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J D Bernal: his legacy to science and to society[1]

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1. Introduction

Desmond Bernal was professor of physics and crystallography at Birkbeck College in London from 1937, 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. Bernal was one of the most remarkable figures of his time, a visionary, a 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 characterised in the book by Eric Hobsbawm, Bernal's contemporary at Birkbeck College, as the "Age of Extremes".

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.

Today, more than a century after Bernal's birth, the world is very different from that in which his world outlook was formed and with which he was imprinted as an infant. As a boy he had become captured or imprinted by science and the powers it offered for understanding things and for changing the world, including the state of the Irish people, and he knew about subject peoples at first hand. As a student in Cambridge, exposed to a mass of new ideas, he was captured too by the vision of a socialist society, he escaped from his Catholic background and became a communist and Marxist. He was always an anti-establishment outsider.

I believe that Bernal had a huge intellectual picture of the universe as a coherent and connected whole, and that he was continually integrating new facts into this system, re-synthesising a unitary picture, so that one item was related to many others and it was only a few steps to connect any item with any other perhaps through a pervading theoretical ether or curvature of space. One day, perhaps, with the new scanning methods of seeing the brain at work, we may be able to understand how this huge mass of data is physically represented in the brain. This was in sharp contrast to many other scientists who kept their science, religion and social relations in quite separate compartments achieving the concentration in science which is usually necessary for the signal work which attracts a Nobel Prize [2]. Many people have remarked on this great power as a synthesist, both at leisure and when summing up a session at a scientific meeting, which he was often asked to do. His visions of how a field of science had developed, how it connected with history and where it should go in the future, were often spell-binding.

Almost all Bernal's contemporaries have now gone and the number of people who remember him is decreasing rapidly. It is therefore appropriate that I should try to devote most of this



Figure 1. Professor Desmond Bernal, c1955, oil on canvas, Peter de Francia, (©Peter de Francia, reproduced with kind permission of Peter de Francia).

lecture, to the man himself, his work and his influence. We must try to reconstruct some of the vast network connecting Bernal with the people and events of his times, scientific, political and cultural although clearly I have no conception of his inner life. Dorothy Hodgkin, his first student and close collaborator, has left an account of Bernal's life, work and character, to which it is difficult to add [3], and we now have the splendid biography by Andrew Brown with much new information.

2. The Republic of Science

Science is an international community, what the mathematician of the Victorian period, William Kingdon Clifford called "The Republic of Science". It does not belong to any nation or religion or ethnicity, but ties closely together a significant section of people who have an increasing influence on the way the world develops. Bernal took a full part in this community and made every attempt to strengthen its coherence and political influence through organisations such as UNESCO, the World Federation of Scientific Workers, The World Peace Council, the International Union of Crystallography and innumerable personal contacts, many with people in positions of real power.

I would like to emphasise the nature and importance of this network of science, locally, internationally and through time. With the development of the Internet and electronic-mail there has been a sudden jump in the connectedness of this Republic of Science [4] and its

reaction time has been shortened. Stalin is supposed to have commented on the telephone, “*No more dangerous instrument of counter-revolution could be imagined*”; but he had seen nothing of the computer, the Xerox machine [5] and the Internet. Somewhat like the Vatican in its universality, the Republic of Science has common standards which form a solid basis for international cooperation. The standards of science are not those of the political world. Phil Abelson, as editor of *Science*, wrote in an editorial:

“Part of the strength of science is that it has tended to attract individuals who love knowledge and the creation of it. Just as important to the integrity of science have been the unwritten rules of the game. These provide recognition and approbation for work which is imaginative and accurate, and apathy or criticism for the trivial or inaccurate.....Thus, it is the communication process which is at the core of the vitality and integrity of science...” [6]

Bernal said himself:

“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.” [7]

He was thus immersed in the net of his own times, as we are ourselves, and to appreciate the effect of this we must recognise the historical processes and how times have changed. John Ziman wrote in 2000:

“In less than a generation we have witnessed a radical, irreversible, world-wide transformation in the way that science is organised, managed and performed.” [8]

Bernal saw only the beginning of this change. Small science became big science, it has become more than ever militarised, commercialised, and planned, although usually not for the ends for which Bernal had worked.

Bernal never sat tight in his laboratory for long enough to solve a Nobel-prize-winning problem. His connections to the arts, politics, architecture, even to the military, were very numerous and his contributions to science were also manifold, but spread out. His influence was part of the climate of science of his times. Having rather slight financial resources for his scientific research, he had to operate a kind of guerilla campaign, reconnoitering the research field for what problems could be solved with the people and equipment to hand, concentrating on a problem, perhaps getting someone installed to deal with it, and then himself passing on to something else. Nevertheless he kept recurring to certain questions, particularly the origin of life, the structure of liquids, and generalisations of crystallography. He operated in the world of small science, the first intimations of big science being the construction of the atomic bomb and the applications of science in the war of 1939–1945.

To understand Bernal and what he did we have, I think, to concentrate on the period from 1914, the beginning of the First World War and 1939, the beginning of the Second, when the world was very different from today. For me, being 25 years younger than Bernal, in that period, the Great War hung like an impenetrable curtain dividing history, everything before the war, from everything afterwards, so that I was imprinted with this background. Bernal went up to Cambridge in October 1919 with the first post-war intake of students. He could not be otherwise than impressed with what the world could be like if it were not cursed with warfare. The 1920s was the period of the economic crash, the British general strike of 1926 and the crushed revolutions in Germany, Hungary and elsewhere. The Russian Revolution had set Russia in a new direction and seemed to offer the possibility of an alternative civilisation.

In the thirties Bernal was involved in the anti-war movements and his practical studies of civil defence led to him being enlisted into the official war effort. It looked as if the government

would take little note of science but the book, *Science in War*, produced by the Tots and Quots dining club in London, and edited by Zuckerman and Bernal, galvanised influential circles and the editors, and many other scientists, eventually played a key role.

Bernal took a very significant part in this war, marked by the Royal Medal of the Royal Society and the United States Medal of Freedom, and it was from this experience that he learnt what science could really do when given sufficient resources. Andrew Brown in his biography of Bernal has found information giving a fuller picture than hitherto of Bernal's contribution to the war effort.

3. The Royal Institution and Cambridge between the Wars

On graduating from Cambridge Bernal went to the Royal Institution to work for Sir William Bragg and became enmeshed in the scientific network. Bernal wrote to Lawrence Bragg when Sir William Bragg died in 1942:

“He, [W. H. Bragg] was in a way, scientifically, my father too. He took me up and helped me through all the critical stages of my career. I was always proud of having worked under him. I had always meant to tell him how grateful I was, but somehow one never does and then it is too late” [9]

Emphasising the durability of this scientific network, messages of condolence came to Lawrence Bragg from Germany through a neutral country, even in the middle of the war. At the RI, with Bill Astbury, Kathleen Lonsdale and many others, he laid the foundations of X-ray crystallography, dealing first with space group theory, the operation of X-ray cameras and X-ray tubes all in the prevailing string and sealing-wax style. He began with the structure of graphite and moved on to take the first X-ray diffraction pictures from biological molecules (Lawrence Bragg and his school had set to work on the minerals). This was almost the simplest of all structures and progress since then has been immense. In caricature we can see the progress from Bernal's first model in the early 1920s of a rotation camera for X-ray diffraction from single crystals, a replica of which is now in the Science Museum, to today's synchrotron installation in Grenoble. With such successes in X-ray diffraction, instrument companies began to manufacture equipment.

The work on biological molecules was very successful and in 1927 Bernal moved back to Cambridge to set up as Lecturer in Structural Crystallography. There, notably with Dorothy Hodgkin, they continued towards the main objective which was to understand life, its origin and operation in terms of the underlying structure, so that this could be applied for human needs. There was a marvellous decade at Cambridge from 1927 to 1937. In particular they established that proteins had a structure which would eventually be found.

As the possibilities for finding the arrangements of atoms in proteins became apparent, Bernal and Bill Astbury agreed to divide the proteins between themselves, Bernal taking the globular proteins and Astbury the fibrous, like the Pope dividing the new world between the Spaniards and the Portuguese by the Treaty of Tordesillas.

4. Birkbeck College and “Science in History”

In 1937 Bernal was elected FRS and moved to Birkbeck. 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.

Bernal also operated in the political world, so that we will need to consider this aspect too. Robert Hooke wrote in 1663 that “*the business and design of the Royal Society is to improve the knowledge of natural things, and all useful arts, etc... not meddling with ... politics*”. Perhaps meddling in politics had hindered the proposal to the Rockefeller Foundation.

However, Bernal had become a Marxist and it was the claim of Friedrich Engels that Marx had begun to make history into a science. We now have university departments of political science, not least the London School of Economics and Political Science. The extent to which politics and government can be scientific is a major question which became acute in the 1960s with the recognition of the scientific and technological revolution, associated primarily with the rise of cybernetics and the computer. Politics and science became more interconnected. The word “cybernetics” was coined, by Norbert Wiener, who was among the host of people who visited the Birkbeck laboratory, from a Greek word for government of a ship. Engels wrote:

“The basic thought running through the Manifesto – that economic production and the structure of society of every historical epoch necessarily arising therefrom constitute the foundation for the political and intellectual history of that epoch” [10].

We might note that there were two fellows of the Royal Society at the funeral of Karl Marx in 1883. In the Victorian period, with a much smaller intellectual base, all kinds of people were in a network of personal communication. One of the fellows present was Edwin Ray Lankester, then professor of zoology at University College, London and the other was Carl Schorlemmer, the first professor of organic chemistry [12] in Britain (at Owens College in Manchester) who was a close friend of Friedrich Engels and was responsible for keeping Marx and Engels up to date with science. Engels had accompanied Schorlemmer to Pennsylvania to look at the nascent oil industry and the later mantra of dialectical materialism about quantity turning into quality, derived directly from research by Schorlemmer, published by the Royal Society, simply showing how the properties of hydrocarbons changed with increasing chain length.

Bernal did not see the fall of the Soviet Union, for which he had such high hopes of developing an alternative society, but it would have meant a tremendous re-adjustment of his world picture. Marxism is in abeyance for the moment but it may appear again in response to the next great crisis, whatever it is.

Productive industry now takes an ever smaller place in Britain in comparison with pseudo-industries such as insurance, advertising, gambling, commercial sport, commercial entertainment, drug trafficking, but the production and sale of weapons and military science [13] are as big as ever and it is a standing question for economists as to whether this activity is necessary for the stability of a capitalist economy. It is now a lively question as to whether Britain can dispense with agriculture as it has largely dispensed with heavy industry.

I wonder what Bernal would predict for the next period. His book “*Science in History*” of 1954 examined the mutual interactions of science and society through the whole span of human history. Unfortunately its publication was at about the time of the death of Stalin and with the denunciation of Stalin’s crimes by Khrushchev in 1956 the assessment of the USSR had to be rewritten. I was present at a meeting in Moscow with the publishers of the Russian translation and the translators were not so pleased that they would have to do several chapters over again.

In November 1957 there was an unique occasion in Moscow when Bernal was invited by the Soviet Academy of Sciences to “*A scientific conference for the discussion of certain theoretical problems of the history of science and technology*” [14] which was entirely devoted to a discussion of this Russian edition of his book [15]. It was attended by some 400 people, almost everyone in the field. The basic concern was that, if there are laws relating the mutual development of science, technology, society, politics and economics, as Marx and Engels had claimed there

should be, then a planned society needed to know them. In a way it was also a meeting of reconciliation between the two schools, of theory and of the actual facts. The official theoretical picture of the economy of the USSR had diverged greatly from the actual facts. In this period of “the thaw” Bernal had the role of re-connecting the academic history of science in the USSR with the rest of the world from which it had been cut off during the Stalin period. It is difficult for us in our very empirical society to realise the importance attached to dogma elsewhere.

Bernal was Irish and could thus see England from the outside. He was 15 at the time of the Easter Rebellion in Dublin in 1916 which led to the Irish Free State in 1922 and thus he had a basis for visualising the October 1917 Revolution in Russia. The chaos and conflict in Ireland was small-scale compared to that in Russia. To be Irish gave Bernal, I think, the opportunity, when he chose to take it, to look at England and the British Empire from the outside with some detachment.

Acquainted with all kinds of society, Bernal was always rather an outsider. Dissociating himself from the empirical English he wrote:

“In England, more than in any other country, science is felt rather than thought... A defect of the English is their almost complete lack of systematic thinking. Science to them consists of a number of successful raids into the unknown.”

Writing in about 1937/38 he must have expected that his readers could all add the lines of T. S. Eliot, current at the time and which he echoed:

“Each venture
Is a new beginning, a raid on the inarticulate
With shabby equipment always deteriorating
In the general mess of imprecision of feeling.”

Probably research at the Royal Institution (1923-1927) and at Cambridge (1927-1937) had been a bit like that!

Bernal’s mother had travelled widely and Bernal had learnt French and no doubt from this and from the Catholic education and background to which he had been exposed, he found the philosophical framework, obligatory in continental Europe, to be necessary and congenial. Thus when he met the excessively theoretical approach of dialectical materialism, the official ideology of the communist movement, it was not so strange. Only recently, a Franco-German physicist and academic, confirms this continental tradition:

“... in the case of conflict between theory and practice, the Gallo-Germans tend to choose theory.” [16]

In many ways Bernal was able to participate fruitfully in both camps. Nikolai Belov, the senior Soviet crystallographer, said of Bernal, that *“like a true Irish man his last enthusiasm was for the laws of lawlessness”*.

The Congress on the History of Science held in London in July 1931 seems to have been a key event in Bernal’s career. The paper by Boris Mikhailovich Hessen defined the occasion and Hessen [17] showed, to the surprise of traditional historians of ideas, that Isaac Newton was immersed in the practical problems and circumstances of his time. I did not know until recently that Hessen studied physics in Edinburgh in 1913-1914, was an expert on the English Revolution of the 17th century, and had introduced relativity and quantum mechanics into Russia. At this congress Bernal met Nikolai Bukharin, the most sympathetic figure among the Bolsheviks, who had been expected to succeed Lenin but whose position had even then begun to slide. He was executed by Stalin in 1938 as was also Hessen. The recent publication of Bukharin’s writings in prison gives a glimpse of how history could have been different. It is probably too late to find out how Bernal got on with Bukharin, but it would be of the greatest interest. Because

Bukharin became a non-person, Bernal did not mention him again in print but there must have been influences. Bukharin was very clear that “*communism implies intelligent, purposive and consequently scientific production*”. In the first few years after the Russian Revolution there was an amazing conjunction of art, science and politics in a background of chaos, recently recalled with the exhibition of “Modernism” at the Victoria and Albert Museum in London.

Bernal in his voluminous writings on the co-development of science and history elaborated the views aired at this 1931 conference. Professional historians did not pay much attention to science or technology so that Bernal said that as an amateur historian he had to do it, but recently historians such as Paul Kennedy [18] have paid much more attention to the material basis on which society stands. For his television series Kenneth Clark did not count science as part of civilisation, and so Bronowski had in turn to remedy this outlook.

Much later, in the Prague Spring of 1968 and the movement for “socialism with a human face”, Radovan Richta and a large team at the Czechoslovak Academy of Sciences, produced a manifesto “*Civilisation at the Cross-roads*”, influenced by Bernal, and alluding to Bukharin’s intervention at the 1931 meeting, and with many revolutionary proposals: such as that the free time of the citizen is an important national resource which is wicked of the bureaucracy to waste.

It was particularly poignant that in the Soviet intervention in Czechoslovakia in 1968 the Academy of Sciences should have been closed down by the Warsaw Pact armies [19]. Later, a greatly blunted and revised analysis of the scientific and technological revolution was published in Prague as a joint effort of the Czechoslovak Academy with the Soviet Academy of Sciences.

I think that Bernal was immensely impressed with the power of coherent mass action. In such movements the amplitudes of all the actors are in phase and add together at the same moment to give an irresistible force. If the same number of people act in their own random times then the intensities add. This is the difference between a candle and a laser. Most of his visions depend on coherent action according to a master plan.

To understand Bernal’s perception of Stalin and of the conditions in the Soviet Union certainly presents us with a problem, especially in hindsight. The problem is comparable to that of Oppenheimer, of Heisenberg and of Sakharov, who had to come to terms with power as it was at the time. The problem is the major one for any revolutionary; the dilemma was put to Jesus Christ and he dodged the question and replied “*Render unto Caesar what is Caesar’s and unto God what is God’s*” [20]. One can imagine Gandhi being shown a rupee, with the image of the King Emperor on it, and being asked whether it was lawful to pay taxes to the Raj, giving essentially the same answer.

The scientific community in the USSR was composed of ordinary people, many greatly talented, who had to work with the powers that existed. There were heroes and villains [21] and many admirable people. Cutting off relations with them would serve no good purpose for them, for science or even for the future of the USSR. We just do not know what Bernal was able to do behind the scenes.

The great contribution of Bernal, Blackett and Waddington to the war effort was the development of operational research, the measurement of what was actually happening and the recommendation of future action on this basis. In many aspects of war this was so effective that publication of Waddington’s book was embargoed for thirty years by secrecy considerations. Between them, faced with the problems of the conduct of war, this group invented a large sector of social science and made it a real science. In particular, in the dispute between Tizard and Lindemann over the effectiveness of aerial bombing, the conclusions of the scientific analysis were overruled on political considerations. Nowadays much operational research is diverted to advertising and less important activities. After the war both Bernal and Blackett were largely excluded from the application of science in national politics until about 1963, when they took part in the Bonnington Group discussions in the preparations for the Labour Government of Harold Wilson.

With this background it is difficult to see how Bernal could not have been aware of the difference between the official picture and the actual facts of the situation in the Soviet Union and Eastern Europe even though he did not read Russian. Stalinism in the USSR eventually poisoned the whole of the world socialist movement. The actual split in the monolithic left movement and the return to reality originated in 1947 on the Youth Railway project in Bosnia where Edward Thompson was the leader of the British group. Edward Thompson began the break with publication of a journal – the *New Reasoner*. Several people in Bernal’s laboratory had taken part in this Yugoslav project and there was fierce discussion at tea-times. It was only after Khrushchev had denounced Stalin’s crimes in 1956 that Bernal was able to offer public criticisms to a very limited degree. What he did privately we do not know. It may be that he was able to help behind the scenes. He had written in the *Spectator* in 1931 reporting the History of Science Congress:

“Is it better to be intellectually free but socially totally ineffective or to become a component part of a system where knowledge and action are joined for one common social purpose?”

He had experienced the effectiveness of the system when part of the British war machine and must have reckoned that it was better to try to divert the machine from inside than to oppose it as an individual from outside.

The Pugwash movement and similar contacts between scientists as people undoubtedly had some effect on preventing global disaster and I am sure that fostering personal contacts between crystallographers and scientists generally is immensely worthwhile.

I think that a major characteristic of Bernal’s scientific work can be summed up in the word “**shape**”. Bernal had absolutely no feeling for music, but a very acute sense of shape and form. Perhaps the difference is between sequential and synoptic storage of information. Brain scanning is beginning to give answers to such questions. More speculatively I wonder if the elaborate Celtic art prepared people for the complexity which later would be found inside matter.

Bernal’s first book, the short essay “*The World, The Flesh and The Devil*” (1929), is full of ideas, some realised, some still under discussion, as to what could be done in the future. Among these he introduced the idea of the construction of a huge sphere, in space. “*Imagine a spherical shell ten miles or so in diameter...*”. Freeman Dyson has drawn attention to this concept and it has now entered the space literature as “The Bernal Sphere”. Later, he referred to the “The Garden of Eden” [22], and the possibilities of roofing over a large area to provide an artificial climate now realised in Cornwall. I think that this particular reference was after Buckminster Fuller, but the ideas had been going for a long time.

In the early 1930s Bernal got to know the group of artists, sculptors and designers: Naum Gabo, Henry Moore, Ben Nicholson, Barbara Hepworth and many others. He was drawn in to write about the arts and about architecture. For example, the introduction to Barbara Hepworth’s first exhibition catalogue in 1937 was written by Bernal, and in it he referred to her introduction of a fourth dimension, “a closed curve in time”, an interest shared by many abstract artists in these years. The interest in art and architecture continued through his career.

Richard Feynman in his famous lecture series (about 1963) emphasised structure:

“Everything is made of atoms. That is the key hypothesis. The most important hypothesis in all of biology, for example, is that everything that animals do, atoms do.”

Curiously Karl Marx, at the age of about 23, wrote his doctoral dissertation on atoms, although, of course in 1840 the concept of atoms was just emerging from the philosophy of Democritus and Lucretius, with the work of John Dalton about 1803 giving more concrete pictures. Marx, Bernal and many others were inspired by the vision and programme of Lucretius to explain everything,

from the weather to the brain in terms of atoms. Although the concept of atoms as billiard balls takes us very far, the actual quantum world at the scale of atoms is very different and counter-intuitive for the understanding of which many very subtle experiments are necessary.

Bernal in his twenties wrote the article on X-ray crystallography for the Encyclopaedia Britannica. He was asked in 1953 to do this again, but his contribution was rejected as being far too long and was replaced by a very pedestrian account. He concluded:

“As a result [of the discovery of the diffraction of X-rays from crystals] science was beginning to find explanations in terms of atoms and their combinations not only of the phenomena of physics and chemistry but of the behaviour of ordinary things. The beating out of metal under the hammer, the brittleness of glass and the cleavage of mica, the plasticity of clay, the lightness of ice, the greasiness of oil, the elasticity of rubber, the contraction of muscle, the waving of hair, and the hardening of a boiled egg are among the hundreds of phenomena that had already been completely or partially explained. They were an earnest of the millions of others, old and new, that still had to be explained.” [23]

He was a Pied Piper recruiting people to crystallography and science generally.

One of the key events of the twentieth century was the discovery of the double helix structure of DNA by Francis Crick and Jim Watson which was published in Nature on 25 April 1953. Many lines of scientific work led to the key event and many again led out of it, but the double helix was a defining event the consequences of which are only now becoming apparent. Genomics and the genetic code has become fashionable but genomics is only half of the secret of life and the other half of the secret is shape, so that at the present time the appearance of larger scale shape from the behaviour of molecules needs more attention. The proposal for an institute of Physico-Chemical Morphogenesis was perceptive.

Returning after the war to Birkbeck, Bernal was not able to do much experimental work himself, but did what he could to promote and facilitate the work of others. Sometimes he asked every day “What’s new?” other times he was away for weeks. He was able, however, to develop his own work on the structure of liquids which was a beautiful dialogue between experimental and theoretical geometry. Computing facilities were only just beginning to come in and most of the work was done by hand. The approach showed how long range order might develop from local order while the traditional view of crystal structure gave the impression that atoms were arrayed in a pre-existing framework of symmetry elements.

The scientific work of the laboratory in the period 1945–1965 is now well known and I will not recount it. The appearance of icosahedral particles of polio virus was a key event which led to the extension of classical crystallography to liquids, quasi-crystals and more general types of order. A key concept was hierarchy, working from local order up to overall order whereas the 230 space groups encourage people to look at crystals as units hung in a picture frame of symmetry elements.

The social solidarity of the crystallographic community has been encouraged by the habits learnt at Birkbeck, of informal use of first names, of doing things for oneself, of workshop practice, of meeting at tea-times, of cooperation rather than competition, habits of which Bernal’s first student, Dorothy Hodgkin, was the great exponent. At the end of his career Bernal made a statement of his programme of generalised crystallography. The paper was written jointly with Harry Carlisle, but the theme had been developing throughout his life. It set out once again his vision of how structure at the atomic level resulted in life in all its variety and richness.

5. Information Science

Scientific information is like the blood circulation of the body scientific and Bernal’s “*Social Function of Science*” of 1938 contained a lot of interesting material about scientific

documentation and how the papers reporting the results of scientific work should be communicated to others. A project by Watson Davis of Science Service in Washington for the establishment of a Scientific Information Institute was reproduced. Information was a continual interest.

In 1948 the Royal Society held a conference on scientific information in the light of the “information explosion” at which Bernal proposed a scheme for the circulation of scientific papers as the units of publication and the demise of all scientific journals. The proposal was an attempt at social science and was based on a questionnaire sent to 300 people. Not surprisingly, it met with strong opposition and was withdrawn, but it has gradually become fact. At a further conference he proposed the use of abstracts to digest papers and anticipated the use of computers in doing this.

Eugene Garfield, the founder about 1955 of the Science Citation Index has written extensively on Bernal’s part in the development of the handling of scientific publication, both for the benefit of the users and as a tool for analysing objectively the phenomena of science, which was labelled at one time “the science of science”. Garfield and Henry Small were able to produce maps showing the **shape of science** which appealed to Bernal. The intuitive spatial expressions, of frontier, area of common interest, topic, used in describing science were shown to have quantitative substance. The science citation index, especially in the hands of Derek Price, became a model for the social sciences and gave the hope that the social sciences would become real sciences. There were visits to Birkbeck College by Professor D. Yu. Panov who was the founder of the Soviet documentation centre VIINITI which published in Russian voluminous abstracts of the world scientific literature. At one time Bernal became a president of ASLIB [24], the Association of Special Libraries and Information Bureaux. *Scientometrics*, since the Bernal period, has continued to try to become a quantitative branch of social sciences but has become increasingly esoteric. The computer and the associated science of cybernetics was beginning to move and politicians were talking about the scientific and technological revolution. Just at the present moment, because of the development of the Internet, there is intense discussion about the free availability of the scientific literature to the people who generate it so that the same question has come up in a new form with conflict between commercial and academic interests [25].

In the early 1960s commercial computers began to proliferate, although from 1945 Donald Booth had begun to develop computers for crystallography. I remember, perhaps about 1965, accompanying Bernal, who was then confined to a wheel chair, and Olga Kennard, on a visit to the Univac computer Boadicea of British Overseas Airways Corporation, which was one of the earliest commercial applications.

In the special field of crystal structures Bernal took a great part in getting the Cambridge Crystal Data Centre established and this became a model for a large number of data banks which have culminated in the data bases of DNA sequences and protein structures. Making the results of crystallography widely available was a major aspect of the International Union of Crystallography which was founded after the war and which had been a very important organisation promoting the coherence of the crystallographic community. Even today one can find big text-books discussing chemical structure but not mentioning how these structures were found.

6. The M.Sc. Degree in Crystallography at Birkbeck

The starting of an M Sc degree in crystallography was an essential step in the strategy of developing the subject.

- (i) It provided local scientific contacts between local institutions and their staff with Kathleen Lonsdale at University College and with G I Finch, H Wilman and Morris Blackman at

Imperial College. It unified electron diffraction, the Imperial College speciality [26] as a technique of crystallography, with the mainstream X-ray diffraction and electron diffraction gradually developed to electron microscopy. The earliest industrial users, GEC Hirst Research Centre and the Building Research Station, found it useful.

- (ii) It brought in students from many British institutions so that for a time the majority of British crystallographers had passed through the course. In particular it had brought students from Chile, notably Nahum Joel, who later went to work for UNESCO in Paris and who still lives there.
- (iii) Overseas students came to take the course and in due course returned to their home countries to establish training on similar lines.
- (iv) It was closely connected with the X-ray Analysis Group of the Institute of Physics which later became the British Crystallographic Association and which held annual winter meetings in London and Spring meetings in the provinces.

All this served to shape the crystallographic community as a significant movement and to prevent its absorption into departments of physics and chemistry as a technical service section. Crystallographers took on research projects which were perhaps half crystallographic and were expected to learn the other half.

7. Latin America

I have come across Bernal's account of a visit which he made to Latin America in 1962. He had been invited to a summer school at the University of Concepcion in Chile. This was on two themes, *The Image of Latin America* and the *Image of Man*. It illustrates how he worked and shows the dense network of intersecting interests and personal contacts. There were both American and Soviet representatives, in particular Robert K Merton from the USA, who talked about the statistics and conditions for simultaneous scientific discoveries, and Anatolii Zvorykin, from the Soviet Academy of Sciences, who was full of the new scientific and technological revolution and its consequences. It seems to have been an occasion where the traditional academic society of Latin America could be confronted with the modern world. He also visited the school of crystallography in Chile founded by people who had been among the earliest M Sc students at Birkbeck College. The network of former students was important.

Bernal wrote a lively account of his visit to Chile and was at the top of his form, the last good period before he began to be incapacitated by strokes and before the Cuban missile crisis of November 1962 and aggravation at Birkbeck wore him down. He analysed the political situation and met both Pablo Neruda, the poet, and Salvador Allende, later elected president, who in 1973, died in the Presidential Palace in the military coup which installed Pinochet.

It is a pleasure to see how he looks at new things and his observations might be contrasted with those of Darwin who came the same way in the 1830s. He noted:

- the state of Chile, its economy, intellectual climate, political situation as a semi-colonial country;
- the geography, climate, natural history.

With the greatest enjoyment he was taken on several excursions to the volcano, to a provincial town, to villages, to hot springs and so on. He was interested in everything and everybody.

Indeed, even at home in Britain, it was always exciting to show something new to him, not easily done, and to watch how he absorbed it, commented on it and assimilated it to his overall world picture.

Chile was, in a way, a touchstone for the development of the social sciences and the scientific and technological revolution:

- (i) The US Army and Department of Defense wanted to make a computer model: “Project Camelot is a study whose objective is to determine the feasibility of developing a general social systems model which would make it possible to predict and influence politically significant aspects of social change in developing nations of the world...” (4 December 1964). The proposal became connected with Chile, there were massive protests, including many from US social scientists, and eventually the project was cancelled.
- (ii) Later, Stafford Beer, one of the major pioneers of cybernetics, who became a close friend of Salvador Allende, became involved in the application of cybernetics to the Chilean economy. His main contribution was to set up machinery, both physical and logistic, to report the state of key economic activities directly to an operations room. Immediately after the coup d’etat of 1973 the Chicago Boys moved in and the economy was run on strict monetarist lines as a test bed for their theories.

The overthrow of the Chilean government in 1973 and the installation of the Pinochet regime, showed the ferocity of the forces which oppose certain kinds of social changes. Many documents have later become available showing the external forces operating on Chile. I mention this because science was deployed on both sides.

8. The exemplary year 1962

Let me try to recall the year 1962, now more than 40 years ago, when Bernal was at his peak. What else was he doing besides the visit to Latin America - he followed an amazing schedule.

- Aaron Klug and his group were just transferring to the MRC in Cambridge to expand what had been started at Birkbeck, the conjunction of all techniques of molecular biology and Torrington Square was reorganising.
- There were reports of “Life forms in meteorites” and John Kerridge began electron microscopy of carbonaceous chondrites, he continued this and eventually became a leading figure in the field of astrobiology in NASA. The question of life forms in meteorites is still being fought over but, as an editorial in *Nature* put it, special claims require special proof. It turns on the forms of iron oxide particles and whether they could be generated by ordinary chemical processes or whether they were characteristic of life forms. I was concerned with topotactic transformations in iron oxides. Electron microscopy was just beginning at Birkbeck after unsatisfactory attempts to use other people’s facilities. As a result of this work there is now an iron hydroxide mineral “bernalite”.
- The Bakerian Lecture (14 June 1962) on liquids was the summit of Bernal’s work on liquids. It put forward the key ideas on the structure of liquids based on his own work and the small-scale facilities available. After that from 1965, John Finney gradually took over and has made the many problems of water in all its forms his life work. The big machines, especially facilities for neutron diffraction, have been the pre-requisite for extended progress.
- The cluster with icosahedral symmetry was not altogether the simple solution to the water problem but nevertheless it was an important step which led to the extension of crystallographic ideas to quasi-crystals.
- On 29 May 1962 in a Lecture “Modern Science in Architecture”, to the Architectural Association Bernal gave a fascinating account of his ideas on housing and building materials.
- He wrote the Royal Society Obituary of William Astbury (d. 4 June 1961) who first used the term “molecular biology”, his long-term friend and colleague from the Royal Institution days, who founded the topic of fibre structure, again a generalisation of traditional crystallography.

- The 50th anniversary of the discovery of XRD was celebrated in Munich on 22–31 July 1962. JDB wrote a large section of “50 years of X-ray diffraction” which was a snapshot of what was going on in crystallography and a complete history to that date. This compilation was the work of Paul Ewald, one of the founders in 1912 of X-ray crystal structure analysis and one which enabled the crystallographic community to realise fully that it was a community.
- Bernal gave his course of lectures on History of Physics in the October term of 1962 and this became his posthumous book *“The Extension of Man”*.
- This was the year of the Cuban missile crisis (April 1961 had seen the “Bay of Pigs” invasion of Cuba). He attended a World Peace Council meeting in Stockholm in May, one in Moscow in September and another in Helsinki in October. There were many other private meetings on the peace front including a Pugwash meeting.
- There was academic struggle. A proposal within Birkbeck College to close down crystallography caused enormous concern and effort and worry. Support had to be organised from outside and contingency plans formulated. Eventually a compromise was reached. But it was an extraordinary time which coincided with the Cuban Missile Crisis. It happened that a delegation from the Azerbaijan Academy of Sciences was visiting the department, I think unaware of either crisis.
- Even in 1962 resources were scarce and Bernal wrote:

“The only time I could get my ideas translated in any way into action in the real world was in the service of war. And, although it was a war which I felt then, and still feel had to be won, its destructive character clouded and spoiled for me the pleasure of being an effective human being.” [28]
- Besides all this he had lectured in Paris on liquids; and also in East Berlin where he attended the opening of a new building for Katy Dornberger’s laboratory; he lectured in New York on various scientific topics, the origin of life, liquids, etc., one series in April and another in June and had private discussions on peace. He lectured in Groningen and Amsterdam and Accra in Ghana.

This indeed was a killing schedule and after another lecture tour in the United States in the summer of 1963 he had a stroke which began a physical decline.

“Bernal and Joliot-Curie believed passionately in the social function of science for solving the problems of mankind but, as with the early pioneers of X-rays and radium, over-exposure to the matter of their studies contributed greatly to their deaths.” [27]

9. Changes since 1962.

In the 40 years since 1962, things have changed and Bernal’s world picture would have to be drastically updated.

- (i) The Soviet Union fell to pieces and the pieces are being cannibalised by other powers and by the Russian Mafia. It remains very uncertain in what form the situation will stabilise. One factor in the fall was the arms race in which capitalism won. The world is faced with one super-power and comparisons are even made with the time of the Roman Empire. I think that people will not press this comparison too far because, at the time of the Roman Empire, there was also a similar empire in China, but with only very tenuous connections between them. The present day connections are now rather close. There is no coherent alternative to global capitalism dominated by the one superpower. Opposition begins to appear but is still fragmented. There are Green parties, the Zapatistas, environmental movements, charitable movements, feminists. Cuba hangs on.

- (ii) The popular regard for science has been seriously compromised by the association of nuclear energy with the production of plutonium. All states have been dishonest with their citizens in the rush to have nuclear weapons at the conference table.
- (iii) Science itself has become more difficult. The work necessary to get to the research front in most places has increased. This has hindered school education and particularly the supply of good science teachers. It has increased the specialisation of professional scientists. The rewards for science teachers, for academics and for scientists generally, especially counting the educational effort necessary, have not kept pace with those of financial circles.
- (iv) The social and humane and literary faculties of our universities appear to be suffering from post-modernism and anti-rationalism. There has been the entertaining counter-attack by Alan Sokal and Jean Bricmont who produced a critique, called “Intellectual Impostures”, which made them instant enemies among fashionable literary circles. There have, of course, been non-scientists, particularly the late Ernest Gellner, who have spoken out. In post-modern circles the terms Bernalism and Needham-ism have been used pejoratively. I do not think that we have cause to worry about this. Bernal and Needham wrote plainly with plenty of facts. More serious is the rise of fundamentalist religious movements which have produced extreme polarisation in many societies.
- (v) There is global climatic change and many other cases where reality, actual facts, begins to break through our synthetic superstructure.
- (vi) Political power has slipped away from nation states. On the whole nation states have become more democratic and more answerable to their citizens, but power has slipped away to less accountable bodies, multinational companies, the World Trade Organisation, the World Bank, the International Monetary Fund. As we see, from the case of Yugoslavia, nation states can fall into the hands of criminals.

10. What then is Bernal’s legacy?

- (i) Bernal’s principal legacy, of course, is the School of Crystallography at Birkbeck College. The description of the distinguished work now coming out of it would fill several lectures, since there are above a hundred full-time people. However, it is still dedicated to **shape**, the way in which the arrangements of atoms generate the manifold properties of life and its environment, and is moving steadily towards processes and systems. W. H. and W. L. Bragg had the superb vision that the microscopic world of atoms is like the world at our scale but smaller and that the ways in which atoms are arranged in space determines their macroscopic properties. Bernal extended this from minerals into the biological world.
- (ii) It is chiefly due to Bernal that the word “crystallographer” has come to have such an extended significance. It denotes someone who has much wider concerns than with crystals as such, someone who wants to know the reasons for things — the Latin tag [29] over the door of the old Cavendish Laboratory — and how they can be applied to better the human situation. There is now a coherent world crystallographic community. Crystallography is not just a service industry.
- (iii) Molecular biology has become a sector of business, industry and economics and thus is a major issue for politics, society and religions. It depends on molecular structure. Genomics is only half of the secret of life; the other half is shape and form, the environment in which the genes are switched on and off to create life. Day by day the operation of the genetic material is found to be more complicated.
- (iv) Bernal was not satisfied that this was the best of all possible worlds and was continually formulating alternatives, some perhaps Utopian. Today we urgently need to see the possible alternative forms of society and to analyse whether they may be reachable from where we are now. We must not give up our critical faculties, even if we have to keep them to ourselves

on occasion. If scientists do not concern themselves with politics then the political decisions involving the applications of science will be taken without them. It is necessary that vision and theory should fit the actual facts.

- (v) When such remarkable individuals as Bernal appear again, places must be found for them and resources made available. I doubt whether he would come out well from The Research Assessment Exercise as practiced these days.

Bernal's final message was, I think, look what science has done in the past under suitable social conditions, look what it could do in the future if people organise socially and politically to use science properly. He said, following, I think, Paul Langevin excusing his inattention to science, "*the scientific work I can do can be done, and will be done, by others, but unless the political work is done, there will be no science at all*". Scientists should make their contribution to politics. That is, the scientific community depends on society for its support, but more significantly, society, economics and human existence depend on the reality of atoms and how they are arranged and how they behave. This, I think is one of the main reasons why this twenty-first century must surely become the "Age of Reality". We will neglect reality at our peril. BSE, AIDS, Foot and Mouth, nuclear waste, genetic modifications of cabbages and kings, cloning, global warming, social chaos, are only an earnest of material problems to come.

Bernal liked diagrams like the tree, the network and the matrix. The visual tree diagram was invented by Ramon Llull in the thirteenth century and has continued as a valuable tool of thought [30]. "I see" means "I understand" and it goes straight into the brain which has evolved from living with trees. Crystallographers now use their genetic familiarity with trees for understanding the spatial complexities of protein molecules. The tree diagram summarised what Bernal liked to quote from Francis Bacon, who wrote in the New Atlantis, a vision of what became the Royal Society:

"The End of our Foundation is the knowledge of Causes, and the secret motions of things; and the enlarging of the bounds of Human Empire, to the effecting of all things possible."

"The Freedom of Necessity" was the title of Bernal's collection of essays published in 1949. We must recognise the limitations of the situation, how things are structured, what might be changed and what is fixed.

The branching of a tree can illustrate, besides how we arrived at where we are, also where we can get to and what is just not reachable from here. It enables us to choose. Bernal with his vision set out many possibilities and constraints for choice. "*Where there is no vision the people perish.*" [31]

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