Pergamon

0969-806X(95)00071-2

Radiat. Phys. Chem. Vol. 47, No. 1, pp. 3–7, 1996
Elsevier Science Ltd. Printed in Great Britain

REFLECTIONS OF A RADIATION CHEMICAL DINOSAUR

F. S. DAINTON
House of Lords, London SW1A 0PW, U.K.

A PERSONAL NOTE

I am very touched to be asked by the organisers of this conference to speak. When Dr Gebicki sent the formal invitation I accepted without hesitation and for two reasons. The first derived from my long friendship with Professor Kroh which goes back over 35 years and from my admiration for the quite unselfish and dedicated work he has done to build up his chosen field of research in Poland, his concern to ensure the well being of his students and, as Rector of Lódz Polytechnica to defend, often in difficult times, the values of free thought, free speech and free association in his University, values which are of the utmost importance not only in universities but also in larger human societies: for without them societies cannot be free, civilised and harmonious. This symposium on the occasion of his retirement, is in his honour. It is right that it should be so and we salute him for the distinguished service he has given to his university, his students and his subject.

The second reason for my acceptance is my admiration for the Polish people and especially their steadfastness and bravery in the face of adversity, so evident 50 years ago during the Warsaw uprising. Moreover one Polish scientist, Marie Sklodowska Curie will forever be remembered above all others as the pioneer of radioactivity and, through her death from persistent aplastic anaemia, as the most celebrated victim of the chemical changes which occur in the living cell subjected to prolonged ionisating radiations.

IS RADIATION CHEMISTRY FACED WITH A PROBLEM?

Having accepted the invitation so readily I soon experienced the full force of the old adage, "Marry in haste, repent at leisure" because for the last quarter of a century I have been a mere, albeit very interested, spectator of you more fortunate people who continue to be practitioners in radiation chemistry. In consequence I can offer no new ideas or experimental data today. Furthermore because in a contribution to the book *Early Developments in Radiation Chemistry*, a brain child of Jerzy Kroh and published in 1989, I had already "reflected" on the maturation of the subject, any scientific thoughts I might put before you five years later could only be seen by you as those of an organism ill-adapted to survive in a contemporary radiation chemical environment. I am probably the last of a species, a true Radiation Chemical Dinosaur.

However from my spectator's vantage point I am concerned by what I see as a decline in the papers in basic radiation chemical topics which appear each year in main stream physical chemistry journals, a decline which is not fully compensated by those appearing in other journals. This prompts a whole series of questions. First, and most acute, is, "Is this decline terminal?" After all some subjects do prove to be unprofitable as subjects of long term study, e.g. tribochemistry, the chemical changes induced by rubbing one solid on another. I do not believe this to be true of radiation chemistry where there are still important questions to be answered both about basic mechanisms and in the chemistry underlying the effects of incident ionising radiation on animate and inanimate systems, whether deliberately or inadvertently exposed. This prompts the question as to whether some of the effort of radiation chemists has merely become more applied and less basic. This is certainly true to some degree. It is also true that ideas and techniques, having their origin in radiation chemistry, have been absorbed into both general chemistry and into biochemistry, general physiology and pathology. No-one can fail to notice the extensive use now made of free radicals in interpreting normal and abnormally functioning biological systems. This idea seems to have been seized upon and used almost too indiscriminately. Such permeation of ideas into sister sciences is quite natural and not to be resisted, because it is good for all science. We radiation chemists in particular have gained massively from physical concepts and techniques.

The most striking feature during my lifetime in chemistry has been the transition from the simple laboratory techniques of the test-tube, simple vacuum apparatus, simple X-ray generators (sometimes home made as was always the case by the late lamented genius Douglas Lea), static photographic spectrometry; all methods for investigating reactions and their mechanisms on a time scale of, at the shortest seconds, to contemporary methods which now reach a time scale of the femtosecond and enable the identification of all the intermediates and their intimate intramolecular rotational and vibrational energy states, including the transition state itself, and of the rise and fall of their concentrations as reaction proceeds. This inevitably has two consequences.

Firstly, for much work experimental resources need to be acquired at a cost beyond those which an individual university departmental budget can meet. This implies, in addition to funding from external sources, the co-operation of scientists in shared facilities if necessary. At the limit this may mean sharing out on an international level, as CERN at Geneva has taught us. Secondly, it necessitates the allocation of funds from national or international sources. This in turn means that government or governments must be involved in these decisions and develop coherent science policies. The halcyon days of the late fifties and sixties when in most developed nations governments were enthusiastic about science and willing to fund almost every request for resources except from the most expensive communities, i.e. nuclear physics and radio-astronomy, have gone forever. The attitudes of governments have changed irreversibly and scientists have to learn to operate in a less comfortable world, the parameters of which are set by national and regional governments. In the rest of this paper I would like to put in front of you some concepts which will help that adjustment and I shall begin by discussing the dynamic interrelationships of natural science, engineering and technology and of each with society.

THE VIRTUOUS UPWARD OR VICIOUS DOWNWARD SPIRAL

First we must be clear about some definitions. Natural science is a body of attested facts about the natural world joined together by speculative theories incorporating rational arguments and fundamental principles. The value of the theories is not just that they relieve us from the necessity of a lot of rote learning (that is what distinguishes science from mere stamp collecting) but that they also enable scientists to make predictions about the unknown from what is known. The theories are our own models of reality judged to be adequate for their time, but many have no ultimate validity and are constantly changing and being replaced by a smaller number of theories of greater comprehensive power. The progress of science is therefore the record of the replacement of existing theories by fewer more powerful and more comprehensive theories.

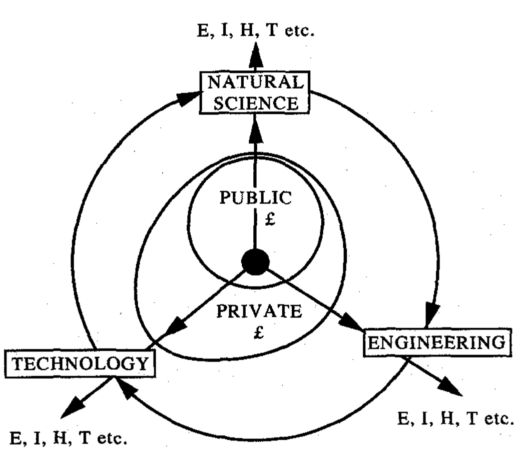
Engineering is different. It began with empirical observations leading to devices like the lever and the wheel which extended man's feeble physical power and therefore gave him tools to survive and achieve dominance on planet Earth. Engineering has now developed enormously to be concerned will almost all ways in which one form of energy is transformed into another. As chemists we are aware of the way in which the energy of combustion can be converted through the steam engine into kinetic energy and thence to electrical energy which can be transmitted widely and can perform all kinds of tasks including locomotion, chemical change and, conversely, chemical energy stored in an electrical battery can be used as a supply of electrical energy. We call the transformation of naturally occurring substances into new substances *chemical* engineering. It is universally true that the more natural science can tell us about the properties of matter, the forces between objects and the molecular processes underlying the transformation of energy or chemicals, the more engineering becomes dependent on science and the more the power of engineers is extended.

Technology is quite different, being concerned with the means and knowledge necessary to provide objects for human sustenance and comfort and is therefore much concerned with the theory and practice of applied science and design. Because most of the objects we need are made in factories a major part of technology is devoted to the theory and practice of manufacture.

The last hundred years has seen phenomenal growth of activity in natural science, engineering and technology, a growth accompanied by a vast increase in the cost of acquiring new knowledge by basic research and the even greater cost of developing a product or a process.

The interrelationships involving these three elements of natural science, engineering and technology are best expressed by placing them on a circle bearing arrows on the circumference in a clockwise direction. This is to denote that natural science has almost completely replaced empiricism as the underpinning for engineering, and that engineering is in turn the basis for good technology. Going further round the circle signifies that, through engineering and technology, natural science very often gets the instruments and means which it requires to

THE VIRTUOUS CIRCLE



KEY: E (energy), I (industry), H (health), T (transport).

Fig. 1.

make further experimental advances. The circle is virtuous because it is also a feed back loop. Consequently progress in all fields would autoaccelerate if it were not resource-limited, and would become an upward spiral and lead to prosperity if the economic benefits outweighed the cost of research, development and manufacture. Conversely, inadequate resources and poor quality of work in natural science, engineering or technology can cause a downward spiral which is to say an accelerating decline.

The outward pointing arrows are there to signify that each of the main three activities, either alone or in combination, can meet a large number of human needs such as health, shelter, communication, travel and the need to reduce the drudgery of physically demanding repetitive work.

Within this external circle you will see two elliptical shapes enclosing the centre of the circle. The distance along a radius to the perimeter of the first ellipse compared with the distance from that point to the perimeter of the second ellipse indicates the relative amounts of money, from private and public sources respectively, which are required to pay for these activities. I shall explain later the reason for the shape of the ellipses.

WHO IS TO PAY FOR RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY?

Research and development cost money and have to be paid for. It is common sense and justice that the beneficiaries should pay. Therefore in deciding whether it is the government, the private individual or private enterprise who should pay, we have to know whether the work has been done for public good or for private gain or perhaps a mixture of both. In my experience this discrimination only makes sense when the activities of science, engineering and technology are subdivided according to the objectives which they are meant to achieve. Table 1 is largely self-explanatory and, I believe, is helpful in achieving such a classification. I must explain some of its features.

At the top of the table is *basic* work which is that chosen by individual scientists with the sole object of advancing knowledge and with no practical end in view. Its outcomes are uncertain in kind and in the time that they take to appear. This kind of research is easy to manage because it needs only to be in the hands of individual scientists or small teams of them, except in the case of large national and international laboratories. Likewise judgement of quality is best done by international peer groups. Flawed though this method undoubtedly is I think it is much preferable to some of the crude and misleading mechanical methods now somewhat in vogue due to the penetration into the management of science of ideas from indifferent business schools.

The next category is *tactical* or near-market research which is the exact opposite of *basic*. Here the purpose is clear from the outset. There is a person or enterprise requiring a product or a process or the improvement of either and who knows that it can be done by the application of existing knowledge or by the acquisition, using existing methods, of more but not markedly different new knowledge. There is therefore a clear customer prepared to pay the people who will do the work efficiently and in the shortest possible time. They may be external contractors or an internal department of the customer's own enterprise. In either case management is relatively easy although competition means that timescales have to be short.

At the bottom of the table is *regulatory* work which means the science, engineering or technology which underpin legislation to protect the public at work or in the home. Radiological protection, of which all radiation chemists are fully aware, is a clear example. Much of the work is of a tactical nature and it is best managed at arms length from government because it is the basis of advice on regulation to protect the

Table 1. Classification of scientific activity by objectives

Purpose	Description(s)	Time to successful outcome	Who selects	Ultimate beneficiary	Who should pay?	Examples
To advance knowledge	Basic	Unpredictable	Scientists	Public and/or private sector	Government via research councils and universities plus charities	All physical biological and earth sciences
To meet immediate need	Tactical, exploitable near market	Short and controllable	Customer	Customer	Customer	Ballpoint pen Aircraft windows Plastic materials
New knowledge possibly applicable in future	Strategic	Very subject dependent	Forum of scientists and potential customers	Public and/or private sector	Research councils charities and universities	Molecular biology Polythene
Advice to Government	Regulatory	Variable	Independent statutary body	Public	Government	Radiological protection Health and safety at work

public which must therefore have a trust in the quality of the work done and in particular of its independence, a trust which can only be gained if the regulatory body is seen to be neither the creature of government nor of any private interest but acting entirely in the public interest.

The most difficult category of all is that which I label *strategic*, a term I introduced in 1971 and which is now largely accepted. This consists of that work in which it is decided to invest because there is a consensus amongst those best able to judge, who come from the worlds of science and the worlds of affairs and industry, that if capable people are allowed to have their head in this or that particular field then it is likely that results of great practical significance will emerge although, at the time of making the decision to invest resources, the precise nature of this outcome cannot be foreseen, nor can the time at which it will appear be predicted, and the ultimate customers are unknown. Payment for this is then a difficult problem but a wise government will try to develop strategies for science, to attempt to foresee what could be useful and it must accept some considerable financial responsibility. A classic case of this is the investment in molecular biology in Cambridge at the end of the Second World War.

Under this classification it is obvious who should pay. Government must be fully responsible for financing regulatory science and a very great deal of basic and strategic science. In both cases it should administer its policies at arms length through *quasi*-independent bodies. It is equally obvious that the customer should pay for tactical work and that customer will often be private industry, although there are certain areas of tactical research connected with, for example defence, where the government is necessarily the customer.

THE INEVITABILITY OF CHOICE

In all countries resources, whether private or public, are limited. If a country is financially successful and the electorate educated, government will apply resources for tactical and regulatory research at an adequate level. However, difficult choices have to be made when wealth creation does not yield taxes sufficient to keep pace with the demand for resources for basic and strategic work. It is these facts which bring together into a triangle government, business and the scientific knowledge industry. The quality of the decision making in each of these sectors, and the implementation of any decisions taken, are critically dependent on the ability and creativity of the scientists and managers involved and on the extent of their awareness of the developments throughout the world in their own filed. Educated and expert scientists are the intellectual oxygen which keeps this triangle healthy and renders a successful economy more likely, and the upward spiral of my virtuous circle more probable.

CONCLUSION

Thus far in examining the relationships involving science, engineering, technology, industry and government, I have been somewhat didactic and analytical because I believe it to be essential to be clear about these matters if only because the historical fact is that in developed countries changes in society, in human prosperity and health, have been largely driven by advances in science, engineering and technology. The near universal acceptance of that assertion, sometimes encapsulated in slogans such as "better living through chemistry" ensured that, for at least 20 years post World War II, governments were willing to increase budgetary appropriations for basic and strategic science, so that it was not resource-limited. But there were questioning voices, mainly from the idealistic young, so that some 23 years ago I felt constrained to defend science in a lecture entitled "Science: Salvation or Damnation".

We are now in the quite different world in which the basic and strategic science budgets in western countries have been restricted for some years and in some western countries have declined in real terms. Moreover those who were expecting this pressure to be relieved, or even removed, by virtue of the expected Peace Dividend following the end of the Cold War, have been disappointed. The reason for this is the growing claims on government funds of unemployment, ageing population, rising health care costs, increasing national debt and the need to cope with international problems such as overseas aid, global environmental deterioration etc. and to meet these claims at a time when the economic orthodoxy is to keep taxes down so as to stimulate the growth of small and medium sized enterprises. The British Research Councils, our traditional guardians of basic and strategic research, have been reminded recently that the ultimate aims of government spending in this area are to enhance the creation of wealth and the quality of life, and have been told to adjust their priorities accordingly.

I believe that this trend will persist for at least a decade and will lead to the withdrawal of even the biggest nations from some expensive basic science projects which will be replaced by international projects. The abandonment by the U.S.A. of the Super Conducting Super Collider is a portent of things to come. In my view that is a good consequence of this policy change, but I must also point out some dangerous trends associated with pushing basic and strategic research ever closer to application, whether for social or for commercial ends. These dangers include:

(1) Because public support for basic research and investment in the able young scientists who are attracted to work in it yields large but unpredictable benefits (e.g. cephalosporin, molecular biology, magnetic resonance imaging etc., etc.) a

diminution of that support now will inevitably retard the accrual of future benefits in the decade after the next.

(2) If potential exploitability of research is increasingly a criterion for attracting government support, then governments will become increasingly possessive about the findings, to a degree which could inhibit the free exchange of knowledge which is the essential precondition of healthy science. Attempts to patent genetic information are a forewarning of this danger.

(3) Already there are signs that some governments feel they are putting more into the sea of knowledge than the economic or other benefits they fish from it and this leads them to a protectionist attitude. I draw a different conclusion, namely that failure to get benefit from research is a sure sign that industries are lacking in the proper understanding and awareness of the benefits that science could bring them. This constitutes an argument for industry to move closer to publicly funded basic and strategic research and even to support some of it itself, for the prizes more often go to those who have the knowledge first.

(4) The intrusion of criteria other than sheer quality of the project itself and the quality of the researchers who want to do it in making judgements on applications for resources is very dangerous. One has only to look at some of the programmes which have been funded by the European Community in its various Framework Programmes to identify easily those projects of second rate quality which have been funded partly because the criterion has been to include promoting social cohesiveness in Europe. That criterion is no justification for funding second rate work or people.

Alas, although I could continue, time constraints necessarily restrict what I can put before you. That I have chosen this subject at all is because I get a real sense that the radiation chemists, in common with many other scientists engaged in basic or strategic research, are concerned, possibly even alarmed, by these changes and wonder what they can do. My reply is that you should not attempt, Canute-like, to prevent change, not least because it is not within your power to do so. However, whatever your country, you can do what the community of basic and strategic scientists has historically been reluctant to do, i.e. accept this situation as a challenge and find ways to assist your own country in devising a strategy that maintains basic science for its cultural value and also as a sure base for assisting in the achievement of your country's democratically chosen objectives. It is no longer sufficient for you to do your work in your ivory tower to the highest standards of which you are capable, undistracted by the busy world. That way that world will pass you by. You must make your input to policy too.