Amedeo Avogadro The Man, the Hypothesis, and the Number

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Abstract: Amedeo Avogadro was a multifaceted and prolific scientist active in many areas of physics and chemistry, but most of his results did not make a scientific impact. His hypothesis, "equal volumes = equal number of molecules," remained in obscurity until Cannizaro rekindled it by making it a stepping-stone in the development of the atomic theory.

Life and Career [1]

Lorenzo Romano Amedeo Carlo Avogadro (1776–1856) (Figure 1) was born in Turin, Italy, on August 9, 1776. He was the son of Count Filippo Avogadro, Conte di Quarequa e di Cerreto, and Anna Maria Vercellone. His father was a distinguished lawyer and civil servant, a senator of Piedmont in 1768, and Advocate General to the Senate of Vittorio Amedeo III in 1777. Under the French rule of 1799, he was made president of the Senate. Amedeo had four brothers and three sisters. In 1787 he became *Conte di Quarequa e di Cerreto* upon the death of his eldest brother Giuseppe. He married Felicita Mazzia and they had seven children.

He probably received his primary education at home and then went to secondary school in Turin. After passing the baccalaureate in 1972, he entered the Faculty of Law of the University of Turin where he obtained the degree of jurisprudence in 1795 and Doctor in Canon Law the following year.

After graduation, Amedeo went to work in the office of the *Avvocato dei Poveri* in Turin and in 1801 moved to the *Avvocatura Generale*, as *Secrétaire du Department* in the Department of Eridanus, recently created by the French Government with Turin as its capital. Following his deep interest in the sciences, he took private lessons in mathematics and physics and decided to make the natural sciences his profession. In 1806 Avogadro, then thirty, left his administrative position and begun his teaching career as *répetiteur* at the *Collegio delle Province*, a boarding institution connected with the University of Turin, having at the time about 100 students chosen among those of high academic standing. The *Collegio* was considered the training school for the Savoyard ruling class. In 1809 he was appointed instructor of "positive philosophy" (or mathematics and physics) at the former Royal College of Vercelli, and in 1820 he was appointed professor of mathematical physics. In 1804 he became a corresponding member of the Royal Academy of Sciences of Turin, probably because of two essays on electricity that he submitted to the Academy. Continuation of his scientific work in Vercelli earned him the status of permanent member of the Royal Academy of Sciences of Turin. In 1820 he received his appointment to the newly established Chair of Mathematical Physics (*Fisica Sublime*) at the University of Turin.

Political unrest that followed the defeat of Napoleon and the return of the monarchy led to severe reaction in many European countries. As a result several institutions of higher education that had participated on the liberal side were closed and students and faculty members expelled or forced to retire. In France, for example, in 1816 Louis XVIII disbanded the famous École Polytechnique and dismissed two hundred and fifty of the students, among them Émile Clapeyron. The École was reopened one year later and Clapeyron allowed to finish his education at the École de Mines. At the University of Turin the 1821 constitutional revolution lead, in 1822, to harsh reprisal measures on both faculty and students. Several chairs were abolished by royal decree, including that of mathematical physics to which Avogadro had been appointed only two years earlier. Although Avogadro had not been involved in any conspiracy, he was reported by the police as not being a "strong enough supporter of the Throne and of his Majesty." Surprinsingly, after his dismissal the Royal government continued paying his salary. For the next twelve years Avogadro was denied the right to teach and perform research in a university. During his forced retirement, he continued his research on specific heats and his attempt to correlate chemical, electrochemical, and thermal properties of bodies. Being barred from academic activities did not obstruct his appointment as president of the Weights and Measures Commission that established the decimal system in Piedmont.

In 1832, the government decided to reinstate the Chair of Fisica Sublime at Turin, but selected Augustin Cauchy as the incumbent. Upon the exile of Charles X in 1830 and the ascension of Louis-Philippe to the throne of France, Cauchy had exiled himself to Turin rather than take the oath of allegiance. Two years later Cauchy resigned the chair and left for a more rewarding office in Prague, as tutor of the Duke of Bordeaux, grandson of Charles X. In 1834 the Sardinian Government reappointed Amedeo Avogadro to his previous position. He remained until his retirement in 1850; Avogadro had remained outside the academic world for over twelve years.

Avogadro passed away on July 9, 1856, after half a century of intense scientific activity, but being little known in Italy and abroad. He was a modest man who led an industrious life, worked in isolation, had few close friends, and devoted his personal life to his family and his work. He was known to avoid social engagements and intellectual contacts, probably because of the political situation in Piedmont, which was

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Figure 1. Picture of Avogadro.

hostile to intellectual activity until 1840. Intellectual activity in Piedmont had been strongly encouraged during Napoleon's short-lived regime and Avogadro conceived and published his molecular hypothesis at the end of this period.

Scientific Work [1]

Avogadro's name is universally recognized, although his work is often misrepresented. Avogadro is described in most textbooks as a chemist, yet he never did chemical experimentation. He was interested in most fields of physics, and he approached chemistry from a strictly physical and mathematical point of view. In an age of skillful experimentalists, he remained a theoretician all his life. His experimental works were few and insignificant, and he often used the empirical results of others to demonstrate the validity of his own speculations [1].

Avogadro wrote a series of papers on the nature of electricity and the function of metals in the voltaic cell. In them he exposes his initial view that all chemical entities constitute a continuous series based on the positive or negative charge they acquire when put in mutual contact. He introduced the notion of *oxygenicity*: some substances like oxymuriatic acid [2] seem more oxygenic or more acidic than others, but the presence of oxygen alone does not always give an acid character to a compound, as some metal oxides clearly indicate with their alkaline nature.

His interest in the electrical behavior of bodies led him to explain the unusual behavior of a layer of insulated material placed between bodies charged with opposite charges. Without recourse to mathematics, Avogadro postulated that a solid insulator is formed by a large number of extremely thin plates, each one displaying the same electrical behavior as the whole insulator. He claimed that the electric charge was the result of the displacement of a fluid from a layer of molecules of the insulator to the next layer. These ideas represent his main contribution to the field of dielectrics [1].

In 1809, while an instructor at the Royal College of Vercelli, Avogadro published his first essay on electrochemistry, in which he tried to find a satisfactory answer to the questions of how acidity and alkalinity can be defined, what distinguishes acids from alkalis, and how essential is the presence of oxygen in determining the acid character of a chemical combination. In previous publications Avogadro had stated clearly that oxygen is not the "principle" of acidity, as proven by its absence in compounds decisively acid, such as hydrogen sulfide. It is appropriate to mention here that according to Antoine Lavoisier's (1743–1794) oxygen principle, acidity is to be explained in terms of the presence of an acidifying principle. Although Lavoisier's theory was not quantitative, it stated that the more oxygen an acid contained the stronger it would be; thus, sulfuric acid is stronger that sulfurous acid. Joseph Gay-Lussac (1778–1850) had added that the quantity of acid necessary to produce neutrality increases in proportion to the quantity of oxygen contained in the base, and that the arrangement of particles in a compound has the greatest influence on the neutral, acidic, or alkaline character of the compound. The latter part of the statement tried to explain the curious fact raised by Claude Berthollet (1748–1822) that hydrogen sulfide (sulphuretted hydrogen) formed an acid in solution apparently independently of oxygen.

According to Avogadro, the fact that not all acid substances contain oxygen and that some radicals combine with more or less oxygen than others do proves that Jöns Jakob Berzelius' (1779–1848) interpretation of bases and acids in terms only of their radicals was erroneous. In 1813 Berzelius had reported that the combustible part of an acid is electronegative towards a base even when the latter is not oxidized and, therefore, substances of opposite electrochemical nature combine with each other always in the same proportion, regardless of the presence of oxygen. Avogadro illustrated this argument by noting that sulfur and potassium enter in the same proportions in different compounds such as K_2S, KHS, and K_2SO_4, and that in these compounds sulfur always behaves as an acid.

Afterwards, Avogadro focused his attention on the study of the behavior of gases and vapors. For twenty years he worked on the problem of the specific heats of bodies in their three states and tried to correlate them with physical and chemical characteristics such as affinity for caloric, refractive power, affinity for oxygen, electropositivity, and so on.

In 1820 Avogadro read an extensive memoir to the Turin Academy of Sciences where he reasserted in the clearest and most direct way his equal-volumes generalization, stressing its superiority over the use of chemical equivalents as a precise method to determine the weights of chemical elements and compounds. According to Avogadro the only way to avoid the uncertainties and the variability observed in other approaches to the problem of combining weights was to adopt a "*nombre proportionel*." In addition, Avogadro claimed that the law of multiple proportions (see below) applied also to organic chemistry, contrary to the claims of Berzelius.

In 1823 he published one of the few experimental works that he ever conducted on electrical measurements performed with a sensitive multiplier built by Vittorio Michelotti (1774–1842), his colleague at the University of Turin. He reported some new conclusions about the electrochemical series of metals that disagreed with the ones determined by Berzelius and Alessandro Volta (1745–1827). For example, Avogadro classified platinum as more electropositive than did Volta and Berzelius. Avogadro explained that the difference between his series and that of Volta was caused by experimental error because his galvanometer was more accurate than Volta's condenser.

In another experimental work, published in 1833, Avogadro reported his measurements of the vapor pressure of mercury in the temperature range 100 to 300 °C, and particularly in the range 230 to 290 °C, close to the normal boiling point (356.9 °C). He expressed his experimental data by modifying an earlier equation proposed by Jean-Baptiste Biot (1774–1862)

$$\log P = \log A + at + bt^2 + ct^3$$

He assumed that log*A* equals 1 based on the information available at the time that the vapor pressure of mercury at 0°C was about one mm Hg (actually it is 1.5×10^{-4} mm Hg!). An interesting point is that Biot and Avogadro were already assuming an exponential functionality between temperature and vapor pressure before Clapeyron would prove theoretically in 1834 [3] that this is the correct relationship.

Avogadro's most extensive work was his treatise *Fisica dei corpi ponderabili*, a four-volume almost 4000-page-long book on theoretical physics, published from 1837 to 1841. The book was dedicated to Charles Albert, King of Sardinia, probably because the King had knighted Avogadro with the Civilian Order of Savoy and had reappointed him to his chair.

In this monumental work, Avogadro studied the constitution of heavy ordinary bodies, discussing the nature of molecules, molecular forces, and how physical states could be interpreted in terms of these forces. Electricity and magnetism, considered imponderable, were not discussed; chemistry was touched only peripherally. In his approach he was following the theory in vogue that Newton's method of inferring laws from close observation of phenomena and then deducing forces from these laws could be applied successfully to phenomena in which no ponderable matter figured. Light, heat, electricity, and magnetism were all entities that were not capable of being weighed, that is, imponderable. In the overall context of European physics, Avogadro's treatise was published too late. By 1830, new fundamental theories were unfolding, and as a result the conceptual foundations on which most of his book rested were obsolete even before the printing had been completed. In this work Avogadro continued to support the caloric theory of heat and a distinctive interpretation of the nature of molecular forces.

In the last years of his career, Avogadro turned to the question of atomic volumes, attempting to establish a link between the densities of liquid and solid elements and their molecular masses.

Avogadro's Hypothesis

To understand Avogadro's contribution we must consider the status of the atomic theory at his time. The idea that matter is composed of atoms goes back to the Greek philosophers, particularly Democritus (469 B.C.E–370 B.C.E.). By the end of the 18th century, many experimenters were already accepting the idea that every chemical compound contains fixed and constant proportions (by weight) of its constituent elements (the law of definite proportions). In 1797 the French chemist Joseph-Louis Proust (1754–1826) first reported conclusive evidence for this principle in a series of experiments on the composition of many substances, especially the oxides of iron. Berthollet (1748–1822) sustained the idea of indefinite proportions; the Scottish chemist Thomas Thomson (1753–1852) confirmed some of Proust's results and claimed that the latter had definitely proved that "metals are not capable of indefinite degrees of oxidation." John Dalton (1766–1844), a British chemist and physicist, converted the atomic Greek philosophy into a scientific theory, and in his book *New System of Chemical Philosophy*, published in two volumes between 1808 and 1810, bared the first application of atomic theory to chemistry. Dalton proposed that the elements are composed of atoms that are indestructible, that atoms of different elements differ in their masses, and that a compound is a characteristic grouping of atoms. He considered the law of definite proportions a postulate and he expressed the law of multiple proportions as a corollary to it: When two elements combine in a series of compounds, the ratios of the masses of one element that combine with a fixed mass of the second are reducible to small whole numbers. Based on these postulates Dalton tried to calculate the masses (molecular weights) of well-known compounds like water, ammonia, NO, and NO_2. In his reasoning he made the faulty assumption that the molecules of an element are always *single atoms*, and that hydrogen and oxygen would combine to form HO (instead of H_2O).

Gay-Lussac extended the relationship between chemical masses implied by Dalton to volumetric relationships of gases. In 1809 he published two observations about gases that have come to be known as Gay-Lussac's laws of combining gases: (a) when gases combine chemically, they do so in numerically simple volume ratios and (b) if gases combine to form gases, the volumes of the products are also in simple numerical ratios to the volume of the original gases. Gay-Lussac illustrated the last statement by the combination of carbon monoxide and oxygen to form carbon dioxide and claimed that the volume of the carbon dioxide produced is equal to the volume of carbon monoxide and is twice the volume of the required oxygen. In doing so, he repeated the mistake of Dalton in not considering that the reason why only half as much oxygen is needed is that the oxygen molecule splits in two to give a single atom to each molecule of carbon monoxide.

In 1811 Avogadro published an article in *Journal de Physique* where he analyzed the laws of Gay-Lussac and Dalton's position with respect to the structure of the elements [4]. In the opening paragraph he claims that Gay-Lussac's laws imply that very simple relations also exist between the volumes of gaseous substances and the number of simple or compound molecules that form them. Not only that, but he also advances that the only admissible hypothesis is that *the number of integral molecules of any gas contained in a given volume is always the same for equal volumes or always proportional to the volumes*. In addition, he clearly draws the distinction between molecule and atom. He points out that Dalton had confused the concepts of atoms and molecules. The "atoms" of nitrogen and oxygen are in reality "molecules containing two atoms each." Thus, two molecules of hydrogen can combine with one molecule of oxygen to produce two molecules of water. Avogadro illustrates the difference between his approach and that of Dalton by saying that because Dalton supposes that water is formed by the union of one molecule of hydrogen with one molecule of oxygen, then from the ratio by weight of the two components it follows that the mass of the molecule of oxygen to that of hydrogen would

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be as 7½:1 or, according to Dalton, as 6:1. According to Avogadro's hypothesis the actual ratio should be *twice* as great, namely as 15:1. Hence, the mass (molecular weight) of water should be roughly 15 + 2 = 17.

Avogadro labored to prove that the apparent opposition between Gay-Lussac's volumetric approach and Dalton's atomistic approach could indeed be bridged. Avogadro asserts the accuracy of his approach in determining chemical composition and states that it allows assigning the mass of compound molecules according to the volumes of the gaseous compounds. He specified that his procedure depended partly on the division of molecules, "a fact unexpected by Dalton." It must be mentioned that the idea of split molecules had been considered by others at the time but rejected because it conflicted with the widely accepted "indivisible" atomic theory of Dalton.

Avogadro and Dalton thought of gases as formed by particles of roughly globular form, whose size was represented by a hard center surrounded by an atmosphere of caloric. A repulsive force, inversely proportional to the particles' affinity for caloric, balanced their mutual attraction. Because different gases had different affinities for caloric, Dalton argued, their particles had to have different sizes and, therefore, they must be in different numbers in a given volume. Avogadro contended these ideas, saying that if they were correct then it would be impossible to explain the simple ratios found in the combination of different gases reported by Gay-Lussac. Avogadro argued that it was more logical to assume that in a gas the intermolecular distances are so large that no mutual action between such molecules could take place. Under these conditions, a change in the attraction for the caloric displayed by each molecule might affect the amount of caloric condensing around it, but not its volume. Thus, it was reasonable to assume that for equal volumes (or for equal temperature and pressure) there was always the same number of molecules.

In a following publication [5] Avogadro restated his gas generalization: "In my 1811 essay I have submitted a very natural hypothesis-as it seems to me-not superseded so far, to explain the discovery of Gay-Lussac that the volumes of gaseous substances mutually combining and those of compound gases thus obtained are always in simple ratios. This hypothesis states that equal volumes of gaseous substances, under the same pressure and temperature, represent equal number of molecules; hence, the densities of different gases are the measure of the molecular masses of these gases and the ratios of volumes in the combinations are nothing else than the ratios among the numbers of molecules which combine to form the compound molecules."

Of the many papers written by Avogadro, only the ones describing the molecular hypothesis "equal volumes equals an equal number of molecules," have survived the test of time, giving him a prominent place in the development of the atomic theory. After its publication in 1811, the molecular hypothesis was ignored, rejected, or misunderstood for almost fifty years. It took another quarter century before it was recognized and restated as a major physical law. Most of Avogadro's contemporaries did not appreciate the significance of his hypothesis and its consequence that through the densities of gaseous molecules it was possible to determine the molecular weight of a compound as well as its correct chemical composition. Men of scientific reputation, such as Berzelius, Dumas, and Gay-Lussac, were certainly aware of Avogadro's generalization, but failed to interpret it correctly. In particular, Berzelius contended incorrectly that all atoms of a similar element repel each other because they have the same electric charge. He thought that only atoms with opposite charges could combine to form molecules.

Avogadro and Cannizaro: The Karlsruhe Congress

By the middle of the 19th century the conflicting opinions on the structure of matter and the indivisibility of molecules had resulted in a chaotic situation regarding chemical notation. Berzelius and his followers, for example, used the general formula MO for the chief metallic oxides, while others assigned the formula used today, M_2O. A single formula stood for different substances, depending on the chemist. For instance, H_2O_2 was water or hydrogen peroxide; C_2H_4 was marsh gas or ethylene, and so on.

In order to solve this and other problems, August Kekulé (1829–1896) suggested the organization of an international meeting of chemists, and on September 1860 the First International Congress of Chemists met in Karlsruhe, Germany. The organizing committee included distinguished scientists, including Robert Bunsen, Stanislao Cannizaro, Jean-Baptiste Dumas, Hermann von Fehling, Hermann Kopp, Julius Liebig, Louis Pasteur, Victor Regnault, Friedrich Wöhler, and Charles Wurtz. The first session of the Congress debated the notions of molecule and atom with Cannizaro and Kekulé as main speakers. Cannizaro repeated the arguments that he had published two years before [6], offering for the first time in the history of the physical sciences, a very clear definition of atoms as distinguished from molecules. To him the atom was the "smallest quantity of each element which enters as a whole into the molecules which contain it." To determine this quantity one must know the weights of all or most of such molecules and their composition. Furthermore, by comparing the composition of equal volumes of gaseous substances under the same physical conditions, it might be established that "the different amounts of the same element contained in equal volumes, either of an element or its compounds, are whole multiples of a same amount." This statement represented a most remarkable contribution to the clarification of the issues debated at the time concerning the relations between volumes, atoms, and molecules in both organic and inorganic compounds; in fact, the molecular weights were identified for every substance with the weights of equal volumes under the same physical condition. With his system of formulas, Cannizaro emphasized the absolute validity of Avogadro's hypothesis and that it could be used to determine not only molar masses, but also, indirectly, atomic masses.

Cannizzaro suggested the following rigorous method for finding atomic weights based on Avogadro's hypothesis.

1. Assume that the atomic weight of hydrogen is 1.0 and that hydrogen is made of diatomic molecules.

2. Assume that Avogadro was correct in deducing that oxygen gas is diatomic (O_2) and hence that the correct molecular formula for water is H_2O. This gives rise to a (relative) atomic weight of atomic oxygen of 16 and the (relative) molecular weight of O_2 as 32.

3. If equal volumes of all gases contain equal numbers of molecules, then the molecular weight (M) of a gas is

Table 1. Values of Avogadro's Number, *N*, Calculated by Different Techniques

$N \times 10^{-23}$	Technique	Author
4.4	Kinetic theory of gases	Loschmidt
6.6	Radioactivity	Boltwood-Rutherford
6.15	Radioactivity	Dewar
6.1	Spectrum of dark bodies	Planck
6.83	Brownian movement	Perrin
6.0	Density fluctuations	Constantin
7.5	Critical opalescence	Keesom-Onnes
7.7	Critical miscibility	Filrth
6.4	Scattering of light	Dember
6.064	Oil-drop experiment	Millikan
6.004	Surface tension of sodium oleate	DuNoò
6.06	X Ray diffraction	Doan-Compton

Table 2. Cannizaro's procedure to determine the value of k

	Gas Density, g L^{-1} (273.15 K, 1 bar)	Molecular Weight, *M* g mol^{-1}	Constant, *k* L mol^{-1}
H_2	0.0894	2.0	22.37
O_2	1.427	32.0	22.42

Average value: $k = 22.4$ L mol^{-1}

proportional to its density (d): $M = kd$. Hydrogen and oxygen are used to evaluate the proportionality constant *k* by using the value of their density at the same pressure and temperature. Table 2 illustrates Cannizaro's procedure to determine the value of k.

In 1869, Alexander Naumann, a physical chemist, published in the *Chemische Berichte* a short, clear note in which the equal-volumes numbers generalization was qualified for the first time, as "Avogadro's law." The 1880s had elevated the gas hypothesis to the present status of universal recognition.

Before closing this section a caveat is in order: Because of the volume of the molecules themselves, Avogadro's hypothesis is not strictly obeyed by real gases, difference is very slight except under conditions of high pressure.

Avogadro's Number

Avogadro's hypothesis leads to the concept of "gram-molecular weight" (a mass of a substance equal to its molecular weight expressed in grams) and to Avogadro's number, which is the number of molecules contained by the gram-molecular weight of a substance. Avogadro's number, usually denoted *N*, was not accurately determined until 1941 when Robert Birge evaluated it to be 6.02486×10^{23}. It was long after Avogadro that the idea of a mole was introduced. Because a molecular weight in grams (mole) of any substance contains the same number of molecules, then, according to Avogadro's principle, the molar volumes of all gases should be the same. The number of molecules in one mole is now called Avogadro's number*,* *N*. It must be emphasized that Avogadro, of course, had no knowledge of moles or of the number that was to bear his name. So, the number was never actually determined by Avogadro himself.

As we all know today, Avogadro's number is very large, the presently accepted value being $6.02214199 \times 10^{23}$. The size of such a number is extremely difficult to comprehend. Many illustrations have been proposed to help in visualizing the enormous size of this number. For example,

(1) An Avogadro's number of standard soft drink cans would cover the surface of the earth to a depth of over 200 miles.

(2) If you had Avogadro's number of unpopped popcorn kernels and spread them across the U.S., the country would be covered in popcorn to a depth of over 9 miles.

(3) If we were able to count atoms at the rate of 10 million per second, it would take about 2 billion years to count the atoms in one mole.

(4) Assuming that the Big Bang took place 5 billion years ago, then the total number of seconds elapsed is about 1.6×10^{17}.

Determination of the Number

The first modern estimates of the size of atoms and the number of atoms in a given volume were made in 1865 by Joseph Loschmidt (1821–1895). Loschmidt used the results of kinetic theory and assumed that the size of the atoms and the distance between them in the gaseous state are related both to the volume of the liquid formed upon liquefaction and to the mean free path traveled by molecules in a gas. The mean free path, in turn, can be found from the thermal conductivity and diffusion rates in the gas. Loschmidt used these relationships to determine the size of a carbon atom (10^{-8} cm) and the number of molecules present in a cubic centimeter of a gas under standard conditions (273.15 K and 101.3 kPa). From the latter value he calculated the value of Avogadro's number as 4.4×10^{23}, a result that is remarkably close to the present accepted value of 6.022×10^{23}. Eventually, a distinction was made between Loschmidt's number (the number of molecules present in a cubic centimeter of a gas under standard conditions) and Avogadro's number (the number of molecules in a gram-molecule).

Since 1865, many scientists have utilized different physical phenomena to calculate the value of the number (Table 1). In his book about atoms [6], Jean Perrin (1870–1942, 1926 Nobel Prize in Physics) introduces for the first time the expression "Avogadro's number" and illustrates how it can be calculated using the kinetic theory of gases, Brownian movement in granular suspensions, diffusion of large molecules, density fluctuations in fluids, and quantum theory.

The most modern method available today calculates Avogadro's number from the density of a crystal, the relative atomic mass, and the unit-cell length, determined from x-ray methods. To be useful for this purpose, the crystal must be free of defects. Very accurate values of these quantities for silicon have been measured at the National Institute for Standards and Technology (NIST). Today's best experimental value of $6.02214199 \times 10^{23}$ atoms per mole (obtained from the NIST web site) is the best average for measurements using the best methods available. That the number today has 9 significantfigures is a testimony to the quality of modern experimental methods.

Epilogue

Avogadro has been honored in several ways: (1) A crater on the far side of the moon (63.1N, 164.9E) is named after Avogadro. (2) On the occasion of the first centennial of

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Figure 2. Italian stamp honoring Avogadro on the centennial of his death.

Avogadro's death, Italy issued a stamp (Figure 2) carrying his photograph and his hypothesis. (3) The Universita' del Piemonte Orientali and the Department of General Physics at the University of Torino are named after Avogadro.

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