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THE CHEMICAL WORLD VIEW IN THE TWENTIETH CENTURY

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We are all aware that the twentieth century has been characterized by a previously unforeseen growth of the sciences — there has been, in effect, a new Scientific Revolution. Yet, while this revolution occurred on the one hand within scientific laboratories throughout the world, it has, on the other hand, been a revolution that has touched tre consciousness of the general public as well. If the former process has been a lengthy one, the latter has not. Indeed, it has only been within the last two generations that the common man has really been aware that his was a «scientific» age. Prior to the second Warld War in the United States, the schoolboy was exposed to little science. Mathematics, yes, and perhaps a little of the geological history of the earth, but for him «science» took on a meaning that had a special relation to the American dream. We were told of the telephone, the electric light, motion pictures and the automobile. The «scientists» we knew were the botanist, Luther Burbank and the inventors, Alexander Graham Bell and Thomas Alva Edison.

For the average American living before the second World War, the «scientists» were inventors, physicians, or naturalists, men who made the world better for mankind while simultaneously assuring their own fortunes. In sharp contrast, the scientists who worked at university research laboratories were little known or considered. They were

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pictured as impractical and forgetful professors who busied themselves with projects which were hardly likely to benefit them or anyone else. How much better it seemed to devote one's life to the emulation of Henry Ford and his automobile or perhaps the experiments on radio by Marconi or DeForest. When we were told of the effects of the Industrial Revolution and other nineteenth-century developments on society we heard of the hard working practical men — the inventors — whose ideas seemed to have little connection with university research. These «heroes» were men who frequently had not gone to college. Rather, they had worked with their hands and had seen their ideas through to fruition even though they had suffered hardships as they pursued their goal.

This anti-intellectual attitude changed for the great bulk of the public only during or after the second World War. Until that time the effect of science and technology on our society — admittedly great — had, nevertheless, been a relatively slow process. It had not been too difficult for a person to live with the changes he had experienced during the course of his lifetime. The changes were far more rapid after 1939. Now the engineer was no longer praised alone. It was clearly recognized that he worked in concert with the theoretical scientist and they were both needed to bring about a victory that would destroy the power of the Axis through a new Crusade for Freedom. This union of theory and practice clearly served to alleviate shortages on the home front as well as to prepare new methods of warfare. Above all, the public awoke to the importance of the scientist through the power of a new force unleashed by the bombing of Hiroshima and Nagasaki in 1945. Newspapers screamed in banner headlines, «Atomic Age Begins», while the Horatio Alger «inventor-scientist» hero of the past was relegated to our cultural mythology. And as the glow associated with the names of Edison, Burbank and DeForest faded, the public turned not only to the new astronauts, but to pure scientists and research physicians as new heroes. With a new and widespread knowledge of spectacular accomplishments these men received respect and admiration undreamt of a decade earlier. This new popular recognition was reflected shortly thereafter in the fields of government and politics where financial support for the sciences and engineering soon became a major part of the annual national budget.

How did this new sensitivity to science occur? In an earlier period the scientists were no more sucessful in forecasting the future or the significance of their research than they are today. At the close of the eighteenth century Antoine Lavoisier was convinced that the Chemical Revolution his work had initiated would surely result in the advance of that science to its greatest possible perfection within the period of a few decades. And in the second half of the nineteenth century it was widely believed in the scientific community that the basic truths of physics had been determined and that in the future it would only be necessary for physicists to further refine measurements.

But if some scientists had developed a sense of complacency by the turn of the century, the scientific world was in reality in the opening stages of what may now be called a second Scientific Revolution. Surely many factors contributed to this development, but for the purpose of this short essay we many limit ourselves to only a few. First, looking back from the fourth quarter of the twentieth century, it is obvious that a number of spectacular discoveries sparked by scientific genius contributed to a rapid series of advancements. Classical concepts in the physical sciences were overturned in the closing decade of the old century and the opening decades of the new one. In their place new concepts, hypotheses and theories were postulated at a pace that bewildered the scientist then no less than it does the historian today who attempts to reconstruct that era. Second, and perhaps no less important for an understanding of twentieth-century science than these internal developments within the sciences, were the parallel origins of a new union of science, industry and government in the late nineteenth century — a union that was essentially nonexistent in earlier periods. Here the result was to create a demand for scientists which the universities with new teaching methods quickly filled. And as newly research-oriented industries began to affect the economic well-being of nations, scientific research inevitably became a matter of concern to politicians and their governments.

It would be impossible to adequately list the major scientific developments of this century. At best one can point to a few of the more significant areas of change. Nowhere had change been less expected than in Physics. Here the spectacular discovery of X-Rays by Roentgen in 1895 quickly impressed itself on the scientific world as well as the

public. Scientists were engaged in work which led in turn from radioactivity to a whole set of new elements and then on to the problems of nuclear physics. In the course of a few decades this discovery resulted in a knowledge of how atoms are arranged in solids. And if we may trace these developments through to the solid-state physics of the present, we may point to a second contemporary major development in the physical sciences in the early part of the new century. At that time a new synthesis of the relative character of motion and of the general theories of relativity. With the latter a far more satisfactory explanation of cosmological phenomena has been made possible.

In chemistry as the fields of biochemistry and physical chemistry developed, a heavy emphasis has been placed on structural problems. The search for answers to biological questions through the use of chemical methods was not a new one, but surely a new key was found in the investigation of enzymes in the final years of the old century. Eduard Büchner's discovery that the juice obtained from triturated yeast cells could ferment sugar opened an entirely new field of scientific investigation. The subsequent development of biochemistry has been dependent on the combination of genetic, physical and chemical methods, and these, in turn, have led to the field of molecular biology. The search for the source controlling the enzymes was to be found in the genes, and by 1951 the research of Watson and Crick had resulted in the definition of DNA, the substance which was seen to provide a molecular mechanism for the duplication of genetic material at each cell division cycle.

In medicine research in all fields resulted in new surgical techniques that were undreamt of at the turn of the century while major diseases were eliminated through the vaccines. I once had the privilege of hearing Morris Fishbeen discuss the changes in medicine he had witnessed in the sixty years since he had graduated from medical school in 1912. If was almost as if the world of 1912 had been a totally different one.

If we limit ourselves to only one other field of pure science currently in a state of flux, we might well choose Geophysics. Here interest in the age of the earth has continued undiminished since the speculations of Lord Kelvin a century ago and much of the research relating to extraterrestrial samples has centered on this problem. At the same time there has been a closely associated search for additional information relating to the earth's interior, and most recently a revived interest in

the setudy of surface phenomena. Within the past twenty years the investigation of the drift of continental land masses has been established in a way not previously possible.

Even this limited listing of scientific developments indicates the fundamental nature of the changes that have occurred in the sciences in the twentieth century. These developments were in turn to result in the elucidation of totally new techniques and new methods of instrumentation. No less important is the fact that scientists began to view their disciplines in an entirely new fashion. Traditional fields which had previously been taught in a compartmentalized fashion were now found to be closely interconnected and new interdisciplinary sciences quickly became among the most cultivated areas of research.

To be sure, the development of the sciences since the turn of the century may be explained in terms of internal and technical factors. Nevertheless, without some understanding of changes that have occurred in the funding of research and in scientific organization the history of recent science is difficult to appreciate. Surely the realization of the potential of scientific advance for national welfare is nothing new. In the seventeenth century Francis Bacon stressed this point in England while Johann Joachim Becher and Johann Rudolf Glauber did the same in Central Europe. And so convinced of this was the French minister Colbert, that he saw to it that the members of the newly founded French Academy of Sciences (1663) were paid salaries by the State.

During the nineteenth century one may speak of a true professionalization of the scientist. While the non-academic «inventor» remained a person of public esteem in the mid-nineteenth century, by the early decades of the new century the «scientific amateur» was rapidly being relegated to the past by scientists if not by the public. If there are a number of factors of importance connected with this development, few are more significant than the new relationship that developed at that time between industry and the academic world. Here the most significant changes occurred first in Germany. Although we all know that the chemical laboratory at Coimbra is much older, there is a special importance connected with the work of Justus Liebig. Liebig made laboratory work an integral part of his courses in chemistry at Giessen

and this development corresponded closely with the new needs of industry. The search for cheap acids, alkalies, bleaching chemicals, fertilizers — and especially explosives — in quantity brought about a new need for well qualified chemists in the second quarter of the century. The new laboratories at Giessen and elsewhere were able to supply this need.

The potential of the German system was clearly made evident in the second half of the century when the study of synthetic dyes became a major field of new research. Although this field was opened in England through the research of William Henry Perkins (1856), it was only a matter of decades before German scientists — and German industry — became preeminent. By 1875 German industrialists and politicians were well aware of the importance of this industry for the economic welfare of the State. This foresighted attitude was to give the German empire a superiority in the sciences as a whole at least until the period of the first World War. Emphasis was placed on pure research and laboratories were closely in touch with academic consultants who were willing to look beyond the immediate interests of an industry and seek out the broader uses of new discoveries.

Among the benefits that the State reaped were those connected with warfare. Because of the flourishing dye industry, the Germans found themselves the world leaders in the research on coal tar derivatives. The result was to be the development of a number of new explosives — as well as the investigation of the effects of a group of new — and deadly — gases. Similarly, the need for raw materials no longer available during the war spurred German industry on to the search for new processes and synthetic substances. It is little wonder that German industrialists fostered scientific research in their own laboratories as well as in the Universities. They helped to organize associations of academic and industrial research scientists in the fields of chemistry and physics — organizations that proved to be so useful that they continued into the post-war years. Recent historical research has shown that these German academic-industrial associations originated the present system of scientific project grant support.

The union of industry and science had clearly contributed to the need for a larger number of better trained scientists. And as the number of scientists increased, the highly individualistic nature of scientific

research changed gradually to the concept of «scientific teams» more common today. The increased number of scientists also contributed to the ever more intricate organization and specialization of the various fields. The nineteenth century saw the founding of many new societies which were to limit their activities to a single field — in sharp contrast to the omnibus national societies that had been founded in the seventeenth and eighteenth centuries. These societies, in turn, fostered new journals to cover the recent work in their own fields. As Derek Price has shown, the hundred journals existing in 1800 had grown to a thousand by mid-century — and these had increased to nearly ten thousand fifty years later. The introduction of abstracting journals for the greatly increased literature was an inevitable result. Their growth has also followed an exponential curve, and with the volume of scientific literature now doubling on the average every decade and an entirely new field related to the retrieval of science information has developed.

In the past thirty years there has been a vast change in the public attitude toward science and scientists. If — in 1940 — we turned with pride to the inventor rather than the scientists, today we would emphasize the achievements of the latter first. Our grammar school students are now exposed to laboratory experiments from their earliest training and they are more likely to hear of Galileo, Newton, and Einstein than Thomas Edison and Luther Burbank. This change is a marked one and the fact that it has happened so recently is surely connected with the contribution made by scientists to the winning of the second World War — as well as the more recent exploits of man in space. Science and scientific technology have both become topics which often receive front page news coverage.

And yet, if the atom bomb, the sputnik, and the landing of man on the moon may be referred to as the most dramatic events that led to a new awareness of science in our society, the roots of this change extend back much more than thirty or forty years. — Let me close by saying a little about the development of science in the United States. While some American scientists were known internationally in the late nineteenth century, they were relatively few in number. Most American scientists had gone to Europe for their training and few American universities gave advanced degrees in the sciences. Between 1870 and 1893 only thirty-three Ph. D.s in Physics were awarded by American

universities and nearly all of these were from Johns Hopkins, Harvard and Yale. However, by the turn of the century doctorates in the sciences were becoming far more common. Indeed, the basis for scientific excellence was being prepared by the establishment of major laboratories. The Jefferson Laboratory was built at Harvard in 1884, the Ryerson Laboratory at Chicago in 1894, and the laboratories at the National Bureau of Standards in 1901. This interest in research carried over to industry as well with the laboratories of the American Telephone and Telegraph Company and General Electric which were established shortly after the turn of the century.

Research was also fostered through the establishment of the American Association for the Advancement of Science and growing numbers of journals devoted to specific sciences. Even before the first world war there was a solid basis for the development of science in the United States. With the effects of the War this pace was accelerated. American students were no longer able to cross the Atlantic to attend German universities and they pursued their studies at home. American industrialists were no longer able to purchase European products which now had to be made at home. Sensing the value of research the American government founded the National Research Council which turned to war-related research associated with submarines, optical glass, chemical warfare and aviation. With the end of the war continued interest in research was to be seen in the establishment of the California Institute of Technology in 1921, really an institute for pure science. This trend toward the sciences continued throughout that decade which also saw a move toward Federal support for the sciences. The worldwide economic Depression only slowed the movement.

The point I am trying to make is that although the public school education I had as a boy did little to introduce me to the sciences, in reality this did not reflect the true state of affairs. It is true that the Western European nations remained predominant in the sciences at the turn of the century, but there was a rapidly growing interest in the sciences among American academics and industrialists. The advent of the first world war had showed the significance of scientific research which contributed to the war effort in many areas — and this accomplishment was rewarded by continued governmental funding in the following decade. The public awareness of the role of science in the

period after the second world war was then due, in large part, to a long period of preparation. I believe that the eminence of American science today rests on a century-long development and it indicates the importance of governmental funding over the years.

There is little doubt that the importance of science is now widely accepted in all societies. Much of this acceptance may be ascribed to scientific genius, but it would be unfair to suggest that industrial, economic and social factors have not played an important part in creating an atmosphere favorable to the furtherance of both pure and applied research. In any case, the continued historical investigation of the science of the past century and its relationship to society will surely establish more firmly the deep roots of the widespread interest in the sciences which exists today.

Bibliographical Note

There are no thoroughly satisfactory accounts of nineteenth and twentieth century science. It is interesting to note the views of nineteenth-century scientists published at the end of the century. There are a number of such evaluations — one of special interest in that by Alfred Russell Wallace, *The Wonderful Century: Its Successes and Its Failures* (New York: Dodd Mead and Co., 1899). *A Century of Science, 1851-1951* edited by Herbert Dingle (London/New York: Hutchinson's Scientific and Technical Publication, 1951) offers an old but useful set of papers on a crucial century, and among recent internalist interpretations of twentieth-century developments may be included *Scientific Thought 1900-1960, A Selected Survey*, edited by R. Harré (Oxfrod: Clarendon Press, 1969) and *Science in the Twentieth Century*, edited by René Taton, translated by A. J. Pomerans (London: Thames and Hudson, 1956).

Recent research in this field may best be followed through the annual volumes (since 1969) of the journal, *Historical Studies in the Physical Sciences*, edited by Russell K. McCormmach (Philadelphia: University of Pennsylvania Press). Some of the most provocative research in this journal will be found in the papers of Paul Forman and the editor, Russell K. McCormmach. Here there will be found studies on the

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DESENVOLVIMENTO DA TERMODINÂMICA QUÍMICA E CULTURA DESTA CIÊNCIA EM PORTUGAL

J. SIMÕES REDINHA *

Summary

A historical outline of chemical thermodynamics, including the main steps of its development up to the earliest decades of this century, is presented in this paper.

A general view of the growth of this science in Portugal is given through the scientific activity of some of the research groups in this field.

1. O desenvolvimento da termodinâmica clássica

A importância que a máquina a vapor passou a ter na vida social, durante o século XIX, fez dela um campo privilegiado de estudo. Os grandes avanços técnicos que foram sendo introduzidos na fase inicial do seu desenvolvimento, ficaram a dever-se aos engenheiros ingleses, autodidactas, com formação essencialmente prática. No início do século XIX a acção destes dirigia-se para a padronização da máquina, passando do fabrico artesanal que imperava até então, para a produção em série. Era a forma de satisfazer a maior procura e de conseguir máquinas mais perfeitas. Por essa altura a máquina a vapor começou também a despertar a atenção dos engenheiros franceses, cuja boa preparação em física e matemática, recebida na Escola Politécnica de Paris, os vocacionava para estudos teóricos.

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