IONIZATION ENERGY

VOL 15

SUMMARY:

Two methods of measuring ionization energy, photo-ionization and electron bombardment, are shown. A high-vacuum system is used with a simple cell to measure electric conductivity of gases. The photo-ionization of sodium by the use of a mercury light source and a monochromator is carried out. The electron-bombardment method is then demonstrated with sodium and three noble gases. Animation shows what occurs on the atomic level during the ionization process. Ionization energy is defined as the minimum energy needed to remove an electron from a gaseous atom, with energy per mole being a more practical unit to use. Relation of ionization energy to chemical reactivity is explained.

PURPOSE:

To provide experimental background for the use of ionization energy in correlating chemical reactivity. To show experiments which measure ionization energy, and to explain with animation what occurs at the atomic level during both photo-ionization and electron bombardment.

OUTLINE:

1. *Chemical reactivities contrasted.*

   Sodium and chlorine reaction; the electron transfer is explained with an orbital board. An attempt is made to react neon and chlorine. The result is explained with an orbital board.

2. *Ionization energy defined.*

   Sodium is vaporized. Animation of a sodium atom is used to define the process of ionization. Light, heat, and high-energy electrons are described as sources of energy for the ionization process.

3. *Photo-ionization presented experimentally.*

   The high-vacuum apparatus is explained. The photo-ionization cell is shown and its function explained. The light source and the prism monochromator are demonstrated. The need for equation $E = h\nu$ is explained.

4. *Ionization energy of sodium determined by photo-ionization.*

   The experiment is started by heating sodium in the cell to produce sodium gas. It is found that 12.4×10^{14} cycle/sec is the frequency which produces ionization. An animated explanation of the photo-ionization experiment is given, along with atomic level details. The ionization energy of sodium is calculated from the equation $E = h\nu$:

$$E = (9.53 \times 10^{-14} \frac{\text{kcal sec}}{\text{mole}})(12.4 \times 10^{14} \frac{1}{\text{sec}}) = 118 \frac{\text{kcal}}{\text{mole}}$$

$$118 \frac{\text{kcal}}{\text{mole}} \times (4.184 \frac{\text{kJoule}}{\text{kcal}}) = 494 \frac{\text{kJoule}}{\text{mole}}$$

5. *Ionization by electron bombardment.*

   The electron-bombardment method is explained. The function of the electron-bombardment cell is described with animation. The experiment is performed for gaseous sodium, obtaining 5 volts as the critical accelerating voltage. Details of the experiment at the atomic level are given. The ionization energy is calculated.

   Each electron is accelerated by 5 volts, acquiring 5 electron-volts of energy. Then conversion to kcal/mole is made:

$$E = (23.1 \frac{\text{kcal}}{\text{mole eV}})(5 \text{ eV}) = 115 \frac{\text{kcal}}{\text{mole}}$$

or

converting to kJoule/mole:

$$115 \frac{\text{kcal}}{\text{mole}} \times (4.184 \frac{\text{kJoule}}{\text{kcal}}) = 483 \frac{\text{kJoule}}{\text{mole}}$$

or

$$E = (96.5 \frac{\text{kJoule}}{\text{mole eV}})(5 \text{ eV}) = 483 \frac{\text{kJoule}}{\text{mole}}$$

   The electron-bombardment method is used on helium, argon, and xenon. The results are compared to established values. Values for neon and krypton are added to the list.

   A complete Reference Table follows:

Element	Atomic Number	Experiment Value (electron volt)	Reference Value (eV)	(kcal/mole)	(kJ/mole)
He	2	25.0	24.6	567	2372
Ne	10		21.6	496	2075
Ar	18	16.5	15.8	363	1518
Kr	36		14.0	320	1338
Xe	54	12.5	12.1	280	1171

6. *Ionization energy as a function of atomic number.*

   The ionization energies of the noble gases are plotted against atomic number. The same is done for the alkali metals. The values for elements up to about atomic number 60 are added to the plot. Periodic variations in ionization energy are discussed and related to chemical periodicity. The ionization energy of iron is about 8eV, a value typical of many metals.
   energy levels. Correlate ionization energy and chemical reactivity.

SUPPLEMENTARY MATERIAL:

Planck's Constant, h, is usually given as 6.62×10^{-27} erg sec, which is on a "per atom" basis. In order to use the equation $E = h\nu$ to obtain energy in kcal/mole, multiplying by conversion factors is needed as follows:

$$\text{one } \frac{\text{erg}}{\text{atom}} \times (2.389 \times 10^{-11} \frac{\text{kcal}}{\text{erg}}) \times (6.022 \times 10^{23} \frac{\text{atom}}{\text{mole}}) = 1.44 \times 10^{13} \frac{\text{kcal}}{\text{mole}}$$

or, to obtain energy in kJoule/mole, convert as follows:

$$\text{one } \frac{\text{erg}}{\text{atom}} \times (1.000 \times 10^{-10} \frac{\text{kJoule}}{\text{erg}}) \times (6.022 \times 10^{23} \frac{\text{atom}}{\text{mole}}) = 6.02 \times 10^{13} \frac{\text{kjoule}}{\text{mole}}$$

The unit of energy "electron-volt" is defined as the energy acquired by an electron when it has been accelerated by a potential difference of one volt. A handbook shows that 3.826×10^{-23} kcal is equivalent to 1 electron volt.

$$\text{one } \frac{\text{eV}}{\text{atom}} \times (3.826 \times 10^{-23} \frac{\text{kcal}}{\text{eV}}) \times (6.022 \times 10^{23} \frac{\text{atom}}{\text{mole}}) = 23.0 \frac{\text{kcal}}{\text{mole}}$$

Also, 1.602×10^{-22} kJoule is equivalent to 1 electron volt, so . . .

$$\text{one } \frac{\text{eV}}{\text{atom}} \times (1.602 \times 10^{-22} \frac{\text{kJoule}}{\text{eV}}) \times (6.022 \times 10^{23} \frac{\text{atom}}{\text{mole}}) = 96.5 \frac{\text{kjoule}}{\text{mole}}$$

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