The Disappearing Gap in the Spectrum.[1]

By Prof. O. W. RICHARDSON, F.R.S.

I.

THE Royal Institution seems a peculiarly fit place to deliver lectures on this subject, because it was while he was professor here 120 years ago that Thomas Young, the great advocate of the wave theory of light, showed how to estimate the wave-lengths of the different parts of the spectrum, and by so doing laid the foundations of spectroscopy as a quantitative science. His determinations of the wave-lengths in the visible spectrum were based on Newton's observations of the colours of thin plates. He also explained the principle of the diffraction grating, and by experiments based on the method of Newton's rings he showed that the actinic or ultra-violet rays had shorter wave-lengths than those in the visible. The wave-lengths of the visible spectrum extend from a little below 4000 to a little above 7000 Ångström[2] units, or, roughly, over about an octave. On the infra-red side we have, first, the invisible rays, often referred to as radiant heat, which contain the major part of the energy in the solar spectrum and a greater proportion still of the energy radiated from bodies at a lower temperature. Beyond these we have the long electromagnetic waves of the type we are familiar with in wireless telegraphy. This side of the spectrum extends to waves of infinite length or of zero frequency.

The gap in which we are interested is on the other side of the visible spectrum in the region of waves of shorter length or higher frequency. In 1801 Ritter showed that there was something beyond the violet end of the visible spectrum which blackened chloride of silver. In other words, there are ultra-violet rays which, as we should now say, are capable of photochemical and photographic action. They also have other properties—they excite fluorescence in substances such as uranium glass, and they liberate electrons from the surface of a metal plate. They are, however, not very freely transmitted by glass; or, to put the matter more precisely, the ultra-violet spectrum which is transmitted by a glass prism spectroscope, does not extend very far beyond the visible limit. By substituting quartz for glass in the spectroscope, and by other improvements, Stokes was able to make a very notable extension and to carry the limit to beyond 2000 Å. This made the ultra-violet extend over more than an octave, and measured in that way its extent had become greater than the whole of the visible spectrum.

The limit to further extension was now found to be set by two things—(1) the absorption of quartz, which becomes fatal about 1850 Å, and (2) the absorption of air, which also becomes prohibitive in the same neighbourhood. These difficulties were faced and overcome up to a certain point by Schumann, who constructed a fluorite spectroscope which he could operate, with all its adjustments, in an evacuated chamber. In this way he succeeded in pushing to the limit of transparency of fluorite, which is in the neighbourhood of 1250 Å with good specimens.

The limit to further development was set, and the possible lines of advance narrowed down, by a very remarkable and important property of the radiation in this part of the spectrum, to wit, that every known material substance is practically completely opaque to it. I believe this high absorbability of the radiation to be due to the combined influence of two facts—(1) that the quantum of this radiation exceeds the ionisation or radiation quantum of every atom, and (2) it does not exceed it by so much that there is any considerable chance of the radiation getting past the atom which, as it were, is set to trap it. We have precise evidence that absorption sets in as soon as, but not earlier than, the frequency at which the quantum of the impinging radiation exceeds the ionisation or radiation quantum of the atom. We also have considerable evidence, both theoretical and experimental, that the chance of absorption is greater when the two frequencies are comparable than when they are widely divergent in magnitude. These considerations exclude completely any apparatus of the type of the prism spectroscope, in which the radiation passes through considerable portions of matter such as the materials of the prisms and lenses.

There is one spectroscopic apparatus which is free from this difficulty, namely, the concave grating invented by Rowland. In this device, if the slit, the grating, and the screen or photographic plate are all arranged to lie on a circle perpendicular to the rulings having a diameter equal to the radius of curvature of the grating, the spectrum is sharply focussed without using any lenses. The adaptation of the concave grating for use in this part of the spectrum is due to Lyman, whose vacuum grating spectroscope has only begun to bear the fruit which we may reasonably hope ultimately to gather from it. With this instrument, which I shall refer to more fully later, by 1913 Lyman had measured the wave-lengths of a large number of lines between the limits reached by Stokes (quartz) and Schumann (fluorite), and had also extended the known spectrum to the neighbourhood of 900 Å, which is the short wave limit of the most fundamental hydrogen atom spectrum series, now known as the Lyman series.

At that time, then, the spectrum was known to be continuous from wave-length infinity to wave-length 900 Å, or in terms of frequency from zero to $3{\cdot}333 \times 10^{15}$ vibrations per second. It was also known that we had in the X-rays and the γ-rays from radioactive substances rays of still higher frequency and shorter wave-length. Prior to the discovery of the crystal diffraction phenomena the wave-lengths of X-rays had been ascertained roughly by photoelectric methods—a fact which seems generally to have been forgotten—but by 1913 they had been measured accurately by the Braggs and Moseley with the crystal spectrometer. Moseley's measurements include such rays as the K-rays of aluminium, which are in the neighbourhood of 8 Å, and this was the longest X-ray wave then known. There was thus a gap from 8 Å to 900 Å, or about seven octaves. This is the gap with which I propose to deal.

I do not know that any systematic or very thorough attempt has been made to push the measurements of

[1] Substance of lectures delivered at the Royal Institution on May 13 and 20 1922.
[2] 1 Ångström unit (Å) = 10^{-8} cm.

X-ray wave-lengths so far as possible in the long wave direction by crystal methods, but it is evident that there must be a limit, and it is possible that this limit has almost been attained, for in spite of the great improvement in technique and the extraordinary activity in this line of work since Moseley's measurements in 1913, the longest wave-length I have been able to find recorded as measured is the zinc L_{a_1} line given by Friman as 12·346 Å. This represents but half an octave out of the seven octaves between the limits left by Lyman and by Moseley.

The failure of crystal methods is due to two causes. The distance between the centres of the atoms in solids is of the order of an Ångström unit, so that at 12 Å the waves are already much longer than the distance between the reflecting planes which form the grating elements. (For the crystals rock-salt and calcite, with which most of the accurate measurements have been carried out, these distances are $2{\cdot}184\times10^{-8}$ and $3{\cdot}028\times10^{-8}$ cm. respectively.) The other difficulty arises from the intense absorbability of these soft X-rays by practically everything, a phenomenon that we have already witnessed in the radiation on the other side of the gap. Sir William Bragg has recently been investigating some organic crystals which have grating spaces very much farther apart than rock-salt and calcite, and it may be that in employing such crystals in an evacuated system we have a way of making considerable advances into the gap from the high-frequency end by the X-ray crystal diffraction methods. It would seem that in Moseley's original apparatus we have an arrangement which could be rather easily developed for this purpose. Another advantage of these crystals is the possibility that they may not absorb the rays so very intensely, as the only known substances which have appreciable transparency in this region are organic compounds or mixtures of them, such as celluloid.

Returning to the position about 1913, this is conveniently exhibited by diagram A of Fig. 1, in which the various spectral limits are marked against an even scale proportional to the logarithms of the corresponding frequencies. These are shown by the numbers on the base line, the numbers given at the top being corresponding wave-lengths in Ångström units. It will be seen that this representation is similar to that of the keyboard of a piano, equal horizontal spacings corresponding everywhere to an equal number of octaves. The great width of the gap between the X-ray and ultra-violet limits is very apparent.

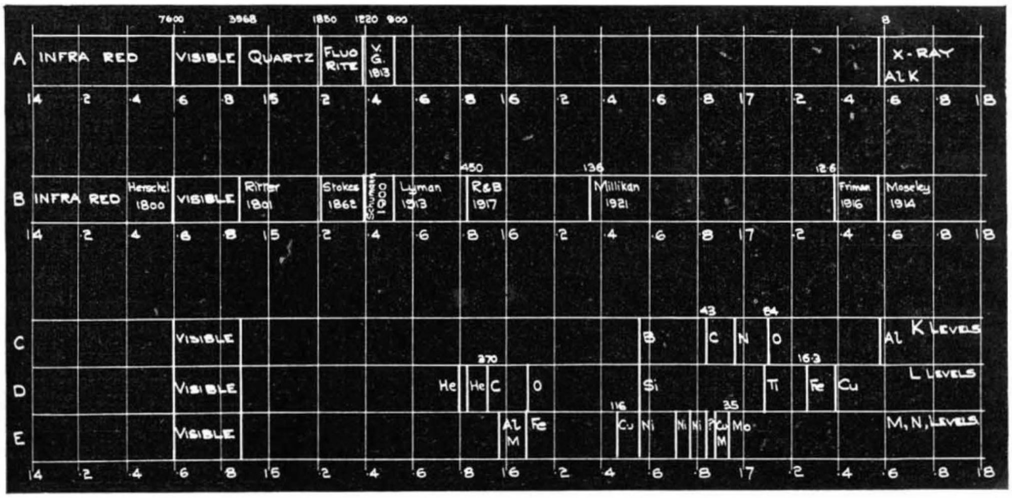

FIG. 1.

A very considerable advance into this gap was made by Dr. Bazzoni and myself in 1917 using a method which was novel in spectroscopy. Our experiments were directed towards the measurement of the short wave limit of the arc spectra of various gases, and more particularly of helium, which are generated when such gases are bombarded by considerable electron currents under moderate voltages (Fig. 2). The radiation from the gas generated under impact of the electrons passing from the incandescent tungsten cathode F to the cold anode A_1, falls on the metal strip T, after passing through the gap between the metal plates P, across which an electric field is maintained of sufficient strength to remove any ions present in the radiation stream. This radiation liberates electrons

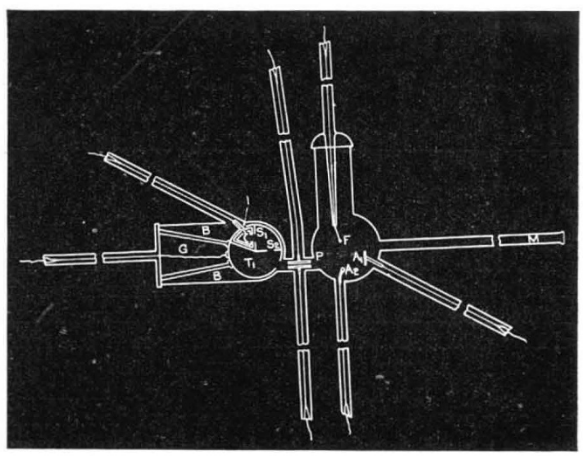

FIG. 2.—Horizontal section of apparatus used for the measurement of the short wave-length limit of arc spectra, drawn to scale.

from the surface of T by photoelectric action, and the energy of the swiftest of these electrons is given by the relation $\frac{1}{2}mv^2 = h(\nu - \nu_0)$, where ν is the frequency of the radiation and ν_0 the threshold frequency of the metal T, h being Planck's constant. The velocity v can be measured by applying a magnetic field perpendicular to the plane of the figure, when the electrons will be constrained to move in spiral paths, the axes of which are parallel to the magnetic field. Only those spiral paths the radii of which lie within certain narrow limits will pass through the gaps S_1, S_2. Consequently, since this radius depends on the velocity of the electrons and on the magnetic field, those electrons which reach the box I in a given magnetic field will have velocities lying between corresponding narrow limits. As the magnetic field is increased it will ultimately curl up the fastest electrons, so that their paths projected on to the plane of the figure lie along the circle TS_2 S_1. Any magnetic field greater than this will give rise to spirals which are too narrow to get into the box I, so that the magnetic field, which is just sufficient to stop the electron current into the box, will determine the velocity of the fastest electrons, and from this datum the equation quoted above enables the greatest frequency present in the radiation to be estimated. In this way we determined the end of the helium spectrum to lie close to the position 15·83 on diagram B of Fig. 1. The corresponding wave-length is about 450 Å.

By 1916 Lyman had succeeded in measuring the wave-lengths of various lines extending to about 600 Å by means of his vacuum grating spectroscope. This instrument of course measures the wave-lengths of the lines with precision, and is the most valuable weapon we have for research in this region. Notable advances have recently been made with it by Millikan, who has made several improvements in technique which have contributed to the success he has attained. These improvements include—(1) the production of special gratings which are ruled with a light touch, so as to have about half the grating surface uncut, and thus throw nearly all the energy into the first-order spectrum; (2) the employment of very high-tension sparks (some hundreds of thousands of volts supplied by Leyden jars and a powerful induction coil) between metal terminals very close together (0·1-2 mms.) in a high vacuum maintained by diffusion pumps. With this apparatus he has succeeded in measuring a large number of lines in the extreme ultra-violet spectra of the light elements lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, sodium, magnesium, and aluminium, extending in the case of aluminium to 136·6 Å. This limit is shown at 16·35 on Fig. 1, B.

All these elements exhibit, under these conditions, characteristic line spectra which extend into the ultra-violet, and, roughly speaking, the spectra go further into the ultra-violet with increasing atomic weight of the elements. The spectra differ very much in character as between the different elements; thus boron has but seven strong lines extending between the limits 676·8 Å and 2497·8 Å, whereas carbon has a very complex spectrum extending from 360·5 Å to 1335·0 Å. In fact the spectra of the elements of odd atomic number such as boron tend to be simpler than those of even atomic number such as carbon. The spectra of these elements in this region resemble the X-ray spectra of the heavier elements in this particular, that they consist of groups of lines separated by very wide intervals. Thus with aluminium there is nothing between 144·3 Å (L_α) and 1200 Å, where a new spectrum starts which extends into the visible.

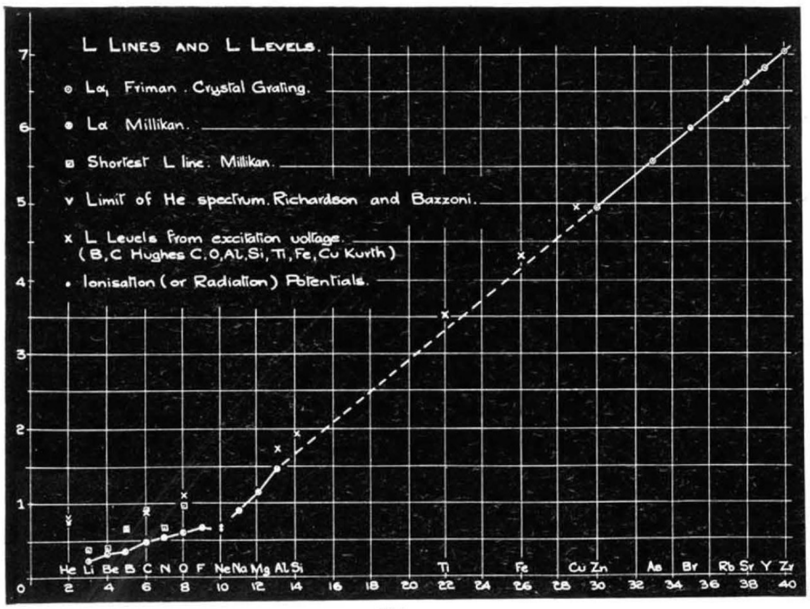

FIG. 3.

There are good grounds for attributing the shorter wave-length groups of the lines of those elements in this region to the L characteristic X-rays of the elements. This will become clear by reference to Fig. 3, which represents the square roots of the various frequencies plotted against the atomic numbers of the corresponding elements. The points encircled between atomic numbers 30-40 (Zn-Zr) belong to the L_{α_1} lines of the elements, the wave-lengths of which have been accurately measured by Friman by the crystal diffraction methods. These points are all practically on a straight line, which, if prolonged in the manner shown by the broken line, reaches the abscissa for atomic number 13 (aluminium) at a value of the ordinate which corresponds almost exactly to the line of wave-length 144·3 Å, which Millikan found to be the longest in his group of aluminium lines in the far ultra-violet. This point is marked thus ⊗ on the diagram. It is of course a long shot from zinc to aluminium, but we shall see later that we have other evidence of the legitimacy of the extrapolation. The other points marked ⊗ refer to the longest lines, and those marked ⊡ to the shortest lines, of the spectra of the various elements of low atomic weight observed by Millikan. It will be seen that the linear relation between the square root of the frequency of corresponding lines and the atomic number which holds for the higher atomic numbers breaks down in this region. In fact, while there is a general tendency for the corresponding frequencies to increase with increasing atomic numbers, one is no longer an approximately continuous function of the other. The vertical spacing between the points ⊗ and ⊡ for any one element is an indication of the extension of the relevant spectrum. It will be seen that this extension varies in an irregular manner in the sequence of elements from lithium to oxygen. The points shown for lithium are those for the well-known red line 6708 Å and the end, 2299 Å, of the series to which it belongs. No lithium lines were found in the ultra-violet beyond 2299 Å in the region in which the vacuum grating is effective; so that if the allocation of these spectra, for the intervening elements up to aluminium, to the L X-ray series of the respective elements is correct, this series is the L series of lithium. This forms very convincing evidence of the essential similarity of X-ray and visible spectra.

(*To be continued.*)

The Natives of Australia.[1]

By SIDNEY H. RAY.

IN the National Museum of Victoria at Melbourne a special gallery has been devoted to a fairly representative collection of objects connected with the daily life of the Australian aborigines. A very instructive and well illustrated account of the exhibits has been written by Sir Baldwin Spencer, and this gives, in a wonderfully succinct form, what are practically short comparative essays on the arts and crafts of the natives.

There seems to be very little doubt that the first inhabitants of Australia were frizzly-haired people of the old Stone Age, using unground axes, chipped stone knives, and scrapers without handles. They had no knowledge of boats or house-building. Part of this population, cut off by a subsidence which now forms Bass Straits, survived in Tasmania until modern times, but on contact with Europeans became exterminated. In the Museum these people are represented by masks of two males and one female and by a cast from the skeleton of Truganini, the last of the Tasmanians. There is also a collection of their stone implements.

On the mainland the primitive population was supplanted by people in a higher grade of development whose origin is still a matter for discussion These people are remarkably uniform throughout the continent. The average height is about 5 ft. 6 in.; the skin a dark chocolate colour and never really black; the head long, the hair wavy, not woolly or frizzly like that of the Tasmanian, Papuan, or Negro. The people are nomadic, living in tribes which have distinctive names, and roam within certain clearly defined limits. They have no villages but only camps or clusters of rude shelters. One of the Museum cases contains a representation of a native camp, Fig. 1. This shows the *mia-mia* or shelter made of bark from gum trees resting on the windward side of a rough framework and forming a sort of lean-to. The man and woman are supposed to be returning from a hunting expedition The woman carries in her hand her digging stick, and on her back a young child secured in its position by the skin cloak. The latter is usually of opossum skins, sewn together with sinews often taken from a kangaroo's tail. The head of the clothed man is decorated with a string forehead band in which are stuck feathers of the black cockatoo. But generally the men wear no clothing. The man in the foreground is making fire with a drill. In connexion with the camp, the *toas* or posts set up by South Australian tribes on departure as a guide to new-comers (see NATURE, February 12, 1920, p. 643) do not appear to be represented in the Victorian collection.

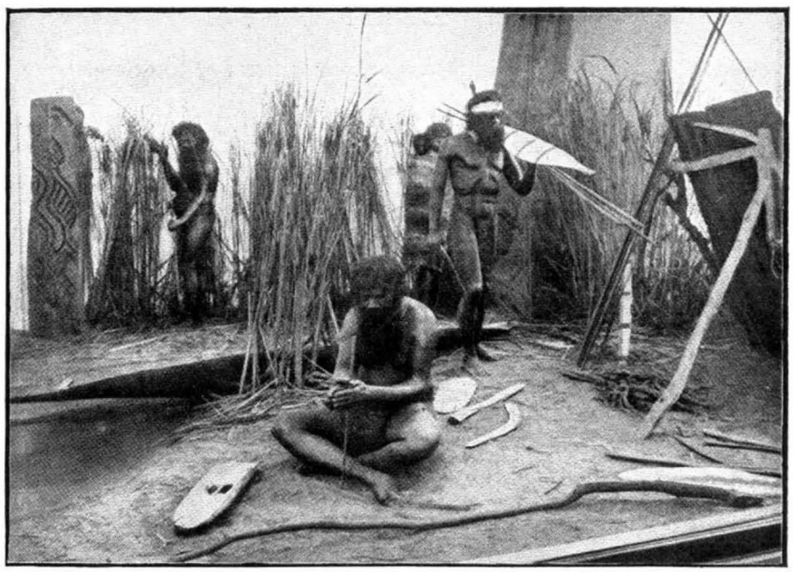

FIG. 1.—Native camp scene.

The languages used differ so much that natives of one tribe cannot understand the speech of their neighbours, and though in some regions, owing to the absence of mountains and rivers, tribes may be closely associated and a few words understood, there is even between these very little community in actual speech. In the Northern Territory the languages appear entirely different in grammatical structure from those in South, West, or East Australia, and approach in character

[1] "Guide to the Australian Ethnological Collection" exhibited in the National Museum of Victoria. By Sir Baldwin Spencer. 142 pp. Third Edition. Illustrated by 33 Plates. Melbourne: Albert J. Mullett, Government Printer, 1922.