Calculating Avogadro's constant from a mass spectrum of methane

Enrico Uva
LaurenHill Academy
2505 Cote Vertu, St Laurent QC H4R 1P3

Introduction

The following activity, which is set up for student use on the next page, allows students to calculate Avogadro's constant from a mass spectrum of methane. It is my simplified version of a paper published in the *The Chemical Educator*, Volume 9, No. 1 by Mustafa Sariyaka in the Department of Science Education at Gazi University. A simple google search can find this article on-line. In his paper, Sariyaka indicates that the mass of a proton ($^1H^+$) and the mass of $^{12}C^+$ ion are proportional to the abscissa lengths of their peak locations (x_1 and x_2, respectively) in a mass spectrum of methane. This leads to the following equation:

$$\frac{\text{mass of } ^{12}C^+ \left(\text{in } \frac{g}{\text{ion}}\right)}{\text{mass of } ^{1}H^+ \left(\text{in } \frac{g}{\text{ion}}\right)} = \frac{x_1 \left(\text{in } \frac{mm}{\text{ion}} \text{ for } ^{12}C^+\right)}{x_2 \left(\text{in } \frac{mm}{\text{ion}} \text{ for } ^{1}H^+\right)}$$

Using the mass of a proton, the mass of a $^{12}C^+$ ion can be calculated. The mass of one electron can be added to the $^{12}C^+$ ion to give the mass of a carbon atom. Avogadro's constant can be calculated according the definition of the mole,

$$N_A = \frac{12.00000 \text{ g}(\text{mol } ^{12}C)^{-1}}{m_{^{12}C} \text{ in g}(\text{atom } ^{12}C)^{-1}} .$$

This activity leads students through the calculation of Avogadro's constant without having to know much about mass spectroscopy. They just need to know stoichiometry and how to use a ruler carefully. To make it more interesting, students are not told what they are looking for; it will become apparent in the last step of the activity. The mass spectrum is scanned from Sariyaka's original article. The top of the spectrum was cut off in order to fit the page. Therefore the peak heights are no longer proportional to the percent abundance. To aid students with their measurements, the peaks from $^1H^+$ and $^{12}C^+$ have been thinned out using MS Photoshop.

The activity is in the format used as part of the Science Olympics I have in class. Students carry out the activities in groups of 2 or 3. Other events include a titration race, a plastic egg-shell firing contest and identification of compounds, elements and other goodies from electron-scanning micrograph slides.

If the students are curious about the other peaks, they can hypothesize about the possible fragments that may account for them. The students can use one carbon atom with four hydrogen atoms in any combination. For example, some of the possible cations that methane produced when bombarded with electrons are as follows.[1]

Methane fragments

	$[CH_4^+]\cdot$	CH_3^+	$[CH_2^+]\cdot$	CH^+	$[C^+]\cdot$	$[H_2^+]\cdot$	$[H^+]$
m/z	16	15	14	13	12	2	1

Answers to worksheet

The assignment was valued at 10 marks. All correct answers were given a 1-mark value except for question 6, which had a value of 3. The conclusion was worth 2 marks.

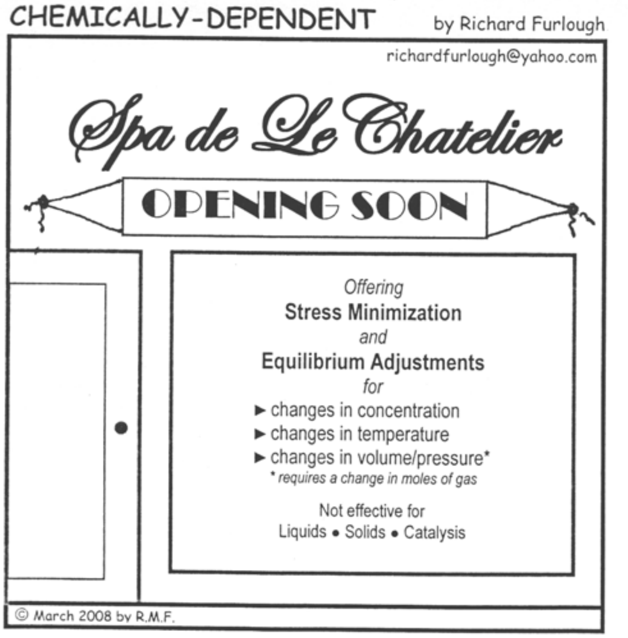
1. 6.5 mm;   2. 77.5 mm
3. 11.92307692 (Significant figures applied to last step only.)
4. $^{12}C^+$ = 11.92307692*1.67262 x 10^{-24} g
   = 1.994277692 x 10^{-23} g
5. 1.994277692 x 10^{-23} g + 9.10938 X 10^{-28}g
   = 1.994368786 x 10^{-23} g
6. 12.000000 g/mole/(1.994368786 X 10^{-23} g/atom)
   = 6.0 X 10^{23} g
   (2 significant figures, because of 6.5 mm measurement)

Conclusion: By using the mass spectrum of CH_4, a ruler and some routine calculations we found the number of atoms in 12.0000 g of ^{12}C to be 6.0 x 10^{23}.

References

1. Andrew Streitweiser and Clayton H. Heathcock, *Introduction to Organic Chemistry 3rd edition,* Macmillan Publishing Company, 1985

Student activity ⇒



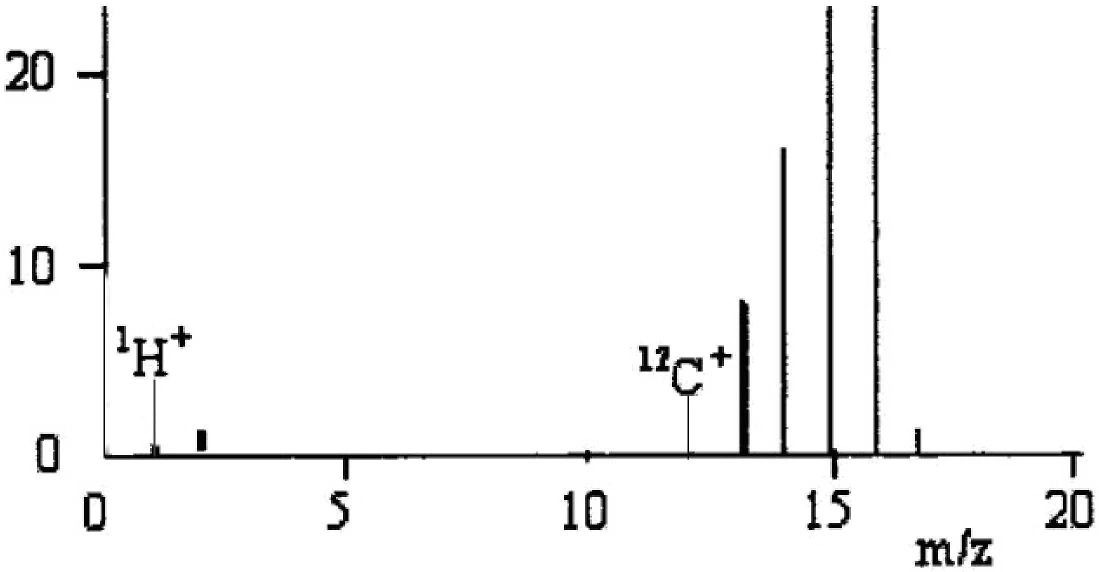
LeChatelier's Principle gets
a long overdue makeover.

Science Olympics

Team ______________________

Event: To use a mass spectrum, a ruler and some routine calculations to come up with an important constant of chemistry.

Procedure: The following is part of the mass spectrum of CH_4. The instrument has broken the molecule into fragments. The ones that concern us are $^{1}H^{+}$ and $^{12}C^{+}$.



Look for these on the x axis. Don't be thrown off by the bold line to the right of $^{12}C^{+}$.

1. As carefully as possible, (to one estimated decimal place), use a ruler to measure the x coordinate of the $^{1}H^{+}$ peak in mm.

   $^{1}H^{+}$ =__________________mm

2. As carefully as possible, (to one estimated decimal place), use a ruler to measure the x coordinate of the $^{12}C^{+}$ peak in mm.

   $^{12}C^{+}$ =__________________mm

3. Express the above measurements as a ratio of **$^{12}C^{+}/^{1}H^{+}$.**

   $^{12}C^{+}/^{1}H^{+}$ =___________________

4. Using this ratio and the mass of the proton = 1.67262×10^{-24} g (which comes from Thomson's and Millikan's experiments), calculate the mass of $^{12}C^{+}$.

5. From the mass of $^{12}C^{+}$ and the mass of the electron = 9.10938×10^{-28} g, calculate the mass of ^{12}C.

6. You have just found the mass of a *single atom* of ^{12}C. Now divide the molar mass of ^{12}C by the mass of a single atom of ^{12}C. Show the calculation with the appropriate units for each measurement. Also express your answer with the appropriate unit.

The Finish line ─ Conclusion:

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