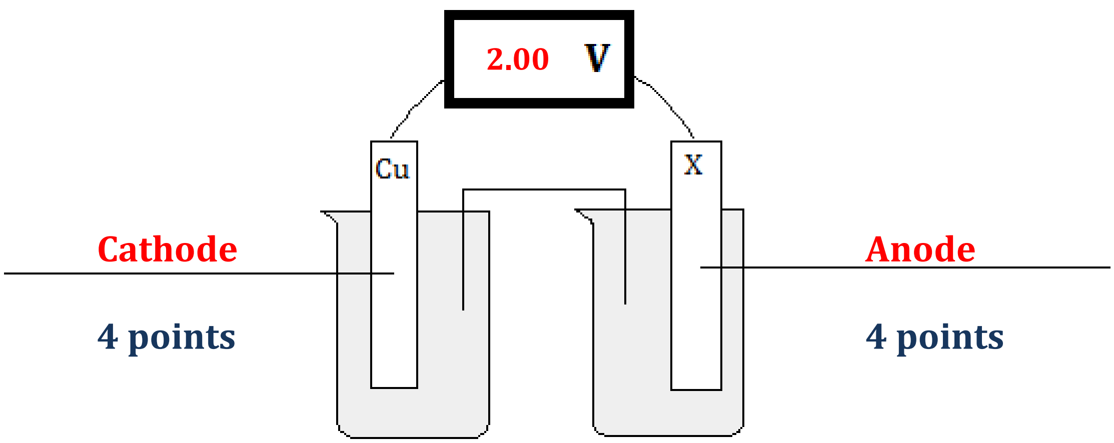
Copper(II) sulfate, when placed in distilled water, is a characteristic blue color. A student prepares a 1.00-M solution of $CuSO_4$ and then separates the solution into four separate beakers. one of the 1.00-M $CuSO_4$ solutions in Part A of this section is used to determine the identity of three unknowns. The other three beakers containing $CuSO_4$ are used for two other experiments: the determination of the value of Faraday's Constant in Part C and the determination of the value of Avogadro's Number in Part D. The identity of an unknown solution will be determined through its reactivity with copper wire in Part B.

Part A: Identification of Unknown Metals

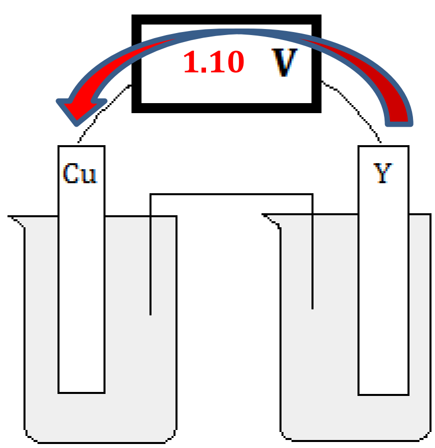
You need to identify two unknown metal electrodes and an unknown solution through the construction of a galvanic cell, as shown in the three diagrams below. 1.00M solutions of both $CuSO_4$ and the unknown metal ion solutions have been provided, in addition to a copper electrode, the unknown metal electrodes, a salt bridge, and a voltmeter. The resulting cell potentials have been provided of these three experimental setups.

Part A Data (17 points total)

Copper + Metal X: Label the electrodes as either the anode or cathode. (8 points)



Copper + Metal Y: Indicate the direction of electron flow in the diagram below. (4 points)



4 points awarded for showing e- moving from zinc to copper through the wire in the diagram. No points will be awarded otherwise.

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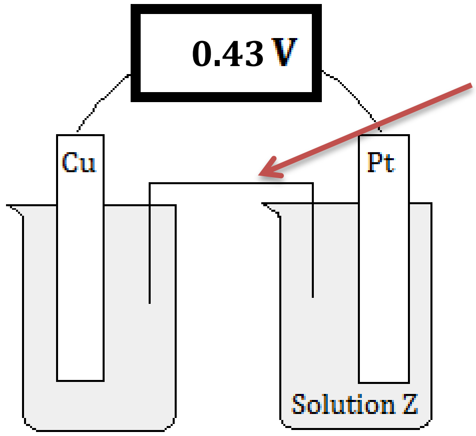
Copper + Solution Z: Clearly label the salt bridge in the diagram below. (4 points)



4 points awarded for showing the correction identification of the salt bridge.

Part A Questions (21 points total)

1. Identify the three unknowns. Support your answers with a calculation. (6 points)

Metal X	**Metal Y**	**Solution Z**
Metal X is aluminum (Al).	**Metal Y is zinc (Zn).**	**Solution Z is Fe^{2+}.**
$E^0_{cell} = E^0_{cath} - E^0_{anode}$	$E^0_{cell} = E^0_{cath} - E^0_{anode}$	$E^0_{cell} = E^0_{cath} - E^0_{anode}$
2.00 V = 0.337 V – x	1.10 V = 0.337 V – x	0.43 V = x – 0.337 V
x = -1.66 V	**x = -0.76 V**	**x = +0.77 V**
1 point ID	**1 point ID**	**1 point ID**
1 point for work	**1 point for work**	**1 point for work**

2. Calculate the expected cell potential of a galvanic cell containing the unknown metal X, metal X ion solution, a silver electrode, and a silver ion solution. (4 points)

$E^0_{cell} = E^0_{cath} - E^0_{anode}$

x = 0.80V – (-1.66 V)

x = 2.46 V

1 point is awarded for showing "V" as unit <u>throughout</u> calculation.
1 point for showing substitution of known quantities.
2 point for showing correct result for the E^0_{cell} (no deduction for sig figs)
Hess's Law can be used in lieu of cell potential equation shown above for 4 points.

3. Calculate the expected cell potential of a battery containing six identical galvanic cells from question 2, constructed in series. (5 points)

$E^0_{battery} = 6 \times E^0_{cell}$

$E^0_{battery} = 6 \times 2.46\ V = 14.76\ V$

2 points are awarded for understanding that 6x voltage will be obtained.
1 point for propagation of units.
2 points for correct numerical answer.

4. Potassium permanganate, a strong oxidizing agent, is used in many redox titrations. However, in order to obtain an accurate concentration of the potassium permanganate solution, standardization against a known solution containing a reducing agent, such as potassium oxalate, needs to be performed. Write the balanced redox reaction which occurs between the $KMnO_4$ and $K_2C_2O_4$ solutions used in the aforementioned standardization process. (6 points*)

$8H^+ + 5e^- + MnO_4^- \rightarrow Mn^{2+} + 4H_2O$ (OR $8H_3O^+ + 5e^- + MnO_4^- \rightarrow Mn^{2+} + 12H_2O$)
$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$
Balanced Reaction: $16H^+ + 2MnO_4^- + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$
(OR $16H_3O^+$ $2MnO_4^- + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 24H_2O + 10CO_2$)

2 points for correctly writing reactants
2 points for correctly writing products
2 points for correctly balancing equation

Part B: Unmarked Solution

You have found an empty beaker in the classroom and your teacher suspects that the solution is silver nitrate. As a test, place a piece of copper wire into the unknown solution A.

Part B Data (4 points)
Record your observations in the space below. Be specific.

If silver nitrate: solution turns slightly blue (2 points) and a silvery metal deposits on the surface of the metal (2 points).

If sodium chloride: solution (2 points) and copper wire (2 points) retain original appearance

Part B Question (5 points)

5. Provide a rationale as to whether unknown solution A is indeed silver nitrate. Be specific.

If silver nitrate: The solution could be silver nitrate. (1 point for identification)
The metal ions in solution were spontaneously replaced by the copper metal atoms; therefore, the copper metal must be more reactive (have a smaller standard reduction potential) than the metal ion in solution. (4 points for explanation)

If sodium chloride: The solution cannot be silver nitrate. (1 point for identification)
No visible signs of a replacement reaction indicate that the copper metal must be less reactive (have a larger reduction potential) than the metal ion in solution, so no spontaneous reaction will occur under these conditions. (4 points for explanation)

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Part C: More Electrochemical Cells

In the third portion of the lab, a student collected the following data based on a galvanic cell comprised of two copper half-cells at 25^{0}C. In half-cell A, a 1.00-M $CuSO_4$ solution is used with a polished copper electrode. In half-cell B, a smaller concentration of $CuSO_4$ solution is used with a different copper electrode. Four different known concentrations were tested against the 1.00-M $CuSO_4$ half-cell and the cell potentials of these trails are shown below. An unknown solution was also examined.

Part C Data (10 points total)
Calculate the natural logarithm of the ratio of the concentrations of copper(II) ions in half-cell B to half-cell A. (4 points) **1 point awarded for each ln calculation.**

Half-Cell A	**Half-Cell B**	**Cell Potential (V)**	$\ln\left(\frac{[\text{Half-Cell B}]}{[\text{Half-Cell A}]}\right)$
1.00 M $CuSO_4$	0.050 M $CuSO_4$	0.037	**-3.00**
1.00 M $CuSO_4$	0.025 M $CuSO_4$	0.045	**-3.69**
1.00 M $CuSO_4$	0.010 M $CuSO_4$	0.061	**-4.61**
1.00 M $CuSO_4$	0.0050 M $CuSO_4$	0.069	**-5.30**
1.00 M $CuSO_4$	Unknown	0.021	

On the graph below, clearly plot how the natural log of the ratio of concentrations affects cell potential. Be sure to include the zero points on both axes. (6 points)

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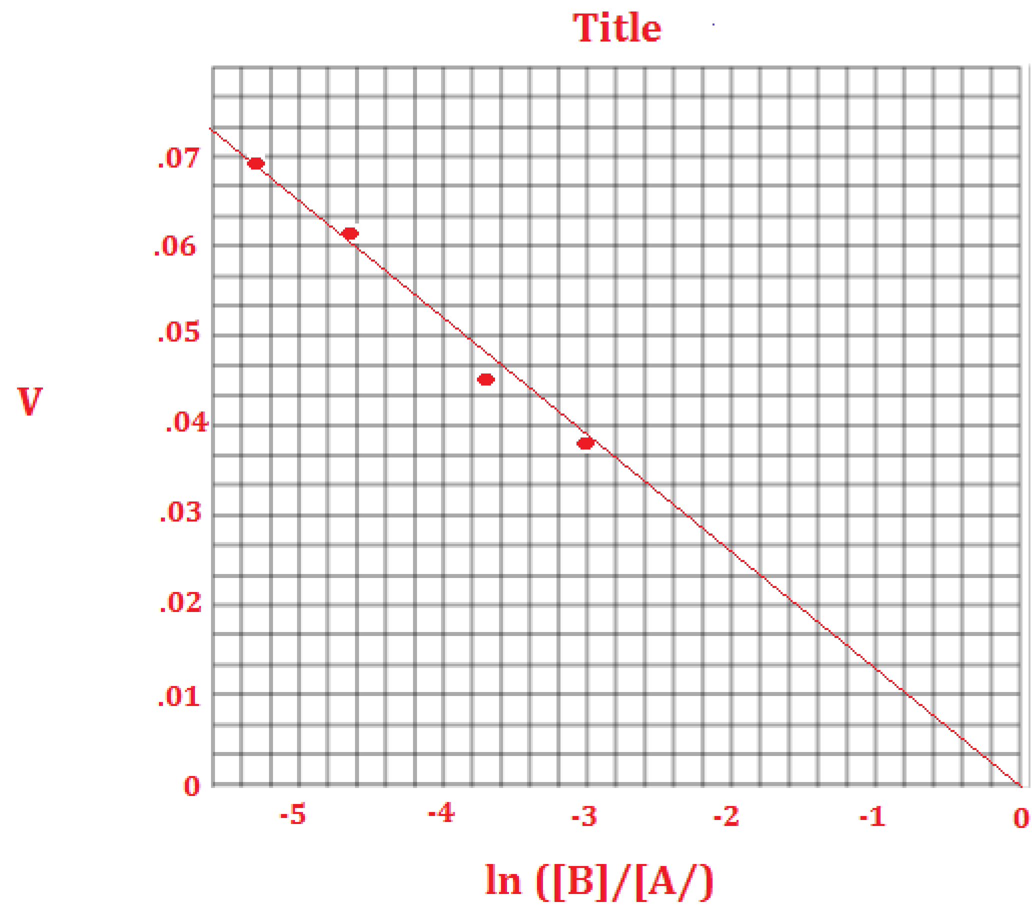

1 point axes label
1 point x-axis scale
1 point y-axis scale
1 point for data plotted
1 point for best-fit line
1 point for title

Both x- and y-axis scales must cover the maximum amount of the graphing space as possible. The line does not need to be connected to the zero point on the x-axis for the 1 point for line of best fit. X-scale must ascend to zero as final righthand point.

Part C Questions

6. Using the graph from the previous page, determine the concentration of the unknown $CuSO_4$ solution. (6 points)

At 0.021 V, the natural logarithm of the ratio is equal to -1.60.

$$\ln\left(\frac{[\text{Half}-\text{Cell B}]}{[\text{Half}-\text{Cell A}]}\right) = -1.60 = \ln\left(\frac{[x]}{[1.00\text{ M}]}\right)$$

$$[x] = e^{-1.60} = 0.202\text{ M } (\pm 0.020\text{ M})$$

1 point for correctly assigning ln related to provided cell potential.
1 point for substitution of -1.60 and 1.00 M into the equation above.
1 point for M units in answer
3 points for correct answer

7. Using the graph from the previous page, determine an experimental value of Faraday's constant. (8 points*)

Slope of the line is equal to –RT/nF.

Slope needs to be determined to be 0.013 V (±0.001).

$$0.013\ V = \frac{-(8.314\ J/K\cdot mol)(298K)}{2\ mol\ (x)}$$

x = 95300 J/V (95300 C)

(Range of values from 88400 C to 103400 C will be accepted)

2 points for calculating slope within range.
2 points for substitution for known variables.
2 points for propagation of units throughout calculation.
2 points for value of constant in acceptable range (with calculations, no points awarded for simply writing down the known quantity or a number without work)

8. The unknown $CuSO_4$ solution was prepared using the 1.00-M $CuSO_4$ solution. In order to prepare enough of the unknown solution for each team, the event supervisor added distilled water to a sample of the 1.00-M $CuSO_4$ until the final volume of the resulting solution was 2.50-L. Determine the volume of the distilled water added to the original solution of $CuSO_4$. (10 points*)

$M_cV_c = M_dV_d$

(1.00M)(x) = (0.202M)(2.5L)

x = 0.505 L of original solution used

Therefore, 2.5 L – 0.505 L = 2.0 L of distilled water added

3 points for calculating volume of original solution.
2 points for substitution for known variables.
2 points for propagation of units throughout calculation.
3 points for calculating volume of distilled water.

Note: If the students obtained the wrong answer on question 7, please award points according to the calculations shown above with incorrect molarity.

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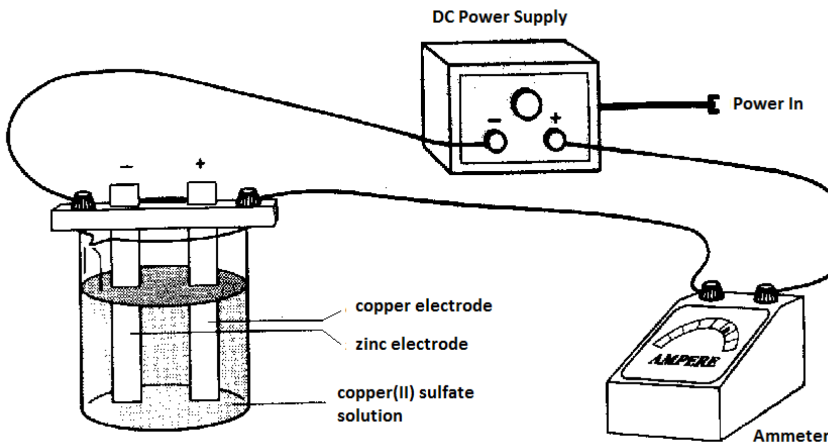
Part D : Avogadro's Number

The principals of electrochemistry can be used to obtain the value of Avogadro's Number. The following experimental procedure was followed to obtain the data shown in the table below.

1. Steel wool was used to clean a strip of copper and a strip of zinc.
2. The initial masses of the two electrodes were recorded.
3. A 250-mL beaker was filled about ¾ full with acidified 1.00-M $CuSO_4$ solution.
4. The following equipment was assembled using the metal electrodes and the 1.00-M $CuSO_4$ solution.



5. The DC power supply was turned on. The initial current was recorded as 0.59 amps.
6. The DC power supply was left to run for 9 minutes.
7. The electrodes were carefully removed from the $CuSO_4$ solution and rinsed with distilled water. Both were carefully dried by gently patting each electrode.
8. The final masses of the two electrodes were recorded.

	Zn electrode	Cu electrode
Initial Mass	10.087 g	9.802 g
Final Mass	10.179 g	9.704 g

Part C Questions (20 points total)

9. The copper electrode served as the anode in this electrochemical cell. Provide the half-reaction for this process and provide evidence from the experiment to support that the copper is indeed the anode. (5 points)

$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ (2 points, phases not needed)
The mass of the copper electrode decreased (1 point), indicating that some of the atoms present on the solid electrode were oxidized to form copper(II) ions in solution. The copper(II) ions now in the solution contain the mass lost from the copper electrode. (2 points)

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10. Calculate the experimental value of Avogadro's Number using the data above. Be sure to include all necessary calculations to arrive at your final answer. (15 points*)

If used Zinc electrode

q = It = (0.59 amp)(540s)
q = 319 Coulombs

2 points for calculated charge supplied.

number of e- = 319 C / 1.60 x 10^{-19} C/e-
number of e- = 1.99 x 10^{21} electrons

2 points for the calculated number of electrons.

number of Cu^{2+} = ½ (number of e-)
number of Cu^{2+} = ½ (1.99 x 10^{21})
number of Cu^{2+} = 9.95 x 10^{20} Cu atoms

2 points for the calculated number of Cu atoms gained on Zn electrode.

mass of Cu = 10.179 g – 10.087 g
mass of Cu = 0.092 g

1 point for the mass of Cu added to Zn.

number of Cu/g =
9.95 x 10^{20} atoms/0.092 g Cu
number of Cu/g = 1.08 x 10^{21} atoms/g

2 points for ratio of atoms to grams. (award if part of dimensional analyses)

atoms/mol =
(1.08 x 10^{21} atoms/g)(63.55 g/mol)
atoms/mol = 6.9 x 10^{23} atoms/mol

3 points for calculated N_A.

3 points for including units throughout calculations.
(2 points if one missing, 1 point if two missing, 0 points for three or more)

SCHOOL NAME: ____________**KEY**____________ TEAM NUMBER: __________

If used Copper electrode

q = It = (0.59 amp)(540s) **q = 319 Coulombs**	**2 points for calculated charge supplied.**
number of e- = 319 C / 1.60 x 10^{-19} C/e- **number of e- = 1.99 x 10^{21} electrons**	**2 points for the calculated number of electrons.**
number of Cu^{2+} = ½ (number of e-) **number of Cu^{2+} = ½ (1.99 x 10^{21})** **number of Cu^{2+} = 9.95 x 10^{20} Cu atoms**	**2 points for the calculated number of Cu atoms gained on Zn electrode.**
mass of Cu = 9.802 g – 9.704 g **mass of Cu = 0.098 g**	**1 point for the mass of Cu added to Zn.**
number of Cu/g = **9.95 x 10^{20} atoms/0.098 g Cu** **number of Cu/g = 1.08 x 10^{21} atoms/g**	**2 points for ratio of atoms to grams. (award if part of dimensional analyses with molar mass)**
atoms/mol = **(1.02 x 10^{21} atoms/g)(63.55 g/mol)** **atoms/mol = 6.5 x 10^{23} atoms/mol**	**3 points for calculated N_A.**
	3 points for including units throughout calculations. **(2 points if one missing, 1 point if two missing, 0 points for three or more)**

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Part II – Thermodynamics

Another method of confirming the identity of an unknown metal is using the principles of thermodynamics. In Part A, you will determine the identity of an unknown metal. You will then determine the constant of proportionality, *k*, for the cooling of the thermometer used in the experiment.

Part A: Unknown Metal

1. Obtain a metal sample from the event supervisor.
2. Record the mass of your metal.
3. Using tongs, carefully place your metal in an ice-water bath. Allow the metal to equilibrate for 5 minutes. The temperature of the ice water bath should not be above 5^0C. If the temperature of the bath increases past 5^0C, add more ice to the bath. Continue to the next steps while you wait.
4. Setup a makeshift calorimeter by placing two Styrofoam cups snuggly in one another.
5. Measure 75-100 mL of room temperature tap water in a graduated cylinder and pour this water into your calorimeter.
6. Record the temperature of the ice water bath as the initial temperature of the metal. Record the initial temperature of the water in the calorimeter.
7. Gently place the thermometer in the calorimeter top, making sure that it does not touch the bottom of the calorimeter.
8. Using tongs, remove the metal from the ice water bath and place it in the calorimeter.
9. Monitor the temperature of the water in the calorimeter. Gently swirl the water in the calorimeter. Once the temperature has stopped changing for at least 30 seconds, record the final temperature of the water in the calorimeter.

<u>Part A Data</u> (15 points)
Record your data in the space below.

3 points for recording mass
3 points for recording initial temperature of metal
3 points for recording initial temperature of water in calorimeter
3 points for recording final temperature of equilibrium system
3 points for recording the volume of the water used in calorimeter.

Deduct 1 point for each measurement if student did not estimate to the next decimal place on the graduated cylinder and the thermometers.

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<u>Part A Question</u> (35 points total)

1. Determine the identity of the unknown metal. Show all relevant calculations to arrive at your final answer. (15 points)

Award points based on the metal used in the event.

4 points for calculating the amount of energy lost by water (1 pt substitution, 2 points answer, 1 point units)

3 points for relating the amount of energy lost by water equals the amount of energy gained by the metal cylinder/block.

4 points for calculating the specific heat of the metal, within 5% of expected amount (1 pt substitution, 2 points answer, 1 point units)

4 points for correct answer (all or nothing)– no partial credit due to incorrect specific heat calculation and no points awarded if identification is not supported by calculations above)

Identity of Unknown Metal: ______________________________

2. Provide two possible sources of experimental error encountered in this experiment. Explain how each one would affect your calculated value of the metal's specific heat capacity. (10 points)

<u>Each of the following explanations are worth five points total. 2 points are awarded for the error identification and 3 points are given for the explanation. If other explanations not listed below are given, award credit for overall feasibility.</u>

The metal is wet which would introduce mass into the calorimeter. The extra water would have additional internal energy which could be lost to the cooler metal block. The temperature decrease would not be as large so the specific heat would be calculated to be lower than the expected value.

During transfer, the metal will gain energy from the surrounding air molecules, thus causing the temperature of the metal to slightly increase; therefore, the water will need to lose less energy to reach thermal equilibrium with the metal and the specific heat would be calculated to be lower than the expected value.

During transfer, some of the water splashed out of the calorimeter when the metal was dropped into the container. The loss of water would result in less water molecules to transfer their thermal energy to the cooler metal rod. We are assuming that the mass is the same as the volume measured previously, so the smaller mass will result in a slightly larger change in temperature of the water and a larger specific heat calculated.

3. You have been asked to determine the specific latent heat of freezing for water. You have been provided a calorimeter, a hot plate, unlimited distilled water, ice cubes, a thermometer, and a 100-mL graduated cylinder. Explain how you would be able to determine the latent heat of freezing for water using this equipment. Be specific. (10 points)

The amount of distilled water to be placed in the calorimeter is measured using the graduated cylinder. (1 point)

Heat the distilled water to above room temperature (~40-50^{0}C) to increase the rate of melting. (1 point)

The initial temperature of the water is determined using the thermometer. (1 point)

The ice cubes are added to the water in the calorimeter. The ice is allowed to melt and the temperature is monitored. (1 point) When the temperature no longer decreases, the final temperature of the water is determined. (1 point)

The mass of the ice cubes can be determined by taking the final volume of the water in the calorimeter. The increase in volume is due to the melting of the ice into the distilled water. (1 point)

The amount of energy lost from the distilled water can be determined using $q = mc\Delta T$, using the initial volume of the water as the mass of the water (density of water is approximately 1 g/mL). (1 point) This is the same amount of energy gained by the ice cube. (1 point)

The amount of energy gained by the ice cube divided by the mass of the ice cube is equal to the specific latent heat of melting. (1 point)

The specific latent heat of freezing is equal in magnitude to the specific latent heat of melting, where the same amount of energy would need to be *released* to freeze the same mass of liquid water. (1 point)

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Part B: Cooling of Thermometer

In the following portion, you will determine the constant of proportionality, *k*, of your thermometer.

1. Record the ambient temperature of the room.
2. Place the thermometer in the hot water bath provided, making sure that the temperature is above 60^0C. Remove the thermometer and quickly dry it, then suspend the thermometer in the air. Record the initial temperature after drying.
3. Use a clock or a stopwatch to keep track of time. Every 15 seconds, record the temperature reading on the thermometer. Continue doing this for between 5 to 7 minutes.

Part B Data (15 points total)
Record your data in the space below.

Award 15 points for collecting data for between 5 to 7 minutes. The following deductions from the maximum points should be given:

- **-5 points for not including units with data points (time and/or Celsius)**
- **-5 points for not approximating the temperatures to the next decimal place, based on the calibration of the instrument used**
- **-5 points for not including data in an organized fashion (i.e. data table with appropriate headers, neatly organized data in space provided, etc.)**

Part B Questions (35 points total)

4. From the data above, calculate the average constant of proportionality, *k*, for the cooling of the thermometer over the course of the experiment. (8 points)

The following calculation depends on the data collected by team:

$$T(t) = T_a + (T_0 - T_a)e^{-kt}$$

The last temperature and time point should be used to solve for *k*. (2 points)
Units used throughout calculations and appropriate units used to report *k*. (2 points)
Appropriate substitution into above equation shown. (2 points)
Correct answer. (2 points)

5. Predict the temperature of the thermometer after 9.5 minutes. Your answer must include an appropriate calculation. (7 points)

Using the value of *k* from question 4, the students must use Newton's Law of Cooling to predict the temperature after 9.5 minutes.
Appropriate substitution of time (seconds or minutes) based on units of *k* from question 4 (1 point)
Units used throughout calculations and appropriate units used to report *k*. (2 points)
Appropriate substitution into above equation shown. (2 points)
Correct answer. (2 points)

6. A student performed a similar experiment by placing two 100-mL samples of water at the same temperature into different containers of equal size, wall thickness, and internal diameters. The first container was a tin can and the second container was a Styrofoam coffee cup. Predict the results of the constant of proportionality, *k*, for the cooling of water between the two containers. Provide a rationale for your argument. (7 points*)

The walls of the tin container will lose energy more readily to the surroundings compared to the Styrofoam container since tin has a higher thermal conductivity. (3 points)

The temperature of the water will therefore decrease more rapidly in the tin container compared to the Styrofoam container due to the differences in thermal conductivity. (2 points)

Since the rate of cooling is faster, the value of the constant of proportionality in the tin container will be higher compared to that of water in the Styrofoam container. (2 points)

7. A student places two containers of water in the freezer. One container has a sample of water at 80^{0}C and the other container has a sample of water at room temperature. The containers are of equal size, wall thickness, chemical composition, and internal diameters. The sample with hotter water was observed to freeze first, which is a manifestation of the Mpemba effect. Discuss at least two proposed scientific reasonings for the Mpemba effect. (6 points*)
    - **Evaporation: due to the higher temperature of the one sample, it would have a greater deal of evaporation and thus require less liquid water to freeze**
    - **Dissolved gases: the smaller amount of dissolved gases in the warmer water might affect the convection currents in the warmer water or decrease the amount of energy needed to be removed during freezing.**
    - **Convection: as the water begins to cool, convection currents will develop where the cooler water will sink and the warmer water will form a hotter top near the surface. If the water sample loses its energy mostly at the surface, the warmer container will lose energy more rapidly at the surface than expected based upon its average temperature. Even when the warmer water reaches the same average temperature as the initial cold water sample, it will still have a warmer surface which will therefore allow the sample to lose energy at a faster rate.**
    - **Frost effect: the cooler water sample will be in contact with the frost layer at the bottom of the freezer, which will act as an insulator for energy exchange. The warmer water could melt the frost layer and thus not have the insulating effect, causing the temperature to decrease at a faster rate.**
    - **Bond effects: the warmer water has more internal energy thus causing the covalent bonds in the water molecules to stretch more than the cooler water. This may cause the warmer water to release energy quicker than the cooler water.**
    - **Supercooling: the warmer water is more likely to become supercooled due to the smaller amount of dissolved gases. The cooler water is more likely to form a layer of ice at the surface due to increases nucleation sites in the cooler water; this results in an insulating layer, less evaporation, and slower cooling. In the supercooled warmer water sample, the freezing occurs throughout the sample instead of solely at the surface.**

Award 1 point each for identifying a potential explanation for the Mpemba effect. Award 2 points each for a corresponding explanation of how it could cause the warmer water sample to freeze earlier than the cooler water sample.

SCHOOL NAME: ____________KEY____________ TEAM NUMBER: ________

8. You are a medical examiner called to the crime scene containing a dead body. Explain how you would be able to determine the time of death and some potential sources of error. (7 points*)

The medical examiners would need to take three important pieces of data:

- **the ambient temperature of the room (1 point)**
- **the temperature of the corpse upon entering the crime scene (1 point)**
- **the temperature of the corpse after a period of time (1 point)**

From these three pieces of data, the medical examiner would be able to determine the rate of cooling of the corpse under these environmental conditions using the Newtonian Law of Cooling. The two temperature readings are needed so that the medical examiner can take an average of the two cooling readings. The medical examiner could then determine how long it must have taken for the body to cool from the normal body temperature of 37^{0}C of a healthy person from these two sets of conditions. (1 point assigned for discussing the need for an average time of death; 1 point assigned for relating the two temperature readings back to the normal body temperature)

Potential sources of error include whether or not the person was sick (higher or lower body temperature) and variations of the ambient temperature of the environment, especially if the body is found outside. (1 point each for identifying up to two sources of error = 2 points max)