Chemical Bonding Explained by Violation of Third Law of Motion

Debjyoti Biswadev Sengupta

Smt. Sulochanadevi Singhania School, Jekegram, Thane(W)- 400606, India

Abstract: ***This paper makes an attempt to explain chemical bonding in terms of electrostatic forces, thermodynamics and takes into consideration the fact that electrostatic forces do not obey Newton's Third Law of Motion***

Keywords: Electrostatic forces, ionization potential, electron gain enthalpy, Newton's Third Law of Motion

1. Introduction

This paper shall discuss how does chemical bonding take place between any two atoms in terms of the electrostatic forces exerted by them and also establishes a relation between electrostatic forces and the ionization potential and electron gain enthalpy. Also, it shall be discussed in detail how the Newton's third law is being violated by electrostatic forces.

2. Violation of Newton's Third Law of Motion

Earlier, in the previous paper [5], we had provided a mathematical proof for the fact that Newton's Third Law of Motion is being violated by the conservative forces, among which electrostatic forces is one of them. Now, we shall be discussing why did we take into consideration the Bohr's model of atom for the mathematical proof as well as a new form of the Heisenberg's uncertainty principle in terms of angular displacement and force.

2.1 Consideration of the Bohr's Model of Atom for Mathematical Proof

The mathematical proof for electrostatic forces violating the Third Law of Motion proceeds in the following way:

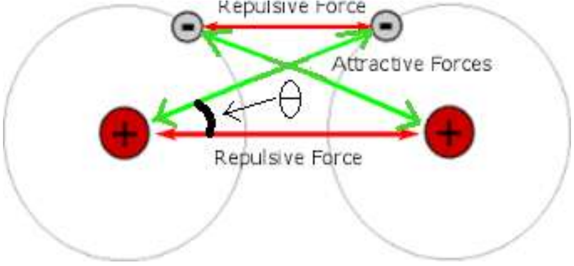

Figure 1: Electrostatic force between two atoms

As per the given diagram, we have four electrostatic forces acting, two each of electrostatic force of attraction as well as repulsion. In this case, we will take into consideration of hydrogen atom. So, let us proceed with the derivation.

Let F_1 *and* F_2 *be the electrostatic force of repulsion*
Let F_3 *and* F_4 *be the electrostatic force of attraction*
Let r *be the internuclear distance between the two atoms*
Let r' *be the distance between the nucleus and the electron*
Let q_1 *and* q_2 *be the charge of the proton and electron*

$$We\ know, F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{(1\cdot 6\times 10^{-19})^2}{r^2}$$

$$Similarly, F_2 = \frac{1}{4\pi\varepsilon_0}\frac{(-1\cdot 6\times 10^{-19})^2}{r^2}$$

$$Now, as\ per\ the\ given\ diagram, r' = \frac{r}{\cos\theta}, where\ \theta\ is\ angle\ between\ r'\ and\ r$$

$$F_3 = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

$$F_3 = \frac{1}{4\pi\varepsilon_0}\frac{-(1\cdot 6\times 10^{-19})^2\ \times\cos^2\theta}{r^2} = F_4$$

$$Let\ F_r\ be\ the\ net\ electrostatic\ force\ of\ repulsion$$
$$Let\ F_a\ be\ the\ net\ electrostatic\ force\ of\ attraction$$
$$F_r = F_1 + F_2$$
$$F_a = F_3 + F_4$$

As per the above calculations, the net electrostatic force of attraction between the atoms is more than the net electrostatic force of repulsion between the two atoms. As per Newton's Third Law of Motion,

$$F_r = F_a$$

but as per our calculations and observations,

$$F_r \neq F_a$$

This show that electrostatic force, which is a non-contact force, disobeys Newton's Third Law of Motion.

Now, looking at the derivation, we must be wondering that why have we taken into consideration the Bohr's Model of Atom for our derivation.

After much research and analysis, we think that the Bohr's Model of Atom is pretty much appropriate for the derivation because firstly, it is in support of the de Broglie's equation which discusses the relation of the particle and the wave nature of an atom. Lastly, we can apply the Heisenberg's uncertainty principle in the Bohr's model of atom by making a slight adjustment in the model by considering that the electrons are revolving around the nucleus in a well-defined electron cloud where there is the maximum probability to find an electron as per quantum rules.

2.2 Heisenberg's Uncertainty Principle in terms of angular displacement and force

We are well aware of the general form of the Heisenberg's Uncertainty Principle, which is given as:

$$\Delta x . \Delta p \ge \frac{\hbar}{2}$$

where $\hbar$ is the reduced Planck's constant which is given by $h/2\pi$.

If we do the following process,

$$\Delta x . \Delta p \ge \frac{\hbar}{2}$$

$$\lim_{\substack{\Delta x \to 0 \\ \Delta p \to 0}} \Delta x . \Delta p \ge \frac{\hbar}{2}$$

$$dp \ge \frac{\hbar}{2dx}$$

$$dm . dv \ge \frac{\hbar}{2dx}$$

$$dm . \frac{dx}{dt} \ge \frac{\hbar}{2dx}$$

$$\frac{dm}{dt} \ge \frac{\hbar}{2(dx)^2}$$

$$dm \ge \frac{\hbar . dt}{2(dx)^2}$$

$$dm . (dx)^2 \ge \frac{\hbar . dt}{2}$$

Integrating both the sides, we get:

$$\int dm . \int_0^{\Delta x} (dx)^2 . dx \ge \frac{\hbar}{2} \int_0^{\Delta t} dt . dt$$

$$\Delta m . \frac{(\Delta x)^3}{3} \ge \frac{\hbar}{2} . \frac{(\Delta t)^2}{2}$$

$$\Delta m . \frac{(\Delta x)^2 . \Delta x}{3(\Delta t)^2} \ge \frac{\hbar}{4}$$

$$But \frac{\Delta x}{(\Delta t)^2} \ can\ be\ given\ by\ \Delta a$$

$$\Delta m . \Delta a . \frac{(\Delta x)^2}{3} \ge \frac{\hbar}{4}$$

$$\Delta m . \Delta a \ge 3 . \frac{\hbar}{4(\Delta x)^2}$$

we will obtain the following expression,

$$\Delta F \ge 3 . \frac{\hbar}{4(\Delta x)^2}$$

As per the derivation mentioned in Heading 2.1, we are aware that by simplifying, we obtain the expression,

$$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2 . \cos^2 \theta}{r^2}$$

Therefore,

$$\frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2 . \cos^2 \Delta\theta}{r^2} \ge 3 . \frac{\hbar}{4(\Delta x)^2}$$

$$\cos^2 \Delta\theta \ge 4\pi\varepsilon_0 . \frac{3 . \hbar . r^2}{4(\Delta x)^2 . q_1 q_2}$$

$$\cos \Delta\theta \ge \sqrt{4\pi\varepsilon_0 . \frac{3 . \hbar . r^2}{4(\Delta x)^2 . q_1 q_2}}$$

$$\Delta\theta \ge \cos^{-1}\left(\sqrt{4\pi\varepsilon_0 . \frac{3 . \hbar . r^2}{4(\Delta x)^2 . q_1 q_2}} \right)$$

$$\Delta\theta \ge \cos^{-1}\left(\sqrt{\frac{3 . \hbar . \cos^2 \Delta\theta}{4(\Delta x)^2 . \Delta F}} \right)$$

where $\Delta\theta$ represents the uncertainty in the angular displacement of an electron in an atom with respect to the same or different atom.

3. Relation of the Electrostatic forces and the Enthalpies of given atoms

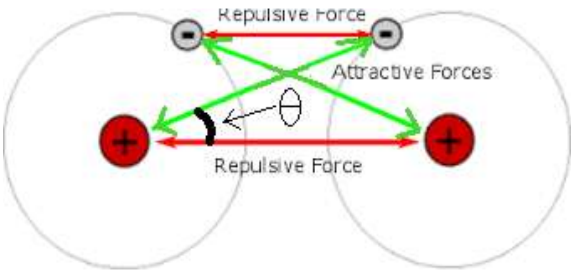

Figure 2: Electrostatic force between two atoms

From the above diagram, it is hypothesized that unless and until the net electrostatic forces between the atom is not equal or less than the limiting value, the two atoms cannot create a bond between them, whether the bond be ionic in nature or covalent, as it has been studied that if the electrostatic forces have a greater value than the limiting value, the repulsive electrostatic forces are strong enough to prevent the bonding from taking place. The limiting value for the electrostatic force beyond which the chemical bonding takes place is given as follows:

$$F = k \cdot \sqrt{\frac{\Delta H_i \cdot \Delta H_{eg}}{r^2}}$$

By the method of dimensions, we can derive the above formula and the experimental data is also in support of the expression. The process is as follows:

$$F \propto (\Delta H_i)^a (\Delta H_{eg})^b (r)^c$$

$$[M\ L\ T^{-2}] = k[M^{a+b} L^{2a+2b+c} T^{-2a-2b}]$$

$$a + b = 1$$

$$2a + 2b + c = 1$$

$$2(a + b) + c = 1$$

$$2 + c = 1$$

$$c = -1$$

$$(a + b)^2 = a^2 + b^2 + 2ab$$

$$1 - 2ab = a^2 + b^2$$

$$2ab = 1 - a^2 - b^2$$

$$(a - b)^2 = a^2 + b^2 - 2ab$$

$$(a - b)^2 = 1 - 4ab$$

$$(a - b)^2 = 1 - 2 + 2b^2 + 2a^2$$

$$(a - b)^2 = -1 + 2b^2 + 2a^2 \ \ldots\ldots\ldots\ldots\ldots 1$$

$$(a - b)^2 = 4ab + 2b^2 + 2a^2 \ \ldots\ldots\ldots\ldots\ldots 2$$

$$Subtracting\ 1\ \&\ 2, we\ get:$$

$$0 = -1 + 4ab$$

$$1 = 4ab$$

$$ab = \frac{1}{4}$$

$$Substituting\ the\ value\ of\ ab, we\ get:$$

$$a - b = 0$$

$$a + b = 1$$

$$2a = 1$$

$$a = \frac{1}{2}$$
$$b = \frac{1}{2}$$
$$F = k \cdot \sqrt{\frac{\mathit{\Delta} H_i \cdot \mathit{\Delta} H_{eg}}{r^2}}$$

4. Experimental Data analysis

After gathering experimental data from the NIST database, we have plotted an exact as well as a trend-line graph of first ionization potentials and electron gain enthalpies given by the expression $\sqrt{\mathit{\Delta} H_i \cdot \mathit{\Delta} H_{eg}}$ v/s Bond length(in nm) when two similar atoms of the same element take part in the chemical bonding process and the graphs look something of this sort:

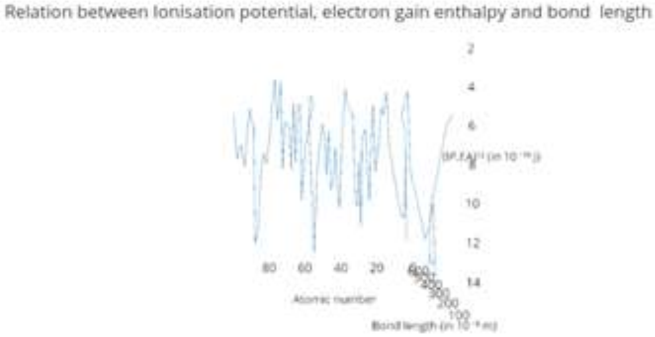

Figure III: Actual graph of the relation between bond length and $\sqrt{\Delta \mathrm{H_i} \cdot \Delta \mathrm{H_{eg}}}$(inverted X, Y and Z axes)

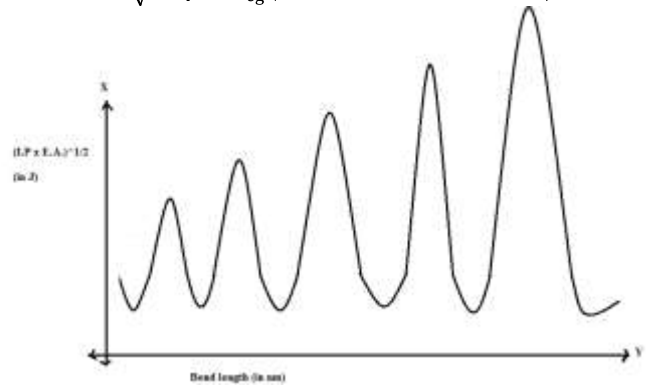

Figure III: Trend-line graph of the relation between bond length and $\sqrt{\mathit{\Delta} H_i \cdot \mathit{\Delta} H_{eg}}$

From the above graphs, we can observe that it resembles the Meyer's Atomic Volume Curve as well as the $4\pi r^2\psi^2$ curve as suggested by the Schrödinger's Wave Equation. Thus, from the above observations, we can also hypothesize that the bond length as well as the expression $\sqrt{\mathit{\Delta} H_i \cdot \mathit{\Delta} H_{eg}}$may have some relation with the wave function as well as atomic volume and atomic mass.

5. Postulates of the Chemical Bonding Theory

- The electrostatic forces play a role in the process of chemical bonding between any two atoms.
- If the chemical bonding has to take place, the value of the electrostatic forces has to be less or equal to the value given by the expression $F = k \cdot \sqrt{\frac{\mathit{\Delta} H_i \cdot \mathit{\Delta} H_{eg}}{r^2}}$ where k represents the constant of proportionality
- The position of the electron can be specified by the given expression

$$\Delta\theta \geq \cos^{-1}(\sqrt{\frac{3.\hbar.\cos^2\Delta\theta}{4(\Delta x)^2.\Delta F}})$$

- When the value of electrostatic forces exceeds the limiting value, it is observed that the repulsive electrostatic forces are strong enough to prevent the bonding to take place, leading to repulsion between the two atoms.
- When the value of electrostatic forces is much less than the limiting value, it will lead to formation of an ionic bond.
- When the value of electrostatic forces is comparable but still less than the limiting value, it leads to formation of a non-polar covalent bond.
- When the value of electrostatic forces is equal to the limiting value, it results to a co-ordinate bond or a polar covalent bond.

References

[1] NIST Data base for Bond length
[2] NIST Data base for ionisation potential
[3] NIST Data base for electron gain enthalpy
[4] InternationalJournal ofScience and Research, ART20173891, Theory of Unidirectional and Multidirectional Forces and Violation of Third Law of Motion, DB Sengupta

Author Profile

Debjyoti Biswadev Sengupta is a Grade 11 student in Smt. Sulochanadevi Singhania School, Thane(W), one of India's best ICSE schools. He published his first paper at the age of 17 titled 'Solving quadratic equations by calculus and its applications' in International Journal of Mathematics Trends and Technology. He currently lives in India.