The Determination of Molar Mass By Boiling Point Elevation

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Abstract: Temperature increase, as measured by decrease in resistance, of a solution of tetrahydrofuran (THF) with various moles of benzoic acid dissolved was measured. Using the same solvent, resistance changes were measured as various masses of an unknown material were added. Knowing that increase in boiling point is directly proportional to the concentration of dissolved solute, the molar mass of the unknown was determined to be 112 g/mol, which compares favorably with the molar mass of the suspected substance, 3-hexenoic acid (molar mass 114 g/mol). This results in less than a 1.8% error.

INTRODUCTION:

The boiling point of a solution increases in direct proportion to the concentration of the solute dissolved in the solvent. In dilute solutions this relationship is given by:

$$\Delta T = K_b m \qquad \text{(Eq. 1)}$$

where ΔT is the change in boiling point, K_b is the boiling point elevation constant and m is the molality of the solution. In this experiment a thermistor will be used to measure these temperature changes and resistance changes of the thermistor will be recorded using an ohmeter. Since change in resistance is directly proportional to temperature change equation 1 can be rewritten as:

$$\Delta R = K_2 m \qquad \text{(Eq. 2)}$$

where ΔR is resistance change. Since the amount of solvent, tetrahydrofuran (THF), is held constant in this experiment the equation can be rewritten as:

$$\Delta R = K_3(\text{moles of solute}) \qquad \text{(Eq. 3)}$$

If ΔR is plotted versus total moles of solute added, the slope of the resulting line will be K_3 for the solvent used in this experiment, THF. Once K_3 is known, the molar mass of an unknown can be calculated by plotting ΔR versus total grams of unknown solute. For any point on the line the molar mass may be calculated from Eq. 3, remembering that moles of solute = grams of solute/molar mass of solute. All terms except molar mass are known.

PROCEDURE:

No changes were made from procedure outlined on video and described in the handout(1). Using the boiling point apparatus described, boiling solutions of various concentrations of benzoic acid and unknown, were circulated over the thermistor positioned between the ports of a Cottrell Pump. These resistance readings were made using a ohmeter.

RESULTS:

Table 1

Resistance readings for various amounts of benzoic acid dissolved in 25 mL tetrahydrofuran (THF)

R (KΩ)	grams benzoic acid	moles benzoic acid	ΔR (KΩ)
12.996	0	0	0
12.785	0.4949	0.004040	0.211
12.519	1.0986	0.009000	0.477
12.310	1.6245	0.01332	0.686
12.079	2.0410	0.01673	0.917
11.820	2.6900	0.02205	1.176
11.564	3.1742	0.02602	1.432

Table 2

Resistance readings for various amounts of unknown dissolved in 25 mL of tetrahydrofuran (THF).

R (KΩ)	grams of unknown	ΔR (KΩ)
13.018	0	0
12.821	0.3995	0.197
12.640	0.7790	0.378
12.476	1.1257	0.542
12.342	1.4532	0.694
12.171	1.7550	0.847
12.001	2.0655	1.017

SAMPLE CALCULATIONS:

Calculations are given for the first addition of benzoic acid to THF.

0.4949 g C_6H_5COOH x 1 mol benzoic acid/122.1 g benzoic acid = 0.004040 mol benzoic acid

ΔR (KΩ) = 12.785 KΩ - 12.996 KΩ = 0.211 KΩ

Figure 1. Graph of linear fit of resistance change with added moles of benzoic acid.

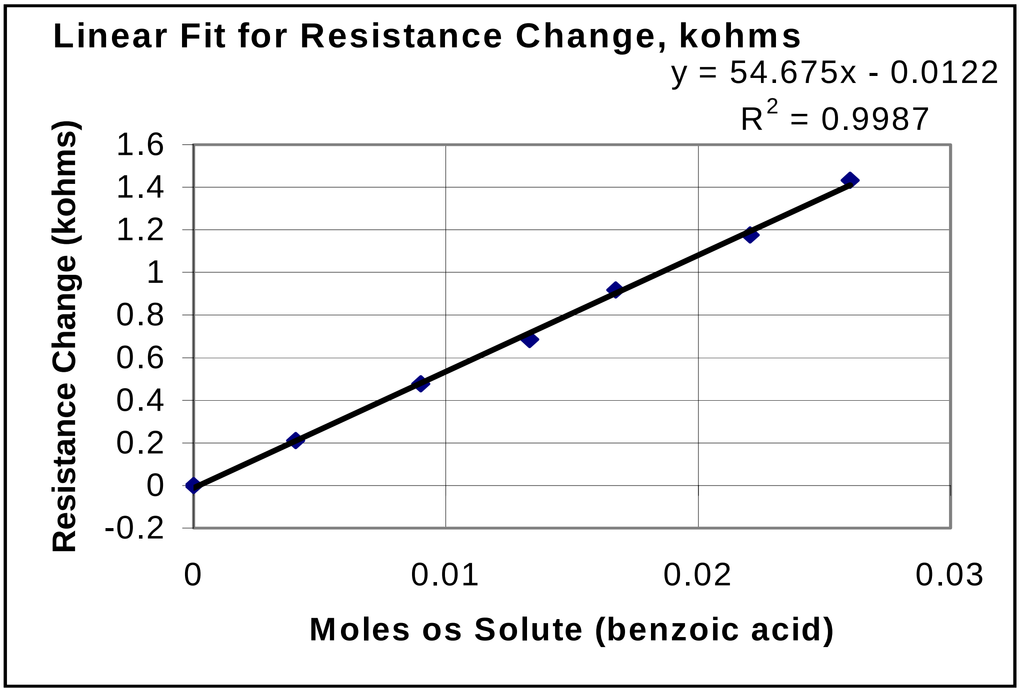
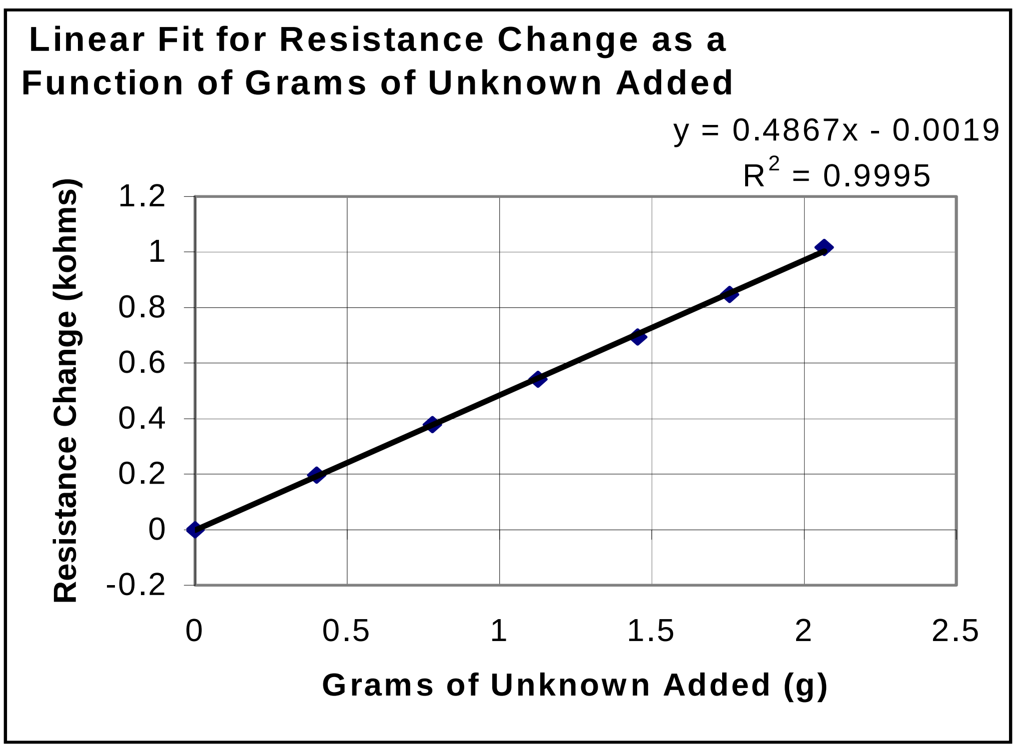


Figure 2. Graph of linear fit of resistance change as a function of grams of unknown added.



Since the slope of the graph moles of benzoic acid vs resistance change and that of the graph grams of unknown vs resistance change is only dependent on the solvent used the slopes are equal. Therefore 54.7 $\Delta K\Omega$/mol = 0.497$\Delta K\Omega$/gram of unknown. This results in a molar mass of the unknown of 112 g/mol. The suspected substance is 3-hexenoic acid with a molar mass of 114 g/mol. The % error is:

$$(112\text{-}114)\text{g}\times100/114\text{g} = 1.75\%\ \text{error}$$

CONCLUSIONS:

Based on the above discussion it is assumed that the unknown material may indeed be 3-hexenoic acid.

REFERENCES:

1. CHM152LL:General Chemistry II Laboratory Manual ,2004-2005, Hayden-McNeil Press