Perspectives

J D Bernal (1901–1971) in perspective

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"*Freedom is the recognition of necessity*".

Friedrich Engels (1820–1895)
[The title chosen by Bernal for his collection of essays]

"*The greater the man the more he is soaked in the atmosphere of his time; only thus can he get a wide enough grasp of it to be able to change substantially the pattern of knowledge and action*".

J D Bernal
"*Science and History*" 1954

"*The world is either the effect of cause or of chance. If the latter, it is a world for all that, that is to say, it is a regular and beautiful structure*".

Antoninus Marcus Aurelius (121–180 AD)
"*Meditations*", IV, 22

"*In less than a generation we have witnessed a radical, irreversible, world-wide transformation in the way that science is organised, managed and performed*"[1].

John Ziman
"*Real science: what it is, and what it means*", 2000

1. Introduction

Desmond Bernal was professor of physics and crystallography at Birkbeck College in London from 1938, when he was a newly elected Fellow of the Royal Society, until about 1968, when his health had finally given way. He died in 1971 after steadily increasing disability[2]. Bernal was one of the most remarkable figures of his time, a visionary, the major founder of molecular biology, one of the great intellectuals of the twentieth century, in the first year of which he was born, the most eventful century in human history, the course of which he influenced to a significant extent. This was the century characterized in the book by Eric Hobsbawm, Bernal's contemporary at Birkbeck College, as the "Age of Extremes". Bernal took an important part in the war as a man of action, particularly with Solly Zuckerman in applying science to explosives and to their actions on people and cities[3] and in Combined Operations. He developed significant areas of social science. He was the closest in our generation to being a universal man, except, as he would have pointed out, in the fields of sports and music. He had vision, but at times there were things, some large, some small, that he did not like to see. He was a Utopian socialist, but was fortunate in that from time to time he was indeed "able to change substantially the pattern of thought and action". He saw in the Russian revolution of 1917 the hope for a new type of society but did not live to see those hopes disappear.

At the beginning of Homer's Odyssey, Odysseus is introduced with the word "*politropos*", variously translated, such as "of many stratagems, versatile, wandering, ingenious", but meaning active in very many dimensions or directions. "Polytropic" is thus the word we should coin to describe Bernal and is the aspect of his life that I would now wish to emphasise. The problem is that of the scientific career, the absorption of such a person into science, where nowadays usually single-minded pursuit of a single objective is what produces a Nobel Prize. He might have had a Nobel Prize for his work in the 1920s and 30s on the structure of biological molecules; after the war his contributions were many but more diffuse. The Nobel archives will, in due course, explain the prize situation, but his bibliography gives a clear picture of manifold activities.

We cannot deal only with Bernal's scientific work, which in any case was starved of official support. There are grounds for supposing that both before and after the war Bernal's political activities counted against him as regards scientific funding[4]. He never had a big institute in the modern sense and did not dispose of large funds or large numbers of people[5]. Conflict between Bernal and

the Master of Birkbeck College (John Lockwood) on the role of science in the college, probably shortened the lives of both. His laboratory and department were typical of "small science" and only after his death did his department laboriously climb up to deal with "big science" as it emerged to be the prevailing style, with big central facilities like the synchrotron and the nuclear reactor. Bernal operated by influence and inspiration. He proposed problems and encouraged others to pursue them. To have as his first students, Max Perutz[6] and Dorothy Crowfoot Hodgkin[7], must have been reward enough, although later in the 1950s Aaron Klug and Rosalind Franklin[8] added still greater distinction to the laboratory. There were, of course, many others. Half a dozen fellows of the Royal Society emerged. Usually Bernal discussed problems, solutions and tactics, but left his colleagues to do the experiments and write the papers. He was a master at summing up the situation in almost any given field and was often called upon to do this at scientific meetings. His picture of the world was a unified one and he fitted new facts into a changing whole. His changing unified world picture could certainly have adapted to incorporate the changes in science, but it would have been of greater interest to see how it would have accommodated to the political changes.

Bernal was deeply engaged in politics from outside the official world and indeed he quoted Paul Langevin who said "The scientific work that I can do can be done by others, but unless the political work is done there may be no science at all". What can an individual do for what he believes in on rational grounds which can be quantitatively argued? He did what he could and in the 1930s Bernal was said to be a member of some 50 committees concerned with science, society and politics and this must have been the state for most of his life.

Bernal lived in desperate times and times remain desperate today. It is difficult to explain to a later generation what the years 1940 to 42 meant in Britain. Only after the Battle of Stalingrad (February 1943) did light begin to return[9]. Later, the Cuban Missile Crisis of October 1962 was also an extremely tense period. This, and the simultaneous crisis in college relations, no doubt contributed to Bernal's stroke in 1963 which set his health into a serious decline.

2. Change and conflict

We are now again on the hinge of history. The future may tilt one way or the other, to chaos or to a new international order, welcome or unwelcome. Science and the world in

Figure 1. J D Bernal (centre) visited the laboratory of Nahum Joel (left) in Chile in 1962. The colleague on the right is unidentified. (Source: Nahum Joel)

general have changed greatly in the last 40 years since Bernal was active. The climate for science has changed with the fall of the Soviet Union, which represented the possibility of an alternative form of social organization, and with the rise of "globalization", the multi-national corporations, US hegemony, the growth of Asian economies, Japan, then South Korea and now China and India. Science itself has changed and the commercialization and militarization of science have intensified.

The problems of being a "polytropic scientist" have increased enormously. In many fields we see conflict between the specialist and the generalist and the sheer volume of new science makes it harder to be a polymath. To keep a significant position in some branch of science is now a full-time job. One person can usually not have a necessary command of neighbouring specialities and team work is needed and this entails organization and money. To be a successful maverick or even a 'loner' is increasingly difficult. The science citation index has chronicled the steady rise of multiple-author papers.

The actual volume of data/information/knowledge/wisdom[10] increases rapidly, and the problem is whether the scientific and technological methods of dealing with it, condensing it, finding general principles, can keep up with the rate of growth and keep the amount to be learnt by a polymath to what is within the physical capabilities of the human brain. Structures in both the real and in the informational world are characteristically hierarchic, because this is the most economical way to manage things. The task is to devise intellectual structures which will enable us, or at least some of us, to manage. Although everything can be reduced to atoms, higher level concepts, relationships and laws are needed to handle structures comprizing enormous numbers of atoms. Having found many of the laws of physics, science must move up and see how even the behaviour of human beings can be understood by human beings themselves.

In the political field there is increasing conflict between the ideologies, the media, "political realities" and the actual technical facts which steadily become more complex. The various religious ideologies are used as much as ever for managing populations. People with power are increasingly ignorant of the technical bases on which their civilization stands and have to make major decisions on the basis of advice as to what is known, what is unknown, and what the scenarios in the various contingencies might be. They have to balance actual facts against public relations. The BSE, the Foot and Mouth Disease crises, AIDS, genetic modification and the various alarms over chemical and biological warfare show the immediate problems where decisions cannot wait for certainty.

The speed and universality of communication has increased greatly since Stalin could say about the telephone: "no greater instrument of counter-revolution and conspiracy can be imagined". Faking a few photographs were then 'state of the art' and he had seen nothing of the modern mechanisms for handling and manipulating information. Now electronic mail and the Internet, free gifts of science to the world at large, have greatly changed the atmosphere and the daily work of scientists, both active and retired as well as that of governments and the military. "The Invisible College" or "The Republic of Science" has a renewed social structure where the constraints of physical distance have been enormously reduced.

3. Crystallography

Bernal was fortunate in being the right man in the right place at the right time as regards the development of crystallography, in which area he established himself as one of the founders of what has become structural molecular biology. As a student in Cambridge just after the Great War, he was exposed to the mathematical structure of crystallography and, on graduation, he joined the laboratory of W H Bragg at the Royal Institution. There the discovery of X-ray diffraction of X-rays by crystals was being developed and for the first time it became possible to "see" the locations of individual atoms in chemical compounds which occurred as crystals. After a productive few years there he returned to Cambridge to set up his own laboratory, the objective of this being to apply the methods of physics and chemistry to molecules of biological importance. The motto over the door of the Cavendish is still "*felix qui potuit rerum cognoscere causas*". [Happy is he who finds out the reasons for things]. They were indeed happy to have a clear untouched field almost to themselves but Bernal would not have been happy to be subjected to the Research Assessment Exercise of the present period where "masters of business administration" seek to extract "value for money". He was Bohemian in his administration as well as in his private life. Bernal's friend from those pre-war days, Peter Kapitsa, wrote: "The year that Rutherford died [1938] there disappeared forever the happy days of free scientific work which gave us such delight in our youth. Science has lost her freedom. Science has become a productive force".

For Bernal, as Marx and Engels said of Francis Bacon, "Matter smiled at man with poetical sensuous brightness". Atoms were real. Proteins were not just shapeless protoplasm but had shape and structure down to exact positions for every atom. An example of his structural insight is to be seen in a statement prepared for the 1931 London Congress on the History of Science. It was then believed that the hereditary material was protein. Bernal pointed out[11] that a three-dimensionally ordered molecule cannot be duplicated; a two-dimensional structure, (a sheet, like the front page of a newspaper) when duplicated would

give a mirror image but, since the molecules of life exist in left- or right-handed forms which operate quite differently, this type of catalysis would not work as it would not preserve the handedness. Thus the hereditary material must be linear; a thread would reproduce itself by the action of a dyad axis. He suggested that this hypothesis could be tested.

In Cambridge there had been a Theoretical Biology Club, based around the Biochemical Laboratory of Gowland Hopkins, in which Joseph Needham also played a leading part, and in 1932 they proposed to the Rockefeller Foundation, through Warren Weaver, the establishment of an Institute of Physico-Chemical Morphology. This was not funded, but in February 1945, before returning to Birkbeck after the war, Bernal produced a plan "to set up a research centre for the study of the structure and properties of large molecules by all available physical and chemical methods". This was based on the thinking of the Cambridge club and was the charter for the Birkbeck Laboratory set-up in 21–22 Torrington Square. A more remote aim was to understand the origin of life itself.

In the pre-war period the research field was wide open and Bernal had been concerned (at the Royal Institution and in Cambridge) with many scientific topics: the structures of graphite (his first paper), metals, water and ice, numerous important biological molecules especially the sterols and sex hormones, the rules or systematics of crystal chemistry (later formalized by Linus Pauling), instrumentation – the collection of the Fourier transform of the molecule – the Bernal chart, the 230 symmetry space groups and the standardization of notations.

After the war his laboratory (at Birkbeck College, London) dealt also with: cement, iron oxides, small molecules, proteins, viruses, liquid crystals, water and hydrates, the origin of life (life on meteorites?) and generalized crystallography[12]. In the last period of his productive life, using what facilities were available, and almost single-handed, he made important contributions to the theory of liquids and of water. His Bakerian Lecture[13] (1964) laid out his position.

4. Information

A key feature of our period is the rise of information as a commodity which can be owned. Earlier, slaves, land, the means of production were subject to ownership. Now, questions of intellectual property are increasing and include ownership of songs, pictures, the genome, the copyright of scientific papers, words[14]. Just at the present time movements are beginning to resist the growing restrictions on the sharing of knowledge. The happy tea-time professional gossip of scientists has disappeared with fears that their patents may be compromized.

Since much of the income of the USA comes from intellectual property with a rising culture of litigation[15], other countries are being forced to police themselves in these areas through TRIPS, the trade-related intellectual property agreement. Copyright spans have been lengthened. Owners of information try to extract the maximum return by measures such as encryption, and others try correspondingly to unlock it, just as silkworms were stolen from China and brought to Constantinople in about 550 AD to provide the whole of the European silk industry and to break the Chinese monopoly. Now silk may be produced by introducing a gene into completely different animals. The question of generic drugs has become acute.

In general, countries which in the past have industrialized, did so by copying, stealing or buying designs, recipes, formulae, processes, etc. from the more advanced countries. For example, Britain acquired the Turkey Red Dye process (madder) from the Ottoman Empire[16]. Other countries, notably India, were developed in a colonial way, neglecting earlier indigenous traditions. The USSR, Japan and South Korea have been the principal exponents of reverse engineering. Now, with the ownership of patents, independent development of technology becomes increasingly difficult. There is now a case for a repetition of Gandhi's salt-making exercise in a modern way. The crisis of disease, especially AIDS and associated diseases has become acute and the necessary drugs are usually proprietary. With the appearance of the Public Library of Science[17] scientists are beginning to regain control of the flow and archive of scientific papers which has been allowed to fall into commercial hands.

Bernal was extremely conscious of the importance of the flow of scientific information. This was a major concern of his book "*The Social Function of Science*" (1938). In 1948 he put forward revolutionary proposals to the Royal Society Conference on Scientific Information. These proposals were rejected then but have since mostly become accomplished facts. These considered the "scientific paper" (rather than the journal and the institution publishing it) as the fundamental unit. Bernal also foresaw, with the increase in the quantity of papers, the necessity for reviewing, condensing, abstracting, distributing operations and the construction of databases. However, many of the basic assumptions in 1948 about the public nature of scientific knowledge[18] have been upset by the rise of large monopolistic publishing concerns and the commercial activities of Robert Maxwell and others.

Even at the beginning of his career in crystallography Bernal took a key part in organizing the International Tables for Crystallography (an essential mathematical compendium of the space groups) and in the summarizing of crystal structures, first as "Strukturbericht", the Structure Reports, and on to the computerization of such data, first by punched cards and then to electronic computers, but always at the technical forefront. The International Union of Crystallography, of which Bernal was

at one time President, has been a model for responsible publishing and the full texts of the back numbers of its journals are freely available.

Bernal was also at one time President of ASLIB (Association of Special Libraries and Information Bureaux) indicating his deep involvement in the handling of information. He was also an advisor to the Science Citation Index and the founder Eugene Garfield, has written about Bernal's key role in this. The corresponding Soviet system, VINITI, was much influenced too in its design by Bernal's views and was set-up by some of the first computer experts of the USSR (D Yu Panov, in particular).

At the end of the war, in 1945, in setting up the laboratory at Birkbeck College, he engaged Donald Booth[19], one of the pioneers of electronic computing, for his laboratory to build a computer for crystallographic purposes, both for the purposes of crystallography and for the handling of data-bases. For some years the data-base of crystal structures was laboriously compiled on cards in the attic of the old house at 21 Torrington Square which was Bernal's laboratory, before it could be mechanized. In about 1963 I accompanied Bernal, he then in a wheel chair, and Olga Kennard, to visit the British Overseas Airways Corporation computer, Boadicea, to examine one of the early commercial applications. The aim was the use of computers for the Cambridge Crystal Data Centre which Olga Kennard developed into an immensely successful enterprise.

5. War

Bernal knew about war, being born in 1901 in Ireland where he witnessed the Irish rising. To be in Britain as a teenager during the First World War, and at Cambridge as an undergraduate was to realize the human cost of war. He took a full part in the Second World War, first in connection with civil defence and later with military operations. Operational Research, as a serious quantitative branch of social science, developed by his friends Waddington[20], Blackett and others, had transformed war and later would transform civilian affairs. He was awarded the US Medal of Freedom in 1945 for his activities in connection with the successful D-Day landings. Like most people involved, the experience of the war was irreversible and "the iron had entered his soul". How could a scientist go back to his Ivory Tower? Bernal wrote that the experience of war, where science could be applied on a large scale in the real world, demonstrated to him what it could do in peace if similarly directed. He enlarged this theme in a book "*World without War*" (1958).

6. Social science

It was one of the principal attractions of Marxism that it promised to provide a science of human history. Engels claimed in his funeral oration for Marx that "Marx discovered the law of evolution in human history", following the aims of Condorcet and the Enlightenment to create a science of society. Bernal also pursued this aim and dialectical materialism and Marxism provided a framework and a method. In the 1950s he spent a great deal of effort on his large volume "*Science in History*" which examined the science and technology underlying society at all periods in history. It echoes the views that the material ways in which society provides food and shelter and the basic necessities of life condition the religion and social relations. There was a unique occasion in November 1958 when a special meeting of the Soviet Academy of Sciences[21] was held to discuss "Certain theoretical problems of the history of science and technology" as formulated in Bernal's book. Everyone of importance was there; Bernal laid out his views and was also given the opportunity to sum up. This was part of the relief after the Stalin period and marked the cautious examination and acknowledgement of outside ideas. Later, in 1968, Soviet historians of science were greatly interested in the current scientific and technological revolution and in particular in the possibilities of creating a "science of science" – a quantitative analysis of the development of science. The development by Derek de Solla Price (at Yale University) of models of science based on the concrete data of the Science Citation Index had intimated that this might be done. Price's brilliant analyses used numerical data and were statistically sound and were a great advance on previous intuitive studies. If there were to be a "science of science", then the Soviet Union had to know about it. Price also testified before the US Congress and his works were widely circulated, but he did not achieve a foothold in the US governmental mechanism. He was regarded as "too clever by half".

We should note that it was and is also the aim of the CIA and related organizations (Warren Weaver was involved with the RAND Corporation in similar social science enterprises) to create a science of society. "Project Camelot"[22] in the 1960s was such an aim and this continues today[23]. Curiously, it happens that Bernal visited Chile in 1962 and met, among others, Salvador Allende, who, as President, was later killed in the military coup of 1973 which installed the military dictatorship of Pinochet, and which was one of the projects presaged by Project Camelot. Both sides looked to science for political purposes and, during Allende's presidency, attempts were made with Stafford Beer[24], to use modern cybernetic methods for running the Chilean economy. However, it was the expressed wish of Henry Kissinger that this Chilean government should be overthrown and the measures which were taken to this end succeeded. Since then the CIA have continued to look to scientific methods[25], although

the application of "systems analysis" failed for political reasons in the Vietnam War. Anthropologists work on treacherous ground.

Bernal, with Solly Zuckerman[26], had done pioneer work in 1940 in quantitative social science as part of the investigations of the effects of air raids on civilian populations. They counted and measured everything and are supposed to have made predictions for the effects of a medium-sized air-raid on a medium-sized city, taking Coventry as an example. The chance that Coventry actually experienced such a raid, with casualties and damage much as predicted, verified their measurements as if it had been a scientific experiment. Their "*Field Study of Air Raid Casualties*" became a standard work of reference. In general Bernal and Zuckerman's studies pointed to the ineffectiveness, in comparison with cost, of mass air raids, particularly of the American daylight raids, but their advice was rejected by Churchill and his scientific advisor Lord Cherwell on other criteria. Blackett is on record as saying that the Bomber Command policy of area bombing was the 'worst strategic mistake of the war'. The same mistake was made again in Vietnam, an asymmetric war. One of the major lasting scientific contributions made during the war by Bernal, Waddington, Blackett, Zuckerman and others, was the development of operational research, applicable in many other areas besides military operations.

7. The Soviet Union

Bernal had become a communist while a student in Cambridge and continued throughout his life to advocate this alternative to the existing capitalist system of organizing society. He thus had to engage with the Soviet Union as an example of this alternative. He did not live to see the collapse of the Soviet Union and its subsequent brutal incorporation into the world capitalist system[27]. In many places this socialist viewpoint caused him to be treated with suspicion. In the second World War his obvious talents and knowledge proved important to the war effort and he had powerful patrons (such as Louis Mountbatten, Chief of Combined Operations, to whom he was Scientific Advisor, 1942–1945), but afterwards during the Cold War, when the Soviet Union was treated as a potential enemy, there were difficulties.

The question of Lysenko and the suppression of genetics in the USSR is often held up against Bernal. Indeed it was a key example of the interaction of science and power comparable to the past and present struggles between the church, the state and individuals who, through observation and experiment reach conclusions different to the official dogmas based on interpreters of "revelations". There are still a number of theocratic states and science is a minority activity. Bernal emphasized that time would sort out the truth of the matter[28], that the relative formative roles of environmental and genetic factors were unclear but a problem for experiment, and that Lysenko had the support of the Communist Party, largely for political reasons connected with agricultural production. J B S Haldane, with similar views, backed out of the party position earlier, while Bernal stayed quiet. It is now a matter for investigation as to whether Bernal's policy of staying on good terms with the Soviet authorities was helpful for scientists in the Soviet Union at the time.

The Soviet Union had immense problems and the best account of its science is by Eric Ashby[29] who was at the Australian Legation in Moscow for the year of 1945. He describes the state of scientists and science with the greatest honesty and acuity and has a particularly clear account of Lysenko and his work. Russian history has been a record of invasions and gigantic upheavals, even before the revolution of 1917, which offered the example of an alternative social system, but inherited imperial problems. The end of the Soviet period has permitted to some extent a discussion of how things might have been different. The most important issue is that of the New Economic Policy of the 1920s where it was proposed that private capitalism should be permitted 'temporarily' to permit development. The proponents of this view were defeated and were executed or exiled. The chief advocate of this was N I Bukharin (1888–1938) who also discussed in this period the development of China which, as we have seen, eventually took this course (over the last 20 years) with the most dramatic results. Similarly, the economy of South Korea has multiplied by some 30 times since 1970 under a dictatorial planning regime[30]. The role of science and technology in societies of all kinds is of the greatest importance.

The chief issue has been that of planning. In the Soviet case the Planning Commission was seen as the most original creation of the revolution. In India, after independence, the Planning Commission, based largely on data collected by the Indian Statistical Institute, run by P C Mahalanobis, a friend of Bernal, was also a key institution for development. It is now a problem to find out to what extent Bukharin and Bernal influenced each other as regards the planning and organization of science[31]. They met in 1931 and 1932. Bernal's book "*The Social Function of Science*" had been written in 1938, the year in which Bukharin was tried and executed by Stalin, and his role could not be mentioned without compromising Bernal's political position. After the denunciation of Stalin's crimes by Khrushchev in 1956, Bernal was able to discuss ideas about the role of science and technology in the Soviet Union and to reopen lines which Bukharin had propagated. The physicist Avram Ioffe[32], who founded the Physico-technical Institute in Leningrad, and influenced Bukharin towards science, visited Bernal at Birkbeck again in the early 1950s.

8. Conclusions

We must conclude that the sub-title of Bernal's "The Social Function of Science" – "What science does: what science could do" is still the relevant challenge and indicates Bernal's chief contribution, besides the foundation of molecular biology to our civilization. It is manifest that resources spent on armaments are a monstrous pathological symptom of our social structure. The ancient problem of "what is property" and what may be "owned" and by whom or by what organs of society is awakening.

How would Bernal's career have developed if he had existed at the present period? We may guess, since science is now big science and has been taken over by big business, that he would be playing a major part in the political development of the anti-globalization movement, the coherent form of which is not yet apparent. But history is the science of things which are not repeated and Bernal himself illustrated the dialogue between heredity and environment which operates at all levels from that of the single fertilized cell onwards. "He who seizes the right moment is the right man". The human species is opportunist and makes its own future as it goes along a unique path. Bernal was a prodigy and he was fortunate, and we are also fortunate, that many of his unique abilities could be employed fruitfully.

Notes and references

1. If you are a scientist at an American research university like mine, you know what to do if you think you've hit on some technique or bit of knowledge that might have commercial potential. You go online to the university's technology transfer office, download an invention and technology disclosure form, and fill in the details. You have to do that because all such intellectual property (IP) discovered by this university's employees belongs to the university. If the local bureaucrats think there's something in it, they will file a provisional patent and after formally offering it to any government agency that funded the research – which usually declines –they will start hawking the IP about to see if any entrepreneurs or companies want to license it. Priority in your IP is protected at this stage, and you can now go ahead and publish if you wish, but eventually you may proceed to full (or utility) patent, where property rights are wrapped up more securely, and, while IP lawyers make fortunes from litigation about who in fact owns the property, basically the matter is now in the domain of formal law. If the university does manage to license the IP, you will get perhaps 35% of the royalty stream. Or, if that's not enough for you, you can cut yourself free from academia and take your chances with the venture capitalists as an independent entrepreneur. – Steven Shaplin, (University of California at San Diego), London Review of Books, 6 March 2003, p. 14.
2. The Royal Society obituary by Dorothy Hodgkin is essential reading. Biographical Memoirs of Fellows of the Royal Society, **26**, 17–84, (December 1980). Andrew Brown (biographer of Chadwick) has a new biography of Bernal in hand.
3. The quantitative estimates from Bernal, Zuckerman and Blackett that the policy of "dehousing the Germans" by the bombing of cities would be costly in airmen's lives (as well as to the civilian population of Germany) and ineffective in hampering the German war production, was over-ridden by Lindemann and Churchill with results which showed that Bernal and colleagues were correct.
4. Blackett P M S, (Nobel Prize, President of the Royal Society, etc.) who also played an important role in the war, found himself isolated from government from 1945 until 1964 because of his political views. R. Anderson, Notes and Record of the Royal Society, **53** (2), 253–273, (1999) and **53**, (3), 345–360, (1999).
5. Bernal J D "A Life in Science and Politics" ed. by Brenda Swann and Francis Aprahamian, with a preface (and chapter) by Eric Hobsbawm, Verso, London, 1999.
6. Perutz M F, "I wish I'd made you angry earlier", Oxford University Press, 1998/2002.
7. Georgina Ferry, "Dorothy Hodgkin: A Life", Granta Books, 1998.
8. Brenda Maddox, "Rosalind Franklin: The Dark Lady of DNA", Harper Collins, 2002.
9. "The lights are going out all over Europe. We shall not see them alight again in our generation". Edward Grey, August 1914.
10. "Where is the wisdom we have lost in knowledge?/Where is the knowledge we have lost in information?" T S Eliot, [Where is the information we have lost in data?/Where is the data we have lost in noise? – added 1980 A.L.M.].
11. I am greatly indebted to Andrew Brown for this item which he found in the Bernal Archive in Cambridge University Library [A4.7 Box 22].
12. Bernal J D and Carlisle C H "The Range of Generalised Crystallography", Soviet Physics – Crystallography, 13, (5), 811–831, (March/April 1969).
13. *Proc. Roy. Soc. Lond.*, **A280**, 299–322, (1964).
14. Burroughs Wellcome, manufacturers of pharmaceuticals, used to write politely, every time the word "tabloid" appeared in the newspapers, that this word was their property and could only be used with their permission.
15. There are some 900,000 lawyers in the USA (population 291,000,000) compared with 18,000 in Japan (population 125,000,000) where society is different.
16. A and N Clow, "The Chemical Revolution", Batchworth, London, 1952 pp 214–221.
17. publiclibraryofscience.org.
18. John Ziman, ("Public Knowledge: the social dimension of science", Cambridge, 1968), defines science as public knowledge but more in contrast to 'knowledge' by revelation or decree, rather than as a subject for 'ownership'.
19. Some of A D Booth's apparatus is to be seen in the Science Museum in London and in the Museum of Science and Industry in Birmingham. He made many significant advances, mostly outside the requirements of crystallography.
20. Publication of Waddington's book on how to hunt submarines and other aspects of operational research was delayed for some 30 years by security concerns.
21. Voprosy Istorii estestvoznaniya i tekhniki, (6), 72–150, (1958).
22. Horowitz I L, "The Rise and Fall of Project Camelot", MIT Press, Cambridge, Mass., 1967.

23. The aims have been scaled down from the over-simple desire to identify a village as friendly or hostile from an aerial photograph to a more in-depth study of the technical, social and economic conditions of "failing states".
24. Beer, Stafford, "Cybernetics and Management", (1959).
25. Adler R, "The crystal ball of chaos", *Nature*, **414**, 480–481, (29 Nov. 2001).
26. John Peyton, "Solly Zuckerman: a scientist out of the ordinary", John Murray, 2001.
27. see, for example, *Failed Crusade: America and the Tragedy of Post-Communist Russia*. By Stephen F Cohen, New York: W. W. Norton, 2000, 320 pp.
28. The roles of heredity and environment become ever more interrelated and questions of the genetic content of behaviour remains a vital issue. e.g. Ridley M "Genome. The autobiography of a species", Fourth Estate, London, 1999. Wilson E O, "Sociobiology", and "Consilience".
29. Ashby E "Scientist in Russia", Penguin, (1947). Enormously more information has become available since 1991. See books by Loren Graham, David Holloway and Paul Josephson, in particular.
30. It is paradoxical that, for example, the Economist ridicules "the command economy" of nation states, while the "free" enterprises, the large companies, practice internally the most severe command economies, using whatever techniques of planning they can muster and are the most totalitarian of societies.
31. Bukharin N I "Metodologiya i Planirovanie Nauki i Tekhniki" ed. P V Volobuev, Moscow, 1989.
32. Paul Josephson (Colby College, USA) has had access to the archives in Leningrad and has also written about Boris Hessen. The biographer of Bukharin, Stephen Cohen, was able, during a window of opportunity in the Gorbachev period, to recover very important manuscript material written by Bukharin in prison.