Chemistry in Modern Life

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AUTHOR'S PREFACE TO THE AMERICAN EDITION

Our age is often called the electric era, sometimes the era of paper. It would be more correct to call it the age of natural sciences, and especially of exact sciences. Physics and chemistry have revolutionized our daily life. It once seemed that physics was most important; for the wonders of electricity appeared more revolutionary than anything else. But on closer consideration we discover that chemistry has been of still greater importance in modern culture. This is because with the aid of chemistry we are able to transform rough raw materials of little or no value into products of extreme value. The most striking example of this is in the production of ammonia and nitric acid. In this case the raw materials are the constituents of air and water. They occur nearly everywhere that man exists, and therefore they have no value. But, for the preparation of the ammonia, and eventually of the nitric acid, a great source of energy is necessary, as well as the labor of men working in factories. The cost of the energy and of the labor, therefore, determine the price of the products. These products are of immense value in agriculture and for the making of explosives.

The bitter experience given us by the World War, and by the after-years of exigency demonstrated with hard fisted emphasis the necessity for chemical industry. So we see today how the nations are trying to develop this branch of science for the best possible improvement of their situation. The most practical way to repair the heavy losses caused by the war lies in the application of chemistry.

A most important question, which has caused much discussion in recent years, is the question of the sufficiency of supply of the raw materials which are used by chemical industry in immense quantities. Only in exceptional cases do these raw materials occur so abundantly that we need have no fear of their eventual exhaustion. Even America, today the land most blessed with natural riches, may use up many of them within a few centuries. Of the ores of the heavy metals, it must be stated that they occur only in very limited quantities. The better iron ores are being worked rapidly, because of their great demand for industrial purposes. But it must be confessed that we have a great abundance of low-grade iron ores, which must be attacked after the exhaustion of the more valuable ores, perhaps in about 1,000 years at most. Furthermore for many purposes we may use the light metals, such as aluminium, at hand in unexhaustible quantities in bauxite and as a constituent of clay, in place of the heavy ones.

Far greater is the danger regarding the energy necessary for chemical operations. The material basis of our present civilization depends on the use of fossil fuel, chiefly coal and petroleum. In earlier periods of history one generation of men lived very nearly as did the preceding one. Centuries were necessary to produce great changes in the conditions of life. This circumstance has been completely altered by the use of fossil fuel, for the development has taken on an explosive character. During the last century as much coal was consumed in each ten years as had been used in the whole preceding time. The conditions for the consumption of iron and most other metals, of petroleum, and of other necessities such as paper, glass, etc., have been similar. The recent war, which marks a great retrogression in civilization, has diminished this rate of progress for a time. But it has been calculated that the accessible fossil coals will be nearly at an end in about 1,000 years, and petroleum in about twenty years. If we do not find some new source of energy within a thousand years, humanity will fall back to a state of civilization similar to that about a century ago, while the number of inhabitants of our planet will have to diminish to a corresponding degree. Luckily we have the energy of the water-falls which will not diminish in a sensible degree in comprehensible time, unless we cut off the forests on which the water reserve is more or less dependent. We must harness these falls to save as much as possible of our present material culture. But even when we have taken them into our service they cannot compensate for the loss of fossil fuels. Humanity stands, therefore, before a great problem of finding new raw materials and new sources of energy that shall never become exhausted. In the meantime we must not waste what we have, but must leave as much as possible for coming generations.

Doubtless humanity will succeed eventually in solving this problem, at least partially. But when the new resources have been found the hearth of civilization will move to the places of their chief occurrence, and the life-conditions of mankind may undergo a great revolution.

THE AUTHOR

STOCKHOLM,
August, 1923.

TRANSLATOR'S PREFACE

HERE in America we sit back and beam about us on a land of plenty and resource. Of course we are bothered by a few petty details — next winter's coal — the cost of electric power for that new factory project — or the rising cost of construction steel, but we lay these evils upon the miner, or the service company, or the steel trust, and continue our serene way.

Do we ever stop to think, "How long can this go on?" Not often. Do we ever stop to consider how much this luxurious, comfortable life we live depends on "material culture," on the development of glass and pottery, on metallurgy, on fossil fuel, on rubber and cellulose, on nitrate and coal tar? The present generation was born to the inheritance of these things. We have no memory of days when these were not. We seem to display no ambition to look whence these things come, nor to look into a future in which perhaps we shall not have them.

Yet days of want for some of the "necessities" are close at hand. American oil in *twenty years*, the world supply of coal perhaps in 1000 years, at a very little above the present rate of consumption! In terms of history the latter period is but a moment longer than the former. Iron increasingly scarce, or obtainable only from poorer and poorer ores with consequent increasing cost. The Age of Heavy Metals dwindles! America can be a little more smug than can Europe in these matters. Iron and coal will last us for a while, if we hoard them, but not if we supply the world; yet such an appeal may come to us shortly.

Our ideal culture, our luxury, our home-life, our urban civilization and our fundamental outlook on life may go overboard all in one great wave, if our material culture, upon which all else is based, and without which these things cannot exist, is to fail us. We have lived upon our principal, we have thrown to the winds our fuel, we have cut down our forests and refused to reforest, careless of the waterpower that is dependent upon them.

The answer is Conservation, — frugal housekeeping before it is too late and substitution where it is possible today. Concrete construction has already begun to lessen the use of steel construction, water powers are substituting coal, though this is not everywhere possible; but more can be done in these fields and in many others. We can reforest — develop our waterpower — economize with the treasures of nature. Coal can be burned at or near the mines to make electricity, and so energy can be transported more efficiently via copper cables then when half the energy (as coal) must be used to haul the rest by railway. Let the government take control, if necessary. Where will our fine development of aviation be, should liquid fuel give out? A launching into the air — a bitter landing for lack of what might have been conserved to this end. Alcohol for motor fuel, you say? There are no definite signs today that it ever will be practical on the scale of our present use of petroleum. Atomic energy, you say? A chimera today — possible, yes, after centuries more of study — or perhaps never. We cannot keep house on the hope that some one will die and leave us a million dollars, nor can we on the chance that atomic energy can safely be unlocked.

Scientists over the earth are concerned in study of these dangers — yet they see no way out save conservation. Thou Shalt Not Waste! We are faced by the "Chemist's Commandment" at every turn of our modern civilization.

Here in substance is the message of this book by Svante Arrhenius, chemist, cosmist, teacher, director of the Nobel Institute, president of the Swedish American Foundation (Sverige Amerika Stiftelsen). From the outermost star to the interior of the atom his searching mind has roamed to find the riddle of the future. Yet the horizons that he sees are dark ones unless we are civilized enough to mend our ways, unless today we take to the game of conservation, now that the frontiers of the earth are gone, as once we took to pioneering.

Professor Arrhenius continues the succession of brilliant names which Sweden has supplied to science, name like Scheele, Linnaeus and Berzelius. The name of Svante Arrhenius is inseparably connected with one of the most important of chemical theories — the theory of electrolytic dissociation. An estimate from the pen of another expert in his field, of the importance of Arrhenius' theory is given by Professor Charles Kraus of Clark University, in his book on the "Properties of Electrically Conducting Systems." "It is to Arrhenius that is due the credit of first having developed a theory of electrolytes quantitative in its nature, the correctness of which it was possible to determine by exact quantitative methods."

To the writer, as a student on the American Scandinavian Foundation, the stimulus of Professor Arrhenius was immense; his interest in the relation of material culture to world affairs, his cosmics, as well as his intricately detailed chemical studies, such as those in the kinetics of immunochemistry — all these, combined with a genial, kindly personality, led to many visits to his home and workshop, the Nobel Laboratory outside Stockholm.

The New Chemistry, the theories of the inner atom and crystal structures, the chemistries of Bohr, Bragg, Moseley, Thompson, Rutherford and Langmuir, receive little mention in this book. These in a sense are but the unborn concepts of the future. They have produced but few effects upon our life. True the chemistry of the vacuum tube gives us radio-broadcasting. Perhaps the nineteen-twenties will come to be known as the transitional decade of the new chemistry and physics. But, outside the field of radiation physics, these have as yet given but slight service to civilization, so they can scarcely be looked upon as more than a shadow of the future across our modern life.

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C. S. L.

NEW HAVEN,
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Chapter I

ANCIENT IDEAS ABOUT THE CONSTITUTION OF MATTER

We commonly fancy that the most ancient folk of whom we have any knowledge held the belief that matter could be destroyed and likewise could appear out of nothing through a sort of act of creation. This belief we first find, however, among people who have come very far, and, let us here add, entirely too far, in ability to think abstractly. The idea appears in the Indian *Vedas* (1500–1000 B.C.) yet it was never developed entirely logically, for even before the world's existence an all-pervading uniform solution was supposed to exist, which solution was made visible by God (Brahma) with the aid of the five elements. Afterwards, the act of creation came to pass as a result of Brahma's will. The creation resulted in annihilation which again resulted in a new creation, and so on. This oscillating process, however, appeared principally to have applied to the living beings and not so much to the matter itself.

Far simpler is Zarathustra's (Zoroaster's) teaching according to which the light god, Ormuzd, who was the unformed matter which like a chaos filled infinite space, formed out of several god-entities and heavenly spaces the following things in the order given:

1. The heavenly bodies: sun, moon and stars.
2. Fire.
3. Water.
4. Earth and the living beings.

Here one finds a division which corresponds to the later four elements. Previously the Indians had introduced a fifth, "Air," while the first, the celestial element, dropped out or was accounted equivalent to "Fire."

Just as in Zarathustra's doctrine one finds among all primitive people the notion regarding the world's primordial state that, until a "beginning," there pre-existed unordered matter, commonly called "Chaos," which was changed to the different natural objects by a divine being. The doctrine of the indestructibility of matter in later times, since man made use of the balance to measure mass, has expanded into one of the basic principles of modern science which says that matter's mass is unchangeable — it can never increase or decrease.

After this first occurrence we also find the doctrine of the four different elements in the oriental countries, in Babylon as well as in Persia and India. Perhaps the Greek philosophers got their ideas about the elements from the Orient. From the first there existed among the Greeks a tendency to simplification in that one of the elements was claimed to be the most important primitive material out of which the other elements could be regarded as taking their origin. Thus, Thales claimed the water, Anaximenes, the air, and Heraklitus, the fire, as the most primitive. Finally, it came about that Empedocles (who lived about 500 B.C.) took all four elements to be equal — that is to say, besides the three last named, also earth. This teaching was taken up by Aristotle and prevailed, protected by Aristotle's enormous authority till long afterward in modern times.

In this very simple theory the ancients summarized their observations of the outer world. Indeed, these were very insignificant. Three of the fundamental elements — air, water and earth — constituted the three fixed states in which matter appeared — the gas form, the fluid and the solid. This knowledge belonged not to the science which we now call chemistry, but rather to that which we as well as the ancients call physics. The fourth element, fire, constituted the shining material which we observe in the celestial bodies and which also appears among strongly heated earthly objects. We now know that the same body can appear in the three different states, the commonest example being water which is fluid, but which can be changed to a solid form, for on cooling it goes over into ice, or to a gas form, since it is transformed to steam through the application of heat. Even the ancient world had an inkling of this fact. Plato said in *Timaios*, "Fire is burning air. Condense and quench this, one gets back air; the air (water-vapor) again condenses to a cloud and fog, which by running together gives fluid water. From the water finally stones and earth form by condensation." This last manifestation refers not to ice formation but to the settling out from impure water of suspended solid particles or the dissolved salts. Plato's observation was consequently quite imperfect and superficial. This characteristically accounts for the philosophical tendencies prevailing among the ancients, for they satisfied themselves with unclear generalizations in place of careful observations. Experimental research was almost wholly disregarded in the ancient world.

In Plato's doctrine condensation was by far the most important factor. Air condensed to cloud and fog, this again to water, which again condensed to earth and stones. Even when fire changed to air there occurred a condensation of space, said Plato. The desire to draw a general conclusion had set the great philosopher on the wrong road. Beyond doubt, a condensation occurs when water vapor changes to the liquid form. But as we well know an increase of volume occurs when water freezes. This was unknown to Plato (428–347 B.C.) just as he did not know that water differs in this particular from the great majority of fluids. The notion of density or specific gravity was first clearly set forth by Archimedes (287–212 B.C.). Only by employing general, unconfirmed notions could the Platonic doctrines about elements be accepted and win popularity.

With regard to the relationship of fire to air it is well known that air becomes warmer when it is compressed, a property which is made use of in the pneumatic tinderbox for the production of fire. Had Plato known of that fact he would hardly have formulated his conceptions about fire and air as he did in *Timaios*.

With the three physical states of Plato and his wrong conception of density as a basis for generalization, his great pupil Aristotle (385–323 B.C.) turned his attention to the importance of heating and drying in nature. In themselves heat and humidity are of the greatest importance for the growth of organisms, and so for man's existence. Drying destroys vegetable growth and changes tillable fields to desert. Cold, which is to say the absence of heat, also hinders the growth of plants, and especially the maturing of their fruit. Aristotle introduced this concept into the definition of the four elements, explaining that warmth and coldness, humidity and dryness, are four fundamental sensations, and he achieved thus the following schematic representation:

Cold and dryness	Earth
Heat and dryness	Fire
Heat and moisture	Air
Cold and moisture	Water

More combinations than these are not to be thought of. Therefore, more than four elements cannot exist. That line of thought is always characteristic of the Platonic-Aristotelean philosophy, which unfortunately ruled the habits of thought for about two thousand years and even in our day strongly persists except in the domains of natural science. How wrong it is may be seen from the fact that air, as ordinary observation teaches, can be either cold or warm and equally may be dry or again moist, namely when it contains water vapor. All gradations may be found between these extremes. Nevertheless, schematic simplicity triumphed over doubts grounded upon observation, and the Aristotelean system solidified in a dry dogma which pinioned the wings of science in its growth.

Somewhat before Plato's time there lived in Abdera in Thrace the greatest truly scientific thinker of ancient times, Democritus (born 460 B.C.). He had made clear to himself that water vapor and water ought not to be characterized as different elements since they really could change over into one another. There must be something common to them both. The very smallest parts in water and water vapor must be the same, only they lay further apart from one another in water vapor and therefore took up greater space than in the liquid water. Observations show us that these tiny parts are invisible. In order to understand why the transformation of water to water vapor (and vice versa) could always be accomplished, it was most logical and simplest to believe that the characteristic small parts were indestructible. Democritus assumed that these tiny parts were not further divisible — he, therefore, called them *atoms* (Greek for *indivisible*) — and he assumed that they were engaged in a perpetual motion. Through union of the atoms in different ways arose the different bodies that we find in nature. The indestructibility of matter had already been postulated by Empedocles, who claimed that all phenomena in the world depended on changes of form and of composition within bodies. Democritus did not let himself be bound to the postulation of four elements. He was powerfully opposed by Aristotle and his school and most of what we know about Democritus is taken from the critique of his teaching by the dominant school.

It is quite remarkable that, through the entire Middle Ages and down to the seventeenth century, no noteworthy advance was made in the teachings about the composition of substances. The chemists occupied themselves above all with the problem of the properties of metals. These seemed to them to be all of one nature and therefore they thought it should be possible to change one metal into another. They sought, therefore, to prepare the most valuable of all metals — namely, gold, out of less precious metals. They imagined that it should be possible to bring this about by some sort of color change. They knew that copper can be colored silver-white by treatment with arsenic compounds and that it takes on a gold color through treatment with *calamine* (zinc carbonate). As we now well know, these changes depend upon the fact that this treatment forms in the one case a white alloy of copper and arsenic, in the other case a golden-yellow alloy of copper and zinc (brass). It had been known since ancient times that copper took on valuable properties by the addition of tin, forming the alloy bronze, notable for its hardness. Therefore, it seemed natural that they should be able to prepare gold and silver out of copper and other less precious metals by suitable additions. This concept was embodied in a theory that all metals contained a common ingredient called quicksilver because it was supposed to occur least-alloyed in the liquid metal, (mercury).

In the Orient, chemistry did not need, perforce, to grow into gold manufacturing. According to Berthelot it took that odd trend from Egypt. The Egyptian goldsmiths, for the purpose of forgery, prepared gold or silver-like alloys out of unprecious metals by which means they became very rich. The Greeks learned from the Egyptians this art of "transmutation" (changing metals into one another); from the Greeks, the Arabs learned, and finally from these latter the medieval Europeans took up the art. If one were to believe with Roger Bacon that a few grams of the philosopher's stone would have power to change a ton of base metal to gold, one would be greatly tempted to seek a fortune in the "Greek Art," as the transmutation of metals to gold was called. That art, then, which made up alchemy's chief aim, originated in Egypt.

The state of things in the Orient was quite different. There chemistry developed as a sort of auxiliary science to medicine, which was practiced after the beginning of our Christian Era in the Buddhistic monasteries, for it was the duty of the priests dwelling in them to cure all sorts of suffering, spiritual as well as corporeal. In such a monastery was to be found a great hospital. They believed that not solely a specific compound, but also the utterance of specific religious formulae were necessary to the physician's healing power. Thus chemistry took on a religious impress. The oldest Hindu writing about medicines is found in one of the Veda-books, Atharva-Veda. Gold was considered as a sort of life elixir, lead as an agent for fighting magic. Pearls served as amulets to protect against sickness and to give one hundred years of life. Most drugs were of organic origin and only a few inorganic drugs were used, such as occur as natural products. Praphulla Chandra Ray who has written a history of Hindu chemistry notes that long before Hippocrates, the Indians developed a humoral-pathology and that it is more or less likely that the Indian teachings influenced the concepts of the Greeks. Little by little medicines of inorganic nature became commoner and they learned to prepare these with ability, especially the sulphur compounds of the metals. Quicksilver again came to take a central place. "It is only quicksilver which can make the body resistant and immortal," they said. Black mercuric sulphide was next believed in as a universal agent which ought to be compounded in all medicines. Mercury preparations were used against leprosy and other skin diseases and very likely the Arabs learned of this medium in India. Even lye, and caustic alkali prepared from it, played an important role. When the alkali acted too strongly they neutralized it with vinegar (acetic acid).

A clear account of the differences between the Occidental and the Oriental science was given by the Arab, Alberuni, (died 1039 A.D.) who visited India from 1017–1030 A.D. "The Hindus," he said, "do not care very much about alchemy, but no nation is a complete stranger to this science. . . . Adepts in the science seek to keep it secret and will not associate with any but their colleagues. Therefore, I could get enlightenment from the Hindus neither about what methods they employ in the science, nor as to what raw material they chiefly employ — mineral, animal or vegetable. I heard them talk only of sublimation, calcining and analysis, and also of 'swelling' talc, which in their speech is called 'talaka'; and therefore I surmise that they interest themselves in the mineral side of alchemy.

"They have a science which is similar to alchemy but is