Experiment 6:
Determination of a Molar Mass of a Volatile Liquid
(تعين الكتلة المولية للسائل المتطاير)

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❖ ***Goals of the experiment :***

1. To measure the physical properties (pressure, volume, and temperature) for a gaseous substance
2. To determine the molar mass of an unknown volatile liquid

Introduction

- *To identify a new compound, a chemist must determine its properties, physical properties such as melting point, density, color, density, and elemental composition are normally measured.*

- *The molar mass (M, g/mol) of the new compound is one of the most properties to be `.*

- *There are many **analytical methods to measure** the M of an unknown substance based on its nature and state,*

1. ***Mass spectrometry (قياس الطيف الكتلي):*** *uses to determine the molar mass of compound as well as to identify the structures of high molar mass compounds in the biochemical fields.*

1. ***Dumas method** (**John Dumas**, 1800–1884) provides an accurate determination of molar mass of a volatile liquid by the use of ideal gas law, PV = nRT.*

In this analytical procedure (Dumas method),

1- The liquid is converted into a gas at an E/M flask at a measured temperature and barometric pressure.

2- Then use of the ideal gas law equation (PV = nRT, assuming ideal gas behavior), to calculatet the number of moles of vaporized liquid, n_{vapor} :

$$n_{\text{vapor}} = \frac{PV}{RT} = \frac{P(atm) \times V(L)}{(0.08206\ L \cdot atm/mol \cdot K) \times T(K)}$$

Where, In this equation,
-R is the universal gas constant (0.08206 L.atm/mol.K),
-P is the barometric pressure (الضغط الجوي) in atmospheres,
-V is the volume in liters of the E/M flask into which the liquid is vaporized, and
-T is the temperature in degrees kelvins of the vapor.

3-The mass of the vapor, m_{vapr}, is determined from the mass difference between the empty *E/M flask* and the vapor-filled vessel.

$$m_{vapor} = m_{flask + vapor} - m_{flask}$$

4-The **molar mass of the compound, M,** is then calculated from the available data:

$$M_{compound} = \frac{m_{vapor}}{n_{vapor}}$$

REMINDEr:

1. The barometer is an instrument accurately measures atmospheric pressure in mmHg (or torr).
2. the temperature of the vaporized liquid is determined in this experiment by measuring the temperature of water bath by using a thermometer,.

❖ **TUTORIAL VIDEO: please see the video (molar mass of a volatile liquid) at the links:**

https://youtu.be/0UJXa9Hd88I Or

https://youtu.be/Cm4n4YOkhNw

Example. Experimental Data and Calculations:

A 0.252 g of an unknown gas was found to have a volume of 175 mL. The temperature was found to be 27 °C and the pressure was 0.995 atm. Calculate the molar mass of the unknown gas.

Solution (Answer):

From the ideal gas law

$$n = PV/RT$$

$$= (0.995\ atm)(0.175\ L) / (0.0821\ L\ atm\ mol^{-1}K^{-1})\ (300\ K) = 0.00707\ mol.$$

then, $M_{gas} = mass/n = 0.252\ g/0.0707\ mol = 35.64\ g/mol$

van der Waals’ equation (معادلة فان دير والس)

-The ideal behavior of the gas assumes no intermolecular forces between its molecules in the vapor state. Also, assumes zero molar volume of the molecules.

-Gases and liquids with relatively large intermolecular forces and large molecular volumes deviate from ideal gas law equation.

-therefore, **van der Waals’ equation**, a modification of the ideal gas law equation, is used to correct for the intermolecular forces and molecular volumes in determining the moles of gas present in the system:

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

In this equation, ***P, V, T, R***, and *n* have the same meanings as in ideal gas eqn;

-***a*** is an experimental value that is representative of the intermolecular forces of the vapor, and

-***b*** is an experimental value that is representative of the volume (or size) of the molecules.

-A more accurate determination of the moles of vapor, $\boldsymbol{n}_{\mathbf{vapor}}$, in the flask is

Done by the use of van der Waals' equation rather than of the ideal gas law equation.

-Values of ***a* and *b*** for a number of low-boiling-point liquids are listed in the following table.

Van der Waals' Constants for Some Low-Boiling-Point Compounds

Name	a $\left(\frac{L^2 \bullet atm}{mol^2}\right)$	b (L/mol)	Boiling Point (°C
Methanol	9.523	0.06702	65.0
Ethanol	12.02	0.08407	78.5
Acetone	13.91	0.0994	56.5
Propanol	14.92	0.1019	82.4
Hexane	24.39	0.1735	69.0
Cyclohexane	22.81	0.1424	80.7
Pentane	19.01	0.1460	36.0
Water	5.46	0.0305	100.0

Experimental Procedure

Procedure Overview:

-A boiling water bath of measured temperature is used to vaporize the unknown liquid in a flask

-The volume of the flask is measured by filling the flask with water

-As the flask is open to the atmosphere, you will record a barometric pressure.

-You are to complete three trials in determining the molar mass of your low boiling point liquid.

-Be aware of the number of significant figures when recording data.

Procedure:

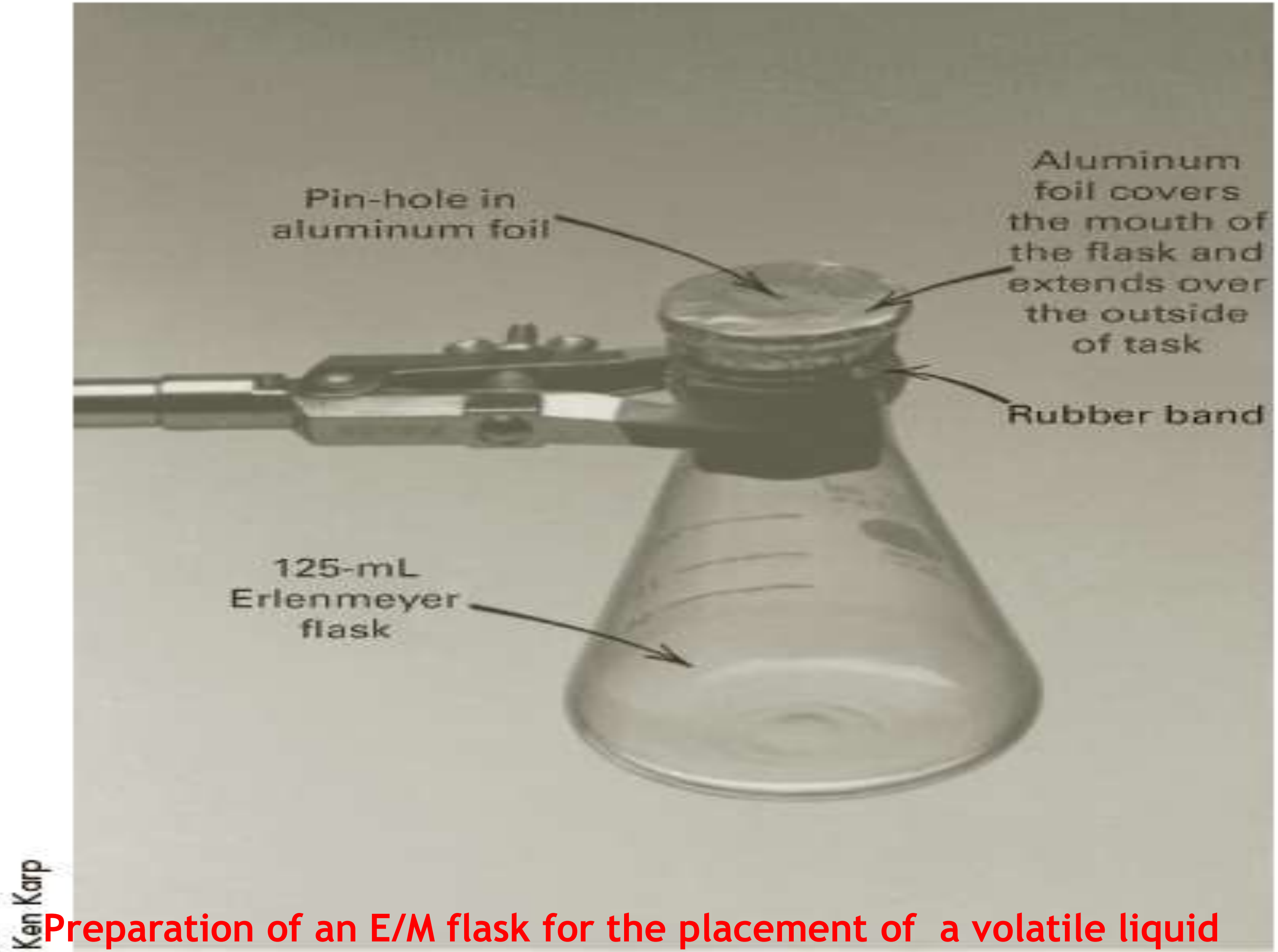
1. Clean and dry a 125 mL Erlenmeyer flask (E. flask). Dry in an oven or blowing hot air, do not wipe-dry or heat on a direct flame.

2. Weigh the dry E. flask to ± 0.001g.

3. Place about 5 mL of the unknown liquid in the E. flask, cover the neck with aluminum foil, and tighten it with the rubber band.

***Caution*:** Do not heat flammable liquids on a direct flame

4. Make few pin-holes (2 to 3) in the center of the aluminum foil.



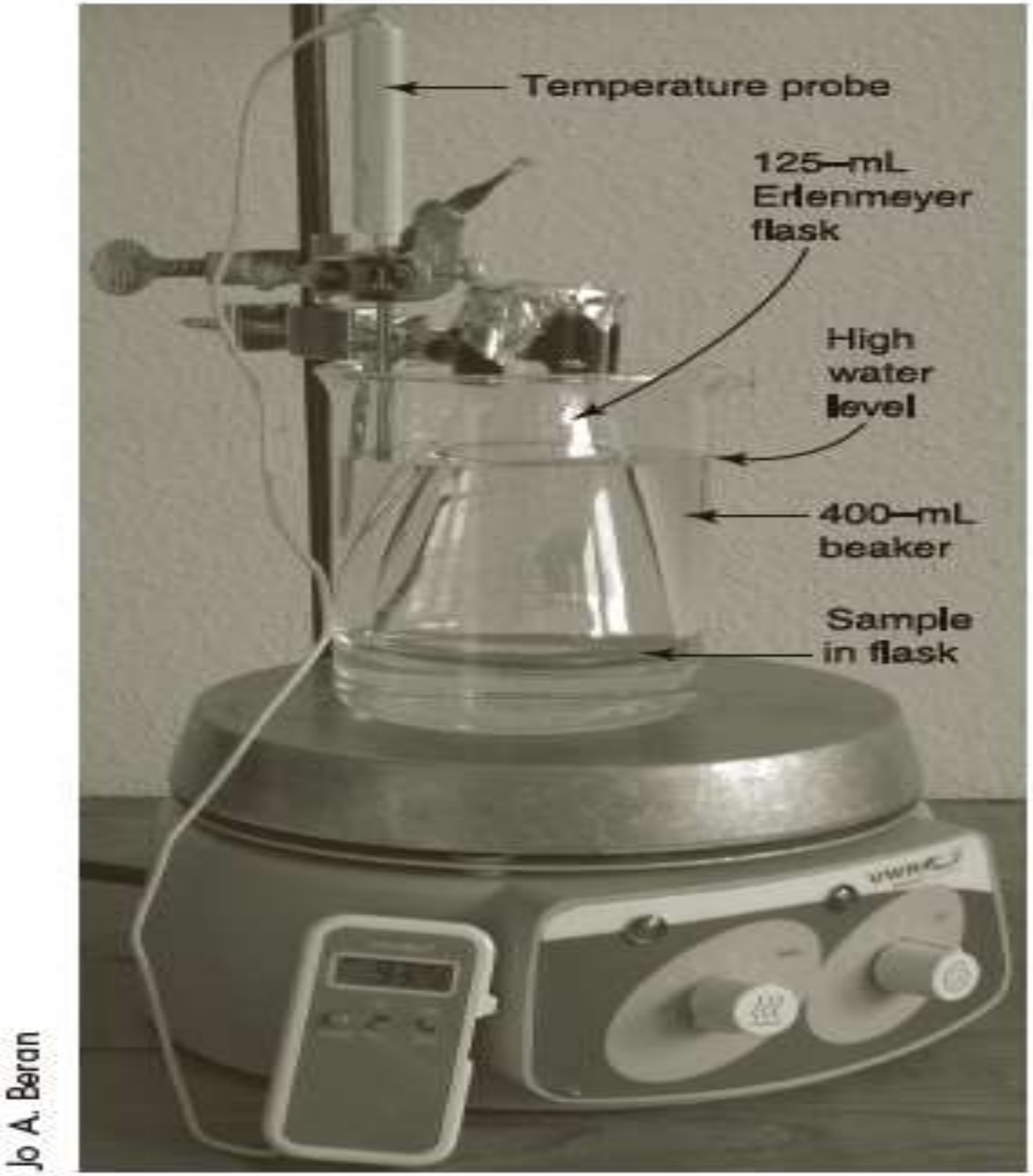
Preparation of an E/M flask for the placement of a volatile liquid

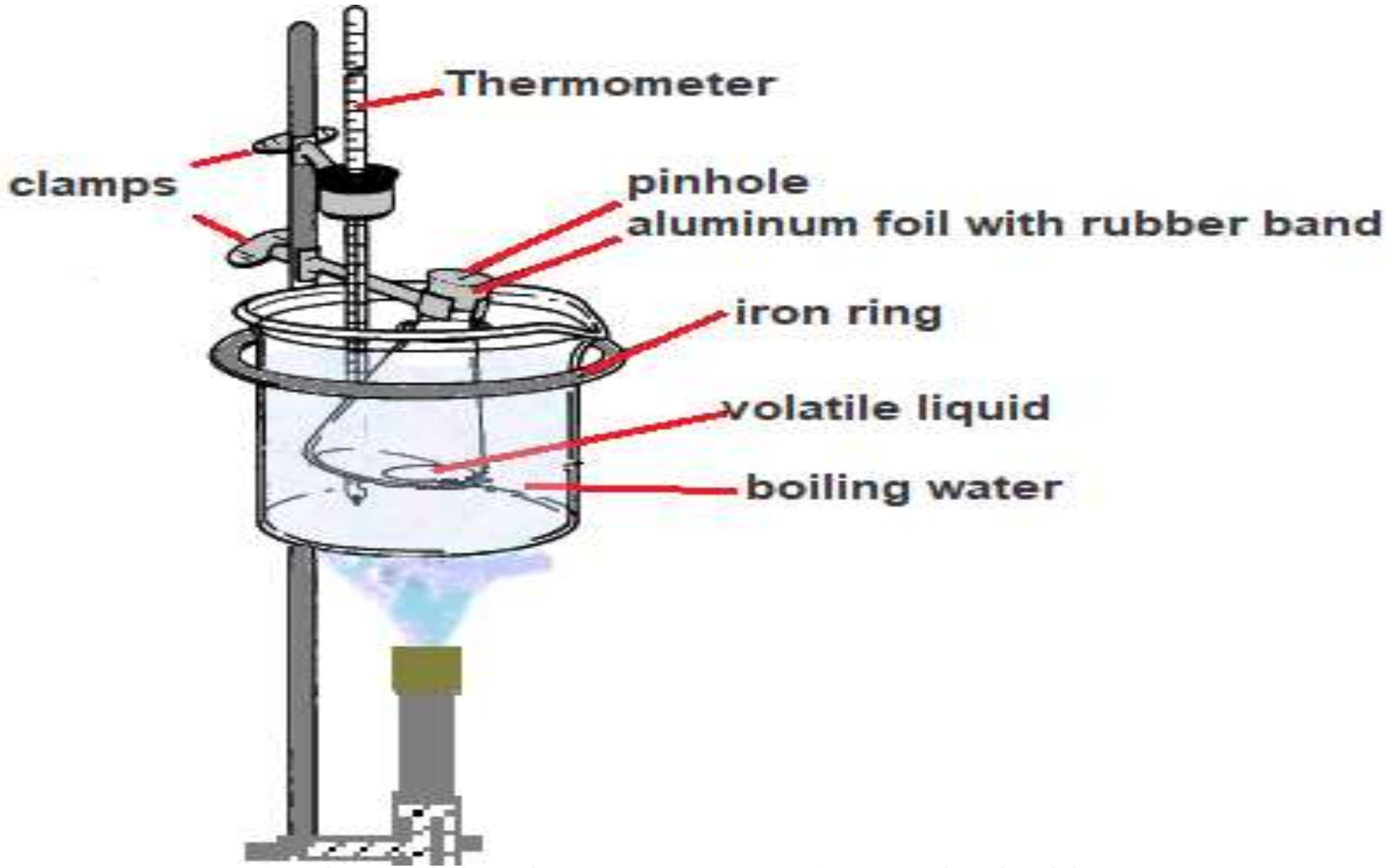
5. **Prepare a boiling water bath**. Make the installation of the water bath by the use of the stand, support ring, wire gauze, 400 mL beaker with suitable amount of water, and Benzene burner or hot plate. Add one or two boiling chips to the water.

Note: *Boiling chip: a piece of porous ceramic that releases air when heated (the bubbles formed prevent water from becoming superheated)*

6. Bring water to boil. Then remove the heat source (Benzene burner).

7. Dip the E. flask in the water bath and secure it with the clamp. Be sure that neither the flask nor the clamp touches the walls of the beaker. Also, the water level is high on the neck of the E. flask. The **complete setup** **for the Apparatus for determining the molar mass of a volatile liquid** is shown in the figure below:


Temperature probe
125-mL Erlenmeyer flask
High water level
400-mL beaker
Sample in flask
Jo A. Beran



Apparatus for determining the molar mass of a volatile liquid.

8. Put the heat source on again and heat gently to allow the vapors of the unknown liquid to go out through the wholes of the aluminum foil.

9. Stop heating when the vapors are no longer visible out of the flask, continue slow and gentle heating for few more minutes.

***Caution*:**
Avoid excessive heat not to allow all of the vapors of the liquid to leave the E. flask, also, the heating should be sufficient not to leave liquid unknown in the E. flask in the liquid form.

10. Use the thermometer in the laboratory to measure the temperature of the boiling water in the water bath and record it to $\pm 0.01^{o}C$.

11. Remove the E. flask, allow it to cool to room temperature, remove the Al-foil and the rubber band, dry the outside of the E. flask and weigh to ±0.001 g.

***Notes*:**

1. You may notice formation of some liquid inside the E. flask. It is the condensed vapor of the unknown liquid.
2. The difference in masses between steps 2 and 11 is the mass of the unknown that is to be used in the calculations.

12. **Measure the volume of the flask.** Fill the empty 125-mL Erlenmeyer flask to the brim with water. Measure the volume (±0.1 mL) of the flask by transferring the water to a 50- or 100-mL graduated cylinder. Record the total volume. Notice that the volume of the water is the volume that was occupied by the vapor the unknown. It is the volume to be used in calculations.

13. Use the barometer in the laboratory to measure the pressure. This is the pressure to be used in the calculations.

14. Molar mass from data.

a. Calculate the molar mass of your unknown for each of the three trials, then
b. Determine the standard deviation (SD) and the relative standard deviation (%RSD) for the molar mass of your unknown from your three trials.

PreLaboratory Questions

- **1. a.** How is the pressure of the vaporized liquid determined in this experiment?
- **b.** How is the volume of the vaporized liquid determined in this experiment?
- **c.** How is the temperature of the vaporized liquid determined in this experiment?
- **d.** How is the mass of the vaporized liquid determined in this experiment?

3. a. The following data were recorded in determining the molar mass of a volatile liquid following the Experimental Procedure of this experiment. Complete the table for analysis. (See ***Report Sheet***.) Record calculated values with the correct number of significant figures.

A. Preparing the Sample *Calculation Zone*

1. Mass of dry flask, foil, and rubber band (*g*) ____________

B. Vaporize the Sample

2. Temperature of boiling water (°*C*) ____________

3. Mass of dry flask, foil, rubber band,
and vapor (*g*) ____________

C. Determine the volume and Pressure of the Vapor

1. Volume of 125 mL flask (*L*) ____________

2. Atmospheric pressure (*torr, atm*) ____________

D. Calculations

1. Moles of vapor, *nvapor* (*mol*)
Equation 12.1.
Show calculation. ____________

2. Mass of vapor, *mvapor* (*g*)
Show calculation. ____________

3. Molar mass of vapor (*g/mol*)
Show calculation. ____________

3. b. For Trials 2 and 3, the molar mass of the vapor was determined to be 46.5g/mol and 43.1 g/mol respectively.

a. What is the average molar mass of the vapor? **Data Analysis, B.**

b. What are the standard deviation and the relative standard deviation (%RSD) for the molar mass of the vapor?

POST-Laboratory Questions

1. Part A.1. The mass of the flask (*before* the sample in placed into the flask) is measured when the outside of the flask is wet. However, in Part B.3, the outside of the flask is dried before its mass is measured.

a. Will the mass of vapor in the flask be reported as too high or too low, or will it be unaffected? Explain.

b. Will the molar mass of vapor in the flask be reported as too high or too low, or will it be unaffected? Explain.

2. Part A.1. From the time the mass of the flask is first measured in Part A.1 until the time it is finally measured in Part B.3, it is handled a number of times with oily fingers. Does this lack of proper technique result in the molar mass of the vapor in the flask being reported as too high or too low or as unaffected? Explain.

3. Part A.2. The aluminum foil is pierced several times with large pencil-size holes instead of pin-size.

a. How will this oversight in the procedure affect the mass of vapor measured in Part B.3, too low, too high, or unaffected? Explain.

b. Will the reported molar mass of the liquid be reported too low, too high, or unaffected? Explain.

4. Part B.2. The flask is completely filled with vapor *only* when it is removed from the hot water bath in Part B.3. However, when the flask cools, some of the vapor condenses in the flask. As a result of this observation, will the reported molar mass of the liquid be too high, too low, or unaffected? Explain.

5. Part B.2. Suppose the thermometer is miscalibrated to read 0.3°C higher than actual. Does this error in calibration result in the molar mass of the vapor in the flask being reported as too high, too low, or as unaffected? Explain.

6. Part C.1. If the volume of the flask is assumed to be 125 mL instead of the measured volume, would the calculated molar mass of the unknown liquid be too high, too low, or unaffected by this experimental error? Explain.

7. Part C.2. The pressure reading from the barometer is recorded higher than it actually is. How does this affect the reported molar mass of the liquid: too high, too low, or unaffected? Explain.