

SCHOOL NAME: \_\_\_\_\_

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 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 (\*).

School Name: \_\_\_\_\_

Team Number: \_\_\_\_\_

Student Names: \_\_\_\_\_

\_\_\_\_\_

### Standard Reduction Potentials in Aqueous Solution at 25<sup>o</sup>C

Reduction Half-Reaction	<i>E</i> <sup>o</sup> (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

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

hydrogen 1 <b>H</b> 1.0079	beryllium 4 <b>Be</b> 9.0122	helium 2 <b>He</b> 4.0026
lithium 3 <b>Li</b> 6.941	boron 5 <b>B</b> 10.811	neon 10 <b>Ne</b> 20.180
sodium 11 <b>Na</b> 22.990	aluminum 13 <b>Al</b> 26.982	argon 18 <b>Ar</b> 39.948
potassium 19 <b>K</b> 39.098	silicon 14 <b>Si</b> 28.086	krypton 36 <b>Kr</b> 83.80
calcium 20 <b>Ca</b> 40.078	germanium 32 <b>Ge</b> 72.61	xenon 54 <b>Xe</b> 131.29
strontium 37 <b>Sr</b> 87.62	gallium 31 <b>Ga</b> 69.723	radon 86 <b>Rn</b> [222]
barium 56 <b>Ba</b> 137.33	zinc 30 <b>Zn</b> 65.39	
caesium 55 <b>Cs</b> 132.91	copper 29 <b>Cu</b> 63.546	
francium 87 <b>Fr</b> [223]	silver 47 <b>Ag</b> 107.87	
	gold 79 <b>Au</b> 196.97	
	mercury 80 <b>Hg</b> 200.59	
	unnilium 112 <b>Uub</b> [277]	
	unnilium 111 <b>Uuu</b> [272]	
	unnilium 110 <b>Uun</b> [271]	
	unnilium 109 <b>Uuo</b> [268]	
	unnilium 108 <b>Uuh</b> [269]	
	unnilium 107 <b>Uuh</b> [264]	
	unnilium 106 <b>Uuo</b> [265]	
	unnilium 105 <b>Uub</b> [262]	
	unnilium 104 <b>Uuf</b> [261]	
	unnilium 103 <b>Uul</b> [262]	
	unnilium 102 <b>Uuq</b> [289]	
	unnilium 101 <b>Uuq</b> [289]	
	unnilium 100 <b>Uuq</b> [289]	
	unnilium 99 <b>Uuq</b> [289]	
	unnilium 98 <b>Uuq</b> [289]	
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	unnilium 92 <b>Uuq</b> [289]	
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	unnilium 88 <b>Uuq</b> [289]	
	unnilium 87 <b>Uuq</b> [289]	
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	unnilium 71 <b>Uuq</b> [289]	
	unnilium 70 <b>Uuq</b> [289]	
	unnilium 69 <b>Uuq</b> [289]	
	unnilium 68 <b>Uuq</b> [289]	
	unnilium 67 <b>Uuq</b> [289]	
	unnilium 66 <b>Uuq</b> [289]	
	unnilium 65 <b>Uuq</b> [289]	
	unnilium 64 <b>Uuq</b> [289]	
	unnilium 63 <b>Uuq</b> [289]	
	unnilium 62 <b>Uuq</b> [289]	
	unnilium 61 <b>Uuq</b> [289]	
	unnilium 60 <b>Uuq</b> [289]	
	unnilium 59 <b>Uuq</b> [289]	
	unnilium 58 <b>Uuq</b> [289]	
	unnilium 57 <b>Uuq</b> [289]	

lanthanum 57 <b>La</b> 138.91	cerium 58 <b>Ce</b> 140.12	praseodymium 59 <b>Pr</b> 140.91	neodymium 60 <b>Nd</b> 144.24	promethium 61 <b>Pm</b> [145]	samarium 62 <b>Sm</b> 150.36	europium 63 <b>Eu</b> 151.96	gadolinium 64 <b>Gd</b> 157.25	terbium 65 <b>Tb</b> 158.93	dysprosium 66 <b>Dy</b> 162.50	holmium 67 <b>Ho</b> 164.93	erbium 68 <b>Er</b> 167.26	thulium 69 <b>Tm</b> 168.93	ytterbium 70 <b>Yb</b> 173.04
actinium 89 <b>Ac</b> [227]	thorium 90 <b>Th</b> 232.04	protactinium 91 <b>Pa</b> 231.04	uranium 92 <b>U</b> 238.03	neptunium 93 <b>Np</b> [237]	plutonium 94 <b>Pu</b> [244]	americium 95 <b>Am</b> [243]	berkelium 96 <b>Bk</b> [247]	californium 97 <b>Cf</b> [251]	lawrencium 98 <b>Lr</b> [260]	roentgenium 99 <b>Rg</b> [289]	meitnerium 100 <b>Mt</b> [289]	nihonium 101 <b>Nh</b> [289]	nobelium 102 <b>Nb</b> [289]

\* Lanthanide series

\*\* Actinide series

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

<b>Metal</b>	<b>Specific Heat Capacity(J/g·K)</b>
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:**  $9.11 \times 10^{-31}$  kilograms

**Charge of an electron:**  $1.60 \times 10^{-19}$  coulombs

**Ideal Gas Constant:** 8.314 J/K·mol

**Section I – Electrochemistry (100 points)**

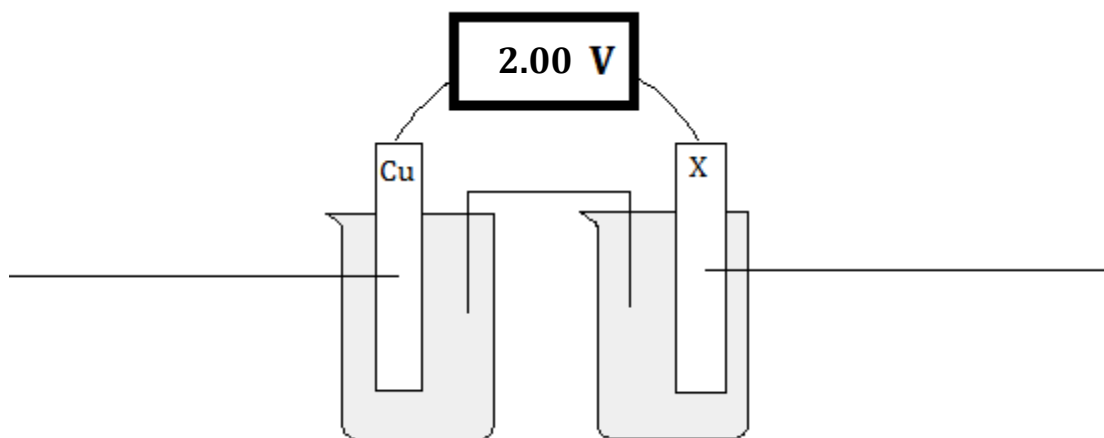
Copper(II) sulfate, when placed in distilled water, is a characteristic blue color. A student prepares a 1.00-M solution of  $\text{CuSO}_4$  and then separates the solution into four separate beakers. One of the 1.00-M  $\text{CuSO}_4$  solutions in Part A of this section is used to determine the identity of three unknowns. The other three beakers containing  $\text{CuSO}_4$  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 (37 points)**

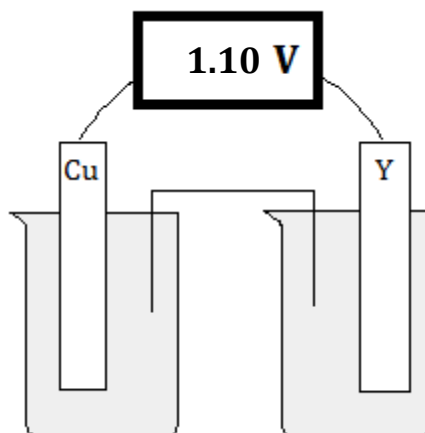
You need to identify two unknown metal electrodes and an unknown solution through the construction of a galvanic cell, as shown in the three diagrams below. 1.00M solutions of both  $\text{CuSO}_4$  and the unknown metal ion solutions have been provided, in addition to a copper electrode, the unknown metal electrodes, a salt bridge, and a voltmeter. The resulting cell potentials have been provided of these three experimental setups.

**Part A Data** (16 points total)

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



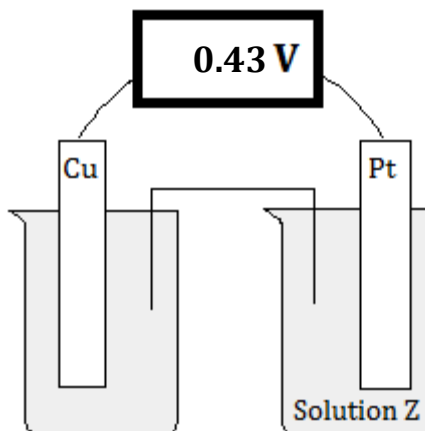
Copper + Metal Y: Indicate the direction of electron flow in the diagram below. (4 points)



SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

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



**Part A Questions** (21 points total)

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

<u>Metal X</u>	<u>Metal Y</u>	<u>Solution Z</u>

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)

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

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

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  $\text{KMnO}_4$  and  $\text{K}_2\text{C}_2\text{O}_4$  solutions used in the aforementioned standardization process. (6 points\*)

**Part B: Unmarked Solution (9 points)**

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.

**Part B Question** (5 points)

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

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

**Part C: More Electrochemical Cells (34 points)**

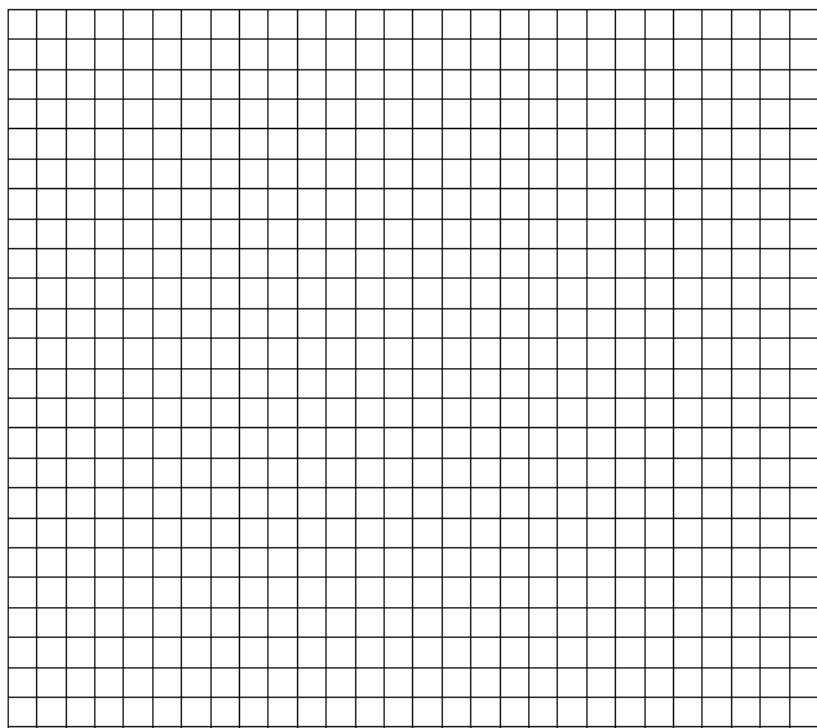
In the third portion of the lab, a student collected the following data based on a galvanic cell comprised of two copper half-cells at 25°C. In half-cell A, a 1.00-M CuSO<sub>4</sub> solution is used with a polished copper electrode. In half-cell B, a smaller concentration of CuSO<sub>4</sub> solution is used with a different copper electrode. Four different known concentrations were tested against the 1.00-M CuSO<sub>4</sub> half-cell and the cell potentials of these trials 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)

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 <sub>4</sub>	0.050 M CuSO <sub>4</sub>	0.037	
1.00 M CuSO <sub>4</sub>	0.025 M CuSO <sub>4</sub>	0.045	
1.00 M CuSO <sub>4</sub>	0.010 M CuSO <sub>4</sub>	0.061	
1.00 M CuSO <sub>4</sub>	0.0050 M CuSO <sub>4</sub>	0.069	
1.00 M CuSO <sub>4</sub>	Unknown CuSO <sub>4</sub>	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)



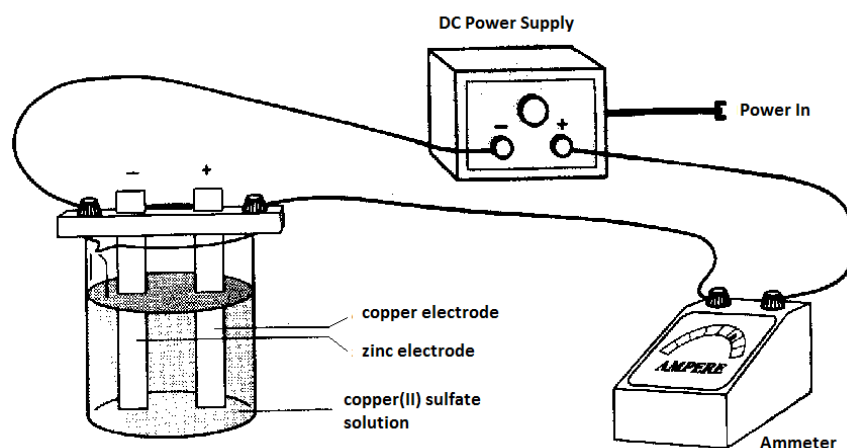




### Part D: Avogadro's Number (20 points)

The principles 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  $\frac{3}{4}$  full with acidified 1.00-M  $\text{CuSO}_4$  solution.
4. The following equipment was assembled using the metal electrodes and the 1.00-M  $\text{CuSO}_4$  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  $\text{CuSO}_4$  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
<b>Initial Mass</b>	10.087 g	9.802 g
<b>Final Mass</b>	10.179 g	9.704 g

#### **Part D 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)

SCHOOL NAME: \_\_\_\_\_ TEAM NUMBER: \_\_\_\_\_

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\*)

**Part II – Thermodynamics (100 points)**

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 (50 points)**

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  $5^{\circ}\text{C}$ . If the temperature of the bath increases past  $5^{\circ}\text{C}$ , add more ice to the bath. Continue to the next steps while you wait.
4. Setup a makeshift calorimeter by placing two Styrofoam cups snugly 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.

**Part A Data** (15 points)

Record your data in the space below.

SCHOOL NAME: \_\_\_\_\_ TEAM NUMBER: \_\_\_\_\_

**Part A Questions** (35 points total)

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

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)

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

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)

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

**Part B: Cooling of Thermometer (50 points)**

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  $60^{\circ}\text{C}$ . 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.

**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)

SCHOOL NAME: \_\_\_\_\_

TEAM NUMBER: \_\_\_\_\_

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



