PRESIDENTIAL ADDRESS

CHEMISTRY, SCIENCE, AND CULTURE

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I wish to address you this evening on the broad subject CHEMISTRY—SCIENCE—AND CULTURE.

When I use the term WESTERN CULTURE each of you here has an instinctive understanding of what I mean; for most of you are scientists, and we are all heirs to the same great tradition of Western Culture. In specific language, we understand well the dictionary's sociological definition that "Culture is the sum total of a way of living—built up by a group of human beings—which is transmitted from one generation to another."

Another, and more specific meaning, defines culture as "The *training* and *refinement* of *mind, tastes,* and *manners*." It implies a *quality* of living—a constantly *improving* and *growing* way of living—through *learning*. And—most importantly—it also implies that Western Culture can continue as a stable culture *only* if its members are of a certain intellectual attainment; and—further—if the benefits of this, our culture, are to be transmitted to future generations there must be a greater appreciation of a *broad spectrum* of comprehension of all knowledge.

But is knowledge (in Latin known as *Scientia*) the *only* ingredient of our present culture? Are the *best* and *wisest* decisions for solving our many social problems always those which derive from the scientifically elite group of experts? During the time period from the end of the Second World War and into the mid-sixties science attained a high peak of influence. Society benefited greatly from the many new consumer products which resulted from wartime research. Television, the jet airplane, the computer, and even the conquest of space became a real part of our culture. Scientists in government, management, and academic life made vital decisions which non-scientists could not deter because science was king. This scientific influence even spread to the humanities and religion and attempts were made to make them "appear more scientific".

But in the short span of ten years we have become abruptly aware that in the total culture of a society there is no knowledge that is in itself king. In fact, we know that the ingredients of a true culture are not merely the "scientia" of the sciences (either physical or social); but that they also include our religious faith, our philosophy, our arts, and our humanities. For beyond all of knowledge there exists an even greater quality if we are to hope for an enduring culture. This quality has always been recognized by mankind. Robert Sinsheimer, Chairman of the Biology Division of Cal Tech, in a talk last June reaffirmed that quality which scientists must seek. He said in part, "We begin to see that truth is not enough—that truth is necessary but not sufficient—that scientific inquiry—the revealer of truth—needs to be coupled with wisdom if our object is to advance the human condition."

We cannot dismiss the acquisition of new knowledge or by law provide for a moratorium on all new research. We trust that the continued discovery of nature's laws will provide us with new technologies which can offer a higher cultural potential to all human beings. Although wisdom is not mere knowledge, wisdom as it is needed in our modern world is not possible *without* knowledge. Wisdom cannot be attained by meditation alone, and unlike other disciplines, wisdom is not a subject which can be taught as a part of our educational system. Wisdom in man is not infallible in the individual. The best source of wisdom derives from individuals who are possessors of great breadth of knowledge regarding the various components of a problem which exists or which is expected to exist at some future date.

If a society can become knowledgeable, in some degree, of the various facets of science, politics, economics, and sociology which are inevitably entwined—then possibly that society can find among its members those individuals who can pool their best wisdom in solving our problems. I firmly believe that scientists have a responsibility to speak of the role of science in our culture. Tonight I wish to speak as a chemist on the role which I believe chemistry has played in the shaping of our present culture. I am sure that each of you could also illustrate how physics, biology, engineering, geology, or any of our scientific disciplines have added their own unique contribution to our developing culture. And so I will speak of a few of the historical landmarks of chemistry.

It is believed that the practical knowledge that would eventually give birth to alchemy first originated in the predynastic period of Egypt (before 3400 B.C.). It is known that the early Egyptians worked with gold and silver. Their ability to produce glass on a large scale was well established by 1400 B.C. Some Chinese literature indicates that as early as the Third Century B.C. ideas characteristic of the beginnings of early alchemy were being employed there as well. But in Ancient Egypt, out of the land of Khem, came the knowledge Arabs would later identify as alchemy. Most of the discoveries in metallurgy, as well as those which lent themselves to the making of various kinds of materials, were obtained by chance. Those noble metals, gold and silver, which were found in the native state, were highly prized by the ancients because they could be worked so easily. The gold mines of Nubia were mined extensively by the Egyptians. One historian, writing in 1890, estimated that the gold mined in just one year in the Nubians would be valued at 125,000,000 pounds sterling, or approximately a billion dollars a year. The accidental discovery of glass in Egypt has been suggested as the result of adding soda to sand which acted as a flux in melting the sands which contained traces of gold. This early striving for gold would continue on into the Alchemical Period and lend its impetus to the search for the Philosopher's Stone.

The Greeks and Romans inherited the knowledge of matter which had originated in the Egyptian civilization. They improved upon these ancient metallurgical processes and developed new products. Bronze, which was probably first produced about 2500 B.C., was probably made from copper and tin oxide ore even before free tin was identified. This early knowledge of matter was of an empirical nature. There were no planned experiments such as are designed today and which are the heart of modern scientific study. It is difficult to understand why the gifted Greeks, who had made so many advances in mathematics and philosophy, did not organize into groups the many careful observations which had been made over the previous centuries and develop theories from these facts. Their disdain for physical work, and their fixed belief that the methods of thought and discourse were the only methods suited to study nature resulted in a philosophy—but not a science.

Even though Democritus proposed an atomic theory as early as the Fifth Century B.C., in which he imagined that all matter was composed of different types of atoms according to the nature of the substance, he had no other scientific bases for its acceptance but that it was a philosophical idea. It was not the result of experimentation. The concept of atoms as a valid scientific theory would not be introduced until the early Nineteenth Century by the chemist John Dalton. One might well pause to reflect that if the methods of philosophy and the dogmas of the many mystery religions (including the Christian faith) had continued as the dominant voices in man's intellectual development, it would have been impossible for modern Western Culture to develop as we know it. The use of an inductive method by a later generation of scientists produced the natural sciences and changed the direction of our culture.

As the Greek and then the Roman influence declined politically, and the devastation of barbarian conquest spread throughout Europe, a group of individuals centered around Alexandria managed somehow to preserve some of the ancient knowledge of matter. It is believed that in some of the writings of these Alexandrians (dating from the Third to the Seventh Century, A.D.) there is evidence of the first beginnings of alchemy. When the Moslems conquered Egypt in the Seventh Century and destroyed the priceless treasures of the great library at Alexandria, few could foresee that these people would be the successors to the learned Greeks.

But alchemy did become the province of the Arabs, and they continued the study of matter and its properties. The erroneous doctrine of transmutation of base metals to gold became entrenched in their thinking. Even so they left behind many valuable descriptions of chemical processes and introduced new methods of separation and the purification of various substances. But why—over the entire Alchemical Period—did no one recognize that the transformation of different substances into new ones was related to an ancient atomic theory? It is hard for us, who have been trained in the inductive methods of science, to understand that at one time the practicing alchemist had the ingrained belief that a substance would be transformed into a new substance only with the complete annihilation of the old substance.

But as the Sixteenth Century approached, alchemy was in the decline. The long-sought-after Philosopher's Stone would become more a matter of faith. Charlatans, in an attempt to maintain their favor in the courts of Europe, claimed that they had Divine assistance in their work. But many among the intellectual class began to distrust the alchemists. In the 1600's an event happened which would change the character of alchemy to that of chemistry. The introduction of printing made possible the dissemination of studies which would now be subject to broader criticism. A new spirit of freedom began to develop and emerge with the geographical discoveries of the New World and the exploration and colonization of these lands. As the century moved on scientific societies were organized in Europe and science began to achieve academic acceptance.

But—most important—some men were beginning to investigate the mysteries of nature, and they possessed new ideas as to how this should be done. Robert Boyle, born in 1626, settled in Oxford in 1654 where he carried on his studies until 1688, when he moved to London. He became the first President of The Royal Society in 1680 and guided its activities until his death in 1691. Boyle turned his thoughts to the concept of the atom of the element. He discarded the old Aristotelian idea of four elements and maintained that these "Certain primitive and simple or perfectly unmingled bodies; which not being made of any other bodies or of one another, are the ingredients of which all those so-called perfectly mixed bodies are immediately compounded."

But even as this new scientific spirit, based upon an inductive method, began to appear, there was also being proclaimed a concept of combustion which became widely accepted by most scientists—but which was entirely incorrect. The burning of matter—combustion—had been the focus of study for many years when Johann Becher set forth his view in 1669 that whenever a substance burned or was calcined, the combustible constituents of that substance—the terra pinguis-escaped. It was the escape of this material which gave the evidences of burning. Later, George Stahl built his similar idea of phlogiston. Each combustible material, including the metals, contained a substance—phlogiston—which escaped when the substance burned away; or, as in the case of a metal, became calcined to a powder. Since coal would burn until almost nothing remained, it was almost pure phlogiston. If a metal was heated, it too lost phlogiston, until its calx alone remained. To prove this had happened, if the metal calx was heated with coal, the phlogiston would again enter the calx and the metal would again reappear. He assumed that sulfur consisted of sulfuric acid and phlogiston, for upon burning sulfur, the phlogiston escaped and sulfuric acid was left.

Why he, or chemists who followed after him, would not question the difference in odor of the phlogiston from carbon as compared to the phlogiston from sulfur; or the fact that the calx of iron, which had lost phlogiston, now weighed more than the original iron, illustrates the hold a theory can have on the minds of knowledgeable individuals even though the theory is erroneous. Chemists such as Joseph Black, Carl Sheele, Henry Cavendish, and Joseph Priestley were phlogistonists in the full sense of the word. This doctrine, which did not completely disappear until the early 1800's, did have the positive effect of proposing an interpretation of many different observations from one common point of view. It was a beginning in the use of theory in the inductive method of reasoning.

It is natural now to turn briefly to Joseph Priestly, and to relate his contribution to the chemical and cultural development of our society. Priestley was born in 1733 in Yorkshire, near Leeds, England. His early training and study was in theology, and he became a Unitarian minister—a dissenter from the established Church of England. He was a free-thinker and prone to oppose his own government in the conflict between England and her American Colonies, and he sympathized with the Revolutionaries during the French Revolution. He was a friend of Benjamin Franklin; and he would heed his advice and that of his intellectual friends who lived in the community of Birmingham and the Severn Valley to embark upon scientific studies. His interests were broad, his natural instincts were to learn all he could about anything and everything.

In 1767, in Leeds, where he lived next door to a brewery, he found a ready source of 'fixed air', and began his studies which would culminate in his publication in 1772 on "Directions for Impregnating Water with Fixed Air." Dr. Joseph Black had obtained "fixed air" from heating limestone in 1754, and Henry Cavendish had produced "inflammable air" in 1766. These gases, it was believed at the time, were mere modifications of ordinary air. There was an excitement in Priestley to learn all he could about these "modifications". He designed a "pneumatic trough" to collect various gases; and he synthesized and collected sulfur dioxide, ammonia, and hydrogen chloride.

Possibly he decided to begin a study of heating various solids to find if they contained a gas, since Black had demonstrated the possibility of obtaining fixed air by heating limestone. It is to be remembered (although few historians record the date) that a memorable occasion in the history of civilization occurred on August 1, 1774, in Wiltshire, England, when Priestley focused his twelve-inch burning lens on a sample of red calx of mercury confined in one of his pneumatic tubes and produced his first sample of "dephlogisticated air". He had discovered, as he reasoned, a new modification of air which he found could support combustion much better than ordinary air and which must therefore contain no contamination of phlogiston since it could accept a much greater quantity of this element of fire more readily. Later in that year, he would visit Antoine Lavoisier in Paris and advise Lavoisier of his work. He subsequently published this study in March, 1775. These were all links in the chain when Lavoisier would report in 1777 on his theory of combustion and the identification of Priestley's gas (which was indeed the life-saving oxygen) as a component of air.

Priestley's outspoken sympathy for the colonists during our Revolution and his support of the French Revolution in 1791 led to the destruction of his home and laboratory in Birmingham by a mob. In 1794 he came to Northumberland, Pennsylvania where he lived out the remainder of his days. He died in 1804 shortly after his 70th year. The famous Priestley Award of the American Chemical Society recognizes Priestley the man and his distinguished work.

Priestley's contemporary in France, Antoine Lavoisier, was ten years younger. From an early age his career was that of a scientist, and he was soon recognized by the French Academy of Science. His work encompassed not only the discovery of new scientific information; but he also served France on many Boards and Commissions solving problems of administration on taxation, banking, scientific agriculture, and many other areas. His chemical research was directed to the quantitative study of reactions and it was not the common type of research prevalent in his day. It was his ability to measure and to weigh reactants and products of reactions which made it possible for him to bring order to the uncertainty which existed in the study of combustion.

In addition to his own detailed experimental work, he took the results of other's work, and wove their findings into a new chemistry. He helped organize a new nomenclature, and he wrote a new textbook on "Elements of Chemistry" which provided a systematic approach to the study of chemistry. His early recognition of oxygen as a constituent of many acids resulted in one forgivable error—when he forgot his own principle "Never to advance but from what is known to what is unknown", by his mistaken insistence that all acids contained oxygen. Lavoisier initiated a revolution in chemistry—but would himself become a victim of another Revolution. In May of 1794, the year Priestley came to America, Antoine Lavoisier was sent to the guillotine. Many would whisper "Only a moment to cut off that head and a hundred years may not give us another like it." Lavoisier well deserves his title of "The Father of Modern Chemistry".

Today we encounter the general belief of many that the influence of chemistry on our culture is the influence which chemical technology provides through the many beneficial, and sometimes not so beneficial, products it provides. But the intellectual contributions of chemistry are not recognized in many cases. The organization of new methods to solve the mysteries of nature—the incitement of a new spirit of intellectual inquiry were a vital part of the same spirit of freedom which burst upon the Western World in the late Eighteenth Century. This new cultural spirit was evidenced in the changes in religion, politics, literature, and the new science which Priestley, Lavoisier, and others helped bring about.

We might briefly retrace our steps and review one great technical development which was occurring at the same time as the sweeping changes in chemistry took place. In 1709, in the small village of Coalbrookdale, Shropshire, England, Abraham Darby I purchased an old iron forge and began to produce cast iron for the making of pots and kettles. In this year he found that in place of the widely used charcoal to reduce the iron ore, he could use—as a replacement for charcoal—coal which had been coked. Others had attempted to use coal for this purpose, but had been unsuccessful. It was Darby's use of sulfur-free coal to make his coke which made the reduction of iron ore possible.

Here was a potentially great industry which had been limited in its capability to produce iron by the lack of sufficient wood to produce charcoal, for the great forests of England and Europe had been dwindling away. Now this bottleneck had been overcome, and the way was open for the production of unlimited quantities of iron. And so in this year of 1709 the great Industrial Revolution was born in a tiny town in England and would spread throughout the world. By 1760 it would greatly influence our cultural direction. In this rural region of England—in the beautiful Severn Gorge—iron forges produced the iron to manufacture steam engines, iron rails and (yes) the cast iron stoves and cooking utensils which revolutionized the housewife's kitchen. The Darby Plant continued to grow—and in 1775 earned lasting claim to fame by building of cast iron the first iron bridge in the world. Completed in 1779, the ribs and beams, which had been cast at Coalbrookdale, were set to span the Severn Gorge, a distance of 120 feet. This structure, the ancestor of our massive bridges of today, still stands across the gorge at what is now known as the town of Ironbridge, England; and a great outdoor industrial museum is developing at this historic site.

This region of the Severn Valley and its outer-lying area was to breed an unusual quality of men. Josiah Wedgewood, the potter who raised his craft to a fine art and who was also a scientist in his own field, became—together with Erasmus Darwin—the grandfather of the great scientist Charles Darwin. They, along with Darby, Matthew Boulten, James Watt, and John Wilkinson, with his brother-in-law Joseph Priestley, were all members of the famous intellectual Lunar Society which had its meeting place in Birmingham and met at the time of the full moon—the better to travel. Their lives, their work, and their intellectual activities opened a new and wonderful door to our present cultural heritage.

One could continue to enumerate the work of chemists such as Dalton, Gay-Lussac, Berzelius, Wöhler, Liebig, Pasteur, and a great many others who lived in the Nineteenth Century; but we must limit our selection since so many of the discoveries of this generation of men were so significant. But I wish to pause briefly to consider some chemical technical developments. At the meeting of The British Association for the Advancement of Science in 1898, Sir William Crooks, in his presidential address, gave emphatic utterance in a warning of the world's future food problems. He stated that there was not enough fixed nitrogen available in the nitrate beds of Chile to supply the nitrogen nutrient for the growth of wheat and other grains to supply the world's needs in the near future. His disquieting message of approaching nitrogen starvation did not cause much worry among the world's politicians; but men of science understood well the danger to the human race. The control of the seas determined what nations would maintain a lifeline to the great Chilean deposits. In the early 1900's Britain, the United States, and France held that control. The Central Powers of Europe, under the leadership of Germany, were unable to undertake any massive military venture since their lack of nitrate kept them from producing the quantities of TNT and nitrocellulose necessary to conduct a long war.

Then in 1912 Professor H. A. Bernthesen announced at the New York meeting of the International Congress of Applied Chemistry that Fritz Haber and his associates in the Badische Anilin and Soda-Fabric located at Oppau, Germany, had at last discovered the method of converting nitrogen and hydrogen to ammonia. Since ammonia can be oxidized in the presence of platinum gauze to nitric oxide, it became possible to synthesize the needed oxide necessary to produce nitric acid. This freedom from the sea blockade of the importation of sodium nitrate from Chile guaranteed Germany a continued production of explosives; and in a brief two years the volatile political situation in Europe erupted into the destructive First World War. The long-sought-for chemical discovery to fertilize the fields of the world with fixed nitrogen did not result in an immediate blessing to mankind—but instead made possible World War I—which in another twenty-five years was followed by World War II. Today, with the blessings of lessened world tension, we are enjoying the benefits of fixed ammonia as we produce bountiful harvests of grain to feed the world.

We simply cannot evade or escape science and technology. The Haber process could not have been withheld from society because it also held within it the potential for devastating war. It was not necessarily the year of 1914 that brought forth the first paradox of the good and the evil in technology. The iron that armed the ancient Greeks came from the same process that ultimately produced the Industrial Revolution and the great modern steel industry. As we know, the potential for both good and evil becomes even greater with each new scientific advance—while, sadly enough, the paradox remains unanswered and unsolved.

Just as we can point to the positive intellectual impact which the study of pure chemistry has had upon the deepest roots of our culture; so too we also recognize that the less fundamental (but more dangerous) technical application of these intellectual discoveries have introduced a sometimes fearful but inescapable impact upon our daily culture. One cannot breathe, nor eat, nor live one's daily life without coming in contact with the potential dangers of modern technology.

Lastly, we should end this historical review of chemistry and science in our culture by joining chemistry with its sister science physics for a brief review of today's most miraculous technical advances. Who in 1780 would have suggested to Luigi Galvani and Allessandro Volta that their discoveries in current electricity would endanger the culture of the Western World? Would one want the work of Faraday stricken from the understanding of the chemical compound? Was Crooks' work in the cathode ray to be classified by a paternal government because it might become dangerous knowledge? And should Röentgen and Becquerel and Marie Curie not have recognized their accidental discoveries as a starting point in our understanding of X-rays and radioactive disintegrations? When Thompson and Chadwick identified the electron, the proton, and the neutron; could society or even the knowledgeable scientists of that day recognize that "When the sun sets, shadows that showed at noon but small, appear most long and terrible"? The shadows had appeared most long and terrible indeed when in August, 1939 Albert Einstein, with the prodding of physicist Leo Szilard, wrote to President Franklin D. Roosevelt;

> Sir: Some recent work by E. Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the near future. Certain aspects of the situation seem to call for watchfulness, and, if necessary, quick action on the part of the Administration.

We all know the results of 'quick action' by President Roosevelt and his Administration during the war years. And so the atomic age was not only born—but was in fact thrust upon us during the travail of a great global war. It came at a faster pace than if the world had been at peace—but perhaps no sooner than was necessary to counteract the then unforeseeable demands on our energy supplies which was to develop within the next thirty-five years.

And now we are concerned with another completely different chemical development with the elucidation of DNA by James Watson and Francis Crick. The potential of this purely scientific excursion into the realm of understanding life itself has been likened to the potential of nuclear energy. We cannot discard the fact that knowledge is power—and power is always dangerous. But any culture which continues to grow through the intellectual ability and creative talent of its philosophers, its theologians, its artists, its writers, and its scientists will always have to exist within the blessings and the dangers which the technologies derived from the intellect will always produce.

As an Academy of Science, with a membership of persons who are more knowledgeable of the good and of the bad which science—through its technology—brings to society, we must accept our responsibility to advise and to educate those possessing a lesser understanding of science. We must also be prepared to work with those who make the decisions for the uses of science so that, to our best ability, the gift of wisdom will continue to bring the blessings of science into our culture.

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