collected works of Meghnad Saha 1

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Edited by
SANTIMAY CHATTERJEE

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PREFACE

The *Collected Scientific Papers* of Meghnad Saha was published in 1969 with financial assistance from the Council of Scientific and Industrial Research. Collection of his other writings written for the lay public proved to be a more formidable task. This has now become possible under a grant-in-aid from the Department of Science and Technology, Government of India, to the Saha Institute of Nuclear Physics, Calcutta.

Saha came from a village in the backwaters of East Bengal. He had to trudge miles through mud to get to school. All these impressions shaped his outlook on life. Later he met his mentor in Acharya Prafulla Chandra Roy and shared his conviction for the betterment of human conditions by the application of science. Floods used to be a common occurrence in those days. As a student volunteer he had accompanied the Acharya on many relief operations. Thus many of the activities he took up later were the results of his exposures to the human suffering he had seen in his early days. He wrote about the social problems that bothered him in journals like *Calcutta Review*, *Modern Review*, and so on. A number of Saha's articles appeared in prestigious Bengali monthlies such as *Prabasi*, *Bharatbarsha*, *Prokriti* and *Basumati*. His writings covered a wide spectrum of subjects, with science and its impact being the main theme. His series on science versus religion provoked fierce controversy at one time. A selection of these articles has been published in *Meghnad Rachana Sankalan*.

In 1933 the Indian Science News Association was formed at Calcutta and the monthly journal *Science and Culture* started. Saha was then at Allahabad but he was the driving force in its founding. Saha wrote profusely in the pages of *Science and Culture* voicing his opinion on a variety of subjects—social implication of science, economic planning, establishment of scientific, technological institutions, planning of the Indian rivers, reform of the calendar. These and other articles and speeches published elsewhere have been put together in this and the forthcoming volumes bringing it to a total of 188 entries. The articles are arranged subjectwise in a chronological order.

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6.1 Humanism and Science
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The present volume which is the first in the series contains articles on scientific topics. It starts with a short biography of Saha by Professor Daulat Singh Kothari reprinted from the *Biographical Memoirs of the Fellows of the Royal Society of London*. We acknowledge our indebtedness to Professor D. S. Kothari and the Royal Society of London for granting permission to reprint the articles. In the Section 1.1—Astronomy and Astrophysics, the first entry is from the *Statesman* of November 13, 1919. The occasion was a news item in the same newspaper that "an announcement has been made at the Royal Society, which is described by the press as overthrowing the certainty of the ages and requiring a new philosophy of the universe.." Actually during the total solar eclipse of 29th May, 1919 Sir Arthur Eddington leading a group of British scientists had observed the two stars which are always in the shadow of the sun's disc and as such should not be visible. This was because light rays from the stars were attracted by the sun's gravitational field as predicted by Einstein's General Theory of Relativity. In a meeting of the Royal Society the Astronomer Royal Sir Frank Dyson finally accepted the result and thus the General Theory of Relativity mathematically deduced by Einstein was proved and accepted. A correspondent from *The Statesman* came to the Science College campus to find out if somebody would enlighten him in the matter. He was told to contact Mr. Meghnad Saha, because Saha was then translating Einstein's Special Theory of Relativity into English. The correspondent found Saha in the astronomical observatory of the Presidency College. Saha promptly wrote an explanation which was published in the same newspaper the following day.

The second entry originally published in the *Calcutta Review* in 1922 is on the total solar eclipse which was due on 21st September, 1922 and was visible only in Southern India. In this article he has explained also how from observations of positions of stars one obtains conclusive proof on the validity of the General Theory of Relativity. But he makes a special appeal to astronomers and astrophysicists that in addition to verifying the predictions of the General Theory of Relativity the optical spectra of the solar chromosphere and solar corona should also be specially studied during totality because that will test many his predictions made on the basis of his theory of thermal ionisation.

The third entry is Saha's address at the 13th Indian Science Congress (Bombay, 1926) as President of the Physics and Mathematics Section. He spoke on the application of his own theory in the understanding of many astrophysical phenomena which were not understood earlier. Saha's "Plea for an Astronomical Observatory at Benaras" was a tribute paid to Pandit Madan Mohan Malaviya in his 70th birthday volume. "Fundamental Cosmological Problems", was the scientific part of Saha's address as the General President of 21st Indian Science Congress held again at Bombay. The two appendics—"On the Need of a River Physics Laboratory" and "On the Formation of a National Academy of Science —are included in Volume 2 and Volume 3 respectively. "Solar Control of the Atmosphere" was Saha's presidential address at the annual meeting of the National Institute of Science at Lahore in 1939. The last entry in this section is Saha's report on the 9th International Astronomical Union held at Dublin in 1955, which he attended.

In Section 1.2 on Spectroscopy, the first article "Dissociation Equilibrium" is being reprinted from the "*Life and Work of Sir Norman Lockyer*," edited by Lady Lockyer and Miss Winifred L.

Lockyer. We are grateful to Macmillan London and Basingstoke, the publishers, for granting permission to reprint the article. In this article Professor Saha has paid his tributes to Sir Norman Lockyer whom he considered as one of the pioneers in modern astrophysics. Unfortunately, Sir Lockyer could not fit in his observations of the Solar and the Stellar Spectra with the spectra of known elements in accordance with any rule known at that time. Consequently, he felt obliged to introduce new forms of elements and concepts which were not found satisfactory. In fact Sir Lockyer died of a broken-heart because none of his theories was accepted in his lifetime. In explaining the spectra of stars Saha showed that the successive ionisation of the same element can be related to Lockyer's dissociation hypothesis. Lady Lockyer had thanked Saha profusely for restoring the lost honour which her husband was denied in his lifetime.

The second entry in this section is a series of six lectures in atomic physics delivered at the Patna University in 1927. The monograph was printed in 1931, but is no longer available. During the period 1923-30, Professor Saha and his students at Allahabad worked on the Theory of Complex Spectra of Elements. These lectures will serve as a historical background to the subject.

"Spectroscopy in the Services of Chemistry" was published by the Indian Chemical Society in 1933 in commemoration of Acharyya Prafulla Chandra Ray's 70th birthday. As the title explains, it contains the various works done by Saha and his students at Allahabad on the Application of Spectroscopy for studying various chemical phenomena.

The Section 1.3 of Nuclear Physics, Cosmic Rays and Nuclear Energy includes 19 articles written during the period 1935 to 1955. Saha's interest in nuclear physics started with the discovery of neutron in 1932. On the occasion of the opening of the Institute of Nuclear Physics in 1951 Saha referred to this—"While at Allahabad myself and a brilliant student of mine, Dr. D. S. Kothari, were discussing in 1932 Chadwick's discovery of the neutron and had come to the conclusion that neutrons could be smuggled more easily into the nucleus of the atom than the proton or the alpha particle and thus it will be possible to induce nuclear reactions in all atoms. We needed a small quantity of radium for the work we planned. While we were still trying to find out some prospective donor for gift of 1 g of radium, the work of Fermi on neutron induced reactions, which were carried out with the aid of about a gram of radium lent to him by the Italian Government, came out. I think many of our brother scientists in India had the same experience, at one or other epoch of their life."

The first entry in this section is an article on the Constituent Elements of Matter published in 1935 in *Science and Culture*. The gradual drift of his interest in nuclear physics and later nuclear energy is evident as one goes through the subsequent papers.

Saha was very excited when uranium fission was discovered and could foresee great changes ahead. As a member of the Indian Scientific Mission Saha visited the UK and the USA in October 1944 where war-time research was going on in full swing. "The Story of the Atomic Bomb," written jointly with B. D. Nag Chaudhuri appeared in *Science and Culture* a few months after the Hiroshima explosion. We thank Professor B. D. Nag Chaudhuri for his permission to reprint the article. The article on Britain's part in evolution of the atomic bomb was very informative considering the time of its publication. Saha was a great supporter of development of nuclear power particularly in India. He was a member of the Atomic Energy Committee of the Government of India (1946-48), but was not a member of the Atomic Energy Commission which was subsequently formed. He initiated a debate on the "Peaceful Uses of Atomic Energy" in the Lok Sabha in 1954. The text of the opening speech is reproduced here from the proceedings of the Lok Sabha. The entire debate was very interesting. Saha advocated that secrecy be removed from all atomic energy research work. He also advocated that President Eisenhower's proposal placed at the UN in December 1953 be accepted. Prime Minister Nehru, who was as great a champion of nuclear energy as Saha, presented his point of view which can serve as a model of political foresight. While Nehru recognised that for rapid industrial growth India had no way but to develop nuclear power, he could distinguish two clear-cut divisions in the world—between what has later come to be known as the developed and the developing nations. For the developed countries nuclear energy is just an additional source of power. But for a poor, power starved country like India, it means survival. In his words, "it may be to the advantage of the countries who have adequate power resources to restrain and restrict the use of atomic energy because they do not want that power. It would be to the disadvantage of a country like India if that is restricted or stopped." Another point which Nehru objected to was the question of control. It was suggested that an international body independent of the UN be set up but Nehru explained the loopholes. The proposed body which would have an unlimited right of inspection thus virtually becomes a super state body and tremendous power would be concentrated in their hands. No independent country could jeopardise her freedom by agreeing to be inspected and ordered by such a body. This parliament debate has now become historic in perspective. It throws into focus the basic difference between a scientist who was forced to enter politics and a politician who had the vision of a scientist.

I record my deep appreciation for the help and support given to me by Professor Ajit Kumar Saha in the compilation work. I am grateful to Dr. Atma Ram for encouragement and support at the initial stages of the work. I acknowledge the services rendered by Professor D. N. Kundu, the then Director and Professor A. P. Patro, the present officiating Director of the Saha Institute of Nuclear Physics. I also thank my wife Enakshi for her ungrudging help without which I could not have completed the work.

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MEGHNAD SAHA

THE name of Professor MEGHNAD SAHA would always remain associated with the theory of thermal ionization and its application to the interpretation of stellar spectra in terms of the physical conditions prevailing in the stellar atmospheres. The theory had all the simplicity and inevitableness which usually characterize a fundamental and epochal contribution. It was almost a direct consequence of the recognition that the laws of thermodynamics and the kinetic theory of gases can be extended to a gas of free electrons. Apart from astrophysics, the theory later found numerous other important applications, such as, to mention some of them, in the study of the ionosphere, conductivity of flames, electric arcs and explosion phenomena. Saha's researches in astrophysics and physics extended over a wide range of subjects. At one time or the other he worked on stellar spectra, thermal ionization, selective radiation pressure, spectroscopy, molecular dissociation, propagation of radio waves in the ionosphere, solar corona, radio emission from the sun, beta radioactivity, and the age of the rocks. Besides physics he took a keen interest, at times almost bordering on the professional, in ancient history and archaeology. He was a devoted and inspiring teacher, and he gave his time generously to his students. He organized active schools of research at Allahabad and Calcutta; and in establishing the Institute of Nuclear Physics at Calcutta, in building the laboratories of the Indian Association for the Cultivation of Science, and in founding academies of sciences in India, his role throughout was of the utmost importance. He, more than anyone else, was responsible in starting the monthly journal *Science and Culture*, and he was its editor for many years. He was from the beginning a member of the Council of Scientific and Industrial Research constituted by the Indian Government in 1942, and member (or chairman) of several of the research and other committees of the Council. He was the Chairman of the Council's Indian Calendar Reform Committee. He was an elected independent member of the Indian Parliament. He took the keenest interest in problems of national planning, particularly in relation to science and industry. He was an active member of the National Planning Committee appointed by the Indian National Congress in 1938 with

Jawaharlal Nehru as chairman. In his criticism of things and men, Saha was fearless and trenchant, and he was motivated by a deep earnestness and sincerity, though often tenaciously, held convictions. His memory and versatility were amazing. He was extremely simple, almost austere, in his habits and personal needs. Outwardly, he sometimes gave the impression of being remote, matter of fact, and even harsh, but once the outer shell was broken, one invariably found in him a person of extreme warmth, deep humanity, sympathy and understanding; and though almost altogether unmindful of his own personal comforts, he was extremely solicitous in the case of others. It was not in his nature to placate others. He was a man of undaunted spirit, resolute determination, untiring energy and dedication. On 16 February 1956, on his way to the Office of the Planning Commission in New Delhi, he succumbed to a sudden heart-attack (some hundred yards from the Office of the Commission) and at the age of sixty-two, a career superb in science and great in its promotion and dissemination was tragically closed.

Meghnad Saha was born on 6 October 1893, in the village of Seoratali in the district of Dacca, now in Bangla Desh. He was the fifth child of his parents, Jagannath Saha and Sm. Bhubaneswari Devi, who had five sons and three daughters. The family depended for its livelihood on the very meagre income from a petty shop-keeping business, and Saha's early education was beset with many hardships. In the village at that time there was no high school. Even the nearest middle school teaching English was in another village seven miles away, and Saha was able to join it due to the generosity of a local medical practitioner, Ananta Kumar Das, who agreed to provide him with free board and lodging in his house. In 1905 Saha joined the Government Collegiate School in Dacca after securing a Government scholarship for standing first, at the middle school examination, in the Dacca district. This was the year of great political unrest in Bengal caused by the partition of the province against popular opinion, and the school also was not without its share of trouble. The young Saha was drawn into a boycott of the visit of the Bengal Governor to his school, and as a sequel he forfeited the scholarship, and had to leave the Government School with many others. He now joined a private school—the Kishori Lal Jubilee School—and passed the Entrance Examination of the Calcutta University in 1909, standing first amongst the East Bengal candidates. He was a precocious student, and he was equally good in mathematics and the languages. He stood first in the all-Bengal competition examination in the Bible, open to school and college students, conducted by the Baptist Mission. In 1911 Saha passed from the Dacca College, Dacca, the Intermediate Science Examination of Calcutta University. He was first in mathematics and chemistry, but third in order of merit in the whole examination. One of his subjects at the examination was the German language which he studied privately—the college had no arrangement for its teaching.

Saha now entered the Presidency College, Calcutta. Here he had amongst his contemporaries many who are familiar names in Indian Science, such as S. N. Bose (the author of the quantum statistics that goes by his name), N. R. Sen, J. N. Mukherjee and the late J. C. Ghosh. P. C. Mahalanobis, the distinguished statistician and planning expert, was his senior by a year; N. R. Dhar was senior by two years. Amongst his teachers Saha had *Acharya* P. C. Ray in chemistry, Jagadish Chandra Bose in physics, and D. N. Mallik and C. E. Cullis in mathematics. Both in the B.Sc. Examination (1913) with Honours in Mathematics and the M.Sc. (Applied Mathematics) Examination (1915), Saha had the second place, the first position going to S. N. Bose. He intended at one time to take the competitive examination for the Indian Finance Service, but was not granted permission by the Government. He resolved to devote himself to study and research in applied mathematics and physics. To support himself and his younger brother staying with him, he for a few months took to private tuitions of which at one time he was doing as many as three in different parts of Calcutta, covering the long distances on a bicycle. In 1916 the Calcutta University under the dynamic leadership of its Vice-Chancellor Asutosh Mukerjee, a Judge of the High Court, opened a new University College of Science for post-graduate studies and research—this was made possible because of the magnificent donations of two eminent lawyers of Calcutta, Tarak Nath Palit and Rash Behari Ghosh. Saha and S. N. Bose were appointed lecturers in the Department of Mathematics with Dr Ganesh Prasad as Professor. He, however, found it irksome to get on with the Professor of Mathematics, and in 1917 he (with S. N. Bose) was transferred to the Department of Physics. About a year later C. V. Raman joined the Department as Palit Professor of Physics.

Saha's early lectures to the post-graduate classes covered diverse subjects such as hydrostatics, the figure of the earth, spectroscopy, and thermodynamics; and he was in charge of the Heat Laboratory.

Many of the subjects were new to him—he had taken physics in the undergraduate classes only—but this only served to stimulate his dauntless spirit all the more, and he studied the new subjects, specially thermodynamics and spectroscopy, with great avidity and zest. It was fortunate, as he often recalled in later life, that about a year earlier he had come across Miss Agnes Clarke's two popular books on the sun and the stars. These books fascinated him greatly and gave him some idea of the main problems in astrophysics. He now read, amongst other books, Planck's *Thermodynamics* and Nernst's *Das Neue Warmesätz*, and he was familiar with the papers of Bohr and also Sommerfeld on the quantum theory of the atom. All this in a sense paved the way for his epochal work on the thermal ionization of elements. More will be said about this presently.

Shortly after the end of the First World War there was announced the momentous discovery of the deflexion of starlight by the gravitational field of the sun, confirming Einstein's theory of general relativity. Saha got deeply interested in the relativity theory. He, jointly with S. N. Bose, prepared an English translation of Einstein's papers, later published in the form of a book by the University of Calcutta. The study of relativity led Saha to some investigations in electromagnetic theory and his first original paper entitled 'On Maxwell's stresses' appeared in the *Philosophical Magazine* in 1917. This was followed by papers on the dynamics of the electron. He derived, on the basis of the special theory of relativity, the Lienard-Wiechert potential due to a point-charge. During these years he also worked on radiation pressure, and in 1918 (with S. Chakravorti) he published in the *Journal of the Royal Asiatic Society of Bengal* (Calcutta) a paper on the measurement of the pressure of light, using a resonance method. Though Saha had little real skill or aptitude for practical work, he always took the keenest interest in and gave every encouragement to experimental work going on in his laboratory, and often suggested fruitful problems for investigation. He held that in a progressive department of physics, research should be vigorously pursued in both theory and experiment, and a high place given to serious and good teaching. Saha's first work in astrophysics, and it was a very important one, was the formulation of the concept of *selective radiation pressure*, and the recognition of its role in the relative distribution of the elements in the solar atmosphere. (He had read in Agnes Clarke's book about the 'hypothetical levitative force' which apparently acted on atoms of some elements only.

e.g. calcium.) A short note 'On radiation pressure and the quantum theory' appeared in the *Astrophysical Journal* in 1919. A detailed paper communicated to the same journal was for some reasons—partly the length of the paper—not accepted for publication, and it was published in the relatively little-known *Journal of the Department of Science, Calcutta University*. Saha did not pursue the subject of selective radiation pressure further. It was raised to an entirely new level by E. A. Milne. In 1918 on the basis of his work in the field of electromagnetic theory and radiation pressure, Saha was awarded the D.Sc. degree of the Calcutta University. His examiners were O. W. Richardson, N. R. Campbell and Porter.

Saha's greatest contribution is, undoubtedly, the theory of high-temperature ionization and its application to stellar atmospheres. The equation that goes by his name was first given in the paper 'On ionization in the solar chromosphere', published in the *Philosophical Magazine* for October 1920. Using the language of physical chemistry he called it the 'equation of the reaction-isobar for ionization'. Discussing the case of the ionization of calcium, he wrote:

'We may regard the ionization of calcium atom as taking place according to the following scheme, familiar in physical chemistry,

$$\mathrm{Ca} \rightleftharpoons \mathrm{Ca}_{+} + e - U$$

where Ca is the normal atom of calcium (in the vapour state), Ca_{+} is an atom which has lost one electron, U is the quantity of energy liberated in the process. The quantity considered, is 1 g atom . . . To calculate the "Reaction-isobar" K, let us assume that P is the total pressure, and a fraction x of the Ca-atom is ionized.

Then we have

$$\log K = \log \frac{x^2}{1-x^2}\, P = -\frac{U}{4{\cdot}571\, T} + 2{\cdot}5 \log T - 6{\cdot}5$$

This is the equation of the "reaction-isobar" which is throughout employed for calculating the "electron-affinity" of the ionized atom.' The value 6·5 in the above expression is the value of the chemical constant obtained from the Sackur-Tetrode-Stern relation.

It is pertinent to remark that the ionization theory was formulated by Saha, working by himself in Calcutta, and the paper quoted above was communicated by him from Calcutta to the *Philosophical Magazine*—incorrectly, statements to the contrary have sometimes been made. (Saha's first visit to Europe was made a couple of months later.) Further papers soon followed. It is not too much to say that the theory of thermal ionization introduced a new epoch in astrophysics by providing for the first time, on the basis of simple thermodynamic considerations and elementary concepts of the quantum theory, a straightforward interpretation of the different classes of stellar spectra in terms of the physical conditions (temperature and to a lesser extent pressure) prevailing in the stellar atmospheres. S. Rosseland in the Introduction to his well-known *Theoretical astrophysics* (Oxford University Press. 1936) has observed: 'Although Bohr must thus be considered the pioneer in the field, it was the Indian physicist Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory. Saha's work is in fact the theoretical formulation of Lockyer's view along modern lines, and from that time the idea that the spectral sequence indicates a progressive transmutation of the elements has been definitely abandoned. From that time dates the hope that a thorough analysis of stellar spectra will afford complete information about the state of the stellar atmospheres, not only as regards the chemical composition, but also as regards the temperature and various deviations from a state of thermal equilibrium, the density distribution of the various elements, the value of gravity in the atmosphere and its state of motion. The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas.'

It may be of some interest to relate how Saha was led to the ionization theory. In his own words*: 'It was while pondering over the problems of astrophysics, and teaching thermodynamics and spectroscopy to the M.Sc. classes that the theory of thermal ionization took a definite shape in my mind in 1919. I was a regular reader of German journals, which had just started coming after four years of First World War, and in course of these studies, I came across a paper by J. Eggert in the *Physikalische Zeitschrift* (p. 573), Dec. 1919, "Uber den Dissoziationzustand der Fixsterngase" in which he applied Nernst's Heat Theorem to explain the high ionization in stars due

* Extract (taken from a copy in the possession of Dr A. K. Saha, son of Professor Saha) from a letter dated 18 December 1946, to Professor H. H. Plaskett, University Observatory, Oxford.

to high temperatures, postulated by Eddington in course of his studies on stellar structures.*

Eggert, who was a pupil of Nernst and was at the time his assistant, had given a formula for thermal ionization, but it is rather strange that he missed the significance of ionization potential of atoms, importance of which was apparent from the theoretical work of Bohr, and practical work of Franck and Hertz which was attracting a good deal of attention in those days. . . . Eggert used Sackur's formula of the chemical constant for calculating that of the electron, but in trying to account for multiple ionization of iron atoms in the interior of stars on this basis, he used very artificial values of ionization potential.

'While reading Eggert's paper I saw at once the importance of introducing the value of "ionization potential" in the formula of Eggert, for calculating accurately the ionization, single or multiple, of any particular element under any combination of temperature and pressure.

'I thus arrived at the formula which now goes by my name. Owing to my previous acquaintance with chromospheric and stellar problems, I could at once see its application I prepared in the course of six months of 1919 (February to September) four papers and communicated them for publication in the *Philosophical Magazine* from India within August to September.'

One of the four papers above referred to was 'On the Harvard classification of stellar spectra'. When shortly after communicating the paper Saha went to London, he withdrew it from the *Philosophical Magazine*, and completely rewrote it in Professor A. Fowler's spectroscopy laboratory in the Imperial College of Science and Technology, London. The revised (and, no doubt, considerably expanded and improved) paper was published in the *Proceedings of the Royal Society* (1921) under the title, suggested by Fowler, 'On a physical theory of stellar spectra'. Saha had the greatest regard for Professor Fowler, and always spoke with warmth and gratefulness of the encouragement and help he had received from him in London. Years afterwards he wrote:† 'I took about four months in rewriting this paper, and all the time I had the advantage of Professor Fowler's criticism, and access to his unrivalled stock of knowledge of spectros-

* Saha in his paper 'On ionization in the solar chromosphere' makes a handsome acknowledgment to Eggert's work.

† Letter to Professor H. H. Plaskett referred to in the preceding footnote.

copy and astrophysics. Though the main ideas and working of the paper remained unchanged, the substance matter was greatly improved on account of Fowler's kindness in placing at my disposal fresh data, and offering criticism wherever I went a little astray, out of mere enthusiasm.'* This paper and the one on the 'Ionization of the solar chromosphere' are by far the most significant and original of Saha's many scientific contributions.

As one of the interesting and immediate results following from the ionization theory, Saha not only was able to explain the absence in the solar spectrum of the lines of Rb and Cs because of the low ionization potential of these elements, but also to predict that their resonance lines were likely to be observed in the relatively cooler regions of the sunspots. H. N. Russell, following Saha's prediction, looked for and found the infra-red pair of Rb-lines, but no Cs-lines, in the Mount Wilson photographs of the spot spectra which, incidentally, had been taken before the publication of Saha's theory.

We may recall at this place that, apart from J. Eggert's paper referred to earlier, a definite suggestion about high-temperature ionization, prior to Saha's papers, was also made by the Oxford physicist F. A. Lindemann (later Lord Cherwell) in connexion with his controversy with S. Chapman about the origin of magnetic storms (*Philosophical Magazine*, December 1919). He gave the ionization formula for hydrogen, and discussed the possibility of the complete ionization of hydrogen in the solar chromosphere. Lindemann, however, did not further develop or generalize the formula; and above all he failed to notice that the theory of thermal ionization (with accurate values of ionization potentials obtained from spectroscopic data or otherwise) constitutes the key to the interpretation of stellar spectra with their almost bewildering complexity. It was Saha who first recognized this, and worked out the consequences in considerable detail, and he did this independently of Lindemann's suggestion about the high-temperature ionization of hydrogen.

In 1919 Saha was awarded the Premchand Roychand Scholarship of the Calcutta University, and this made it possible for him to spend some two years in Europe. He first went to London and spent about five months in the laboratory of Professor A. Fowler. Later he moved to W. Nernst's laboratory in Berlin, and did some experimental work

* Professor H. Dingle once observed: 'On thinking back to the relation which existed between Saha and Fowler I am tempted to compare it with that between Maxwell and Faraday'. (*The Observatory*, 66, 22 (1945).

on the conductivity of heated caesium vapour to seek an experimental verification of the theory of thermal ionization. The results were inconclusive. Some years later, when at Allahabad, Saha again returned to this problem, and an account of the investigation, jointly with K. Majumdar and N. K. Sur, was published in the *Zeitschrift für Physik* (1926).

In the early twenties R. H. Fowler (in collaboration with C. G. Darwin) developed a very powerful method in statistical mechanics permitting a systematic exposition and working out of the equilibrium properties of matter. He used this to provide a (rigorous) derivation of the ionization formula which as described earlier Saha had obtained by extending (and justifiably) to ionization of atoms the theorem of van't Hoff, well-known in physical chemistry for its application to molecular dissociation. Also, a significant improvement in the Saha equation introduced by Fowler was to include the effect of the excited states of atoms and ions. Further, it marked an important step forward when in 1923 E. A. Milne and R. H. Fowler in a paper in the *Monthly Notices of the Royal Astronomical Society* showed that the criterion of the *maximum intensity* of absorption lines (belonging to subordinate series of a neutral atom) was much more fruitful in giving information about physical parameters of stellar atmospheres than the criterion employed by Saha which consisted in the *marginal appearance or disappearance* of absorption lines. (The latter criterion requires some knowledge of the relevant pressures in the stellar atmospheres, and Saha following the generally accepted view at the time assumed a value of the order of 1 to 0·1 atmosphere.) To quote from E. A. Milne:* 'Saha had concentrated on the marginal appearances and disappearances of absorption lines in the stellar sequence, assuming an order of magnitude for the pressure in a stellar atmosphere and calculating the temperature where increasing ionization, for example, inhibited further absorption of the line in question owing to the loss of the series electron. As Fowler and I were one day stamping round my rooms in Trinity and discussing this, it suddenly occurred to me that the *maximum* intensity of the Balmer lines of hydrogen, for example, was readily explained by the consideration that at the lower temperatures there were too few excited atoms to give appreciable absorption, whilst at the higher temperatures there are too few neutral atoms left to give any absorp-

* E. A. Milne, Obituary Notice of R. H. Fowler (1889-1944), *Obituary Notices of the Fellows of the Royal Society*, 5, 61-78 (1945).

tion . . . That evening I did a hasty order of magnitude calculation of the effect and found that to agree with a temperature of 10000° for the stars of type AO, where the Balmer lines have their maximum. a pressure of the order of 10^{-4} atmosphere was required. This was very exciting, because standard determinations of pressures in stellar atmospheres from line shifts and line widths had been supposed to indicate a pressure of the order of one atmosphere or more, and I had begun on other grounds to disbelieve this.'

In November 1921 Saha returned from Europe and joined the University of Calcutta as Khaira Professor of Physics, a new chair created from the endowment of Kumar Gurprasad Singh of Khaira. In 1923 Saha left Calcutta to take up the appointment of Professor and Head of the Physics Department in the University of Allahabad. He held this appointment for 15 years. At Allahabad he gave a large part of his time to teaching—he regularly lectured to undergraduate and postgraduate classes. His lectures were systematically and carefully prepared, and a very large part of what he spoke, he worte on the blackboard in his characteristically clear and bold handwriting. He made copious use of lantern slides, and was fond of demonstration experiments.†

He initiated and organized research in several subjects, such as statistical mechanics, atomic and molecular spectroscopy, experiments on thermal ionization and 'electron affinity' of electronegative elements, active modification of nitrogen, high-temperature dissociation of molecules, and ionospheric propagation of radio waves and physics of the upper atmosphere. In 1926 Saha presided at the Physics and Mathematics Section of the Indian Science Congress Association. His address was on thermal ionization. Within less than a decade of Saha's arrival the Physics Department of the Allahabad University became one of the most active centres of research in the country, particularly in the field of spectroscopy.'Amongst his earliest associates in research mention may be made of P. K. Kichlu (now

† Saha often quoted the following rather remarkable passage from the 9th century Sanskrit work, *Rasendra-Chintamani:*

'I have heard much from the lips of savants, I have seen many (formulae) well established in Scriptures, but I am not recording any which I have not done myself.

'I am only recording those fearlessly which I have carried out before my elders with my own hand. They are alone to be regarded as real teachers who can show by experiments what they teach. They are the deserving pupils, who, having learnt from their teachers can actually perform them and improve upon them. The rest are merely stage-actors.'

Professor of Physics in the Delhi University), K. Majumdar and N. K. Sur. The Department attracted students from all over India. R. C. Majumdar, now Professor of Physics in the Delhi University, S. Basu, the present Director-General of the Department of Meteorology, and D. S. Kothari were Saha's students at Allahabad. It was in 1927 that at the age of thirty-four Saha was elected to the Royal Society. The United Provinces Government sanctioned a personal annual grant of Rs. 5000 for his reaserch work.

In 1927, at the invitation of the Italian Government, Saha attended the Volta Centenary Celebration held at Como, and presented a paper 'On the explanation of complicated spectra of elements'. He later joined a total solar eclipse expedition to Ringebu (68° N) led by L. Vegard of Oslo University. In 1936 he was elected to an overseas fellowship of the Carnegie Trust of the British Empire, and he visited Germany, England, and the United States and spent about two months with H. Shapley at the Harvard College Observatory. (Saha took keen interest in archaeology and ancient history, and on his way to Europe he visited the ruins of Ur of the Chaldees then recently excavated by Sir Leonard Woolley.) In a paper 'On a stratospheric astrophysical observatory' which appeared in the *Records of Harvard College Observatory*, Saha made what at the time (1936) was a very ambitious plea of photographing the solar spectrum at a height of some 50 kilometres, well above the ozone layer; and he pointed out the enormous gain that would accrue for astrophysics. In this paper, as also in that on the action of ultraviolet sunlight upon the upper atmosphere published in the *Proceedings of the Royal Society* (1937) and in his Presidential Address to the National Institute of Sciences of India given at Lahore in 1938, he discussed the possibility that the ultra-violet radiation from the sun may be several orders of magnitude above that corresponding to a black-body at about 6500 °K. He wrote: 'This may possibly be due to the fact that the ultra-violet spectrum of the sun may consist of a continuous background of faint light on which are superposed emission lines of H, He, He^{+}, Fe^{+}, and other elements which are represented in the visible range by lines of subordinate series, or by patches of ultra-violet continuous light (near about λ 500) leaking through the solar atmosphere from a much hotter region inside the photosphere, as suggested by Professor H. N. Russell.'*

* M. N. Saha. *Proc. Roy. Soc.* A, 160, 55 (1937).

In December 1937, Sir Arthur Eddington visited India as a member of the delegation of the British Association for the Advancement of Science to the Jubilee Session (1938) of the Indian Science Congress Association held in Calcutta. (Lord Rutherford was to preside at the session but he died a few months before, and his place was taken by Sir James Jeans.) At Saha's invitation Eddington paid a short but memorable visit to Allahabad: he was presented a civic address by the Allahabad Municipality.

In 1938 Saha was offered the Palit Chair in Physics at the University of Calcutta, vacated some years earlier by C. V. Raman who had gone to Bangalore as Director of the Indian Institute of Science. (Raman was succeeded by D. M. Bose who was Palit Professor from 1932 to 1937.) Saha accepted the offer and left Allahabad after a stay of fifteen years there. He occupied the Palit Chair for fifteen years, retiring in 1953 at the age of 60. In Calcutta Saha could not give as much of his time to his research as was possible in the relatively quiet atmosphere of Allahabad. Here a large part of his time was taken up in the administration of the laboratories, in building a new Institute of Nuclear Physics, and the reorganization and expansion of the laboratories of the Indian Association for the Cultivation of Science. Apart from all this, after the partition of India in 1947, he gave a substantial part of his time and energy to the massive human and economic problem of the 'refugees' from East Bengal (Pakistan)—it was a call that a man, himself from East Bengal, of his temperament and intense sensibility could not resist.

His researches in Calcutta were concerned largely with the systematics of atomic nuclei, particularly beta-activity: the propagation of electromagnetic waves in the ionosphere: and the problem of the solar corona. In the case of the corona an outstanding problem is that of the mechanism or source responsible for the high-degree ionization—loss of 9 to 13 electrons—of the iron atoms, and also nickel in the inner corona, as conclusively demonstrated by B. Edlen's remarkable work (1938) on the origin of the coronal bright spectral lines. D N Kundu working under Saha showed that some of the lines may be due to highly ionized cobalt atoms. The intense ionization, as also the excessive boradening of the Fraunhofer lines in the scattered radiation from the outer corona, and the strong coronal radio-emission in the region of wavelengths of the order of a few metres, all suggest coronal temperatures of the order of millions of degrees, but the origin of these temperatures which are comparable to those occurring in stellar interiors is largely still an unsolved problem. Saha found it difficult to accept the existence of such high temperatures. In fact, to account for the Edlen lines he advanced in a number of papers the somewhat quaint hypothesis that the highly charged ions necessary for the emission are produced as a result of nuclear fission occurring in the sun's outer atmosphere—he suggested tri- or quadrifission of U or Th. The problem of the emission of radio waves from the sun and other stellar bodies also engaged his attention, and he discussed the likely role of the magnetic field and the hyperfine-structure level-splitting of the ground state of the H-atom (*Nature, Lond.* **158,** 717, 1946). He failed to recognize, at any rate explicitly, the possibility of the occurrence as *line emission* of the 21-cm hydrogen line in radio spectra. [He was not aware at the time of the earlier prediction (1944) of H. C. van de Hulst.] In collaboration with B. D. Nag Chaudhuri (the present Palit Professor of Physics) Saha investigated the problem of the geological age of some of the Indian rocks.

Saha early realized the growing importance of nuclear physics and the impact it was likely to make on the country's sceintific and industrial progress. He felt that in the context of current developments there was a real and urgent need for a separate institution of nuclear physics devoted to post-graduate study and research. The result of his dedicated and untiring efforts was the Institute of Nuclear Physics in Calcutta, founded in April 1948 (and formally opened in 1950). The Institute is attached to the University. It runs a postgraduate course, and its research activities cover, amongst other subjects, beta-ray spectroscopy, nuclear resonance, and the use of radioactive isotopes in medicine. There is also an active theoretical group; a separate biophysics section and an instrument section. It has a 38-inch cyclotron—the magnet and some of the other critical parts were obtained from Lawrence's Laboratory in Berkeley. Saha was elected Honorary Director of the Institute for life. After his death, the Institute befittingly has been named after him.

Though the Institute of Nuclear Physics took much of Saha's energy and time, yet there was another institution, the Indian Association for the Cultivation of Science, which was always in his mind, and for its reorganization and expansion he worked hard and ceaselessly. The Association, the oldest institution devoted to science and its cultivation in modern India, was founded in 1876 by a private medical practitioner of Calcutta, Dr. Mahendra Lal Sircar. He intended it 'to combine the character, scope and objects of the Royal

Institution of London and of the British Association for the Advancement of Science'. As is well-known the Raman effect was discovered in the laboratories of the Association in 1928. At the time Raman was Palit Professor of the University and also the honorary head of the Laboratories of the Association.

Saha, shortly after his coming to Calcutta as Palit Professor in 1938 (Raman left Calcutta in 1932) began to take a keen interest in the activities of the Association. He was elected the Honorary Secretary in 1944, and in 1946 he was elected the President of the Association. He was succeeded by J. C. Ghosh in 1950. The large-scale expansion in the research activities of the Association wich has taken place in recent years is almost entirely the result of Saha's initiative, resourcefulness and devoted work. The Association has now a new building in Jadavpur (Calcutta) where it moved in 1951 from 210 Bowbazar Street.

In 1952 the post of a full-time Director of the Laboratories of the Association was created and the choice of the first Director obviously fell on Saha. He accepted the appointment in 1953 on retirement from the Palit Chair of the University which he held for fifteen years. He was Director of the Laboratories of the Association and Honorary Director of the Institute of Nuclear Physics at the time of his death in 1956.

Saha was the General President of the twenty-first annual session of the Indian Science Congress Association held in Bombay in January 1934. The first part of his address dealt with some of the current astrophysical problems, and in the second part he advocated the formation of an All-India Academy of Sciences. In the same address he drew pointed attention to the serious problem—still largely unsolved—of recurring disastrous floods in many Indian rivers, and stressed the need for a River Research Laboratory to make a scientific study of the complex problems involved in flood control and river utilization generally. He was one of the first in India to realize the great importance of this subject. He had personal experience of some of the catastrophic floods in the Damodar Valley area (Bengal), and he often took an active part in relief measures organized to deal with them. The writings of Saha, many of which appeared in *Science and Culture*, on flood control and harnessing the water of the rivers were to no small extent responsible in creating a public awareness of these problems. In 1943 the Bengal Government appointed the Damodar Flood Enquiry Committee. Saha was a member of the Committee, and his contribution was widely recognized as a vital one. Largely as a result of the committee's report came, eventually, the multipurpose Damodar Valley Project (very much on the lines of the Tennessee Valley Authority in the U.S.A.) which has been the forerunner of the Bhakra Nangal and other multi-purpose river projects in India. The establishment of the River Research Institute (Haringhata, Calcutta) was also, to no small extent, the result of Saha's initiative and efforts.

It was during the early thirties that the National Academy of Sciences at Allahabad (originally called the Academy of Sciences for the Provinces of Agra and Oudh), the Indian Academy of Sciencs at Bangalore, and the National Institute of Sciences at Calcutta (headquarters transferred to Delhi in 1946) were founded. In the case of the Allahabad Academy, and also the National Institute, the role of Saha was of the utmost importance. He was the first President (1932-34) of the Allahabad Academy and the second President (1937-39) of the National Institute of Sciences. (The first President of the Institute was Sir Lewis Fermor, the Director-General of the Geological Survey of India.) Saha was President of the Royal Asiatic Society of Bengal (now the Asiatic Society)for 1944-46.

Saha from the very beginning was closely associated with the work of the Indian Council of Scientific and Industrial Research (which corresponds to the D.S.I.R. in the U.K.) first constituted in 1942. He was a member of the Governing Body; and was for many years chairman of the Atmospheric Research Committee, and chairman or member of several other research and planning committees of the C.S.I.R. He was closely connected with the planning and establishment of the Central Glass and Ceramics Research Institute at Calcutta—one of the national laboratories under the C.S.I.R.—and was for many years chairman of its Advisory Committee. He was the chairman of the Indian Calendar Reform Committee, appointed by the C.S.I.R. in 1953.

Saha was a member of the University Education Commission appointed by the Government of India in 1948 under the chairmanship of Dr. S. Radhakrishnan.

The monthly journal *Science and Culture*, published by the Indian Science News Association (Calcutta), was started by Saha in 1934. The journal is now running in its 24th volume. Saha wrote prolifically for the journal, and his many articles and editorials bear witness to his remarkable versatility, and his passionate interest in and grasp of the many scientific, industrial and economic problems facing the country.

Saha was a keen student and ardent advocate of social and economic planning in India, particularly, in its relation to science, large-scale industry and technology. His general philosophy in these matters is perhaps best expressed in the following words (*Nature, Lond.* **155**, 221, 1945): 'The philosophy of kindliness and service to our fellowmen was preached by all founders of great religions, and no doubt some great kings and ministers of religions in every country and at all ages tried to give effect to this (altruistic) philosophy. But the efforts were not successful, for the simple reason that the methods of production of commodities were too inefficient to yield plenty for all, which is an indispensable condition for practical altruism. We can, therefore, hold that *so far as individual life is concerned*, science has achieved a target aimed at by the great founders of religions in advanced countries of the world. The effects of maldistribution of wealth, due to historical causes, are being rapidly cured by the introduction of social laws.'

He was an active member of the National Planning Committee appointed by the Indian National Congress in 1938. Saha was chairman of the power and fuels sub-committee, and member of the sub-committee on river training and irrigation.

In 1951 Saha was elected, as an independent candidate, to the Indian Parliament from the North-West Calcutta constituency. His contribution to the debates in the House, because of his special knowledge and background, was particularly valuable in relation to subjects such as education, industrial policy, river-valley projects and atomic energy.

Saha was widely travelled in Europe and the U.S.A. He had been twice to the U.S.S.R. He was the Indian delegate to the 220th Anniversary Celebrations (1945) of the Soviet Academy of Sciences.

In March 1954 the 60th birthday of Saha was celebrated in Calcutta, Allahabad and Delhi by his many friends, old students and admirers. A Commemoration Volume *Professor Meghnad Saha—His life, work and philosophy*, edited by S. N. Sen was published on the occasion.

During the last years of his life Saha was keeping an indifferent health. He was suffering from high blood pressure. But the end came rather suddenly. He passed away on 16 February 1956.

The life of Saha was in a sense an integral part of the growth of scientific research and progress in India, and the effect of his views and powerful personality would be felt for a long time to come in almost every aspect of scientific activity in the country. His dedication to science, his forthrightness and utter disregard of personal comforts in the pursuit of his chosen vocation will long remain an inspiration and an example.

Saha was married in June 1918 to Shrimati Radha Rani Saha. Her kindliness and genuine simplicity of character have won for her the affection and respect of generations of students and colleagues of Saha. Saha is survived by his wife, three sons and four daughters. The eldest son, A. K. Saha, is Professor in the Institute of Nuclear Physics.

In the preparation of this memoir I have drawn rather freely on the Commemoration Volume presented to Saha on his 60th birthday.

D. S. KOTHARI*

* Reprinted from the *Biographical Memories of Fellows of the Royal Society, 5*, 217-230 (1960). D. S. Kothari was one of the first few research students of Saha at Allahabad. He later became Professor and Head of the Department of Physics and Astronomy of the Delhi University, Adviser to the Minister of Defence, Government of India, and the Chairman of the the University Grants Commission.

1. SCIENCES

1.1, ASTRONOMY AND ASTROPHYSICS

1.2. SPECTROSCOPY

1.3. NUCLEAR PHYSICS, COSMIC RAYS AND NUCLEAR ENERGY

1.1. ASTRONOMY AND ASTROPHYSICS

1.1.1. TIME AND SPACE—THE NEW SCIENTIFIC THEORY*

The announcement conveyed in yesterday's Reuter's cable that Professor Einstein's theory of the equivalence of Time and Space has at last been verified by observations made during the last total solar eclipse, will be hailed with joy by scientific circles all over the world. If the announcement be true, then the time-honour dogma, that time and space are quite independent of each other, will be subverted once for all.

It is not possible to convey, without the use of proper mathematical symbols, a very precise concept of the greatness of the discovery. The theory of relativity was first formulated by the great Dutch physicist, H. A. Lorentz, during the closing years of the last century, but was largely recast and elaborated by Einstein, then a rising mathematical physicist of Switzerland, and Minkowski, a Russian Jew, whom the persecutions of his country drove into Germany. The generalised theory of Relativity, which has just been brilliantly confirmed, is, on the other hand, the sole work of Einstein and was first formulated in the year 1911 and elucidated in a number of papers published from 1911 to 1917. Other workers in the same field are Weyl in Germany, de Sitter in Holland, and Prof. E. A. Eddington at Cambridge, England. Prof. Eddington has recently published a book in which the main features of the theory have been treated with great ability.

We are generally apt to regard time as the absolutely independent variable, or as Sir William Rowan Hamilton puts it, time is absolute and uniform flux. But this concept of time, which is the cornerstone of Newtonian dynamics, was first challenged by H. A. Lorentz in the year 1895. The challenge was based upon the famous experiments of Michelson and Morley, two Harvard physicists, who showed from optical experiments that the length of a certain material rod seemed to vary according as it was placed parallel to the motion of the earth or perpendicular to it, in other words the length of a rod as measured by the waves of light was different according as the rod was stationary

*STATESMAN, Calcutta Nov 13, 1919.

or moving. We may quintessentially express it by saying that arod would seem to reduce to a point if it moved with the velocity of light.

Lorentz found that this result would follow if we give up the idea that time as measured by an observer is independent of the state of motion of the observer.

Our ideas of time are derived from ideas of uniform motion, and therefore it must depend upon the motion of the observer. As Minkowski put it—no one has observed time except at a particular space, or has observed a space except at a particular time. The two must therefore be interdependent.

By a purely mathematical analysis, Lorentz obtained time as dependent upon the motion of the observer. Incidentally it was found that the theory successfully accounted for many unsuccessful experiments to detect the motion of aether, Maxwell's luminiferous medium, and therefore it was supposed that the idea of aether as absolute space of reference must be given up.

The physical explanation of Lorentz's mathematical formula was first elucidated by Einstein, who showed how the idea of absolute space must be given up, and time as determined by signals of light from the motion of uniformity between observers. A and B, should also involve the velocity of A and B in the same manner as demanded by Lorentz's theory. Minkowski showed that the new ideas of time and space demanded a recasting of the whole Newtonian dynamics. He showed that this can be best done by supposing that time and ordinary space taken together form a short of four-dimensional space.

The relativity mechanics of Einstenin were greatly successful in accounting for the law of variation of mass of the atom of electricity, the electron, with its motion. Here is another time-honoured dogma —the constancy of mass—which is going to be sacrificed as a result of the new concept of time and space. The electron was discovered by Sir J. J. Thomson in 1898, and has since been found to be the primordial constituent of atoms of all types. Now, radium, the wonderful element discovered by Madame Curie, is constantly shooting up electrons with velocities ranging from 1/10 to 9/10 of the velocity of light. Sir J. J. Thomson, and almost simultaneously Kaufmann, a practising physician of Gottingen, found that the mass of the electron varied with the velocity with which it is shot forward. This was also predicated by the older theory, but the agreement failed when actual figures were compared. As a result of observations carried out in many leading laboratories of the world, it is now established beyond doubt that the variation of mass follows the Lorentz-Einstein theory of relativity.

The older theory of relativity deals with the mutual relations of time and space when the observer moves uniformly. What would be the relation when the observer moves with any velocity? This question was elucidated by Einstein in the papers above-mentioned. He holds that the physical laws as expressed by mathetical symbols would have the same form in whichever space the observer may find himself. Without entering more in details, which are exacting even for a practised mathematician, we may take some of the deductions.

It was known for a long time that the perihelion of Mercury has a slow motion along the orbit, about 43″ per century, which baffled all the attempts of Newtonian dynamics to account for it. The first triumph of Einstein's new theory of time and space was to explain successfully this motion. The other deduction was that as a ray of light passes near a gravitational field, it will be swerved from its right course by an amount depending on the mass of the field. This is a very startling deduction, for light is completely non-material and it is hard to understand that it will be influenced in its propagation by a material agency.

The greatest gravitational mass which is available to us is the sun. According to Einstein, light from a star just on the limb of the sun would be deflected by 1.74″ as it reaches us.

This prediction was made early in the year 1915. But it can be verified only during a total solar eclipse. For the glare of the sun is so great as to mask completely the most dazzling star. It can be verified during a total solar eclipse, when the disc of the sun being hidden by the moon, the light falls to about 1/15,000 of its ordinary value, bright stars may be visible for the few minutes of totality.

These precious few minutes were afforded this year on May 29, when there was a total solar eclipse. The track of the moon's shadow passed from Mauritius, over the continent of Africa, Liberia, and over some parts of the Amazon basin. Astronomical expeditions were organised by leading observatories of England and America. The opportunity was favourable, for during the totality the large star, Aldebaran, the brightest in the group of the Hyades, was over the limb of the sun.

It now appears that Einstein's prediction has been found to be right in a most brilliant manner. I learnt from a friend now working at Eddington's laboratory, that the preliminary results were quite favourable to Einstein's theory. It now appears that Prof. Sir Frank Watson Dyson, the Astronomer Royal, has also come to an identical conclusion from his own measurements, and the Royal Society accepts the prediction as fulfilled.

The new theory is thus of great interest to astronomers and the physicists from the point of view of absolute measurements. It will prove to be of interest to those physicists who are trying to unravel the inner constitution of the atom with the aid of dynamics. But for the measurements in the solar system, nothing appreciable is to be excepted.

Editor's note

The above article was written on request by the Statesman, Calcutta to explain a news item which appeared on November 12, 1919 as follows:

A Scientific Sensation —Certainty of the Ages Overthrown by Recent Experiments.

London, Nov. 7

"An announcement made at the Royal Society, which is described in the Press as overthrowing the certainty of the ages, and requiring a new philosophy of the universe has aroused intense interest in Scientific circles in view of its all important bearing on the fundamental physical problem. Sir Frank Dyson, Astronomer Royal, expressed the conviction that the results of recent experiments were definite and conclusive; that light from the stars as it passed the sun was deflected owing to the presence of the sun, this deflection closely according with the theoretical degree, predicted by Professor Einstein, namely that the deflection was twice the amount laid down by Newton. The discussion which followed was very intricate, no speaker succeeding in giving a clear non-mathematical statement. The results of the experiments were generally accepted, but the theoretical bearings provoked much debate.

Special interest attached to the presence of Sir Oliver Lodge who in February asserted that the deflection, if observed, would follow the Law of Newton. The meeting was very disappointed at Sir Oliver Lodge leaving early without contributing to the discussion. As far as can be described in everyday language the position is stated to be that the Newtonian principles assume space to be invariable, but certain physical facts suggest that space may acquire a twist or wrap; as for instance under the influence of gravitation, this dislocation applying to instruments of measurement as well as to things measured. Professor Einstein's doctrine is that the qualities of space, hitherto believed to be absolute, are relative to their circumstances.—Reuter's Special Service."

A letter appeared next day November 14, 1919 In Stateman as follows:

Dr. Saha's contribution to this morning's issue of the Stateman on "The New Scientific Theory" of time and space appears to be intended for the non-expert who is sufficiently interested in such matters to wish to know. That is my case, but I confees myself still completely at a loss. This "relativity of space" is evidently something not metaphysical at all, not the Kantian "form of thought", but physical; apparently, on this view, an inch is not always an inch but more or less according to circumstances. Obviously I am talking nonsense, which may be regarded as the pathological effect of Reuter's and Dr. Saha's explanations of things on an average mind. Can nobody help?

SIMPLICIMUS

The subsequent reply by Saha (Statesman November 15, 1919) is also reproduced.

TIME AND SPACE (continued)

Apropos of Simplicimus's letter to this morning's issue of The Statesman, I wish to add the following lines which I hope may make certain passages of Reuter's telegram (especially the words 'certainty of ages overthrown', etc.) clearer.

The classical theory of Newtonian dynamics regard space as absolute, and invariable, i.e. not subject to the physical circumstances in which the observer may find himself. Time is regarded as absolute, uniform flux. The absolute space of Newtonian dynamics is sometimes identified with the Aether of the Physicist.

The great success which attended Newton's efforts in solving the motions of planets with the aid of the universal law of gravitation and his dynamics did not diminish with the progress of time, as has been the fate of many physical theories; on the contrary, the investigation of his great followers, Laplace, Lagrange, Gauss, Le Verrier, and Adams resulted only in the strengthening of the belief in the absolute correctness of Newton's conceptions. From time to time, mathematicians believed they had detected some flaw in the Newtonian law, but closer investigations have aways shown these to be due either to want of mathematical skill or the presence of some disturbing factor of unknown origin. A very well-known example is connected with the discovery of the planet, Neptune. Uranus, which was discovered by Hereschel in 1781, was at first found not to follow the path laid down for it by the law of gravitation, and for a time, the correctness of the law was in question. But Admas and Le Verrier, working on the assumption that the variation might be caused by an external planet, tried to hunt this out on the lines pointed by the Newtonian law. The result was the discovery of Neptune.

On account of this unbroken record of successes attending Newton's theory during the last two centuries, the belief has crystallised that Newton's law and dynamics are really infalliable. The only outstanding cases were the perihelion motion of planets, notably that of Mercury, but this could be ascribed to the disturbing action of intervening meteoric swarms.

Now this belief in the infallibility of the Newtonian law and dynamics—the certainty of the last two centuries and a half—is going to be overthrown. It will not be correct to say that Newton's law of inverse square is false. The real point at issue is "what is meant by the mass of a body, or the distance between two particles?" It will not do for precise astronomical purpose, as we have hitherto done, to take a standard rod, and find out how many times this is contained between the two particles, but we must go deeper into the conception of time and space.

In his "generalized theory of relativity" Prof. Einstein shows how to arrive at logical concepts of time and space, and how the physical laws may be described with these new concepts. The best introduction to the reading of these papers is a paper by Einstein himself, published in 1905 in German; an English translation of this is being published by the Calcutta University. For the rest, it is not possible to give a popular idea of the theory which even the savants of the Royal Society found rather exacting.

Einstein's theories have not be accepted unchallenged. Early in 1918, Sir Oliver Lodge tried to show that the perihelion motion might be explained by simply assuming the variation of mass, with motion, which is an experimental fact, and thought that Einstein's theory was unnecessary. But he was rather severly handled by Eddington, who showed that his results were vitiated by serious mathematical errors. This was frankly admitted by Lodge, who broke off the controversy with the remark that 'traps may lie in wait for the unwary, and one is apt to overlook some of the consequences'.

The deflection of rays of light on passing close to the gravitational field of the sun, was not predicted by any other theory, and its recent confirmation would always form the main basis of the new theory.

1.1.2. PHYSICAL OBSERVATIONS DURING A TOTAL SOLAR ECLIPSE*

THE occurrence of a total solar eclipse is a phenomenon of unusual interest to the astronomer. It affords him an opportunity of studying physical conditions in the sun on a scale which is not otherwise available. The memory of the last eclipse which we had, may be still fresh in the public mind. It occurred on the 29th May, 1919, and is celebrated as the occasion, on which Prof. Einstein's famous predictions about the deflection of light rays by the gravitation field of the sun was verified. Another total eclipse is coming shortly—September 21st, 1922—and this time the track of the moon's shadow will sweep across the Indian Ocean from the Maldive Islands to the West Coast of Australia passing close to Java. The chief item in the programme is to obtain fresh support for Einstein's theory by securing photographs of stars during the moments of totality.

But the interest and importance of a total solar eclipse to the astronomer is older than Einstein by at least six decades. It began from the year 1859 when Kirchoff in Germany discovered spectrum analysis and placed in the hands of scientists a method which enabled them to study the chemical composition of not only terrestrial minerals, but also of such distant and unapproachable bodies as the sun and the stars.

To the unaided eye, the sun appears as an intensely bright circular disc. But about this disc (which is known in the astronomer's language as the **photo-sphere**) there is an atmosphere (known to the astsonomer as the **chromosphere**) of glowing gases. We cannot see this atmosphere in broad daylight because it is lost in the general glare of the sun; for the same reason the stars and the planets are not visible in daytime. If somehow the bright disc could be veiled, the atmosphere would be visible to the naked eye.

Fortunately for us, this is done by the moon during a total solar eclipse. The moon comes just between the earth and the sun and sends out a conical shadow with a maximum diameter of 168 miles at the point where it meets the earth. The shadow sweeps across the surface of the earth with a minimum velocity of 1,000 miles per hour (almost

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the same as that of a cannon ball). To all persons lying within the track of the shadow, the disc of the sun becomes invisible for the maximum period of nine minutes (equal to $\frac{168}{1000}$ hours). This is known as the period of totality. It is well to bear in mind that 9 minutes is the greatest possible duration of totality. The actual period of totality may be anything from 9 minutes to nothing.

In ancient times when people had not yet learnt to calculate the date and time of a total solar eclipse in advance, and await the phenemena with stoic indifference, such occurrences often gave rise to much terror and superstition. This is scarcely to be wondered at, because people lying within the zone of totality suddenly find themselves plunged from bright sunshine into the deepest gloom. The sky-light is so much reduced that planets and big stars and sometimes stars of the third or the fourth magnitude become visible. The transition is extremely sudden and abrupt. (It is said that once in ancient times, two contending armies were caught up in a total solar eclipse and were so much smitten with fear that they broke action and fled away in panic). In a few minutes, however, the gloom passes away, giving place to full sunshine.

Let us see how the astronomers use these precious few minutes. They are precious, not only on account of the extreme shortness of duration of totality, but also because of their rarity. 13 total eclipses occur in a period of 18 years $10\frac{1}{3}$ days (usually known as the Chaldean Saros after the nation which discovered this period), yet only a minute fraction of the earth's surface is fortunate or unfortunate to receive them. It is calculated that if a total solar eclipse happens to occur once in a certain place, the probable time that will elapse, before it occurs there again, is 360 years. "Nine minutes once in 360 years" has certainly a claim to be called precious.

Before the discovery of spectroscopy, the programme was limited to the observation of the gradual progress of the moon across the sun's disc with the aid of a telescope (with the usual darkening devices). Four stages are distinguished. The moon just touches the disc of the sun (first contact), then gradually creeps along the disc making the intersected crescent thinner and thinner; this occupies about an hour. The cusp is gradually reduced to a line and then vanishes abruptly. At this point, the moon just touches the disc on its inner side (second contact), and totality begins. The photo-sphere is completely veiled.

The maximum possible excess of the moon's disc over that of the sun is only 79″—so that within at most 4 minutes of second contact, the moon creeps along and touches the sun's disc at the point opposite to that of the second contact (third contact), totality is now at an end. The moon continues to creep on, the thin crescent gradually waxes, till the two discs separate (4th contact). Eclipse is now at an end. For the astronomer, the period between the 2nd and 3rd contacts is most valuable.

While carefully watching the progress of the eclipse through the telescope, it was observed by Airy and many other observers, that at the moment of second contact, when the cusp of the sun just disappeared, red columnar flames shot out across the field of vision. To these the name **'Protuberances'** or **'Prominences'** were given, but

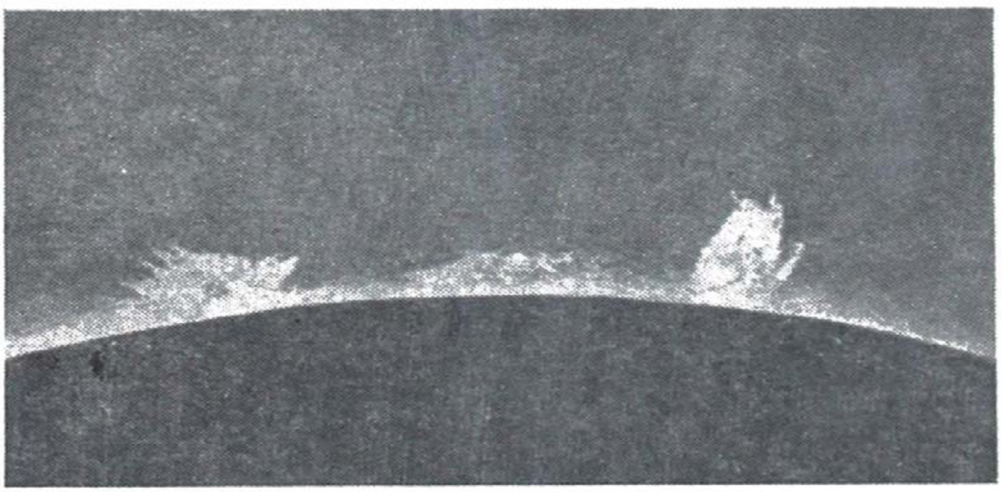


Fig. 1 A Typical Solar Prominence photographed during the total solar eclipse on May 29, 1900 (From Hale's Stellar Evolution)

opinions were divided about their physical nature. Some said that they were parts of the moon, others said they were illusions, while a few held that they were huge jets of gas projected from the surface of the sun forming part of a general solar atmosphere.

The controversy was settled by the Italian Padre Sechni, and by Warren de la Rue taking a series of photographs of the solar atmosphere during a total eclipse 1860. These photographs established beyond doubt that the prominences formed part of the sun, and consisted of luminous masses emitting rays of great actinic power.

But the most imposing sight about the sun during the moments of totality is a magnificent luminous halo extending to great distances in free space. Very often, this luminous halo is topped with bright pointed arches, which give it the appearance of a crown. Hence the name "Corona" has been given to it. It seems to have been observed at a very early time, for it was known to Kepler and Galileo. Since 1851, innumerable photographs of the corona have been secured, showing great variety of form, and extension.

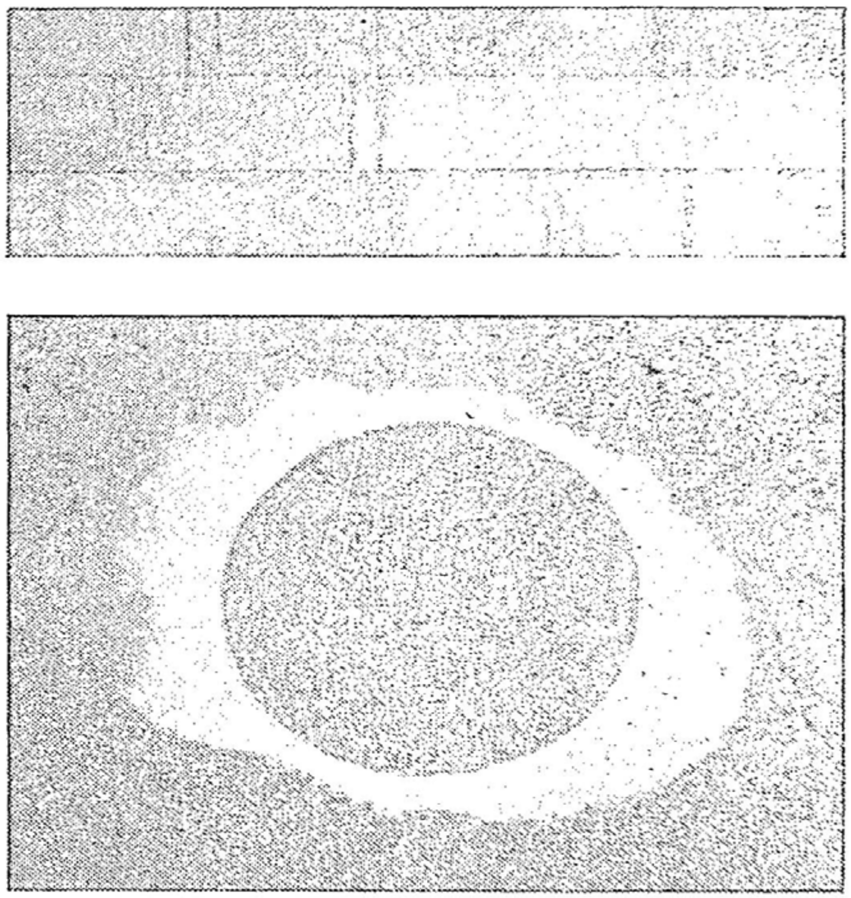


Fig. 2 The lower figure represents a photograph of the Solar Corona
(from Hale's Stellar Evolution)

Near about the solar disc, the coronal light becomes more intense, and passes into a brilliant red ring of light, to which the name **'chromosphere'** has been given. The observation of the corona, the chromosphere, and the prominences formed the chief items in the older eclipse programmes. But lately, methods were devised by means of which, the chromosphere and the prominences can be observed in full daylight.

Application of the spectroscope to solar physics

In 1859, Kirchoff announced to the world the news of his discovery of spectrum analysis. The effect of this discovery may be likened to the annexation of a fresh world of knowledge to the domain of human intellect. Newton had shown about 1680 that solar light consists of the seven colours of the rainbow. In 1813, Fraunhofer, then a humble spectacle-maker of Munich, surprised the scientific world by his announcement that the solar spectrum was not continuous, but was intersceted in places by fine dark line. These dark lines remained a perfect mystery for about forty years in spite of many efforts by scientific men to explain them (or rather explain them away). But Fraunhofer recognised that deep meaning might be hidden in them, measured and catalogued them for future use.

Continuous spectrum and Line spectrum

The explanation, which we owe to Kirchoff, is as follows. A piece of white-hot iron or the glowing carbons of an arc emits a continuous spectrum. A gas on the other hand, emits a line spectrum. If a flame is sprinkled with the salt of some metal, it is well-known that it is tinged with definite colours. Thus sodium salt tinges the flame yellow, strontium makes it red, copper makes it peacock-green. On spectroscopic examination, these colours are resolved into a number of fine bright lines; which are characteristic of the element present in the flame. Thus sodium emits two lines in the yellow, copper emits a number of lines in the blue, and every element has its own array of lines. It was observed by Fraunhofer himself, that the yellow lines of sodium were identical with the dark lines D_1 and D_2 of the solar spectrum. Later observations showed that most of the Fraunhofer lines could be identified with the lines of elements known on the earth.

Fraunhofer Spectrum and Reversal of lines

With the aid of new ideas on emission and absorption of radiant energy, these facts were woven by Kirchoff into a consistent theory of the Fraunhofer spectrum. This explanation is now a matter of common knowledge. The continuous spectrum comes from the highly condensed central nucleus (photosphere) of the sun, which emits like a solid body (this does not mean that the nucleus is solid—the more probable theory is that the nucleus consists of highly compressed gas).

The light from the photosphere has to pass through a surrounding thinner atmosphere in which all terrestrial elements e.g. iron, sodium, calcium, etc are present in the state of vapour. These vapours act like filters, and rob the continuous spectrum of the light which they themselves can emit. Thus sodium vapour in the solar atmosphere absorbs the D_1 and D_2 light from the photospheric spectrum; they also emit the same light but the intensity is very much smaller owing to the lower temperature of the atmosphere. The transmitted light which is made up of what remains of the photospheric light after absorption plus the light emitted by the vapours themselves is less intense than the original beam from the photosphere. Hence the beam appears dark in comparison.

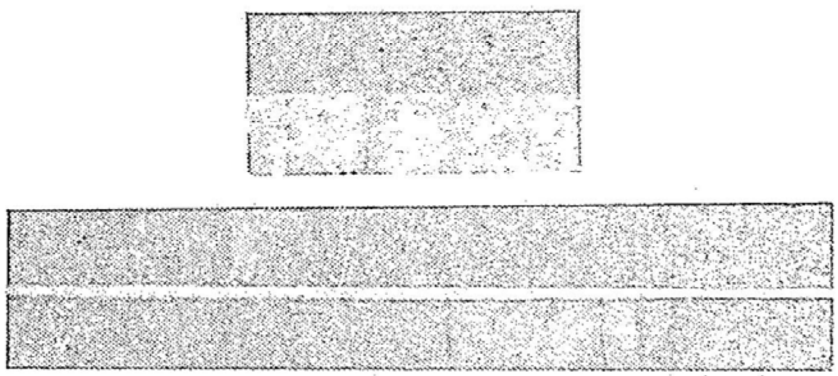


Fig. 3 The upper figure shows the Sodium lines in arc, and in the Sun. The lower figure shows the coincidence of iron in the arc with those in the Sun (Hale, Steller Evolution).

It is well to bear in mind that the darkness is only comparative. In reality, the dark lines are as intense as the lines of the flame or sometimes of the arc, as is proved from the fact, that with sufficient exposure, all parts of the photographic plate become dark. It naturally follows that if the photospheric light could be somehow cut off, and the solar atmosphere isolated, its spectrum would be found to consist of bright lines like that of a gas. *In place of each dark Fraunhofer line, we shall get a bright line, in other words, the spectrum of the solar atmosphere would be a complete reversal of the Fraunhofer spectrum.* This opportunity is afforded only during the moments of a total solar eclipse. It may be supposed that if we hold a sufficiently large disc before the telescope, so as to cover the photosphere completely, our object would be achieved. But this is not so. Besides getting light direct from the sun, we get light from all parts of the sky, which is simply sunlight scattered by the dust and air molecules of the atmosphere. The intensity of the sky-light is sufficient to mask the solar atmosphere completely. The bigger the disc the less intense will be the sky-light, but it actually requires a disc as big as that of the moon to make the solar atmosphere at all visible.

The importance of a total solar eclipse will now be quite evident, but the reader must not underestimate the difficulties. It is very difficult to catch the exact moment of totality. Then the moon shoots across the surface of the sun with tremendous velocity, covering 270 kms of the solar surface per sec. Hence if any spectroscopic study is to be made about the 100 kms just next to the solar disc, it must be started and finished with $\frac{1}{3}$ of a second beginning from the instant of second contact.

Spectra of Prominences

At first astronomers concentrated their attention on the observations of the spectra of red prominences, which extend to great heights, and can be observed for a considerable length of time. Observations of the spectra of red prominences stood in the forefront of the expeditions to observe the total solar eclipse of 1868, which passed over India. Parties were organised by the French, English, and American astronomers, but success was reserved for the Frenchman Jansen. But before relating the account of this success, we must mention the appearance on the scene of a very remarkable personality—the late Sir Norman Lockyer—one of the greatest figures in solar physics, and one who was destined to influence the course of astrophysics for the next fifty years. Lockyer was, at this time, earning a small pittance as a humble clerk in the Admiralty. He was a man without regular University education, but what he lacked in routine education was made up by his energy ("tumultuous" is the adjective with which his biographer describes it), insight, and great powers of organisation, and above all his love of the subject. Lockyer hit upon the bold idea of photographing the spectrum of the red prominences in broad daylight, and with his own scanty means, set about the work in great earnest.

Lockyer recognised that the chief difficulty in his way was the sky-light, which, as explained before, completely masks all light from the solar atmosphere. The sky-light is simply solar light scattered by the terrestrial atmosphere, and its spectrum is the same as that of the sun. So a method had to be found by means of which the sky-light could be weakened, while the intensity of the line spectrum from the prominences would remain unaffected.

The way in which this was effected occurred independently and simultaneously to Lockyer and Jansen, under different circumstances. It is this—suppose we have a spectroscope consisting of simple prism, and observe with it the continuous spectrum of sky-light, and line spectrum of say a vacuum tube. Suppose, the total length of the continuous spectrum betewen C and F is 3 cm. Now let us add another prism having the same dispersion. The length of the spectrum (C-F) will now be 6 cm the intensity of the continuous spectrum will therefore be halved. The intensity of the individual lines of the line-spectrum would however remain unaltered, for they are monochromatic. If we have n prisms, then neglecting the weakening in intensity due to absorption and reflection, the intensity of the continuous spectrum would be reduced n-times, that of the line spectrum would remain unchanged.

The perfection of the experimental method was, however, not the only difficulty which Lockyer had to encounter. The prominences were shown by Sechhi to be isolated masses, scattered irregularly over the solar disc. Nobody knew at which part of the sun's disc one had to look for them. So we need not wonder why it was after three years' labour that the difficulties of the work were overcome. In October, 1868, Lockyer succeeded in photographing the spectrum of the protuberances in broad daylight.

Indian Eclipse Expedition in 1868

But Lockyer had to share the honours jointly with Jansen. While engaged in the eclipse observations at Guntoor, it occurred to Jansen that the spectrum of the protuberances might be photographed in daylight, and the same method which was being perfected by Lockyer occurred to him independntly. He was howeve. more fortunate than Lockyer, for from his observations during the total eclipse, he had come to know the exact spot where he had to look for the prominences. Not only that, his observations showed that the most prominent line in the prominence spectrum was the C-line of hydrogen, not the sodium D-line, which had monopolised all the attention before this time. Jansen confirmed this on the next day by actual observation, and was so elated with success that he telegraphed to Paris "We have now total solar eclipse for the whole day." The observation was continued up to the 4th Spetember; and then posted to France.

Jansen's observations were made at Guntoor in India. The news of his discovery reached Paris on the 26th October when it was read by Faye before the Paris Academy. By a mere accident, the news of Lockyer's discovery reached the Academy the same day. To commemorate this event, the French Government struck a medal containing, on one side, the effigies of the two astronomers, on the other side, the Sungod carried away as a captive in a chariot drawn by four horses and containing the inscription "Analyse des Protuberances Solaires, 18 Aout, 1868."

Shortly after Lockyer's discovery, Huggins showed that by placing the slit tangentially to the solar disc, and opening it rather wide on the side of the chromosphere, the whole protuberances could be observed. In 1892, Hale in America, Deslandres in France, and a little later Evershed in India discovered an instrument called the spectroheliograph, by means of which it is possible to photograph the prominences in broad daylight. Photographing the prominences is now a regular routine work at Kodaikanal, Mount Wilson, and many other solar observatories. Mr. Evershed of the Kodaikanal observatory has observed a huge number of prominences and published them in a book form.

Discovery of Helium in the Sun

In many respect, Lockyer went further than his contemporaries. He confirmed Sechhi's view that the protuberances were elevations from a continuous atmosphere surrounding the sun, for which he in conjunction with his friend Frankland suggested the name chromosphere (sea of colours). He showed that the D-line of the protuberance spectrum was not identical with the sodium lines, but its wave-length was considerably shorter (5867 against 5890-96 of D_1 and D_2). He called it D_3. It is not represented in the Fraunhofer spectrum, and was ascribed by Lockyer to a new element still undiscovered on the earth. He christened this hypothetical element Helium, after Helios, the Greek name for the "sun-god". Thirty years later, Helium was discovered by Ramsay in the Norwegian mineral clevite.

But the proof that the spectrum of the chromosphere would be the reversal of the Fraunhofer spectrum was not yet forthcoming. Instead of showing thousands of bright lines the spectrum of protuberances showed only a few bright lines (11 in all)[1]. This discrepancy cleared itself in 1870.

[1] In 1870, Lockyer showed that the spectra of protuberances showed hundreds of lines,

Spectrum of the chromosphere

Prof. Young of Princeton, was observing a total solar eclipse on Mt. Sherman. With the slit of his spectroscope tangential to the sun's limb, and perpendicular to the moon's advance, he was awaiting the moments of the second contact. "The thin solar crescent narrowed second by second, then all at once, as suddenly as a bursting rocket shoots out its stars, the ordinary Fraunhofer lines previously visible were replaced by a serried array of bright lines on a dark background. This seemed a complete reversal of the familiar absorption rays and the impression was also conveyed to Mr. Pye, a member of the same party." (The description is taken from Mrs. Clerke's Problems in Astrophysics).

This flash-like reversal had been looked for, and been confirmed. But a photographic record could be taken only 26 years later 1896, by Mr. Shackleton at Novaya Zembya, during the Arctic Eclipse of 9th August, 1896.

Flash Spectrum

In this expedition, a prismatic camera was used. It is a simple form of spectrograph, without slit and collimating lens. The slit is unnecessary, because at the moment of totality, the source of light is the thin crescent-like part of the solar chromosphere intercepted by the moon's disc. By means of the prism, this thin crecent shaped source of light is drawn out into a series of monochromatic images. Some of these arcs are long, others are short. The employment of this apparatus in eclipse work is mainly due to the initiative of Lockyer. It is generally known as the **Flash spectrum,** on account of the flash-like rapidity with which it appears and disappears.

A magnificent opportunity presented itself in the year 1898, Jan. 22, when there was a total solar eclipse passing over India. Photographs of the flash spectrum and the corona were secured by Lockyer at Viziadrug in the Bombay Presidency, by Evershed at Talni, and by Naegamvela.

Indian expedition in 1908

The full story of these expeditions is told by Lockyer himself in the pages of the Philosophical Transaction, Vol. 197, 1901, and by Evershed in the same journal. At Viziadurg totality began at 13 h, 45 m. 53 s and lasted for 127 seconds. Many photographs of the flash spectrum were secured, one set with a six inch prismatic camera, the other set with a nine inch camera. Photographs of the corona were secured; and its spectrum was also observed, though not very satisfactorily.

The eclipse of 1898 was the first occasion in which, there was no mishap, the programme went like clockwork. The ice being once broken, all the subsequent total eclipses have been fully exploited by astronomers, English, American, Dutch, French, and German. But anything like an account of these expeditions is quite out of the question.

All eclipse expeditions did not prove successful. Sometimes at the psychological moment, clouds gather in the field of view spoiling all labour and money. Sometimes, the occurrence of the eclipse causes disagreeable activity among the surrounding populace. One eclipse expedition to India is said to have been completely spoilt by some jungle tribes setting fire to forests at the commencement of the eclipse. In 1914, owing to the outbreak of the Great War, the British expedition to Crimea in south Russia had to beat a precipitate retreat, abandoning all the instruments, which were never recovered.

Physical observation during a total solar eclipse.

Up to 1919, the programme had not much varied. The items were—

(1) Precise observations of the times of four contacts; these observations determine with great accuracy the relative positions of the sun and the time at the moment. and serve as useful data in the theory of lunar motion.

(2) The search for a possible intramercurial planet.

Mercury is the innermost planet of the solar system, but accurate observation of Mercury does not follow the Newtonian law of Gravitation; the apse-line has a progressive motion of 540″ per century, of which 43″ cannot be accounted for by the law of gravitation. The observed perturbation was formerly supposed to be due to the presence of a hypothetical planet between the sun and mercury, and the name "Vulcan" was coined for it. If such a planet really exists, it may become visible during the moments of totality.

But "Vulcan" has never turned up. The perihelion motion of Mercury is now explained completely by Einstein's theory of generalized relativity. So it seems doubtful if Vulcan at all exists.

(3) Photographic records of the form of the "Corona" and photometric measurement of the intensity of Coronal light.

The Corona is an essentially "Eclipse Phenomena" as all attempts to photograph it during daytime has failed. At outer regions, it is only half as intense as the full moon.

(4) Certain meteorological observations, such as effects on the thermometer, the barometer, and the magnetic elements of the earth. (L. Bauer of the Carnegie Trust has specialised in this line.)

(5) Examination both visual and photographic of the spectra of the flash, the corona, and the prominences.

This item is by far the most important in an eclipse expedition.

Since 1919, another item has been added to the programme:—The verification of Einstein's prediction that rays of light would be deflected on passing close to the disc of the sun. The predicted deflection is $1-74 \frac{r}{R,}$ where "r" is the semidiameter of the sun, R is the angular distance of the star from the centre of the sun.

Photographs of the field of stars about the sun are secured during the moments of totality. These photographs are compared with another set secured either before or after this event, when the sun is not in this region of the sky. The comparison reveals any displacement which star might have suffered owing to its rays having to pass close to the sun's disc during the moments of totality.

It is hardly necessary to add that the results of the British expedition of 1919 confirmed Einstein's predictions in a most brilliant manner. The coming eclipse is also said to present a very favourable opportunity, as the field about the sun contains a number of sufficiently bright stars. A method proposed by Prof. Lindemann of Oxford of securing photographs of stars in daytime in infra-red light was tried by Evershed, at Kodaikanal but did not yield any positive result.

Results of the spectroscopic examinations

Interest in these observations has somewhat flágged of late owing to the sensational nature of Einstein's prediction but this attitude is scarcely to be justified. The results which have accrued from these observations are highly interesting and present a number of problems still awaiting solution.

We have already remarked that Rowland measured about 20,000, dark lines in the solar spectrum in the region between 3000 A.U. to 7800 A.U. A number of these are due to absorption by the gases of the earth's atmosphere. About 6,000 have been identified with the lines of known elements. Altogether about 45 elements are known to exist in the sun.

The total number of lines recorded in a flash spectrum is not so great, owing to the limitations imposed on the power of instruments which can be carried to the eclipse station, and the short duration of the eclipse. Evershed counted ablout, 1,500 lines on his plates, Mitchell in America, using instruments of higher power during the total eclipse of 1905, increased the number to 2500.

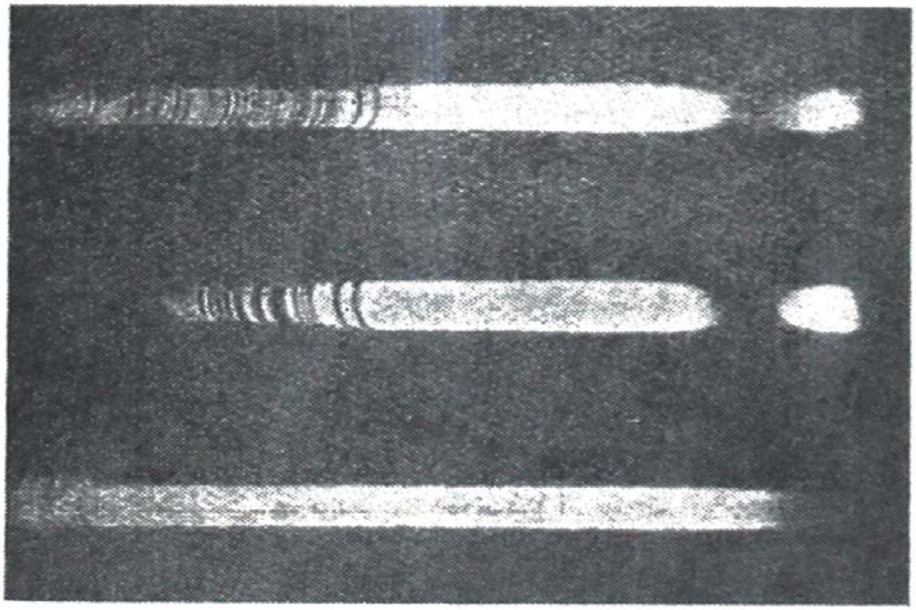
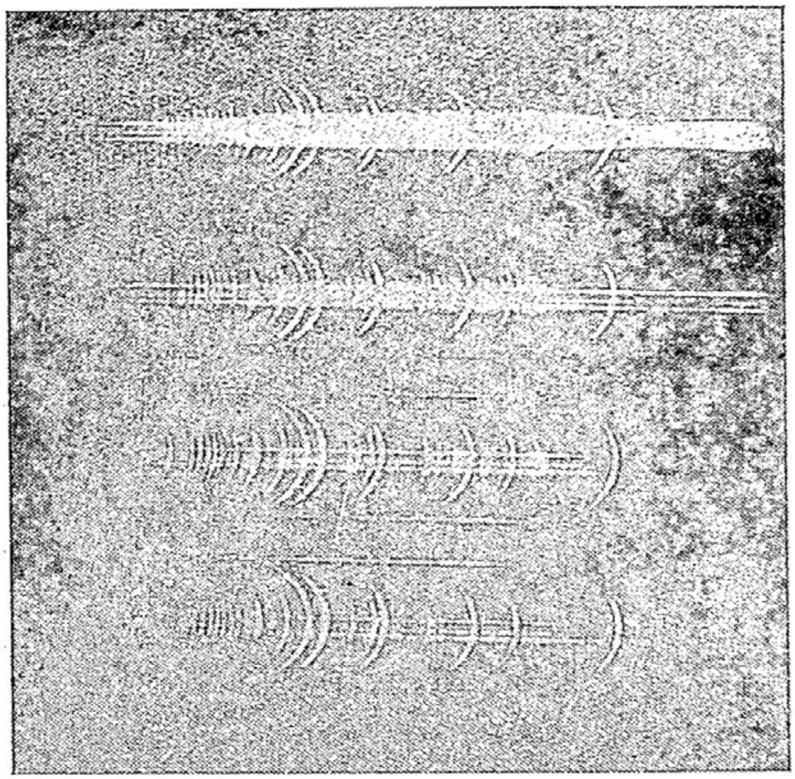


Fig. 4 (From an article in the Phil. Trans., Vol. 197, by Evershed). The uppermost figure is the spectrum of the thin solar cusp just before totality. The middle one represents the spectrum of an artificial cusp on an ordinary day.

From these observations, it appears that the flash spectrum is mainly a reversal of the Fraunhofer spectrum, that is to say, corresponding to very dark line of moderate intensity in the Fraunhofer spectrum, there is a bright line in the flash spectrum. But there are a lot of important differences. We have already alluded to the discovery of helium in the sun. A scrutiny of the Fraunhofer spectrum reveals not the slightest trace of single helium line. On the other hand, more than 15 or 20 helium lines occur in the flash spectrum and some of them, e.g., the D_3 line—rival the lines of hydrogen in brilliancy. Helium is certainly present in the sun, but why it fails at all to appear in the Fraunhofer spectrum is still wrapped up in mystery.

A similar behaviour is shown by Hydrogen. Hydrowgen gives four lines in the visible spectrum, the red line $\lambda=6563$, corresponding to the O-line of Fraunhofer; the green line $\lambda=4861$, the F line of Fraunhofer; the blue line $\lambda=4340$, f of Fraunhofer; the violet line $\lambda=4101.8$, the h of Fraunhofer. These four lines are amongst the strongest in the



Flash Spectrum

Fig. 5 (From an article by Lockyer in the Phil. Trans., Vol. 197.) The longest arcs are due to Calcium lines H and K. The shorter arcs to the left of H and K are the ultra-violet lines of hydrogen. They are not present in the Fraunhofer spectrum.

Fraunhofer spectrum. About 1885, Balmer of Basle showed that the frequency 'ν' of these lines are represented with great accuracy by the simple formula.

$$\nu=\frac{1}{\lambda}=N\left[\frac{1}{2^2}-\frac{1}{m^2}\right],\ m=3,\ 4,\ 5\ \text{and}\ 6.$$

$m=3$ represent the red line, $m=5$ the green line, etc.

The extreme simplicity of the formula suggests that a deep meaning is hidden in this expression. In fact, in recent years, this formula has proved to be one of the main keys to the problem of atomic structure.

Hydrogen in the Flash

The formula shows that the hydrogen series ought not to stop at H_δ (the 4th line of the above group), but ought to extend further in the ultraviolet, giving a large number of lines in serial order and ending at $\lambda=3645$. The Fraunhofer spectrum shows indeed a line corresponding to $m=7$, but most careful scrutiny fails to reveal any other lines of the series in the Fraunhofer spectrum. A number of other lines were subsequently discovered in the spectrum of the star Sirius, and in the laboratory, but none in the sun.

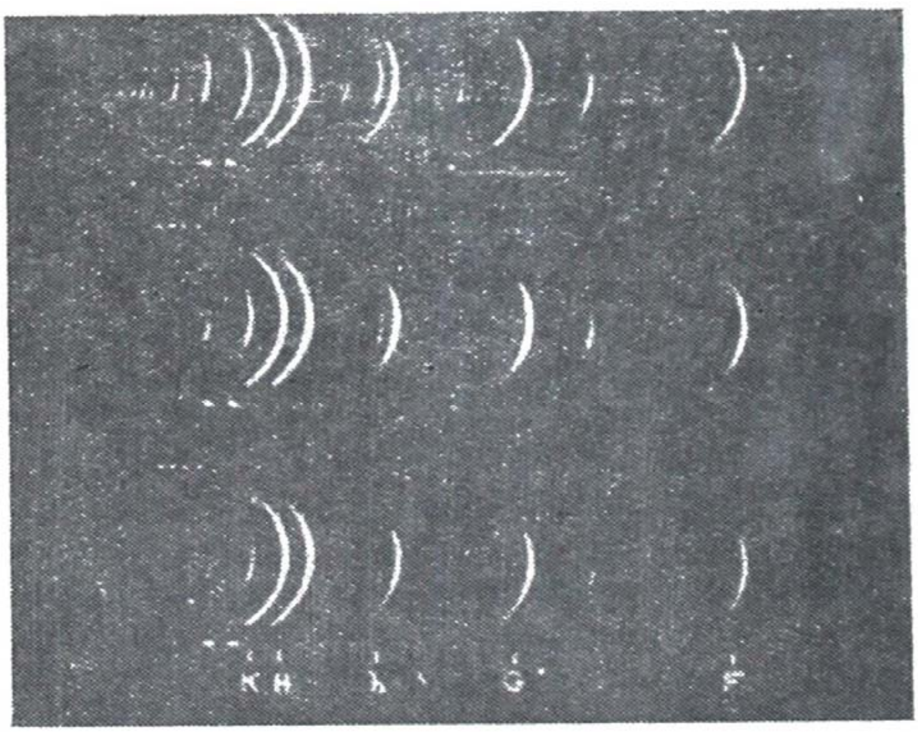


Fig. 6 Photograph of the Flash Spectrum on Jan. 22, 1898, at Viziadrug in the Bombay Presidency by the Lockyer Expedition (from Phil. Trans. Vol. 197). The H-K arcs are due to radiant calcium, F. G. h. are due to radiant hydrogen.

This mystery cleared itself in the eclipse expedition of 1898. Evershed found that 29 lines corresponding to the Balmer formula are present in the flash spectrum. Mitchell later on increased the number to 35. But it is not yet clear why only 5 of them are present in the Fraunhofer spectrum.

If the reader looks carefully on the adjoining figure he will find two very big arcs, denoted by the letters H and K. They are by far the longest arcs in the flash, greatly exceeding the hydrogen arcs in length and intensity. These two arcs correspond to the H and K bands of Fraunhofer, which are the strongest absorption lines in the solar spectrum. It may be mentioned here that from the length of the arc, it is quite easy to deduce the height of the corresponding element in the solar atmosphere. The longer the arc, the greater is the height reached by the element.

These considerations show that the lines H and K occur in the highest layers of the sun. To quote exact figures, they reach the height of 14,000 km while hydrogen reaches the height of 8,000 km only.

The earlier astronomers, Huggins, Young and others, at first believed that the H,K lines were due to some element lighter than hydrogen, **"some subtle form of hydrogen."** But laboratory experiments soon dispelled this illusion. It was found that the twin lines are due to Calcium.

Levity of Calcium in the Solar Atmosphere

Here is a strange enigma, a perfect riddle to astronomers. If we suppose that gravitation is the only force in the sun, it ought to act 40 times more strongly on a calcium atom than on an H-atom. Hydrogen would reach the highest levels, and then would come the other elements in order of their atomic weight.

But this expectation is apparently most flagrantly violated in the atmosphere of the sun. Then again gravitation is 28 times stronger on the surface of the sun, hence it ought to have practically no atmosphere. A closer scrutiny brings out many other flagrant discrepancies from the physical laws as known on the earth.

Quite a crop of theories were introduced to explain these facts. Many astronomers were of opinion that there is a force of **'levity'** in the sun, which largely neutralises the pull due to gravity. This force of levity is sometimes supposed to be due to electrical forces, sometimes to the pressure of light, sometimes to the action of convection currents. But no attempt was ever made to explain why the force of levity should act on calcium alone (and a number of other elements).

Mention ought to be made here of an ingenious theory of Prof. Julius which tries to explain away the whole set of eclipse phenomena —the chromosphere, the flash spectrum, the corona—as mere "optical illusions". The theory explains some of the general features quite well, but breaks down entirely in the treatment of details.

The first step in the elucidation of these problems was taken by Lockyer. He showed that the spectra of an element varies with the stimulus sent through the element. One set of lines come out distinctly under low stimulus (such as the flame and the arc). But if the stimulus be gradually increased this set does not so much gain in intensity; but another set begins to appear, and rapidly gains in intensity. A stage can be reached when the first set is entirely suppressed, and the second set alone remains.

The first set of lines (low stimulus lines) are generally known as arc lines; to the second set (high stimulus lines) Lockyer gave the name 'enchanced lines', or 'spark lines'.

Lockyer discovered the remarkable fact that the high level chromospheric lines are invariably 'enhanced lines of elements' viz., of Ca, Sr, Ti, Fe, Mn, and Sc. The low stimulus group always occur at a lower level. To take one example, the H and K are the enhanced lines of Calcium. The line which is strongest at low temperature ('*g*' of Fraunhofer, $\lambda = 4227$) is represented by a rather short arc in the chromosphere, corresponding to a level of 4,000-5,000 kilometres. Similar behaviour is shown by the lines of other elements which are strongly represented in the solar spectrum. Their low stimulus lines fail to reach any great heights; the enhanced lines, on the contrary, reach very high levels in the solar atmosphere. From these evidences, Lockyer drew the conclusion that the chromosphere is the seat of much higher stimulus than the photosphere.

Lockyer's studies on the solar stellar spectra

Further development of Lockyer's idea cannot be followed without a brief digression on the spectra of stars. With the aid of naked eye, it is possible to distinguish 4 classes of stars, white, yellow, yellow-red, deep-red. These stars are in the order of descending temperature, deep-red stars have the lowest temperature, white stars have the highest temperature. Secchi showed that the spectra of stars corroborate the classification based on visual observations. The spectra of the star of a particular colour is almost typical of that class.

Lockyer worked out the transition stages very fully, and showed that the spectra of red and yellow-red stars are practically made up of low stimulus lines. The enhanced lines are only faintly present. But in the spectra of higher classes, the low stimulus lines become fainter, while the enhanced line begin to gain in intensity. The high temperatures stars practically show only 'enhanced lines'.

These facts led Lockyer to a number of hypotheses. He assumed that the spark was equivalent to a high temperature. Led by the belief that white stars represent an earlier stage in the process of evolution, he thought that elements were present there in a more primitive (or *proto*) condition. The enhanced lines are due to the **"protoforms** of the elements". Thus the 'g' line is due to ordinary calcium, while the 'H' and 'K' are due to **'Proto.calcium'.**

But the very idea that the atom, the indivisible unit of matter can be in any way further subdivided was regarded as a sort of 'heresy' in those days. In astronomical circles: the distrust with which Lockyer's views were regarded was enhanced by his attempted explanation of the spectra of the solar atmosphere. As we remarked before, the spectrum of the high level chromosphere is practically made up of "enhanced lines"; in other words, the spectrum is the same as that of a star of higher surface temperature. Lockyer therefore believed that the temperature of the chromosphere was higher than that of the disc. In other words, the temperature increases as we go outwards in the sun. This is a rather startling conslusion and common sense never allows us to accept such a hypothesis. In the earth, to take a concrete example, the surface temperature is something like 300° (Kelivin or Absolute scale), but this decreases at the rate of 5° per kilometre as we go higher up in the atmosphere. This decrease continues for 10 to 12 kms the temperature falls about 240°K and then it reaches an almost steady value: the temperature being maintained by exchange of radiant energy. There are very good reasons to believe that the same state of affairs holds also in the sun. The surface temperaturs has been determined to be about 7000°K. This decreases at a very rapid rate, but assumes a rather steday value of 5500°K at the higher levels. This view is apparently inconsistent with Lockyer's idea. Still, the fact that the chromospere is the seat of higher stimulus has to be explained.

A theory to explain these facts was given by the present writer about a year and a half ago, which has met with general acceptance. But an account of this theory will be out of place here.

The coronal spectrum. The spectrum of the corona is one of the most puzzling-riddles of solar physics. The spectrum shows a number of lines which are not coincident with any Fraunhofer or flash line, or with the line of any known element. The best known line is $\lambda = 5303$, which was in early times confused with a line of iron having the wave lenght of $\lambda = 5316$. This line and its associate line are ascribed to a hypothetical element called **"coronium"**. But "coronium" has not yet made its appearance on the earth.

In the light of modern theories of atomic structure, it does not seem probable that "coronium" will turn out to be a newcomer in Mendelieff's family of elements, but will prove to be, like Lockyer's Protocalcium or Protovanadium, only a modified form of some known element.

The coming total solar eclipse

It will be seen that beginning with the memorable eclipse of 1868, most of the important eclipse observations were made in India. The eclipse of Sept. 21, 1922, will however pass south of India. The Figure 7. shows the track of the eclipse. Beginning from the east coast of Africa, it will sweep across the Indian Ocean. The original

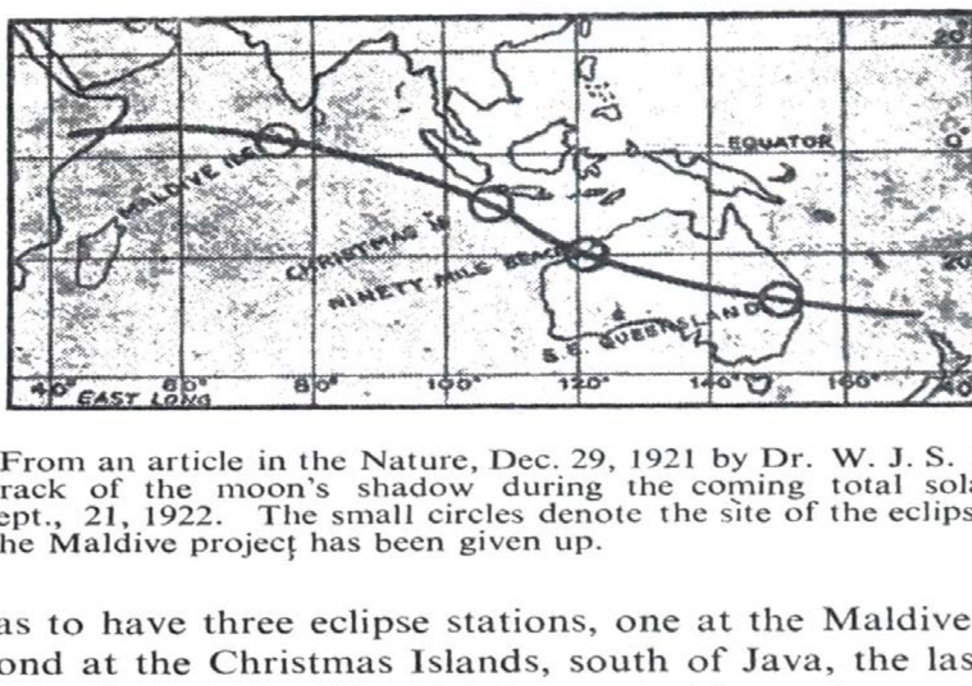


Fig. 7 (From an article in the Nature, Dec. 29, 1921 by Dr. W. J. S. Lockyer). Track of the moon's shadow during the coming total solar eclipse, Sept., 21, 1922. The small circles denote the site of the eclipse stations. The Maldive project has been given up.

plan was to have three eclipse stations, one at the Maldive Islands, the second at the Christmas Islands, south of Java, the last on the west coast of Australia. The Maldive project has subsequently been given up. A British party and a joint Dutch and German party will camp at the Christmas Islands. Here the duration will be 3′ 40″ but the station is not exactly at the centre of the moon's shadow, but fifty miles south of it. The sun will be nearly at the zenith and here are good prospects of fair weather. The British party is composed of Mr. Spencer Jones, M. Melotte and observers from the Greenwich observatory, while the Dutch party will be under the leadership of J. G. Voute, Director of Meteorological Survey in the Dutch Indies. Germany will be represented by Freundlich, Kohlschütteer, and probably Einstein.

In Australia, probably both the west and east coasts will be occupied by an American party under Prof. Campbell of the Lick Observatory, and an English party in which Australia will be represented. Mr. Evershed from India will probably encamp somewhere in the west cost of Australia. Here the duration will be 5′ 18″ and the sun will be nearly 60° high. The weather propects are said to be favourable.

A question which is asked in this country—what is the good of all this fuss—may be answered here. The sun is the source of all life on this earth. It controls the weather, the winds, the rainfall, the currents in the ocean. All sources of power and energy are to be traced ultimately to the sun. If the physics of the sun were accurately known, it is only a question of time that meteorological problems, vital to mankind would find their complete solution. Wind, rainfall, changes of weather would be then calculated in advance like the motion of planets. It seems that the attainments of this goal is only a question of time. The journey is long, the goal is not yet in sight, but if the scientific activity of mankind be allowed to continue, probably some day it will be reached.

1.1.3 APPLICATION OF SUBATOMIC THERMODYNAMICS TO ASTROPHYSICS*

INTRODUCTION

Before I take the chair, I wish to express my heartfelt thanks to you for inviting me to preside over this annual gathering of the mathematicians and physicists of India. But I must confess that I feel extremely diffident regarding my ability to entertain you with a topic worthy of the occasion. For we are living in an Augustan age of discovery in the physical science. Even leaving spectacular achievements of our science aside, you will probably agree with me that no period in the history of our science has been so rich in discoveries of the first magnitude as the period 1895-1920. X-rays, Radioactivity, the Electron Theory, the Quantum Theory of Radiation, and the last, though not the least, the Theory of Relativity—all these taken together constitute a revolution in human thought, a revolution which cannot but profoundly modify the future of mankind.

I have, however, chosen to speak on a subject which, in the language of the poet Heine, may be described as 'die alte, die ewig junge Wissenschaft'—the old, the ever-young science.

Let us begin with a little historical retrospect. We know that even in the dawn of civilisation on this globe of ours, astronomy had a peculiar fascination for the thinking section of mankind, and

> "In Babylon, in Babylon,
> They baked their tablets of the clay,
> And year by year, wrote thereon
> The dark eclipses of their day,
> They saw the moving finger write,
> Its Mene, Mene on their Sun,
> A mightier shadow cloaks their light
> And clay is clay in Babylon."
>
> A. NOYES—*The Torchbearers*.

You are all aware that every period of renaissance in physical and mathematical sciences has been marked by an outburst of activity in

*Address as the President, Physics and Mathematics Section of the 13th Indian Science Congress, held at Bombay, 1926.

astronomy as well, and very often, the relations have been reciprocal. The recent discoveries in the physical science have been no exception to the general rule. Indeed, they have blown a new breath of life into her old frame, and in this address, I have tried to give you a picture of this process of rejuvenation.

Spectrum Analysis

It was just sixty years ago that Kirchoff in Germany discovered the principles of spectrum analysis. Astronomers all over the world awoke to the consciousness that an instrument with vast potentialities was placed in their hands for surveying the physical nature of the Sun, and those island universes which we call Stars. I need not tell you how they took advantage of this discovery, and found that in the dark, hitherto mysterious, lines of Fraunhofer, the Sun-god has written the story of its own constitution; or how it was established by Sechi, Lockyer, Pickering and others that from an analysis of the spectra of stars, we can draw conclusions regarding the constitution and physical nature of the stars. My story begins with the details of decipherment.

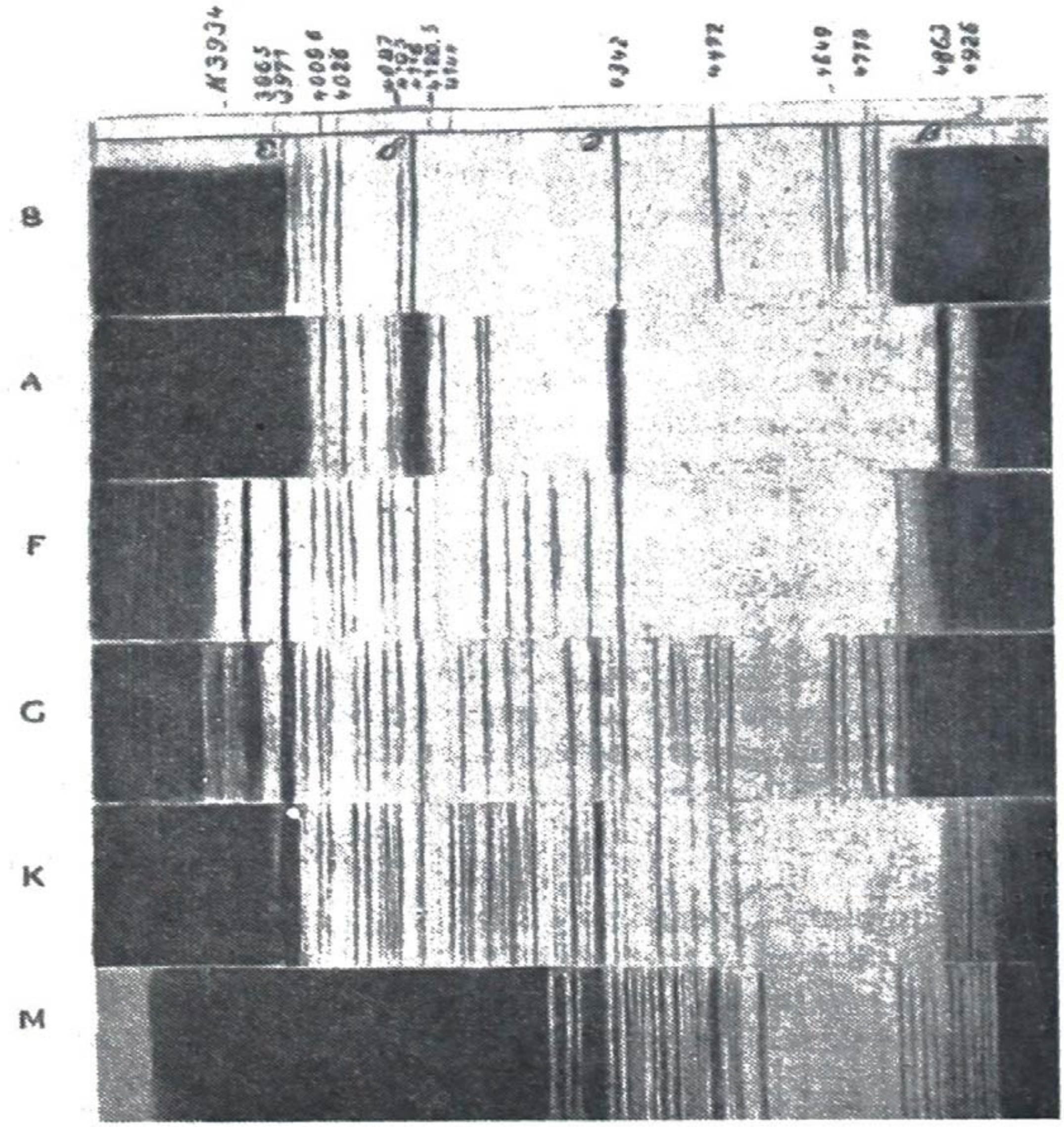
Fraunhofer-Spectrum of the Sun
(The central part has been over-exposed and washed out)

The solar spectrum contains about 20,000 dark lines of which only 6,000 can with certainty be identified with lines of 36 of the known elements. But we know that this earth of ours is composed of 92 different elements, and supposing that the earth is simply a fragment of the sun, it is only natural to conclude that the sun would also show the same number of elements.

The same difficulty presents itself in a more acute form when we turn to the spectra of stars. Yellow stars show spectra similar to that of the sun, white stars show spectra in which hydrogen lines are very prominent at the expense of metallic lines, and bluish white stars were found to show a number of unknown lines which have since been identified with the lines of helium. Lockyer, who undertook a systematic survey of different varieties of spectra of stars found that almost all stars can be subdivided into a number of well-marked groups which gradually merge into one another. The classification was con-

firmed by the spectroscopic survey of 200,000 stars at the Harvard College Observatory by Prof. Pickering and Miss Canon, who denoted these groups by the rather arbitrary sequence of letters.
P· · · ·O· · · ·B· · · ·A· · · ·F· · · ·G· · · ·K· · · ·M· · · ·N· · · ·R· · · ·S
It became customary to speak of B-stars as helium stars, or A-stars as hydrogen stars, because most of the lines appearing in their spectra belong to these elements.

Such a designation carries with it the idea that the star in question is chiefly composed of hydrogen, or helium. The other metals whose lines are not to be found in the spectrum of the star are either absent,



(Spectra of Different Classes of Stars—from Phys. Zeit., 1922) or not formed at all under the physical conditions prevailing in the star.

But there is an inherent difficulty in such an explanation: for if we regard the different classes of stars to be in different stages of evolution (*e.g.* let us suppose the white A-stars will in course of billion, billion years cool down and reduce to the yellow G-stage); then we must admit that they are composed of the same elements. But as we have just seen, this is not borne out by analysis of their spectra. We are therefore driven to the hypothesis that in the course of evolution of stars, there is also a parallel evolution of elements. For example, Ca is not found in very hot stars, but come out only in the cooler stages. We have then to admit that calcium is evolved from simpler constituents.

Lockyer's Hypothesis of Inorganic Evolution

Such a theory was presented by the late Sir Norman Lockyer in his 'Inorganic Evolution', and he supported his contention by laboratory experiments. Lockyer proved that the spectrum of an element was not invariable, but changes with the stimulus. A very good example is afforded by calcium which gives a line 4227, (called *g* by Fraunhofer) very strongly in the flame and the arc, but fades away in the spark, while two other lines, the *H* and *K* of calcium which are very faint in the flame become prominent in the arc, and completely dominate the spectrum of the spark. He found similar results in the spectra of other elements, and in the case of silicon, he found no less than four successive stages. If the atom was invariable, argued Lockyer, how do you account for these variations?

But the scientific world, trained to the fetish of an invariable and further indivisible atom, refused to listen to the arguments of Lockyer. As I had occasion to remark elsewhere, he was like the mythical Greek aeronaut Icarus who, in trying to reach the heavens with wings of wax, had to end by falling into the sea. But such unsuccessful attempts are more important for the progress of science than spectacular successes in narrow, well-chalked out lines.

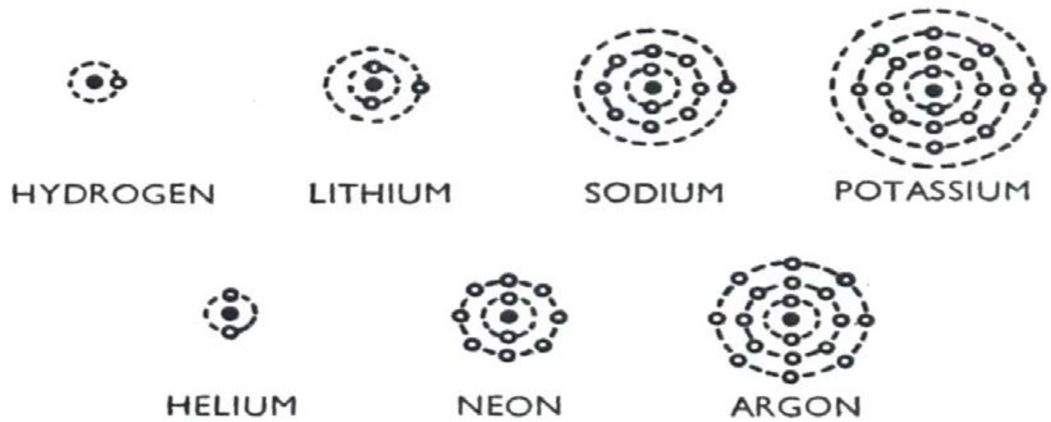
Twentyseven years have elapsed since the date of Lockyer's 'Theory of Inorganic Evolution' and within these twentyseven years, our ideas of matter, energy and other physical concepts have undergone a complete and radical change. The idea of the divisibility of the atom is no longer foreign to us; in fact, it is a matter of common knowledge now. Let us now see how these modern discoveries have led us to a solution of the difficulties confronting Lockyer, and others.

Influence of Heat on Matter

Subatomic Thermodynamics

We can start by considering the influence of a gradually increasing temperature on matter. At the lowest temperature all matter exists in the form of solids. With gradually increasing temperature, the parts loosen; it first becomes liquid, then gaseous, when the molecules fly away from each other. With further rise of temperature, the molecules break up into atmos. What happens next?

The answer to this question could be given only after the Rutherford-Bohr theory of the atom had taken a definite shape. We now know that the atom consists of a central positive charge of N ($N=$ ordinal position of the element in the Periodic Table), surrounded by N electrons grouped in different layers. The spectral lines are due to the vibration of the outer electrons according to the quantum mechanics of Bohr. It is now easy to see that with increasing temperature, the electrons will come against each other more frequently; the



electron will be displaced to higher orbits, and ultimately it will be knocked off. Taking the element calcium, the last process may be described by the chemical symbol:—

$$Ca \leftrightarrows Ca^{+} + e.$$

It is a well-known law in Chemistry that when a complex molecule, say NH_4 Cl, breaks up under the influence of heat into simpler molecules, (NH_3 and HCl in the present case), then at a particular temperature and pressure, there will be a definite proportion between the number of undissociated and dissociated molecules. Guldberg and Waage, Van't Hoff, Nernst and Sackur have shown that the amount of dissociation can be calculated as a function of temperature, and pressure, provided the heat of reaction, the specific heat and the vapour pressure of the substances are known over a wide range of temperature. The idea occurred to Eggert that the same equations with some modification may be applied to calculate the ionisation of elements in stellar masses which, according to Jeans and Eddington, consisted of highly ionised atoms in equilibrium with radiation. Taking the case in hand, if we agree in treating Ca^+, and electrons as monatomic gases, we easily perceive that the effect of gradually increasing the heat stimulus will be first to drive the outermost electron to higher and higher orbits. This is marked by the emission of characteristic lines of Ca, particularly Fraunhofer's *g* line, λ 4227 which is the fundamental line of Ca. Then a certain fraction of Ca-atoms will be ionised. At a certain temperature and pressure, there will be equilibrium between normal Ca-atoms, Ca-atoms, in higher orbits, the characteristic radiation of Ca, Ca^+ and free electrons. The problem is thus complicated, but we assume, as a first step towards solution, that the number of Ca-atoms in intermediate stages is negligible. The fraction x of a Ca-atoms ionised is given by:—

$$log \frac{x}{1-x^2} P = - \frac{U}{2{\cdot}3RT} + \frac{5}{2} log T - 6{\cdot}5 \qquad (1)$$

where U is now the heat of ionisation. In Chemistry, U has to be determined by a separate set of calorimetric experiments, but in the present case, U can be determined from spectral data, or experimental values of the ionisation potential, as done by Franck, Hertz, and other workers.

Formula (1) is derived on the assumption that all the electrons arise from decomposition of the original mass of Ca. In other words, the system is unicomponent. But the electron can also arise from the decomposition of other elements. Hence it is useful to consider the modification of formula (1) when the system is a bicomponent one, *i.e.* there is an excess of electrons. The equation takes the form, first given by Russell

$$log \frac{x}{1+x} \frac{y}{1-y} P = - \frac{U}{2{\cdot}3RT} + \frac{5}{2} log T - 6.5 \qquad (2)$$

Neither formula (1) nor (2) are perfect for we have not considered the mechanism of ionisation, and a number of other points which will be discussed later on. Yet, let us see, how far we can proceed with formula (1) and (2).

Spectra of Ionised Elements

The next question is how we can detect ionisation? This can be done with the greatest ease, spectroscopically. From the works of Fowler and Bohr, it is now certain that the enhanced lines of Lockyer are due to atoms which have lost one or more electrons. Thus Fowler has established that

Lockyer's *Si* I—is neutral *Si*
Si II—Si^{+} (*Si*-atom which has lost one electron)
Si III—Si^{++} (do. two ,,)
Si IV—Si^{+++} (do. three ,,)

To see the application of formulae (1) and (2), let us take the case of *Ca* cited above. According to Fowler and Bohr, λ 4227 indicates the presence of *Ca*. The *H* and *K* lines indicate the presence of Ca^{+}. If in a luminous mass, we obtain the *H* and *K* lines by spectroscopic examination, we at once conclude that *Ca* present in the mass is whooly or partially ionised. The following table illustrates how with increasing temperature, the ionisation of *Ca* gradually becomes complete.

TABLE

Ionisation of Calcium in different Luminous Masses

Luminous Mass	Temp.	Int. $Ca-g$	$Ca^{+}(K)$	$\frac{Ca^{+}}{Ca}$
Flame: King's ..	2000°	300	20	1 : 15
Flame: Furnace ..	2500°	500	30	1 : 16
Flame: Spectra ..	3000°	1000	60	1 : 16
Arc ..	4000°	400	500	8 : 10
Vacuum Arc	4000° (Low pressure)	8	25	25 : 8
Solar Photosphere ..	6500°-7000°	20	1000	50 : 1
Chromosphere ..	5000°-6000° (Low pressure)	8	75	
Sirius ..	10000°	Almost disappeared	Very bright	

N.B.—The intensity scales are different in the different cases, and attention is to be fixed on the relative intensities alone.

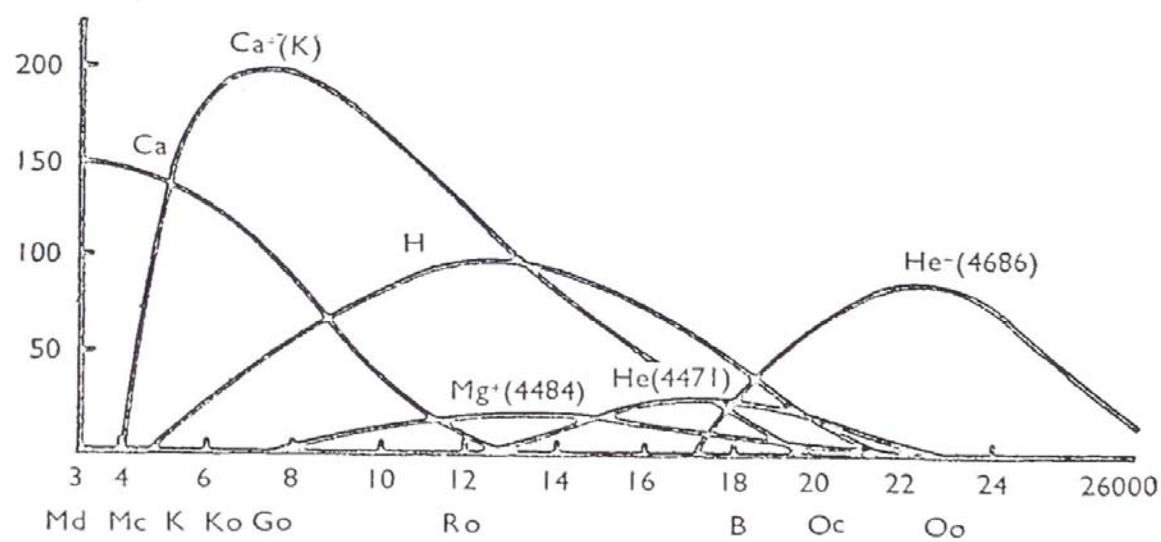
There is a very close correspondence between the ionisation of calcium with varying temperature, and the intensification of the line

K in the stellar classes. There is also a close correspondence between the gradual decrease in the intensity of the g-line, and decrement in the percentage of neutral Ca with increasing temperature. We are therefore justified in saying that the stellar spectra are simply a function of the surface temperature (taking pressure to be of the same order of magnitude in all cases), a view advocated for a long time by Prof. H. N. Russell.

Similar calculations of ionisation can be made in the case of all elements of which the ionisation potentials are known and x, the fraction ionised, can be calculated as a function of T and p.

An application of above ideas lead, for the first time, to a clear understanding of the regular and continuous gradation in the spectra of stars, and thus to a physical explanation of the Harvard classification of stars. Cooler stars show only arc lines because the temperature is not high enough for ionising the elements. The enhanced lines become more and more prominent in the hotter stars, because with increasing temperature, ionisation becomes more complete. From the marginal appearance or disappearance of lines of Ca, Ca^+, Mg, Mg^+, Na, Sr, Sr^+, He, He^+, ... , it is possible to obtain rough values of the temperature of the stars. Values obtained in this way are in agreement with the results obtained by King, Wilsing and Scheiner by more direct methods.

We are also led out of the difficulty mentioned in the outset, viz.

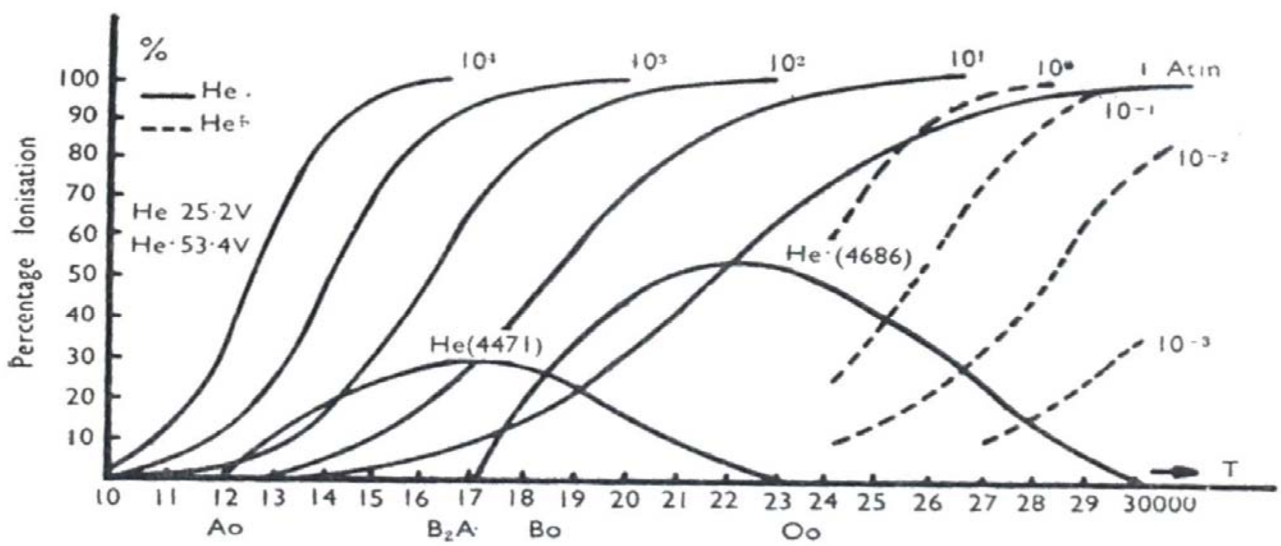


Curve of intensity of Ca-, Ca^+, H^-, Mg^+, He and He^+ lines according to Harvard Publication Ordinates are in arbitrary units, abscissa represent spectral classes and the temperature are those given by Saha (taken from an article by R. Emden in the Phys. Zeit. (1922)

why in the hotter stars, only lines of *H*, *He* and certain light elements are prominent, and metallic lines entirely disappear. This is so because at the high temperature prevailing in the star, the metals, owing to their low ionisation potential become entirely ionised while *H* and *He* become only luminous. Thus the tendency in former years, to label these stars as hydrogen or helium stars, must now be given up. There is no reason to suppose that the chemical composition varies materially from star to star.

Influence of Pressure on Ionisation

If we refer back to formula (1), we find that besides temperature, pressure has an appreciable influence on ionisation. A reduction in pressure is always accompanied by an increase in the percentage ionisation. The following table shows how the percentage ionisation of hydrogen, and helium increases with decreasing pressure:—

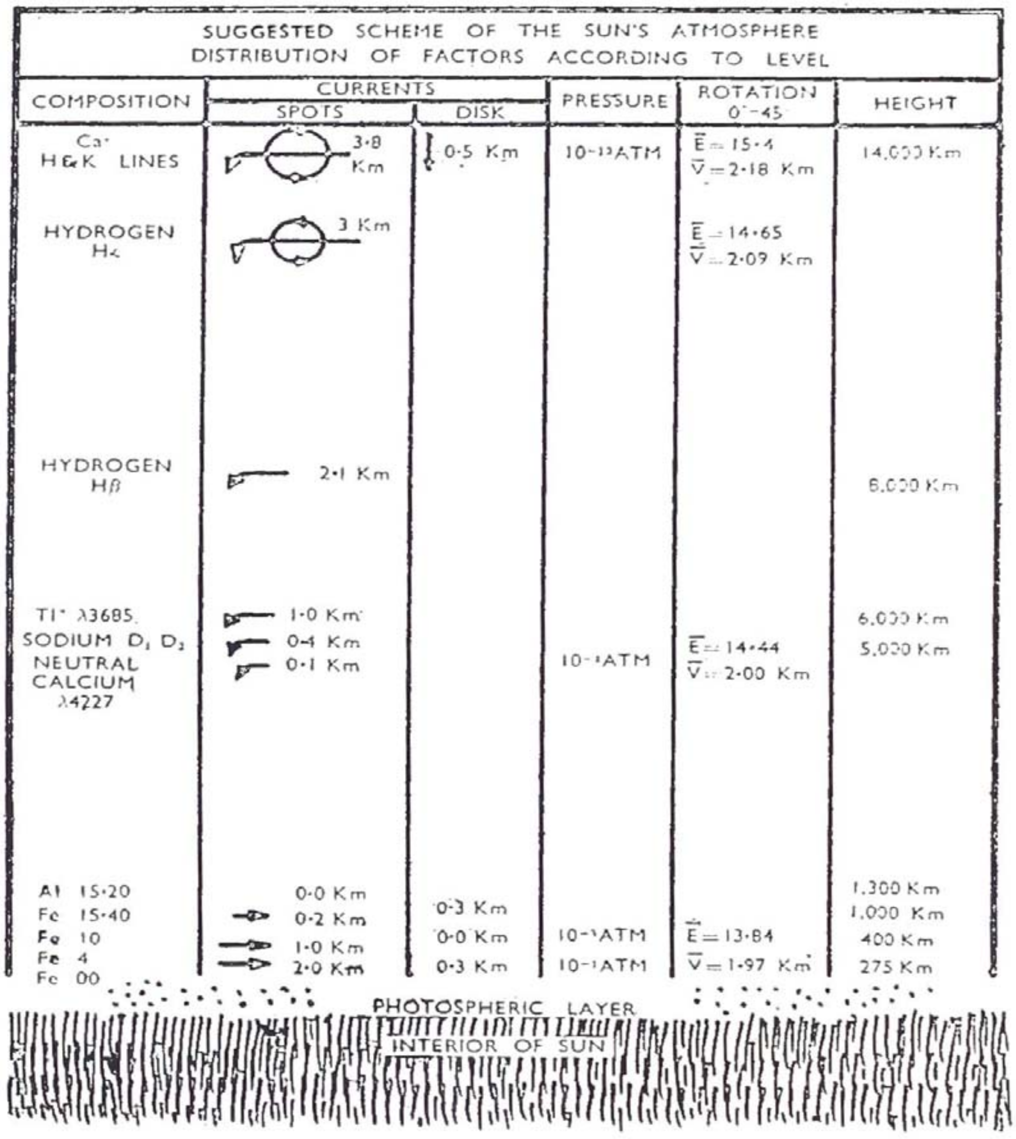


[From an article by R. Emden, Phys. Zeit 1922]

This simple fact provides us with the explanation of the important differences between the Fraunhofer spectrum, and the spectrum of the solar chromosphere. Lockyer was the first to find out that the two are not the exact reversal of each other, as an application of Kirchoff's law would lead us to expect. The main differences are:

(1) Fraunhofer spectrum contains only 5 hydrogen absorption lines, viz. $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, while Lockyer, Evershed, and Mitchell discovered no less than 35 hydrogen Balmer lines in the flash spectrum.

(2) No helium lines occur in the Fraunhofer spectrum, while the flash spectrum shows a pretty large number. In fact as is well-known, the D_3, line was first discovered by Lockyer in the flash spectrum, and anticipating that it was due to some



[Taken from a paper by St. John, Astrophysical Journal]

element still unknown on the earth, he took the bold step of christening it Helium after Helios, the Sun-god.

(3) The enhanced lines of all elements are more prominent in the flash spectrum that the lines of the neutral atom. They reach a greater height in the solar chromosphere that the un-

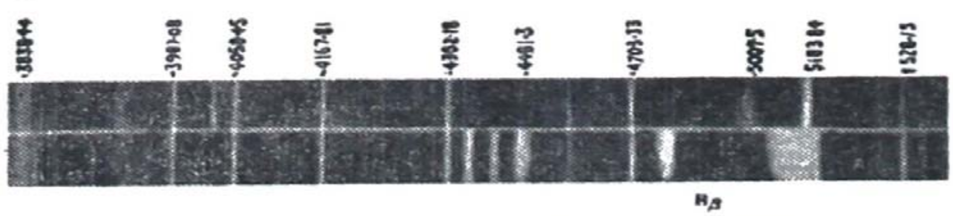
enhanced lines. In fact, the upper chromosphere is entirely made up of ionised elements as illustrated in Plate 7, diagram which is based on the eclipse data of Mitchell, and is taken from a recent paper by St. John.

Lockyer expressed these results by saying that the spectrum of the flash was similar to that of the hotter star, α-Cygni, class $g\ A_2$. Thus in terms of temperature, the chromosphere shows as large a stimulus as temperature of 10000°K, while on the photosphere, the temperature cannot exceed 7000°K.

The enhancement of stimulus on the chromosphere is of course unquestionable, and Lockyer did not hesitate to assert, that the temperature of the chromosphere was higher than that of the photosphere. But the analogy was pushed too far, and he said that the temperature of a star decreased inwards and that the interior might be quite cold. But he failed to convince anybody of the correctness of his arguments.

The ionisation theory leads easily out of this dilemma. The enhancement of stimulus in the chromosphere is due, not to increased temperature, but to reduction in pressure, and this takes place in spite of reduction in temperature.

That reduction in pressure may give rise to enhancement of stimulus has been definitely asserted by Mitchell in 1913 in his study of flash spectra, and Fowler and Payn had actually given an experimental proof of it as early as 1903. They showed that the vaccum arc of *Mg* gives the enhanced line λ 4481, while the ordinary arc does not show a trace of it.



Spectra of *Mg* arc in air and in vacuum. Note the development of 4481, due to Mg^+ in vacuum arc. It is entirely absent in the open arc. It is due to reduction in pressure. Taken from a paper by Fowler and Payn in Proc. Roy. Soc. 1903

The occurrence of helium lines in the chromosphere can also be explained on the same grounds. The visible lines of helium arise not from its normal orbit, but from higher orbits, requiring an excitation potential of over 19 volts, and such a high stimulus is not present in the layer which gives rise to Fraunhofer lines. But this stimulus is produced in the higher layers owing to reduction in pressure, with the result that we get the visible lines of He in the flash. Probably experiments can be devised which will give us quantitative data regarding the difference in pressure between the usual reversing layer and the higher chromosphere.

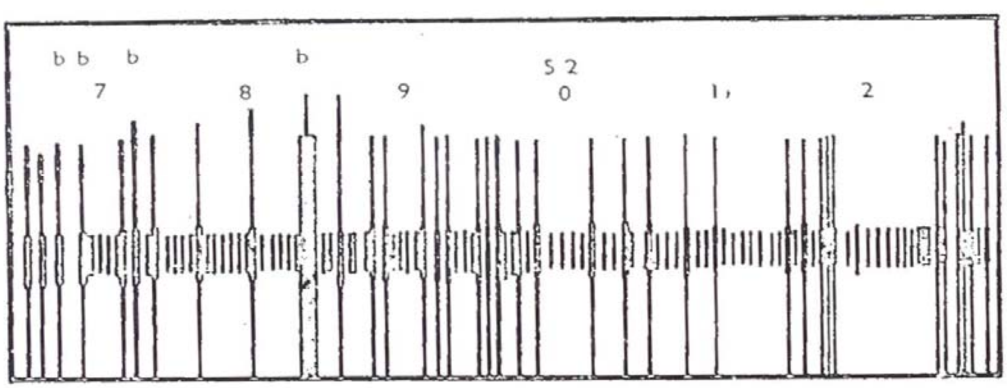
Elements in the sun

We shall now see how the ionisation theory helps us in understanding the difficulties connected with the identification of lines in the Fraunhofer spectrum, and the occurrence of only 36 elements on the solar surface.

In the alkali group, *Rb* and *Cs* are the two elements of which no lines could be found in the Fraunhofer spectrum. These two elements have the lowest ionisation potential of all, and actual calculation shows that on the surface of the sun, they would be completely ionised. The chief lines of the enhanced spectra lie far in the ultraviolet. Hence as regards the identification of these elements, we are placed, to use a rather slang expression, between the devil and the deep sea. This is true not only of *Rb* and *Cs*, but also of many other elements, because most intense lines lie beyond the range within which our observations have to be limited.

But if any part of the solar surface undergoes a local cooling, *Rb* and *Cs* may partly return to the neutral state. This actually happens in the sunspots, for Fowler has proved that the spectra of spots is similar to that of the *K*-type of stars and hence the temperature cannot be far beyond 4000°C.

It was predicted from the above-mentioned line of argument, that *Rb* and *Cs* may occur in the spot in the neutral state. The verification of this prediction by Prof. H. N. Russell, who discovered the infrared



Spectrum of Sunspot in the middle compared to the general spectrum of the sun. Taken from Pringsheim's Physik der Sonne pair $\lambda \left.\begin{matrix}7911\\7800\end{matrix}\right\}$ of *Rb* in some spot spectra taken by Dr. Brackett of the Mount Wilson Solar Observatory constitutes one of the earliest and the greatest triumphs of the ionisation theory. In recent years some enchanced lines of *Rb* and *Cs* have been indentified in the solar spectrum, so that the presence of these elements in the sun is now established beyond doubt.

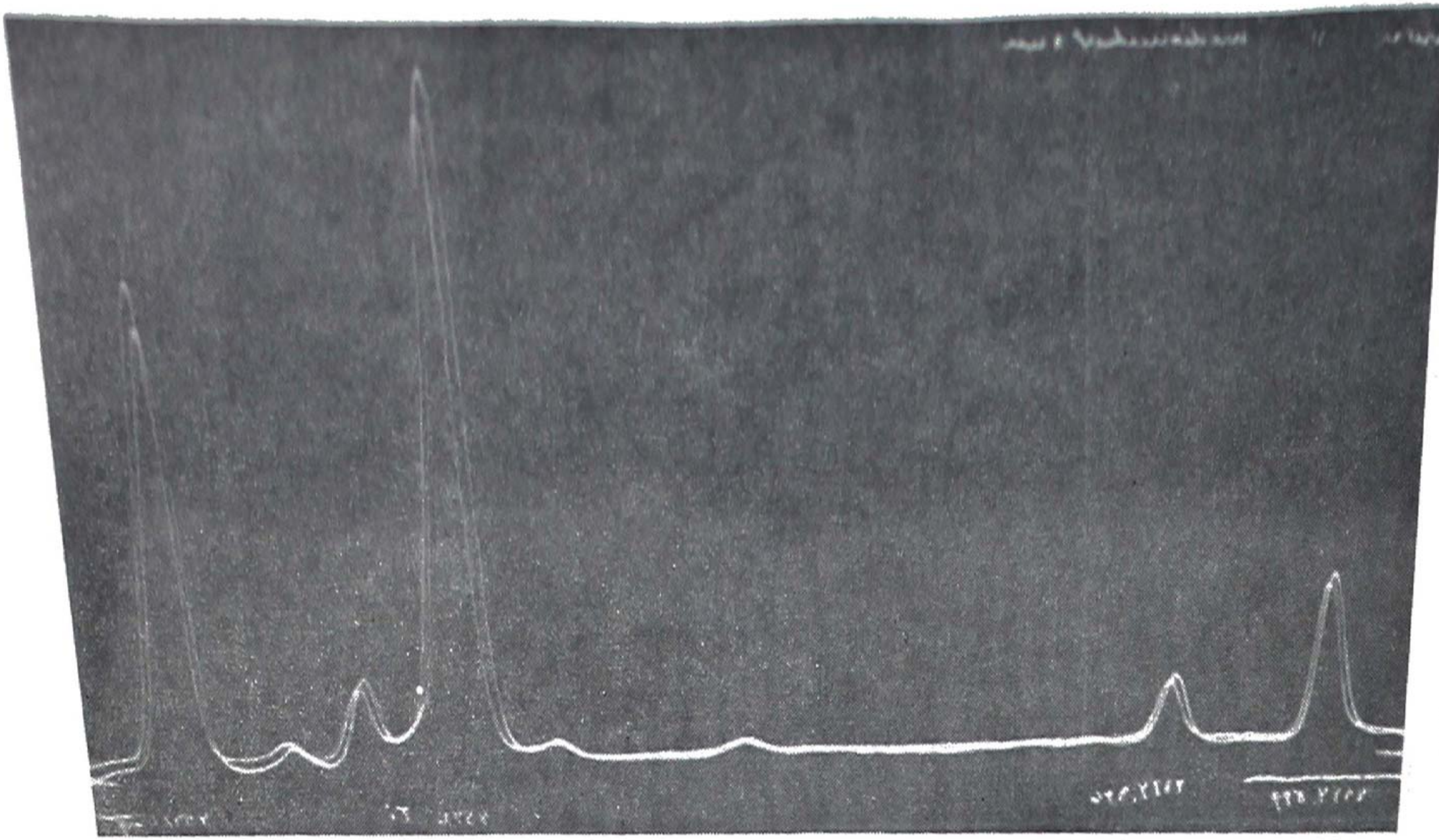
As regards other missing elements, we come across difficulties of a nature peculiar to each element. Take, for example, the element oxygen. This is the most plentiful element on the earth and it was naturally expected that it would show very prominently in the sun. But for a long time, no trace of any line of oxygen could be found in the Fraunhofer spectrum. It was only in 1914, forty-five years after Kirchoff's discovery, that Runge identified a triplet in the extreme red which he proved to be identical with an oxygen triplet. But why did this triplet of oxygen occur so faintly in the Fraunhofer spectrum? The answer has been provided only recently from an analysis of the spectrum of oxygen. Hopfield has recently shown that the principal lines of oxygen are in the Schumann region, and hence they are entirely cut off. The lines of oxygen which can be used for identification belong to minor combinations, and require very high stimulus,—about 10 volts for their production. Hence the prospect of getting *O*-lines in the sun is very small, though the element may be more plentiful than hydrogen or calcium, the lines of which are so prominent on the sun. Similar explanations may hold for the inert group *Ne*, *A*, *Kr*, *Xe* and Nitrogen.

In fact the ionisation theory coupled with a knowledge of the constitution of the spectra of elements lead us to a complete justification of the saying of Rowland "If the earth were suddenly heated to the temperature of the sun, its spectrum would be the same as that of the sun."

Spectra of Faculae

Just as spots are regions of local cooling, the faculae are regions where the temperature has been increased over that of the general photosphere. Hence it was predicted that the spectrum of the faculae would be similar to that of *F*-class of stars. This prediction has been verified by Dr. St. John of the Mount Wilson Solar Observatory who took simultaneous photographs of the spectra of the sun and the faculae, and found that the lines of Ti^+ were considerably enhanced in the faculae.

Lower "undistrubed sun"



4571 Mg. 4572 Ti. 4574, 396 4574, 899

[Microspectrophotogram of a portion of the solar and facular spectrum in the region 4400, containing enhanced lines of Ti. Note that the intensity (represented by the ordinate) of Ti^{+} lines increases in the facula. From a copy kindly presented to the author by Dr. St John]

Conductivity of Flames

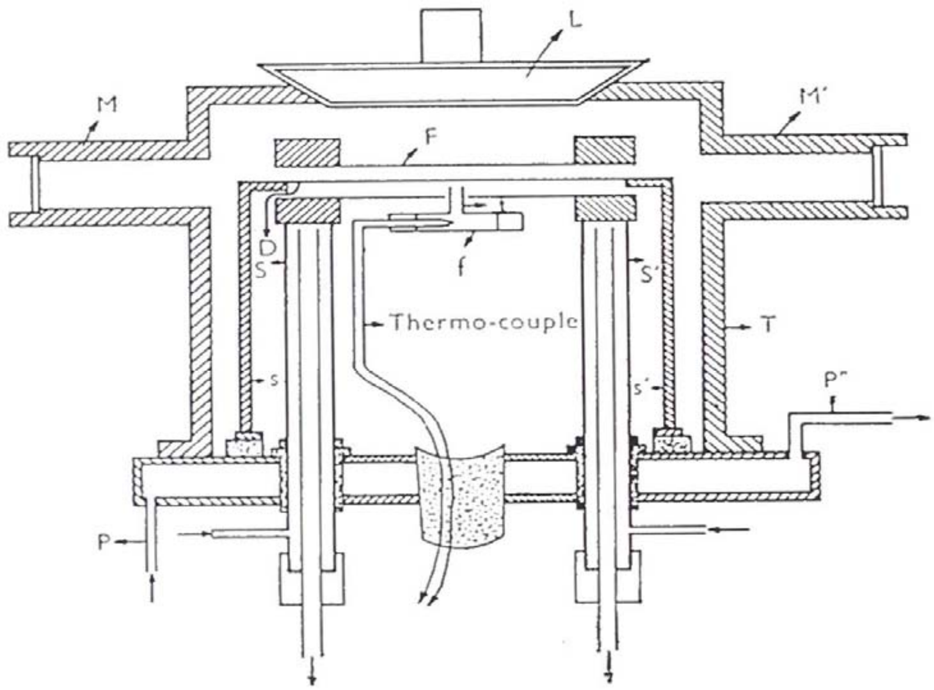
Recently, the ionisation theory has received confirmation from an unexpected quarter. It is well-known that a Bunsen flame becomes conducting when sprinkled with metallic salts. Very careful experiments on the subject were carried out by Gold and H.A. Wilson, who found that the conductivity was highest in the case of the alkali elements, and in fact in the order *Cs*, *Rb*, *K*, *Na*, *Li*. After the ionisation theory was published, Noyes and Wilson undertook a re-examination of the whole data, and found that they could be explained on the supposition that the metals were ionised at the temperature of the flame, according to equation (2), and the conductivity was wholly due to the free electrons arising out of the ionisation of the atoms. In fact the agreement was so good, that according to Noyes and Wilson, the ionisation potential could be calculated in the reverse way from the conductivity of flames when sprinkled with metallic salts.

Experimental Verification

According to the ionisation theory, all atoms would be split up, at high temperatures into electrons and a positive residue. At low temperatures the gas would be electrically neutral, i.e. it would not conduct electricity at all. But at high temperatures owing to the presence of free electrons, a considerable amount of electrical conductivity may be expected.

When the ionisation theory was first propounded there was no experiment to verify this deduction from the theory though indeed a large number of experiments to observe this effect had previously been done by J.J. Thomson and Mac Lennan on mercury vapoure with entirely inconclusive results. Now mercury has an ionisation potential of 10·45 volts, and calculation shows that a temperature of at least 6000°K is required to produce apprecialble ionisation. Such a temperature cannot be realised in the laboratory, and we have to fall back upon a substance for which the ionisation potential is very low. Analysis of series spectra shows that the alkali elements, particularly Cs, have the lowest ionisation potentials, but experiments with them are naturally more difficult to perform.

Some preliminary experiments at Prof. Nernst's laboratory at Berlin on alkali vapours confirmed these predictions. Recently a more elaborate series of experiments in collaboration with Mr. N. K. Sur of the Ewing Christian College, Allahabad, have been undertaken in my laboratory at Allahabad. The apparatus is shown in the adjoining figure. Experiments were undertaken with *Na*, *Ca*, *Sr*, *Mg*, and *Zn*, and the results, though preliminary were found to be incomplete accord with the ionisation theory.



[The apparatus consists of a vacuum furnace F enclosed within an iron chamber M which is closed by quartz windows. The furnace is heated to temperatures of 2500° by electric current. The element is kept in the smaller furnace *f* which, when heated, yields vapour in F. Electrical conductivity of the vapour space in F is measured between the surface of F and a centrally mounted wire by the ammeter voltmeter method]

Ionisation in a Mixture of Gases.

As remarked above, ioniastion in a mixture of gases is given by Russell's equation

$$\log\frac{x}{1-x}\;\frac{f}{1+f}=\frac{U}{-2{\cdot}3RT}+\frac{5}{2}\log T-6{\cdot}5$$

where f=concentration of electrons, is arbitrary. Russell applied this equation to a discussion of the difference between the spectra of spots and of the photosphere. He found that as a rule the spark lines of all elements (particularly of the alkaline earths) are weakened in the spot, while the arc lines are greatly strengthened. The discussion was also extended to *Ti*, *Fe*, *Zn*, and *V*.

Russell drew another very important consclusion from equation (B). If we start with *Ca* alone and continue heating it, then at a certain temperature a definite equailibrium will be reached between *Ca*, Ca^+, and electrons. If we now add some other substance like potassium which becomes ionised more readily, the stimulus will, by preference, pass through the more easily ioniasble atom, and the proportion of *Ca* atoms will become less, the enhanced lines *H* and *K* will become greatly weakened. The experiment was actually performed by Dr. A. S. King in his tube furnace. A tempenature of 1800°C was chosen, and with *Ca* alone in the tube, the lines *H* and *K* were obtained in absorption. A small quantity of potassium was then introduced. The *H* and *K* now completely disappeared, while the *g*-line remained entirely unaffected. This also explains the phenomenon recorded by Paschen that if an element under some condition of excitement gives a spectrum in which neutral lines and enhanced lines are freely mixed together, the enhanced lines can be almost entirely suppressed if the element is mixed up with some more easily excitable element.

Luminosity of Heated Vapours

The ionisation theory also puts an end to the long-standing controversy whether gases can be make luminous by heat alone. A large number of experiments was done by Pingsheim and others, and they concluded that at least up to 2000°C it is not possible to excite permanent gases like *H*, *He*, *Ne*, *A*, *O*, and *N*, to luminescence by heat alone. On the other hand, King had shown that the alkalies, the alkaline earths, thallium, *Fe*, *Ni*, *Co*, and many other elements can be made to give out their line spectrum in his tube furnace, where temperatures varying from 1800°C to 3000°C are produced by passing electric current through a graphite tube in vacuunm. King took spectra at different temperatures, and showed that different classes of lines are emitted at different temperatures.

Many investigators like Hemsalech and others tried to interpret these results as purely electrical phenomena, but King stoutly defended his point, and showed that the lines persisted even when the current was cut off, as long as the temperature did not fall very low.

According to the conceptions presented above, the standpoint taken by King was undoubtedly right, though as a result of Bohr's theory, the controversy electrical stimulus *versus* thermal stimulus is seen to be without any significance. According to Bohr's theory, the line radiation of an element is due to the jump of the electron from a meta-stable to a more stable orbit, and hence luminiscence depends entirely upon the transference of the electron to the higher state. This can be produced by electrical discharge as well by heat, if the temperature is sufficiently high. Thus as mentioned above, if we start with calcium, the products of reaction at high temperature are not only Ca^+ and e, but calcium atoms in excited states, and these give rise to the arc spectrum of calcium. The temperature required for luminiscence will depend upon the exciation potential of the line, i.e. upon the difference in the energy between the metastable state to which the line belongs and the normal state.

Now in the case of metals studied by King, the excitation potentials are rather low; hence the spectrum was obtained even at as low temperatures as 2000°C. But Pringsheim, on the other hand, chose elements of which the excitation potentials for visible lines are very high. Thus to produce the $H\alpha$-line of the hydrogen we require at least 13·6 volts; the D_3 line of helium requires at least 21 volts. Such large stimulii cannot be produced even at the highest temperatures available in a laboratory. In the case of helium, in fact, we know from stellar data that they do not occur earlier than at B class of stars, and temperature here cannot be less than 12000°C.

King's data on the classification of lines on a temperature basis are thus a valuable guide to a knowledge of the excitation potential of the element in question, and in recent years, they have been used with great advantage by Catalan, Laporte, Meggers, Kiess, Walters and others for the classification of line-spectra of elements of higher groups. But the exact law of the production of these orbits at higher temperatures has yet to be worked out.

Subatomic Thermodynamics

The considerations presented in the previous pages foreshadow an extension in the "Thermodynamics" which may be fitly styled as "Subatomic Themodynamics." It will deal with the physical processes which occur when atoms are split up by heat into electrons and positive residues. At present, the application is confined to stellar bodies, but it is expected that in future, more experiments bearing on the subject will be carried out in the laboratory. The theoretical progress in the subject will naturally go hand in hand with our knowledge of the structure of the atom, and with physical study of radiation which, according to Bohr's theory, is simply a byeproduct of the changes in the position of the component electrons. But much will depend on the introduction of new and more powerful methods in thermodynamics, and works in this direction are already appearing.

New Methods in Thermodynamics

Before dealing with these new works on subatomic thermodynamics, we shall give a short sketch of the more recent methods in thermodynamics, which have made it possible to start with a working theory of thermal radiation and ionisation of gases. It was Boltzmann who first cleared up the nature of the mysterious and elusive function 'Entropy,' and established the first link between thermodynamics and statistics. As is well known, according to Boltzmann, S (Entorypy)$=k \log W$, where W denotes the probability of a statistical system. Boltzmann dealt with only comparative values of the probability, but Planck showed that it was possible to assign an integral and absolute value to the probability of every thermodynamical system. Following a method given by Gibbs, he calculated the value of absolute probability for a perfect gas, and for perfectly black radiation. It was in this latter connection, that he was led to the introduction of the famous universal constant 'h' bearing his name. Planck recognised very early that $h=\iint dp.dq$, where p and q are the momental and positional co-ordinate of each unit in a thermodynamical system for each of its degrees of freedom. Sackur and Tetrode simultaneously calculated the absolute value of entropy of a perfect monatomic gas by using the theorem that $h=\iint dp.\ dq$. It was in this connection that Sackur deduced the correct value of the chemical constant for a monatomic gas (viz. $C=-1{\cdot}62+\frac{3}{4}\log M$). The idea of chemical constant we owe to Nernst, and it is superfluous to add what a great part it has played not only in the study of chemical equilibria, but also in the development of the theory of thermal ionisation of gases.

A few years ago, (1920), Professor Ehrenfest of Leiden undertook a re-examination of the fundamental points of Planck's thermodynamics, and showed that problems of dissociation equilibrium are best dealt with by the introduction of a function $\{\gamma\}$, which may be defined as the total phase space described by the system, when it is built up from the elementary units. Ehrenfest's method has been very largely followed by recent workers on thermal ionisation of gases, particularly by Fowler and Milne, by Becker, and by the present writer and R. K. Sur. The present writer and R. K. Sur, have shown that Planck's W and Ehrenfest's $\{\gamma\}$ are connected by a very simple relation, and there is essentially not much difference between the two methods. Ehrenfest's method, it may be mentioned, is equally applicable to matter as well as to radiation.

Fowler and Milne's Work

The essential points in Fowler and Milne's work will be realised from the following breif summary:—As mentioned above when an original mass of Ca is heated, the products of decomposition are not only Ca^+, e, but also Ca–atoms in the excited states, which, being unstable, are giving rise to the line spectrum of Ca. As the spectrum of Ca is rather complicated we shall take a simpler case viz. H. The products of decomposition are than H, e, H–atoms in 1_1, 2_2, 2_1, 3_3, 3_2, 3_1 . . . . states, radiation

$$\nu = N\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$$

constituting the Lyman Series, the lines

$$\nu = N\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$$

constituting the Balmer series etc. . . . In the simple theory sketched above, we neglected these intermediate orbits which is justified on the ground that even at the highest temperatures, their proportion, calculated according to Maxwell's theorem, is negligible.

By applying Ehrenfest's method, (which has been improved on mathematical points), R. H. Fowler obtains the equation:

$$log \frac{x^2}{1-x^2} P = K - b\ (T)$$

in place of the original equation. The function $b\ (T)$ represents the occurrence of intermediate orbits

$$b\ (T) = g_0 + g_1\ e^{-\frac{u_1}{RT}} + g_2\ e^{-\frac{u_2}{RT}} + \ldots .$$

where g_0, g_1, g_2 ... are the intrinsic weights, of the normal state, and the excited states having the total quantum numbers 2, 3 . . . u_1, u_2 represent the energy of excitation of these states.

For the hydrogen atom, $u_n = Nh\left(1 - \frac{1}{n^2}\right)$, according to Bohr, and $g_n = n\ (n+1)$ according to Herzfeld and Epstein.

Fowler and Milne have drawn very interesting conclusions from this equation, but before giving an account of their work, it ought to be mentioned that $b(T)$ is divergent. This is due to the fact that g_n has been taken to be proportional to the number of orbits possible having the total quantum number n. The procedure seems to be unsound on physical grounds. Fowler is of opinion that the difficulty can be avoided by cutting the series at some finite term. He justifies the procedure on the following ground:—The radius or the major axis of the *n-th* orbit is $a_0 n^2$, and hence at a finite pressure, when n is sufficiently large, the vibrating electron may run to such a distance from the nucleus, that it passes under the influence of other nucleii as well, it passes, so to speak, into No-man's land. As was pointed out in a recent note to Nature, there must therefore be a limit to the number of orbits developed, a limit depending on pressure.

The above speculations are confirmed by the experiments of Wood who has shown that higher Balmer lines are produced only when the pressure in the discharge tube is very low, and also from the number of Balmer lines occurring in stars having varying pressure in the reversing layer. But these considerations by no means justify the assumption $g_n = n(n+1)$.

The conclusions reached by Fowler and Milne are however largely independent of the particular value which may be assigned to g_n, and depend on the occurrence of the factor $e^{-U_n/KT}$ in $b(T)$. It will be recalled that many elements in the Sun and the stars have to be identified by subordinate lines. e.g. Mg which is identified by the b-lines, $2\,p-ms$, or Mg^+ which is represented by λ 4481, $3d-mf$. Fowler and Milne discovered that there is a very remarkable difference in the bahaviour of the principal lines and subordinate lines of known elements in the stellar sequence. The principal lines are most intense at the lowest temperatures and gradually die out with increase of temperature. The subordinate lines are at first very faint, gradually rise to a maximum and then again fall off to zero.

Fowler and Milne explain the phenomena on the following grounds:—At the lowest temperatures, all atoms are in the normal state; there are none in the higher states. With increase of temperatures, the higher states begin to come out. When the temperature is still further increased, the atoms begin to get ionised, and hence the proportion of atoms in the subordinate series begins to fall off. A maximum must have been reached in the interval.

When the above ideas are translated into mathematical language, and conditions for maximum concentration of subordinate levels applied, we get a relation connecting the electron pressure in the reversing layer and this temperature:

In fact

$$P \text{ (electron pressure)} = \frac{\cdot 322}{b\,(T)} \frac{u_r + \frac{5}{2}RT}{u_1 - u_r} \; T^{\frac{5}{2}} e^{-\frac{u_1}{RT}} \qquad (D)$$

For example, the Balmer lines of hydrogen arise from the 2_2 orbit, and they reach their maximum in the A-class. The temperatures of these stars lie between 10,000°K and 12,000°K, substituting these values in (D), we obtain

$$P_e = 1{\cdot}31 \times 10^{-4} \text{ to } 3{\cdot}07 \times 10^{-3} \text{ atmospheres.}$$

Fowler and Milne have thus found a very elegant method of determining the pressure. This is in itself a result of the first magnitude. for ionisation depends very largely upon pressure. and after Einstein's discovery of the shift of the lines by gravitational potential. the older values which were based on pressure-shift of the lines have been rendered obsolete.

Values of P_e have been calculated from considerations of the maxima of several elements, and they invariably give a range of pressure varying from 10^{-4} to 10^{-5} atmospheres. These values recall the statement of Jewell that "the whole mass in the reversing layer of the sun can be contained in a thimble."

Ionisation of elements of higher groups

Elements of higher groups, like C and Si, having two or more electrons in the outer ring show multiple stages of ionisation in the stellar range. Thus we get lines of Si, Si^{+}, Si^{++}, Si^{+++} in the stellar range. In the case of ionised elements, principal as well as subordinate lines would show maxima owing to the commencement of the next stage in ionisation. But a scrutiny of stellar data in these cases shows that the ionisation potential is not the only factor in determining ionisation. Thus Ba and Na have the same I.P viz 5·1 volts, but Ba is completely ionised in the sun, while Na is at best only 60 or 70 % ionised. For elements with higher valency, i.e., with more electrons in the outer ring, the effect is much more pronounced.

The matter is very closely connected with the structure of the atom, and the nature of its spectrum. A comparison between Na and Ca will bring out the point clearly. Sodium has only one electron in the outer ring, the electrons in the inner ring being very tightly coupled to the core. This is shown from the fact that the first I.P. of

Na is 5·1 volts, the second I.P. is not less than 35 volts (Bureau of Standards measurements). When a stimulus falls on *Na*, the whole shock falls on the outer electron. Besides *Na* has got a very pronounced principal series, the leading members of which, the D_1 and D_2, completely dominate the spectrum. In other words, ionisation can take place only in one way, by passage from *Is* (normal) through 2*p*-stages.

Calcium has two electrons in the outer ring and both of them are rather loosely attached, for the first I.P is 6·1 volts, the second about 13 volts. Hence when any stimulus falls on *Ca*, both electrons may sometimes be simultaneously excited. The reality of simultaneous excitation of two electrons has been established by Russell and Saunders and Wentzel who have recently shown that a strong group of arc lines owe their existence to such a process.

Generalising we may say that for alkalies and for elements which acquire an alkali-like structure by loss of electrons (say Ca^{+}, Al^{++} . . .) the stimulus can excite only the outermost electron, and most of it is spent in disturbing the normal level. For elements with two or more outer electrons, the stimulus can sometimes excite, more than one electron at the same time and the stimulus is distributed amongst a number of levels.

Recent work on the analysis of spectra of elements of higher groups shows that the terms normal level, and principal level, lose, in these cases, much of their significance. There are always a number of close lying normal levels, and the stimulus is distributed amongst them.

While the nature of the phenomena is well understood, it is very difficult to translate these ideas into a thermodynamical theory. Meanwhile all attempts to frame a rigorous theory of ionisation and radiation for higher elements must be of an *ad hoc* nature, pending a fuller knowledge of their spectra, and of the intrinsic weights of the different orbits.

Kinetic Method

Prof. Milne has recently given an entirely new method of dealing with thermal ionisation of gases. In contradiction to the thermodynamical method hitherto used, this method may be called the kinetic method. These two method find their parallel even in the study of chemical equilibria. Let us represent a typical homogeneous equilibrium by the equation

$$mA+nB \leftrightarrows pC+qD.$$

Then according to the thermodynamical method (mA denoting m-atoms of type A) we put

$$mS_A+nS_B-pS_C-qS_D=-\frac{U}{T}$$

where S's are the entropies, and U is the heat of reaction.

In the kinetic method, the rate of change from left to right depends on the number of times m molecules of A come into contact with n molecules of B. The velocity of reaction

$$V_{AB}=K_1\ C_A^m\ C_B^n,$$

and

$$V_{CD}=K_2\ C_C^p\ C_D^q,\ C=\text{concentration}.$$

In the equilibrium case

$$V_{AB}=V_{CD}\ \text{or}\ \frac{C_A^m\ C_B^n}{C_C^p\ C_D^q}=\frac{K_2}{K_1}=\text{a constant}$$

By using this method, Boltzmann deduced a formula for molecular dissociation which has the same form as the formula derived from thermodynamics.

Thermal ionisation of gases is only a particular form of chemical dissociation with the difference that the details of the mechanism are much better understood in the former case. Hence, it is expected that the kinetic method would be fruitful here, but a detailed treatment of the reaction is necessary.

The Unit Mechanism and Principle of Detailed Balancing

Every kinetic method depends on a closer treament of the mechanism of reaction. The reaction in the present case is the decomposition of M into M^+ and e, and this can take place in a variety of ways. To any one of these processes, there must be an opposite process resulting in recombination of M^+ and e to M. A pair of such oppositely directed processes has been called by R. H. Fowler "Unit Mechanism." Each one of these mechanisms, by themselves and without the aid of any other process, would give us some fundamental laws of general validity. This is known "As the principle of detailed balancing."

The ionisation of M-atoms placed in a thermal enclosure can occur:

(*a*) As a result of collision of two M-atoms (ionisation by collision)—the rate of ionisation is then proportional to the square of the pressure.

(*b*) As a result of absorption of radiation by *H*-atoms, normal as well as excited (photo electric ionisation).

Thus, according to Bohr's theory, radiation of frequency greater than $\frac{N}{1^2}$, when falling on a normal *H*-atom would completely ionise it. If the electron is in the 2-state, radiation shorter than $\nu = \frac{N}{2^2}$ would ionise the atom. This is true of every element, and in the case of alkalies it has been definitely proved that these vapours are ionised by radiation shorter than that corresponding to the limit of the principal series. The reverse process of capture when M^+ and e come together must also be radiationless. Hence when M^+ and e combine together, the energy set free must be carried away by a third body. Hence the reverse process to (*a*) is a three body encounter between M^+, e, and M (or e), the energy liberated being carried off by M. The unit mechanism (*a*), (*a'*) has been studied by R. H. Fowler in an extension of the ideas of Klein and Rosseland on the so called collisions of the second type.

(*b*) The reverse process to (*b'*) must naturally be the capture of an electron by the ion M, with liberation of radiant energy. But Milne finds that (*b*) and (*b'*) together do not give the law of reaction isochore. So he postulates that electrons may be captured even under the influence of radiation. This last process is analogous to Einstein's "Negative Einstrahlung" or stimulated emission. Thus we may write

Rate of photoelectric ionisation = Rate of capture with emission of radiation + Rate of capture under the influence of radiation.

Compare it with Einstein's well-known method of deducing the law of black body radiation.

Rate of absorption of light = Rate of spontaneous emission + Rate of emission under the influence of the field of radiation.

With the aid of certain assumptions, Milne calculates the rates of free and stimulated captures and equates it to the number of photoelectric ejections. The equation may be used in two ways. It may be employed to evaluate the degree of ionisation, in which case some further assumptions are necessary. Conversely, assuming the thermodymamic formula for ionisation, it can be used for finding out the law of probability of electron capture. In this way Milne arrives at the conclusion previously arrived at by Eddington in his study of opacity of stars, namely the electron is captured, only when it actually hits the nucleus. Probably a more rational way of expressing the result will be that only one in 10^5 collisions result in a capture.

Applied to *H*, *Ca*. and *Hg*, Milne's method furnishes values of absorption coefficients which are in general agreement with experimental values.

It is yet too early to predict how far Milne's method in its present form will be able to advance the theory of thermal ionisation. The great difficulty which is encountered in the development of these methods is due to the absence of any suitable quantum theory of absorption of lines. The present theories are a sort of half-hearted compromises, with the old Lorentz theory which ascribes absorption to damping produced by collision.

Influence of Radiation on Ionisation Equilibrium

The formulae for ionisation which have been given above yet suffer from another defect. We have been making the tacit assumption that the radiation is in equilibrium with matter at the temperature concerned. While this assumption is quite true when we heat the metal in a closed space, or in the interior of stars, it is evident that in many cases, the assumption is far from the actual truth. We take the following typical examples:

(1) When continuous radiation is allowed to pass through a mass of sodium vapour as in Wood's absorption experiments. Here the vapour may be at a temperature of 500-600°C, while the radiation, if it comes from the arc, is at a temperature of 4000°K.

It may be pointed out that all photo-chemical reactions—such as the ozonisation of oxygen by ultraviolet light, etc.—belong to this class. Only in this case, the mechanism of the reaction is not quite so clear as in the case of sodium absorption.

(2) The chromospheric phenomena,

The chromosphere is at a much lower temperature than the photosphere (say 5000°K to 6500°K). Hence the radiation from the photosphere which is pouring through chromopheric gases is at a higher temperature, as was first pointed out by Milne.

In this case, we cannot speak of thermodynamic equilibrium in the strict sense, but there is a sort of dynamical equilibrium.

(3) The phenomena in the Novae and O-type of stars.

There are reasons to believe that in many stars, particularly in Novae and those with a dense atmosphere, the region from which the continuous radiation comes, and the outer envelope where the absorption takes place are at different and varying temperatures, sometimes the one, sometimes the other temperature becoming higher.

In all these cases, the reacting radiation is to be regarded as a new component. The equilibrium condition can be easily deduced by slightly modifying Sackur's equation.

Then the law of ionisation takes the form

$$log \frac{x^2}{1-x^2}P = -\frac{U-Nh\nu)}{RT} + log \frac{\rho\nu}{\frac{8\pi h\nu^3}{C^3}+\rho\nu} + \frac{5}{2} log\, T - 6{\cdot}5$$

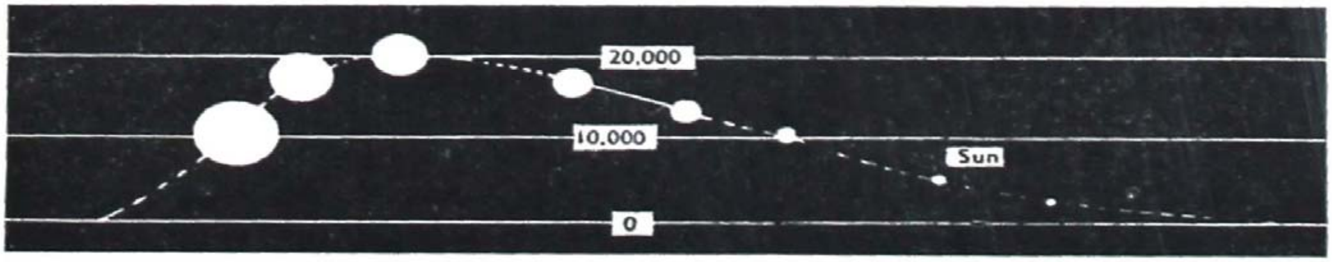
$\rho\nu$=density of radiation

When the radiation is due to the temperature of the system, i.e., there is thermodynamic equilibrium, the equation reduces to the form 1).

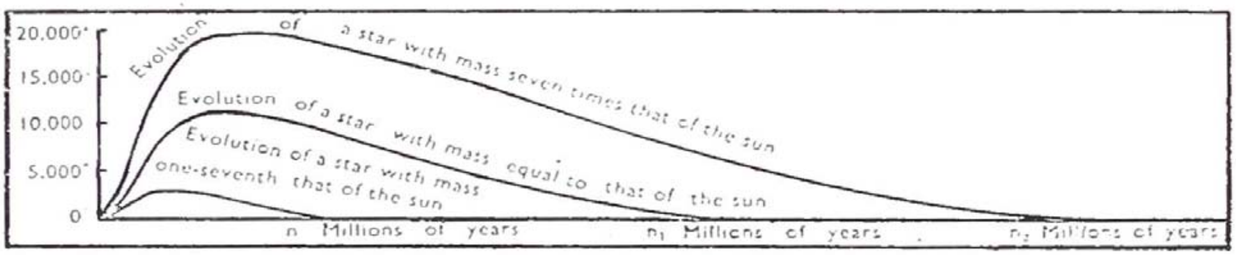
This is the general form of a formula given by Einstein in 1911 for photo chemical reaction.

Eddington's Theory of Stellar Evolution

Mention of Einstein reminds me of the important lesson he has taught us, viz. that both space and time are limited. I believe that many of you would like to remind me of this lesson. I would however crave your indulgence in extending for my benefit both the time and the space-limit. From what has been said you will see that in sub-atomic thermodynamics we have a combination of the methods of physical chemistry, the quantum theory, and of theories of atomic



(Diagrammatic representation of the theoretical development of a massive star from an original nebula to a final cold, dense body) structure. If offers vast possibilities of work, experimental, theoretical, as well as observational. It is already engaging the attention of a large number of workers in Europe, and America. and very fine results are being achieved. I have given a very brief account of these works.



(Curves illustrating the course of evolution of stars of differing mass, showing that, the more massive the star, the longer is its life and the greater is the range of temperature through which it passes. Both diagrams are taken from an article by Prof. H. Dingle in Nature)

In the present address I have dealt chiefly with stellar atmospheres. in which the temperature varies from 3000°C to 50000°C. But Eddington has taken us deep into the interior of stars, where temperatures of the order of billion degrees prevail. He has dealt with the large question of the life history of stars, which is inseparable from the present theme. He starts by considering a mass of extremely rarefied dark matter, which gradually goes on contracting owing to the mutual gravitation of its part. A stage is reached when the interior becomes exceedingly hot, and begins to radiate. Radiation as it flows through the outer envelope of matter exerts pressure on them. A considerable fraction of gravity is counterbalanced by the pressure of the escaping radiation. This causes the rate of evolution to slow down and a consideration of the relations between the total mass. density. and effective temperature shows that the limit of evolution is reached at a certain stage depending upon the total initial mass. Thus a mass having the same quantity of matter as our Sun can at best reach the *F*-stage (surface temperature-9000°C), while a star like Sirius having 4 times the solar mass, may reach the *B*-stage (having the surface temperature of 20000°C). Once the maximum stage is reached, the star will begin its downward career, i.e., the loss of energy by radiation will be larger than the evolution of energy due to contraction. The star will become cooler and cooler until it dies a natural death, as is the case with the moon.

According to Eddington, a star will have the same surface temperature twice in its life career (first) when it is rising in temperature;

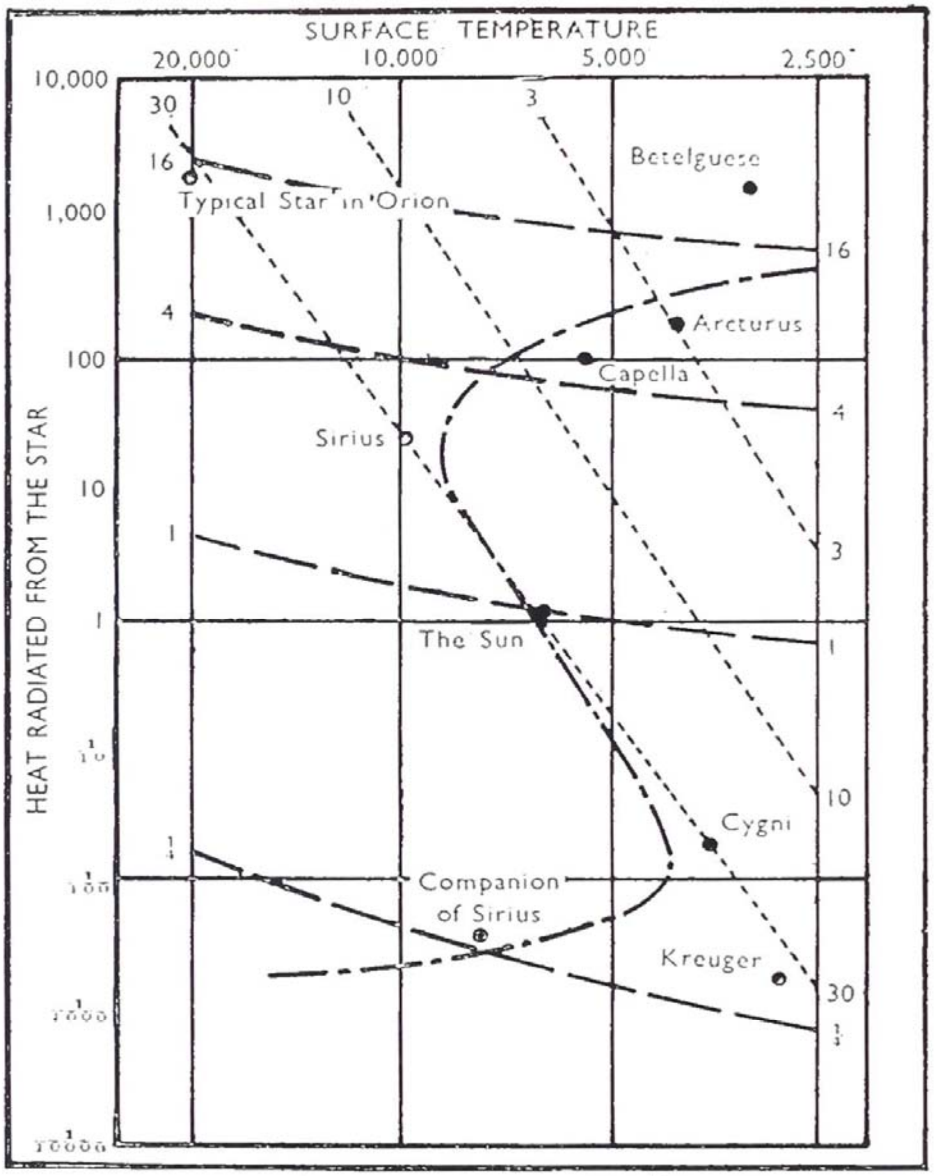
at this stage the density is very low and the star will therefore have a very large surface. This is known as the giant stage; secondly, when it is falling in temperature; the star had reached the maximum contraction and hence its density is very large, and total luminous surface is very small. This is known as the dwarf stage. Eddington's theory explains in a very clear way Lockyer's hypothesis of ascending and descending stages, which was subsequently amplified and put on a firmer basis by the researches of Russell and Hertzsprung.

I have not the time to speak of the many triumphs of Eddington's theory, but one spectacular triumph must not be omitted, and is probably known to many of you. The bright red stars are all giants, and have an extensive surface. Eddington predicted from his theory that the bright star α-Orionis (Betelgeuze) would have a diameter of $3{\cdot}4\times 10^{-8}$ Kms. with a parallax of $\cdot 045''$. This was brilliantly confirmed in 1921, when Pease and Anderson of the Mount Wilson. Solar Observatory, by an application of Michelson's interferometric method measured the actual diameter of the star and found it to be closely agreeing with the values predicted by Eddington, and by H. N. Russell.

Source of Stellar Energy

But the puzzling question of "Sources of Stellar Energy" still defies all attempts at solution. Throughout its trillion years of existence, a star must be radiating enormous amounts of energy. The question now rises 'where does all this energy come from ?' It was first raised in connection with the sun. The sun is radiating 5×10^{27} calories of heat every minute, and unless this loss is replenished by some other source, it would become extinct in a few thousand years. Helmholtz showed that if we assume that the sun is contracting by 28 yards every year, the energy obtained from this contraction would suffice to restore the loss. But the actual time scale is infinitely large compared to the rate of evolution of heat obtained from gravitational contraction.

Dealing with the larger question of the source of energy in stellar masses, attempts have been made to show that evolution of heat by radioactive emission or some other subatomic source of energy might be the long-sought-for source. The inside of a star must be highly ionised, and further contraction would result in the recombination of the free electron with the positive residue. This would liberate a certain amount of energy, as in the recombination of Ca^{+} and



THE "S" CURVE OF THE MODIFIED THEORY

[Modified form of the Theory of Giant and Dwarf stars according to H. N. Russell. In this scheme, Super Dwarfs (e.g. companion of Sirius), as well as Super Giants (c—stars) have a place]

e to form *Ca*, $1{\cdot}40\times10^5$ calories of heat are evolved. But Russell, as well as Nernst in his 'Werden der Welte' finds that this source is also insufficient to account for the observed time scale. Attempts have been made to show that the radiated energy may be retransformed into matter, according to the Einsteinian law $m=\frac{E}{c^2}$ but this does not seem to be more than a vague suggestion.

White Dwarfs—Companion of Sirius

At the present time, all speculations have been thrown into disorder by the discovery of "white dwarfs" and on account of the importance of this discovery, I would dwell at some length on its probable significance. Sirius which is the brightest star in the heavens, has got a companion 10^{-4} times fainter than itself which was discovered in 1845 by Alvan Clark. From calculations of the orbit, the mass was found to be 1/4 of Sirius, i.e. about 3/4 of the sun. In spite of its large mass, the star is extremely faint, and hence either the temperature must be very low or the surface very small. But the star is almost white and the spectrum is of the early *F*-type. Hence the surface must be extremely small, and actual calculation shows that the diameter cannot be larger than that of Uranus.

In the companion of Sirius, we have therefore a star with 3/4 the mass of the sun, but with a diameter which is about $\frac{1}{30}$ of the solar diameter, and a surface temperature of about 9000°C. The density reaches the enormous value of 50,000 while the density of the solar mass is only 1·31. The gravitational potential is 32 times the gravitational potential on the sun. Hence it was pointed out by Böttlinger that the star was very suitable for testing the Einstein prediction of shift of lines towards the red. On the Companion of Sirius, a line of wave length 5,000A° would be shifted by about ·3A° units, while the shift on the sun is only ·013 units. Actual measurement of spectrograms of the companion of Sirius taken by Adams in the Mount Wilson Solar Observatory shows, that the absorption lines on the spectra of this star are actually shifted by this amount. This is a brilliant confirmation of Einstein's theory of Relativity and probably removes the last shade of doubt about the validity of that theory. But the discovery is of far greater consequence to theories of evolution, for matter is compressed in this star to a density which is about 2,000 times the density of the heaviest metal known on earth. A few years ago, such a fact would have presented insurmountable difficulty, but thanks to the development of the atomic theories, the case does not appear so hopeless now. It is apparent that the star consists only of stripped atoms, that is to say of atoms which have lost some of their outer rings of electrons. This must be due to the high temperature prevailing in the star, but it is not at all clear how stripped atoms with a large excess of positive electricity can be so closely packed; because as the charges are of the same sign, the tendency would be for infinite dispersion, instead of abnormal condensation. But such cases of abnormal condensation are not altogether unknown in Physics. The nucleus of atoms consist of a large excess of positive charges which are somehow packed within a very, very small compass. The forces which hold together the positive charges, in spite of their mutual electrical repulsion, must be of a nature which is yet undreamt of in any theory of physics. An analysis of stellar data shows that such forces are developed when the central temperature exceeds a certain value. In the case of a heavy element like Uranium the first ring of electrons, and outer periphery of the nucleus are almost coterminous, and Jeans shows from stellar data that in such atoms, the intra atomic energy cannot arise solely from electrical forces. It is not improbable that the stripped atoms within a white dwarf are so much compressed that the nucleus becomes coterminous with the outer rings, and the forces surmised by Jeans come into operation even in the case of lighter atoms.

Conclusion

Gentlemen, I feel I have taken too much of your time, and further continuation of the theme would be torture to you. It is certainly very flattering to find that the number of papers in this section has exceeded a hundred, and contributions have been received from all parts of India. It signifies that a creative impulse has come amongst the teachers of our subject, and this is replacing the old habit of pedantry and stage acting. It is generally thought that the importance of regarding creative work as the noblest ideal for a teacher was never recognised in this country and that this idea has been a recent import from Europe. This is at best a half truth for otherwise, we could never have such positive sciences as medicine, astronomy and mathematics. My revered teacher Prof. Sir P. C. Roy, has unearthed for us the following remarkable passage from a writer of the ninth century (Dhundukanath in Rasendra Chintamani):

अश्रौषं बहुविदुषां मुखादपश्यम्
शास्त्रेषु स्थितमकृतं न तल्लिखामि ।
यत् कर्म व्यरचयमग्रती गुरूणां
प्रौढाणां तदिह वदामि बीतशङ्कः ।।
अध्यापयन्ति यदि दर्शयितुं क्षमन्ते
सूतेन्द्र कर्मगुरवे । गुरवस्त एव ।
शिष्यास्त एव वचयन्ति गुरोः पुरे ये ।
शेषाः पुनस्तद्‌द्वयाभिनयं भजन्ते ।।

"I have heard much from the lips of savants, I have seen many (formulae) well established in Scriptures, but I am not recording any which I have not done myself.

I am only recording those fearlessly which I have carried out before my elders with my own hand. They are alone to be regarded as real teachers who can show by experiments what they teach. They are the deserving pupils, who, having learnt from their teachers can actually perform them, and (improve upon them). The rest are merely stage actors."

Unfortunately for India, this high ideal was wrecked by pedants—men who regarded worship of ancient scriptures as the highest ideal of scholarship. Europe was also drifting into the same mess, her scholars at one time used to regard the worship of the Bible, Plato and Aristotle as the highest consummation of scholarship. But she was rescued out of the abyss into which she was drifting by the life blood of Galileo, Bruno and Kepler. Unfortunately India had no martyrs of the above type for Science. But recently examples have been forthcoming which show that the Indian brain is quite capable in the matter of creative scientific work. Encouraged by these examples, teachers are now taking in large number to creative work, and the Sadler commission has wisely set a legal stampo n such works.

The Sadler Commission has recommended the organisation of the teaching profession on a basis, which, if loyally adhered to, will foster the spirit of research and scholarship. But though many universities have been remodelled on the basis of these recommendations, the menace from pedants and stage actors has not entirely disappeared. Another menace is the want of encouragement and dearth of facilities for research work. It is our experience that with the transfer of education to popular control, and consequent reorganisation of university education, the whole machinery has become so complex that it is next to impossible to get any extra money for research work. The researcher who wants more money for his work is not infrequently treated like Oliver Twist in the Charity House "he has asked for more !" Even in medieval and ancient times, it was considered a duty on the part of the State to help the seekers after truth. I am thankful to the learned Vice-Chancellor of our University for the following remarkable passage in the writings of Rajsekhar, the Court poet of King Mahendrapal of Kanauj: who lived in the ninth century A.D.

महानगरेषु च काव्यशास्त्रपरीक्षार्थं ब्रह्मसभा कारयेत् । तत्र परीक्षोत्तीर्णानां ब्रह्मरथप्रयानं पट्टबन्धश्च ।

"In big cities, assemblies of learned men (Brahmasabha's) should be held under the patronage of the king for examining poetical and scientific works. And the successful should be conveyed in a special chariot (Brahmaratha) and should be crowned with a fillet."

Well, if the medieval states could be so solicitous for the encouragement of the seeker after truth, he has surely a claim on the modern civilized state.

Regarding the theme of this address, I may conclude in the words of Prof. Henry Norris Russell:

"The possibilities of the new method (method of subatomic thermodynamics) appear to be very great. To utilize it fully, years of work will be required to study the behaviour of the elements mentioned above and of others, in the stars, in laboratory spectra, and by the direct measurement of ionization, but the prospect of increase of our knowledge, both of atoms and of stars, as a result of such researches, makes it urgently desirable that they should be carried out."

1.1.4. A PLEA FOR AN ASTRONOMICAL OBSERVATORY AT BENARES*

In India, at the present time, we are having a clash of civilisations. The will-less East, having implicit faith in a preordained has been assailed by a Faustian West, strong believer in Free Will, and striving for the Infinite. The clash should result in the evolution of a new Culture. Pandit Madan Mohan Malaviya, a true representative of the older system believes in the possibility of this evolution and has founded an institution based on European models in the heart of the old system. This institution, however, is lacking a very important element, viz., an organisation for the investigation of the Physical Universe about us, an Astronomical Observatory.

The starry firmanent above us with its inlaid stars and their mysterious motions has always exerted the profoundest charm and influence on the human mind. The science of Astronomy owes its origin to this influence. In the words of the poet Heine it may be described as die alte, die ewigjunge Wissenschaft—the old, ever young science.

Let us begin with a little historical retrospect. We know that even in the dawn of civilisation on this globe of ours, astronomy had a peculiar fascination for the thinking section of mankind.

A rudimentary knowledge of astronomy is found amongst primitive people, particularly nomads, shepherds, and sailors, but the need for a more systematic knowledge becomes more imperative when the communities settle down to an organised life. The sun and the moon, the two apparently biggest luminaries, are our eternal Time keepers; the sun determining the period of the day and the moon the period called the month. The length of the year was at first derived from the recurrence of seasons, but it was very early found more correct to determine the length of the year from the apparent motion of the sun amongst the fixed stars. Time-keeping is a very important function amongst all settled communities, and both in Egypt as well as in Babylonia, the two countries whose past has been explored with some amount of completeness, astronomy in the begining arose out the necessity for exact time reckoning. But it

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*Pandit Madan Mohan Malaviyaji 70th Birthday Commemoration Volume, Edited by A. B. Dhruba 1932.

acquired great importance on account of its association with religion. In Babylon, in very times, the heavenly bodies became, in some mysterious way, associated with gods, who were supposed to guide the destinies of every human being. Thus Marduk, the presiding deity of the Babylonian Pantheon, was identified with the Planet Jupiter; Shamash, the god of law and justice with the sun; sin with the Moon the female god Ishtar with Venus, and Naby, the god of Scribes with Saturn.

From this notion arose the pseudo science of astrology i.e., fortune-telling from the observed motions of planets. In Babylonia, the observation of stars acquired great importance and was carried out in Ziggurats which were temples and observatories combined, dedicated to some great god. Thus astronomy became interwoven into their religious life and was entrusted to the priestly caste. In spite of their wastage of energy in astrological speculations, the Babylonians made great discoveries in pure science and were the teachers of the Greeks, the Persians, the Hindus and the Chinese, though it is quite possible that all these nations had some rudimentary knowledge of astronomical lore before they came into contact with the Babylonians. It was a Babylonian named Berossus who started an astronomical observatory at the island of Cos, and transmitted the Babylonian knowledge of astronomy to the Greeks. The early Greeks, particularly Thales of Miletus, the first amongst the seven wise men of Greece, were probably pupils of the Babylonians. Thales used to astonish his fellow countrymen by fortelling the time of solar and lunar eclipse, the knowledge of which he must have derived from his Babylonian teachers.

In India we can distinguish between several stages of development. The knowledge of astronomy revealed in the Vedas and the oldest Siddhanta (the Paitamaha) is very rudimentary and characteristic of rather primitive societies. The next stage is that of the more advance Siddhanta, particularly of the Surya siddhanta, which, according to Prof. P. C. Sengupta, was due to stimulus received from the Babylonians, probably through the Persian Maghi. The Persians, an Aryan tribe, gained supreme power in the middle East during the 6th century B.C. and became the successors of the Babylonians as torch-bearers of civilisation. Darius, the third of the Great Persian Emperors, included parts of India amongst his dominions, and Babylonian culture must have spread through the Persian wisemen to India. This is clear form the fact that in India itself, the class professing astronomy is known as Maga or Sakadwipi Brahmins, and are regarded as distinct from orthodox Brahmins.

Both in Greece as well as in India, astronomy developed on different lines. It did not become entirely dissociated from astrology or theology. But in both places there was a distinct culture epoch which afterwards got atrophied in a stereotyped civilisation stage. The greatest of the Greek astronomers was Hipparchus who, besides possessing a comprehensive knowledge of the Babylonian system, made many remarkable discoveries himself. The Greek knowledge in astronomy was worked out into a comprehensive system by Ptolemy, an astronomer who lived in Alexandria about 150 A.D., which was later utilised by the Arabs under the name Al Magset and became the standard astronomical treatise up to the time of Copernicus.

The Babylonian conception of the world mainly centered round man as the primary object of interest. Their attention was absorbed in the countries about themselves and the stars were of interest because they were supposed, as remarked already to rule the destinies of man. The Greeks after the time of Socrates made a heroic effort to free themselves from the dead weight of tradition. They arrived at the knowledge that the earth is a sphere and Eratosthenes even formed an estimate of its radius and Aristarchus of Samos is even credited with the then staggering idea that the earth was not the centre of the universe, but it was a planet moving round the sun. But the heliocentric view was turned down by the great authority of Hipparchus to be revived fifteen hundred years later by Copernicus.

In India, the first stage in the culture of astronomical knowledge (the Surya-Siddhanta stage) was succeeded by a second stage which was due to contact with the Greeks, and the Iranian Sakas (or Scythians). But in India, the votaries of the astronomical science apparently found it difficult to go against the scriptures. The Greek savants, with characteristic boldness and freedom of thought, had pooh-poohed the Homeric and Hesiodic cosmogony, they made light of the Olympic Gods. But the Indian savant never showed equal boldness. On the other hand, being accustomed to easy-going pantheistic tendencies, he was always ready to comporomise and be accomodating in his views. His achievements lay in Arithmetic and Trigonometry and their application to astronomy. In these, he made very creditable and lasting contributions, including the famous decimal notation. Many Indian treatise were translated into Arabic, particularly Brahmagupta's Brahmasiddhanta (598 A.D.) under the name Sind-Hind. But they were never courageous enough to propose a bolder theory of the universe in opposition to current ideas. Aryabhata of Kusumpur (pataliputra) (born in 476 A.D.) thought that the earth, by turning round its axis caused day and night, but his successors did not seem to be impressed with his ideas. It is, however clear that they were keenly alive to the stupidity of public beliefs or utter inadequacy of the Sastric lore. "It is said," says Bhaskaracharya, "that the earth rests on the hood of a huge snake, which when it feels uneasy gives a shake and causes earthquakes. Well, the snake must have something to rest upon, let it be the tortoise; but this also must have something else to rest upon. So we have to assume the hypothesis of an endless string of the supported and supporters. A better explanation would be that the earth has no support, i.e., is suspended in space." But the next sentence, he is careful to say 'but since these things are mentioned in the Sastras, there may be some truth in them.'

In the middle ages, the torch of knowledge was kept alive by the Arabs. Their savants were mostly drawn from the Perso-Chaldean and Hellenic group who found it better to put their ideas in the then world language, viz., Arabic. Great observatories were erected at Baghdad, in Spain and in Persia and at Samarkand in Central Asia. The Arabic astronomers made valuable observations of planetary motion, collected tables, cast horoscopes, and in mysterious ways, connected Alchemy with Astronomy, and kept alive the traditions of the Chaldean, Greek and Indian systems, and through their educational centres in Spain and Egypt, became the teachers of the modern Europeans. One of the best known observatories was that founded by Ulugh Begh, grandson of Tamerlane at Samarkand in the year 1461, and the tables of planetary positions he published were for a long time regarded as standard works.

Raja Sawai Jai Singh—The Astromer-Prince

Bhaskaracharya seems to have been the last great luminary amongst the Indian astronomers. After him, the Indian pundits showed little originality, and were content, with a few exceptions, to cast horoscopes and frame almanacs according to rules laid down in the older works. But during the maelstrom of Indian politics in the eighteenth century, there appeared the unique figure of a genuine astronomer in a ruling Indian prince, viz., Sawai Raja Jai Singh, the Rajpur state of Jaipur (1686-1743). The following account of Jai Singh's work and achievements in astronomy is taken from Ernst Binner's Geschichte der Sternkeunde (History of Astronomy) written in the German Language.

"A new era in Indian Astronomy begins with the prince Sawai Jai Singh II who lived from 1675-1743 and furthered the cause of astronomy. He caused the great treatise of Ptolemaios in Arabic (the Almagest) to be translated into Sanskrit by a Pundit called Jagannath (the translation is known as the Siddhanta Samrat). He possessed the tables of La Hire, and the star catalogue of the Astronomer Royal Flamsteed. He caused observatories to be built in Jaipur, Delhi, Benares, Ujjain, and Mathura. The latitude and longitude of the Observatories were determined (the last with reference to Paris) by the Jeuits Boudier and Andreas Stroeble. At Jaipur an astronomer named Don Pedro de Sylva was his adviser. Hence he had access to European as well as to Arabic astronomy, but he preferred Arabic. At first he made a brass astrolable according to Arabic models. As on account of difficulties of suspension and of inaccurate division, these were not accurate enough, so he began construction in limestone and marble, with which he hoped to make better observations. As he himself tells us, he invented himself three instruments, Samrat, Jai Prakash and Ram Yantra. Samrat is a Sun clock with the figure plated in the Equator which was well known to the Greeks, the Arabs, and the Germans. Jai Prakash is a hemisphere open above, divided into sections and provided with cross-wires for observing the positions of the stars. The construction of this as well as of the Ram Yantra was known to the Arabs and Jai Singh's share in the work seems to have been to construct them on a large scale and with greater accuracy. There were some other instruments also and a few more added by Madhu Singh, his son. The Delhi Observatory was built in 1724, and observations were taken in 1729. Jai Singh published a table of planetary and stellar positions, and showed that the tables of La Hire, which were the regarded as the most accurate in Europe, were wrong as regards the position of the moon by 8″, and the calculated time of eclipse was wrong by 6 minutes. The tables were dedicated to the emperor Mahammad Shah."

Sawai Raja Singh died in 1737, and astronomical science died with him in India; in spite of our admiration of the astronomer-king, we are forced to remark that he was the last representative of an expiring age: He had apparently either not heard of telescopes which had already appeared in Europe, or failed to appreciate their great usefulness.

The Cultural Influence of European Astronomy

Modern European astronomy begins from the time of Copernicus, a Polish monk who published his heliocentric theory of the universe. He showed that the motions of the planets could be better explained if the Sun were replaced at the centre of the universe instead of the earth, and the planets along with the earth were regarded as moving round the Sun in circles. This simple theory not only gave a better explanation of the motions of the planets, but it created a revolution in human thought. For the idea persued to its logical limits, meant the doom of sacred pages, of God-men, and of all classes enjoying privileged positions; for had not man been accustomed and sedulously taught in all ages to regard himself as reproduction of the creator, to regard his little city or country or his tribe as specially favoured of God, the object of His special attention to the exclusion of others ? But now the Earth becomes a tiny object, one amongst many, playing a vagrant course in space. We can therefore understand the rage of the Priest and the Potentate, the men who burnt Giordno Bruno for teaching the heresies of Copernicus, and imprisoned the great Galileo—who by his invention of the telescope enabled mankind to penetrate furthest into space beyond the dreams of poets and seers, and by his discovery of dynamics placed a wonderful instrument of thought for analysing the secrets of nature,—to lifelong imprisonment and persecution.

But the blood of the martyr is the seed of the Church, and the new Church which grew, the Church of Science and Reason, has been a more powerful factor in welding the destinies of mankind than religion or politics. In the words of Oswald Spengler, the new Church has a Faustian Soul, striving for the limitless.

It is not my object to describe the achievements of modern science or of the recent progress in astronomy. My object has been to show that Astronomy has a great cultural value, and its possibilities are infinite, for it takes the limitless space with millions of island universes for its subject of study. No poet in his flight of imagination could ever dream of the picture of the universe which has been revealed by the patient study of the astronomer-savants of the past and the present age. Think of the fact that this great earth in which we live is a mere tiny speck of dust which, separated from his parent, the sun, milliards of years ago, still continues to go about it, being guided by the mysterious law first revealed to Newton: think of the great sun, thirteen million times bigger than the earth, and containing a huge store of energy cruising in space with its family of planets towards a point in the Hersules group with the enormous velocity of 26 km per second. Think again of the fact that the sun is but a second class member of the myriads of stars forming the Galaxy (the milky way). The Galaxy to which we belong is again one of many millions which are crusing past each other with enormous velocities approaching 11,000 km per second. And then comes a Kirchoff who shows that yet in spite of these enormous distances which separate us from our nearest neighbour, we can study the chemical composition of these stars with as much facility as that of a piece of stone on the earth.

The cultural value of astronomy has been recognised by all the advanced nations of the present day. Kings, and potentates, and business magnates in the West have vied in the past with each other in founding and endowing the modern temple of Marduk, the interpreter of the Cosmic will to mankind. In the new Atlantis (America) there are hundreds of observatories with 2,500 professional astronomers, and many amateurs; and the greatest of them, the Mount Wilson Solar Observatory erected at a height of 7,000 ft amidst the blue sky and provided with a hundred inch telescope, owes its inception to the munificence of the late Mr. Andrew Carnegie. Wonderful results have come out of this observatory; the diameters of stars have been measured, vast distances have been explored, the physical constitution of hundreds of stars has been observed, and the discovery has been made that besides our Milky way, there are hundreds of other Galaxies moving past us with enormous velocities. The exploration of this universe has just rendered the maxim of Einstein possible that the universe though without boundary, is not infinite. Not content with this discovery, the Americans are building a second one for housing a two hundred inch telescope; when this new observatory comes into existence many new revelations are expected.

Lick Observatory Mount Hamilton

The story of the erection of these observatories is sometimes very entertaining. The Lick Observatory which comes next to the Mount Wilson, was founded on the endowments left by Mr. Lick who earned a huge fortune on the Pacific coast during the early days of migration to the West. Having no children, he did not know what to do with his fortune. The story goes that he wanted to erect a huge bronze statue of himself and his wife, surpassing the famous Colossus of Rhodes in size, and wanted to place these statues on the San Fransisco Harbour over looking the Pacific ocean. Some educationist came in time to know of this project, and was able to persuade him to the belief that an astronomical observatory would be a more fitting memoral to this munificence than a modern bronze Colossus.

It is a great pity that in spite of the fact that in the past. India produced a number of great astronomers like Aryabhata, Braahmagupta, and Bhaskaracharya, at the present time, she possesses no astronomical observatory worthy of her traditions. excepting a State observatory at Kodaikanal in Madras and one at Hyderabad-Decan founded by the munificence of H.E.H. the Nizam. These two observatories have done quite creditable work in spite of their limited sources. But compared to the great European and American observatories, these are merely babies. The Astronomer-king (Raja Jai Singh) has yet found no successor amongst the Indian princes. Yet though lacking in a first class observatory, some very notable contributions to theoretical astronomy have been made in India in recent years. The importance of the ionisation theory has been recognised in Europe and America, and half the papers in Astrophysics are now on the application of the Ionisation Theory to problems of stellar structure. In 1921, Prof. H. N. Russel, a foremost astronomer of America wrote:

> "The possibilities of the new method (Ionisation Theory) appear to be very great. To utilize it fully, years of work will be required to study the behaviour of the elements mentioned above and of others, in the stars, in laboratory spectra, and by direct measurement of ionisation; but the prospect of increase of our knowledge, both of atoms and of stars, as a result of such researches, makes it urgently desirable that they should be carried out."

I have remarked elsewhere that the great scientific activities of the West European nations means a virtual return from the worship of the rigid God, of codified scriptures to the worship of the Nature Gods, as was the practice in early times and amongst early nations. But worship now means the act of knowing nature, and the laboratories and observatories have rightly taken the place of Temples. So long the different Nature-phenomena have been investigated on distinct lines, but now Einstein comes forward with the bold idea that all Nature-phenomena, Electricity, Gravitation and Light—are due to the metrical properties of space. If we may use the figurative language of the Vedic Poet, this reduces to the oldest Vedic conception that all Nature-gods are the children of Dyaus Pitar—the God of limitless space. The Hindu University has not yet constructed a Temple for the investigation of space according to the Einsteinian conception, and this is a very great omission.

We would therefore appeal to the Indian princes, merchants and other rich men that in the great city of Benares, where Buddha, two thousand five hundred years ago preached the gospel of Love and Amity, and where in the present times, the foundations of a great temple of Learning have been laid, they should erect a Temple dedicated to the service of Dyaus Pitar—the great God of limitless Space, the father of all Gods—who guided the unsophisticated Aryan nomads in their primitive wanderings, and endowed them with the yearning after the Infinite, the Beautiful, and the Truth which is the heritage, and characteristic of the great Aryan race.

1.1.5. FUNDAMENTAL COSMOLOGICAL PROBLEMS*

I

THE return of the Indian Science Congress to Bombay for the third time after the lapse of eight years bespeaks of the large-hearted liberality for which the citizens of Bombay have been distinguished. On this occasion, specially on behalf of the scientists assembled here, I have to convey to the hosts our heart-felt thanks for the ready response which they made to our call of distress. I have further to remind my colleagues that to-day at Bombay the Science Congress attains the legal age for majority, when we shall be quite within our rights to claim for the Congress, from the state as well as from the public, those rights and privileges which are enjoyed by similar associations in other countries of the world. But of these demands, I shall speak only during the concluding parts of my address.

In 1925, the occupant of the Presidential Chair was Mr. Howard, well-known for his valuable contributions to *Indian Agriculture*. The present speaker cannot claim to have been so useful to the public. In 1925, while presiding over the Physics section at this very city, he occupied himself with the rather abstruse topic of application of recent advances in Physics to the study of the heavenly bodies. It is rather regrettable that even in a place like Bombay which is a city of pragmatic philosophers, the speaker has not been able to change to a subject having a more human appeal. On the contrary, he wishes to start from the point where he left on the last occasion and deal with the story of the universe of which we form an organic, though insignificant, part. The subject has been chosen for a variety of reasons: first, the speaker is personally interested in it; secondly, as a cultural subject, it led to the emancipation of the human mind during middle ages, when Copernicus deposed the Earth from its proud position of being regarded as the centre of the Universe. This stimulated men in Western Europe to further fields of exploration and ultimately led to the development of modern science; thirdly, in India, in spite of our traditional boast of caring for knowledge for the sake of know-

*Address as General President on the 21st Indian Science Congress held at Bombay, 1934.

ledge alone, the claims of pure science are being sadly neglected for subjects of utilitarian value; lastly, because it had so far no exponent in the chair which I have the honour and privilege of occupying to-day[1].

The Creation Myths

At the outset I would remind you that like all other higher activities of the human mind, scientific activity is based on faith . . . the faith in the reality of an external world, independent of the idiosyncrasies of the participant subject (the human mind). Scientific knowledge therefore claims to be objective, knows no limitation of race, country or age and has been built up by the united labour of past and present generations of mankind. These remarks apply all the more strongly even to our subject which can be traced to the remotest antiquity; it is certain that even in the primitive savage stage, when man must have spent most of his existence in caves for fear of wild beasts and departed spirits, he must have stolen occasional glances at Nature: at the smiling Earth teeming with fruit, flower and game; the life-giving Sun in all his majesty; the Moon with her soothing rays; rain and cloud with occasional thunders and the blue firmament with its inlaid stars and their mysterious motions; nothing seems to have stirred the human imagination so much as these phenomena of Nature. When civilization developed and man felt the necessity of defining his relation with fellowmen and with the surrounding world, he was led to ponder over all these phenomena of the sky, and was led to wave cobwebs of mystic cults of gods and spirits, and construct labyrinths of metaphysics in which the heavenly bodies played a conspicuous part.

It is a remarkable fact with almost every civilization, that the sages of ancient times were constrained to construct a story of Creation. This points to a fundamental trait of the human mind from which, I submit, that even the modern man has not been able to free himself: that man feels himself to be a part of the Universe and is anxious to know his position in the Universe. Take for example the following creation myth of the ancient Sumerians who conceived that the world

[1]A well-known scientist of India once remarked in a public lecture that astronomy has never been of any practical use to mankind. He seems to have forgotten that the greatest event of medieval times, the discovery of America and circumnavigation of the world would have been impossible without a knowledge of astronomy and even to-day, without knowledge of astronomy navigation is not possible.

had sprung out of water; and the gods who were mostly identified with heavenly bodies stood for order.

> When on high, heaven was not named.
> Below, dry land was not named,
> Apsu, their first begetter,
> Mummu and Tiamat, the Mother of all of them
> Their Waters combined together.
> Field was not marked off, sprout had not come forth
> When none of the Gods had come forth
> Had not borne a name,
> No names nad been fixed
> The Gods were created in the midst of heaven.

The story then goes that man was created for doing homage to the gods.[1]

Later Jewish theology, which still finds currency in many Christian countries even to-day, regarded man as created in the image of God, in a spirit of rather vainglorious exaltation of man.

The New Creation Stories—The Nebular Hypothesis

In all old creation myths, the creation of the organic world of life and of the physical world were hopelessly mixed together. But after the discovery of the knowledge that the Earth is an insignificant planet in the train of a second-rate star which is only one of a numberless multitude, and man is only the culmination of forms of life which came into existence, flourished and died out in the successive gelog-gical epochs, the old creation myths became untenable. It was Immanuel Kant, the great surveyor of human knowledge in the eighteenth century, who first drew a clear-cut line between the organic and the inorganic worlds. In his 'Anthropology' the possibility of animal origin of mankind was suggested in words which smack of Darwinism. But the same Kant also undertook a survey of the Inorganic World in his 'Theory of Heavens' which was later elaborated by Laplace into the famous Nebular Hypothesis. In fact, Kant and Laplace attempted a mechanical explanation of the origin and motion of planets and their developments out of a primeval Nebula or fog of vast dimensions.

The next great Evolutionist on the physical side was Sir Norman Lockyer who sketched his ideas in numerous papers and publications culminating in a book on 'Inorganic Evolution' published in 1900.

[1]The belief still persists, for Bishop Barnes writes: "The religious outlook of many of us is determined by our belief that God has created man for his Service."—*Nature*, 130, 721.

The story of creation as constructed by Kant and Laplace was an attempt at a synthetic view of the world as revealed by the new knowledge which was acquired by mankind since Copernicus gave out his heliocentric theory of the world, and the laws of planetary motion were discovered by the successive labours of Kepler, Galileo, and Newton, and perfected by Laplace, Lagrange and other mathematicians. Up to the time of Kant, man's interest had not yet outgrown the solar system. The stars were still objects of curiosity. But by the earlier part of the nineteenth century, Bessel and Henderson perfected the parallax method of determining the distances of stars, and Lord Rosse, in his great telescope first saw in 1845, the Nebula in spiral motion as mentally pictured by Laplace and Herschel. The discovery of photography and of Spectrum analysis in 1859 by Kirchhoff provided the astronomers with the necessary means of undertaking the physical and trigonometric survey of heavens on a scale which could not be dreamt of by the previous generation of astronomers.

Lockyer's Theory of Inorganic Evolution

Regarding Lockyer's theories, I can do no better than quote from an article which I contributed to the Sir Norman Lockyer Memorial Volume: 'Lockyer was called to astronomical work by Kirchhoff's profound discovery of spectrum analysis (which placed in the hands of astronomers an instrument of unrivalled power and potency for surveying the physical nature of the sun, stars). (After Sechhi in Italy and Huggins in England) Lockyer was one of the first to set to himself the task of exploring the Sun and the stellar universe with the new instrument on a large scale. He obtained results for which the existing theories or ideas were quite insufficient; he initiated laboratory work for elucidating these results. The confusion became worse confounded. He had to formulate theories of his own which were a direct challenge to the accepted theories of those days and for which the scientific world was the least prepared.

For, in those days, it was almost universally held that the atom was the ultimate constituent of all matter. It was held that like a tuning-fork, the atom could be made to emit only a few simple notes, *i.e.* spectral lines which were invariable. But Lockyer's experience of stellar spectra and spectra of elements in the laboratory told him that these ideas were not only insufficient but also misleading. He found that by subjecting elements to varying stimuli, the nature of the spectrum could be varied within wide limits. A very good example is afforded by calcium, which gives a line called by Fraunhofer g, λ 4227; this line is very strong in the flame and in the arc, but fades in the spark. On the other hand, two other lines, the H and K of Fraunhofer, which are faint in the flame, become prominent in the arc and completely dominate the spectrum of the spark. Lockyer found similar results in the spectra of other elements, and in the case of silicon he found no less than four successive stages. If the atom was invariable, argued Lockyer, how could these variations be accounted for?

Lockyer was first and foremost a pioneer explorer of the stellar world, and the laboratory work of which we have just spoken was undertaken in order to obtain a clear explanation of the phenomena which he had discovered in a systematic study of the spectra of the Sun and Stars.

He had discovered that these spectra could be arranged in a number of well-marked groups, which by gradual steps merge into each other. This classification was confirmed in essential points by the spectroscopic survey of 200,000 stars at the Harvard College Observatory by Professor Pickering and Miss Cannon. They denoted these groups by the letters

N — M — K— G — F — A — B — O — P

Lockyer found that the spectra of red and yellow stars mostly consisted of arc lines, while in the spectra of white stars the metallic lines became fainter, and the enhanced lines became more prominent.'

Decoding the Messages—The Ionisation Theory

Lockyer's speculations were rather in advance of his times. Icarus-like, he wished to soar to the sun with, if one may be permitted to say so, wings of wax with the inevitable result. But it is clear that if we wish to learn more about the sidereal universe, we must be able to decode the messages which these distant bodies are sending to us in the form of light, for light is the only agency by which knowledge of these distant bodies can be conveyed to us. As mentioned already, an immense amount of these code messages in the form of spectra was collected by Lockyer, and other astronomers, particularly the Harvard group, but up to 1920, a satisfactory method of deciphering them was not known.

It is now a matter of history that in 1920, a method was obtained for the first time for decoding these messages. This consisted in the formulation of the ionisation theory and the theory of selective radiation pressure. The ionisation theory has given us a simple clue for tracing the changes in matter as the temperature is increased from laboratory values to those which we obtain in stars. It tells us that when the atoms are heated to higher and higher temperatures, the outermost electrons are knocked off one after the other, and the enhanced lines appear in greater strength. From the marginal appearance and disappearance of these lines, it is possible to calculate the temperatures and pressures of the outer atmospheres of the stars and form a general idea of the physical conditions prevailing in these bodies.

The theory of selective radiation pressure, which was formulated almost simultaneously with the ionisation theory, is a necessary supplement to the latter and it accounts, in a satisfactory way, for the existence of the stellar atmosphere. For on these heavenly bodies, the value of gravitation is sometimes so great, that unless this is counterbalanced by some other force, the atmosphere would collapse. But the theory of selective radiation pressure, further elaborated by Milne, showed that the force of gravity is counterbalanced by the pressure of radiation from the inside of the star. The radiation as it flows outwards is absorbed by the atoms. In this act, the quanta administer to the atom a forward kick which goes on multiplying owing to the number of acts of absorption per second. This simple theory has been shown to account in a satisfactory way for the anomalous distribution in stellar atmospheres of heavy elements like Calcium, Scandium, Titanium .... and absence of others, which appeared rather puzzling to the astronomer.

Physical Survey of the Heavens

The successful application of the ionisation theory requires a complete knowledge of the structure of the atom, of their spectra in different stages of ionisation and a satisfactory theory of the intensities of spectral lines. At the time when the theory was first given, our knowledge of the atom was confined only to hydrogen though there were enormous masses of floating information about other atoms lying scattered in journals and special treatises. Within the last twelve years, all the information has geen arranged into systematized knowledge, thanks to the activities, chiefly of the Bohr and Sommerfeld Schools of Physicists, so that now practically the lacunæ in our knowledge of the spectra of elements, which largely hampered the activities of the astrophysicist in 1920, have disappeared. This has enabled us to ascertain accurately the physical conditions in the wide variety of heavenly bodies which the astronomer comes across, planets and comets, giant and dwarf stars, planetary and diffuse nebulæ, interstellar matter, and extragalactic nebulæ.

The Trigonomentric Survey of Heavens

It is impossible to have a complete grasp of the cosmological problems unless one has some idea of the Geography of the Universe about us. Twenty years ago, exploration of space was hampered by the limitations of the parallax method, but the discovery of the cepheid variables provided us with lampposts with which exploration into undreamt-of depths of space has been rendered possible. To give an idea of the discoveries in this direction, I would ask the audience to take with me a trip to space with the velocity of light.

After the lapse of a second and half, we shall reach the moon which is our nearest neighbour and is at a distance $2{\cdot}4\times 10^5$ miles. In eight minutes, we shall pass the *Sun*, the source of our light, and life. In a few hours time, we shall be past *Pluto*, our last neighbour in the solar system and then we shall meet with nothing of importance except dust and cosmic radiation for about four years. At the end of four years, we approach our nearst neighbour outside the solar family, *proxima Centauri* which is a faint star, radiating only 10^{-4} times the light of the sun and a little later her more powerful neighbours, the twin stars at α *Centauri*. After eight years, we make the acquaintance of *Sirius*, and of his still more wonderful companion of which we shall talk later. From the earth, Sirius appears to be the brightest star in the heavens and you may be knowing that owing to its brilliancy it excited innumerable stories and myths in the minds of all nations beginning from the old Egyptians. Sirius is not merely apparently bright, it actually emits twentynine times the light of the sun. After leaving Sirius, we cruise for 135 years, till we come to a rich field of luminaries which we have noted from the Earth. These are the famous *Pleiades* containing, to the naked eye, seven stars, but the telescope resolves the group into thousands. The Pleiades, on account of their striking appearance, have also like Sirius formed topics for numerous myths and legends. The size of this stellar colony is about 10^{19} cm, i.e. we shall take about ten years to traverse it from end to end. Close to it is another similar group called the *Hyades*. This cluster, unlike the Pleiades which contains only blue or white stars, is populated with stars of all colours. Clusters like the Pleiades and the Hyades are called *Galactic Clusters*. They are found distributed all along the *Milky Way* and we continue to meet them till we have been 4,000 years on our journey. When 10,000 years have passed, we are amidst Clusters of another type. These are much richer in stars than the richest of the Galactic Clusters and are in general found near the rim of the Milky Way. These are the *Globular Clusters*. About a hundred of them are known. In size a Globular Cluster is about ten times larger than a Galactic Cluster. The Globular Clusters mark the outer limits of our local *Galaxy*—also called the Local System. The local system forms a unit in a much bigger stellar organization which contains also the *Magellanic* clouds, a striking group of stars in the southern hemisphere called after the great explorer, Ferdinand Magellan, who observed them in his memorable first circumnavigation of the world. This is called the Galactic system or popularly the Milky Way which you can see on any clear night, as a luminous belt across the sky. The galactic system is about 10^{23} cm in diameter and contains about 10^{10} individual stars. We shall have to cruise on monotonously for a hundred thousand years and then we are out of our galactic system. It will take us another million years before we reach a second galaxy which is our nearest neighbour—the *Spiral Nebula in Andromeda*. It is a gaint amongst external galaxies, its longest diameter being a little over 40,000 light years. The Andromeda nebula is not a solitary system but has associated with it two other fainter and smaller galaxies—the two forming a super-galaxy like the Milky Way. Several systems like our galactic system containing hundreds of galaxies have been found in the constellations Coma and Virgo. All the super-galaxies possibly form a larger organization which Shapley calls a *Metagalaxy*' and which to use Shapely's words is 'All comprehensive but still incomprehensible'. The *metagalaxy* is estimated to be about 10^{27} cm in diameter. In exploring the distant regions of this metagalaxy, we shall have travelled for over many hundred million years and might, after so long a sojourn, feel tired of the monotony of infinity and inclined to give up the task of penetrating further into the endless depths of space. At this stage, we might gain some stimulus from the investigations of Einstein and others who say that space is not infinite but turns on itself, like the skin of a football bladder. The Radius of the Einstein universe has been estimated at 10^{29} cm with the hundred-inch telescope of Mt. Wilson, we can reach about one-sixth of this distance, but when the two hundred-inch telescope is completed we shall be able to reach double the distance. A time may come when we have reached the limit of the universe, then nothing but void will remain.

II. Problems of Evolution

You will see from the foregoing sketchy account that the problems which an Evolutionist has to face to-day are much more imposing and complex than those confronting the famous scientists who were first bold enough to substitute old creation myths by the Nebular Hypothesis. You would like to know what is the present view regarding the Nebular Hypothesis. It is not possible to give a straight answer to this question, for the interest of Kant and Laplace was mainly confined to the solar system, while a present-day Evolutionist has to consider the whole Sidereal Universe of which the solar system forms but an insignificant part. We have further to define the meaning of the word 'Nebula.' Laplace used the term, if I may say so, in a truly nebulous sense, and it is regrettable that the bad habit is being still continued by the present-day astronomers. Anything which appears hazy in the telescope is indiscriminately termed a Nebula. But it is not difficult to perceive that haziness may be due to two distinct causes: (i) Physical haziness—because the substance is really composed of foggy matter. Such are planetary or diffuse nebulæ found in the Milky Way, which generally possess a star in its core. Density of matter in such nebulæ is probably not more than $10^{-17}-10^{-20}$ gm/cm^3 and far from being the Father of stars, it has now been ascertained that these nebulæ are due to some catastrophe which overtook the star in bygone days, when its outer shell was blown off, and gases were driven out with tremendous velocities forming the hazy envelope which is now called the nebula; (ii) the second class comprises foggy masses like the Andromeda Nebula which are found outside the Milky Way, and are therefore known as Extra-galactic Nebulæ. Here the nebular appearance is merely visual, for due to enormous distance, the component stars are not resolved. It is only in recent years that these so-called nebulæ are yielding their secrets to the gigantic American telescopes as I have already described. Briefly speaking they are distant galaxies, like our own Milky Way, composed of billions of stars in different stages of evolutions. In fact, to a resident on one of the planets in the Andromeda Nebula our own Milky Way would appear as a huge spiral nebula, and the sun may appear as a fourteenth magnitude star, provided the beings there have developed powers of exploration like ourselves.

As far as our present knowledge goes, the Universe consists of billions of galaxies distributed in space. But compared to the immensity of space, they are like little patches of oases of matter in a vast desert with huge distances intervening between each other. But it is probably not correct to say that there is absolutely no matter in the inter-galactic space. There is some evidence that while matter in the galactic spaces has a density of about 10^{-26} gm/cm^3 the density of matter in the spaces between neighbouring galaxies including our own Milky Way may be of the order of 10^{-31} gm/cm^3 The Nebulæ are found to possess a definite arrangement and are found rotating as a whole round definite axes.

Recently another very puzzling fact has been found. If the evidence of the spectroscope be correct, the galaxies are probably running away, from each other with tremendous speeds—in fact the speed is found proportional to the distance the value being 176 km per million light years. We have already likened the universe to the skin of a four-dimensional football. We have now to postulate that the football is expanding continuously, so that every point may be supposed to be receding from its neighbour with a speed which is proportional to their distance apart.

The problems which nowconfront the astrophysicist are asfollows:

(*a*) How do stars come into existence and what is their life-history?

(*b*) How do they maintain their stock of energy?

(*c*) What happens to the radiation which is being poured in space?

(*d*) What is the ultimate fate of the Universe?

The Life-History of a Star

Before dealing with the question of life-history of a star, it will not be out of place to indicate in brief how such a history has been compiled. The life of a star probably extends over billions of years. But as you all know, the span of human activity extends barely over forty years. Even the accumulated experience of mankind, the age of civilization, extends barely over a few thousand years. It is clear that these periods of time are too short to enable us to observe any substantial change in the appearance position or luminosity of any single star. How do we then trace the life-history of a star? The procedure followed by the astronomers may be illustrated by the following fine analogy due to Sir J. Herschel: 'suppose an intelligent observer who has never seen a tree is allowed one hour's walk in a forest. During this time, he will not see a single leaf unfold; yet he could find sprouting seeds, small saplings, young, full-grown, and decrepit trees, and fallen trunks mouldering into earth, and in that brief hour he might form a correct idea of the life-history of a tree.'

What the astronomer does is exactly parallel. With his telescope and spectroscope, he finds out the distance, distribution, and temperature, density, composition and physical characteristics of as many stars as he can manage. Then he pieces together these data, tries to trace the chain of causation and effect and endeavours to construct the full life-story of a stellar mass. It should however be remembered that the astronomer acts under very severe limitations. First the power of his telescope is limited. It has been estimated that even with the 100 inch telescope of Mount Wilson Observatory in America we can barely reach one-seventh diameter of the Einstein World. Further, only comparatively big bodies which are hot enough to give visible radiation are picked up by the telescopes. Bodies which are small, or dark, escape the astronomer's attention altogether. And there may be more dark bodies in space than bright ones. The power of the spectroscope is still more limited. Owing to severe limitations of the photographic plate, and the absorption by our atmosphere we have to rely on an insignifiacnt part of the electromagnetic spectrum, extending from λ 3000 to λ 6000 barely a region of one octave. But it is presumed that the radiation filling the space, range in wavelength from 10^{14} cm (Cosmic rays) to an unknown length which may be in the Hertzian region. This comprises about 45 octaves. The longer part of it, lying beyond 6000 AU, gets lost partly due to insensitiveness of the photographic plate, partly due to absorption by our atmosphere. The waves shorter than 3000 all get absorbed by our atmosphere, excepting a short region beyond $4 \cdot 7 \times 10^{11}$ cm But in spite of this fact there is unmistakable evidence, that they do exist, and exert a profound influence on cosmic events.

The totality of our experience regarding the stars, which has been gained amidst these limitations is expressed in the well-known Russell-Hertzsprung diagram representing the total amount of light (luminosity) and the temperature of the stars as well as the frequency of occurrence of these stars but it is expressed in technical language which demands some explanation

Construction of the Life-History.

From the above facts, the picture which the astronomer drew about the life-history of a star was as follows: A mass of extremely rarefied dark matter is supposed to go on contracting owing to the mutual gravitation of its parts. A stage is reached when the interior becomes exceedingly hot and the heat gradually spreads to the surface, till the temperature rises to a value when the surface begins to emit a dull red light. This the stage marked by 'N' in the diagram. 'N' is a technical name denoting a star which appears fiery red to the naked eye, and which spectroscopic investigation shows to consist of an extremely dilute nebulous fog, at a temperature of about 3,000°C. The process of contraction goes on, and the inside of the star grows still hotter. But as radiation flows through the superincumbent envelope of matter, it is absorbed and exerts pressure on them. A considerable fraction of gravity is counterbalanced by the pressure of escaping radiation. This causes the process of contraction to slow down, and a consideration of the relations between total mass, density, and effective temperature shows that the limit of contraction is reached at a stage depending upon the total initial mass. A star of 10 to 12 times the mass of the sun can successively reach the stages denoted by the letters M,K,G,F,A and B. These terms have some technical significance which is known only to a professional astrophysicist, but for the layman it will suffice to say that they are regions of higher surface temperatures and greater concentration. Stars M,K . . . . . appear red to the naked eye; G,F are yellowish, A and B are white. But the limiting stage which can be reached depends only on the initial mass. Thus a star having the same quantity of matter as our sun can at best reach the F-stage (surface temperature 8,000°C), while a star like Sirius having three times the mass of the sun may reach the B-stage (surface temperature 20,000°C). Once the maximum stage is reached the star will begin its downward career, i.e. the loss of energy by radiation will be larger than the evolution of energy due to contraction and other attendant processes. The star will become cooler and cooler until it ceases to emit light, and gradually passes out of sight.

According to this view, a star will have the same surface temperature twice in its life career: firstly, when due to contraction it is rising in temperature—at this stage the density is low and the surface is large. This is known as the *Giant stage;* secondly, when after reaching the maximum contraction, it radiates more energy than it gains by contraction. Now the density is very large, and the surface shrinks down to a moitie of its previous value. This is known as the *Dwarf stage*. The hypothesis of an ascending and descending stage in the evolution of a star was first suggested by Sir N. Lockyer on spectroscopic grounds, and was supported by Russell and Hertzsprung on the strength of a large amount of observational data.

On the theoretical side, the contraction of a gas sphere under the gravitational attraction was first treated by Emden, but Eddington was the first to consider the influence of radiation pressure on the process. Though these mathematical works suffer from the defect of having to take too many things for granted in which physical reality had often to be sacrificed for mathematical convenience, it yielede a result regarding mass and luminosity which was found to account for most of the facts observed up to 1921. One spectacular triumph of this view may be cited. Eddington and Russell predicted from these theories that the bright M-star α-Orionis (Betelgeuze) would have a diameter of $3{\cdot}4 \times 10^{-8}$ km, with a parallax of ·045 seconds. This prediction was brilliantly confirmed in 1921, when Pease and Anderson, at the Mount Wilson Solar Observatory, successfully devised a method for measuring the diameter of stars and found that α-Orionis had a diameter closely agreeing with the value predicted by Eddington and Russell.

For a time it was thought that this picture described correctly the actual life-history of a star, but facts began to come to light since 1922 which showed, to say the least, that the theory was untenable. We have to refer to the discovery of an entirely new species of stars, viz. the white dwarfs which are found to possess an enormous density of 50,000: i.e. 2,000 times the highest density of matter found on earth. Though up to this time only a few of such extraordinary bodies have been found, yet they are not supposed to be mere freaks of nature, for such bodies would mostly escape detection owing to their extremely small surface and small luminosity. Recently it has been suggested on good grounds that the cores of stars may be mostly white dwarfs and Milne has even suggested that all stars have a core of white dwarf type. The white dwarfs are a problem for the contraction theory of evolution, for according to this theory the limiting desnity cannot exceed 5 or 6, like our Earth. But the fact that the highly ionised matter inside a star can exceed the limiting value thousand times shows that the theory needs radical revision. It is impossible that such bodies can be due to any difference in composition, for they are undoubtedly binary: amongst many binary pairs which are undoubtedly formed out of the fission of one and the same body one is found to be an ordinary star while the other is a white dwarf. The best example is afforded by the Sirius pair. Sirius A having a mass of about 3 is an ordinary A-class star with the mean density of 0·93, while Sirius B having the mass of ·85, is a white dwarf having the density of 50,000. How two stars, composed of the same material, and starting their career at the same epoch could have developed along such different lines is a problem which still requires elucidation. In addition to white dwarfs, recent explorations have been bringing to light other bodies with characteristic properties which cannot be fitted into the above scheme of evolution. Such are the supergiants, the peculiar distribution of stars in the globular clusters, the Cepheid variables, and a mass of other details too vast to be discussed here.

Sources of Stellar Energy

It has now been recognized that a mathematician working with theories of stellar evolution is almost as much handicapped in his work as those who are unlucky enough to be called to the profession of weather-prophets. The problem is too difficult for a deductive treatment, as there are too many factors and it becomes difficult to trace the succession of cause and effect. As I mentioned above, we have to deal with the problem of flow of radiation through a highly ionised gaseous mass and the problem cannot be properly handled unless we know how energy is generated inside the mass (source of stellar energy), what resistance the gases offer to the flow of radiation (opacity problem), and what is the relation between pressure, temperature and density (equation of state) and further the composition of the stellar mass. On all these points, our present knowledge of atomic physics fails to give any guidance as the conditions cannot be reproduced in the laboratory. The question of the source of stellar energy has been a baffling problem to the astrophysicist. The point may be illustrated with reference to the sun which is radiating $1{\cdot}2\times 10^{41}$ erg of energy per year, i.e. about 6.1×10^{7} erg per gm of its mass per year. Supposing the present age of the sun to be 10^{13} years which is known to be a good estimate from other grounds, 1 gm. of solar mass must be radiating $6{\cdot}1\times 10^{20}$ erg, i.e. $1{\cdot}5\times 10^{13}$ cal of energy during its life course. Where could it have drawn upon such an enormous stock of energy? Detailed treatment has shown that all the stocks of energy known to us are utterly inefficient. Let us take some of these: chemical, radioactive and gravitational. If we burn 2 gm of H with 16 gm of O we get 58×10^{3} calories of heat, i.e. altogether $3{\cdot}2\times 10^{3}$ calories per gm. This is 10^{10} times the amount needed and no chemical reaction will give an amount of energy substantially larger than the above. The next alternative is radioactivity; if the sun were entirely made of Ur, 1 gm. of it, on passing through all changes, would emit only 5×10^9 calories: if the sun were made of radium, the amount would be sufficient but the sun would run out its life in 2,000 years. The energy of gravitational contraction, once invoked by Helmholtz which postulates that the star gets heated as it contracts has been also found to be utterly inadequate.

A fresh, and apparently inexhaustible, source of energy has been opened out, since Einstein proved, from the theory of relativity, that mass and energy are equivalent being given by $E=mc^2$, so that if one gm of matter is fully converted to radiation, we would get 9×10^{20} ergs or $2 \cdot 10^{13}$ cal. Applied to stars this would mean that the stars subsist by *burning their masses* into radiation so that in process of time a star radiates most of its mass. There is some evidence that a star, as it gets old, loses mass, so that the hypothesis appears to rest on a substratum of truth but one would like to know the detailed steps by which mass is being converted to radiation inside a star. On this point, the rate of evolution of energy by stars possessing different physical characteristics will be helpful, as the example of the Sun is not typical but many stars are found to evolve a far larger amount of energy per gm than the Sun.

Star	Spectral Type	Mass	Density	Radius	Temperature (°)	Erg/gm sec
Betelgeuse (α-Orionis)	M_0	40	$2 \cdot 10^{-5}$	290	3,000	300
Arcturus ..	K_0					
Capella A ..	G_0	4·2	$4 \cdot 10^{-3}$	11	5,650	48
Capella B ..	F_0	3·3	$2 \cdot 8 \cdot 10^{-2}$	5·5	7,400	41
H.D. 1337 A	O_8	36·3	$4 \cdot 10^{-3}$	23·8	28,000	15,000
V. Puppis ..	B_1	19·2	$6 \cdot 10^{-2}$	7·6	22,000	1,100
Sirius A ..	A_0	2·45	$9 \cdot 3 \cdot 10^{-1}$	1·58	11,200	29
Procyon A ..	F_5	1·13	$2 \cdot 8 \cdot 10^{-1}$	1·80	7,000	10
Sun ..	G_0	1·00	1·42	1·00	6,000	1·90
o_2 Eridani A ..	G_5	·90	3·7	·70	5,600	·80
α-Centauri B..	K_5	·97	$7 \cdot 6 \cdot 10^{-1}$	1·22	4,400	·90
Kruger 60 A ..	M_3	·25	9·6	·33	3,200	·068
B ..	M	·20	60·0	·17	..	·021
Sirius B ..	A_7	·85	5×10^4	·03	8,000	·007
o_2 Eridani B ..	A_0	·40	$9 \cdot 8 \times 10^4$	·018	11,200	·002

The table shows that the rate of evolution of energy is very different in different varieties of stars. It varies from 1×10^4 erg to one thousandth of an erg for white dwarfs, and is almost nil for the planetary bodies. What may be the cause of such wide divergence? Surmise has been made that either the stars may essentially differ in chemical composition, or the rate of conversion of matter to energy is being largely influenced by physical conditions in the inside of stars in a way of which as yet we are completely ignorant. The treatments are highly speculative for as H. N. Russell says, 'we here lose the valuable guidance of atomic physics'. So far two distinct processes have been suggested; in one hypothesis it is supposed that originally stars mostly consisted of hydrogen, i.e. of protons and electrons. In course of time the protons inside the star combine to form more complex nuclei, and the amount of energy which is set free is available as radiation. This process may be called by the familiar term: *Transmutation of Elements;* in the second hypothesis it is suggested that when a proton and electron collide with each other, they disappear leaving a quantum of radiation in their place. This process is known as '*Annihilation of matter*'. It was claimed, by the protagonists of both of these views, that radiations arising from these processes which take place in the inside of star though very hard (supergamma rays) gets degraded as it makes its way out and gradually gets converted into visible radiation. In support, they held that even in interstellar space, conversion of matter to energy takes place and the radiations arising in this way may be wandering in space, for they would altogether escape absorption, or any other form of degradiation owing to their hardness. And they identified them with Cosmic Radiation.

Cosmic Radiation

Subsequent investigations however showed that the identification was too premature for the only way for investigating the cosmic rays was by observation of their absorption coefficients. From this, the wavelength was extrapolated by utilizing the empirical formula between absorption coefficient and wavelength as obtained in the laboratory. But the rays produced in the laboratory are too soft, and subsequent investigations showed that the extrapolation was unjustified. The question of wavelength of cosmic rays may be said to be still hanging in the balance. We are looking forward to the day when the cosmic radiation curves will be properly analysed, and the energy-content and the intensity of the constituents will be satisfactorily determined. But at present, there is not a shred of evidence in favour of the view put forward very enthusiastically by some distinguished investigators that a number of protons and other positive particles are conspiring in the depths of space to form heavier nuclei, and releasing the radiation which we may call cosmic.

Another fatal objection against this hypothesis is that on this view, cosmic rays would be strongly directional, i.e. coming most copiously from regions of the sky where there is some concentration of matter, the Milky Way or the globular clusters. But this has been disproved. Cosmic rays are diffuse, and the variation which has been found by Clay and Compton are more to be ascribed to the deflecting action of the earth's magnetic field on the secondary electrons and positrons formed by the electrofission of the cosmic rays as they enter our atmosphere. I do not wish to disparage the investigations on cosmic radiation. In fact, I shall show that no astrophysicist can afford to neglect cosmic rays in any scheme of evolution.

III. New Light from Nuclear Physics

The aid of atomic physics, so eagerly expected by H. N. Russell, has been however forthcoming for sometime past. It is however not so complete as to justify one in the attempt to construct a system, but even from the preliminary results it is clear that the riddle of the problems of stellar structure is locked up in the physics of the nucleus of the atom, just as that of the stellar atmospheres was locked up in the physics of the extranuclear electrons. For the discovery of white dwarfs and Milne's hypothesis that the cores of all stars are in the white dwarf stage renders the hypothesis extremely probable that the stars are mostly composed of light elements which, under the temperature in the inside of stars, are stripped completely of their outer shell of electrons. The stellar core therefore mostly consits of free nuclei in close packing, with free electrons slipping in the interspaces. So most of the reactions in the interior of stars would be nuclear.

The physics of the nucleus is a subject of only recent growth. For a long time the physicists' attention was confined to extra nuclear electrons, and he was content to regard the nucleus as a point charge of positive electricity which, for some mysterious reason, possessed the whole mass ascribed to the atom. The investigations on the nucleus are barely ten years old, and though much still remains to be learnt, a review of the recent progress, and a discussion of the bearing of the new results on astrophysical problems is expected to stimulate interest and activity. Even two years ago, it was confidently supposed that the ultimate constituents of matter were the proton and the electron. Their charges were equal and opposite, but there was striking dissimilarity in their masses, the proton containing practically the whole mass ascribed to the atom being about 1,850 times heavier than tihe electron. This dissimilarity in masses has never been satisfactorily explained, but the physicist bowed to the incontrovertible fact with stoic unconcern and proceeded to weave his theories on what appeared to be a basic fact. But the situation has entirely changed owing to fundamental discoveries made last year, viz. (i) that of the *Neutron* . . . . by Chadwick in the Cavendish Laboratory, England. This is a neutral body having almost the whole mass of the H-atom, but possessing no charge; (ii) by the discovery of the *Positron* which is the exact positive analogue of the electron. It was first recognized by C. D. Anderson at Pasadena in the Wilson photographs of Cosmic Rays Positron Tracks. In view of these discoveries, the claim of the proton to be regarded as a fundamental particle has come to be seriously questioned. There are at present two schools of opinion: one school, including my young friend Dr. Kothari, is of opinion that the proton is a compound of the neutron and the positron. The other school which includes Chadwick himself is of the opinion that it is a dipole composed of the proton and the electron. So far no decisive evidence in favour of the one or the other view has been obtained, but I am on the whole inclined to support the view put forward by Kothari and others and I believe that this view has far-reaching astrophysical consequences. For, according to many astrophysicists, hydrogen is found in abundance in the atmospheres of all classes of stars. Either the abundance continues as far as the interior or hydrogen is being constantly formed out of protons and electrons reaching the stellar exterior from the core. In any case, there is likely to be an abundance of protons inside stars. The proton, if it is a compound will be further broken up into the *neutron* and the *positron*, for the binding energy is small, between 10^4 to 10^5 eV and even the smallest temperature ascribed to stellar interiors is sufficient for complete breaking of the proton. The other view does not allow this breaking, for the proton being fundamental, cannot be further divided. So on the first view the atomic core will consist of neutrons, positrons and electrons; while on the second view it will consist of protons and electrons. This is fraught with farreaching consequences. For enutrons have been found to possess the remarkable property of passing through matter till stopped by the nucleus, and when they strike the nucleus, they excite radical changes in it, resulting in the emission of protons, α-particles and γ-rays?

Electrofission of Quantum

The recent investigations on cosmic rays have also brought further definiteness to the idea of so-called annihilation of matter into radiation which, in addition to its bearing on the structure of stellar cores, may produce far-reaching repercussions on the much debated problem of '*Fate of Radiation*'. What becomes of the tremendous flood of radiation which stars are pouring out and have for ages poured out into space without interruption? This question has been a matter of as much concern to astrophysicists as the question of exhaustion of petrol supply to the power-grabbing politicians of different countries. It is well-known that very little of this tremendous flood of energy can be stopped by matter in space. In a few millions of years, the radiation must have passed beyond the most distant Nebulae. On the hypothesis of an infinite Universe, it was believed that all this radiation ultimately gets lost into the great unknown, so that as ages pass by the world will undergo a *Wärmetod:* death due to complete exhaustion of energy supply. If we accept Einstein's theory of a closed world, radiation cannot get lost into space, it will turn back, and go on cruising round the universe, making a complete revolution once in some thousand million years. But even with this picture, we are not past the danger zone. We are still faced with the crisis that ultimately the world may separate into dead matter and free radiation, or according to some protagonists of the theory of expanding universe, who do not always agree, the radiation may be spent in the work of expansion of the universe and converted into the kinetic energy of extra-galactic nebulae. Even this view at the present time cannot be considered as other than speculative for the sponsors of the Expanding Universe theory demand a time scale which is too rapid for the stolid race of physicists to swallow. Further it appears to me that the authors of these theories have ignored two further possibilities: firstly, the possibility of radiation getting reconverted into matter: secondly . . . . the possibility of small energy quanta combining to form high energy or cosmic ray quanta.

Speaking of the first alternative, which is the inverse of annihilation of matter, Jeans wrote in 1931: 'Many, giving rein to their fancy, have speculated that this low level heat energy may in due course reform itself into new electrons and protons. As the existing universe dissolves away into radiation, their imagination sees new heavens and a new earth coming into being out of the ashes of the old. But science can give no support to such fancies. Perhaps it is as well; it is hard to see what advantage could accrue from an eternal reiteration of the same theme, or even from endless variations of it'.

But Sir James Jeans who seemingly prefers Nirvana to cycles of birth for the stellar system must change his views now since the conversion of radiation into electricity is no longer a matter of speculation, but has been actually observed in the laboratory. Anderson and Neddermeyer in America, Blackett and Ochiallini at Cambridge, and Curie and Joliot in Paris have proved that γ-ray quanta of sufficient energy are converted into pairs of positron and electron inside the nucleus. We have termed this phenomenon as *Electrofission of Quantum* which means that under the influence of the intense nuclear fields a quantum of sufficient energy undergoes a *fission* into equal amounts of positive and negative electricity and gives rise to a pair of electrons and positrons. Dr. Kothari, Mr. R. Rai and myself have shown that this phenomenon of electrofission of quantum accounts, in a very convincing way, for the β-ray-activity of radioactive bodies and thus saves the physicist from a very perplexing dilemma in nuclear physics to which attention was first drawn by Bohr in his Faraday lecture of 1932: the problem of accounting for the spontaneous emission of electrons from the nucleus which ordinarily contains no electrons free or bound. Bohr suggested that the phenomenon probably requires abandonment of the law of conservation of energy, and suggested an alternative which was virtually equivalent to creation of energy out of nothing, but before such a time honoured principle is abandoned, other avenues should be explored. It has been shown, at least to our entire satisfaction, that the phenomenon of electrofission saves us from having recourse to such a revolutionary change. The phenomenon of electrofission is the first experimental demonstration of conversion of energy into electricity, but it should be pointed out that it has brought us no nearer to the problem of wholesale conversion of mass into energy demanded by astrophysicists who want a very long time scale for cosmic events. For according to these timegrabbers, there should be a possibility of the whole mass burning into radiation. But as far as our present knowledge goes the main mass is locked up in the neutron and we do not yet know whether or how it can be changed into radiation. In this connection, some speculations of Dr. Kothari may be noted; he thinks that the neutron is a magnetic dipole consisting of two Dirac free magnetic poles of opposite signs. The force of attraction between these two poles is so great that it cannot be ruptured even by the intense field of the nucleus, so that it is thought that in the inside of stars, the neutron is largely in a free state, and able to perform the reactions alluded to above. It can undergo a fission only when subjected to the intense field of a cosmic ray. What happens after that can at the present stage be only a matter of speculation.

The second point is still more speculative but it may throw some light on the question of origin of cosmic rays which is still open. On this point, I wish to dwell a little in detail; for, apart from the peculiar pleasure which cosmic rays have afforded to the physicists of grappling with an elusive unknown, it is not often realized that the cosmic rays may be of far greater cosmological interest than has hitherto been thought. It has now been almost surely established that they are electromagnetic in nature, being in fact hard gamma rays. Further, they seem to be quite diffuse, i.e. originating in no particular part of the sky, like the Milky Way or any nebulae. Thirdly, their intensity in space, sufficiently distant from any nebula, is about hundred times larger than that of visible radiation, being in fact 10^{-3} erg/cm^3 the equivalent mass-density in interstellar space being 10^{-33} which is only hundred times smaller than the massdesnity ascribed by Hubble to free space.

Regarding the origin of cosmic rays, a probability of great importance seems to have escaped the notice of previous investigators. As I pointed out earlier, the astronomer has to work under severe limitations on account of the mantle of atmosphere which lies about the earth. On the cosmic ray side, rays softer than those having the energy 2·6 MeV are cut off even when observations are taken at the height of 22 km which is the highest reached by Kohlhörster, Piccard and Millikan. It is not impossible that in addition to the radiation we observe, space is filled with softer radiation up to 3,000 Å, i.e. an interval of 44 octaves in considerable amount which fails to reach us on account of atmospheric absorption. I personally have found no reason why the cosmic radiation should suddenly stop at any particular value. Whether the rays postulated by me really exist can be proved or disproved by further cosmic ray ascents into heights of 40 to 50 km. To me it seems that there is a strong probability that such rays do exist, for it has been found with each ascent into higher heights of the atmosphere that the ionisation considerably increased and Kohlhörster finds evidence of softer radiations coming into play. If such radiations do exist, I think that our estimate of the space density of radiation has to be completely revised. It may amount to even a hundred times of the value accepted now. There is some evidence that the assumption of such radiation can explain the occurrence of bright emission lines in the spectra of many stars with extended atmospheres about them or of the occurrence of high excitation lines in the atmospheres of systems known as planetary nebulae for whose explanation, the ionisation theory has to be twisted beyond what seems to me its legitimate limits of applicability.

For the present we suppose that such radiations do exist. The question is how they and the harder cosmic rays are formed: I have already alluded to the fact that on the view that the universe is closed, the quanta of radiation emitted from distant ages must have been wandering in space. We may suppose that in course of time two quanta may be frequently coming together, and, by a Compton collision, may produce a quantum of higher energy. It is true that experiments to observe the fusion of quanta have so far yielded negative results, and they are said to be precluded from approaching each other by Bose-Statistics,[1] but some of such collisions may take place inside matter and then the fusion we have failed to achieve in the laboratory may be brought about by what we may call in the absence of a better term by the catalytic action of matter. The quanta wandering in space may in this way go on fusing with each other till it becomes a cosmic ray quanta. This on encountering matter may undergo an electrofission, and be reconverted into the electron and the positron. Thus the hypothesis of fusion of quantum which I must admit is yet without a shred of experimental proof provides us with the missing link for rendering the whole cycle of cosmic processes reversible and cyclic. We thus get the vision of a complete picture of conversion of matter into energy quanta and of energy-quanta back into radiation. Probably the picture will be completed when experimenters succeed in causing a fission in the neutron, and isolating the free magnetic poles first conceived by Dirac.

Is there any Evolution?

Probably my audience would like to get a straight answer to the

[1]This seems to be due to misunderstanding on the part of these experimenters (Jauncey and Hughes, *Phys. Rev.*, 36, 773) regarding the significance of Bose-Statistics which assert, contrary to what the authors say, that quanta have got a gregarious habit of accumulating in the same point of phase space. The failure of the experiment is probably due to some deeper-lying reason, and two quanta on account of their rapid motion may not have been crossing the same point of space at the same instant of time.

question: Is there any evolution? On such a point, one is largely guided by his own sense of aesthetics, as Sir Arthur Eddington blandly puts it. You have probably realized from my hasty snapshots that at the present time owing to improvements in the technique of exploration, and to the employment of a large number of workers, a large mass of floating information has been gathered. As de Sitter says, we have Tycho Brahes, Copernicus, Galileos and Keplers of the new Cosmogeny—but we still want a Newton to arrange the information into a system. Any view regarding Evolution at the present stage is bound to be highly speculative.

According to the protagonists of the expanding universe, the world is closed, and if there by any other universe besides ours, we have not discovered any method for knowing it. The main ideas of this view have gained such wide currency, owing to the good services of the modern world news agency, that it is unnecessary to dwell at length on the subject, particularly as my colleague Prof. A. C. Banerji will deal with it in sufficient detail. The best that can be said of this theory is that it is highly speculative, and cannot be accepted unless we succeed in finding out some other solid peg besides the recession of extra-galactic nebulae (which may yet admit of some other interpretation) on which the conclusions can be shown to rest. Eddington describes himself as a detective in search of such a peg on which the cosmological constant may be hung, and he believes he has found one in a supposed connection between the electron radius, the radius of the universe, and the number of particles in the universe. It is debatable if these values have been properly chosen, and it is at best a long distance hit like long range weather prediction. I feel no hesitation in putting forth an alternative theory which is however based largely on the instincts of a physicist and may be taken for what it is worth. To illustrate my view, I shall again take shelter under the analogy of tropical forest quoted above; suppose a set of intelligent observers allowed one hour's walk inside the forest at intervals of ten years. Will the reports of the observers differ greatly regarding the general appearance of the forest. It is expected that if the forest were a self-contained system there will be the same proportion of young saplings, full-grown trees, giant patriarchs, and mouldering trunks decaying to earth. Individual trees may be born or grow, or decay, but there will not be much of a change in the general appearance of the forest. I would submit that in Cosmos as well, Evolution may be confined to individual systems in their own way like the Earth, or the Solar System, or the Globular Clusters but when old concentrations of mass become dead new concentrations may take their place in a cyclic way. The luminous bodies are incessantly pouring out radiations into space at the expense of their mass, but probably the quanta gather up into Cosmic Rays which again break up into matter, which may gather up in the depths of space, condense and again form into stellar system. The cosmic process is thus cyclic. Matter, acting on quanta and causing electrofission, acts like a Maxwell demon which reverses the inexorable march of Entropy, a doom which has been dreaded by all Evolutionists. But the whole secret of this chain of processes seems to be locked up in the physics of the atomic nucleus to which we must look up in the next few years for clearing up the riddles which confront us in our efforts to know the mysterious Universe about us.

IV

You may now justly complain that I have soared to such aethereal heights that matters concerning life have been completely ignored. To an astrophysicist, life is a trivial, though a perplexing episode, merely disease of matter as one astrophysicist humorously puts it .... which can flourish only within severe limitations of physical conditions. Living creatures, particularly men, may be compared to colonies of ants clinging for dear life to tiny fragments of a wrecked ship in a tumultuous sea and men have somehow been persuaded to the belief that they can hold out only by practising cannibalism on a large scale. To a scientist life is a queer thing, not subject to reason or law like inanimate objects but swayed in its action by inexplicable impulses which Schopenhauer collectively calls 'Will'. So far not much progress has been achieved in the understanding of the problems of life from the physical viewpoint. But for the mere reason that life is dear to us all, we cannot but be interested in its problems, but being for long unable to make any headway from the sceintific side, we are not infrequently tempted, as Bishop Barnes puts it, to escape from the blind forces of Nature to the friendly care of a hypothetical and elusive Providence. The idea of helplessness, which was more keenly felt by men before the era of Science, is probably the origin of religion, but it is doubtful whether the older religions which were based upon an insufficient acquaintance of the Universe, of Nature, as well as of Organic Life, and are largely subjective in origin, have ever served the purpose claimed by their protagonists. In this connection one would like to know whether on any of the myriads of heavenly bodies I have described, there may be intelligent beings and whether they have been able to evolve a system of controlling life better than ours. There is no reason to think life should be confined to our planet alone, but it must be admitted that nobody has yet succeeded in establishing communication with such extraterrestrial beings, though the French Academy has been proclaiming a prize of one hundred thousand francs for several decades for finding out a practical method of opening communication with Mars, our nearest neighbour. On this point, the following opinion of Bishop Barnes is well-worth quoting:

'As I have already indicated, I have no doubt that there are many other inhabited worlds, and that on some of them beings exist who are immeasurably beyond our mental level. We should be rash to deny that they can use radiation so penetrating as to convey messages to the earth. Probably such messages now come. When they are first made intelligible a new era in the history of humanity will begin. At the beginning of the era the opposition between those who welcome the new knowledge and those who deem it dangerously subversive will doubtless lead to a world war. But the survivors, when they extricate themselves from the economic consequences of the peace treaty, will begin what we may correctly term a strenuous correspondence course. I should like to be living then. We might get a true understanding of the evolution of the universe.' (*Nature*, 1931).

The present-day world requires a Prince Henry the Navigator who can conceive, organize, and finance an enterprise for largescale experiment on these lines. Money spent on such experiments would be better spent than money spent on armaments and though we cannot much blame a politician in his actions, for he has to face problems of the immediate, it will be statesmanlike on their part if they can have the courage to organize and finance experiments which will lead to the realization of the above dream.

We believe that for long years yet to come, men on this planet will be left very much to their own unaided resources, and the best way to ensure the future is to foster the scientific spirit, by education as well as by propaganda, and to encourage scientific enquiry into not only purely scientific subjects like physics or biology, but also into Social Sciences. For up to the present time, the forces which have been used for controlling human passions are religious, political and social laws. As I have very often remarked, these laws have been arrived at from an imperfect understanding of the problems of life, of world problems, and from the exigencies of situations of an ephemeral nature. In this connection, it may be worthwhile to quote from the speech of an experienced and sympathetic ruler of men, His Excellency Sir William Malcolm Hailey, Governor of U.P., on the occasion of Inauguration of the U.P. Academy of Sceinces in 1931:

'I suppose that we would all agree, that what we look for in the future is the assistance of science,—if it can give it—in securing a more rational manipulation of human nature. Can it, for instance, give man a domination over his own passions equal to that which it seems to be achieving over the physical forces of the external world? We used to think of the domination of passion as an ethical problem for the individual; but it is the unhappy tendency of modern times to translate individual into mass action, and collections of people now seem to find excuse for passional absurdities in the mass which we should certainly recognize as harmful in the individual. It is perhaps a common-place, but it is nevertheless true, that a generation which ridicules its predecessors for their scientific ignorance, has shown emotional irrationalism on a larger scale than the world has evr seen before. I do not refer merely to the fact that it made a world war; perhaps that was only a temporary ebullition fo world passion; but its subsequent performances in tariff wars, in dealing with its principal medium of exchange or with the problem of disarmament,certainly do not seem to show that it has grown in mental balance. Can science again do anything to rectify the psychology of fear which now seems to dominate the world—fear of national ruin, and fear of material insecurity both to the individual and to collections of people? A sense of insecurity, or a sense of thwarted life, physical or material, is a real source alike of mischief and unhappiness. Can science again do anything to aid the moralist in removing some of the malevolence which does actually seem to form a part of common human nature and which continues to thwart the progress made by the growth of the social sense? It is possibly physiological in origin, which may make scientific attack in the end more efficacious than purely moral suasion. Our conclusion must I suppose be that science is really only one of the agencies which are available for removing these somewhat basic disturbances in the human balance.'

The way in which Science can be of help in aiding the statesmen of the world in solving the problems above referred to is contained in my speech delivered on the same occasion:

'Though there are many evil things on which all shades of opinion are agreed, most of the human tragedies, national, social or civic are, as Hegel aptly remarked, due to conflict between Right and Right, i.e. what is right to one group, has appeared just the opposite to the other group. Is it not possible to find out an absolute standard of the Right, independent of time, locality or tradition? Most of the present views of the Right are derived from the so-called Scriptures, law books and social codes; they still govern the majority of mankind though they date from distant antiquity; but if we discard the pretension of divine origin which is claimed for them by Pundits of the orthodox class, it should be admitted that they were based upon insufficient knowledge and analysis of Nature, of life, and of the actions of the human mind. Is it not possible to subject these last to a searching scientific analysis, and find out absolute standards? Spinoza thought that this was quite feasible.

'Not to laugh or weep over the actions of men but simply to understand them, and to contemplate their affections and passions, such as love, hate, anger, arrogance, pity and all other disturbances of the soul, not as vices of human nature, but as properties belonging to it in the same way as heat, cold, storm and thunder belonging to the atmosphere. For these, though troublesome, are yet necessary, and have certain causes through which we may come to understand them, and thus by contemplating them in their truth, gain for our minds as much pleasure as by the knowledge of things that are pleasing to the sense.'

Scientific methods have been applied by scholars to the study of subjects of more human interest like Civics, Politics, Economics, History, Social Eugenics, and Experimental Psychology, and it is generally the custom to designate them under the collective name of 'Anthropological or Social Sciences'. They deal with the 'Human Mind', and therefore form a natural sequel to the study of the physical sciences which deal with Nature, and biological sciences which deal with individual life. These sciences deal with collected human-life and invade the forbidden grounds of religion, social codes and politics, and some of their findings alarm the vested interests to the same extent as Copernicus's heliocentric theory of the solar system frightened the churchmen of the fifteenth century. But for the good of the world, it is not only desirable that they should be pursued with greater vigour, but their lessons should be applied with great determination to all forms of human activity.

In fact it has appeared to many thinking men that much of the evils of the present-day world are due to the non-adaptation of the human organizations to the changing conditions of the world. Owing to improved methods of communication and to much better contact between different parts of the world, the world is fast becoming one economic and cultural unit. But the politicians still persist in their Olympian attitudes.

Before the great World War, the politician was at the stage where the Physicist found himself before the time of Archimedes, or better in the days of Homer and Hesiod. His country was his Olympus, his own people were his gods, all others were demons, barbarians fit only to be secured against the stroke of the sword, or exploited as helots. The Great War, and all other wars before it were the result of such a mentality, but the Great War exceeded all previous wars in the intensity of destruction and havoc because science placed more power in the hands of men. But it did one great thing, it exposed the absurdity of international quarrels. When the late M. Clemenceau visited Egypt, and was taken round the Pyramids, he commented rather sarcastically on the vanity of the Egyptian Pharaohs who built huge stone monuments with slave labour for the sake of housing their Ka (Soul). He was reminded by a Cairo paper that if the Soul of Cheops, the Pyramid building Pharaoh, could be released from his stony sepulchre, he could have retorted that the Treaty of Versailles and the expenditure on Dreadnoughts, and on military armaments and sacrificing the finest youths of the country before the bloody altar of Nationalism, were far greater absurdities; as one-tenth of the money wasted in the war, if spent on internal development of the natural resources, would have given every belligerent country a far greater amount of security and prosperity than the politicians ever dream to achieve by methods peculiar to them.

The Present World—one Economic and Cultural Unit

At present, the fact is only slowly dawning on the public that the world is fast becoming one great economic unit. A crash in Wall Street leads to a strike in the Bombay Mills, and unemployment in Lancashire leads to fall in the price of jute in Bengal, and ultimately to Hindu-Muslim riots. A prosperous year in India leads to an increased consumption of foreign goods. Overpopulation in Japan and China causes a clash in Manchuria between the two peoples, and is fraught with menace towards Australia and insular India and to world peace. The rulers of countries cannot therefore persist in their Olympian attitude towards other nations—they must become earth-wide in their outlook. But this is prevented by the present faulty system of education which seeks to perpetuate the mediaeval mind, and brings only a small percentage of the population under the humanizing influence of science. The result is disastrous; those who are called upon to guide the nations are mostly men with a rigid outlook, quite unfit to fathom the depths of present-day troubles, or analyse the intricacies of political and economic issues, and unable to hold out any programme of reconstruction. In our country, the result is competitive communalism; among the free nations—a tense atmosphere of competitive nationalism, and between the ruler and subject nations—a spirit of revolt against suffocating imperialism.

But economic and scientific studies show that the world has resources enough for her whole population, and if there be a rational programme of production, and a programme of judicious and equitable distribution, nobody should suffer from hunger, privation, and can even afford to have much better amenities of life. But for this purpose, rivalry amongst nations and communities should give way to co-operative construction, and the politicians should hand over many of his functions to an international board of trained scientific industrialists, economists, and eugenists, who will think in terms of the whole world as a unit, and devise means by which more necessities of life can be got out of the earth; the whole production should be controlled by scientific industrialists, and the distribution should be supervised by the economists. The eugenists should devise means for assigning a fixed quota of population to each geographical unit, which it should not be allowed to exceed. It may seem to be a dream, but is perfectly feasible provided the educational programme is thoroughly revised. A new educational scheme should be devised by a World's Congress of foremost thinkers like Bergson, Einstein, Bertrand Russell, Smuts, Spengler, and others, with the special objective of weeding out mediæval passions from the minds of the coming generation, and for training them to a proper grasp and sufficient appreciation of the beauty and powers of science. The joy of life for the grown-up men will be provided not in designing means for the plunder or exploitation of our fellow-men in various ways but in administering to their needs, and in free development and display of the finer faculties of the mind.

1.1.6 MINOR PLANETS*

THE ancient people believed in the idea that there was something mystical about certain numbers. Of the numbers which received such distinction, seven is the best known. It is recorded that when in 1610, Galileo discovered the telescope, and observed with it the four satellites of Jupiter, one of his colleagues, Francensco Sizzi, a Florentine astronomer, argued against the discovery as follows:

> "There are seven windows in the head, two nostrils, two eyes, two ears, and a mouth; so in the heavens, there are two favourable stars, two unpropitious, two luminaries, and Mercury alone undecided and indifferent. From which and many other similar phenomena of Nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of planets is necessarily seven.
>
> "Moreover, the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore would be useless, and therefore do not exist.
>
> "Besides, the Jews and other ancient nations as well as modern Europeans have adopted the division of the week into seven days, and have named them from the seven planets; now if we increase the number of planets this whole system falls to the ground."[1]

Really speaking, the number of planets known before 1781 was six—Mercury, Venus, the Earth, Mars, Jupiter, and Saturn. Uranus was discovered by Herschel in 1781, and its discovery gave rise to a fresh chapter of activity in planetary investigation.

Bode's Law

The stimulus for this activity was provided by the widespread and almost universal belief that Nature abhors complicated laws. Students of astronomy know well how Kepler was guided in his epoch-making discoveries by the belief that the distances of the planets follow some simple geometrical law: after he had groped to his great discoveries, it was found that his earlier speculations about planetary

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* Sci & Cult **3,** 312, 1937

1 Sir Oliver Lodge, *Pioneer of Science.*

distances did not agree with facts. But the heuristic value of the belief still remained, and the human mind even to this day, persists in the same track. In 1772, another astronomer Bode thought that the distances of the planets were approximately given by a very simple law.

This is obtained as follows: Let us first take the series of numbers

0	1	2	4	8	16	32	64	128	256

in which, it will be seen, each number after the first is double the preceding. Now multiply each by 3, so that we get

0	3	6	12	24	48	96	192	384	768

Add 4 to each of these, giving

4	7	10	16	28	52	100	196	388	772

These numbers are approximately proportional to the actual distances of the planets from the sun, which are (taking the Earth's distance to be 10):

Mercury	Venus	Earth	Mars	×	Jupiter	Saturn	Uranus	Neptune	Pluto
3·9	7·2	10	15·2	-	52	95·4	191·9	300·7	400

At the time Bode enunciated the law, Uranus and Neptune were not known. After the discovery by Sir William Herschel of Uranus in 1781 it was found that its distance from the sun was close to the value predicted by Bode's Law, and this confirmed the belief that there might be some truth underlying the Law.

There is a gap, it will be seen, in the Law, between Mars and Jupiter at the place marked 28 at which number no planet exists. It was noted by Kepler, and a medieval astronomer Titius predicted the existence of a planet between Mars and Jupiter. After the discovery of Uranus the idea became stronger that originally a planet probably existed in this position (28), which was broken up by some unknown catastrophe into a number of smaller planets, each being very small and invisible to the naked eye.

Discovery of Ceres

This speculation set a number of astronomers to the exciting game of hunting for new planets. A society composed of 24 astronomers was formed with Baron von Zach at their head, to look for the missing planets. The first success was achieved by the Italian astronomer, Piazzi, who on the New Year's day of the year 1801 found a star of the 7th magnitude through his telescope at a place where previously he had not observed any. A closer examination revealed that the star had a motion like that of any other planet. It is well-known that the so-called fixed stars have very little motion so that their relative positions in the sky remain almost invariable. The planets, however, move in the field of the stars. So an examination of a suspected new body at an interval of a few hours suffices to show whether it is a star or a planet.

The new-comer was proved to be actually a planet and its distance was found to be 2·8 times that of the earth from the sun, as predicted by Bode. But the planet was extremely small (only 800 km. in diameter, and possessing 1/2000th mass of the earth as later observations showed). In honour of the patron deity of his native island of Sicily, Piazzi called it "*Ceres*". It was only a seventh-magnitude star and invisible to the naked eye. After the discovery of this planet it was believed that there were probably others still to be discovered. But "Ceres" was lost to view before sufficient observations had been taken of its position and any computation could be made of its orbit. This was a sad misfortune, but situations like this sometimes call forth an unexpected genius. On this occasion, the difficulty was solved by the appearance of a new star in the mathematical horizon. This was Frederich Gauss, then a young rising German mathematician at Göttingen, who was earning his livelihood by giving private lessons in Mathematics. The loss of Ceres, called forth his mathematical resources and he worked out a new mathematical method of calculating the orbits of planets from three close positions quite accurately. It was a most powerful method and has been a very helpful guide in finding the orbits of other minor planets. Guided by the calculations of Gauss, Olbers of Breslau, one of the 24 "Celestial Policemen" appointed by von Zach was able to rediscover *Ceres*.

A number of other small planets or asteroids were discovered in quick succession but they all proved to be extremely small. Pallas was discovered by Olbers in 1802, Juno was found by Hardinge in 1807, and Olbers discovered Vesta which is the only asteroid just visible to the naked eye. Then after a long period in 1845, after the astronomers had practically given up the hunt the 5th asteroid was discovered by Hencke, an amateur, and was called Astraea. The discovery of Astraea revived interest in the belief that there were more such small bodies in existence which could not be discovered on account of their extremely small size. In fact, the method was like hunting for grains of gold in a sandy river-bed. But by patient and persistent work, astronomers were able to discover 300 small planets or asteroids by 1890.

A New Method of Planetoid Hunting

In 1891, a very powerful method for finding out the asteroids was discovered by Max Wolf of Konigstühl Observatory near the famous Heidelberg City in Germany. He set up a camera consisting of a wide angle lens, mounted equitorially and moved by clock-work against a field of stars; the camera was rotated at the same rate as the celestial globe. In the focal plane of the camera, the stars would therefore appear as mere dots, as they have no proper motion. But the little planets, if any, in the area sellcted would be represented by elongated lines. An examination of the plate would easily reveal whether any asteroid was situated in the field of view of the camera at the time of exposure. This new method at once replaced the older method of painfully hunting the whole heavens through a telescope in search of asteroids. All that is needed is to set up the camera to do this reconnoitring work and any asteroid which comes within the field of view, provided it is sufficiently large, cannot fail to respond to the roll-call. The powerfulness of this new method will be apparent from the fact that since 1891, from 100 to 200 asteroids are being discovered annually, by this method. The following is a census of the detections since 1931.

1931	1932	1933	1934	1935	1936
162	200	188	269	252	262

This method has the disadvantage that very small planetoids fail to make any impression on the camera, as their light is spread out. So another modification of the method has been worked out: in this, the camera is given a motion equal and opposite to the average motion of the asteroids. So on the plate, the asteroids are reduced to rest, while the stars describe small curves. As the light of the asteroids is concentrated at one point for a long time, even very small ones are recorded by this method.

A number of observatories have made planetoid-hunting their chief activity, *e.g.*, Observatory of Max Wolf at Konigstühl in Heidelberg, Simeis in Russia, Uccle near Brussels in Belgium.

How Planetoids are Christened

Up to this time more than 3000 observations of the asteroids have been made. But all of them are not discoveries. Some of them are rediscoveries of planetoids already detected. The work has been systematized by the International Astronomical Union. The Rechen Institute of Berlin has been entrusted with the task of finding out whether an announced detection actually represents a new object or is simply a re-detection of one already discovered. When they are convinced that it is a new discovery, a number is given to the new object. Up to this time, about 2000 numbers have been given. Thus Ceres is (1), Astraea is (5) and so on.

The naming of the planetoids presents a great difficulty. Formerly they used to be named after the old gods and goddesses of Greece and Rome. These names were soon exhausted. Then they were named after distinguished astronomers, cities, colleges, friends and even after pet dogs and ocean steamers. But it is better to call them by the number given to them by the Rechen Institute which publishes annual catalogues of these planetoids and tries to collect at one place all their characteristics, namely mass, distance, orbit and reflecting power.

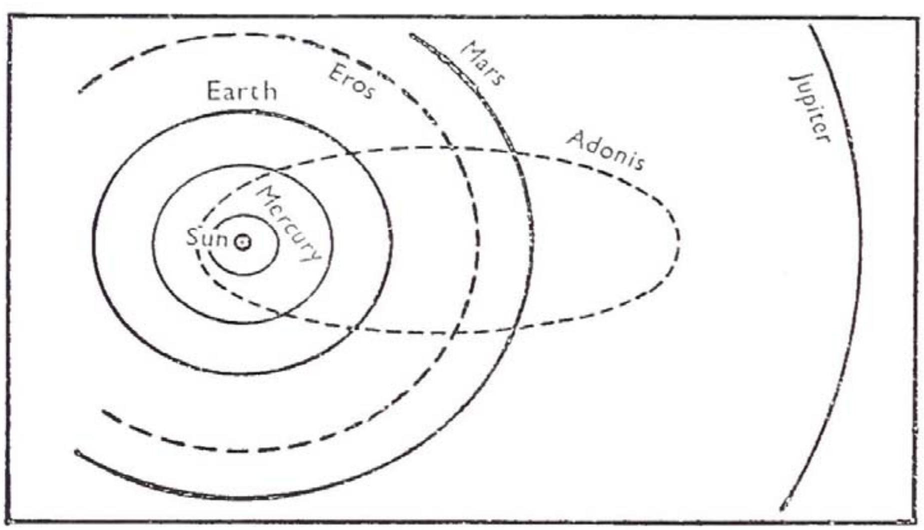
A study of these asteriods has shown certain very remarkable facts. Their mean distance is found to be 2·8 as predicted by Bode. But individual asteriods have been found, which are much farther and others others which are very near, (944) Hidalgo discovered by Baade in 1920 has been found to have a mean distance of 5·7 and a period of 13·7 years. Its orbit is inclined at 40 degrees to the ecliptic, and has an eccentricity equal to ·65. When it is nearest to the sun, the distance is nearly two units, and when it is farthest it passes beyond the orbit of Saturn.

Eros

The asteroid which caused the greatest amount of interest is (433) called Eros, discovered in 1898 by Dr. Witt of Berlin. Eros has been found to have the remarkably short period of 1 years. As a matter of fact, its orbit is for the most part between that of the Earth and Mars, and at its nearest approach to the Earth, it is at a little more than half the distance of Venus which is our nearest planet. This little planet which is probably not more than 25 miles in diameter therefore affords the best opportunity of finding out the scale of astronomical distances. All familiar with astronomy know that for expressing the distances of planetary bodies. the mean distances of the Earth to the Sun is used as the unit. The gravitational theories enable us to find out the distances of other bodies only in terms of this primary standard. To find out the actual distance in centimetres we have to find out the value of this fundamental astronomical unit in centimetres. It will suffice for this purpose. however, to know the actual distance of any of these heavenly bodies in centimetres. Prior to the discovery of Eros, Venus was used for this purpose on those rare moments when it passed across the disc of the Sun (transit of Venus). But these transits are few and far between. Eros is much closer, and transits more frequently across the dise of the Sun. It has therefore supplanted Venus for this purpose. But even Eros will probably be supplanted by a new acquisition made last year (1936).

Adonis

This remarkable, small planet was discovered on the 12th February 1936, by Mr. Delporte, Director of the Royal Belgian Observatory at Uccle near Brussels. Adonis has been found to move in a very elongated ellipse. When nearest the Sun, it is well near the orbit of Mercury and when it is farthest from the earth it is between Mars and Jupiter. In fact, it was found to have passed within 1·2 million kilometres of the earth a few days before its discovery. Its orbit is inclined at one degree to the ecliptic, so that there is a probability



The Orbit of the Planets

that in course of its motion near the earth, it may approach very close to the latter. As a matter of fact, calculations have shown that in 1955 Adonis will pass very close to the Earth. What will happen to the earth then? There are three possibilities:

(1) Most probably Adonis will have such a large velocity that it will be only slightly disturbed by the attraction of the earth and will pass on its orbit.

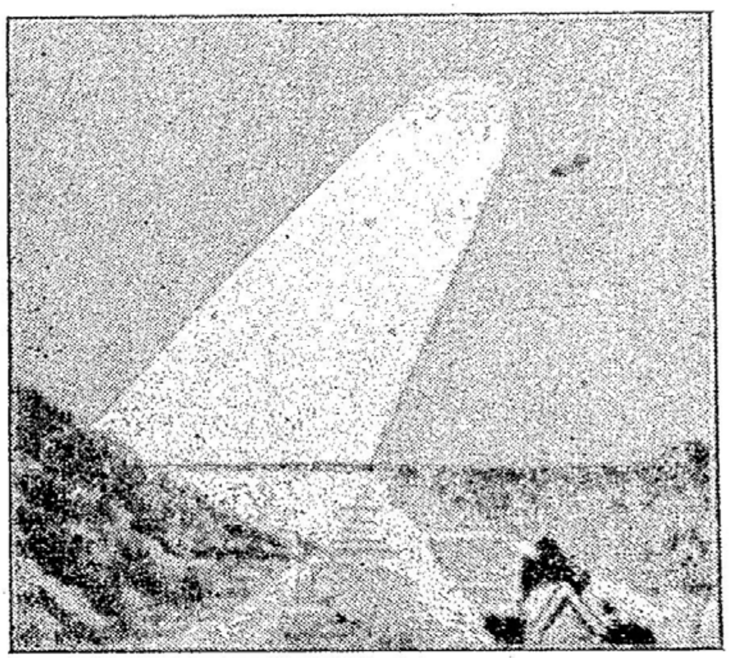
(2) The second probability is that it will be captured by the earth and will form a tiny moon, tiny because though called a planetoid it is only a big meteorite, having a diameter of about half a kilometre.

(3) But the third possibility which the astronomer H. N. Russell calculates to be one in 50,000 is the most staggering. It might be that Adonis may have very insufficient velocity when approaching close to the earth. It will then be subjected to so much attraction that like a huge meteor, it will flash across the atmosphere and strike the surface of the earth with a velocity of 30 kilometres per second.

While one can shudder at the consequences of such a catastrophe; the only parallel case known is that of a great meteor which fell in Siberia in 1908. It weighed only 100 tons, but the atmospheric disturbances and seismic influences produced by it were registered all over the world. Adonis, on the other hand, has a weight of 2 billion tons, so that the consequences of a collision, if it ever happens, can better be imagined than described.

The Origin of the Asteroids

The discovery of Adonis has given rise to fresh speculations about the origin of these interesting bodies. The original idea which set astronomers to this task was that there was a planet between Mars and Jupiter which was broken up by some impact into millions of pieces. This idea has been given up for a long time. The present theory is that smaller asteroids form a kind of ring round the Sun very much like the rings of Saturn, which have been shown to consist of small pebbles each moving in its orbit round the parent planet. The sizes of these pebbles vary from few centimetres to mere dust. Probably the inhabitants of Saturn, if there be any as such beings, would find the Sun surrounded by a similar set of rings, but it is doubtful whether, unless they possess big telescopes like ourselves they would be conscious of the existence of the rings we get a very dim view of this ring in the so-called Zodiacal Light, which is a familiar feature in the sub-tropical regions on any clear moonless night, and, no place is better suitted for its observation than Upper Egypt which has got a perfectly clear atmosphere. Here after the setting of the sun, one can discern within the heavens a luminous fog extending along the ecliptic and having an intensity which is com-



Zodiacal Light

parable to that of the Milky Way. It generally extends up to 90 degrees to the Sun. Sometimes it extends through the whole heavens along the path of the ecliptic, and on the point opposite the Sun there is a concentration of light which is known as the *Gegenschein*, a German word, meaning *Antilight*. The origin of this light has puzzled the astronomers for a long time. From a study of spectra it has been found that the Zodiacal Light is simply reflected sunlight, because the spectrum consists of a continuous background intersected by dark Fraunhofer lines. But it does not at all tell us whether reflection is due to gases or to dust particles. If the cloud is gaseous, the reflected light will be perfectly polarised like the sky light. If it is formed by solid dust no trace of polarisation will appear. Observations show that the Zodiacal Light is slightly polarised. The conclusion is that the ring is constituted by solid particles which on approaching the orbit of Mercury and the Earth get partly vaporised. It is surmised that this ring of pebbles, dust and vapour constitutes Zodiacal Light which extends as far back as the orbits of Mars and Jupiter and what we call the asteroids are only the larger numbers of these rings. As a matter of fact, a number of small planetoids, similar to Adonis, though not so striking, have already been found. One such planetoid was discovered by Reinmuth in 1932, and is now called Apollo. This is about 1·5 km in diameter, has a period of 1·8 years, and the greatest distance is 2·32, but while at perihelion, its orbit is 12 million kilometers inside the orbit of Venus.

1.1.7. SOLAR CONTROL OF THE ATMOSPHERE*

Introduction

Let me now come to the scientific part of my lecture. I wish to tell you about the Solar Control of the Atmosphere. It is a matter of common knowledge that weather and climate, so important to human life, are completely controlled by the Sun. But our troubles begin when we wish to have precise knowledge of the way in which this control operates. This has been an eternal problem with mankind. In ancient communities, there was a profession of Weather Prophets whose duty it was to foretell and, if possible, to control with magic, the weather. Such was the importance attached to the office that a successful rain-maker was very often asked to rule over the tribe. But when he failed, as he must have done frequently, he was sacrificed before the altar of the tribal god. In later times, the office was transferred to Astrologers who are still found in many parts of the world to be issuing weather forecasts for the year. Scientific study of weather and climate dates from the time of discovery of the barometer by Torricelli, but from the very nature of things, early meteorology could not find out a Newton, and it was realized that meteorological data must be patiently collected, classified and analyzed by a world-wide survey, before we can have any inkling of the secrets of the very puzzling complex of phenomena presented by meteorology. For this purpose, meteorological surveys have been organized almost by every State, and a system of short and long range forecasting has been undertaken. But short range forecasting owes, whatever success it can claim, more to powers of quick transmission of news rendered possible by modern discoveries in Physics than to any profound insight into the nature of the problems involved. But what would really benefit mankind is a system of successful long range forecasting six months or at least 10 or 15 days ahead. It is well known that the meteorologist has not succeeded in this task because the problems confronting him are too intricate and he

* Address as the President of the National Institute of Sciences of India (now renamed as National Academy of Sciences of India) in their annual meeting at Lahore in 1939. The general remarks of the President are added at the end of the article.

has to deal with a large number of complex factors. I must not, however, forget to mention that within recent years, Franz Baur in Germany, and Multanovsky in Russia have developed methods for medium-range forecasting which have attained a certain amount of success. Their methods are based on combination of Synoptics and Statistics, and in Franz Baur's method, atmospheric conditions at a height of 5 km are supposed to control ground weather for the next 10 days. But no physical basis has yet been found why this should be the case.

It would probably be considered strange that in spite of the great accretion in our knowledge of physics, and in spite of the large number of qualified men employed in the study of meteorology, we should be forced to admit that success still eludes us. Probably one of the reasons is, as one great Physicist once told the present writer, that meteorology has not yet engaged the attention of a Newton, or as I may add of a Bohr or Heisenberg. Another reason appears to me that the meteorologists long confined themselves to ground phenomena and neglected the Upper Regions. It is true, that in recent years, upper air surveys have been receiving greater and greater attention. There are the spectacular stratospheric flights, exploration of the Upper Atmosphere by Radio-meteorographs, and instruments carried in balloons which signal by radio weather conditions up to heights of 30 kms.

It is usually thought that ground weather is controlled less by the interaction of solar radiation on the atmospheric gases of the sun, than by the direct heating of the surface of the earth by the solar rays. But in the light of the discovery of the stratospheric region, and suspected influence of upper air movements on ground weather possibly the upper air studies have been too much neglected. But in view of the prospective use of the stratosphere for air-travel, and the use of the still higher region for radio propagation, probably the need will soon be felt for a better knowledge of not only the stratosphere, but also of the still higher regions. Here photochemical action of solar radiation ont he atmospheric gases play the chief part. For studying these reactions, we must have a good knowledge of the radiative properties of the sun, but it is not usually realized how defective and imperfect our knowledge in this respect is. We have not, as yet, a comprehensive knowledge of the reactions produced by sunlight on the constituents of our atmosphere.

Incomplete Knowledge of Radiation from the Sun

The Ozone Screen

The sun is regarded usually as a black body at 6000°K. But it has been known for a long time that this is only a first approximation. We find several very glaring deviations from the black body curve. Even after allowing for loss by absorption and scattering by the atmospheric constituents, we find that the emissivity of the sun cannot be referred to any definite temperature. Our knowledge is particularly defective in the ultra-violet region because the solar spectrum is abruptly cut off below λ 2900 Å. This was regarded as a great puzzle to the earlier workers. In 1881 Hartley showed that this abrupt termination of the solar spectrum is due to a small amount of ozone present in our atmosphere. But ozone is not distributed according to the laws of hydro-statics as in the case of the other gases, but was shown by Fabry and Buisson in 1913 to be localized in the upper regions. Interest has now shifted to an actual determination of the total amount of ozone in the atmosphere, its variation with altitude, season of the year and the time of the day. A successful carrying out of the programme involves a world-wide survey which has been initiated by Dobson, Götz and Meetham and are being carried out in different countries of the world. But what is most surprising is the extremely small amount of ozone which is responsible for the complete obliteration of the whole solar spectrum between λ2900 Å and λ 2200 Å. The amount is found to be not more than ·3 cm. of the gas at N.T.P. spread over the atmospheric layer from 20 km to 50 km having a maximum density at abuot 30 km., but the amount undergoes variations which are clearly connected with meteorological conditions. The ozone itself is not an original constituent in the sense O_2 or N_2 is, as in that case, instead of occurring at a height it would have settled down at the bottom, but this is not the case; it has been found that O_3 is produced by the photochemical action of sunlight on the oxygen of the atmosphere in a way which is not yet completely elucidated. But this small amount is sufficient to cut off the whole amount of ultra-violet light below λ 3000 Å. In a sense this is lucky, as otherwise sunlight would have had a very harmful action on living matter on the earth and probably would have made life very trying, if not impossible.

Above the Ozone Screen

Suppose we can push above the ozone screen. What would the spectrum of the Sun be like? Such a feat does not appear to be quite impossible. In fact, Regener, to whom the world is indebted for the cosmic ray exploration of the Upper Atmosphere, sent up in his sounding balloon an automatically working spectrograph up to a height of about 30 km and secured spectrum of the sun from this height. It was found that the ultra-violet limit is slightly pushed down and much smaller time is needed to secure the solar spectrum at λ2900 Å. It is quite possible, as was suggested by the present author in a Harvard Bulletin[1] three years ago, that in the future automatically working quartz or fluorite spectographs would be regularly sent up in balloons up to a height of 50 km and the spectrum of the sun below λ 3000 Å would be secured. Such work will greatly add to our knowledge of the radiation from the sun in this region which is subject to greater fluctuations with disturbances on the sun than the spectral region directly accessible and entirely set at rest the speculation regarding solar radiation in this region which is otherwise inaccessible.

Quiet and Active Sun

But as long as such direct evidences are not forthcoming, it will be necessary for us to obtain conclusions from indirect sources. These are the phenomena which are observed in the part of the atmosphere above the ozonosphere. This region does not contain more than 2 per cent of the total mass of the atmosphere, but it is found to be as much crowded with interesting phenomena, nay even more than the 98% down below. Amongst these phenomena, the most well known is the Aurora or the polar lights which are familiar to the dwellers of the northern regions which suffer from a long winter night. The sky is frequently illuminated in these regions by brilliant flashes of light which naturally enough have engaged the attention of generations of Scandinavian physicists, Birkeland in the early part of this century, Störmer, Vegard, Rosseland and their pupils at the present times. Even before systematic studies were started it was found that the occurrence of these northern lights was subject to solar control. It was found that the brilliancy and frequency of these auroral lights were not constant from year to year, but varied in the same way as the spots of the sun. The period was nearly 10·32 years, roughly known as the 11 year period of the sun.

The close connection between sunspot activity and occurrence of aurora led Birkeland to the view that auroral phenomena were

[1]Collected Scientic Papers of Meghnad Saha, CSIR 1969, 240.

probably due to injection of streams of electrons coming straight from the sun in a narrow jet into the atmosphere of the earth, a view which he further confirmed by laboratory experiments repeated in recent years by Brüche. The streams, on their entry into the earth's atmosphere, are deflected by the magnetic action of the earth's field and are focussed round about the magnetic pole. The complete mathematical theory of the orbits of electrons in the earth's atmosphere has been worked out by Störmer in several important treatises. Paulsen, on the other hand, thought the swarm of electrons which produce the aurora does not come direct from the sun, but are produced by ultra-violet rays of the sun acting photochemically on the constituents in the upper atmosphere. This theory has been worked out in great detail in recent years by Maris and Hulburt and supported by numerous cogent arguments. The great difficulty of Störmer's explanation is that according to his theory, the region of maximum occurrence of aurora would be a region about 2° to 3° round about the magnetic pole, while actually the zone of maximum occurrence forms a girdle of about 20° radius about the magnetic pole. Further, as Hulbert noted, the electron-projection theories are mostly geometrical and do not attempt to go into the physics of the thing. For this, we must turn to an examination of the spectrum of the aurora which has been carried out for a long time by Vegard, Störmer and others. The most important line is a green line, the origin of which was unknown for a long time. As it apparently occurs at a great height of the atmosphere, at first sight it appeared that it must be due to a gas which is very light, even lighter than hydrogen. This hypothesis was rendered necessary because hydrodynamical calculations showed that with reasonable assumptions about the temperature distribution in the upper layers of the atmosphere, there would be very little of the heavier gases left at heights of about 200-300 km in the regions where the aurora appear. In fact, there would be scarcely a single molecule of nitrogen or oxygen in a cubic centimetre. The upper atmosphere would consist entirely of light elements like hydrogen and helium. But surprisingly enough, neither the green line nor any other auroral lines could be ascribed to either hydrogen or helium; hence we must exclude the possibility of existence of these elements in the upper regions. This green line was therefore ascribed to a hypothetical element even lighter than hydrogen, called Geocoronium by Wegener. But when Moseley definitely proved that there was no place for such an element in the Periodic Table, it was found necessary to look for the origin of the lines from amongst the known elements. After an epic struggle, the line was traced, chiefly due to the efforts of the late Sir John MacLennan, to the old familiar oxygen atom, in a peculiar state of excitation. The reason why this identification was not made earlier is that the line does not occur in the ordinary discharge spectrum of oxygen. It is given by the oxygen atom when it is in a metastable condition, by what is known as the forbidden transition from one metastable level to another. Though the subtility of the origin of the line, and its implication can only be realized by one having an intimate knowledge of spectroscopy, the discovery shows that oxygen, contrary to hydrodynamical conceptions, is present in the auroral regions (80 km-400 km) in the atomic state and in a peculiar state of excitation; a closer examination of which alone can lead us to a knowledge of the peculiar physical conditions prevailing in this region.

Further examination of the spectrum of the aurora reveals lines which have been identified with those of ionized nitrogen and neutral nitrogen molecules. Recently Kaplan has reported a forbidden line of atomic nitrogen. Before we turn to an examination of the solar control of the aurora, let us consider another associated phenomena.

Quiet Sun—Night Sky Phenomena

But it is not merely the region round the magnetic poles which show such unexpected behaviour. It has been well known that if one observes the sky from the countryside far away from the city lights at the dead of night, the starless parts of the sky do not appear to be absolutely dark, as one finds when one is placed in an absolutely light-tight chamber, but the sky appears to possess considerable luminosity. This must originate from the upper regions of the atmosphere, even on stations far removed from the magnetic poles; hence the luminosity must be due to some other cause besides artificial stimulation by electrons which give rise to aurora. An examination of the spectrum of the luminous night sky carried out at different regions of the world reveals very interesting information. It shows the same green line of oxygen and certain other band lines which have been identified with those of nitrogen. There is, however, one important difference between the spectrum of the night sky and the aurora. In the latter, bands due to ionized nitrogen predominate and the lines due to uncharged nitrogen molecules are very feeble. The reverse is the case with the spectrum of the luminous night sky. Here the negative bands are faint and sometimes even absent, whereas band lines due to neutral nitrogen molecule are extremely strong. The origin of the luminescent night sky must be traced to the fact that at these heights, sunlight is absorbed by the atmospheric gases in daytime and stored in some way and is re-emitted at night. A closer examination of the phenomenon therefore promises to throw much light on the nature of the solar radiation, because the night sky phenomenon can be due to no other cause except the action of the ultra-violet rays of the sun below λ 2000 Å on the constituents of the upper atmosphere.

From the above short account, it will be clear that the luminescent night sky, and the aurora, both represent optical excitation of the constituents of the upper atmosphere, but under different conditions. The former is a purely photochemical excitation, by a normal sun—the latter is due to an active sun, and further complicated by the peculiar way in which optical excitation is provided through the agency of electrons which, according to one view, comes directly from the sun, but according to another, is photoelectrically liberated in the outer regions of the sunlit part, but are deflected by the field of the earth towards the magnetic poles. It will be seen that all upper atmospheric phenomena, electrical as well as magnetic, can be divided into these two main categories, as shown in Table I.

Solar Control of Terrestrial Magnetism

The solar control of the magnetic field of the earth is illustrated by disturbances of two types—an erratic one called Magnetic Storms, first observed by Celsius in Sweden as early as 1741, who found that coming of the aurora was heralded by a certain amount of restlessness of the magnetic needle: the Magnetic Storms have since been much studied and have been found, in general, to occur in greater intensity and frequency simultaneously with periods of solar activity indicated by spots and aurora. But though correspondence between the two sets of phenomena has been established in a general way, individual correspondence has not been established, i.e., every big spot has not been found to be associated with large scale auroral displays or with large Magnetic Storms.

The second type of disturbance of the magnetic needle is of more regular nature and shows a diurnal and a monthly period. At sunrise, the N.E. of the needle is slightly east of its position; at noon, it

TABLE I

Sun	Quiet	Active	Erratic	Long Period Variations
	Eleven year Period			
..	..	Spots, Faculae, Prominences	Bright Eruptions	80,000 years
Total Radiation	1·92 cal/per cm /sec	1·92 + ·0007 (sunspot no.)	..	..
Optical	Luminous Nightsky	Aurora	..	..
Magnetic	Solar and Lunar Terms in Variation of Terrestrial Magnetic Elements	Magnetic Storms	Magnetic pulses	..
Radio	E —region, F —region (day), F —region	General strengthening of ionization, C, D and other occasional layer formations	Radio Fade-outs (short and medium waves) strengthening of long wave and Atmospheric reception	..
Electrical Lower Atmosphere	..	..	..	..
Climatic	?	..	?	Glacial and Interglacial epochs

points approximately to its mean position, towards sunset it moves to the west, and regains the mean position again at midnight.

A Gaussian analysis of these types of disturbances showed that they originate in the earth's atmosphere and the first explanation was given by Balfour Stewart about 1860, and considerably extended by Schuster. The theory conceives that the daily disturbances are caused by horizontal movements of electric currents in the upper atmosphere across the vertical field of the earth's field. The nature of these currents could not be explained at the time, but after the discovery of the electron, they were naturally ascribed to movements of electrons, and detailed theories of daily variation of magnetic elements was worked out by Chapman and others.

The Ionosphere

The idea that there are charged particles moving in the upper atmosphere was rescued from the cold storage into which it had fallen in a rather romantic way, when Marconi in 1898 succeeded in transmitting electromagnetic waves from England to America. When the result was communicated to the Royal Society, Lord Raleigh very pertinently remarked that the waves could not have travelled in a straight line, as there are hundreds of kilometers of solid obstacle presented by the curvature of the earth when the two stations are connected by a straight line. They must therefore be guided along the surface of the earth, or got reflected from the upper atmosphere. To explain this difficulty, Kennelly and Heaviside about three years later almost simultaneoulsy proposed that the upper atmosphere contains a number of free electrons which form a sort of metallic shield about the earth, reflecting the wireless waves and thus keeping them confined within a narrow shell about the earth.

The prediction was at that time in the nature of speculation but success of wireless propagation and failure of other explanations showed that all other alternative explanations were either useless or insufficient and that the hypothesis of existence of the ionized layers higher up in the sky was one in the right direction. Precise theory has evolved as a result of successful refinements by Eccles, Larmor, Appleton and others. At the present time it is known that the electrons which act as reflectors of the wireless waves are stratified in different layers of which two are permanent. They are known as the E_1 which is at a height of about 100 km., and F_2 discovered by Appleton in 1923, which is at a height of about 200-250 km. Methods have now been perfected for finding out the night and day variation of the heights of these layers, their maximum electron concentration and variation of these quantities during the hours of the day and night and also during the whole year. In addition to these permanent layers there are subsidiary ones, of which mention will be made later.

Origin of Reflecting Layers

We can now ask ourselves about the origin of these electron layers. Here, as in the questions about the origin of the aurora, there were long controversies whether these layers were formed by electrons coming direct from the sun as originally proposed by Birkeland or were they due to electrons liberated by the ionizing action of ultra-violet sunlight. The question was answered in a decisive way by observations of the density of electrons during the total solar eclipse of 1932. These showed conclusively that at least in the E and F-regions the electrons were produced by the ultra-violet sunlight because, as soon as during the instant of totality the light was cut off, the density of electrons fell to a very small value. It is therefore clear that the production of electrons in the E and F-regions is entirely controlled by the sun, through its ultra-violet radiation.

A thermo-dynamical theory of ionization of the upper air constituents by the ultra-violet rays of the sun was worked out in a general way six years before the eclipse observations gave a clear reply to the controversy by Prof. Pannekoek of Amsterdam in 1926. In 1931 Prof. Chapman, following an earlier work by Lenard, worked out a *mathematical* theory of production of electrons by monochromatic light which enabled one to obtain a formula showing the variation of electron concentration with the zenith angle of the sun. We have here the gases constituting the earth's atmosphere, which are being traversed by the rays of the sun at varying angles. The rays produce dissociation of molecules into atoms, and ions and electrons. But these processes cannot go on unchecked but the free ions and electrons recombine producing again neutral particles and sometimes the electrons attach themselves to elements having electron affinity and form negative ions.

The general theory of ionization of the atmospheric constituents by sunlight was worked out by Pannekoek by extending the theory of Thermal Ionization given by the present author six years earlier with the aid of a modification proposed by E.A. Milne for the case when the temperature of radiation is very different from that of the gas traversed. Pannekoek calculated the equilibrium number of electrons produced by sunlight from nitrogen, oxygen and hydrogen molecules making certain plausible assumptions regarding the quantities which are needed for the calculation. These are the ionization potentials of the molecules and the elements, the temperature of the sun regarded as a black body, and the temperature of the upper atmosphere. The values adopted for all these quantities were rather rough, but nothing better could be done at that time. Pannekoek was, however, able to show that the number of electrons obtained from such calculations and the height at which the maximum concentration occurs was in rough agreement with the number obtained from the ionospheric experiments. By 1931 much more had been known about the ionosphere, e.g. there were, thanks to the work of Appleton, Nichols and Schellung, Gilliland and Kirby, precise information regarding variation of the maximum number of electrons in the E and F-layers, during hours of the day, with season and latitude, and to account for these Chapman worked out in greater detail the variation of the number of electrons produced by a monochromatic beam of light when the rays of the sun fall at different slanting angles and was able to show that his conclusions were in substantial agreement with the results just mentioned. Chapman's theory is, however, severely mathematical and he had to assume that the equilibrium is of the unicomponent type, that is to say, the electrons are produced from one component, say from the nitrogen or the oxygen molecule or the oxygen atom, and the electron produced combined with the ion of that component alone. But on account of mathematical difficulties the theory, although in a position to explain the results of observations for the E and F-regions roughly, did not enable him to make any exact calculation of the number of electrons produced as Pannekoek had done. In fact, the two theories existed side by side, and no connection was shown between them.

This fact and the arbitrary assumptions regarding the values of the ionization potentials, and of the values of the absorption coefficients of the photo-ionizing radiation made it extremely desirable that foundations of both the theories should be further critically examined.

A beginning in this direction has been made by the author and R. N. Rai. It is a re-working of the Pannekoek theory, since they found that the Chapman theory was implicitly contained in the fuller theory of Pannekoek. But they have shown that a satisfactory theory involves accurate knowledge of many factors, which are set out in detail in Table 2. Some of these, e.g. ionization potentials which were roughly known when Pannekoek had been working, more precisely determined by 1936. But a knowledge of I.P. alone is not sufficient, we must have a knowledge of the intensity and variation of the absorption coefficient of these radiations with frequency for atmospheric constituents, atoms or the molecules concerned. The necessity of this was not realized before, but as the height of maximum ion-production varies inversely as τ_0, the maximum absorption coefficient, the importance of determining accurately the nature of $\tau(\nu)/\nu$ curve becomes apparent.

The previous workers had used for this purpose a formula given by Kramers, which was deduced on the basis of old quantum theory for explaining the absorption of X-rays by matter. But, as Rosseland remarked, the usefulness of the formula was overstressed, and even in the case of hydrogen, where it is most expected to hold, Leigh Page has recently found the formula defective. The best course would have been to obtain the nature of $\tau(\nu)/\nu$ cur.ves from actual laboratory experiments, but obviously such experiments can be carried out only for O_2 and N_2, but it cannot be seen yet how they can be carried out for O and N-atoms. Even in the case of molecules, the experiments are very difficult, and complicated by other phenomena. But such experiments as exist (e.g. those of Hopfield and Takamine) and their theoretical interpretations show that for each of the O_2 and N_2-molecule, two types of ionization exist—first, a feeble one, caused by a forbidden electronic transition, and the second one, caused by an allowed transition. The τ-values for the two processes are entirely of a different order, the second process being at least 10^4 times more intense than the first.

A tentative wave-mechanical theory for photo-ionization of atoms like O and N can be worked with some effort, but it appears wrong to utilize the same or a slightly modified formula for molecular photo-ionization. It is rather surprising that no theory of photo-ionization of molecules has yet been attempted. A beginning in this direction has been made by B. D. Nagchowduri and K. M. Bose for H_2, because the cases of O_2 and N_2 present almost insuperable mathematical difficulties. The point to be noted is that the $\tau(\nu)/\nu$ curve does not begin with a maximum at ν_0, the minimum photo-ionizing frequency, but this is reached at some distance, depending on the values of the nuclear distances of the atom, and the ion respectively. Further, the curve is not smooth like that of the atomic photo-ionization curve, but is broken up at points $\nu=\nu_0+n\omega$, where ω is the frequency of vibration of the ion, and n is the number denoting the upper harmonic.

It will possibly take some time before such curves, so much necessary for calculating ionization of the upper atmosphere, are accurately determined. It is, however, pleasant to notice that Takamine has already started such experiments, and obtained a certain amount of verification for ionization of the N_2-molecule by Neon-light.

The Formation of Electron Layers

An unexpected result, which comes from the revised Pannekoek theory of ionization, is a successful explanation of electron layer formation, which was originally attempted by Lenard and more fully from the mathematical point of view by Chapman. They showed that if *monochromatic light* is absorbed by atmospheric constituents with liberation of electrons, the constituents being assumed to be distributed according to isothermal equilibrium, a layer of electrons is formed in the regions where absorption takes place. The electron-density attains a maximum at a certain level, where the pressure is proportional to Mg/T_0, and falls off nearly parabolically on both sides. The haif width of the layer varies as $\frac{kT}{Mg} = H$, usually known as the height of homogeneous atmosphere. This theory was roughly verified by investigations of the form of the lower side of the E_1-layer and the F_1-layer. It appeared that to explain the form of the E_1-layer, we have to assume that H is small, of the order of 10-15 kms., while that of the F_1-layer is about four times as great. These might be ascribed to the fact that the temperature of the F_1-region is, according to some workers, about four times larger than that of the E-region, but if the F_1-region is due to ionization of the oxygen atom, as suggested here, we need not make the temperature four times larger than that of the E-layer. A temperature double that of E would do.

But apart from other difficulties Chapman's work was insufficient in one respect, namely, that it was proved only for monochromatic light, whereas actually if we suppose the sun to be a black body at 6000°K the ionizing radiation should consist of the whole spectrum beginning from a certain limit and extending indefinitely towards the ultra-violet. It could not be seen off hand if ionization by such a spectrum would not destroy much of the properties of the layer. But in the revised theory, it so happens, and it is a rather unexpected result, that even continuous spectrum produces a layer very much similar to the simple one made familiar by the work of Chapman. It must be admitted, however, that the form of the layer depends to some extent on that of the photoionizing absorption curve, which is not yet known for the ionization processes actually occurring in the atmosphere but is only deduced from a plausible theory. As long as this is not known, it is of course not possible to give further precision to the theory, but approximate values of electron concentration can be obtained with the aid of some plausible assumptions regarding the radiation from the sun and the temperature of the Upper Regions.

The considerations, therefore, lead us to the conclusion that the different stable layers as observed in the ionosphere are due to ionization, by the appropriate solar radiation, of distinct constituents of the atmosphere, viz., N_2, O_2, N, O, the maximum of the layer occurring at the height where total absorption of ionizing radiation by the particles reaches its maximum value. We may proceed to identify the processes. The E_1-layer must be due to a process of ionization which is effective only at a height of 100 km. As the amount of gaseous oxygen and nitrogen molecule above this height is of the order of a few cm, the radiation which causes E-layer ionization should be such that it can be transmitted through a few cm of nitrogen and oxygen gas at NTP These considerations prove that the E-layer is probably formed by the first process of ionization of O_2 and N_2 at 12·2 and 15·5 volt. The pressure at the apex of the layer is given by $P \simeq \frac{Mg}{T}$, now for an allowed transition, τ_0 is of the order of 3×10^{17}, for a forbidden transition it may be taken to 10^4-times smaller, say 10^{-22}. We then get $P = 10^{-2} - 10^{-3}$ mm of mercury. This is just the pressure in the E-layer. The F_2-layer, on the other hand, should be due to ionization by radiation which can be stopped by about a thousandth mm of the gas, because at a height of 200-250 km where this layer is formed, the amount of gas lying above cannot exceed this amount. We can easily link up this fact with the second ionization of N_2 and O_2 which gives rise to excited O_2^+ and N_2^+, because the ionization occurs with an intensity which as mentioned before is about 1,0000 times stronger than the first ionization. The pressure, calculated from the formula $P \simeq \frac{Mg}{T}$, is of the order of 10^{-6} to 10^{-7} mm which is of the order of pressure at the F-layer. The F_1-layer is a purely daylight phenomenon. It is found that the night F-layer splits up into F_1 and F_2 when the sun is sufficiently high up in the sky and towards nightfall, when the sun's altitude has fallen, F_1 and F_2 unite to form one single layer. The F_1-layer is therefore a purely daylight phenomenon and is probably due to an extra process besides ionization which is operative only during daytime. All the available knowledge points to the probability and this has also been mathematically demonstrated by Dr. R. C. Majumdar that during daytime the oxygen molecule probably completely dissociates into atoms at a height of about 200 km on account of absorption of radiation between the wave-lengths 1750 Å and 1300 Å. a process which has been very thoroughly studied in the laboratory by Ladenburg and Van Voorhis. P, the pressure at which the maximum absorption of this radiation occurs, is of the order of 10^{-4} to 10^{-5} mm of mercury and hence it is between the E and F-layers. The electrons which give rise to the F_1-layer must be due to further ionization of the oxygen atoms, so produced during daytime. At night time or when the sun is sufficiently slanting, probably most of the oxygen atoms at this level would recombine to form molecules and therefore F_1-layer will disappear, as there are not sufficient oxygen atoms to be ionized.

The F_2-layer

This explanation may appear to be apparently at variance with certain other observations, for example, the anomalous behaviour of the F_2-layer. It has been already remarked that the formation of the E_1 and F_1-layers follows solar control and they demonstrate approximately the validity of the theory of photo-ionization by sunlight and theory of recombination as in a unicomponent system. The concentration in these layers attain a maximum at about noon and follow the fourth power of the cosine of the sun's zenith angle, a result which can be deduced from these theories. The seasonal variations are also in accordance with the theory of solar control. But not so with the F_2-layer for which maximum concentration is found to occur for Slough in summer at about 9-10 A.M., is followed by a minimum at 2 P.M., followed by a maximum at 8 P.M., and a pronounced minimum at 3 A.M. Even during winter, though a midday maximum is obtained, there is an unaccountable smaller maximum at midnight. For other latitudes as well, the behaviour is anomalous. During total solar eclipses, the F_2-region ionization appears to remain unaffected. All these and other facts show that either the solar control theory is insufficient for this region, or in working out the theory of photo-ionization we should not regard the system to be a unicomponent one. Probably in the F_2-region the pressure is so low that collision between the electrons and ions must be extremely infrequent, neutralization takes place after intervals of the same order of magnitude as the day and hence the equilibrium theory has probably to be considerably modified.

It must not be supposed that even if we except the high perplexing features of the F_2-region, the theory of solar control can explain all the characteristics of the ionosphere. Rather puzzling is the persistence of ionization in the E-region at night. According to the solar control theory, the E-region should entirely disappear as soon as light is withdrawn because in this region collision frequency is quite large (10^5 in a sec.) and recombination must be very quick, but we find that there is residual ionization about 1/20th of the maximum amount, which is present throughout night. It does not appear probable that this is due to positive ions. We must therefore suppose, as Martyn and Pulley have done, that at night there is probably some mechanism at work by which fresh electrons are produced. It is not improbable that a neutral molecule colliding with a negative ion might knock out the electron, and supply the electrons forming the residual E-layer at night.

A complete theory of the various puzzling ionospheric phenomena will probably take years of work. Much depends on the correct interpretation of the results obtained by the method of reflection of radio waves from the ionosphere. It must not be supposed that the magneto-ionic theory of propagation of e.m. waves which is now holding the field is infallible.

Radio Fade-outs.

Probably the solar control of the upper atmosphere is nowhere more strongly illustrated than in the phenomenon of Radio Fade-outs, which has been studied in recent years as an international programme by a number of workers in Europe and America, particularly by Dellinger in the U.S.A. and Jouast in France. It was observed for some years that sometimes radio signals which were being usually received from a distant station suddenly stop and the normal conditions are obtained after lapse of time which extends usually over a few minutes. Observations showed that many of these sudden radio fade-outs were simultaneous with the appearance on the surface of the sun of small bright patches of intense white light observed by Carrington as early as 1859. Spectorscopic observations caried out at Mt. Wilson and elsewhere showed that these patches emit the Balmer lines of hydrogen in great strength. From the international programme carried out by Dellinger and Jouast it was found that the phenomenon is confined only over the sunlit part of the globe and the interruptions were simultaneous over different parts of the earth within the sunlit regions, and that the sudden stoppage was connected with intense chromospheric eruptions, though all eruptions did not give rise to radio fade-outs. Further investigations showed that neither the ionization nor height of the E and F-layers was very much disturbed during these sudden radio fade-outs. The cause of the disturbance must, therefore, be sought below the E-region or in an intense transitory ionization of the regions below E, which is sometimes called D by Appleton. This is further confirmed by increase in intensity of long-distance radio by means of very long waves during radio fade-outs, which refer only to short and medium waves, because long waves are reflected from the low, i.e.D-layer. Further, the radio fade-outs are accompanied by magnetic disturbance of short duration, which are strongest over the part of the globe directly under the sun at the time of the eruption. This shows that the small particles send out a flare of ultra-violet which produces intense ionization of the region D.

Let us see how this flare works. The great strengthening of the hydrogen lines is merely a token that something unusual is hapening on the sun. Spectroscopy tells us that when the Balmer lines are emitted in great strength, the Lyman lines would be in fact far stronger, but it can be shown that neither the Balmer lines nor the first two Lyman lines can produce any ionization in the atmosphere, because the amount of energy they carry is below the critical limit required for ionizing any of the atomspheric constituents. It is only the third Lyman γ and the subsequent lines which can ionize O_2 to O_2^+ by the first process of ionization which, being feeble, can penetrate to lower levels. This is also confirmed by the experiment of Takamine and Suga who found that the $L\alpha$ and $L\beta$ lines can be transmitted in undiminished strength through thin columns of O_2, but slightest trace of O_2 obliterate $L\gamma$. There may be, besides, radiation of other elements of approximately the same wave-length and they will reach the D-level which contains, above itself, nearly 11 cm of N_2 and ·57 cm of O_2 at NTP The above is only a suggestion. The particular part of the solar spectrum which is responsible for the extra ionization in the D-layer will be found out after extensive research. But the phenomenon illustrates that even transient disturbances on the surface of the sun find their echo on the doings of mankind on the earth, which involve the upper atmosphere.

The Luminous Night Sky

We might briefly pass over the problem of the luminous night sky phenomenon, which has been briefly reviewed before. There is no difficulty in comprehending that the luminescence of the night sky must be in some way intimately connected with the action of sunlight on the constituents of the upper atmosphere. But the great puzzle is the persistence of the phenomenon. Take for example the green line, which is a permanent feature of the night sky. We can suppose that during daytime, photo-electric action of the solar rays decomposes oxygen molecules into normal O atoms and excited O atoms, and the excited one if it is in the $O'S_0$-state reverts back to a lower state giving rise to the green line. It must be added, however, that no such photo-electric phenomenon has yet been discovered. This explanation cannot hold for the night sky emission of the green line, because the life of no excited atom can ever be much larger than a second, and hence as soon as sunlight is withdrawn all metastable oxygen atoms will promptly revert back to the normal state. How does the green line then originate in the night sky? The only explanation which promises a certain amount of success is a theory of recombination between ions and electrons, which must be going on when sunlight is withdrawn from these heights. At daytime in the F-region, illuminated by sunlight the upper atmosphere would consist mainly of electrons and ionized atoms of O and N and probably also of O_2^+ and N_2^+. When sunlightis withdrawn at night, the electrons will combine with the ionized atoms and molecules. To fix our attention, let us take the ease of O^+. An electron colliding with it may form oxygen atom in the normal state as well as any one of the two metasttable states ($O'S$ or $O'D_2$). The metastable states, after they are formed, will emit the green line or the red line and revert back to the normal state after a fraction of a second, because they have nothing else to do. This theory of night sky luminescence recalls to the mind of the author the stimulating theory of Zanstra of emission lines of Planetary Nebulae, all of which are forbidden lines of the type of the green line. This also explains to some extent the Height-effect of Vegard, who found that the green line is intensified in the higher part of the sky. The explanation is that at the lower parts, the $O'S_0$-atom will collide with other particles and lose its energy by collisions of the second type before it has a chance to radiate. The emission of the green line is therefore a consequence of recapture of electrons by the O^+-ion, and its persistence is due to infrequency of collisions in this region due to small pressure. It is estimated that at these heights, the mean free path of the electron is extermely large, say about 10^8 cms. and the velocity is probably in the neighbourhood of 10^7. So there may not be more than one collision per second but only one in 10^5 gets captured to form an $O'S_0$ or $O'D$ -atom. These will then have nothing to do except radiate the green or the red auroral lines. We can by the same hypothesis explain the absence of the negative bands of nitrogen from the night sky spectrum. It is well known that the negative bands arise from an excited state of N_2^+ which however can be produced by direct ionization of normal N_2 by ultra-violet sunlight possessing energy of the order of about 21 volt. Any excited N_2^+ which is produced in these upper layers must immediately disappear as soon as the sunlight is withdrawn, a hypothesis which explains in a convincing way Slipher's observation that during the morning or evening flash of sunlight, the negative bands of nitrogen are obtained from the upper atmosphere in great strength but they disappear as soon as sunlight passes away. At night time therefore the N_2^+-ion which remains is non-luminous and there can be no further emission of negative bands, unless N_2^+-normal is further activated by electron impact. The electrons will combine with this N_2^+ forming different excited states and immediately after the recombination, the exci_ed N_2 will revert back to the lower states giving rise to the second and first positive bands and the Vegard-Paplan bands. The persistence of luminosity in the sky throughout the night, therefore, seems to be due to the fact that on account of extreme rarefaction at these heights, the rate of recombination is extremely slow. As a matter of fact even without fresh sunlight, the electrons and free positive ions can probably exist for days together, as is shown by the existence of the F_2-region in the polar atmosphere, even when these regions are perpetually in the dark for days together.

Bright Emission Lines from the Sun

The Astrophysical Theories of the Sun

You will see from the above incomplete review that a correct interpretation of upper atmospheric phenomena suffers greatly from the desired data that we have no direct knowledge of the ultra-violet part of the solar spectrum as it would appear to an observer outside our own atmosphere. For our purpose, this knowledge is most important because almost all the Upper Air Phenomena are due to the action of ultra-violet light on the constituents of the atmosphere and when a disturbance takes place on the sun, it is the ultra-violet radiation which is most affected. But the question may be put why not tackle the question from the astrophysical side ? As a matter of fact, astrophysicists have not been idle. Mention may be made of a famous paper by Sir A. S. Eddington which aimed at giving a quantitative idea of the formation of Fraunhofer lines and its subsequent extensions by Milne, Chandrasekhar, Wooley and Stromgren. But if one goes every deeply into the fundamental assumption underlying these works, it is found very difficult to be able to agree with many of their basic assumptions, e.g. there is no reason to suppose that the radiation from all layers of the sun should be black body radiation. In fact, the assumption is positively contradicted by certain observations. If the temperature of the surface of the sun, which gives us the continuous background of light, were 6000°K, it can give us only such absorption lines which require moderate excitation and the chromospheric spectrum would give us emission lines whose excitation potential should not be greater than 6 to 9 volts. But it is a well-known fact that the chromospheric spectrum of the sun gives us the lines of helium requiring an excitation potential of over 20 volts, and also a line of helium$^+$ (λ=4686 Å) which requires an excitation potential of about 79 volts. It is therefore clear that the common notion that the sun radiates like a black body at a temperature of 6000°K can only be an approximation and a very rough approximation. In fact, the Russian observes, Perepelkin and Melnikov, in a publication from the Pulkovo Observatory have shown that the intensity of these emission helium lines is almost nil on the limb of the sun, and gradually rises to a maximum at a height of 2500 km in the solar atmosphere and then steadily falls. This shows that the mechanism, which is responsible for the emission of these helium lines must be very different from what is associated with a state of black body radiation. We can suppose that the intense ultra-violet radiation from the interior passes through the upper layers of solar gases, produce ionization in these layers and subsequently these ionized electrons and atoms recombine giving rise to the intense helium lines which are observed from the chromospheric spectrum of the sun but are absent from the Fraunhofer spectrum. If the lines of subordinate series to which belong most of the helium lines in the visible and the He$^+$-line λ 4686 Å can come out prominently, it is clear from fundamental consideration of atomic excitation that the line of the fundamental series λ 584 Å due to He, and λ 304 Å due to He should come out still more prominently. Thus if we could observe the spectrum of the sun in the ultra-violet region, probably the principal lines of helium, hydrogen and iron$^+$ and many other elements would be obtained as emission lines. But at the present time all theoretical works would be merely speculative. The decisive evidence would be obtained if a spectrum of the sun could be secured at a height of 40-50 km, i.e., considerably above the ozone layer.

Conclusion

The above short review shows that though it is easy to say that the atmosphere, upper as well as the lower, is entirely controlled by the sun, it is very difficult to work out the details and present a complete unified theory. For this purpose we must know more about the normal behaviour of the sun, as well as of its abnormal behaviour which manifests these in the form of spots, prominences, faculae, the small patches of intense light responsible for radio fade-outs. But even this does not appear to be the whole story.

Long Period Variation of the Sun

In a very thought-provoking paper Sir George Simpson has pointed out that in addition to the short period variation, the sun has also probably a long and somewhat irregular period of variation, extending about over 80,000 years. He supposes that there is periodic fluctuation in the amount of radiation which is emitted by the sun. When the amount increased, it caused on the earth intense cloud formation in the equatorial regions which paradoxically enough caused intense glaciation, over the poles. In this way he has been able to explain successfully the occurrence in the Pleistocene age of four successive glacial epochs separated by interglacial ones observed in Europe by Penck and Brückner and connected by the anthropologists with different cultural epochs of *Homo Sapiens*. Possibly the Chellean epoch, when *Homo Sapiens* began to make tools and thus lay the foundation of civilization, was started by such a caprice on the part of the sun. It is a thought-provoking idea, but the astronomer has probably no chance of verifying it, as neither he, nor the civilization of which he is a bye-product, can hope to exist for 80,000 years. This short review will probably convince you that the romance of our knowledge of the sun is still in the making.

Appendix: General Remarks by the President

Last year we met at Calcutta under the congenial atmosphere of a great event in the annals of Indian Science—namely, the Silver Jubilee of the Indian Science Congress. Most of us will remember the thrill and joy of the occasion and the benefit we derived in contact with our distinguished overseas guests. We held on that occasion a symposium on River Physics in which experts on different lines, geologists, zoologists, engineers actually connected in field and laboratory operations, took part. The Report of the Symposium has been published so as to be available to the general public. This symposium had a wonderful reception in the press, Indian as well as foreign, as it emphasized the need of organizing scientific study on a subject which is of the highest importance to the welfare of the Indian nation. Two other symposia were held in course of the year, one at Poona on 'Weather Prediction' on the 25th and 26th of July and the second one at Bombay on the 26th and 27th of September on the 'Recent work on the Synthesis of organic substances occurring in Nature'. Both these meetings dealt with matters of the highest practical importance, were very largely attended by actual workers on the subject and a number of public lectures were given under the auspices of the National Institute of Sciences. It is my experience that these miniature Science Congresses, devoted to discussions on a particular subject provide far greater intellectual stimulus than the annual session, when one gets lost in the plethora of dinners, parties, and entertainments. I hope that the National Institute of Sciences will find it possible to organize a larger number of such symposia in future years.

The publication of our Proceedings and Transactions have been continued. The Indian Science Abstracts for 1936 and 1937 have been almost completed and are in course of publication. Our General Editor, Dr. Baini Prashad has with his characteristic energy made up our arrears, and hopes to bring them out within a short time. On account of the increasing nature of the work it has been found necessary to associate with him as Associate Editor, Dr. M. S. Krishnan, thus giving an accession of strength to our publication side.

We have received from the Government of India grants for two years amounting to Rs. 12,000. The universities of Calcutta, Osmania and Dacca, and the Imperial Council of Agricultural Research have agreed to continue their grants. Our grateful thanks are due to these bodies. We are this year issuing an appeal to the Provincial Governments and other States and we hope that some response will be found.

We are glad to note that this year we have been lucky enough to suffer no losses by death. Our total number of Fellows (including the new entrants) has risen to 157. The fear expressed in certain quarters that on account of the constant addition of 10 per year our number would swell to unmanageable proportions is thus seen to be falsified. As a matter of fact for the last four years, there has been a steady balance between losses end gains. I feel, however, and this is strictly a personal opinion, that if the Institute is to be really useful to the Nation, the membership should be increased to at least 300, so that younger men of promise who have otherwise to wait for a long time, may be early admitted into the Institute—for without accession of fresh blood, there can be no strength.

After two years of work I am glad to lay down my office and hand over the charge to Brevet-Col. R.N. Chopra. one of the leading medical men and pharmacologists of India. It is well known to you that as Director of the School of Tropical Medicine, Calcutta, Col. Chopra has built up a fine school of Research and as President of the Drug Enquiry Committee he has rendered unique services to the State. His original works and treatises on Indian Drugs have made him an International authority on the subject and I hope that under his distinguished guidance, the National Institute of Science will continue to make steady progress and achieve the ideal for which it was established. I wish also to thank my colleagues. the two Secretaries, Drs. Agharkar and Heron and our General Editor, Dr. Baini Prashad, for the loyal co-operation which I received from them. We worked like a team and I am glad to report to you that for the last two years there has not been a single occasion giving rise to any difference of opinion amongst us or fostering any ill-feeling due to controversial matters.

Before coming to the subject-matter of my address I wish to make some general remarks with respect to the future of Science in this country. It is probably well known to all of you that there have been three stages in the progress of Science in this country. First. due to establishment of Scientific Surveys of the Government of India during the last century, a measure prompted by administrative needs: Secondly, in the early years of this century due to the recognition of the different Sciences as subjects of study in the curricula of the universities and the starting of teaching universities in which research on scientific subjects was recognized to be one of the duties of the teachers and research qualification was regarded as a requisite to appointment and promotion to higher grades. I regret to note, however, that owing to intrigues by vested interests. and defects in the constitution, these ideals are being lost sight of. nay even abandoned in many of the universities, and some of them are being reconverted to the high school stage from which they were rescued by the reforms of 1921-22. I give a timely warning, so that the evil may be nipped in the bud, before it entirely destroys the foundations of learning and scholarship. The time has now come not only to strengthen the scientific surveys and the research atmosphere of the universities, but we ought to enter on a third phase, namely, scientific research should now be *applied* for solving the industrial problems of the country and properly trained scientific men should be more largely employed by the already existing industries.

As you are all aware, last year I devoted a large part of my address to the necessity of large scale industrialization of this country for solving the problems of poverty, unemployment and defence. It was supposed that the Indian public was averse to schemes of large scale industrialization as we find in foreign countries. But last year's discussions in the press have shown that this is not a correct representation of the public feeling. It is recognized that the problems of poverty and unemployment from which the Indian population suffers and which make her a bye-word of contempt amongst the civilized nations of the world can only be solved if the country plunges with feverish energy into schemes for exploiting the natural resources of the country and starting large scale key industries. In my address last year I gave an indication of the extremely low level of prosperity in this country. Take whatever modern products you like, the number of units of electricity consumed, the number of radio sets used, the number of motor cars used per head of population, the quantity of paper used, or the number of newspapers read, we have the same story, and it is found that India is about 200 times behind other countries. She is mainly a mass of mediaeval humanity, without strength or cohesion, ready to be exploited by anybody. Present-day measures, both Government and private, to improve this state of affairs are extremely inadequate. For example, if the present policy of the All India Radio is not radically changed, we shall take 6,000 years to have the same number of radio sets in this country per head of population as in western countries. In fact this observation can be generalized. It can be shown with facts and figures that unless there is a fundamental and radical change in policy and in the activities of the people and the State, we shall have to wait for nearly 1,000 years to reach that level of prosperity which is enjoyed in modern times by Europe, America and Japan. It was, therefore, a great relief to find that the President of the Indian National Congress, Mr. Subhas Chandra Bose, declared it as a policy of the Indian National Congress that there must be a forced march as regards policies of industrialization in this country. We hope the National Planning Committee, which has been appointed, will produce a document which will give real guidance in this matter to the Indian people, and the National Planning Commission will devise ways and means to give effect to the recommendations of the Committee.

1.1.8 THE MYSTERY OF THE SOLAR CORONA SOLVED*

THE outbreak of the World War II is threatening to put a stop to scientific activities in belligerent as well as non-belligerent countries, and whatever little account of progress is published, very often fails to reach this country. Readers of SCIENCE AND CULTURE will therefore greatly welcome the news of the reported solution of the time-honoured problem of the solar corona which has baffled physicists and astronomers ever since its emergence in the seventies of the last century.

The solar corona[1] is an essentially total solar eclipse phenomenon. The sun, like our earth, has a thin atmosphere; but on account of the intense glare of the sunlight, we cannot in the usual course observe it in day-time. During a total solar eclipse, when the bright disc or the photosphere of the sun is hidden by the dark body of the moon, this atmosphere, being luminous, becomes visible. The duration of totality can never exceed seven minutes, and sometimes may be a few seconds only. The appearance of the solar atmosphere is therefore just like a flash. From observations made during these precious minutes, the atmosphere is known to be bright red in colour, due to the great strength of the red line of hydrogen. On that account, it was christened "Chromosphere" by Sir Norman Lockyer in 1868. In appearance, the chromosphere is a thin crescent of red light enveloping the dark lunar disc, and scarcely extending beyond twelve seconds of arc (the solar radius is nearly fifteen minutes, *i.e.*, about eighty times larger). But the actual height measured in kilometers is nearly 10,000 kilometers. The chromosphere is traversed in places by huge clouds of luminous gas, mostly hydrogen, to which the name "Prominences" are given. With special apparatus, it is now possible to photograph the chromosphere and the prominences even during day light, and thus keep a continuous watch on them. Many

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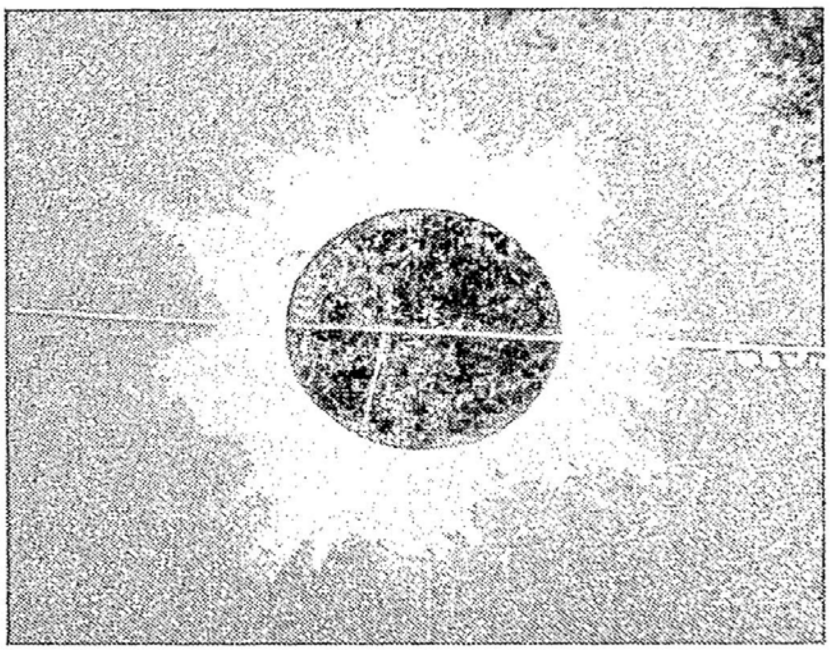
* Sci & Cult 7, 247, 1941

[1] According to certain authorities, the solar corona was known to some ancient nations, *e.g.*, Egyptians and Babylo-Assyrians. They point out the similarity between the winged circular halo on which the Assyrian chief god Asshur, and later the Persian supreme deity Ahura Mada are represented to ride, and the equatorial form of the corona. There is nothing improbable in this hypothesis, as the corona was certainly known to Plutarch (First Century A.D. Roman times) whose material aids to vision were if anything, inferior to those of the Assyrians.

observatories *e.g.*, the Kodaikanal Solar Observatory under the India Meteorological Department specialize in this line, and the MacMutt Observatory in Michigan, U.S.A., keeps a cinematographic record of the rapid changes in the prominences.

But the phenomenon which arrests the observer's attention is the corona, a crown-like halo of pearl white-light which surrounds the chromosphere, and extends, on favourable occasions, to more than a few solar diameters. The corona has been till recently a purely eclipse phenomenon, and the total time which has been available



CORONA OF JANUARY 14, 1926. POLAR TYPE
(Observed by the Italian Mission in Oltregiuba: drawing by Taffara from photographs)

for its observation (the first photograph was secured in 1851 by Busch in Königsberg by the daguerreotype process) cannot exceed an hour. In 1934, B. Lyot of the Meudon Observatory, Paris, was able to devise a 'Coronagraph' which, in the clear atmosphere of Pic du Midi in France at a height of 2000 metres, made it possible to observe the more intense inner parts even in daylight.

Description of Corona

On the previous page is reproduced a plate from "*The Sun*" by G. Aetti. The eclipse was observed by the Italian Mission in Oltregiuba on January 14, 1926, and the picture is reproduced from a drawing by Taffara, which was based on actual photographs. The corona is of the polar type, showing a great wealth of streamers reaching great heights. The prominences are also indicated. There are globular coronas, coronas with long arches and streamers, sometimes extending to nearly 10 radii.

The inner part of the corona, extending from 8 to 10 minutes of arc (*i.e.*, from 3·2 to 4×10^5 km) gives us the bright coronium lines, and the outer corona gives us continuous light sometimes traversed by Fraunhofer lines.

Problem of the Corona

What is the problem of the corona which has taxed the brains of physicists and astronomers for nearly a century? The coronal light extends to great heights, sometimes to several solar diameters, and therefore there must be present some material gas or dispersed particles at these heights (reflecting or scattering sunlight) which it is difficult to understand owing to the strong gravitational pull of the sun. We can get an idea of the amount of matter at these heights from observation of intensity of coronal light which at a distance of 1′, is nearly 10^{-7} times smaller than sunlight, *i.e.*, of the same order as that of the full moon. It falls off rapidly as we move outwards.

An examination of the corona by the spectrograph gives us more information; the spectrum is found to be continuous, just like the continuous spectrum of the sun. But over and above this, from the inner corona, we get a number of spectral lines of which the most prominent are $\lambda 5303$ and $\lambda 6374$; altogether nearly 20 coronal lines have been observed.

There are in fact two distinct but associated problems which may be called respectively as (1) the problem of the corona *i.e.*, the physical agency which gives rise to the halo of continuous light and explanation of the changes in the form of the corona as we observed with the sun's activity, and (2) the problem of the coronium, *i.e.*, the discovery of the elements which give rise to the coronium lines.

The corona problem has been partially solved by the hypothesis that the sun is enveloped in an atmosphere of electrons which, being light, can float at great heights and the general coronal light is merely sunlight suffering Rayleigh scattering from this atmosphere. The hypothesis has been well-established by observations, and we can as a matter of fact, find out, from intensity and polarisation of coronal light, the number of electrons per cc in the coronal region. But it has given rise to fresh complications, first regarding the origin of these electrons, secondly regarding the stability of the electron atmosphere. The electrons must come from the ionisation of some atoms, but the coronal region does not reveal any of the familiar atoms. In fact, we should not expect any because the value of gravity is so large on the sun (it is 27·8 times as much as on the earth) that any ordinary atom would sink in no time to the surface. Only the electron, on account of its lightness, can exist at these heights. The second difficulty also demands that there should be positive particles mixed up with electrons, as otherwise the cloud, on account of the strong repulsion existing between electrons, would blow itself to nothing in no time. The discovery of positrons opened up a new explanation, but explanations based on the presence of electrons mixed up with positions have to be ruled out as a positron and an electron would annihilate each other in no time. So the origin of the electron atmosphere of the corona still remains an open pιoblem.

The Coronium Problem

Far more intriguing has been the coronium problem. The early investigators who failed to trace the corona line $\lambda 5303$ and its associates to any known element, invented the name "Coronium" in the belief that some still undiscovered element was responsible for these lines.

There is no longer any scope for such speculation as the origin of any spectral line. Whether we observed it in the earth or in the stars, it has now to be looked for in some one of the 92 elements known to us (either in the normal or the ionised state) and there is no possibility of the existence of any elements beyond the limits of the periodic chart.

Every element, it is well known, gives a large number of lines—in fact an element like iron gives no less than 6000 lines in the visible region and some of the rare earth elements give far more lines. It might appear a hopeless task to try to understand the origin of so many lines, all coming from a simple atom, but thanks to persistent efforts within the last 25 years, even this miracle has been achieved. We can now list every one of the 6000 lines either to Fe, or Fe^{+} (*i.e.*, an iron atom which has lost an electron) and trace its origin to a definite electron-composition, and electron-transition. Thus the strong iron-line $\lambda 3560$ is due to

Fe. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2\ (^5D) - 3d^64s\ 4p^3F$.

The meaning of this symbolism is not difficult to master and can be found in any higher text-book on atomic physics.

The physicist, who was asked to solve the coronium problem or in other words to find out the particular atom, and the particular transition which gave rise to such lines, had a very wide choice before him. In fact, at first sight it might appear that he was like a man who was asked to pick up a number of specified sand grains from the beach. But matters were not actually so bad, as he was not without clues; but in spite of best efforts, the origin was not found so far. Not one of the coronal lines was found to agree with any one of the myriads of atomic lines so far recorded and whenever any chance coincidence has been reported, it has been invariably disproved.

Much hope was raised when a sister problem, *viz.*, that of nebulium lines was solved by Bowen in a dramatic way in 1927. The spectra of planetary nebulae (*e.g.*, the Ring Nebula) shows like the solar corona a number of strong lines, *e.g.*, λ5007, λ4959. . . . . which baffled identification for a long time. They were also ascribed to hypothetical "Nebulium". Bowen, who at the time was engaged in the production and analysis of the spectrum of O^{++} *i.e.*, the oxygen atom which has lost two electrons, found that these lines are really due to O^{++}. But they do not arise in the regular way *i.e.*, by the jumping of the electron from one level to another but in a way which is technically known as forbidden. In these transitions the electron does not change its position, but only its spin. Technically, the process is written as

$$O^{++} \ldots 1s^2\, 2s^2\, 2p^2\, 3P_{0\,1\,2} \qquad {}^1D_2 \quad {}^1S_0 \ldots \lambda 5007$$

$$4959.$$

Almost the whole set of nebular lines has been traced by Bowen to forbidden transitions of O^{+}, O^{++}, N^{+}, N^{++}, N^{++}, N^{+++}, etc., with the ($2p^2$, $2p^3$, $2p^4$)—composition of the electron shell. It may be mentioned in passing that very few of these lines (in fact none except the oxygen lines λ5577 and λ6302) have yet been produced in the laboratory, because it is difficult to reproduce the physical conditions of nebula on the earth (high temperature, plenty of ultraviolet light, and extremely rarefied condition). But to any one familiar with current thought in physics, Bowen's identification is considered as accurate as any other deduction in physics.

The success of the nebular experiment raised the hope that the coronium lines may have a similar origin. But all attempts to trace coronal lines to known forbidden transitions had so far signally failed, and the mystery deepened farther. Add to this the further fact that while nebulium lines are found to occur widely in spectra of nebulae and sometimes also in certain stars, the coronium lines have not been till 1933, found in any other source except the solar corona. In that year, Adams and Joy of the Mount Wilson Observatory discovered that five of the most prominent coronal lines flashed out for a short while in the spectrum of a star which is known to belong to the type known as 'Recurrent Nova'. Novas or new stars are nothing but old, regular stars which owing to some internal explosion, burst out in a sudden blaze, producing 1,000 to 10,000 times their normal light for a short period and then gradually fade into insignificance. Careful observations have shown that only the outer shell is blown out. The inner core, which survives the disaster, gradually passes to the stage known as 'White Dwarf'. But in a few stars, the Nova phenomenon appears to recur at regular intervals. It is amongst one of these that the coronium lines were found, and that also for a short while.

News have just been received that the prominent coronium lines have been traced by Dr Bengt Edlen, a Swedish physicist, to the forbidden transitions of the familar elements iron, nickel and calcium, after a large number of electrons have been stripped off from them. We show symbolically the origin of the two most prominent coronal lines:—

$\lambda 5303$	due to Fe^{+13}	$1S^2\ 2S^2\ 2p^6\ 3S\ \ 3p\ \ (^2P_{\frac{1}{2}} \leftarrow {}^2P_{\frac{3}{2}})$
$\lambda 6704$	due to Fe^{+9}	$1S^2\ 2S^2\ 2p^6\ 3S^2\ 3p^5\ (^2P_{\frac{3}{2}} \leftarrow {}^2P_{\frac{1}{2}})$

The usual iron-atom has twenty-six electrons arranged as $1S^2\ 2S^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$. In the production of $\lambda 5303$, the green coronal line, as many as 13 of these electrons have been torn off: and in the production of $\lambda 6704$, as many as nine have been torn off !

An announcement like this coming from any other source, would have been received with incredulity, but when it comes from an investigator of Elden's stamp, it is bound to command respect even from the most hard-boiled doubting Thomas in Science!

Dr Bengt Edlen, who works in the physical laboratory of Professor M. Siegbahn in the University of Upsaala, has prefected, for years, a special technique of stripping the atoms of their outer shell of electrons in successive stages. This is done by sending the most violent condenser discharge through the element in vacuum (method of hot sparks). Depending on the intensity of discharge, the atoms are stripped of a few of their outer electrons, and emit characteristic spectra. These spectral lines are measured, classified and data analysed according to approved methods, and their origins are assigned to the proper electron-composition and suitable transitions. The method, though extremely laborious, is unimpeachable, and gives us data from which the forbidden transitions can be worked out with the strictest mathematical rigour for any stripped atom. In this way Elden has gone up to iron atoms which have lost as many as 16 electrons.

As a result of such laborious investigations extending over years Elden came to the conclusion that some of the most prominent coronal lines are due to iron, nickel and calcium atoms which have lost a large number of their electrons and the most prominent green line $\lambda 5303$ is due to an iron atom which has lost 13 electrons. The result was so unexpected, and so much contrary to the prevailing views that he kept it to himself for 2 years, and then cautiously submitted it to the judgment of Harvard astrophysicists who must have been at first equally incredulous. But after critical examination, they have evidently found the claim O.K., and it appears that the time-honoured problem of the coronium has yielded its secret to Scandinavian tenacity. After Bowen's discovery of the origin of nebular lines this is by far the most important discovery in astrophysics in recent years.

Aftermath

It is well known in science that every problem solved raises a host more, and this is nowhere truer than in the present case. We immediately come to the question:—What is the physical mechanism producing such highly ionised heavy atoms at these heights from the sun? In the ordinary solar atomsphere, we have only singly or doubly ionised atoms, *e.g.* Fe and Fe^{+}, and their occurrence is satisfactorily explained by the thermal ionisation theory *i.e.*, on the hypothesis that on account of the great heat motion, the atoms knock against each other, become luminous and at most lose one electron. But in this case, we have iron and other heavy elements which have lost as many as thirteen electrons. Thermal ionisation cannot account for this phenomenon, we shall require nearly 6 million degrees temperature in the corona. Where is then the agency which strips the atoms of so many electrons?

According to one view, the phenomenon is only a large scale 'meteor flash' in the solar atmosphere. We are all familar with "shooting stars" or "meteoric flashes" in our own atmosphere. These meteors are solid matter (which may sometimes attain great dimensions and are then called meteorites), usually travelling in space, which happen to come within the sphere of the earth's gravitational field. They then enter the earth's atmosphere with tremendous velocities ranging between 19 and 41 km per sec and in some cases, velocity may be larger. On account of resistance, they are vaporised, and rendered luminous, the component atoms emitting their characteristic light. In the case of the sun's atmosphere the velocity would be far larger *viz.*, 600 km/sec and any solid particle entering the solar atmosphere would not only be vaporised, but it is expected that the atoms would be stripped of many of their electrons. Actually a few meteors cannot be responsible for the coronal lines—the sun should have to pass through myriads of them *i.e.*, through a cloud of cosmic dust. The presence of such a cloud has also been inferred from other phenomena *e.g.*, zodiacal light.

There are difficulties in this view of the origin of coronal light, and an alternate view may be presented. It is quite possible that stripped iron and nickel atoms are produced in the chromosphere or somewhat lower as a result of some type of nuclear reaction, analogous to uranium fission, and are projected upwards with energies amounting to millions of electron volts. Such particles, on passing through the upper layers, will go on losing, and capturing electrons, and releasing fresh electrons from the atoms and ions which they encounter, by the process known as 'Ionisation by Collision', very much in the same way as an α-particle in its passage through a Wilson cloud chamber. In such collionions, the released electrons, technically called δ-rays, are thrust forward with nearly double the velocity of the electrons, and these rising to greater heights may form the envelope of electrons which, byscattering sunlight from the photosphere, form the 'Corona'. There are difficulties in this view as well, and further work is necessary to decide between the two. If this view be correct, the coronal line emission unmistakably points out that nuclear reactions are taking place on the surface of the sun.

Application to Terrestrial Phenomena

The discovery also probably paves the way to the elucidation of many terrestrial problems which have so long produced headache in physicists. Such are the problems of the aurora, of magnetic storms and of the ionosphere.

If highly stripped iron and other atoms are being continuously projected through the solar atmosphere from its interior, it is apparent that these stripped atoms will be continuously catching electrons, and emitting X-radiation in considerable intensity. The coronal line is due to a forbidden transiton, and the X-rays are due to allowed captures, hence their intensity is expected to be million times greater. Their wavelength is expecged to vary from 1 to 10 Å units, and therefore they carry energy of the order of one to ten kilovolts. When such soft X-rays fall on the outermost layers of our atmosphere they would be producing electrons of considerable energy by photoionisation, and may be by Compton Effect in the case of harder rays.

This may be the long-sought physical process for the production of electrons which are responsible for the ionosphere, the aurora, and the magnetic storms. There are still difficulties in the way of a complete explanation, but a break has been made and as our knowledge of coronal emission advances further, more data will be forthcoming for a complete explanation of these puzzling phenomena.

1.1.9 NINTH SESSION OF THE INTERNATIONAL ASTRONOMICAL UNION, DUBLIN—IRELAND*

THE ninth session of the International Astronimocal Union was held at Dublin, capital of free Ireland, from August 30 to September 8. This afforded a unique opportunity to astronomers and astrophysicists of all countries of the world numbering about 800 to assemble for over a week at the Irish capital and take part in the great intellectual entertainments, consisting of debates, lectures, and personal contacts which had been arranged for over three years.

The International Astronomical Union was started in 1922, and had so far nine sessions, as given below with names of Presidents of each session. The Commission accepted the invitation of Soviet Russia to have its next (tenth) session at Moscow in 1958.

(1) Italy (Rome) : 1962
J. Baillaurd, Director of National Observatory of France, Paris.

(2) The U.S.A. (Harvard) : 1925
Sir F. Watson-Dyson, Astronomer Royal of U.K.

(3) Holland (Leiden): 1928
Dr. W. de Sitter, Professor of Astromony, University of Leiden.

(4) England (Cambridge): 1931
Dr. W. W. Campbell, Director of the Lick Observatory.

(5) France (Paris): 1935
Dr. F. Schlesinger, Director of the Yale Observatory.

(6) Sweden (Stockholm): 1938
M. Esclangon.

(7) Switzerland (Zürich): 1948
Sir H. Spencer-Jones, Astronomer Royal of England.

(8) Italy (Rome): 1952
Prof. B. Lindblad, Director of the Swedish National Observatory at Stockholm.

(9) Ireland (Dublin): 1955
Dr. Otto Struve, Late Director of the Yerkes Observatory, U.S.A.

(10) Soviet Russia (Moscow): 1958
Dr. A. Danjon, Director, National Observatory of France.

(11) U.S.A.: 1961

Prof. A.S. Eddington, the great astrophysicist was elected President of the Union in 1941, and his untimely death in 1944 still in the fullness of powers was an irreparable loss to the astronomical science. Dr. Sir Harold Spencer-Jones, Astronomer Royal of England was selected in his place and presided over the Zürich session of the Union, held in August, 1948.

The first Secretary of the Union was Prof. Albert Fowler of the Imperial College of Science and Technology. He was followed by F.J.M. Stratton, who served for years, J.H. Oort and B. Strömgren.

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*Sci & Cult **21**, 183, 1955

The present Secretary is Prof. Oostterhoof, of the University of Leiden.

Dr. Otto Struve (1), the Chairman of the session at Dublin, relates the following story as to how the meeting came to be held at Dublin.

"You will recall that soon after the end of the war, Sir Harold Spencer-Jones and Dr. J. H. Oort decided to hold a meeting of the executive committee in Copenhagen and invited a number of astronomers who were not members of the committee. And so, on a stormy morning in March, 1946, Harlow Shapley, Joel Stebbins, and I alighted at the Shannon airport from a transatlantic plane. Shannon was not then, as it is now, the daily meeting place of thousands of travellers. Yet, to our surprise, the waiting room was crowded with people. As we were waiting for the announcement that our flight was ready to proceed, Dr. Stebbins called my attention to a distinguished appearing gentleman who was sitting across the room. I saw a face that seemed strikingly familiar, yet I could not identify it. So we called an attendant and asked him. The boy seemed surprised and slightly impatient at our ignorance. "You don't know?" he said. "This is the one and only Dev!" To us Americans this was the finest demonstration of Irish democracy we could have had. Dr. Shapley, who is always interested in the international aspects of astronomy and who, at this particular time, was engaged in planning a joint observatory in Africa with the participation of Armagh, Dunsink, and Harvard, asked the boy whether he could speak with Mr. de Valera. 'Of course', replied the boy, '*in our country anyone speaks to the prime minister*!'*

Mr. de Valera was at the airport to receive the American cardinals who were returning home from a trip to the Vatican. Bad weather had delayed their plane, and it forced us to remain in Ireland for 24 hours. We spent the night in a small hotel, the Blue Boar, in Tipperary—a name known to me from the words of the popular song, "It's a long way to Tipperary."

The Purpose of the Union

The purpose of the Union is stated in Article I of the statutes as follows:

(*i*) to facilitate the relations between astronomers of different countries where international co-operation is necessary or useful;

* Italics ours.

(*ii*) to promote the study of astronomy in all its departments.

Successive Presidents of the Union have featured the high-lights of the activities of the Union as follows:

"There was Baillaurd's insistence upon the supreme importance of great telescopes.

There was Campbell's warning that we should engage only in those activities which really require international cooperation, and that we should never interfere with the individual initiative of great minds.

There was de Sitter's emphasis upon the fact that the apparent uselessness of astronomy renders it the most beneficial of all sciences in serving the ideal aims of mankinds, and

There was Dyson's quotation from Herschel that whatever shines must be observed."

Dr. Otto Struve, Chairman of the Dublin session reiterates the principles as follows:

"1. Astronomy is international in character and requires the active participation of all civilized nations. The International Astronomical Union solicits the adherence of all countries that are interested in research. It now has a membership of 36 nations, and several new applications are pending at this meeting or are in the process of formulation.

2. Astronomy is also global in extent, and many of its most pressing problems can only be solved by means of observations distributed over the entire surface of the earth.

3. Astronomy is, as de Sitter has said, "the most beneficial of all sciences" because it uplifts the minds of all people and, more than any other science, serves "the ideal aims of mankind". Just before the outbreak of the Second World War, in 1938, Sir Arthur Eddington remarked, in accepting the Presidentship of the Union: "....if in international politics the sky seems heavy with clouds, such as meeting as this at Stockholm is as when the sun comes forth from behind the clouds. *Here we have formed and renewed bands of friendship which will resist the forces of disruption.*"

"The success of our Union since the end of the war has shown that ideological and political differences fade away in our common goal, the exploration of the universe. Moreover, astronomy is no longer so "useless" as it was 27 years ago, largely because of the stimulus it has given to the study of nuclear energy. And in these days of serious consideration of further developments such as an artificial satellite of the earth, and even space travel, it promises to become one of the useful sciences in a practical sense."

The Chairman referred to the disquieting increase in the disparity of astronomical effort in different countries.

"In the U.S.A., the annual expenditure on astronomy was, between 1923 and 1948, of the order of 1·5 million dollars, and the Chairman estimated that at the present time this figure should be more than doubled. The National Science Foundation spends about $. 200,000 annually for small research projects by individual investigators. It plans to spend several million dollars a year for larger enterprise such as a new national observatory, several large radio telescopes, and several large electronic computing centers.

The Chairman stressed on the training of astronomers; he said that special effort should be made to induce persons of great ability to enter the field of astronomy, and *individual workers of the 'Ivory Tower' variety should be encouraged.*

The Chairman stressed on the necessity of installing large telescopes in as many countries as possible, and of initiating radio telescopic research in countries having poor climatic conditions.

Welcome Speech of the Taoiseach (Prime Minister) of Ireland

In opening the session, the Taoiseach (Prime Minister), Mr. Costello who spoke in Irish and English, remarked:

"They felt honoured that Dublin should have been selected for holding of what was not merely the greatest scientific congress ever held in Ireland but one of the biggest, if not the biggest congress of the Union ever held in any country. While this was an ancient nation, it was but a small country with neither the wealth nor the natural resources which would enable them to make a major contribution to modern scientific research."

Work of Irishmen in Astronomy

They were, however, not quite newcomers to astronomical studies. They could justly claim to have played some little part in the foundations of the science. Irish was the first language in Western Europe to be used in the service of astronomy. Since the fifth century, Irish annals had been chronicling solar and lunar eclipses.

It was William Parsons (2), (Earl of Ross) an Irishman, who by means of what was in his time the largest telescope in the world, discovered, a century ago, the spiral nature of the nebulae, or "island universe," which filled space and which it was the purpose of the present congress to study. The work of another Irishman, Rowan Hamilton (3), on dynamics had, in their own day, proved of great value, both directly and indirectly, to astronomers, for it lay at the root of wave mechanics, a subject fundamental to the understanding of atomic structure and so one with which every astro-phyicist must be familiar.

Dunsink Observatory, now approaching its second centenary was one of the oldest observatories in the world.

Mr. Costello, continuing, said that science, like peace, was indivisible. It was coming more and more to be seen that in the search for truth all branches of knowledge converged. With their finite intellects they could not hope to attain in this world to the Ultimate Truth but, to the lay mind at least, if there was one branch of science to which the search for truth was peculiarly appropriate, that branch was astronomy, for the astronomer of whatever race or nation was not so much concerned with petty, mundane affairs as with the whole universe, indeed with a universe of universes stretching to the uttermost bounds of human ken.

Good and Evil

"To-day, as never before" said the Taoiseach, "the scientist is entitled to say of himself 'in Nature's infinite book of secrecy a little can I read'. But even that little which he can read has brought home to the human race more forcibly than ever before the terrible truth that confronted man in the day of his creation, that the fruit of the tree of knowledge is both good and evil."

"During my own youth it was the fashion among some of the camp followers of science to promise mankind the millennium, but man's misuse of the power he has acquired over Nature has brought a sad disillusionment. Not heaven upon earth but something more in the shape of hell upon earth would seem to be in store for us if we continue to turn to evil purpose the mighty, weapons that science has put into our hands."

He hoped that the present congress would be a milestone on the road back from the abyss into which the world had for many years been gazing with horror; that it would be successful in its attempt to extend the frontiers of knowledge and at the same time be a solid contribution towards international peace and goodwill.

Example of Co-operation

Mr. de Valera, T. D., who joined in welcoming the delegates, hoped that they would find in the old city of Dublin a congenial setting for their discussions.

"Men", he said, "whose works lie in the fields in which the unpredictable deviousness of man is dominant, envy men of science the relative stability of that in which they deal, but all can follow your example of loyal universal co-operation and learn the lesson which you teach that generous sharing is the truest road to riches."

Speaking in Irish, he said that he hoped their discussions would be fruitful and prayed that the marvels which they studied and contemplated might lead mankind to a just knowledge of God.

Professor Brück, director of the Dunsink Observatory welcomed particularly the delegates from Africa, the Americas, Asia and Australia. Nearly a quarter of the Assembly was made up of delegates from the U.S.A. The Union had always been proud of its truly international character, and had always jealously guarded the spirit of supra-national scientific co-operation. It was encouraging to see how at the Geneva Conference on nuclear energy, that same spirit of friendly co-operation, without which progress in astronomy would be very difficult, had descended from stars to atoms.

In Dublin they were hoping that astronomers from all over the world would be able to say, when the congress was over, that their discussions had been fruitful and their journeys worthwhile.

The present Institution at the Dunsink Observatory was opened only a few years ago and was now sustained by the generosity of the Irish Government. *He paid tribute to Mr. de Valera, whose personal interest in all scientific matters was responsible originally for the reopening of the Observatory.*

A century ago the third Earl of Ross built in Birr, with local resources, a telescope which for many years remained the world's largest and which was put to excellent use in the study of the nebulae.

Dr. Brück also referred to the work in Ireland of the astronomers Dreyer and H. C. Plummer and said that Rowan Hamilton's work on dynamics and optics had maintained its vitality to the present day. They had now set up at Dunsink an effective solar installation with facilities for spectrographic and spectroheliosopic observations. They had concentrated on developing electronic methods of photometry testing stars with a new medium-sized reflector.

Right Rev. Moneignor de Vrun said that it was a privilege and an honour to welcome to Ireland on behalf of the Dublin Institute of Advanced Studies, astronomers from all places under the Sun.

Prof. Otto Struve, President of the Union said that 100 years ago the most important advances in astronomical science were made by single men of genius, like Rowan Hamilton, working in the privacy of their "ivory towers", and by a few able observers using small telescopes at a single observatory. At the present time the emphasis was upon team work and upon the use of very large and expensive instruments at many observatories. .

It was an intriguing question to decide whether this emphasis upon team work had deprived the world of individual thinkers like Hamilton, but nobody would deny that their numbers had not increased as rapidly as had the number of more or less anonymous scientific workers whose results now accounted for the major share of scientific production.

The International Astronomical Union works in 42 Commissions, covering all aspects of astronomy including astrophysics and radio-astronomy, as follows:

1. Administrative, 2. Finance, 3. Notation, units, economy of publications, 4. Ephemerides, 5. Analysis of works and bibliography, 6. Astronomical telegrams, 7. Celestial mechanics, 8. Meridian astronomy, 8a. Photographic catalogues of stars brighter than the ninth magnitude, 9. (discontinued), 10. Photospheric phenomena. 11. Exterior layer of the sun, 11a. Cinematograph of chromospheric phenomena, 12. Solar radiation and solar spectroscopy, 13. Eclipses of the sun, 14. Standard of wave length and tables of the solar spectrum, 14a. Tables of intensities: Tables of F-values, 15. Physics of comets, 16. Observations of physics of the planets and satellites, 17. Movement and the figure of the moon, 18. (discontinued), 19. Variation of altitude, 20. Position and movements of minor planets, comets and satellites, 20a. Short period comets, 21. (discontinued), 22. Meteors, zodiacal light etc. 23. Map of the sky, 24. Stellar parallaxes and proper motion, 25. Stellar photometry, 25a. Sequence of mangitude, 25b. Standard of stellar magnitudes, 26. Double stars, 27. Variable stars, 27a. Co-ordination of galactic researches, 28. (discontinued), 29. Stellar spectrum, 29b. Spectrum of variable stars, 29c. Molecular belt in stellar spectrum, 30. Stellar radial velocity, 30a. Fundamentals of radial velocity, 30b. Spectroscopic observations of double stars, 31. Time, 32. Selected areas, 33. Stellar statistics, 34. Inter-stellar matter in planetary nebulae, 34a. Catalogue of diffuse emission nebulae, 35.

Constitution of stars, 36. Spectro-photometry, 36a. Line intensity standard, 36b. Theory of stellar atmosphere, 37. Stellar clusters, 38. Exchange of astronomers, 39. International observatory, 40. Radio-Astronomy, 41. History of Astronomy.

The commissions comprise all the branches into which astronomy has ramified since the earliest times. The list of commissions justify the saying: "*That Astronomy is the Oldest, yet the Ever Youngest Science*". For example, the subject matter of Commission 4, Ephemerides *i.e.*, calculating in advance the positions of the sun, the moon and the planets, can be traced to as early a period as 500 B.C., when it was cultivated in the plains of Mesopotamia by the Chaldean priest-astornomers. On the other hand, the subject matter of Commission 40, Radio Astronomy is of very recent origin, as it had its birth during World War II in 1942.

It is naturally impossible to give an account of all the discussions held under the auspices of the different commissions. For this purpose the Transactions of the Union, of which a draft copy was with every participant, has to be consulted. Account may be given of a few highlights.

Birth of A New Star

In the Symposium held on Non-stable Stars (held on Speetmber 1, at the Mansion House, Dawson Street, Dublin), Dr. G. E. Herbig of the Lick Observatory, U.S.A. reported the probable birth of a new star. He compared photographs taken in January, 1947 and December 1954 of the same area of the sky "not far from the Orion Nebula". This area showed in a dense dark cloud the brightest known examples of a very peculiar class of nebulous stars that had been called the "Herbig-Haro Objects" by the Russian astronomer Ambarstuman. These objects had been studied by himself, by Guillermo Haro (Mexico) and very recently by K. H. Bohm.

The Opening Phase

The photographs taken seven years apart showed that two objects which seemed to be stellar and appeared in one of the brighter "Herbig-Haro Objects" encouraged the speculation that they were somehow connected with star formation.

"Photographically," he said, "these newly appeared objects have brightened up through ranges of at least three magnitudes.

"Our understanding of what may be taking place could hardly be more incomplete but, perhaps, we have witnessed the opening phase of an episode in stellar evolution.

"The Lick Observatory direct photographs show that the newly appeared objects in Orion certainly did not develop out of any stars that has been visible at those positions before. If these 'new' stars are to be identified with the beginning of the development of a 'T-Tauri' star then this evidence (within its limitations as to absolute magnitude) also supports the hypothesis that the 'T-Tauri' stars are not rejuvenated interlopers from the surrounding field but are in fact newly formed objects."

Travel to the Moon and the Earth Satellite

Travel to the moon was really an engineering problem but the results of such a venture would be of great interest not only to astronomy but to physics, said Dr. J. J. Nassau (U.S.A.). Such a journey would permit the study of the ultraviolet rays from the sun, which they were unable to do at present because of the influence of the Earth's atmosphere.

Equally important would be the study of matter in the Earth's atmosphere at a height of 200 miles with regard to density and the various components. Human observation would not be necessary, as instruments were now designed in such a way that they could do the work of the human eye. Space satellites would also enable astronomers to study meteors which were affected by the structure of the Earth's atmosphere.

It was definitely realistic, he said, to say that within two years, efforts would be made with chances of definite success to launch a satellite which would revolve about the earth in little more than an hour. It would be at a height about 200 miles above the earth.

Dr. Toussey of the Naval Observatory, Washington, exhibited spectrographs of the sun which he had obtained from rockets reaching a height of 200 km. They showed Lyman α, β and faint traces of Lyman γ, which appear to have been highly absorbed. In addition, lines of C^{+}, C^{++}, C^{+3}, O^{+6}, and many other highly ionised elements have been obtained in emission.

Radio Waves from Jupiter

Addressing Commission 16, which is responsible for physical observations of the planets, Dr. Burke of the Department of Terrestrial Magnetism, Washington, U.S.A., described the reception of bursts of short radio waves from Jupiter, which have been made in Washington and confirmed by independent observations from Australia.

Jupiter, largest of the nine known planets, is fifth out from the sun (in order outwards, the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto).

It is ten times the diameter of the earth, 300 times as heavy and five times as far from the sun.

The Jupiter year is almost as large as twelve of our years but the Jupiter day is less than half of the Earth day. Jupiter rotates on its axis approximately once every 10 hours.

Accidental Discovery

Dr. Burke and his collaborators discovered the radio emission from Jupiter more or less accidentally in January of this year. They noticed that a large radio receiver, directed towards the sky and receiving waves in the 13.5 metre band, indicated that sudden sharp bursts of radiation were coming from the general direction of Jupiter, and by careful observations over several months they were able to identify that planet definitely as the source of the waves.

The Australian investigators were able to go even further discovering from which part of the planet the waves originate.

They come from a small white spot in the south temperate zone, one of a pair of such spots near to the famous "red spot" which is one of Jupiter's most prominent markings.

It is not definitely known of what either the red spot or the white spots are composed, nor even whether they are attached to the solid surface of the planet or only part of the atmoshere around it. Neither it is known what kind of disturbance causes the radio waves to be sent out, although, of course, astronomers assume that it is some kind of natural phenomenon and not the action of any "extraterrestrial intelligence."

Frequent observations of the planet, both with ordinary telescopes and with radio instruments were among the plans announced for future research.

No Canals on Mars

The red planet Mars is another of the cares of Commission 16, and in his report, the Commission President, G. P. Kuiper, of the Yerkes

Observatory University of Chicago, reaffirmed once more that there is no evidence, for the existence of canals on the planet.

The whole misconception about the existence of intelligently constructed canals on Mars arose in the first place through a mistranslation of the Italian word 'canali' which means 'channels', and had been used by Italian astronomers to describe the long narrow markings which they observed on Mars.

But the use of larger telescopes and improved modern instruments leaves no doubt that even these long narrow markings were in the minds of the observers—or at least in their eyes.

Some of the blame must be laid on the Earth's atmosphere, which even on the clearest of nights is a little hazy and irregular.

Turbulence on Sun

In the joint discussions on Solar Flares, which were defined by Dr. M. A. Ellison of Great Britain, as "catastrophic events on the sun, which have immediate repercussions on the earth".

Among the repercussions are believed to be magnetic storms, fade out of radio transmission, and the Aurora Borealis. In 1942 it was discovered that the emission of radio waves from the surface of the sun was associated with the sudden brightening of portions of the hot gaseous filaments near sunspots on the surface.

This sudden brightening in areas of the surface as much as 150,000 miles across, was dramatically illustrated in a film shown by Dr. Helen W. Dodson, a member of the Mac Muth Observatory, Ann Arbor, Michigan, who has specialised in these lines.

The film consisted of a sequence of pictures of the sun's surface, taken once every eight seconds over a period of hours and then speeded up more than 200 times to give a continuous picture of the rolling turbulent motion of the hot gases of the sun.

These pictures are not taken directly but by first separating out from the sun's light rays of one particular wave length, and photographing only those. In this way a detailed view of processes going on near the solar surface can be obtained. The flares are accompanied by the shooting out of vast streamers of the hot gas, with speeds up to 300 miles a second.

Astronomers hope that by studying such phenomena they can get a better understanding of the physical behaviour of the sun, and so of the universe.

In addition to the main session at Dublin, the following symposia, and discussions were arranged:

Symposium on Radio Astronomy (Aug., 25-27) at the Jodrell Bank, Manchester.

In this symposium, discussions took place on the 21 cm (Hydrogen radiation) survey of the galaxy, a model of which, based on the survey, was exhibited by Prof. H. C. Van de Hulst of Leiden. Discussions were also held on meteor astronomy, on features of solar radio emission, radio astronomy planning and many other interesting topics.

Further symposia were held at the Hamburg Bergedorf Observatory on Aug., 19-20; and on Aurora and Airglow at Belfast on Sept., 6-7 (organised by Prof. D. H. Bates). There was a meeting in London on solar eclipses and the ionosphere.

Excursions were arranged to the Dunsink Observatory in the suburbs of Dublin where Hamilton worked; and all day excursions were arranged to Killarney, and Connemara.

Prof. M. N. Saha, has been a member of the I.A.U., and of a number of Commissions since the inception of the Union in 1922; but this was the first occasion he was enabled to attend due to the generous gesture of the Government of India to bear his expenses. The other members are Dr. D. S. Kothari, Dr. P. L. Bhatnagar, Prof. A. C. Banerjee, Prof. S. K. Mitra and Dr. H. Rakshit, who have been elected to different Commissions in their individual capacity, and Dr. A. K. Das, Director of the Kodaikanal Solar Observatory, who is a member of the Executive Commission of the I.A.U. Dr. Das attended this session, as well as the previous session at Rome. This year, Sri N. C. Lahiri, Secretary of the Calendar Reform Committee, has been added to the 'Ephemerides Commission'. The Government of India were too late to take the decision to send the delegation. It was not possible for the members of the delegation to meet before hand, and plan concerted action as is done in other countries. It is hoped that for the forthcoming session at Moscow, the Government will chose a larger delegation, months ahead, name a leader and a secretary, so that the delegation gives a good show of itself and represents free India in a way befitting her dignity as a free nation.

APPENDIX

Personalities Mentioned in the Article

(1) Dr. Otto Struve, (1897-) the President of the Union from 1952-1955, is a descendant of F.G.W. Struve (1793-1864), German astronomer, who was

called by Czar Nicholas I, in 1839, to take cahrge of the new Russian central observatory, at Pulkowa. The first Struve, himself a great astronomer, was the ancestor of a long line of astronomers. The present Struve is the fifth of his line and was drafted, as a young man of 18, into the Russian Army, during the first World War, before he could complete his high school education. He was taken prisoner by the Turks, and after armistice, was released by them and thrown adrift into the streets of Istambul, to earn his daily bread as best as he could. After a good deal of suffering, he introduced himself to the authorities of the American College at Istambul, who found out who he was, and gave him a university education, and sent him to the U.S.A. to become an astronomer, in which he was in his natural elements. He rose to be the direcotr of the Yerkes Observatory, founded by G. E. Hale, and has made classic contributions to the spectra of peculiar stars and their interpretation. He has retired before his time from the Directorship, in order to be free from administrative burdens and concentrate his whole attention on 'Original Researches on Astrophysics.'

(2) William Parsons, the third Earl of Ross, was an Irish nobleman, who was a self-taught astronomer. He constructed in 1845 at Parsontown (Birr), Ireland, with local materials the largest telescope of these times—which was a reflector 6 ft in diameter, made of speculum. With this telescope, he was the first to observe the spiral structure of extragallactic nebulae,—which was subsequently verified by actual photographs of these objects taken with the biggest reflectors.

(3) William Rowan Hamilton (1805-1865) is the greatest man of science Ireland has produced. Son of a first rate businessman, he was taught in his early years by his uncle, the Rev. J. Hamilton, and is said to have picked up at the age of twelve, as many languages as the number of years he had lived: Greek, Latin, Sanskrit, Pali, Hindusthani, Hebrew, Persian Arabic, etc., etc. His attention from languages to science was diverted by contact with a calculating American fellow-student, Z. Colburn, and he quickly picked up mathematics and physics. He carried off all the prizes in the Trinity College, Dublin, and when he submitted his thesis to the Royal Irish Academy, Dr. Brinkley, the Professor of Astronomy, remarked, "I do not say he will be, but, is the first mathematician of his age".

Elected to the Professorship of Astronomy in 1827, in preference to many older deserving candidates, he was put in charge of the Dunsink Observatory, but wisely enough, as his biographer syas, neglected astronomical observations, for mathematical contemplations. As a mathematician, he ranks as one of the highest in the world. He is the author of '*Quaternions*' familiar to every student of mathematics. The ideas materialized after fifteen years of contemplation, but when they dawned on him, as he was out walking with his wife, he carved the fundamental formulae of the new algebra in the stone of the bridge on which he found himself at the moment (Oct. 16, 1843). He made contributions to wave theory of light, and dynamics, which are classics in these lines. The 'Hamiltonian' in dynamics is used by every student of quantum mechanics.

1.2 SPECTROSCOPY

1.2.1 DISSOCIATION EQUILIBRIUM*

I

HENRI POINCARE, the great mathematician and philosopher, invented a hypothetical being Lumen, who could move more swiftly than light. To such a being, as he cruises through space, time-intervals will be completely effaced. He will see the whole past at a glance; he will fail to see the interval separating events of 1860 from events of 1925. The popular mind often functions Lumen-like and fails to grasp the difficulties, practical as well as theoretical, which confronted the workers of the last century.

No scientist has been a worse sufferer in this respect than Sir Norman Lockyer. Called to scientific work by Kirchhoff's profound discovery of spectrum analysis, he set himself the task of exploring the Sun and the stellar universe with the new instrument. He obtained results for which the existing theories or ideas were quite insufficient; he initiated laboratory work for elucidating these results. The confusion became worse confounded. He had to formulate theories of his own which were a direct challenge to the accepted theories of those days and for which the scientific world was the least prepared.

For, in those days, it was almost universally held that the atom was the ultimate constituent of all matter. It was held that like a tuning-fork, the atom could be made to emit only a few simple notes, i.e. spectral lines which were invariable. But Lockyer's experience of stellar spectra and spectra of elements in the laboratory told him that these ideas were not only insufficient but also misleading. He found that by subjecting elements to varying stimuli, the nature of the spectrum could be varied within wide limits. A very good example is afforded by Calcium, which gives a line called by Fraunhofer g($\lambda=4227$); this line is very strong in the flame and in the arc, but fades in the spark. On the other hand, two other lines, the H and K of Fraunhofer, which are very faint in the flame, become prominent in the arc and completely dominate the spectrum of the spark. Lockyer

*From Life and Work of Sir Norman Lockyer. Edited by Lady Lockyer & L. Winifred, 1928, p. 316.

found similar results in the spectra of other elements, and in the case of silicon he found no less than four successive stages. If the atom was invariable, argued Lockyer, how could these variations be accounted for?

Lockyer was first and foremost a pioneer explorer of the stellar world, and the laboratory work of which we have just spoken was undertaken in order to obtain a clear explanation of the phenomena which he had discovered in a systematic study of the spectra of the Sun and stars.

He had discovered that these spectra could be arranged in a number of well-marked groups, which by gradual steps merge into each other. This classification was confirmed in the essential points by the spectroscopic survey of 200,000 stars at the Harvard College Observatory by Professor Pickering and Miss Cannon. They denoted these groups by the letters :

M—N
P———O———B———A———F———G———K<
0, 1, 2, 3; ·10 R—S

Lockyer found that the spectra of red and yellow stars mostly consisted of arc lines, while in the spectra of white stars the metallic lines became fainter and the enhanced lines became more prominent.

The explanation of these facts was attempted by Lockyer in a small paper in the *Proceedings of the Royal Society*, and later elaborated by him in what is known as "The Theory of Inorganic Evolution." The essential point of this theory was that the atoms existed in the hotter stars in a primitive (or proto) form, and underwent a synthesis into more complex forms in the cooler stars. The idea of dissociation of atoms into simpler constituents occurred to Lockyer in 1874. Moving along the time axis, we perceive that the conception is prior to

(1) the discovery of the electron by Sir J. J. Thomson by twenty-two years;
(2) the formation of the quantum theory of radiation by M. Planck by twenty-four years;
(3) the nuclear theory of the atom by Sir Ernest Rutherford by thirty-seven years;
(4) the formulation of the heat theorem by Nernst by thirty-two years;

(5) the quantum theory of spectral radiation by N. Bohr by thirty-nine years.

These are the five cardinal discoveries in physical science, which have to be pressed into service for elucidating the wonderful array of facts amassed by the labour of Lockyer.

II

A correct interpretation of Lockyer's ideas can only be arrived at by considering the action of a gradually increasing temperature on matter. At the lowest temperature all matter exists in the form of solids. With gradually increasing temperature, the parts gradually loosen, the solid first becomes liquid and then gascous, when the molecules fly away from each other; with further rise of tempeature the molecules break up into atoms. What happens next ?

The answer to this question could be given only after the Rutherford-Bohr theory of the atom had taken a definite shape. We now know that the atom consists of a central positive charge of N (N=ordinal position of the element in the Periodic Table) surrounded by N electrons grouped in different layers. The spectral lines are due to the vibration of the outer electrons according to the quantum mechanics of Bohr. It is now easy to see that with increasing temperature, the atoms will collide with each other more frequently; the "outermost" electron will be displaced to higher orbits, and ultimately it may be knocked off. Taking the element calcium, the process may be described by the chemical symbol

$$Ca \rightleftharpoons Ca^{+} + e.$$

It is a well-known law in chemistry that when a complex molecule, say NH_4Cl, breaks up under the influence of heat into simpler molecules (NH_3 and HCl in the present case), then at a particular temperature and pressure there will be a definite proportion between the number of undissociated and dissociated molecules. Guldberg and Waage, Van't Hoff, Nernst and Sackur[1] have shown that the amount of dissociation can be calculated as a function of temperature and pressure, provided the heat of reaction, and the specific heat and the vapour pressure of the substances are known over a wide range of temperature. The idea occurred to Eggert[2] that the same equations

[1] Sackur, *Thermodynamics*.

[2] Eggert, *Phys. Zeits.*, 1919, vol. 20, p. 570.

with some modification might be applied to calculate the ionisation of elements in stellar masses, which, according to Jeans, and Eddington[3] consist of highly ionised atoms in equilibrium with radiation. Taking the case in hand, if we agree in treating Ca^{+} and electrons as monatomic gases, we easily perceive that the effect of a gradually increasing heat stimulus will be first to drive the outermost electron to higher and higher orbits, and thereby make possible the emission of characteristic lines of Ca, particularly g, $\lambda=4227$. Then at a higher temperature a certain fraction of Ca-atoms will be ionised, this fraction increasing as the temperature rises. At each temperature and pressure, there will be equilibrium between normal Ca-atoms, Ca-atoms in higher orbits, the characteristic radiation of Ca, Ca^{+} and electrons. The problem is thus complicated, but we assume, as a first step towards solution, that the number of Ca-atoms in intermediate stages is negligible. Then the fraction x of Ca^{+}-atoms is given by the formula:[4]

$$\log \frac{x^2}{1-x^2} P = -\frac{U}{2\cdot 3\ RT} + \tfrac{5}{2} \log T - 6\cdot 5 \qquad \text{.. (1)}$$

where U is now the heat of ionisation. In chemistry, U has to be determined by a separate set of calorimetric experiments; but in the present case U can be determined from spectral data, or experimental values of the ionisation potential, as has been done by Franck, Hertz, and other workers.

Formula (1) is derived on the assumption that all the electrons arise from decomposition of the orginal mass of Ca. In other words, the system is unicomponent. But the electron can arise from the decomposition of other elements as well. Hence it is useful to consider the modification of formula (1), when the system is a bicomponent one, the electron forming an independent component. The equation takes the form, first given by Russell:[5]

$$\log \frac{x}{1-x} \cdot \frac{f}{1+f} P = -\frac{U}{2\cdot 3\ RT} + \tfrac{5}{2} \log T - 6\cdot 5 \qquad \text{.. (2)}$$

where f=concentration of electrons/concentration of the element.

Neither formula (1) nor (2) is perfect, for we have not considered the mechanism of ionisation and a number of other points which

[3] Jeans, *Phil. Trans.* 218 A, p. 209 (1917); Eddington, *M.N.R.A.S.* vol. 77, pp. 16 and 596; vol. 79, p. 2. Jeans, *M.N.R.A.S.* vol. 79, p. 319.

[4] Saha, *Proc. Roy. Soc. Lond.* A, vol. 99, p. 135.

[5] Russell, *Ap. J.*, 1922, vol. 55, p. 119.

will be discussed later on. Yet, let us see how far we can proceed with formulae (1) and (2).

The next question is how we can detect the ionisation. This can be done with the greatest case, spectroscopically. From the work of Fowler and Bohr, it is now certain that Lockyer's enhanced lines are due to atoms which have lost one or more electrons. Thus Fowler[6] has established that

Si I is neutral Si.
Si II is Si^{+} (Si-atom which has lost one electron).
Si III is Si^{++} (,, ,, ,, two electrons).
Si IV is Si^{+++} (,, ,, ,, three electrons).

To see the application of formulae (1) and (2), let us take the case of calcium cited above. According to Fowler and Bohr, $\lambda=4227$ indicates the presence of Ca. The H and K lines indicate the presence of Ca^{+}. If in a luminous mass we obtain H and K by spectroscopic examination, we at once conclude that calcium present in the mass is

TABLE I

IONISATION OF CALCIUM, IN DIFFERENT LUMINOUS MASSES

Luminous mass.	Temp.	Intensity	
		Ca.. g..	Ca^{+} ..K.
	2,000°	300	20
Flame (electric furnace)	2,500°	500	30
	3,000°	1,000	60
Arc	4,000°	400	500
Vacumm arc	4,000°	8	25
Solar photosphere	6,300°-7,000°	20	1,000
Chromosphere	5,000°	8	75
Sirius	10,000°	almost invisible	very strong

[6] Fowler, *Phil. Trans.*, 1925, vol. 225, p. 1.

wholly or partly ionised. The preceeding table[7] illustrates how, with increasing temperature, the ionisation of calcium gradually becomes complete.

The intensity scales are different in different cases, and attention is to be fixed on relative intensity alone.

Similar calculations of ionisation can be made in the case of all elements of which the ionisation potentials are known, and x acn be calculated as a function of T and P.

The theory thus leads, for the first time, to a clear understanding of the regular and continuous gradation in the spectra of stars. Cooler stars show only arc lines, because the temperature is not high enough for ionising the elements. The enhanced lines becomes more and more prominent in the hotter stars, because with increasing temperature, ionisation becomes more complete. Thus from the marginal appearance and disappearance of lines of Ca, Ca^+, Mg, Mg^+, Na, Sr, Sr^+, H, He, it is possible to obtain rough values of the temperatures of different classes of stars. Values obtained in this way are in agreement with the results obtained by King, Wilsing, and Scheiner. The calculations, for which the reader is referred to the original papers, confirm Russell's view that the stellar spectrum is primarily a function of the surface temperature.

The only uncertain thing in these calculations is the pressure P. A reference to formulae (1) and (2) will show that the pressure has a marked influence on the percentage ionisation. For the same temperature, a lower pressure will cause more ionisation. This fact has made it possible to explain the important differences between the Fraunhofer and the flash spectrum, between the spectra of giant (low presure) and dwarf (high pressure) stars. Stewart and Russell, Fowler, Darwin, and Milne, have initiated methods for obtaining more precise values of P in stellar atmospheres. These investigations show that the pressures in the reversing layers of stars are probably much lower (10^{-3} to 10^{-5} Atms.) than was formerly supposed (1 to 10^{-1} Atms.).

In the hotter stars (B and O classes) metallic lines almost entirely disappear and the spectra consist largely of lines of H, He, C^+, C^{++}, N^+, S^+, etc. From this fact, there was a tendency, in former years, to label these stars as hydrogen or helium stars. The idea was that the stars contained chiefly hydrogen or helium and not much of other elements. These ideas must now be given up, because the ionisation

[7] Saha, *Phil. Mag.*, 1920, vol. 40, p. 482.

theory gives a complete and perfectly satisfactory explanation of the whole range of phenomena, on the assumption that the composition of all heavenly bodies is essentially the same.

Influence of Pressure on Ionisation—Ionisation in the Solar Chromosphere

The entry of Lockyer into the scientific world was signalised by a singular success—perfection of a method for observing the spectra of prominences and later on the spectrum of the chromosphere a success which he shared with Janssen. But Lockyer went further and initiated methods for examining whether the spectrum of the chromosphere was an exact reversal of the Fraunhofer spectrum, as would be expected from Kirchhoffs theory. The expectation proved to be only roughly correct. Lockyer and eclipse observers after him discovered many important differences. These are summarised below:

(1) The Fraunhofer spectrum contains only 5 hydrogen absorption lines—H_α, H_β, H_γ, H_δ, H_ϵ, while Lockyer, Evershed, and Mitchell[8] after him discovered no less than 35 lines of hydrogen (Balmer series) in the spectrum of the flash.

(2) No helium lines normally occur in the Fraunhofer spectrum, while the chromosphere shows a large number of them, the most prominent being the D_3, $\lambda = 5876$.

(3) The enhanced lines of all elements are more prominent in the chromosphere. In fact, Lockyer concluded that the chromospheric spectrum is more like the spectrum of *a*-Cygni (A-class, temperature 10,000° K). The enhanced lines reach a greater height than the arc lines, in fact the upper chromosphere is entirely made up of ionised elements, as illustrated in Fig. 1.[9]

Heights of Elements in the Chromosphere

How can we explain these facts? The chromosphere is evidently a seat of higher stimulus than the photosphere, but where does this higher stimulus arise from? Lockyer had only temperature in his mind, and he naturally concluded that the temperature of the chromosphere was higher than that of the photosphere. But, of course, this explanation could not be accepted.

A first step towards the correct explanation was taken by Fowler[10]

[8] Mitchell, *Astrophysical Journal*, vol. 38, p. 410.
[9] Taken from *Zeits. fur Phys.* vol. 6, p. 40.
[10] Fowler and Payn, *Proc. Roy. Soc.*, 1903, vol. 72, p. 253.

who showed experimentally that the enhanced line of magnesium, $\lambda=4481$, occurs very prominently in the vacuum arc, while it is

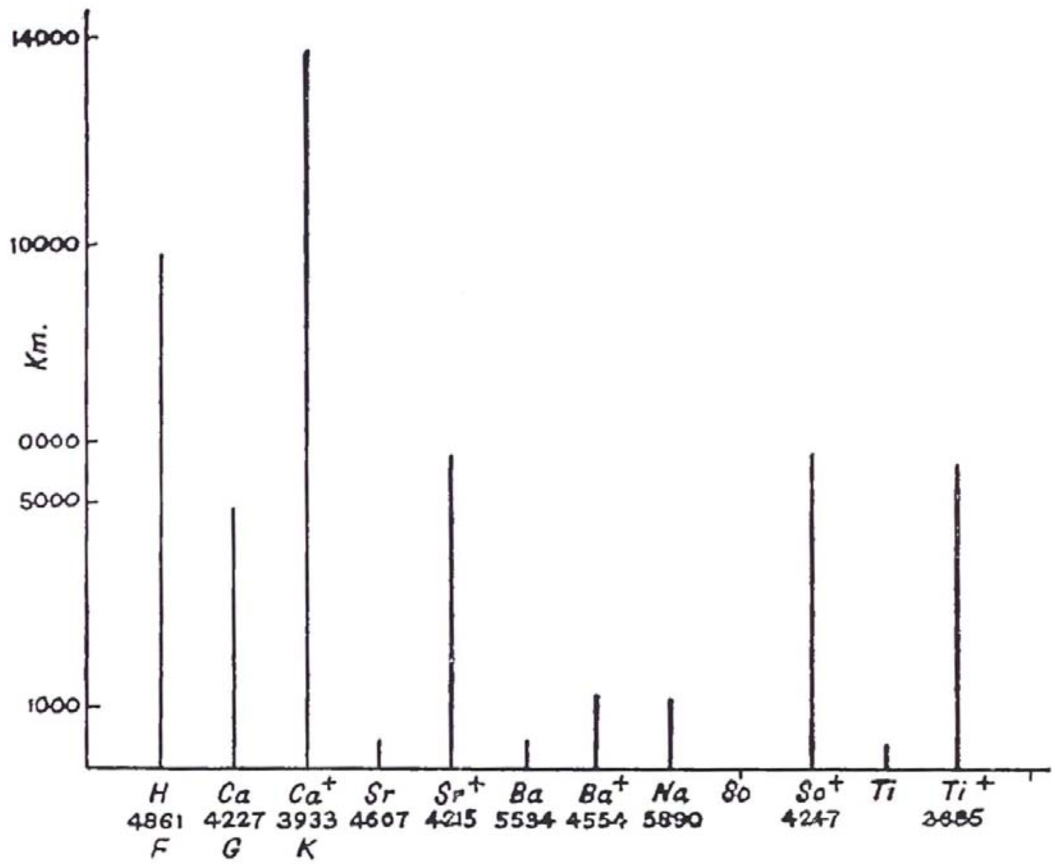

FIG. 1.

entirely absent from the ordinary arc. In fact, a reduction of pressure calls forth a higher stimulus. Mitchell pointed out in his discussion of the flash spectrum taken during the total solar eclipse of 1905 that a reduction of pressure called forth higher stimulus, and was probably accountable for the strengthening of enhanced lines in the

TABLE II

IONISATION OF CALCIUM
(Calculated from Russell's Formula, *Astrophysical Journal*, vol. 55)

P in atmospheres.

		1.	10^{-1}.	10^{-2}.	10^{-3}.	10^{-4}.	10^{-5}.	
Temp. 6000°	Ca	96·1	84·0	41·0	6·8	·7	·07	·007
	Ca+	3·9	16	59	93·2	99·3	99·93	
Temp. 4000°	Ca	99·89	99·62	98·7	94·1	68·5	18·7	2·3
	Ca+	·11	·38	1·3	5·9	31·5	81·3	97·7

chromosphere. The explanation is obvious if we look back to the formula (1). If P is diminished, x the percentage of ionisation, is proportionately raised. The following table shows how the percentage ionisation of calcium increases with decreasing pressure.
We can explain the occurrence of He-lines and Hydrogen lines beyond H_ϵ in the flash spectrum in a similar way.

Fowler and Milne have applied the same considerations for explaining the important differences between the spectra of giant and dwarf stars. Giant stars are characterised by having an extensive atmosphere. The pressures in the reversing layers must be exceedingly small compared to the pressures in the reversing layers of dwarfs. Hence, as a general rule, we shall get more ionisation in giants than in dwarfs.

Elements in the Sun

According to a widely accepted theory of evolution of the solar system, the Earth is a fragment of the Sun hence the Sun ought to show the same 92 elements which have been found on the Earth. But spectroscopic evidence reveals only 36 elements. For example the solar spectrum shows no lines of Rb, Cs, N, Ne, A, and the halogen group, and elements like K, Cu, O, are very feebly represented.

The absence or feeble presence of the alkali elements K, Rb, Cs, is completely explained by the ionisation theory. For these elements have very low ionisation potentials, and it can be shown from formula (2) that they are almost completely ionised on the solar surface. The chief lines of K^+, Rb^+, Cs^+, mostly lie in the ultra-violet, hence they escape observation.[11]

Spectrum of Sunspots

The nature of sunspots was a matter of controversy for a long time, but Fowler and Hale definitely settled the question by showing that the spectrum of the spot was similar to that of the K-type of stars. This proved that the spots are regions of local cooling, and if the ionisation theory be correct, then elements like Rb or Cs, which are completely ionised in the Sun, ought to recombine and show arc lines in the spectrum of sunspots. This prediction was verified by Russell in the case of Rb on some photographs of the spot spectrum taken by Mr. Brackett in the Mount Wilson Solar Observatory.

[11]Mitchell, *loc cit*. p. 489.

Russell[12] has made a very thorough comparative study of the Fraunhofer spectrum and the spot spectrum, and has proved that the arc lines are, as a rule, intensified in the spot, as is expected from the ionisation theory.

III

Recent Development in the Theory of Ionisation

It has already been mentioned that even in form (2) the equation does not meet the actual conditions which generally present themselves for solution. For according to Bohr's theory the atom does not become ionised all of a sudden, but has to proceed through a number of intermediate, metastable stages. Taking H-gas at 3000° C, all the atoms are in the lowest or 1_1 stage. When the temperature is raised, the electron in some will pass to the 2_1 or 2_2, 3_1, 3_2, or 3_3. . . . stages. The orbit will become more and more swollen, as shown in Fig. 2. These higher orbits are not stable, but there is continuous exchange of electrons between successive orbits, giving rise to the characteristic lines of hydrogen. At any temperature, normal H-atoms (1_1-state), metastable H-atoms (2_1, 2_2, 3_1, 3_2, 3_3. . . .), free

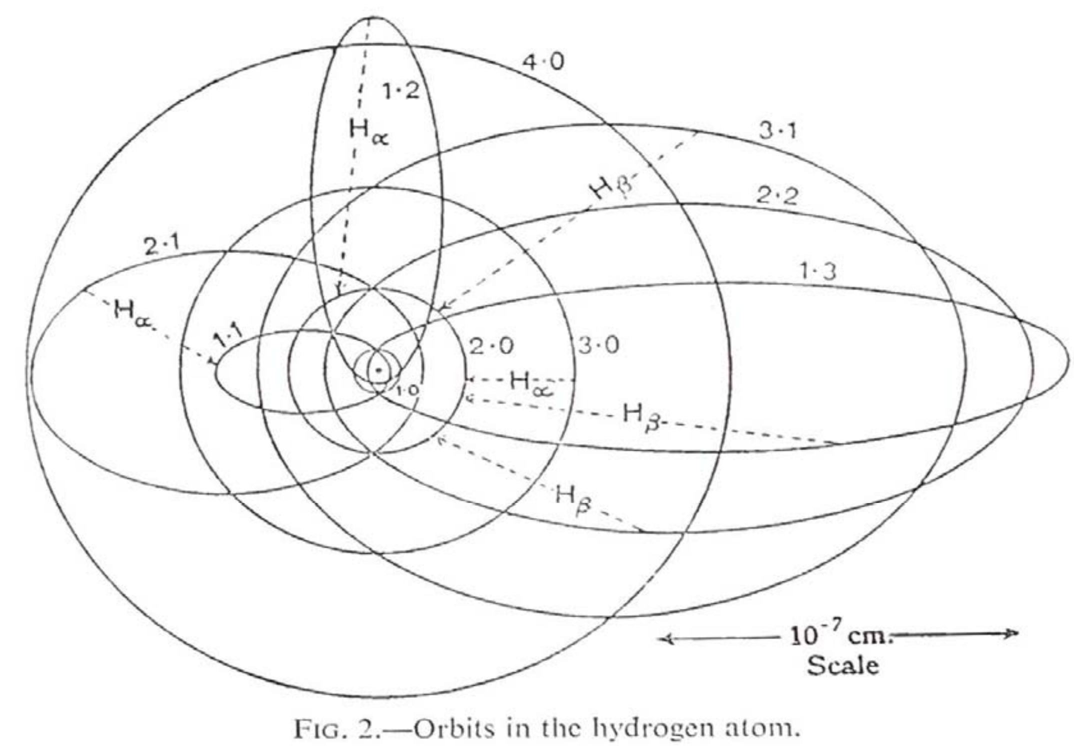

FIG. 2.—Orbits in the hydrogen atom.

[12]Russell, *Astrophysical Journal*, 1922, vol. 55, p. 119.

electrons, with the radiation produced, will be in thermodynamic equilibrium. A perfect formula must take into account all these facts.

Formulae purporting to meet these conditions have been given by Darwin, Fowler,[13] and Milne[14] in England, and by Beeker[15] in Germany, They are all based on a general method for calculating the dissociation equilibrium first given by Prof. Ehrenfest[16] of Leiden. It will be sufficient to reproduce the formula given by Darwin and Fowler:

$$\log \frac{x^2}{1-x^2} \mathrm{P} = \frac{\mathrm{U}}{2{\cdot}3\mathrm{RT}} + \frac{5}{2} \log \mathrm{T} + \log \frac{(2\pi m)^{\frac{3}{2}} k^{\frac{3}{2}} \nu}{h^3} - \log \mathrm{B(T)}. \quad (3)$$

The function $\mathrm{B(T)} = \sum_{n=2} q_n e^{\frac{\mathrm{R}h}{k\mathrm{T}}\left(\frac{1}{1^2}-\frac{1}{n^2}\right)}$ and represents the occurrence of the intervening metastable stages. The function can, however, be introduced from a simple application of Maxwell's theorem of distribution. Let N_1 be the number of particles in the normal orbit, N_n the number of particles in the metastable stages defined by the total quantum number n, then according to Maxwell's theorem,

$$\mathrm{N}_n = \mathrm{N}_1 e^{-(x_1 - x_n)/k\mathrm{T}}$$

where x_n is energy of state n, q_n the thermodynamical weight of the nth state.

According to Bohr,

$$q_n = n(n+1)$$

$$x_1 = -\frac{\mathrm{N}h}{1^2},\ x_n = -\frac{\mathrm{N}h}{n^2}$$

It should, however, be pointed out that the function B(T) is divergent.

Darwin and Fowler think that the difficulty can be avoided by cutting the series at some finite term. They justify the procedure on the following grounds. The radius of the orbit of the electron in the nth metastable state is $a_0 n^2$; the atomic volume, therefore, varies as n^6. When the H-gas is at a finite pressure, then for some value of

[13] Darwin and Fowler, *Phil. Mag.* vol. 44, p. 450; vol. 45, p. 21.
[14] Fowler and Milne, *M.N.R.A.S.* vol. 83, p. 403.
[15] Beeker, *Zeits, fur Phys.* vol. 18.
[16] Ehrenfest and Trkal, *Proc. Amst. Soc.*, 1920.