Presidential Address

A PRESENT DAY EXAMINATION OF THE POSTULATES OF JOHN DALTON

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The constitution of the Ohio Academy of Science prescribes that on this occasion its President shall deliver an address. As much as I should like to confine my remarks to a discussion of some recent advances in the chemistry of the carbohydrates—an area of organic chemistry in which I find my greatest research satisfactions—a discussion of this special field of work on this occasion would have but a limited interest. However, there is one topic in which I am bold enough to believe that all members of the Academy have genuine interest. I refer to John Dalton's atomic theory of matter.

The concept of the discrete nature of matter has been one of the central themes of the science of chemistry since the first decade of the nineteenth century. In the middle nineties, the physicist became busily engaged with his brother chemist in a study of the nature of this small unit, in fact, a large share of his research endeavor is now directed toward the solution of this very fundamental problem. With the time at my disposal I shall attempt to make a brief examination of the postulates of John Dalton in the light of present day knowledge.

The atomic concept of matter finds its roots in philosophical thought that comes to us from remote antiquity. In an ancient Chinese document (Shoo King) it is conjectured that there are five elements, namely, water, fire, wood, metal, and earth. These elements were probably regarded as the materials from which all natural substances were derived, in quite the same way as we read today that the newly synthesized silk, nylon, can be made from air, water, and coal, which is true, but the actual process is a long journey. In the distant past, Kanada, the East Indian philosopher, gave utterance to the following opinion: "the mote which is seen in a sunbeam is the smallest perceptible quantity. Being a substance and an effect, it must be composed of what is less than itself. This again must be composed of what is smaller, and that smaller thing is an atom."

In the four or five centuries preceding the time of Christ, the Grecian philosophers gave much thought to this general problem. Leucippus (circa 500 B. C.) believed that all material substances were made up of atoms and empty spaces. His distinguished pupil, Democritus, reasoned as follows: "If every substance is divisible to infinity, and the division is never arrested, we come to one or two conclusions—*either nothing remains or something is always left.* From this reasoning he concluded that it was necessary to assume the existence of real, indivisible units of matter. This group of philosophers called themselves Atomists. Another school of Grecian philosophers under the influence of Aristotle maintained that matter was continuous and filled all space, a point of view that has had its adherents until relatively recent times.

The outstanding contribution in the pre-Christian era was the epic poem of Lucretius, "De Rerum Natura." In this poem Lucretius showed himself to be an ardent adherent of the atomic concept of matter, and by means of it he foreshadowed some of the fundamental notions underlying modern physics and chemistry. May I quote but one suggestive passage:

> "Infinite atoms in a boundless world,
> By endless motion build the frame of things."
> —Bk. I, 63, Johnson translation.

This and other examples of early philosophical inquiry should command our deepest admiration by reason of the general correctness of the views expressed concerning the nature of matter. Had the experimental method of verification of such ideas been in vogue at that time it is safe to assert that our present state of knowledge concerning Nature would have been much more advanced than it is at the present time.

Many important experimental discoveries were made in the latter decades of the 18th Century. From the laboratories of those fruitful years of scientific work came certain fundamental laws bearing upon the quantitative character of chemical reactions. We are indebted to Richter, the German, for the Law of Inter-proportionality, to Proust, the Frenchman, for the Law of Definite Composition, and to John Dalton, the Englishman, for the Law of Multiple Proportion. In an attempt to find a satisfying explanation for the quantitative relationships set forth in these three generalizations and that concerning the indestructibility of matter, John Dalton formulated the postulates which constitute his now well known atomic theory. The postulates of this important doctrine were these:

1. All bodies of sensible magnitude are constituted of a vast number of extremely small particles or atoms of matter bound together by a force of attraction which, as it endeavors to prevent their separation, is called attraction of cohesion; but as it collects them from a dispersed state is called attraction of aggregation or more simply affinity.
2. The ultimate particles of all homogeneous bodies are perfectly alike in weight, figure, etc. In other words, every particle of water is like every other particle of water; every particle of hydrogen is like every other particle of hydrogen, etc.
3. No new creation or destruction of matter is within the reach of chemical agency. All the elements we can produce consist in separating particles that are in a state of cohesion or combination and joining those that were previously at a distance.
4. The ultimate particles of all simple bodies are atoms incapable of further division. These atoms (at least viewed along with their atmospheres of heat) are all spheres and are possessed of particular weights which may be denoted by number.
5. If there are two bodies which are disposed to combine, then their combination takes place by atoms.
6. In an elastic gas each particle occupies the center of a comparatively large sphere and supports its dignity by keeping all the rest, which by their gravity or otherwise are disposed to encroach upon it, at a respectful distance.

In a discussion of these postulates it must be remembered that they were formulated in the earlier years of a period in which the answer to questions concerning man's physical surroundings were being sought by the laboratory method—a procedure that was destined to exercise a profound influence on the development of our civilization. In the first postulate Dalton was merely saying that all available quantitative experimental data concerning chemical reactions acquired fundamental significance if it were assumed that "all bodies of sensible magnitude are constituted of a vast number of extremely small particles or atoms," that is, matter behaves experimentally *as though* it were atomic, or granular in nature, as contrasted with the point of view that it is continuous in structure.

In support of this assertion the sciences of chemistry and physics of today furnish convincing experimental evidence. The laboratory records of chemistry reveal the existence of over a half million compounds, the vast majority of which have been synthesized by processes in which the existence of atoms was taken for granted. In no case do we find a departure in the composition of these compounds from that which could have been easily predicted, i. e., in no case do we find an exception to the laws of chemical combination upon which Dalton erected his theory. Throughout the world, the chemist, more especially the organic chemist, is constantly preparing pure compounds hitherto unknown. The foundation upon which the chemist's great success rests is the very spirit of that portion of postulate one which assumes the existence of atoms.

In the field of physics we find equally convincing laboratory evidence in support of the Daltonian doctrine with reference to the discrete nature of matter. I have chosen as illustrations the experimental determination of Avogadro's number (6.06×10^{23}), a physical constant which gives the number of molecules present in a gram molecular weight of any pure substance.

Jean Perrin, Professor of Physical Chemistry at the Sorbonne, found, in his classical study of the Brownian movement, that the value of Avogadro's Number was 6.82×10^{23} molecules. From a calculation based on the ratio of the mass to the electrical charge of the hydrogen ion, the value of this constant has been found to be 6.06×10^{23}, a value confirmed by Langmuir with his oil film technique. Again, on the basis of the volume of helium ion emitted from radium in one day, and also the number of such particles given off in one second, Rutherford and Boltwood calculated the value of this constant to be 6.16×10^{23}. Here we have four separate and entirely distinct methods of experimental approach to the determination of this important constant that yield data that are sufficiently in accord with one another to justify the spirit of postulate one, which to repeat assumes that matter is granular in its nature. Furthermore, it should be pointed out that the Avogadro Constant and the gram-molecular weight permit us to calculate the *actual* weight of any molecule, and from the result so obtained in the case of hydrogen we can determine the actual weight of an *atom* and that of the *electron*. The actual weight of the hydrogen atom was thus found to be 1.64×10^{-24} grams.

It may be added that were he living today Dalton would undoubtedly admit with the utmost satisfaction that 6.06×10^{23} molecules and

1.64×10^{-24} were numbers sufficiently large and sufficiently small respectively to justify and confirm his use of the phrase "a vast number of extremely small particles". Thus, it becomes evident that the modern physical sciences furnish what seems to be conclusive experimental data which justify the assumption of Dalton that matter is atomic in structure.

Since Dalton belonged to that group of natural philosophers who believed in the discontinuity of matter it was only natural for him to make the assumption in postulate four that "the ultimate particles of all simple bodies are incapable of further division—and are possessed of particular weights which may be denoted by number." What have our modern activities to say with reference to these assertions?

Concerning atoms having characteristic weight it should be noted that in 1905 John Dalton published the first atomic weight table. Among some of its features of interest to the chemist are these:

1. Hydrogen was used as a standard of comparison, and was assigned the value of 1, a procedure followed until relatively recent times. 2. An examination of the table shows that Dalton used the term "atom" to designate the smallest particle of both the present day element as well as the present day compound. 3. He arrived at the value for water, namely, 6.5, by adding his atomic weights of hydrogen and oxygen. The translation of these values into modern chemical symbols and formulas would give HO as the formula for water, i. e., one atom of each element. 4. Out of this table of atomic weights and the more accurate ones which followed it emerged a distinct effort to correlate these characteristic weights of the elements and their chemical properties. This is clearly shown in the publication of Doebereiner's idea of triad groups of elements in 1817, Newlands Law of Octaves in 1864, and the concept of periodicity amongst the properties of the elements as announced by Lothar Meyer in 1864 and by Mendeleeff in 1869.

In the eighteen-nineties, some ninety years after Dalton postulated that "the ultimate particles of all simple bodies are incapable of further division," three very important and apparently non-related discoveries were made. I refer to the discovery of radio activity and the element radium by Bequerel and the Curies, respectively; the discovery of the noble gases of the atmosphere by Ramsay and Rayleigh; and the discovery of X-rays by Roentgen. Today we know that these epoch making events are inextricably interwoven when they are considered in connection with the problem under discussion. We need only to be reminded that radium, thorium, and uranium are elements undergoing decomposition with an attendant evolution of three different rays, the alpha rays, or the He^{++}, beta-rays or the electrons, and the gamma rays, or X-rays of a very high frequency. The final product in each case was found to be the element, lead. Here then were atoms of certain known elements giving birth to the helium ion (He^{++}) an element of lower atomic weight, and to the age long known element, lead, truly a new kind of alchemy, and a case where elements were undergoing "further division" but not into like particles.

In his efforts to obtain more intimate knowledge concerning the nature of the atom, the present day physicist has attempted to shatter the atom into small particles through a vigorous bombardment. His projectiles are the electron, the alpha particle, (or He^{++}), the proton, (or H^{+}), the recently discovered neutron, and deuteron, that is the ion of heavy hydrogen, (D^{+}). The heaviest piece of artillery is the modern cyclotron, an instrument which is capable of imparting a speed to these projectiles of the order of 9000–18000 miles per second with an energy of the order of 10,000,000 electron volts. Therefore, it is not a matter of great surprise that an occasional atom may be broken down into more simple particles when it is struck under these conditions.

Within recent months only the fission of uranium, the heaviest known atom, has been announced. This was accomplished by the bombardment of uranium with fast moving neutrons. Fourteen different elements were found in the atomic debris. (Ba, La, Ce, Kr, Rb, Sr, Y, Zr, Xe, Cs, Sb, Te, I, and Br.). By some authorities the fission of the uranium atom is regarded as the most important discovery of the year 1939, and it is also the greatest explosion in atomic history. With reference to that portion of postulate 4 which asserts that "the ultimate particles of all simple bodies are atoms incapable of further division," the modern physical sciences have shown that the fact of "further division" is a natural process as well as a laboratory one. However, this portion of the Daltonian doctrine which asserts that the atoms have characteristic weight which may be denoted by a number is in itself a great contribution to knowledge. It need only be remarked that all our analytical and synthetic processes in the field of chemistry whether they be academic or industrial rest upon these numbers which tell us the relative weight of each atom referred to some element chosen as a standard. Again we must not forget the stimulus which these numbers gave to a study of the possible relationship which might exist between these numbers and the chemical properties of their respective elements, thus leading to the discovery of the Periodic Law, which has pointed so unerringly to relationships and properties hitherto unperceived.

Again, we find Dalton referring to the property of weight in postulate two when he asserts that "The ultimate particles of all *homogeneous* bodies are perfectly alike in weight, figure, etc. In other words, every particle of water is like every other particle of water; every particle of hydrogen is like every other particle of hydrogen."

Some of the important present day facts bearing on the validity of postulate two are these: When the *atomic weights* of the specimens of lead obtained from the three radioactive sources mentioned above were determined by Theodore William Richards and others, a surprising fact came to light, namely, that the atomic weights of the lead obtained from these sources showed a variation from the classical value which was in excess of that due to experimental error. Here then we had experimental evidence for the existence of an element whose ultimate particles were not perfectly alike in weight. These atomic species of a given element are known today as isotopes, since a study of the various steps in the natural degradation of radium, thorium, and uranium show that these new kinds of lead atoms occupy the same position in the periodic arrangement of the elements. May we press this point further.

The discovery of deuterium, or heavy hydrogen, by Urey, Brickewedde and Murphy in 1932, was another event that had an important bearing on the views of Dalton with respect to the homogenity of atoms. The atomic weight of heavy hydrogen (2.0147) is approximately twice that of ordinary hydrogen. (1.0078). The density of heavy water at 25° (1.1076) is approximately 11% greater than that of ordinary water (0.99707) at the same temperature (25°). Heavy water boils at 101.4° C. and freezes at 3.77° C. Since Giaque and Johnston found that oxygen existed as three isotopes then it follows that it is possible to have nine different molecules of water. (These would have the following formulas: H_2O', H_2O'', H_2O''', D_2O', D_2O'', D_2O''', HDO', HDO'', and HDO'''). This number may be increased in the future through the discovery of other isotopes of either hydrogen or oxygen.

Although our postulate asserts that "every particle of water is like every other particle of water, and every particle of hydrogen is like every other particle of hydrogen," your attention is invited to a fine example of clear and careful thinking on the part of John Dalton with respect to this one point. I will quote from his book entitled "A New System of Chemical Philosophy" published in 1808, volume I, page 142: "whether the ultimate particles of a body, such as water, are all alike, that is, of the same figure, weight, etc., is a question of some importance. From what is known, we have no reason to apprehend a diversity in these particulars; if it does exist in water, it must equally exist in the elements constituting water, hydrogen and oxygen. If some of the particles of water were heavier than others, if a parcel of the liquid on any occasion were constituted principally of these heavier particles, it must be supposed to affect the gravity of the mass, a circumstance not known. Similar observations may be made on other substances." This paragraph is one which clearly foreshadows the possible existence of isotopic elements, and the new compounds that might be formed from them.

These data with reference to the discovery of isotopic elements immediately raise the query concerning the significance of the chemist's atomic weight. It may be said at once that the chemist's atomic weights are the *average* weight of all the isotopic atoms composing a given element. Since the isotopes of any given element are generally chemically indistinguishable it is necessary to use *physical* methods for the determination of their respective atomic weights and the relative amounts of each species present. One of the most notable procedures for this purpose is that known as positive ray analysis, a fruitful method of research with which the names of Thomson, Aston, Dempster and Bainbridge are intimately associated. By this method it has been found that the atomic weights of the individual species are practically whole numbers, a fact which awakens a renewed interest in Prout's hypothesis. A comparison of the chemist's atomic weight of magnesium (24.32) with that determined by positive ray analysis (24.375) shows a difference of only 22 parts in 10,000. This remarkable concordance obtained by procedures as remotely different in the fields of chemistry and physics bears eloquent testimony to the sound thinking of the investigators to whom we are indebted for these experimental data.

With reference to the use of the word homogeneous in this postulate, John Dalton probably had in mind what we ourselves believed concerning the nature of an element and a compound prior to the "isotopian age." What was thought to be homogeneous we now know to be heterogeneous when regarded from the standpoint of weight and the various implications of weight. It must be remembered that the atoms of a given isotope are homogeneous, but the atoms of the several isotopic species are heterogeneous.

At this point reference must be made to that part of postulate 2 which asserts that "the ultimate particles of all homogeneous bodies are perfectly alike in . . . figure," and to that part of postulate 4, which declares that "*the atoms* of all simple bodies are spheres." Obviously, these statements have reference to shape and structure, a question that has occupied the attention of both the chemist and the physicist, regardless of whether the homogeneous bodies are elements or compounds. In this discussion we will confine ourselves to a brief review of the present day views concerning the structure of the atom. From the facts of the natural degradation of radioactive elements and the bombardment of atoms of various elements, we find that all elementary matter is associated with the following particles—some or all of which may be considered as the building stones of the atoms: (a) the *electron*, 1/1845 of the mass of the hydrogen atom and associated with a negative charge of electricity; (b) the *proton*, or the hydrogen ion, being a mass with a positive electrical charge; (c) the *neutron*, having a mass approximately that of the hydrogen atom but electrically neutral; (d) the *positron*, having the same mass as the electron but associated with a positive electrical charge; (e) the *mesotron*, a recently discovered particle of fleeting existence; (f) the *neutrino*, as yet of doubtful existence. At the present time we can hypothetically build atoms from the electron, the proton, and the neutron which will meet many of the specifications imposed by physics and chemistry of which the following are a few: these structures must account for the facts of periodicity in the properties of the elements; the facts of ionization; the valence theory; the existence of isotopic elements; the facts of radioactivity; and facts of spectroscopy.

As an illustration, may we discuss the existence of isotopic elements as related to their possible hypothetical structures. Our present point of view regards the atoms of ordinary or light hydrogen as consisting of a nuclear proton which bears one positive electrical charge, and one planetary electron with its one negative charge revolving about the positive nucleus at different energy levels. Physical theory tells us that if energy is absorbed by the atom, the electron moves to a higher energy level but if it falls to a lower energy level it emits energy. The energy so absorbed or emitted gives rise to absorption or emission spectra respectively. The quantity of energy so absorbed or emitted can be easily calculated from a knowledge of the light frequency and Planck's Constant or the quantum. For these ideas we are indebted chiefly to Rutherford, Bohr, and Sommerfeld.

Deuterium, or heavy hydrogen, is also regarded as having a nucleus consisting of one proton, and, in addition thereto one neutron, a particle that is electrically neutral; in other words, the nucleus of the heavy hydrogen atom is approximately (2.0186) double the weight of the ordinary, or the light hydrogen atom. Revolving about this nucleus also is one electron as in the case of the light hydrogen atom. Hence, we see that the electrical charge on the nuclei of both light and heavy hydrogen atoms is the same, i. e., one positive charge; and each of these atoms has but one electron, i. e., one negative charge. From these two illustrations it is evident that within the nucleus resides practically all the mass of the atom since the mass of the electron in each case is negligible.

The fact that these two different atoms have the same nuclear charge but different nuclear mass is one of the first importance. In his now classical experiments, Moseley, in a study of the X-ray phenomena produced by the use of several different solid elements as targets in his apparatus found that the frequency of the emitted X-ray in each case was a function of the ordinal number of the element used. These ordinal numbers, i. e., hydrogen, 1, helium, 2, lithium, 3, and uranium, 92, are identical with the charge on the nucleus. They are called "atomic numbers." Out of this situation emerges the interesting fact that the *isotopic species of a given element have the same atomic number* regardless of the atomic weights of the several species. The composition of the three isotopes of magnesium to which reference has been made above is given in the following table:

	Particles Composing the Nucleus		Extra-Nuclear Particles	Number of Electrons in Energy Levels		
Symbol	Protons	Neutrons	Electrons	K-shell	L-shell	M-shell
$_{12}Mg^{24}$	12	12	12	2	8	2
$_{12}Mg^{25}$	12	13	12	2	8	2
$_{12}Mg^{26}$	12	14	12	2	8	2

The electrons are distributed about the nucleus at different energy levels or shells as shown in the above table. Since their number and distribution is the same in each case, it is clear why the chemical reactions of the isotopic species of a given element are generally identical.

We must now be reminded that recent discoveries have shown that the proton, neutron and the electron are not sufficient to account for the facts of radio-activity. This may be illustrated by the behavior of radio phosphorus whose formation and behavior are shown by the following reactions:

(a) $_{13}\text{Aluminum}^{27} + {_2}\text{Helium}^4\text{(ion)} \longrightarrow {_{15}}\text{Phosphorus}^{30}\text{(radio)} + {_0}\text{Neutron}^1$

(b) $_{15}\text{Phosphorus}^{30}\text{(radio)} \longrightarrow {_{14}}\text{Silicon}^{30} + {_1}\text{Positron}$

It is now believed that the positron is a manifestation of the binding or cementing energy which holds the nuclear portion of the radio-phosphorus atom together until the explosion occurs. Whether the mesotron, or meson, also functions as a cementing force cannot be definitely stated at this moment.

Thus far in our discussion of atomic structure we have confined ourselves to the use of building stones which were particles of definite magnitude. In 1924, de Broglie, the Frenchman, suggested that discrete particles, such as atoms, ions, and electrons should have wave properties as well as those of a corpuscular character, a point of view which reminds us of the discussion concerning the wave and corpuscular theories of light. This postulate was experimentally verified by Davisson and

Germer in the Research Laboratories of the Bell Telephone Company in 1927 when they found that a stream of electrons showed diffraction and interference phenomena when reflected from the surface of a crystal. In the following year (1928), G. B. Thomson obtained the same results when he projected a beam of electrons through a very thin gold film. Two years later (1930) Stern and Eastermann demonstrated that atoms of hydrogen and helium also have such wave properties in addition to those due to their corpuscular character. Out of the implications of these discoveries and the quantum mechanics emerged the powerful wave mechanics by means of which it was possible to determine the exact number of energy levels in the hydrogen atom and thus verify the assumptions which Bohr had made with reference to the spectrum of this element.

Since the atom has both corpuscular and wave properties it is evident that a mechanical structure alone is not sufficient to serve as a model of the atom—a particle which is so very complex in its properties.

In the beginning of our discussion it was stated that Dalton had formulated his theory in order to give significance to the laws of chemical combination and the law of indestructibility of matter. Since his theory advocated that matter was atomic in nature, the most natural conclusion for him to make was that the individual atoms themselves must also be indestructible. Hence, he asserts in postulate three that "No new creation or destruction of matter is within the reach of chemical agency." The spirit of this postulate has been one of the classical principles in the physical sciences. The following would be another expression of Dalton's thought. "Within the limits of experimental accuracy no change in the total mass can be detected as a result of any transformation which matter may undergo."

In 1906, Landolt performed a series of chemical experiments in sealed glass containers to test the validity of the law of conservation of mass and as a result he found that his experimental differences were of the order of only one part in ten million, i. e., a few hundredths of a milligram in 100 grams of reacting materials, a value so small that its significance could well have been disregarded.

Thanks to modern theoretical physics, the principle of the conversation of mass is merely one aspect of the principle of the conservation of energy, or, as Berthoud has so well expressed it, "matter and energy are not principles of different natures; they comprise a physical unity." This would imply that matter and energy are reversibly interconvertible. Einstein has expressed the relationship by his well known equation

$$E = mC^2$$

in which E is energy, m is the mass, and C is the velocity of light. This equation means that "an increase in the energy of a body means an increase in its mass, and that every form of energy has an equivalent mass." Kaufmann, a German worker, seems to have furnished experimental evidence for these relationships when he found that an increase in the velocity of an electron produced an increase in its mass.

By the use of Einstein's equation, it can be shown that the energy evolved in the formation of one gram molecular weight of water from its elements has a mass of 3 millionths of a milligram. When compared to the 18 grams of reacting materials this seems to be a very small quantity, but it is none the less a very real one (3×10^{12} ergs).

Thus it becomes clear that there must be an increase in mass in all endothermic chemical changes in quite the same manner as there must be a diminution of mass in all exothermic chemical changes.

The contribution of present day workers in the physical sciences has greatly enlarged the meaning of the relationship which Dalton enunciated in this postulate. Today as well as in Dalton's time the fundamental character of this great generalization remains unchanged, i. e., we are only becoming aware of its comprehensive character.

Our natural philosopher was also concerned with the mechanism of chemical reactions as is evidenced by postulate five wherein it is stated that "if two bodies are disposed to combine, then their combination takes place by atoms." The chemist has always been interested in knowing the number of atoms of one element which will unite with a definite number of atoms of another element, an inquiry out of which the theory of valence was born. Today we believe that the electronic section of the atom, i. e., the extra nuclear part, is the one that functions in chemical reactions, that is, that the forces to which John Dalton referred are electrical in their nature. This is equivalent to saying that today we regard the valence concept to be an electronic one. If this is true and our present picture of the orientation of the electrons about the nucleus is correct, we have reason to expect a number of different electronic mechanisms whereby chemical union would take place to form at least three types of compounds whose existence are realized in the following classes:

1. *Electrovalent Compounds:* These compounds are formed by the transfer of electrons from the metallic to the non-metallic element, an action which yields a positive ion and a negative one. These changes may be represented by the union of a sodium atom to a chlorine atom to form sodium chloride, a reaction in which the chlorine atom acquires an electron from the sodium atom thus leaving the sodium with a positive electrical charge and the chlorine with a negative charge. These charged particles are called ions. An X-ray examination of solid sodium chloride confirms the view that the crystal of this compound contains the ions of its components and not its atoms.

2. *Covalent Compounds:* The covalent compounds are formed by a mutual sharing of electrons of the elements composing the new substance, a point of view which should be credited to G. N. Lewis, of the University of California. In general, the chemical bond thus formed consists of two electrons, one each having been contributed by two individual atoms. The bond thus formed is usually equivalent to the single bond of an organic compound. This electronic concept of shared electrons may be represented by the marsh gas molecule as follows:

$$4\mathrm{H}\cdot + \cdot\overset{\cdot}{\underset{\cdot}{\mathrm{C}}}\cdot \longrightarrow \begin{matrix} & \mathrm{H} & \\ & \ddot{} & \\ \mathrm{H}: & \mathrm{C} & :\mathrm{H} \\ & \ddot{} & \\ & \mathrm{H} & \end{matrix}$$

It should be pointed out that the theoretical physicists, Heitler and London, in their studies of the nature of valence assumed that the electron pairs which give rise to a covalent bond must be of opposite spin.

3. *Coordination Compounds.* In coordination compounds the "two electron valence bond" is furnished by a single atom which in turn may unite with another atom in order to bring the outer shell of the second atom up to eight or more electrons. The following is a familiar illustration:

$$\begin{matrix} \mathrm{H} \\ \mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{N}}}: \\ \mathrm{H} \end{matrix} \quad + \quad \mathrm{H^+Cl^-} \longrightarrow \left[\begin{matrix} \mathrm{H} \\ \mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{N}}}:\mathrm{H} \\ \mathrm{H} \end{matrix}\right]^+ \mathrm{Cl^-}$$

$$\text{Ammonia} + \begin{matrix}\text{Hydrochloric} \\ \text{Acid}\end{matrix} \longrightarrow \text{Amonium Chloride}$$

The bond here consists in the nitrogen having a "lone pair" of electrons, or a duplet available for the hydrogen ion. Thus we see that the modern conception of the structure of the atom furnishes us a satisfying mechanism whereby chemical combination takes place between atoms as was postulated by Dalton. Furthermore, we have been able to classify many compounds into groups by reason of the electronic mechanism whereby chemical union takes place.

Postulate VI. The sixth and last postulate assumes that "in an elastic gas each particle occupies the center of a comparatively large sphere and supports its dignity by keeping all the rest, which by their gravity or otherwise are disposed to encroach upon it, at a respectful distance." This quaint statement is easily recognized as the now universally accepted kinetic-molecular theory of matter. It is said that the kinetic concept involved in this postulate comes to us from Daniel Bernouilli, a Swiss mathematical physicist, who, in 1738, developed a kinetic theory of gases.

That Dalton was correct with reference to his statement concerning each molecule occupying "the center of a comparatively large sphere" is evident from the fact that the space between the molecules composing steam at 100° is 99.94% of the total volume, i. e., the actual molecules of steam occupy only .06% of the total volume, i. e., only 6 cc. in 10,000 cc.

This postulate also tells us of the unceasing motion of gaseous particles. One of the most convincing pieces of evidence of molecular motion is the Brownian movement. As a result of Perrin's work referred to above on the Brownian movement in emulsions, Ostwald, *one* of the early German workers in physical chemistry, was moved to say that "the agreements of the Brownian movement with the requirements of the kinetic hypothesis justify the most cautious scientist in now speaking of the experimental proof of the atomic theory of matter." In this connection it only is necessary to refer to the great contribution made to the science of chemistry and physics by the kinetic molecular approach to a vast number of well known chemical and physical phenomena.

Finally, in the light of present day knowledge, we arrive at the following conclusions in evaluating the postulates of John Dalton enunciated one hundred and thirty-five years ago.

1. Modern physics and chemistry furnish convincing laboratory evidence for the existence of atoms as John Dalton set forth in his theory.
2. The degradation of these atoms into other particles is a natural as well as a laboratory process.
3. The atoms of a given element are not homogeneous as Dalton

believed, but they are found to possess different masses. These different species are known as isotopes.

4. Atoms consist of the following corpuscular particles, the electron, the proton, the neutron, the positron, the mesotron (meson), and possibly the neutrino.

5. Atoms have wave properties as well as those properties arising from their corpuscular character.

6. The atoms consist of a nucleus made up of protons and neutrons while the extra-nuclear portion of the atoms consists of electrons. The isotopes of a given element are due to the variable number of neutrons.

7. The spirit of Dalton's view that no new creation of matter is within the reach of chemical agency has been greatly enlarged in its meaning.

8. Dalton's view that chemical combination takes place by atoms has been greatly enriched by our present electronic conception of valence.

9. Dalton's Kinetic picture of the atoms has in no wise been changed.

The purpose of this discussion has been to trace in brief outline the life history of one of the basic theories underlying so much that is fundamental in the fields of knowledge represented in this Academy. It would seem that the enlargement of the points of view in certain of these postulates and other changes which have been made by reason of later experimental and theoretical considerations would be fairly typical of the philosophical process which aids us in a better understanding of the surroundings in which we find ourselves as human beings. In closing may I quote from the dedication inscribed by Charles Daubeny in his book entitled "Atomic Theory"—published in its second edition in 1850—a dedication by an academician who had an appreciation of the scholarship of John Dalton.

TO

THE MEMORY OF
JOHN DALTON, F. R. S.

Late President of the Literary and Philosophical Society of Manchester,
Corresponding Member of the Academy of Sciences of the Royal Institute of France, and Honorary, D. C. L. of the University of Oxford,

THE FRAMER OF A THEORY
WITH RESPECT TO THE MODE OF COMBINATION BETWEEN BODIES,
WHICH STANDS FOREMOST AMONG THE DISCOVERIES OF THE PRESENT AGE,
FOR THE UNIVERSALITY OF ITS APPLICATIONS,
AND THE IMPORTANCE OF ITS PRACTICAL RESULTS;
HOLDING THE SAME KIND OF RELATION TO THE SCIENCE OF CHEMISTRY,
WHICH THE NEWTONIAN SYSTEM DOES TO THAT OF MECHANICS:
AND THROWING LIGHT,
NOT ONLY UPON ALL THE ORDINARY SUBJECTS OF CHEMICAL INVESTIGATION,
BUT EVEN UPON THOSE MORE SPECULATIVE QUESTIONS
WITH RESPECT TO THE CONSTITUTION OF MATTER,
WHICH SEEMED TO LIE BEYOND THE REACH OF
EXPERIMENTAL INQUIRY.