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Excerpt
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The scientific background

The growth of space science in the United Kingdom naturally depended very much on the scientific and technological background in the country in the years just after the Second World War. It was a fortunate fact that, by 1953, while there were a number of scientists whose research work would be greatly expanded if space research techniques became available, technological progress through defence requirements had proceeded to a stage where it could be utilized successfully. Once these possibilities became apparent to the scientists and arrangements made so that they could be realized, space science developed rapidly. The story of the way this occurred, involving many fortuitous circumstances, and of how British space science has developed to the time of writing, forms the subject matter of this account.

1 Ionospheric research in Britain

We begin by describing the scientific and technological background, the former in this chapter and the latter in the following chapter. Perhaps the most important early scientific discoveries in the present context were those of the E region of the ionosphere made by E.V. Appleton and M.A.F. Barnett in 1925 and the F region by Appleton in 1927. These confirmed the speculation of Kennelly and Heaviside that an ionized region in the high atmosphere was responsible for the long-distance transmission of radio waves demonstrated by Marconi. Appleton enthusiastically expanded this work to study the properties of the ionosphere and soon there was a vigorous school of British scientists interested in research in this subject. The discovery of the ionosphere was important not only for radio transmission but also for geomagnetism, of which the leading exponent at the time was S. Chapman then Professor of Mathematics at Imperial College London. He took an immediate interest in the ionosphere and in the earth's atmosphere generally and soon became the leading authority on the subject.

In the present context these developments are of special importance because they were concerned with the earth's atmosphere at altitudes far above those accessible by balloon. Thus the lowest layer of the ionosphere useful for radio transmission, the E region, is at an altitude of 100–120 km and the main, F_2, region extends upwards from 200 km or more. The maximum height which could be reached by balloon was about 32 km. While astronomers are used to observing regions which are permanently inaccessible, the ionosphere seemed to be tantalizingly just out of reach.

The fact that the ionosphere is subject to solar control was established at an early stage. Atmospheric ionization could be produced both by solar electromagnetic and corpuscular radiation. It was some time before it was established from eclipse observations that the ionizing agents responsible for the normal mid-latitude ionosphere travelled with the speed of light and hence must be solar ultra-violet or X-radiation. At higher latitudes, on the other hand, solar particles contribute to the ionization under conditions of great variability. It soon became clear that, for a proper understanding of the ionosphere, it would be necessary to know the intensity and spectral distribution of solar ultra-violet and X-radiation. Since this radiation is absorbed in the atmosphere at ionospheric heights in ionizing atmospheric atoms and molecules, no information could be obtained from ground-based or balloon observations. To attempt any theoretical discussion of the formation of the ionospheric layers before the days of space research it was necessary to make crude assumptions about the sun as a black-body radiator in the far ultra-violet.

It is obvious also that knowledge of the pressure, density, temperature and composition of the atmosphere is required as a function of altitude. Very slender information was available in pre-rocket days about these quantities at ionospheric altitudes.

Figure 1.1 shows a schematic representation of the ionosphere in which the regions where the electron concentration could be measured by contemporary ground-based sounding methods are distinguished from those which are inaccessible in this way. Even for this basic quantity it will be seen that ground-based sounding could only give a partial picture. It was not for many years (the 1960s) that the introduction of radar scatter techniques extended greatly the range of ground-based methods.

The problems of ionospheric theory were compounded by the need for knowledge of a wide variety of rates of reaction between electrons, atmospheric ions and neutral atmospheric atoms and molecules. In particular, the key question of determining the concentration n_e of electrons in the ionosphere at a particular altitude can be expressed in terms of the equation

$$\frac{dn_e}{dt} = q - \alpha\, n_e^2$$

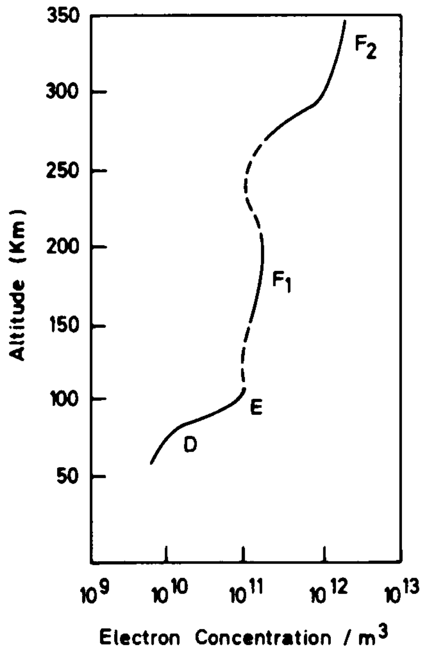
where q is the rate of electron production by solar radiation at the altitude concerned and α is the effective coefficient for recombination of electrons and positive ions. In equilibrium

$$n_e = (q/\alpha)^{\frac{1}{2}}$$

Values for n_e could be derived from ground-based ionospheric observations. The interpretation of these results presented a major theoretical problem.

Despite the daunting lack of precise information about the solar ionizing radiation, the atmospheric structure at high altitudes and the rates of key ionic reactions, ionospheric workers in Britain began to tackle the wide-ranging problems involved. They included, in addition to Appleton and Chapman, J.A. Ratcliffe, W.G. Beynon and K. Weekes. In 1936, following

Fig. 1.1. Schematic representation of the electron concentration with altitude in the atmosphere under average conditions.
—— obtained directly from contemporary ground-based sounding.
- - - interpolated.



some leading suggestions by D.F. Martyn, the first attempt was made by H.S.W. Massey to formulate an atomic theory of the ionosphere. This was devoted particularly towards the determination of the effective recombination coefficient, a subject which was followed up in succeeding papers. The problem proved very difficult, but already by 1947 D.R. Bates and Massey proposed that the basic process is one of dissociative recombination, as for example,

$$O_2^+ + e \rightarrow O' + O''.$$

This can only occur with molecular ions so that the effective recombination coefficient would depend on the fraction of molecular ions present. On this basis a consistent description of the variation of n_e with height in the ionosphere could be given but at the time could not be confirmed, partly through lack of knowledge of the reaction rates and partly through an equally profound ignorance of the molecular composition at ionospheric altitudes.

The reason for the layered structure of the ionosphere presented a baffling problem because of complete lack of knowledge of the short-wave solar spectrum. The high temperature of the solar corona was discovered in 1939 but attempts to link it with formation of one or more of the layers proved inconclusive.

It is no wonder that the possibility of direct observation of the solar ultraviolet and X-radiation, and of atmospheric structure, from rocket-propelled vehicles was a matter of great interest to those concerned with ionospheric research in Britain. This was especially so for those who were attempting to construct an ionospheric model at the atomic level. Some of these scientists played a considerable part in the war effort during which they became familiar with the existing methods of propulsion and deduced, by a little simple arithmetic, that while not yet adequate these methods would seem not so far short of being able to reach the ionosphere. The appearance of the V2 rocket showed at once that much could indeed be done to provide means of making *in situ* measurements at ionospheric altitudes. Nevertheless, much was to happen before these hopes were realized for British scientists; and in these developments ionospheric physicists played a leading role as we shall see.

2 The Gassiot Committee of the Royal Society and atmospheric research

Remarkably enough, the first steps taken which led to the establishment of a scientific programme of research in atmospheric physics using rocket propelled vehicles were taken during the Second World War. In 1941 the Meteorological Research Committee of the Air Ministry recommended that the Royal Society be asked to mount a programme of research in meteorology on a wider basis than hitherto, dealing in particular with the conditions of radiative equilibrium in the earth's atmosphere. The Air Ministry, in the very middle of the war, accepted this recommendation. A letter was sent to the Secretary of the Royal Society on behalf of the Air Council, enquiring whether the Society would be prepared to undertake this task.

The Royal Society referred the matter to its Gassiot Committee for consideration. This committee was set up as long ago as 1871 to supervise the management of the Kew Observatory when this responsibility was taken over by the Royal Society from the British Association for the Advancement of Science. The name of Gassiot was associated with it because Gassiot who, while an FRS through his contribution to experimental electrical science,[1] was also a wealthy wine merchant, had made possible the transfer to the Royal Society by establishing a trust fund of £10,000 to be used for the operation of the Observatory. He was naturally the first chairman of the committee which in the course of time became the Royal Society committee dealing with meteorological research.

In 1942 its terms of reference were as follows: 'To recommend as to the work of the meteorological and magnetic observatories with which the Society is connected and to administer the Gassiot and other trust funds applicable to their maintenance.' A further reference to Indian observatories was included which need not detain us here. G.M.B. Dobson was the chairman and apart from the ex officio members (the Astronomer Royal, the President of the Royal Astronomical Society and the Director of the Meteorological Office) the members were Sir Edward Appleton, D. Brunt, S. Chapman, A.E.G. Egerton, Sir Henry Lyons, Sir George Simpson, G.I. Taylor and Sir Gilbert Walker.

The Committee recommended that the proposal from the Air Ministry be accepted and the Council of the Royal Society then agreed in principle, pending a more detailed report. This was submitted on 8 March 1943. The chief problems to be investigated were summarized as the following.

(a) What gases are of primary importance in determining the radiation balance?
(b) What are the concentrations of different species at different altitudes?
(c) What are the absorption coefficients of different wavelengths of electromagnetic radiation under atmospheric conditions?

(d) What photochemical reactions lead to ozone formation in the atmosphere?
(e) What is the solar spectrum for wavelengths < 3000 Å?

The report was published in the Report of Progress in Physics in 1943.

2.1 The sub-committees of the Gassiot Committee

To implement the programme it was proposed that three sub-committees of the Gassiot Committee be set up. The first, Sub-committee A, was concerned with atmospheric composition, B with photochemistry of the atmosphere, and C with atmospheric temperature and radiation. Dobson, Massey and T.G. Gowling were named as the respective chairmen.

During wartime these sub-committees did not function at all regularly as many of the members were engaged in war work of some kind. However, soon after the war ended they became very active. From the present point of view, it was Sub-committee B which was most concerned with the possibility of *in situ* observations in the high atmosphere from rocket vehicles. Already at a meeting of the Sub-committee in 1946, A. Hunter had drawn attention to the possibility of observing short wave solar radiation in this way and at the same meeting the following recommendation was made. 'Contact should be made with departments developing rockets with a view to designing apparatus to be carried up by rockets and to measure the solar spectrum at heights above the absorbing atmosphere.' Bates, who had become chairman of the Sub-committee at the end of 1946, spent nine months in the USA in 1950. During this period he was in contact with developments there in the use of sounding rockets and suggested the possibility of seeding the high atmosphere with sodium evaporated from a rocket to produce a strong yellow glow in the sky – the first suggestion of an active experiment from a rocket (see Chapter 3, p. 30). It was not at all clear to the scientists of the Gassiot Committee and sub-committees in 1946 and for several subsequent years how the Sub-committee B recommendation could be implemented. Work on rocket development concerned with military applications was known to be going on vigorously in government establishments but security was so strict that little was known about what possibilities existed for the use of military rockets for scientific purposes.

3 The American Upper Atmosphere Research Panel

Meanwhile, important developments[2] had been taking place in the United States arising again through interest in the exploration of the upper atmosphere. It happened that, about the same time as a number of scientists and engineers at the Communications Security Section of the Naval

Research Laboratory in Washington were deciding in favour of rocket exploration of the upper atmosphere as a post-war research programme in which to engage, the United States Army offered space for such experiments in captured V2 rockets which were to be launched from the White Sands Proving Ground in New Mexico. As the rockets, of necessity, had to be launched nearly vertically for safety reasons, this was an excellent opportunity to introduce the research programme without delay. The interested scientists spontaneously formed in early 1946 a panel known at first as the V-2 Upper Atmosphere Research Panel, under the initial chairmanship of E.H. Krause who was succeeded in that post by J.A. van Allen in 1947.

While having no formal charter the Panel played from the outset a very influential role in the development of space science. Under its auspices the basis for a very sound and extensive research programme was established. By 1952 when all the V-2s had been used up, much information had already been obtained about the upper atmosphere, the solar radiation and cosmic rays. Well before this time a rocket to take over from the V-2, known as the Aerobee, was successfully developed locally and was in full operation. In 1948 the panel had assumed the title of Upper Atmosphere Rocket Research Panel.

We shall say more about the American rocket programme in Chapter 3. Here we are concerned with the part it played in bringing together the British scientists anxious to explore the upper atmosphere with instruments transported by rocket and the British rocket engineers who could provide the vehicles.

4 Proposal for a conference on rocket exploration of the upper air

The breakthrough came from a proposal by Chapman in 1951, that the Gassiot Committee invite the American Upper Atmosphere Rocket Research Panel to take part in a conference on rocket exploration of the upper air to be organized by the Committee in Britain. Chapman, by this time, had been in close touch with the Panel and had discussed the proposal with them. The Committee had no hesitation in accepting the proposal. In 1951 Massey had become Chairman of the Gassiot Committee in succession to Brunt who had become Physical Secretary of the Royal Society in 1948. A sub-committee to organize the Conference was set up consisting of Massey as Chairman with Chapman, W.S. Normand and F.A. Paneth.

In the event the Conference took place in 1953 at Oxford. In the course of preparation for the Conference, contact was established with work going on in the Ministry of Supply which proved to be very appropriate and at such a stage of development as to be very adaptable to sounding rocket research. However, before describing in Chapter 3 the sequence of events which led directly to the establishment of a sounding rocket programme we shall pause to describe in Chapter 2 what had been going on in rocket development and associated matters in the Ministry of Supply.

It is of interest to note in passing that the Gassiot Committee in 1952 made a grant to Paneth of £2000 to enable him to analyse samples of stratospheric air obtained from rockets, in collaboration with the Engineering Research Institute of the University of Michigan, the first example of Anglo–American collaboration in sounding rocket studies!

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The technological background

The background of technology which was available in Britain in the mid-1950s and which was relevant, indeed was essential, for the development of a significant UK space science programme in the succeeding years, was generated largely during and shortly after the Second World War. Rocket technology was at the heart of the matter, and this had a long history at least back to the Chinese of the 13th century. We have no technical details of the rocket weapons used by the Chinese although it is reasonable to assume that the basic ingredient was black gunpowder.[1] Rockets were used intermittently in Europe either as weapons or in firework displays throughout the 16th, 17th and 18th centuries, although there appears to have been no systematic development of the techniques used.

One of the first major engagements in which Europeans were subjected to rocket attacks occurred during the invasion of the Indian state of Mysore by British forces under Wellesley (later the Duke of Wellington). In 1799 enemy rockets from the forces of Tipoo Sultan fell on the British encampment outside Seringapatam. Perhaps it was this first-hand experience which stimulated the British to take serious steps themselves in the development of rockets. At the Royal Laboratory of Woolwich Arsenal, Colonel (later Sir William) Congreve developed a 32 lb rocket with a range of 2000 to 3000 yards. Many thousands of these were produced, but without conspicuous military success. For instance, in the war of 1812 between Britain and the USA, Baltimore was bombarded by British rockets, and in the Peninsular war, Congreve rockets were given at least two trials by Wellington. In the second of these, in 1813 against cavalry, Wellington reported that 'they would have scared the horses stiff if only they had gone near them.'[2] The Congreve rockets were stabilized by a 15 foot long stick, which must have posed problems in handling on the battle field. However, in the second half of the nineteenth century, an English inventor named William Hale developed and patented a method of spin stabilization, which was a significant advance in design. In the same period, Lt. Col. R.A. Boxer, a British officer at the Royal Laboratory, Woolwich, developed a two-stage tandem rocket, giving the possibility of much longer ranges.[3] Despite these improvements, only limited use was made of rockets in the period up to the end of the First World War. This was possibly due to the problems caused by propellant instability in storage, and to the superior accuracy, for military purposes, of conventional artillery.

It was the perseverance and enthusiasm of mainly non-government groups and individuals which led to the development by government agencies of the modern reliable and efficient rocket motor, the key to all operations in space. The theoretical studies of Tsiolkovsky in Russia and Oberth in Germany, and the experimental work of Goddard in the USA were pre-eminent in the years before 1939. In Britain, the subject was comparatively dormant until the War Office, in 1934, began to take serious notice of the activities of the German military authorities, who were embarking on an extensive rocket research and development programme. In 1935 the Research Department of Woolwich Arsenal was asked to propose a development programme for military rockets using cordite as the propellant. From 1936 onwards, Sir Alwyn Crow was in general control of an intensive programme which included studies of long-range (900-mile) rockets.[4] These might have been relevant to the design of vertical sounding rockets, but in the event the threat of war caused all efforts to be concentrated on the more pressing problems of rockets for anti-aircraft defence. For the immediate purposes of the war, only solid fuel propellant systems were considered, for reasons of logistics and economy, although some effort was devoted to liquid fuel systems on a longer term basis. Much technical progress was to be made on the design of solid fuel rockets with diameters of 2, 3 and 5 inches. Difficult problems relating to propellant burning rates, the ratio of propellant weight to overall weight, the manufacture of sufficiently accurate steel tubing and the stability of performance at extremes of temperature, were all mastered. The foundations were laid for the post-war development of propulsion systems for guided weapons, for upper atmosphere research rockets, and for satellite launching rockets. The wartime rockets were used almost exclusively for the carriage of explosive warheads but some experience was also gained in the carriage of relatively fragile items such as specially rugged thermionic valves and photo-cells. Advances in rocket technology during the war years may have been the most directly relevant contribution to the future space