ON THE SPECTRUM OF NEUTRAL HELIUM

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ABSTRACT

Silberstein's formula for the lines of neutral helium.—As objections to the validity of the formula $\nu=4N\left(\frac{1}{n_1^2}-\frac{1}{m_1^2}+\frac{1}{n_2^2}-\frac{1}{m_2^2}\right)$ it is pointed out that the ionizing potential computed by means of this formula does not agree with that given by experiments; that no definite principle of selection has been given to indicate observable lines; that there is no arrangement of lines as regards series relationship, division into singlet and doublet systems, or of intensities. The difference between the actual and the calculated frequencies is shown to be the same as that to be expected on the assumption that the coincidences are purely accidental; and the same frequencies can be obtained with different sets of numbers.

In his paper on this subject contributed to the September number of the *Astrophysical Journal* (**56**, 119, 1922), Dr. Silberstein has suggested a formula for the explanation of the spectrum of neutral helium. This formula may be written as follows:

$$\nu=4N\left\{\left(\frac{1}{n_1^2}-\frac{1}{m_1^2}\right)+\left(\frac{1}{n_2^2}-\frac{1}{m_2^2}\right)\right\},$$

where n_1, n_2, m_1, m_2 are four independent integers such that $m_1>n_1$ and $m_2>n_2$. "This formula amounts, obviously, to putting $\nu=\nu_1+\nu_2$ where ν_1 and ν_2 are frequencies of any two lines of ionized helium, observed or only theoretical. This would then be a new kind of combination principle, the sum of the frequencies belonging to one atomic system (ionized helium) giving the frequency for another system (neutral helium)." With this formula Dr. Silberstein has succeeded in explaining 84 of the total 111 observed lines of the helium spectrum, to a very close approximation.

Now, the question is whether the formula has any physical basis or significance. Silberstein derives it on the assumption that "the mutual perturbation of the two electrons is practically nil or negligible," and in support of this says that "as a matter of fact we have no good evidence that the electrons, especially as trabants of the nucleus within the atom, do act upon each other at all, and some bold modern physicist, encouraged by the recognized prohibition to radiate, might deny the electrons the right to interact while they are busy obeying the orders of the central body driving them around on stationary orbits."

But there are some very weighty objections against the formula and the results derived therefrom.

The ionization potential as calculated with this formula is quite different from that which is actually observed. The ionization potential is the work per unit charge required in moving an electron out of the influence of the atom. On the assumption that the two electrons do not act on each other, the ionization potential would obviously be

$$V=\frac{4\times 109723.2}{8102}=54.2 \text{ volts.}$$

But actually it is known that to doubly ionize the helium atom about 80 volts are necessary.

The formula, as it stands, represents a very large number of lines and there is absolutely no principle of selection followed which prima facie indicates the lines to be chosen and those to be rejected. As a matter of fact, the selection actually made appears to be more or less haphazard, the only aim being to choose such numbers as happen to give values coinciding most closely with the observed values. The want of a definite principle of selection is a strong objection against accepting the proposed formula as having any physical significance.

Again, as is well known, the observed lines of the helium spectrum fall into certain definite series which Silberstein dismisses as empirical, but which nevertheless have a definite physical meaning. Thus in each series as we pass from the less to the more refrangible part of the spectrum the lines become more and more crowded, grow fainter and fainter, and tend to converge to a definite limit. But Silberstein's formula shows no arrangement either with reference to series relationships or with reference to singlet and doublet systems of lines.

Nor does it suggest any arrangement with regard to the intensity of the lines. Bohr's theory, which has successfully explained the spectra of hydrogen and ionized helium, suggests that the probability of electrons remaining in distant orbits is very small and that more electrons are to be found in orbits closer to the nucleus. And from the analogy with the spectra of hydrogen and ionized helium, we should expect that more intense lines are obtained by using comparatively smaller quantum numbers than for the less intense ones. In Silberstein's table of values some of the first lines of great intensities are not to be seen at all (probably no combination within the limits prescribed for m and n gives them), and of the rest, more frequently than not, the more intense lines are obtained by larger quantum numbers than the less intense ones. Table I gives some examples.

TABLE I

Observed ν	Intensity	Quantum Numbers, and Calculated ν
9231.86 } 9230.83 }	200 (P.d.)	Not included
25708.63	10 "	Not included
31361.12	8 "	$\left(\frac{16}{4}\cdot\frac{19}{8}\right)$ 31358.
33944.75	6 "	$\left(\frac{15}{4}\cdot\frac{30}{7}\right)$ 33950.
37537.5	1 "	$\left(\frac{4}{3}\cdot\frac{18}{5}\right)$ 37536.
37798.22	"	$\left(\frac{4}{3}\cdot\frac{20}{5}\right)$ 37794.
41150	5 (S.d.)	Not included
21211.35	3 "	$\left(\frac{6}{5}\cdot\frac{16}{5}\right)$ 21205.5
27374.48	1 "	$\left(\frac{6}{4}\cdot\frac{9}{5}\right)$ 27377.
4857.34	20 (S.s.)	$\left(\frac{10}{7}\cdot\frac{15}{4}\right)$ 4856.7
22528.65	1 "	$\left(\frac{7}{5}\cdot\frac{11}{5}\right)$ 22527.4

Many of the lines can be obtained by numbers other than those chosen by Silberstein (confined, of course, between his limits

$m \ngtr 32$ and $n \ngtr 9$), and in some cases these agree more closely with the observed values than those given by Silberstein. Thus to give a few examples:

TABLE II

Observed	Silberstein's Values		Other Values	
24830..........	$\left(\frac{13}{4}\cdot\frac{n}{n}\right)$	24834.	$\left(\frac{10}{11}\cdot\frac{11}{9}\right)$	24833.
26938..........	$\left(\frac{30}{4}\cdot\frac{n}{n}\right)$	26943.	$\left(\frac{16}{5}\cdot\frac{20}{6}\right)$	26935.4
28574..........	$\left(\frac{4}{3}\cdot\frac{16}{7}\right)$	28577.	$\left(\frac{11}{4}\cdot\frac{26}{9}\right)$	28572.8
36208..........	$\left(\frac{5}{4}\cdot\frac{20}{4}\right)$	36208.7	$\left(\frac{10}{4}\cdot\frac{10}{5}\right)$	36208.7
36592..........	$\left(\frac{5}{4}\cdot\frac{25}{4}\right)$	36603.	$\left(\frac{17}{4}\cdot\frac{17}{6}\right)$	36585.
			$\left(\frac{13}{4}\cdot\frac{32}{6}\right)$	36596.7
19824..........	$\left(\frac{5}{4}\cdot\frac{14}{6}\right)$	19827.	$\left(\frac{6}{\text{[illegible]}}\cdot\frac{23}{9}\right)$	19828.
			$\left(\frac{14}{5}\cdot\frac{22}{9}\right)$	19828.
			$\left(\frac{28}{6}\cdot\frac{24}{7}\right)$	19827.
20358..........	$\left(\frac{5}{4}\cdot\frac{16}{6}\right)$	20352.	$\left(\frac{17}{5}\cdot\frac{20}{9}\right)$	20358.3
			$\left(\frac{11}{5}\cdot\frac{32}{8}\right)$	20357.6
27508..........	$\left(\frac{9}{4}\cdot\frac{18}{8}\right)$	27516.	$\left(\frac{11}{4}\cdot\frac{16}{9}\right)$	27507.6

The average difference between the actual frequencies of the helium lines and the values nearest to them given by Silberstein's formula is exactly what we should expect from the simple theory of probability on assuming the coincidences to be fortuitous. Thus for instance, if $m \ngtr 32$ and $n \ngtr 9$, the total number of lines obtained with Silberstein's formula, lying between $\nu = 28000$ and $\nu = 29000$, is found to be 161. If these lines were evenly distributed between these limits, the interval between successive lines would be $\frac{1000}{161}=6.1$ and the maximum difference of any value of ν between 28000 and 29000, chosen at random, and the nearest number in the list would be 3.0. The minimum error being 0, the average error would be 1.5. Taking the 19 observed lines of helium between these limits and finding for each the nearest number from the list, the average actual error is found to be 2.6; that is, actually greater than the number indicated on the assumption that the coincidences are purely fortuitous. This is what we should expect; for, owing to the non-even distribution of the numbers, there are certain gaps with differences of about 20 to 25, and some 3 of the 19 lines falling in these gaps eventually increase the average error. From Silberstein's table the average error for the 15 lines which he has given between these limits is about 3.5. This is due to the fact that there are combinations other than Silberstein's that are nearer the observed values.

These facts clearly show that coincidences between the actual frequencies and those given by Silberstein's formula must all be regarded as purely fortuitous and having no physical significance whatever.

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