The Spectra of Silicon at Successive Stages of Ionisation.[1]

By Prof. A. FOWLER, F.R.S.

THE present lecture may be regarded as a continuation of the Bakerian Lecture of 1914, in which it was established that series in spark spectra, though otherwise similar to arc series, are characterised by a fourfold value of the series constant N. This result was in complete agreement with Bohr's theory, according to which arc series originate in neutral atoms, and spark series in ionised atoms. The theory further suggested that atoms which had lost two electrons, or had become doubly ionised, would give series having 9N for the constant; atoms which had lost three electrons would yield series with 16N for constant, and so on.

In a search for spectra of the higher orders, one of the most promising elements appeared to be silicon, which Sir Norman Lockyer had already shown to be represented by different groups of lines in stars of successively higher temperatures. The spectra obtainable from this element under the action of discharges of increasing intensity have accordingly been investigated over the long range of spectrum necessary for the investigation of series relationships. The results of the inquiry are in accordance with theoretical prediction so far as the fourth spectrum.

Theoretical expectations in regard to the relations between these spectra and those of elements which immediately precede silicon in the periodic table have also been realised, the necessary additional data for a full comparison being provided by Paschen's recent work on the second and third spectra of aluminium. The relations between the various spectra may conveniently be indicated as follows:

	Doublets.	Triplets.	Doublets.	Triplets.
$n=1$	Na I	Mg I	Al I	Si I
C=N	11+, 10 −	12+, 11 −	13+, 12 −	14+, 13 −
$n=2$	Mg II	Al II	Si II	
C=4N	12+, 10 −	13+, 11 −	14+, 12 −	
$n=3$	Al III	Si III		
C=9N	13+, 10 −	14+, 11 −		
$n=4$	Si IV			
C=16N	14+, 10 −			

$$\text{Series constant} = C = \frac{2\pi^2 e^2 m}{ch_3} \cdot \frac{M}{M+m} \cdot (ne)^2.$$

Under each symbol the number preceding the + sign represents the nuclear charge, and that preceding the − sign the number of external electrons in addition to the one which generates the spectrum, so that in the first row the atoms as a whole are neutral. All spectra in the same vertical column have been found to be similar, but as n increases, corresponding lines are of higher frequencies, and the doublet or triplet separations are increased.

The principal numerical data, some of which are of immediate importance in connexion with work on the temperatures of the hotter stars, are included in the following brief references to the four spectra of silicon.

[1] Substance of Bakerian Lecture of the Royal Society delivered on Thursday, May 15.

Si I.—Theory suggests that new features will be presented by this spectrum, inasmuch as the effective electron probably traverses a 3_2 orbit; a p or P term may therefore be expected for the highest limit, and not an S term as in Mg I. The triplets are very feebly developed, there being but one representative of each of the s and d series. From analogy with other triplet spectra, however, the limit $3p_2$ may be expected to be in the neighbourhood of 85000. Six singlets which are reversed in the arc can be arranged in two series of subordinate type converging near to 60000, which may be taken as the value of 3P. If the resonance line $3p_2 - 3P$ be $\lambda 3905$ ($\nu 25598$), as is not improbable, the term $3p_2$ will be 85600, in close accordance with the first estimate. Further work on this spectrum is necessary, but the resonance and first ionisation potentials may provisionally be taken as 3·2 and 10·6 volts respectively. Some of the strongest lines of the arc spectrum form two multiplets of the pp' type.

Si II.—The spectrum forms a doublet system analogous with that of Al I, and the various constituent series are well represented. Lines at $\lambda\lambda 1533{\cdot}55$, $1526{\cdot}83$ ($\nu\nu 65208$, 65495) form the leading pair of the sharp series, the limits of which are $3\pi_1 = 131531$, $3\pi_2 = 131818$. The resonance potential is therefore 8·09 volts and the second ionisation potential 16·27 volts. Besides the usual sets of terms, there is a double term of d type, $x_1 = 76498$, $x_2 = 76514$, which yields a strong series of fundamental type in the far ultra-violet; no corresponding terms have been noted in aluminium.

Si III.—The spectrum is of the same type as that of Al II and Mg I, consisting of triplets and singlets. The first line of the first d triplet is at $\lambda 1113{\cdot}76$, and that of the first s at $\lambda 997{\cdot}7$. The limits of the triplet series are $3p_1 = 216879$, $3p_2 = 217142$, $3p_3 = 217273$. The singlet series have not been certainly identified, but there is evidence that the resonance line $3S - 3p_2 = \nu 39330$, and the first principal line $3S - 3P = \nu 82857$. If so, the resonance potential will be 4·85 volts, and the third ionisation potential 31·66 volts ($3S = 256472$).

Si IV.—Additional lines of the doublet system of Si IV have been photographed by Millikan in the extreme ultra-violet, but the series limits previously published are not materially modified. The resonance lines are $\lambda\lambda 1393{\cdot}9$, $1402{\cdot}9$ ($\nu\nu 71740$, 71280), indicating a resonance potential of 8·86 volts. The fourth ionisation potential is 44·95 volts.

The ionisation potentials, and the doublet or triplet separations of elements in the same column of the foregoing table, are more simply related than those of elements in corresponding columns of the periodic table.

International Congress on Applied Mechanics.

THE International Congress on Applied Mechanics, held at Delft during the last week of April, was an extremely successful gathering of about two hundred scientific men drawn from all parts of Europe and America for the discussion of papers covering a wide range of subjects, which may be roughly classified as dealing with the theory of elasticity and recent researches in plasticity, hydrodynamics, and aerodynamics. It was mainly due to the energy and organising ability of the chairman, Prof. Biezeno, and secretary, Prof. Burgers, that the meeting was such a pronounced success.

Delft is an admirable centre for a congress on applied science, as it is the focus of most of Dutch activity in this field, with an extensive range of buildings and laboratories in which teaching and research work go on side by side.

The Dutch contributions to the fifty or more papers presented were naturally a prominent feature and included a very interesting theoretical paper, by Prof. Biezeno, on graphical and numerical stress determinations in beams and plates, a paper on the motion of a fluid in the boundary layer along a plane surface, by Dr. Burgers, forming an extension of the well-known work of Osborne Reynolds, Prandtl and Lorenz, and also an extremely interesting account of measurements of the gravitation constant made in seas between Java and Holland from a submarine, by Dr. Vening Meinesz (v. NATURE, May 3, p. 641).

An important part of the proceedings dealt with stress distribution of materials in the plastic state, to which Dr. Hencky, of Delft, contributed a theoretical discussion, while Prof. Prandtl gave a valuable summary of the work in this field associated with his name and the Göttingen school. The English contributions in this branch were also of importance, as Mr. Southwell gave an account of his recent work on the stability of plates under shear stress, Mr. Griffiths described his well-known theory of rupture by the aid of some interesting experiments on quartz fibres, while Prof. Haigh also contributed an interesting account of his theory of rupture by fatigue.

Closely related to this group there were papers by Dr. Masing on season cracking and volume changes due to internal stress, Dr. Nadai on slip bands in plastic material, Dr. Schmid on recent researches on single metallic crystals, and the theory of deformation structure by Dr. Weissenberg.

In the elastic field, Dr. Wyse contributed a valuable survey of the stress distribution in hook-shaped bodies based on strain measurements of a most exhaustive kind and giving results which, if necessary, could be readily confirmed by photo-elastic measurements, in which latter subject Prof. Coker contributed a paper on his recent researches of the stress distribution in foundations of masonry structures, incompletely braced frames, and the effects of planing, milling, and lathe tools on various materials. In this section there was also a discussion of the solution of boundary problems by the valuable method of Ritz.

The section on hydrodynamics and aerodynamics was very naturally largely taken up with aeroplane problems, to which Prof. Bjerknes contributed a notable paper relating to the forces which lift aeroplanes, while Prof. Witoszynski discussed the theory of circulation around them by some interesting applications of the complex variable.

A most interesting experimental lecture, by Prof. G. I. Taylor, on the hydrodynamics of rotating fluids, was especially remarkable for the effective experimental demonstration of the instability of motion produced between rotating cylinders, resulting in the formation of vortices separated by equidistant planes perpendicular to the common axis of the cylinders. Another paper, by Sir Napier Shaw, of interest in this field, related to the physical structure of the atmosphere treated from the dynamical point of view.

A visit to the Government Aeronautical Institution at Amsterdam was made by members of the Congress.

A very complete volume of abstracts of the papers, about seventy in number, was available, and it is proposed later to issue a volume giving a more extended account of the proceedings, while it is also hoped to arrange a further congress in 1926 either at Zurich or Rome.

E. G. C.

Water Power Resources of Canada.

By Dr. BRYSSON CUNNINGHAM.

THERE has recently been issued by the Water Power Branch of the Canadian Department of the Interior a report, dated February 1 last, which reviews the present position of water power development in the Dominion. During the year 1923 there was an increase of more than a quarter of a million horse-power, and the total hydraulic power installation of the country now aggregates the imposing total of 3,227,414 h.p. The known available water power from all sources is computed at 18,255,000 h.p. for conditions of ordinary minimum flow, and at 32,076,000 h.p. under a flow estimated for maximum development, *i.e.* a flow which can be depended upon for, at least, six months of the year. These estimates are of a conservative character; from observations of existing plant it is found that the average machine installation is 30 per cent. greater than the six-months' flow maximum power. Accordingly, it may be safely inferred that the present turbine installation of 3,227,414 h.p. represents only 8 per cent. of the recorded available water power resources.

An analysis of the foregoing figures shows them to be distributed as shown in the accompanying table.

Subdivided according to method of utilisation, it is of interest to note that the existing installations comprise:

2,411,701 h.p. in central stations for general distribution for all purposes. The average installation is of about 8550 h.p.

497,620 h.p. in pulp and paper mills. This is exclusive of 228,755 h.p. purchased by pulp and paper companies from central stations.

318,093 h.p. in industries other than central stations and pulp and paper mills.

The total installation for the Dominion averages 353 h.p. per thousand of population, Canada thus ranking, among the countries of the world, third to Norway and Switzerland in the *per capita* utilisation of water power.

The report expresses the view that there is every reason to expect a continued and rapid development of water power. At the present time there are actually in process of construction, or in active prospect, hydro-electric plants aggregating 900,000 h.p.

Province.	Available 24-hour Power at 80 % Efficiency.		Turbine Installation.
	At Ordinary Min. Flow.	At Ordinary 6-months Flow.	
British Columbia	1,931,142	5,103,460	355,517
Alberta	475,281	1,137,505	33,067
Saskatchewan	513,481	1,087,756	...
Manitoba	3,270,491	5,769,444	162,025
Ontario	4,950,300	6,808,190	1,445,480
Quebec	6,915,244	11,640,052	1,116,398
New Brunswick	50,406	120,807	44,539
Nova Scotia	20,751	128,264	54,950
Prince Edward Is.	3,000	5,270	2,239
Yukon and N.W. Territories	125,220	275,250	13,199
	18,255,316	32,075,998	3,227,414

On a moderate estimate, the effective working increase will be at the rate of one million h.p. every 5 years, so that by the year 1940 no less than 7 million h.p. should be developed. The cost of the existing installations represents a capital outlay of more than 687,000,000 dollars, which, in fifteen years' time on the same basis of increase, will reach 1,500,000,000 dollars. Hence the outstanding importance of an intelligent administrative policy to govern the exploitation of the valuable water power resources of the country.