

ated that there is still undeveloped in the streams of the United States about 35,000,000 horse-power.

It is a popular misconception that, owing to a diminishing coal supply, the cost of steam-power is constantly rising, so that water-powers are becoming more and more in control of the power situation. The fact is exactly the reverse. Methods of deriving the energy of the coal are constantly improving in efficiency, and even if the cost of coal should rise it would in all probability be more than offset by the increased economy of use. There is nothing to indicate that the limit to the reduction in cost of steam-power has been reached or is in sight, inasmuch as the best type of steam-electric plants to-day utilize only about 20 per cent of the total energy of the coal. Water-power plants are at present, however, about as efficient as can be hoped for, with 93 per cent efficiency for water turbines and 98 per cent for electric generators.

As the cost of steam-power falls, the total water-power of the country susceptible of profitable commercial development continually shrinks, and many water-powers which a few years ago could have successfully competed with steam plants and might have been developed, will not be developed to-day on account of steam-turbine competition. The proposed taxation of water-powers and other legislative restrictions will increase the list of water-powers that cannot be developed with a profit.

Even California and other Western States, where a few years ago the high price of coal gave water-power a practical monopoly in the power field, no longer hold this position, on account of the development of the local oil fields, which makes fuel available at a cost low enough for successful exploitation of the steam turbine where long transmissions are required from the competing water-power plant and where the hydraulic development is not of exceptionally low cost.

In South America there are apparently numerous water-powers which could be economically developed. The present high cost there of coal and oil should give water-power development a great economic advantage in the South American countries. The same is true of Canada to a great extent, where there are a large number of exceptionally favorable water-power sites and where coal and oil are in each case relatively high in price.

Where a water-power plant is required to deliver a practically uniform daily load throughout the year, which is generally necessary on a miscellaneous power distribution system, and where seasonable variations in load are not permissible, the deficiency at low water flow must be made up either by storage of water or by steam. Usually both are required.

Nearly all water-powers are subject to a period of low water for at least two or three months in the year, and in order to utilize the energy available during the

high-water months a combination of steam and water-power is necessary and profitable. The two together will be found in most cases to give a lower cost of annual output than either one or the other alone.

A steam auxiliary is an important and necessary part of a water-power development. This steam-generated power can either be secured by operating occasionally the old steam plants of power customers which have been shut down by purchase of power from a water-power company or by constructing new steam-turbine plants as part of the water-power system.

Where steam-power is to be supplied to make up the deficiency in the water-generated power it is important to operate the steam plant, when running, in the most economical way. The lowest labor and fuel cost will be obtained per kilowatt-hour when the steam plant is operating at practically constant load throughout the day. The operating expense and efficiency of a water-power plant is not so dependent upon constant output, so that it can be operated in the combination at a lower load-factor, taking the peaks of the load.

The outlook for the future development of water-powers appears, therefore, to be largely in the line either of power plants exclusively driven by water-power for seasonable variation in output, or for constant output developments, where steam storage and water-power are combined, each contributing to the economy of the joint operation.

Extension of the Spectrum Beyond the Schumann Region—II*

Difficulties Encountered and Methods of Procedure Followed

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Concluded from SCIENTIFIC AMERICAN SUPPLEMENT No. 2122, Page 147, September 2, 1916

THE electrodeless discharge is easily dismissed; no radiation on the more refrangible side of λ 800 has been obtained with it. The arc discharge in quartz, both when calcium electrodes were used and when magnesium was employed, showed no lines more refrangible than λ 1000 which could be certainly attributed to these metals. The spectra in both case consisted mainly of secondary hydrogen lines; the primary lines at λ 1216 and λ 1026 were, however, quite strong. The spectrum, which is intense, terminates near λ 905.

The absence of metallic lines in this region is also confirmed by experiments with the spark-discharge at reduced pressures. Pointed terminals of both aluminium and iron, about 1 centimeter apart, were arranged in a small globular vessel communicating directly with the spectroscope. A spark-gap in air, in series with the terminals, insured the disruptive nature of the discharge. At a pressure of about 1 centimeter of hydrogen the spectra obtained with both metals were characteristic of the gas-filling. They contained no lines which could be ascribed with certainty to either aluminium or iron. The spectra terminated near λ 1030. The amount of gas present in the light-path was about equivalent to that in a column of hydrogen at atmospheric pressure 2.5 centimeters long. The experiment, therefore, is of some interest as giving an idea of the order of transparency of hydrogen for these short wavelengths.

The relation between the spectra of helium and of hydrogen forms a fascinating subject for speculation, and the spectral region now under consideration is an excellent field for the test of hypotheses. However, as has already been pointed out, the data at hand cannot be made to yield conclusive answers to the questions involved. The difficulty is inherent in the nature of the problem since the type of the apparatus which must be employed, if the region in question is to be studied at all, precludes the separation of the effects of absorption from those produced by radiation, and at the same time renders the elimination of traces of hydrogen from an atmosphere of helium extremely difficult. In considering the spectra obtained from the discharge tube, therefore, it must suffice for the present at least, to confine the attention to their general character.

On comparing the spectra obtained from hydrogen excited with and without capacity, it becomes evident that when the lines obtained in the latter case are subtracted from those produced with a disruptive discharge, some seventeen strong lines remain. Of these, $\lambda\lambda$ 1216, 1026, and 972 form the Balmer analogue predicted by Ritz; λ 1216 is one of the strongest lines in the spec-

trum; the second member, however, is so feeble as to be hardly visible in spectrum *a*, Plate III, but it is easily seen in spectrum *d*. This illustrates the curious fact, to which reference has been already made, namely, that the extreme lines of the Ritz series appear to be produced more strongly in helium with a non-disruptive discharge than in hydrogen when a condenser and spark-gap are employed. The line λ 972 is not visible in spectrum *a*, but may be seen quite clearly on the original negative from which spectrum *d* was taken. In connection with Bohr's speculations it is important to observe that λ 1216, which forms the first member of the Ritz series, occupies exactly the same position when obtained from helium as when it is produced in hydrogen.

The striking pair of strong lines near λ 1086 and the wider pair near λ 992 have already been attributed to an impurity. They occur in both quartz and glass discharge tubes and their appearance is independent of the nature of the electrodes. They occur very strongly in nitrogen and may perhaps be attributed to this gas, though not with perfect certainty. They may possibly be produced by an oxide of carbon, a trace of which has been occasionally detected in the visible spectrum of helium and which probably takes its origin from the wax used to seal the spectroscope. An inspection of spectra *a* and *b* will show that these lines are less intense in helium than in hydrogen; they cannot, therefore, be ascribed to helium, though Bohr has hinted that they belong to this gas.¹³ The line at λ 1176 is perhaps the strongest in the whole hydrogen spectrum; it is equally strong in helium and is very strong in nitrogen; of its origin nothing positive can be said. All the remaining lines to λ 977 are stronger in nitrogen than in either helium or hydrogen; all occur in argon. From λ 997 to λ 904 all the lines, with one exception, occur in hydrogen, helium, and argon, but with relative intensities depending on the gas in which they are produced. All the lines on the more refrangible side of λ 900 are obtained only when helium is employed, with the exception of λ 833 which occurs in argon. The strength of the pair near λ 835 is striking. An examination of the print from which Plate III was made showed in spectrum *b*, if a magnifying glass was used, the extreme line near λ 600 \AA ; however, this line is probably lost in the reproduction.

Nitrogen yields a few strong lines with a disruptive discharge besides those which it appears to contribute to the hydrogen spectra; with a non-disruptive discharge it yields but two or three weak lines near λ 1200. As its spectrum does not extend beyond λ 977, I have been chiefly interested in the gas in its character of an im-

purity and have made no measurements upon its lines.

As has been mentioned already, argon gives a spectrum containing many lines terminating only near λ 800, but here, again, I have not delayed the progress of this research in order to make measurements. A careful study of the argon spectrum in the future, however, will probably well repay the trouble.

The wave-lengths which are to be found in Table I were obtained by the two-slit method which I have frequently employed.¹⁴ They rest on the hydrogen line λ 1216.0 and upon the shifted spectra of iron and aluminium. They make no claim to extreme accuracy, but I hope that, when standard wave-lengths shall have been established in this region, the values given in the table will not be found to depart from the standards by more than one unit.

The numbers in the first column indicate the intensities of the lines as they occur in helium.

It must be remembered that $\lambda\lambda$ 1216, 1026, and 972 represent the only strong radiations on the less refrangible side of λ 900 which can be attributed to helium or to hydrogen with any degree of certainty. Even the extreme lines produced in helium alone may owe their appearance on the photographic plate to the superior transparency of the gas and may be produced by some subtle impurity.

| TABLE I. | | | |
|---|-----------|---------------------|-----------|
| STRONG LINES IN THE EXTREME ULTRA-VIOLET. | | | |
| Intensity in Helium | λ | Intensity in Helium | λ |
| 1 | 590.0 | 3 | 992.0 |
| 1 | 643.7 | 4 | 1010.6 |
| 2 | 702.4 | 4 | 1026.0 |
| 3 | 703.5 | 5 | 1037.0 |
| 5 | 718.2 | 2 | 1084.9 |
| 2 | 796.8 | 5 | 1081.1 |
| 8 | 833.4 | 1 | 1134.7 |
| 7 | 834.8 | 8 | 1175.5 |
| 4 | 904.6 | 10 | 1176.3 |
| 2 | 916.7 | 5 | 1199.8 |
| 1 | 972.7 | 10 | 1216.0 |
| 2 | 976.8 | 1 | 1236.0 |
| 6 | 977.6 | 5 | 1247.9 |
| 1 | 990.2 | | |

The result of this investigation is easily stated; the spectrum has been extended to λ 600 \AA .

I cannot conclude this article without expressing my appreciation of the skill and patience which my assistant, Dr. Paul Sabine, has shown during the whole course of this research.

*The Astrophysical Journal.

¹³Philosophical Magazine, 30, 401, 1915, note.

¹⁴Lyman, op. cit., p. 45.