



LXXXII. Some dimensions of the atom

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LXXXII. *Some Dimensions of the Atom.**By* L. St. C. BROUGHALL*.

IN the majority of the theories so far advanced on the subject of the structure of the atom, little has been said about the actual dimensions.

The diameter of the molecule varies approximately between 1 and 10×10^{-8} cm., the value for hydrogen being somewhere in the region of 2×10^{-8} cm. Now in the case of the inert gases we conclude, on the evidence afforded by the ratio of the specific heat at constant pressure to the specific heat at constant volume, that the molecules are monatomic. Therefore, any investigation on the size of the molecule is also, for these gases, an investigation on atomic dimensions.

There are several methods which have been applied to the measurement of σ , the diameter of the molecule of a gas, and the experimental values for the inert gas have been found particularly in two ways, namely—(i.) the value deduced from “ b ” in Van der Waals’ equation; (ii.) the value obtained from the viscosity of the gas.

Now in the first case we have the equation $\left(p + \frac{a^2}{v}\right)(v - b) = R\theta$, where “ b ” is a numerical constant required to correct the simple gas law for the volume of the molecules present. In order to obtain the diameter we use the equation $\sigma = \left(\frac{3b}{2\pi N}\right)^{\frac{1}{3}}$ where $N = 2.75 \times 10^{19}$.

In the second case σ can be calculated from the equation $\sigma = \left(0.0912 \frac{\rho G}{N\eta}\right)^{\frac{1}{3}}$ where ρ = density of gas in gms./c.c. at S.T.P., G = velocity of molecule in cms./sec. at 0° C., η = viscosity, N = number of molecules per c.c. at 0° C. and 76 cm. pressure $= 2.75 \times 10^{19}$.

Using the above formulæ we find that the values for the inert gases are as follows:—

Gas.	Molecular diameter deduced from	
	η .	b .
Helium	2.02×10^{-8} cm.	2.30×10^{-8} cm.
Neon	2.37 „ „
Argon	3.41 „ „	2.86 „ „
Krypton ...	3.89 „ „	3.14 „ „
Xenon	4.58 „ „	3.42 „ „

* Communicated by the Author.

Now, owing to the differences between the values obtained by the two methods, it is apparent that the diameter can only be found to one significant figure, and in some cases even this accuracy cannot be obtained. On the other hand, we would expect that the values deduced from one source would show any relation existing between the respective molecules.

Now both sets of values show an increase in σ with increase in the atomic number of the element, presuming it is a monatomic gas; but the values obtained from " b " of Van der Waals' equation show a much more remarkable fact, namely, that the increase in moving from one inert gas to the succeeding one is a constant. Thus :

$$\sigma_{\text{Xe}} - \sigma_{\text{Kr}} = .28 \times 10^{-8} \text{ cm.}; \quad \sigma_{\text{Kr}} - \sigma_{\text{A}} = .28 \times 10^{-8} \text{ cm.};$$

$$\sigma_{\text{A}} - \sigma_{\text{He}} = .56 = .28 \times 2 \times 10^{-8} \text{ cm.}$$

Unluckily I have not got the value for Neon, but it is almost certain that its diameter is 2.58×10^{-8} cm.

These figures become much more interesting when compared with Langmuir's "Theory of Atomic Structure," published in the Journal of the American Chemical Society for 1919.

Now, it was found by H. J. Moseley in 1913 that the number of electrons in the atom of an element is equal to the atomic number of that element. Thus the atomic number (N) for Helium = 2; Neon = 10; Argon = 18; Krypton = 36; Xenon = 54; Niton = 86.

These figures were shown in Langmuir's paper to obey a very simple law, namely, that $N = 2(1^2 + 2^2 + 2^2 + 3^2 + 3^2 + 4^2)$ for the inert gases. Thus N for Helium = $2(1^2)$. N for Neon = $2(1^2 + 2^2)$, etc.

On this, and in order to explain the valency of the elements and their magnetic properties, Langmuir advanced the explanation that each of the terms in the above equation represents a complete shell of electrons, but the Neon-Argon shells are formed into one shell, as also the Krypton-Xenon shells.

The respective shells are referred to as I, II *a*, II *b*, III *a*, III *b*, IV. Now he further states that the distance between the first shell and shell II *b* is equal to the distance between shells II *b* and III *b*. Now the above figures prove that this is the case, and it follows that each electron has the same free space at its disposal irrespective of the shell it belongs to, as the number of electrons increases in the same proportion as the space available; but owing to the existence of the shells II *b* and III *b*, one has to presume that two electrons can be squeezed into the space for one without

making the atom unstable. This is the case of the Argon and Xenon atoms.

In the case of the inert gases the outer shell is always complete and there is no tendency to acquire other electrons; their valency is therefore zero. All the other elements have the outer shell incomplete, and the valency is given by the number of electrons which must be gained or lost in order to produce the stable structure peculiar to the inert gases.

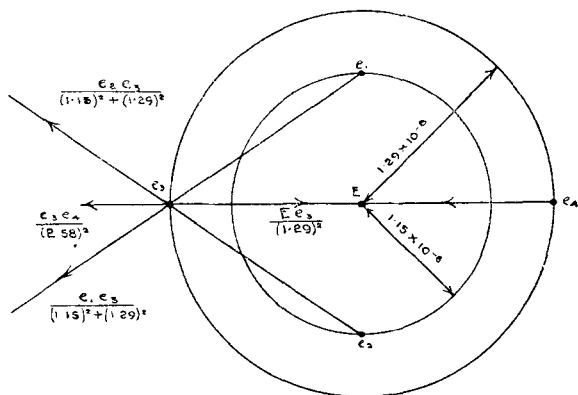
The Boron atom with an atomic number of 5 consists of a positive nucleus; then there are two electrons corresponding to the Helium atom, and finally a ring of three electrons in the shell corresponding to the Neon shell.

The diameter of the atom should therefore be the same as that of the Neon atom, namely 2.58×10^{-8} cm. These figures therefore give considerable support to this interesting theory; but it must be remembered that only when the atomic diameter is calculated from "b" of Van der Waals' equation is this constant increase in diameter to be found.

Now, knowing the ratio of the diameter of one shell to that of the next, one can obtain some further atomic values.

The element Beryllium has an atomic number "4," therefore the electrons are four in number, and so the atom can be represented by a plain figure as the electrons are distributed between two shells.

Fig. 1.



BERYLLIUM

Now all the electrons have the same charge, which we will call "e," and we will further call the respective electrons $e_1, e_2, e_3,$ and e_4 . Further, let us give the positive nucleus a

on opposite sides of the positive nucleus, and we can obviously represent the atom by a plane diagram.

$$\text{Attractive force on } e_1 = \frac{Ee}{(1.15)^2};$$

$$\text{Repulsive force on } e_1 = \frac{e^2}{(2.30)^2};$$

$$\text{therefore } \frac{Ee}{(1.15)^2} = \frac{e^2}{(2.30)^2} \text{ and so } E = 25e.$$

These values for E are calculated on the presumption that (a) the electrons are not in motion round the positive nucleus, and so have no acceleration towards the centre, and (b) only electrostatic forces are present. It may be mentioned here, however, that in the case of atoms where two electrons are squeezed into the space nominally provided for one, then there is a second force which comes into play, and this exactly balances the repulsive electrostatic force between the electrons. It is therefore an attractive force of some nature.

If we do not presume this, then when we meet with the first case of two electrons above one another there will be a very large increase in the value of E , which although possible is not probable. We can, however, find the distance to which these two forces annul each other.

Let us take a completed Neon atom, then upon adding eight more electrons we shall obtain an Argon atom, of course the positive nucleus must alter at the same time. All the shells I, II, and II *b* are now completed, and in the second shell we have crowded two electrons into the space for one.

If one above the other, it seems feasible that the distance between them should be the same as the distance between the radii of the shells II *a* and II *b* = 14×10^{-8} cm. Consequently at this distance the two forces balance; but this attractive force does not seem to be noticeable between electrons which are a greater distance apart. Therefore it probably varies as a higher power of the distance than the 2nd.

Owing to the complexity of the elements with atomic numbers above 10, it becomes very difficult to calculate the dimensions of E . From the value of b in Van der Waals' equation we obtain no information respecting the actual arrangement of the electrons in the atom. Langmuir's positions for them have been used throughout; the figures only showing that when moving from one inert gas to the next the radius of the atomic sphere increases by a constant quantity.