ENVIRONMENTAL CHEMISTRY

Edited by

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Preface

There is no need in the 1970s to explain the writing of a book on "Environmental Chemistry." The despoliation of the environment by man's activities has long been clear to chemists. However, it has been the subject of public debate for a short time—since the late 1960s.

Curiously, there has been little reaction in the textbook literature to reflect this concern. Apart from some brief and sketchy paperbacks for schools, there has not yet been published a substantial review of environmental chemistry. One reason for this is the breadth of the chemistry involved: it could scarcely be covered by one or two authors, for it is as wide as chemistry itself.

The ideal way to write such a book would be to gather a couple of dozen authors in one place and keep them together for 6 months of discussions and writing. This not being very practical, it was decided to do the next best thing and to attempt to network a number of men together in mutual correspondence and interaction, which would lead to a book that had the advantages of the expertise of a large number of persons, and lacked many of the usual disadvantages of the multiauthor book. Thus, synopses of the various articles were sent to each author, and they were encouraged to interact with each other in attempting to avoid repetition and in keeping their symbols uniform and their presentation style coordinated.

In respect to the choice of authors, they have been sought independently of geography wherever good reputation had been heard of in a given scientific area. An exceptionally large number of authors are from the antipodes. Since the present editor has relocated his activities to this area of the world, he has been impressed by the fact that, in countries so relatively unsullied by air and water pollution, such a (relatively) large number of people are working vigorously in areas of environmental chemistry. Perhaps Australian and New Zealand scientists have taken the hint from their frequent visits to the Northern Hemisphere and are inspired to prevent similar things from happening as their countries grow more industrialized.

The next question which had to be decided was the audience. There are two extreme audiences for which a book on environmental chemistry could be written: the scientific public—the readers of the *Scientific American*—or the graduate students who are working in subjects relevant to environmental chemistry and the professionals who are employed to work in the field. We have tried to appeal to both ends of the spectrum by writing a text that we believe will appeal primarily to the undergraduate university student, as the main user, and will also include some persons at both ends of the spectrum.

What of the choice of topics? This is the editor's greatest responsibility. It is a difficult one to make in an area which is so broad. The subjects in the present book were chosen in collaboration with the author's colleagues, particularly those at Flinders University, but also in correspondence with workers in many parts of the world, and with the publishers. Some subjects may be criticized as borderlines to chemistry, e.g., discussions of electrochemical transportation. However, there is no doubt whatsoever that the change of motive power in transportation would be the most important part of a change toward a less-polluting environment, and it is the *chemistry* of batteries and fuel cells, and their possible advances, that is the rate-determining step in this area.

Lastly, a brief word concerning the evolution of chemistry. There has been pessimism in many quarters during the last decade concerning the future of chemistry. The thin front edge in fundamental and theoretical chemistry is full of operators, themselves used by physicists thinly disguised as theoretical chemists. The fat back end of the subject in organic chemistry is being increasingly pulled into biology. And as for that increasingly thin wraith called "inorganic chemistry," who will say nowadays what *that* means?

But it does not seem that there is a case for pessimism when one considers the future of chemistry, as long as one makes a slight change and calls it chemical science. Thus, the realm which fans out in front of chemically oriented scientists and chemical engineers is the enormous one of making man's desire for a comfortable world continue to be realizable without the consequences of pollution and the exhaustion of materials which it is indeed bringing. In short, the chemist is in for very active years; he again must become the center of the science and technology picture, for the essential task now is to make every process on which we now run our works into a nonpolluting recyclic process with zero material loss. There is enough chemistry in that to employ most chemists for (nearly) all time.

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Environmental Chemistry

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1. *The General Cultural Background of the Last Century*

Seventeenth-century man lived in a world which, in respect to the amount of energy per capita, differed little from that in which he had lived since he became a recognizable species. In the eighteenth, Newcomen invented a steam engine which pumped water from coal mines; Watt made the steam engine a practical transducer of heat to mechanical work and took out a patent on it in 1796.

The nineteenth century was a time of great optimism. It bore one of the greatest achievements of fundamental science, the electromagnetic theory, from which is derived much of today's technology. Rationalism, coupled with science and engineering, was thought capable of bringing enlightenment and comfort to all and was thought to be wholly good. The novels of Jules Verne[1] and the early novels of H. G. Wells[2,3] reflected this period of optimism in man's ability to fend for himself.

The first quarter of the twentieth century was also a period of major upheaval and progress in fundamental science: it brought the theory of

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relativity, with the realization of the equivalence of mass and energy; and it brought the strange quantum mechanics, in which was widely realized the extremely disturbing concept that different laws govern those worlds which our senses do not perceive. Dirac wrote that in the quantum mechanical equations lay all the possibilities for the theoretical determination of material events.

In the 1920s there was already a strong reaction against rational and scientific thinking in the Weimar Republic of Germany, where man's spirit bubbled up in multicolored display; and the deep plunge into the blood baths of the wars of 1914 and 1939 brought a similar reaction.

Then, in 1939 and 1942, two energy-oriented events of great importance occurred. In the first, Hahn and Strassmann[4] observed nuclear fission. In the second, a team under Fermi made the first energy-producing atomic reactor at the University of Chicago.[5] During the twenty years from 1945 to 1965 there occurred the climax of a period of optimism concerning science and engineering. Scientists, and particularly atomic physicists, were highly esteemed and were looked to as progenitors of a rising living standard. The end of physical work and the automated paradise was seriously considered by many to be only a few decades away for those in technologically advanced countries. The era is ambivalently characterized in Stent's book, *The End of Science and the Coming of the Golden Age.*[6] Stent proposed that the Uncertainty Principle had a macro-equivalent: that realizations of further principles in science were unlikely. Science had run not only into one of its plateaus of progress, but into a final asymptote.* Little more could be conceived by man, since knowledge had become too complex for further progress. He also proposed that the basis for the materialistic Utopia was here, unrecognized only because of inhibitions due to social and economic factors. A limitless supply of energy, obtainable principally from the atom, he thought, would give man the power earlier attributed to gods.

Synthesis is followed by antithesis, and that by thesis. The antithesis was *Future Shock.*[7] The bright and brittle 1960s in the United States brought a diminution of American confidence and hegemony. Instead of glorying in the further results of applied science, Americans—materially the most advanced of men—began to revolt against the pace and some of the results of technology, and in particular against pollution. A loss of spirit could be discerned in the mid-1960s, and became a clear downturn in 1968, a year of inflections in America. In 1970, the United States Congress voted to let other countries build the first supersonic passenger aircraft. A malaise came upon American students, precipitated by Leary and Alpert's experiments at Harvard on perception-broadening drugs. Those who thought they had perceived the whole picture to a greater degree wanted no more to work hard at attaining more material goods. By 1969, those few who made long term projections began to see many icebergs in the path of the further growth of population and the spread of affluence to the two-thirds of the world which lacked it (Fig. 1).[8]

* Of course, Stent is not referring to engineering.

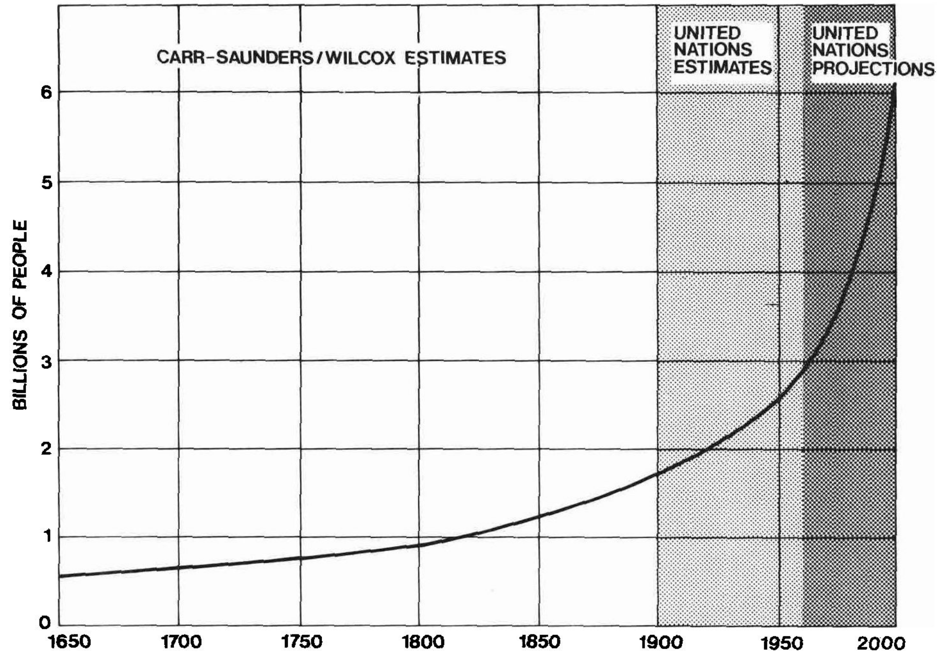

Figure 1. World population since 1650 has been growing exponentially at an increasing rate. Present world population growth rate is about 2.1% per year, corresponding to a doubling time of 33 years.[8]

Some of these icebergs were identified in 1972 in a seminal work by Meadows *et al.*[9] Here, what simple logic could have—but did not seem to have—predicted qualitatively was set forth quantitatively: industry and prosperity gave rise to air and water pollution (Fig. 2).[10] Previous estimates of the number of years in which resources (e.g., metals) would be available had been made with linear extrapolations of growth, neglecting the fact that growth of demand becomes exponential with time. The chill which came with the Meadows *et al.* book was the realization that exhaustion times came much sooner than expected: in respect to metals, many would be exhausted within 1–3 decades (Fig. 3).[9] Fossil fuels, the basis of affluence, were in sight of ending before atomic energy production could be developed to replace them. The race between the materials-depletion technologies and the abundant energy and recycling technologies was being won overwhelmingly by the former. Mankind's "progress," which in 1969 looked hardly worthwhile to a growing number of university students, now seemed threatened with extinction even to the majority who wanted it. Stent's Golden Age had not lasted half a decade before it was seen that a possibility of its doom existed.

But something of the lusty nineteenth-century heart—the Hertzian oscillator and its electromagnetic radiation—still beat. Man's lonesomeness was

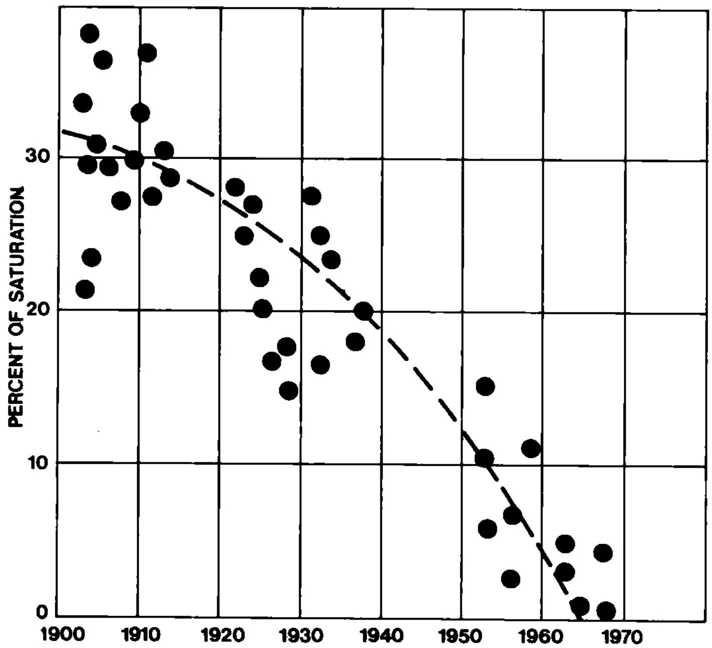

Figure 2. Increasing accumulation of organic wastes in the Baltic Sea, where water circulation is minimal, has resulted in a steadily decreasing oxygen concentration in the water. In some areas, especially in deeper waters, oxygen concentration is zero and almost no forms of aquatic life can be supported.[10]

less than in earlier crises. Electronics made communication simultaneous throughout the world. Small village communities now contained conservation societies; their members followed the declining situation through the media and through the easily available books and sent petitions to central governments.

Childhood's End, Clark's novel about the evolution of a world consciousness, seemed to demand attention.[11] One hundred years after Maxwell and Gibbs man began to reach out with a reaction characteristic of the new time. Quantum mechanics showed that "sense data" deceive: experimental laws of the behavior of things were conglomerate laws, and laws governing the tiny particles which make up macro-objects were entirely different. Time occasionally seemed to reverse. Smith, a former employee of the scientific staff at the Boeing Scientific Laboratory, examined the ability of persons to know which light would next be lit in a random event generator and found a number of persons who could predict these events.[12]

This book is being written in 1976, a time which again presages great changes in fundamental physics and much promise in the relation between science and society. There hangs over this period the great threat of the rising

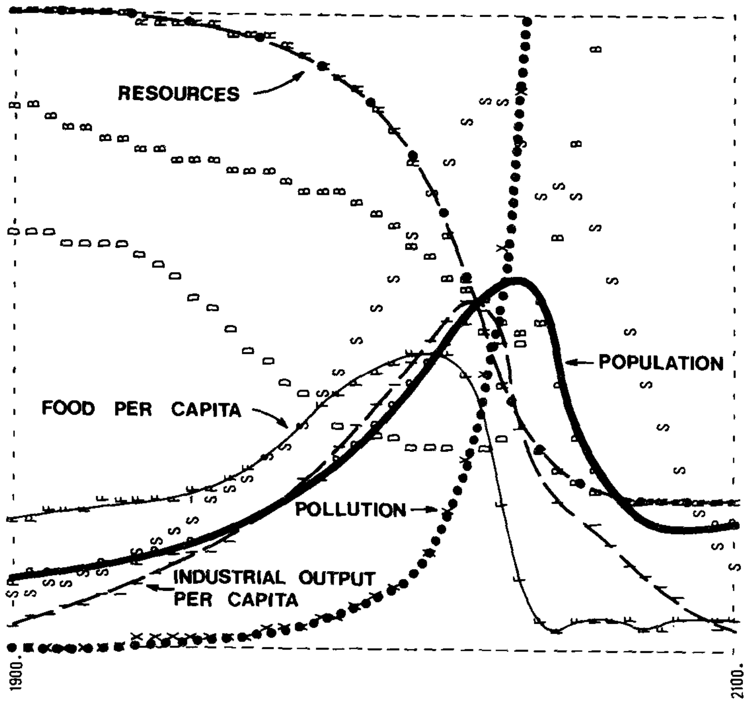

Figure 3. To test the model assumption about available resources, the resource reserves in 1900 were doubled, keeping all other assumptions identical to those in the standard run. Industrialization can now reach a higher level since resources are not so quickly depleted. The larger industrial plant releases pollution at such a rate, however, that the environmental pollution absorption mechanisms become saturated. Pollution rises very rapidly, causing an immediate increase in the death rate and a decline in food production. At the end of the run, resources are severely depleted in spite of the doubled amount initially available.[9]

price of energy, i.e., its exhaustion, and the parallel threat of air pollution from fossil, and probably from atomic, sources. Concepts which may reverse the situation demand an abundance of clean energy and an extremely high degree of recycling of the products of its use. If population growth can be stopped below some ten billions, and if man has the will to organize the necessary research and development efforts in time, Stent's Golden Age is still to come (Fig. 4).

2. *Too Many People?*

The concept is quite new of a branch of chemistry devoted to the untoward happenings which follow the injection of a number of industrial side products

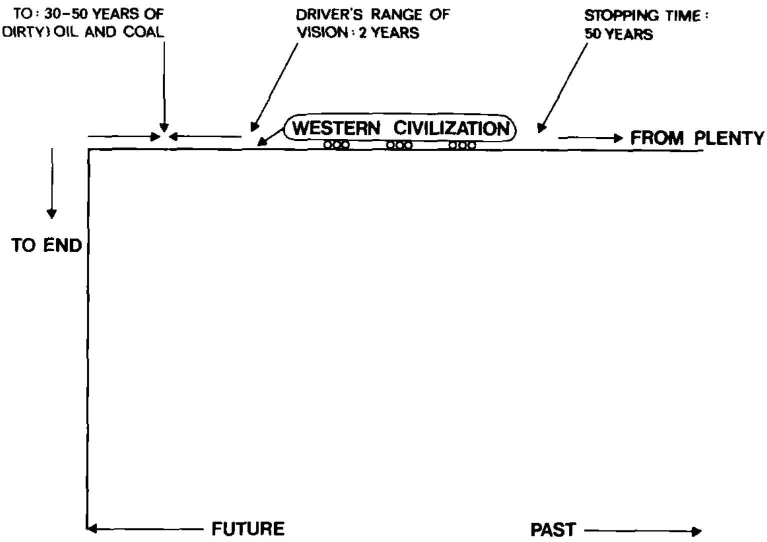

Figure 4. In Western political systems, an elected representative on the average is about 2 years away from the time at which he must prove popular in terms of the present, or else give up his chance of influencing events in the future.

into the air and the water. In 1965, it would have been thought esoteric, as we now regard, say, lunar chemistry.

Man is the original and basic pollutant. Life on this planet has existed for billions of years, animals for hundreds of millions of years, and man for a few million. During all this very long time there has been harmonious ecological development. The individual life, as it evolved, has been subject to the whole, and it has fitted in with the chemical happenings going on around it. The balanced situation was not affected significantly by man until this century. There have been two causes of the increasing disturbance which man must now face. On the one hand, the rate at which chemical and other industries are now pumping materials into the waters and the atmosphere is too much for the natural processes of recycling to deal with. Natural processes, mostly bacterial, do exist for dealing with the ingress of new materials into the waters, but not at the rate at which this has been happening in many of our rivers or in large bodies of water, e.g., the Baltic Sea. The result is visible pollution, and a whole series of changes which come upon the loss of balance in a part of the natural and long-lasting—and therefore balanced—system. Likewise, for the atmosphere, there are photochemical processes which recycle artificial impurities and reattain balance. However, from the beginning of the twentieth century, the amount of unnatural materials which man has placed into the atmosphere has increasingly beaten nature's methods of reestablishing balance. It is the rate of contamination which is crucial, and this depends entirely upon the number of people present in the world and upon their living standards. This then leads us to the background for Chapter 2, which concerns the biochemistry of contraception.

3. *Controlling Pregnancy*

Of all the things which have to be done if we are to attain a balanced world, without being subject to the horrible previous methods of reestablishing balance after accelerated aggregation in numbers, i.e., famine and mass starvation, the most important is to attain rational control of the rate of inception of new individuals. In earlier times, the number of pregnancies per woman must have been approximately the same as those which now occur in communities in which contraception is not practiced. The difference is that, in earlier times, a large number of these pregnancies were terminated naturally before birth, or resulted in children who died at an early age. The spread of the use of antiseptics and of pre- and postnatal medical treatment for pregnant women has, however, been very thorough, even in nonaffluent societies, such as the Indian. What has not kept pace, however, with this population-increasing speed of medical care, has been the corresponding necessary reduction in the number of successful pregnancies per female. The net result must be a vast increase in the rate of population growth in the less educated, and therefore less affluent, parts of the world, those being the economies and resources which are least able to adjust to a large increase in population.

Adequate care of pregnant females must be accompanied by contraception, except perhaps in those very scarce parts of the world which could bear a population increase. But artificial contraception has been well known, available, and practiced for many decades in affluent countries (Don Juan used the condom). There is now little difficulty with population growth in such communities. The difficulty occurs in those communities in which people are less disciplined in handling the artificial aspects of natural processes. The successful practice of contraception demands remembering and bothering, at a time when the libido is streaming toward its natural goal. What is needed is a contraceptive method which would offer a way of reversibly turning off the procreative function. For developments of this kind to become likely, however, it is necessary for chemists to learn something about the basic biochemistry of the processes which lie behind the chemistry of fertilization.

In these considerations, it must not be overlooked that even an ideally simple and successful method of individual contraception needs the volition of one partner in the sexual act. Thus, in India, the social system is such that the only support people can expect in old age is from their children. A maximization of successful pregnancies per female is the desired result. Here, therefore, the social arrangements must change before contraception is desired. Famine and disaster are also less feared when they occur rhythmically, and, to the illiterate population, seemingly unavoidably. Contraceptive chemistry can only be effective at a sufficient level of recognition.

4. *Do Pollutants Affect Our Minds?*

Pollution of the environment is directly related to overpopulation, and one of the feedback effects of some of these pollutants may be upon the brain. This area of knowledge is as yet a tenuous one. Sheer poisons (e.g., CO) and their physiological actions are well known, but there exist other situations, in which parts of biological functioning, including the brain, are very slightly affected below the toxic level by an element such as lead, giving rise to changes in mood and in psychic energy. One may envisage, therefore, the danger of a widespread downturn in activity of those in affluent surroundings and in their determination to achieve, which could arise as a result of new materials in the atmosphere at low levels. The effects would creep in gradually over a number of years, and their objective establishment (and separation from parallel effects of affluence) would be difficult.

Such considerations are conjectural. They certainly could happen—and with some pollutants which we know are in the atmosphere. But our knowledge as to whether they do happen, what the mechanism is, and what we can do about it, is in a rudimentary state.

5. *Can We Get Food Chemically?*

While the diminution of the population must be the first goal in a rational environmental policy, there are limits to the degree to which men will agree to kill each other. Hence, any intended rational diminution of the population can only occur over several generations.* During the time in which the present overly large number of people continues to live upon this planet, our natures (identification and empathy) are such that we shall try to feed them. This is becoming increasingly difficult, largely because the fertility of land in many parts of the world is becoming exhausted due to over-use. There are chemical approaches for overcoming this difficulty, such as the utilization of new fertilizers, or of new agriculture in respect to the development of new crop strains (e.g., wheat). However, there is a growing appreciation of the concept that men do occasionally improve upon nature,† and the concept that we could

* This is true of the democratically based wish. However, government leaders can be less humane. The further away a people is from sources of masses of food (e.g., in the North American countries and Australia), the easier it is *not* to identify with the populace. When the giving of food tends to deprive their own population, even if overdeveloped, the far-off country and its starving citizens is rapidly forgotten, and the older, more irrational mechanisms for population balancing (i.e., famine and mass starvation) reassert themselves.

† In view of the general area dealt with in this book, and the difficulties caused by man's unsuccessful disturbance of nature, the validity of this statement may be doubted. However, it is obvious that, in some respects, man has improved upon nature, at least in small areas, e.g., computing machines do perform arithmetic more quickly than man. And cars do transport him to more places than those to which he could walk.