PRESIDENTIAL ADDRESS

HISTORICAL COMMITMENTS OF BIOLOGY*

By A. C. CROMBIE

"Aussi bien cette solidarité des âges a-t-elle tant de force qu'entre eux les liens d'intelligibilité sont véritablement à double sens. L'incompréhension du présent naît fatalement de l'ignorance du passé. Mais il n'est peut-être pas moins vain de s'épuiser à comprendre le passé, si l'on ne sait rien du présent."

(Marc Bloch, *Métier d'historien*)

BY an ancient and honourable tradition, which began last year when I spared you this exercise, the President gives a Presidential Address only once during his term of office, on retirement. A presidential address in the summer season is a privileged occasion. Coming at the end of an active day, it is not the moment for a massive account of research. Rather it is an occasion when one may indulge with privilege in some directed impressionism, and that is what I propose to do.

I propose to look at the history of biology from the point of view of the well-known remark by Marc Bloch about the "bonds of intelligibility" linking past and present in a double sense. The present is incomprehensible without knowledge of the past; but we impoverish our understanding of the past if we are ignorant of the present. No one will be naïve enough to think that this means reading history backwards, or for that matter forwards. The fact that historical research is an adventure in self-discovery does not make it the less objective. I intend to indulge the privilege of the occasion by using some examples with which some of you of local provenance will be all too familiar. The intelligible links connecting the past, present and possible future of biology can, I think, be found in certain commitments persisting and developing through the rich matrix of beliefs and problems associated with the study of living things. These throw an interesting light not only on biology as a science but on the history of scientific thought and on history in general. A clue to the way we might approach it is given near the beginning of the characteristically Western scientific enterprise in the comment of Plato's friend, the famous mathematician Archytas of Tarentum, on the preceding generation of scientists: "Because they passed excellent judgement on the nature of the whole world, they were bound to have good judgement on detailed problems." My brief discourse can be regarded as an historical exegesis of this profound if seemingly paradoxical statement.

Before the general direction of the route to scientific knowledge had been settled, either in antiquity or in early modern times, two essen-

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tial general questions remained open. It was an open question what kind of world men found themselves inhabiting, and so it was also an open question what kind of means they should use to explore, explain and control it. By deciding on a world about which all applicable propositions must satisfy the condition of non-contradiction, a world of exclusive and discoverable rationality, the Greek philosophers closed for their Western successors all the other routes that before then might have turned out to be the right ones. Anthropology and the comparative history of civilizations have shown that other societies made this commitment and learnt to be scientific systematically only with the Europeanization of the globe. Following this first general decision there are further increasingly particular decisions in the scientific commitment. There may be decisions leading to habits of intellectual and social behaviour that, while not themselves producing any immediate scientific results, may be necessary antecedent conditions for scientific activity. Not all societies make these in the same way: for example ancient society did not, as modern European society did, either use its scientific knowledge technologically on a large scale, or establish through education and communication a philosophical or scientific community with generally agreed aims, method and criteria of cogency in scientific thought. Within the modern scientific community itself science still proceeds by a series of decisions both about the nature of the world we live in and about means to investigate, explain, control and exploit it. For the student of intellectual behaviour in this field, the doubts, hesitations and unsuccessful theories are as essential a source of data as the successes making up the accepted canon of scientific knowledge.

In this succession of decisions from general to particular we have an invitation to look beneath the surface of particular scientific discoveries for the "bonds of intelligibility" linking past, present and foreseeable future in two ways. There are, first, the historical commitments and conditions that make a given kind of discovery intellectually and socially possible in one period but difficult or impossible in another. The commitments of a period to dominant general beliefs about nature and about science make certain kinds of question appear cogent and give certain kinds of explanation their power to convince, and exclude others, because they establish, in anticipation of any particular research, the kind of world supposed to be there to be discovered. It may be supposed to be a product of divine economy and hence possessing appropriate characteristics of simplicity and harmony, or a system of mechanisms, or a manifestation of probabilities. Such beliefs establish the kind of explanation that will give satisfaction because the supposedly discoverable has been discovered, and they point to what to do in scientific research. Beliefs about nature exercising this influence over the formulation of scientific questions have come in the past from a variety of sources in the social environment, from theology and cosmology as well as analogies with human artefacts which change with the artefacts available. To see how they operate in scientific thinking it is important to make a comparative study which will show how, while cogency may change from one generation to another, each can use its beliefs to add effectively to the sum of valid scientific knowledge. The relevance of historical experience for our imaginations is that it shows us that valid discoveries can be based on beliefs that may seem to us now wholly uncogent.

Secondly, there are the links of logical structure common to different historical situations. Comparative history provides data, beside which a mere study of the present had too restricted a range, for a classification of scientific thinking into logical types differentiated by various related features: by the concept of nature formulating the questions asked, by subject-matter, and by method. It also shows us reasons for the variety of scientific methods. We could dramatize the whole history of scientific thinking from Greek antiquity as a never-ending attempt by mathematics to impose everywhere a simple, homogeneous, postulational, axiomatic system, met by an equally resourceful resistance led by the bio-medical sciences with an excess of experience of the complex, heterogenous enigmas of matter. The simple mathematical programme begun successfully by the Greek geometers was carried to its triumph by classical physics in taking over the whole realm of phenomena that could be analysed into functional relationships with a small number of variables, ideally reduced to two. The discovery that there is such a realm was an insight of genius brought to maturity by the generations from Galileo to Newton. It was essentially the discovery of a realm of simplicity in nature. With some subject-matter, such as mechanics for Galileo, the image of nature might be an open book written in mathematics; scientific research was directed largely towards learning to read the language and soon became a primarily theoretical inquiry carried out in the head. With other subject-matter, such as magnetism and electricity for Galileo's contemporary Gilbert, where theory was still relatively undeveloped, nature was seen as more like a labyrinth or jungle to be explored experimentally with the hands. In whatever subject-matter, the aim of classical physics over its whole range was the discovery and conquest of the realm of mathematical simplicity with few variables, with the suggestion that this was the only realm there is.

The bio-medical resistance had known better since Hippocrates. It was committed to a realm of complexity, and was forced to characterize its problems differently from mathematically simple physics if it was to find answerable questions to put to its subject-matter. It discovered realms of complexity of two kinds, the science of the organized individual and the science of populations, which between them make up biology. The former has used physics and chemistry for its own purposes; the latter in the end has changed the nature of physical science itself.

The biology of the individual can be called, stealing the phrase from Dr. Warren Weaver, the realm of organized complexity. It is distinguished from the realm of simple, universal functions, such as the laws of motion, comprising classical physics because its subject-matter is complex entities each with a specific organization of its simpler components. The biology of the individual is more like engineering than physics, in that each type of living organism is a solution to a specific set of engineering problems—problems of intake and conversion of fuel, locomotion, communication, replication and so on, which it has to solve to survive. This subject-matter has imposed on physiology its characteristic programme: to find out how an organism works by taking it to pieces and trying to put it together again from knowledge of the parts. The programme developed into a search for simpler and more and more general structures and processes from which to reconstruct theoretically not only one complex original but, by means of systematic variations, the whole range of known or possible types of original. This has been carried out by two characteristic methods, both begun by Greek physiologists but made explicit by the genius of their successors in the seventeenth century: the comparative study of the material constituents of living systems, and the modelling of living processes by human artefacts. Since then the history of the biology of the individual has been the discovery by these methods of common structures and processes of increasing generality, from the comparative anatomy and physiology of organs to tissues, cells, protoplasm and so on, to D.N.A. and R.N.A. and the reduction of particular macroscopic physiology to general microscopic chemistry and physics. As everyone knows, this programme is accelerating into the future. How did it start in this explicit modern form and what light do its origins throw on the relation of its commitments to its subject-matter?

We have a clue to both questions in a new "judgement on the nature of the whole world" that can be seen in the history of one very important problem in the biology of the individual: the relation of the perceiving organism to the world perceived. How does the living organism receive information about the external world and what is the nature and validity of this information? The best example is the ancient problem of vision, which in Kepler's discovery in 1604 of the dioptric mechanism by which the eye produces the retinal image yielded the first major discovery of modern physiology, two decades before Harvey's discovery of the circulation of the blood. Kepler's intellectual moves in making his elementary discovery, with those of Descartes and their immediate successors, illustrate clearly and dramatically how at a given moment a new conception of nature as a whole, which seems to have been impossible before, can give a fresh insight into not just one but a new range of answerable questions.

All the technical knowledge for a solution of the problem of how the eye operates dioptrically as a receptor of light was available in the geometrical optics and anatomy known to Ptolemy and Galen in second-century Alexandria. But no Greek saw the problem in this way, let alone solved it. The barrier seems to have been not technical but conceptual. The Greeks developed geometrical optics, as part of their profound theoretical commitment to the geometrization of space, as a geometrical theory of visual perception. Taking the eye as the point of origin of lines of vision, they developed the science of geometrical perspective as a study of the visual field seen with direct, reflected and refracted light. They recognized that the questions of what passed between the eye and the thing seen and of how it effected sensation were major problems, but they made their answers serve as immediate explanations of the separate question of visual perception. All insisted that an eye is a living eye with which we see; a dead eye was not an eye at all. The most accepted explanation came to be that vision is effected by images of the object passing into the eye, but their formulation of the problem did not allow them to see in the eye itself a subject for optical analysis.

Modern physiological optics began with the brilliant insight of the medieval Arabic scientist Alhazen that the eye must be treated as an optical system, and with his attempt to impose on its anatomy a geometrical-optical model in order to discover how it forms an image. But Alhazen failed because he again tried to make the dioptric mechanism give an immediate explanation of visual perception and he was put on the wrong track by, among other things, the inverted image. Although the eye, the most complex optical system then known, was assiduously studied by mathematicians and physiologists following Alhazen, technical advance still pressed against this inherited conceptual barrier. Kepler finally succeeded in breaking through it because, as he tells us explicitly, he came to accept the new judgement that nature, including the human body, is effectively a system of mechanisms. In the light of this he could make the strategic decision to separate the physical and physiological problem of the eye's dioptric mechanism from the other, quite distinct questions of how images effect vision and of what visual perceptions we do in fact have. He restricted the problem in the first place only to that of discovering how the eye operates as an optical instrument like any other, in fact as a dead eye. He solved it by seeing that a well-known model gave the answer: optically the dead eye was a *camera obscura* with a lens. Having done this and dismissed the puzzle of the inverted image with a simple rule: for top read bottom and for right read left, he was in a position to look at the other questions of vision with a living eye in a new way.

The strategic commitment by Kepler and Descartes and their contemporaries to the mechanistic hypothesis of nature in some form opened new worlds for discovery in the biology of the individual organism for two reasons. In the first place, encouraged as Descartes tells us himself by the various kinds of machines by that time working in Europe and by the evident success of scientific mechanics, the mechanistic hypothesis ruthlessly committed physiology, in advance of making any observations, to asking only one kind of question. This defined the immediate problems to be solved and gave a programme for research in the realm of organized complexity: in a world assumed to be simply a system of mechanisms this was to look for the particular mechanisms concerned in each case—in other words to treat the whole living body as a dead machine. It also made explicit the method foreshadowed in one of Leonardo da Vinci's most pregnant dicta: to understand is to construct. The seventeenth-century physiologists became the first masters of the engineering approach to their problems by showing how to use a "relational" model, constructed with formal correspondence to the process modelled but without identity of parts, as a method of antecedent theoretical analysis suggesting new questions to guide experimentation. In this way they used models of the eye, ear, heart, muscles and bones, and other structures, some helpful and others mistaken. Success in the search for mechanisms has depended on the contemporary knowledge by which they have to be characterized, but this search in the seventeenth century both established for physiology its continuing programme of reduction to simpler and more general physico-chemical processes, and gave it a clear view of its technical frontier at any moment.

As might be expected, this ruthless mechanistic commitment to only one kind of question also brought into focus other kinds of question pointing to other frontiers. The Greek formulation of the problem of vision (and indeed of other problems accepting organisms as unanalysed entities) had concealed these. The immediate effect of Kepler's identification and solution of one limited problem of visual machinery was to stimulate strictly physiological analysis of the further mechanisms of the eye in vision, followed by the similar research which has never ceased into hearing and the other senses, and into the nerves as conductors and the brain as co-ordinator of sensory information and of behaviour. But it was soon recognized (although the point gets lost from time to time in physiology) that the discovery simply of mechanisms cannot answer the ancient question of how physical motions of any kind can cause sensations in a living body, as distinct from merely other physical motions as in a dead one. A perceiving organism cannot be reduced logically to a homogeneous set of primitive postulates. Recognizing this, Descartes and Locke drew attention to a new field of empirical inquiry by exchanging the question of how sensations are caused for the different, answerable question of discovering the physical and physiological clues by which the organism makes its distinctions of sensation and perception. It was soon recognized also that the psychology of perception can be studied as another empirical field independently both of current physical theories of these

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clues and of the body's apparatus, and of the philosophical, logical problem of causation. So the mechanistic hypothesis itself showed that these different questions should be liberated from the tyranny of each other and that in liberty they could create new sciences.

There is a parallel to this in the history of painting. The Italian *quattrocento* discovered a new visual world by an explicit use of the Greek theory of geometrical perspective; but, as Leonardo tells us, the limitation soon found in a purely geometrical analysis of space itself forced artists to explore other clues, such as tone and shadow, to represent distance and scaling. But the creative geniuses who design a programme often see a need for liberty and variety that becomes lost in the enthusiasm of their immediate successors. It took a further revolution to open painting to a free exploration of visual clues by Turner and the French impressionists. The scientific study of the senses has been liberated in practice from the largely speculative programme of reduction on the naïve model of physics partly by experience of the variety of its own subject-matter, and partly by a more experienced understanding of the physical sciences themselves.

We know now that the passive, camera-like features of the eye which took such intellectual efforts to discover raise the least interesting problems of vision. Biochemistry, quantum physics, information theory and the invention of new physical artefacts have given us a succession of more likely models of eye and brain: a television camera, a scanning system with a computer, a system for feeding coded neural information to the brain which decodes it in the form of visual perceptions. The comparative study of animal sensory systems has shown us a fascinating variety of solutions to these engineering problems. As the Oxford physiologist Thomas Willis, as well as the Oxford philosopher John Locke, who also had a medical training, foresaw in the seventeenth century, these, and such studies as those of the congenitally blind and of the effects of sensory deprivation on spacemen and desert hermits, show us the variety of forms in which our fellow creatures can perceive our common world. Experiments with abnormal perception produced by drugs have shown us that perception of space is linked with that of time and that both seem to be correlated with rates of metabolism. We create as it were our own space-time co-ordinates as a spider creates its web. Time speeds by in childhood but slows down as our metabolic rate decreases. Drugs stimulating the metabolic rate make time go faster and space expand so that handwriting becomes larger; tranquillizers have the opposite effect and make spiders spin smaller webs. All these physiological studies and many others are leading us to a model showing how the body's machinery decodes its physical clues and how we may control its operations. But recent work on colour mixtures has shown us also that too successful a theory of the physical clues can lose for us phenomena that depend not only on such things as wave-lengths and intensities but also on what we expect to see. Possibly

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the most important result of all from the experimental study of perception has been to show that the living organism, animal as well as human, is not a mere passive recipient of stimuli but actively looks for patterns and meaning in these clues and actively creates from them the meaningful world it perceives.

We create a large part of our own mental ecology, perceptual as well as conceptual, but we can control our belief in it by common, empirical tests. We can model much of this situation with machines and we can construct machines to extend the range of our senses in precision and in detecting new kinds of physical clue. But in the material being modelled we meet the obvious heterogeneity: we do not simply decode information, we know it. In creating the conceptual ecology in which we make our decisions about science and about ourselves as individuals and in society, it would be an arbitrary break in scientific empiricism to exclude from the realm of organized complexity something so obvious as these irreducibly heterogeneous items which are our individual selves.

The second realm of biology, the science of populations, can be distinguished from the first as the realm of unorganized complexity. It is distinguished in logical structure by its method of explaining its subject-matter as a product of statistical mechanisms. To biology it has offered above all a method of explaining the development of ordered complexity by statistical mechanisms operating through time. The history of this approach to the science of living organisms through theories of evolution and genetics is familiar in outline and its present use in biology needs no comment. But if we look briefly at its intellectual origins we will see again how a structural change in far more general beliefs and activities can open a new world of strictly scientific questions. The essence of the change was a new use of time to account for both natural and social order and in consequence a new conception of order itself.

The older view of order inherited from the Greek geometers was essentially spatial. Aristotle thought as a geometer in relating the individual behaviour of the parts to their position in the whole both in living organisms and in the organization of the whole universe. When in the seventeenth century the whole of nature, living and dead, was made into a system of mechanisms, it was still left, for example by Newton, in this essential respect the same: it had been created in a state of stable harmony and so would remain as long as it lasted. The mechanistic philosophers, political as well as natural, saw in the existing order of nature and of the state conditions of stable equilibrium between mechanical forces which had in themselves no power to bring about change. In a famous essay, "On the increase of the habitable earth", Linnaeus applied this belief in the perpetual stability and pre-established harmony, not simply of the laws of nature but of their detailed products, even to the populations of human beings and of the different species of animals and plants found on the earth.

The view of nature and society as in some sense "daughters of time" is as old as Plato and Democritus, and in the seventeenth and eighteenth centuries it was renewed in the study both of human history and of geological strata and their fossils as documents for the history of the earth and of the life on it. The essentially new idea was to apply the mechanistic model to the biology of populations in a new form, making the order of nature and society a succession of states not of pre-established harmony but of statistical equilibrium developing through time. Technically this meant discovering how to quantify a realm of statistical regularities already recognized in antiquity by Egyptian, Assyrian and Hippocratic physicians in their attempts to forecast, at some personal as well as professional risk, the courses of diseases from collections of symptoms frequently but not always associated. The mathematical techniques were first developed in the social sciences. Technically the mathematics of increasingly complex phenomena becomes more difficult if they are treated, as in classical physics, in terms of numerous simultaneous equations, but it becomes easier again if the phenomena are treated as statistical problems of populations. In the sixteenth century the Venetian Republic employed a mathematician to make the actuarial calculations for insuring ships, and by the eighteenth century the techniques were good enough for Voltaire to add to his fortune by speculating in safety on the risks taken by his fellow men. Techniques of scientific demography developed in the same period gave Malthus the basis of his *Essay on Population* (1798), and other techniques made possible Condorcet's analysis of collective political and judicial decisions. But the impulse towards the new model was not simply technical; it was a new conception of nature and society. Descartes had envisaged the construction of machines that could reproduce themselves without outside intervention and saw no difference between these and the natural machines we call alive. In the middle of the eighteenth century the French mathematician and geneticist Maupertius worked out a formal hypothesis showing how increasing diversity, and increasing order in the sense of complexity and degree of adaptation, would be generated in time automatically from unordered inherited variations by the operation of a purely statistical selection through birth, competition and survival. He concluded:

"Cannot we explain in this way how, from only two individuals, the multiplication of the most diverse species could follow? They would owe their first origin only to chance products in which the elementary particles would not keep the order they had in the father and mother animal: each degree of error would make a new species, and from the force of repeated deviations would come the infinite diversity of animals that we see today, which will perhaps go on increasing with the passage of time but to which each century will add only an imperceptible increment" (*Système de la nature*, 1751).

Darwin and Wallace used Malthus's ratio of survival to birth to give factual body to this piece of speculation, but they were able to work with an established commitment to a realm in which it was natural to look for statistical mechanisms as the explanations of economic, social and biological change.

It is no accident that physical science was developing at the same time a statistical conception of the constituents of nature as a whole. In the last decade it had decoded the material link between the two realms of biology. In doing so the spiral of discovery has found that in filling space with repetitive units, geometrical necessity has imposed on the components of viruses and genes the symmetries of the regular solids out of which Plato constructed the five elements and which Kepler found in snowflakes, and the helices studied long ago by Archimedes and Descartes.

I have given you an impressionistic picture of links between some of the past and present commitments of biology. I want to make some suggestions for the future about the relevance of the past and present of biology and the study of biology for human history and the study of history. We are concerned with the decisions, a few large ones and literally millions of smaller ones, that have given our tradition its direction and kept it going through changing circumstances. It might be a useful exercise to look at these in the manner of the eighteenth-century philosophical historians as an aspect of human ecology. Historical and biological research have a large common area of subject matter and of method. The comparative method pioneered by Aristotle in the study of the organization of states as well as of animal bodies is essential to both. The study of populations is one realm of history as of biology. The search for statistical regularities long practised separately by economists and by ecologists and geneticists, and the use of models and of the comparative method applied to the whole realm of living organisms, together make a common area for research into the past and present of the human race that has only just begun. The bio-medical and the environmental sciences provide essential knowledge of the physical conditions of history, even of political history which is strangely illuminated by such recent work as that on the effects of crowding and isolation on the social behaviour of animals. History with archaeology provides the only material available for the study of human biology in time. The written documents go back over 3,000 years; the parallel anthropological and archaeological evidence extends over a much longer period. Even though this common ground does not include those unique events and irreducible individual decisions that form a large part of the realm of human behaviour, it could have an interesting yield for investment in the immediate future of history and of biology.

More relevant to the historical commitments of biology and of science in general is the mental rather than the physical ecology of human society —especially the mental ecology of innovation and resistance to it within which these decisions are made. History shows us certain constants of

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intellectual and practical behaviour that can help to explain why ideas and opportunities and certain kinds of tension release creative energy in some circumstances and the reverse in others. Western history has made its mark, as we are told often enough, as a search for control over our physical and mental environment that becomes daily more efficient. The aims of both magic and philosophy have become transposed into science. In some sciences control by highly developed theory has now become so efficient that it may make discoveries more and more difficult, and certainly makes them more and more expensive. This contains a degree of warning for the programming of research, even the most imaginative, because inevitably we plan from past success, which may have paid its main dividends. It also contains a warning both for our understanding of our own history as we watch one belief about nature succeed another, and for our understanding of neighbours with different traditions forced increasingly on our overcrowded globe to endure our enthusiasms. Nature, as Pascal said, remains in herself always unchanged; but nobody knows what she is except whatever it is that falsifies our hypotheses. She also reveals herself, or appears to reveal herself, differently to different ages, societies and individuals. Our contacts with non-Western societies bring not only science, medicine and technology; they bring to them new ways of thinking about themselves, about cosmology, about the value of life, about the meaning of health and disease. Our legitimate pride in the efficiency of our validly established knowledge and our control over life and death can make us insensitive to other kinds of judgement about why life is worth living. This process has parallels in the contacts of confidently sophisticated civilizations with their neighbours in the past. It happened to the West in reverse in the early Middle Ages. So my final suggestion is that we should pay more systematic attention to this aspect of comparative history, for our own benefit as well as that of our neighbours. It is accepted that within the proper field of the history of science we should balance the study of the internal development of different sciences by the study of the scientific activity as a whole in the context of societies and periods: treating history as the study of human behaviour, it would be equally illuminating to compare this evidence with that from societies whose attitudes to nature we should not classify as scientific.

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