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Islip Invitational 2013
Technical Problem Solving Examination

Do not open this booklet until instructed to do so.
Goggles must be worn at all times during this 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.

Please note that the teams have to perform two separate experiments as part of the examination. Both experiments are found in "Part A" of each section of the examination. Please allow sufficient time to complete both parts.

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

You are allowed to separate the packet and work in any order as long as the packet is stapled in the correct order when submitted to the event supervisor.

<u>Potentially Helpful Information</u>

$\mathcal{R}$ = 0.08206 L•atm/mol•K = 8.314 J/K•mol
C_{water} = 4.18 J/g•K

Student Names: ____

____

Standard Reduction Potentials in Aqueous Solution at 25⁰C

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

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hydrogen 1 H 1.0079																	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

* Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
* * Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

VAPOR PRESSURE OF WATER

T	P	T	P	T	P	T	P
°C	torr	°C	torr	°C	torr	°C	torr
19.1	16.581	22.1	19.948	25.1	23.897	28.1	28.514
19.2	16.685	22.2	20.070	25.2	24.039	28.2	28.680
19.3	16.789	22.3	20.193	25.3	24.182	28.3	28.847
19.4	16.894	22.4	20.316	25.4	24.326	28.4	29.015
19.5	16.999	22.5	20.440	25.5	24.471	28.5	29.184
19.6	17.105	22.6	20.565	25.6	24.617	28.6	29.354
19.7	17.212	22.7	20.690	25.7	24.764	28.7	29.525
19.8	17.319	22.8	20.815	25.8	24.912	28.8	29.697
19.9	17.427	22.9	20.941	25.9	25.060	28.9	29.870
20.0	17.535	23.0	21.068	26.0	25.209	29.0	30.043
20.1	17.644	23.1	21.196	26.1	25.359	29.1	30.217
20.2	17.753	23.2	21.324	26.2	25.509	29.2	30.392
20.3	17.863	23.3	21.453	26.3	25.660	29.3	30.568
20.4	17.974	23.4	21.583	26.4	25.812	29.4	30.745
20.5	18.085	23.5	21.714	26.5	25.964	29.5	30.923
20.6	18.197	23.6	21.845	26.6	26.117	29.6	31.102
20.7	18.309	23.7	21.977	26.7	26.271	29.7	31.281
20.8	18.422	23.8	22.110	26.8	26.426	29.8	31.461
20.9	18.536	23.9	22.243	26.9	26.582	29.9	31.642
21.0	18.650	24.0	22.377	27.0	26.739	30.0	31.824
21.1	18.765	24.1	22.512	27.1	27.897	30.1	32.007
21.2	18.880	24.2	22.648	27.2	27.055	30.2	32.191
21.3	18.996	24.3	22.785	27.3	27.214	30.3	32.376
21.4	19.113	24.4	22.922	27.4	27.374	30.4	32.561
21.5	19.231	24.5	23.060	27.5	27.535	30.5	32.747
21.6	19.349	24.6	23.198	27.6	27.696	30.6	32.934
21.7	19.468	24.7	23.337	27.7	27.858	30.7	33.122
21.8	19.587	24.8	23.476	27.8	28.021	30.8	33.312
21.9	19.707	24.9	23.616	27.9	28.185	30.9	33.503
22.0	19.827	25.0	23.756	28.0	28.349	31.0	33.695

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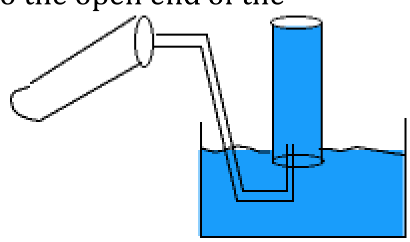
PART I: ELECTROCHEMISTRY

In the first portion of the examination, you will be asked to use the principles of electrochemistry to either perform a laboratory investigation or answer specific questions. In Part A, you will determine an experimental value of the atomic mass of aluminum and in Part B, you will determine an experimental value of Faraday's Constant.

Part A: Atomic Mass of Aluminum

In this section, you need to determine the atomic mass of the element aluminum by following the steps outlined below. You will be reacting the aluminum foil with hydrochloric acid, HCl(aq).

1. Take the mass of the sample of aluminum provided.
2. Fill the large beaker with tap water, leaving approximately 1 cm of space at the top.
3. Fill the syringe with water by pushing it under the water surface. The air in the syringe will be displaced by the water. Push a tip cap onto the open end of the syringe.
4. Place the J-tube as shown in the diagram to the right. The curved portion of the J-tube is placed in the bottom of the syringe so that the gas can be bubbled in. Be sure not to allow any water to escape from the syringe while inserting the J-tube.



5. Roll the foil into a loose ball and place it in a test tube. Then add 3.0 mL of 4 M hydrochloric acid. Press the stopper assembly firmly into the test tube. Check to make sure that all of the connections are tight to avoid a loss of hydrogen gas.
6. Swirl the test tube containing the acid and aluminum metal until the reaction begins to proceed rapidly. It may take a couple of minutes depending on the acid temperature and level of oxide formation on the surface of the aluminum foil.
7. When all the aluminum has been reacted, equalize the pressure inside the syringe with the atmosphere. Move the entire apparatus up or down until the water level inside the syringe is equal to the water level in the beaker. Record the volume of the hydrogen gas in the tube once equalized. Please note that the tip of the syringe does not have calibration points, but the gas could still occupy that space; therefore, add 1.2 mL to your recorded volume to correct for this extra possible volume of the gas.
8. Record the water temperature and atmospheric pressure.

Part A Data (15 points)

Make a data table below of any data collected during the laboratory investigation.

Mass of Al Foil = 3 points
Water Temperature = 4 points (2 points data, 2 points precision)
Atmospheric Pressure = 4 points
Volume of H_2 Gas = 4 points (2 points data, 2 points precision)

Part A Questions (35 points total)

1. Calculate the partial pressure of the hydrogen gas collected in the syringe. (5 points)

1 point for correct water vapor pressure
2 points for correct answer
2 points for calculations with appropriate units

2. Calculate the number of moles of hydrogen gas collected in the syringe. (5 points)

1 point for conversion of volume to Liters
2 points for correct answer
2 points for calculations with appropriate units

3. Write the net ionic equation of the process investigated in Part A. (5 points)

$$2Al(s) + 6H^{+}(aq) \rightarrow 2Al^{3+}(aq) + 3H_2(g)$$

2 points for correctly written reactants
2 points for correctly written products
1 point for balancing equation

4. Determine the atomic mass of aluminum using the data collected. (10 points)

3 points for calculating the number of moles of Al from mole ratio
3 points for calculating molar mass from mass and moles
2 points for calculations with appropriate units
2 points for molar mass within ± 1 g/mol

5. A voltaic cell can be constructed with the substances used in this investigation. In the space below, sketch a voltaic cell using these substances (with anything else that is needed) and clearly label the following components of your sketch. (10 points)
   - anode
   - cathode
   - direction of electron flow
   - expected voltage
   - half-reaction in anode compartment
   - half-reaction in cathode compartment

1 point for assigning Al as anode
1 point for assigning Pt/inert electrode as cathode
1 point for drawing salt bridge
1 point for drawing electrolytes in two half-cells
1 point for drawing external conductor
1 point for indicating direction of electron flow
2 points for indicating correct voltage (1.66 V)
1 point for indicating correct oxidation half-reaction
1 point for indicating correct reduction half-reaction

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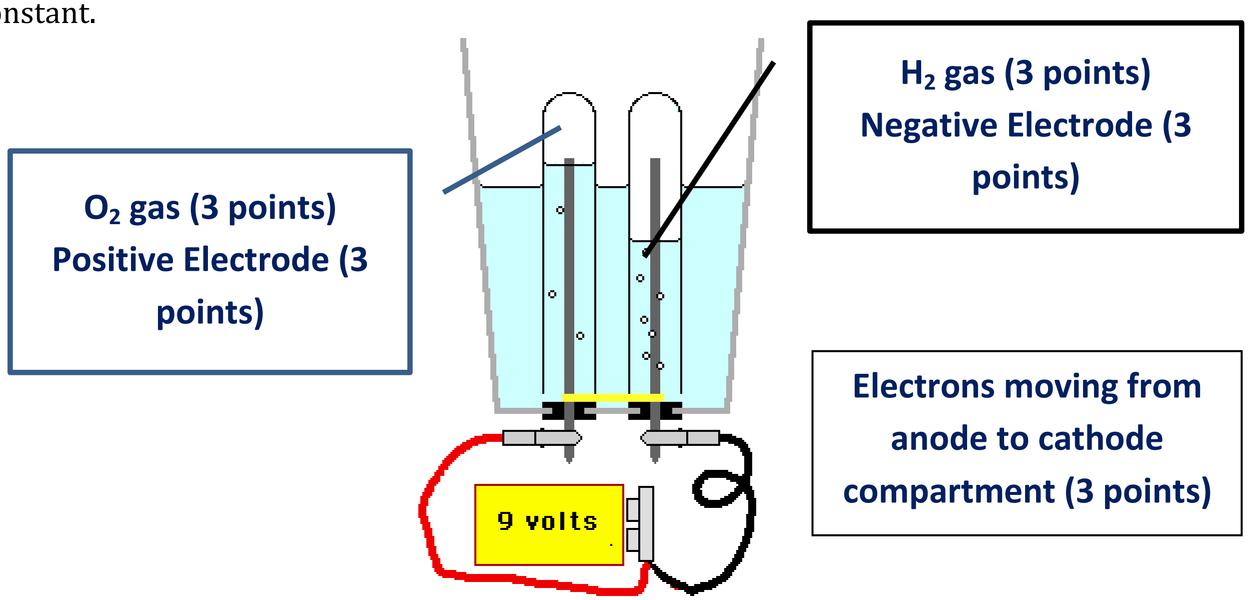
Part B: Electrolysis of Water and Faraday's Constant

A student prepared an electrolytic cell with distilled water, two inverted test tubes, two graphite electrodes, and a 9V battery (which supplies an average current of 0.5A). When he connected all of the components, no visible reaction occurred. His teacher advised him to add a little sulfuric acid to the distilled water. Once the sulfuric acid was added, the student began to observe gas evolution around each of the electrodes. After about 3 minutes, the student made a sketch of the experimental setup, as shown below. After 5 minutes, the student disconnected the battery and measured the volume of the gas in the righthand test tube in the setup to be 18.6 mL at 1 atm and 22^{0}C (i.e. the test tube with the larger volume of gas). From this information, he is asked to determine an experimental value of Faraday's Constant.



Part B Data (15 points)

On the diagram above, clearly label the positive and negative electrode. Also clearly label the identity of the gases contained within the test tubes and the direction of electron flow.

Part B Questions (35 points total)

6. Explain why the initial electrolytic cell did not operate properly and explain why the teacher's suggestion solved this problem. (5 points)

The distilled water does not contain electrolytes to complete the electrical circuit between the two electrodes. The addition of sulfuric acid provides ions in solution which will allow the electrolytic cell to operate.

3 points for explaining the need for electrolytes to conduct
2 points for explaining that sulfuric acid provides electrolytes

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7. Calculate the amount of charge supplied to the electrolytic cell. (5 points)

q = It
q = (0.5A)(300 seconds) = 150 C

1 point for conversion of minutes to seconds
2 points for correct answer
2 points for calculations with appropriate units

8. Calculate the number of moles of gas collected after 5 minutes. (5 points)

n = PV/RT
n = (1atm)(0.0186L)/(0.08206Latm/molK)(295K)
n = 7.68 x 10^{-4} mol H_2 gas

1 point for conversion of milliliters to liters
2 points for correct answer
2 points for calculations with appropriate units

9. Determine an experimental value of Faraday's Constant based on the data collected in this experiment. (10 points)

$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$
Reduction: $4e^- + 4H_2O(l) \rightarrow 2H_2(g) + 4OH^-$
moles of electrons = 2(7.68x10^{-4} mol) = 1.54 x 10^{-3} mol e-
F = q/mol e- = (150 C)/(1.54 x 10^{-3} mol e-) = 97400 C/mol e-

5 points for determining mole ratio between H_2 gas and electrons supplied
3 points for calculation of Faraday's Constant
2 points for calculations with appropriate units

10. Would the same products be observed if brine was used instead of the substances in the student's setup? (N.B. Brine is a solution of sodium chloride.) Explain any similarities and/or differences which would be observed. (10 points*)

H_2 gas would still be collected at the cathode. Cl_2 would be collected at the anode instead of O_2 gas. Also, the ratio of gases would be the same based on the mole ratio present in the balanced equation. The Cl_2 gas is collected instead of O_2 gas despite the smaller E_{red} for the chloride ion due to overvoltage needed to initiate the oxidation of water, so the chloride is preferentially oxidized.

2 points for explaining H_2 gas still evolved
4 points for explaining Cl_2 gas evolved instead of O_2 gas
2 points for explaining overvoltage rationale
2 points for explaining difference in mole ratio between two reactions

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PART II: THERMODYNAMICS

In the second portion of the examination, you will be asked to use the principles of thermodynamics to either perform a laboratory investigation or answer specific questions. In Part A, you will determine an experimental value of the heat of vaporization of rubbing alcohol and in Part B, you will determine the result of mixing ethanol and water.

Part A: Heat of Vaporization of Rubbing Alcohol

In this portion, you are asked to determine the heat of vaporization of rubbing alcohol (isopropyl alcohol) using the Clausius-Clapeyron relationship between the vapor pressure of the substance and its temperature. The equation for the Clausius-Clapeyron relationship is shown below.

$$\ln P = \left(\frac{\Delta H_{vap}}{R}\right)\frac{1}{T} + C$$

A student followed the following experimental conditions when collecting the pressure of the isopropyl alcohol.

1. Detach syringe from rubber stopper by twisting the connector. Open the valve of the syringe and add 3 mL of isopropyl alcohol. Close the valve.
2. Attach syringe to the rubber stopper assembly. Make sure the stopper is tight.
3. Measure the initial pressure at room temperature. Make sure that the pressure readings are in kPa.
4. Open valve connected to the syringe. Quickly depress the syringe plunger all the way and then retract it to the 3 mL mark.
5. Close the value connected to the syringe (back to the original position).
6. Gently submerge the container into the warm water bath. Make sure the wires and tubes are not touching the hot plate. Allow the sample to heat, recording temperature and pressure values every 2 minutes as the water bath heats. Stop collecting data after 10 minutes.
7. When finished taking data, remove the flask from the water bath and remove the rubber stopper. Empty the small amount of liquid into the designated waste container.

The student obtained the following data:

Atmospheric Pressure at 22^{o}C	100.0 kPa
Pressure of Flask at 27.35^{o}C	108.4 kPa
Pressure of Flask at 33.05^{o}C	113.2 kPa
Pressure of Flask at 38.45^{o}C	118.3 kPa
Pressure of Flask at 44.35^{o}C	125.1 kPa
Pressure of Flask at 51.35^{o}C	135.1 kPa

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Part A Questions (45 points total)

1. The pressure measured after the liquid has been added is a mixture of the original gases in the container and the gases that have vaporized. As the temperature increases, the pressure of the original gases will increase due to the increase in temperature. In the table below, adjust the original atmospheric pressure at the elevated temperatures by using the combined gas law. Show your work in each cell. (5 points) – **1 point each**

t	2 minutes	4 minutes	6 minutes	8 minutes	10 minutes
Adjusted Pressure	**101.8 kPa**	**103.4 kPa**	**105.6 kPa**	**107.6 kPa**	**109.9 kPa**

2. Determine the vapor pressure of the isopropyl alcohol at each time point. Show your work in each cell. (5 points) – **1 point each**

t	2 minutes	4 minutes	6 minutes	8 minutes	10 minutes
Vapor Pressure	**108.4 – 101.8 6.6 kPa**	**113.2 – 103.4 9.8 kPa**	**118.3 – 105.6 12.7 kPa**	**125.1 – 107.6 17.5 kPa**	**135.1 – 109.9 25.2 kPa**

3. Determine the natural logarithm of the vapor pressure and the inverse temperature, in Kelvin, for each data point. (5 points) – **0.5 points each**

Time	2 minutes	4 minutes	6 minutes	8 minutes	10 minutes
ln P	**1.89**	**2.28**	**2.54**	**2.86**	**3.23**
1/T	**1/300.35 = 3.33×10^{-3} K^{-1}**	**1/306.05 = 3.27×10^{-3} K^{-1}**	**1/311.45 = 3.21×10^{-3} K^{-1}**	**1/317.35 = 3.15×10^{-3} K^{-1}**	**1/324.35 = 3.08×10^{-3} K^{-1}**

4. Using the data collected, determine the heat of vaporization of isopropyl alcohol, in kJ/mol. (10 points*)

Take two data points and use Clausius-Clapeyron Relationship

$$\ln P_1 - \ln P_2 = -(\Delta H_{vap}/R)(1/T_1 - 1/T_2)$$

$$3.23 - 1.89 = -(x/8.314\ J/Kmol)(3.08 \times 10^{-3}\ K^{-1} - 3.33 \times 10^{-3}\ K^{-1})$$

$$x = 44.5\ kJ/mol$$

2 points for rearrangement of equation
3 points for substitution of values
3 points for correct answer
2 points for units

5. Predict the normal boiling point of isopropyl alcohol, in Celsius, using the data collected in the experiment. Support your answer with a calculation. (10 points*)

$$\ln P_1 - \ln P_2 = -(\Delta H_{vap}/R)(1/T_1 - 1/T_2)$$

$$\ln (101.3) - 3.23 = -[(44500)/(8.314)](1/x - 3.08 \times 10^{-3}\ K^{-1})$$

$$x = 354.7\ K = 81.7\ {}^0C$$

2 points for recognizing normal boiling point = 101.3 kPa
3 points for substitution of values
3 points for correct answer in Celsius
2 points for units

6. Hand sanitizer is applied as a microbial agent to kill many biological pathogens present in our environment. When applied to the skin, it has a cooling effect. The major ingredient in hand sanitizers is ethyl alcohol.
   a. Describe the process which occurs when the hand sanitizer is applied and why is has a cooling effect. (5 points)

As the hand sanitizer is applied to the skin, the surface area of the liquid increases dramatically (1 point), thus increasing the rate of evaporation (1 point). The evaporation of the ethanol is endothermic (1 point) as intermolecular forces between adjacent ethanol molecules need to be broken (1 point). The energy is absorbed from the skin of the person, causing the skin to feel cool (1 point).

   b. Would ethanol or isopropyl alcohol have a larger heat of vaporization? Provide a justification for your response. (5 points)

Isopropyl alcohol would have a larger heat of vaporization (2 points). Both molecules have hydrogen bonding (1 point); however, the isopropyl alcohol molecule is larger in size and will thus have larger London dispersion forces present between adjacent molecules (1 point). This will require more energy to break in isopropyl alcohol (1 point).

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Part B: Ethanol-Water Mixtures

Each team will perform a set of calorimetric experiments that will measure the temperature change that occurs when two solvents are mixed in an insulated calorimeter. You will run the experiment with five different water/ethanol (EtOH) mole ratios. The density of water is 1.00 g/mL and the density of EtOH is 0.789 g/mL.

1. Whichever solvent is largest in volume in the particular trial you are performing will be measured using a graduated cylinder and poured into the cup. The top of the calorimeter will have a hole where you can stick a temperature probe. Once the initial temperature stabilizes, record the initial temperature of the solvent.
2. Measure the other solvent to be added using a different graduated cylinder. Press the Play button (▶) on the LabQuest to start data collection. With the thermometer in place, carefully crack the top open enough to quickly (but carefully) pour the solvent into the calorimeter.
3. Gently stir the mixture. The temperature of the solvent will change fairly rapidly upon mixing and should level out at a new temperature after a minute or so. Record the final temperature from the LabQuest interface.
4. Repeat the above procedure with the other four EtOH/water mixtures.

The following mixtures will be analyzed.

1. 3.0 mL H_2O and 22.0 mL EtOH
2. 7.0 mL H_2O and 22.0 mL EtOH
3. 12.0 mL H_2O and 17.0 mL EtOH
4. 15.0 mL H_2O and 12.0 mL EtOH
5. 20.0 mL H_2O and 7.0 mL EtOH

Part B Data (25 points total)

Record your initial and final temperatures in the table below. (15 points)

Mixture	Initial Temperature	Final Temperature
3.0 mL H_2O and 22.0 mL EtOH		
7.0 mL H_2O and 22.0 mL EtOH		
12.0 mL H_2O and 17.0 mL EtOH		
15.0 mL H_2O and 12.0 mL EtOH		
20.0 mL H_2O and 7.0 mL EtOH		

1 point for each data point
5 total points for indicating units of temperature

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Calculate the mole fractions (χ) of water (H_2O) and ethanol (CH_3CH_2OH) in each of the mixtures. (10 points).

Mixture	χ_{water}	χ_{EtOH}
3.0 mL H_2O and 22.0 mL EtOH	**3.0 g / 18.02 g/mol = 0.166 mol water** **0.166 / 0.544 = 0.305**	**17.4 g / 46.07 g/mol = 0.378 mol EtOH** **1-0.305 = 0.695**
7.0 mL H_2O and 22.0 mL EtOH	**7.0 g / 18.02 g/mol = 0.388 mol water** **0.388 / 0.766 = 0.507**	**17.4 g / 46.07 g/mol = 0.378 mol EtOH** **1-0.507 = 0.493**
12.0 mL H_2O and 17.0 mL EtOH	**12.0 g / 18.02 g/mol = 0.666 mol water** **0.666 / 0.957 = 0.696**	**13.4 g / 46.07 g/mol = 0.291 mol EtOH** **1-0.696 = 0.304**
15.0 mL H_2O and 12.0 mL EtOH	**15.0 g / 18.02 g/mol = 0.832 mol water** **0.832 / 1.038 = 0.802**	**9.47 g / 46.07 g/mol = 0.206 mol EtOH** **1-0.802 = 0.198**
20.0 mL H_2O and 7.0 mL EtOH	**20.0 g / 18.02 g/mol = 1.11 mol water** **1.11 / 1.23 = 0.902**	**5.52 g / 46.07 g/mol = 0.120 mol EtOH** **1-0.902 = 0.098**

1 point for each calculation

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Part B Questions (30 points total)

7. Graph the change in temperature as a function of the mole fraction of ethanol. At which mole fraction was the greatest amount of energy exchanged? (8 points)

Appropriate scale on each axis = 2 points

Title of Graph = 1 point

Axis Labels = 1 points

Data Points = 1 points

Line Connecting Data Points = 1 point

χ_{EtOH} of Largest Energy Exchange: **0.198 (2 points)**

8. Explain why the energy exchange was observed. Be as specific as possible. Relate your answer to the χ_{EtOH} of largest energy exchange from above. (8 points*)

When mixed, the water-water hydrogen bonds and the ethanol-ethanol hydrogen bonds are broken (2 points); however, hydrogen bonds between water-ethanol molecules are formed, releasing more energy than required to break the hydrogen bonds between the solvent molecules (2 points). Ethanol tends to form smaller spheres of hydrogen bonds than water does. The exothermic process indicates that the size of the spheres of molecules forming hydrogen bonds has increased (2 points). The largest energy exchange at 0.198 indicates that the greatest increase in hydrogen bond formation occurs at or around this concentration of ethanol and water solvents (2 points).

9. Does this demonstrate an ideal solution or a deviation from ideality? Explain your answer. (7 points*)
   This demonstrates a non-ideal solution (2 points). If the solution were ideal, the relative strengths of the intermolecular forces between the separate solvents and the solvent mixtures will be the same (2 points); therefore, no energy will be lost or absorbed (1 point). However, since the water-solvent attractive forces are greater than the separate water-water and ethanol-ethanol solvents, the mixing resulted in the loss of energy (2 points).

10. If 1-butanol were used instead of ethanol at room temperature, discuss the predicted effect on the change in temperature of the mixture. Justify your answer. (7 points)

    The larger surface of 1-butanol will result in the predominant force of attraction between adjacent molecules to be London dispersion forces (2 points). The terminal hydroxyl group will form hydrogen bonds with the water, but not as readily as with the ethanol due to the drastic difference in size (2 points). Since the number of potential interactions has decreased, the heat of mixing for 1-butanol and water should be less than the heat of mixing for ethanol and water (3 points). (In fact, the enthalpy of mixing is positive under conditions of high 1-butanol mole fractions; therefore, the mixing would be unfavored. Only when the mole fraction of water becomes greater than at least 0.85 does the heat of mixing become exothermic. This would explain the smaller solubility of 1-butanol in water compared to the complete miscibility of ethanol and water).