Amedeo Avogadro

Counting Atoms and Molecules

When you hear the name 'Avogadro', you would immediately form a picture of a huge, awe-inspiring number on your mental screen, called Avogadro number or Avogadro constant, $N_A = 6.02 \times 10^{23}$. This refers to the number of atoms of an element or of molecules of a compound in 1 mole. This applies also to ions, electrons, protons, neutrons or other particles. One mole (unit: mol) of an element is its atomic weight in grams and of a compound is its molecular weight in grams; e.g., 2 g of molecular hydrogen, 12 g of C-12, 32 g of molecular oxygen, 56 g of iron, 108 g of silver, 17 g of ammonia, 16 g of methane, etc. (the decimal values are left out for simplicity). The number of particles contained in a mole is so huge that it is not easy to visualize its value. To appreciate it and to amuse, take a look at the following examples.

1. If you count at the rate of 10 million per second, it would take about 2 billion years to count the atoms in a mole.

2. It takes about 2 million years to deliver Avogadro number of grains of rice at the rate of 1 lorry load every 10 minutes.

3. If Avogadro number of rupees are distributed among every one of the 1 billion of us, each one would get about 100,000 billion rupees. Each one would need about 300 billion years to spend all this money at the rate of 10 million rupees per day.

4. There are almost 100 times as many particles in a mole as there are stars in all the galaxies in the whole universe.

It took almost a century since Avogadro proposed his principle in 1811 that the number 6.02×10^{23} was called the Avogadro constant, and it had taken almost half a century before the principle's significance was recognized. The evolution may be briefly traced as follows.

Around 1800 a lot of experimental work on the properties of gases was being carried out, particularly relating to pressure, volume and temperature. Gay-Lussac (1778-1850), had studied the variation in volumes when two gases combine (react), and had noted that the ratios of volumes were small integral numbers (1809). Avogadro was not a good experimentalist, but his scrutiny of Gay-Lussac's results provided him the basis for his brilliant hypothesis put forth in 1811.

Gay-Lussac's Law

Whenever two or more gases are involved in a chemical reaction, the ratios of the volumes of the gases may be expressed as the ratios of small integral numbers, provided the volumes are measured at the same temperature and pressure. Examples: 1 volume of hydrogen reacts with 1 volume of chlorine to give 2 volumes of hydrogen chloride. 1 volume of oxygen reacts with 2 volumes of hydrogen to give 2 volumes of water vapours.

Avogadro's Principle

Using Gay-Lussac's data, Avogadro correctly judged that ordinary hydrogen, oxygen, and chlorine contained two simpler units each, and that water is composed of two hydrogen atoms and one of oxygen. Similar arguments were extended to other gases as well.

Avogadro's principle states that equal volumes of gases at the same temperature and pressure contain equal number of molecules ($V/n = k$). This shows that the ratio of the masses of the molecules is the same as that of the densities of the different gases at equal temperatures and pressures.

Cannizzaro's Analysis

How Cannizzaro revived Avogadro's Principle is illustrated below with a simple example. 1 litre of oxygen weighs 1.429 g and 1 litre of hydrogen weighs 0.0899 g at STP. As the number of particles of oxygen and hydrogen are the same, individual oxygen particles are 16 times as heavy as individual hydrogen atoms ($1.429 \div 0.0899 = 15.9$).

By 1860, the atomic theory was well established. Scientists understood very well what an element, a compound, an atom or a molecule meant. Fairly good technique for elemental analysis had also been established by then. However, one was unsure about the molecular formulas derived by using such techniques, and the structural chemistry, which was just then taking birth, could not make much headway, because of the uncertainties in the values of atomic weights. This was due not only to the deficiency in the then prevailing analytical techniques but also to wrong assumptions about the underlying principles. It was amply clear that, to make progress in the formulation of molecular structures, it was necessary to know correct atomic weights, which could not be obtained from the available theoretical and experimental procedures. In order to achieve this goal a new direction in this area had to be initiated.

During 1855-59, Stanislao Cannizzaro (1826-1910), a professor at Genoa and a compatriot of Avogadro, studied his work and recognized the importance of the simple but brilliant hypothesis propounded by him in 1811, almost half a century earlier. It was ignored for so long because when Avogadro published his work in 1811, Dalton (1766-1844) and Berzelius (1779-1848), who were dominating the scientific scene at that time, did not accept Avogadro's propositions which were contradicting Dalton's and Berzelius' ideas of chemical combination. He also tried to extend his principle to metals without any experimental support. Besides, he hardly interacted with scientific community outside of Italy. The definitive moment for the hypothesis' resurrection arrived in 1860 at the First International Chemistry Congress held at Karlsruhe, Germany, where Cannizzaro forcefully argued about the significance of Avogadro's work and demonstrated its utility in clarifying the distinctive nature of element, compound, atom and molecule, and more importantly in obtaining accurate atomic weights. This paved the way for developing structural chemistry by Kekule (*Resonance*, April 2001) and others, and formulation of the periodic table by Mendeleev (*Resonance*, May 2000) Amedeo Avogadro was immortalized and his name became one of the most common names in scientific literature.

Brief Life Sketch

Amedeo Avogadro was born on 9th August, 1776, in an aristocratic family in Turin, Italy. His father was Count Filippo Avogadro and mother Anna Maria Vercelli. Befitting his aristocracy, his full name was Lorenzo Romano Amedeo Carlo Avogadro, Conte di Queregna e di Cerreto. His family members practiced law for generations. His father too was a distinguished lawyer and a civil servant, serving as senator of Piedmont, Advocate General to the senate of Vittorio Amedeo III, and later as president of the senate. With such strong legal background Amedeo Avogadro naturally took up the family profession after receiving bachelor of jurisprudence when he was just sixteen years of age and four years later, doctorate in ecclesiastical law. He had a successful practice in law and succeeded to his father's title in 1787. In 1801, he was appointed as secretary to the prefecture of the administrative district of Eridano, under French rule. Despite such accomplishments in law, he became interested in Natural Philosophy, and trained himself in Physics and Mathematics privately. In 1803, he started the study of electricity with his brother Felice, probably inspired by his great compatriots Galvani (1737-1798) and Volta (1745-1827). This earned him and his brother, in the following year, nomination to the Royal Academy of Sciences in Turin. He was appointed as Demonstrator in 1806, at the Royal College of Turin, but continued to hold the public offices connected with National Statistics, Meteorology, Weights and Measures, and the Superior Council of Public Instruction. Three years later, he became Professor of Natural Philosophy at the Royal College of Vercelli, and taught Physics and Mathematics. He published the hypothesis now known after him in 1811. In 1820, the first chair of Mathematical Physics was established in Italy at University of Turin, and Avogadro was appointed to it. He lost this job in 1822 due to political developments, but regained it in 1834 which he held on till retirement in 1850. Avogadro's scientific activity did not stop with the hypothesis published in 1811. He brought out a publication in 1814 on gas entities, in 1821 a paper on theories of combinations and in 1841 a 4-volume work.

Though very little information is available on Avogadro's private life, it is known that he had married Felicita Mazze and had six sons. It is interesting to note that none of his children took to science, but continued the family's traditional law profession. He was a religious man (note his doctorate in ecclesiastical law), but not a fanatic, and was known for his correctness of thought and gentle generosity. As noted earlier, Avogadro held many high ranking government posts. He passed away in Turin on 9th July, 1856, without realizing the great impact his hypothesis was about to make, thanks to Cannizzaro, at the 1860 Karlsruhe Convention.

Postscript

Both Avogadro and Cannizzaro had very little laboratory facility. In fact, Avogadro was not even a good experimentalist. He essentially depended on the enormous amount of data available from the work of Dalton, Gay-Lussac and others, particularly Gay-Lussac. But his keen sense of observation and brilliant analytical intellect has gifted us one of the most important constants of nature.

G Nagendrappa
Central College, Bangalore University, Bangalore 560 001, India.
Email:nagendrappa@vsnl.net