being: 1.324, 1.638, 1.454, 1.795, 1.732, 1.93, 1.159, 1.281, 1.255, 1.206, 1.829, 1.412, 1.006, 1.392, 1.08, 0.576, 0.867, 0.735, 0.598, 0.31, and 0.515 Mev. These energies are in million electron volts, and have not been corrected for target thickness, so do not represent actual resonance energies. The peak at 0.31 Mev is due to a resonance reported by Gentner,[2] in whose work the resonance is more sharply defined. The resonances between 0.4 and 0.9 Mev have all been reported by Curran and Strothers,[3] although their work does not appear to resolve them as clearly as does curve *B*.

The half-widths of the resonance peaks (with the exception of that at 1.638 Mev) vary from 10 to 25 kev, and are to be regarded as largely experimental, since: (1) the generator voltage fluctuated by 5 or 10 kilovolts during any single observation; (2) there was a spread of energy in the proton beam due to ionization in the probe canal of the ion source and in the accelerating tube; and (3) no corrections have been applied for target thickness. However, the 1.638-Mev resonance has an observed half-width of 70 kev, so that it must be due either to a wide level, or to an unresolved group of closely spaced levels.

Acknowledgments

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The Paschen-Back Effect

VIII. The Reality of the Distant Components

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The helium line λ7066 has been investigated in order to show that the distant components, whose predicted intensities are extremely small, really do exist. Agreement between theory and experiment, as regards both position and intensities of these components, is excellent.

In all elementary discussions of the Paschen-Back effect, we find statements to the effect that in very strong fields, the Zeeman pattern of a multiplet degenerates into a normal triplet. A more careful analysis of the problem shows, however, that the perpendicular components of this triplet should show structure, each of the lines consisting of a number of components equal to the multiplicity involved in the transition, when we are dealing with *LS* coupling. The reality of this structure has been shown in an earlier communication[1] and by Jacquinot.[2] But in addition to this so-called "normal" triplet, there should also be some components of twice the normal distance (for doublet spectra) and also at three times the normal distance (for triplet spectra). These far distant components have never been separated[3] and it is the purpose of this paper to complete the record. It may be shown quite simply that the most distant component is $\Delta\nu_{\text{norm}}\times$the multiplicity $(2S+1)$ if the full multiplicity of one of the groups of L levels has been reached. We must find the largest value of $(m_S+2m_L)-(m_S'+2m_L')$ subject to the condition that $(m_S+m_L)=(m_S'+m_L')\pm 1$ for the perpendicular components. This will obviously be

[1] J. B. Green and R. A. Loring, Phys. Rev. **49**, 630 (1936).

[2] P. Jacquinot, *Verh. Zeeman* (Amsterdam, 1935).

[3] Paschen and Back report weak components in the oxygen triplet, but this is really a quintet spectrum and should have more distant components.

$m_S - m_S' \pm 1$ and since the largest value of m_S is S and the smallest value of m_S' is $-S$, the largest value of $m_S - m_S' \pm 1$ is $2S+1$. If, however, neither of the levels has reached full multiplicity, then the values of m_S and m_S' for given $m = m_S + m_L$ and $m' = m \pm 1 = m_S' + m_L'$ may not have the full run from $+S$ to $-S$. If, for a given m' the values of m_S run from S to $S-2L$ (L being the larger L), then for the neighboring $m = m' - 1$, m_S will run from $S-2$ to $S-2L$ and the largest value of $m_S - m_S' \pm 1$ is $2L+1$. For $m = m'+1$, m_S will run from S to $S-2L+2$, and again the largest value of $m_S - m_S' \pm 1$ is $2L+1$.

In a previous communication[4] the Paschen-Back[5] effect of the triplet spectrum of Be was studied to investigate the effect of the spin-spin interaction. It was not pointed out at the time that in the case of LS coupling, the only effect of the magnetic field would be the terms due to $(SLJM|L_Z + 2S_Z|SL'J'M')$, the spin-spin terms affecting only the zero positions of the diagonal elements. This, indeed, is what was assumed in the earlier paper without any justification other than the pragmatic one that agreement existed between theory and experiment.

In our recent work on the rare gases, very intense sources have been produced and it was found possible to extend our investigations to determining whether these predicted distant components really existed. These lines should be extremely faint lines, and unless a very intense source is available, the inertia of the photographic plate would render their observation well-nigh impossible. The strong helium line at λ7066 was chosen and photographed on Eastman IN plates. Certainly, if for any spectrum, the assumption of LS coupling holds for He, since no interior combination lines between singlet and triplet levels are known to exist. Figure 1 shows the microphotogram and the calculated results for the above-mentioned line and the agreement between theory and experiment for the positions of the expected lines is excellent. The figure is the result of a 120-hour exposure, which was necessary in order to bring out the weak outside components to a sufficient density that they might be recorded against the very dense background of the stronger components. Such a great difference in intensity existed between the strong and weak components that it was thought advisable to indicate the logarithm of the intensity by the length of the line, and a difference in length of one centimeter is equivalent to a factor of 100. The polarizations were not separated, and hence the weaker parallel components (indicated by dashed lines) are lost in the background. But the weak perpendicular distant components are clearly evident and with the predicted intensity ratios. The great deal of overexposure required to make these components recordable is shown by the considerable fog density in their neighborhood. The ghosts on either side of the main line at the edges of the figure are approximately the correct density for good recording.

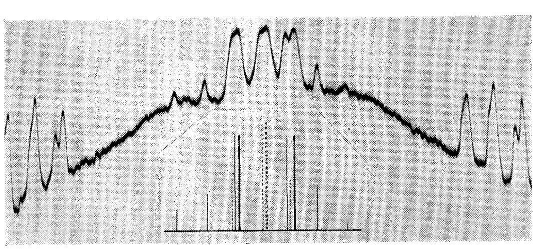

FIG. 1. The Paschen-Back effect of the helium line λ7066.

The attention of the reader is called to the fact that even at this high field strength, there is still considerable asymmetry in the spacing of the components. It is unfortunate that the low atomic number of He and the rather high temperature which probably existed in the discharge has precluded the possibility of resolving the triplet structure of the closest perpendicular components. However, the existence of the components at $3\Delta\nu_{\text{norm}}$ indicate that the levels involved have a multiplicity of at least 3, as indicated in the discussion.

[4] J. B. Green and R. A. Loring, Phys. Rev. **49**, 632 (1936).
[5] Paschen and Back, Ann. d. Physik **39**, 897 (1912).

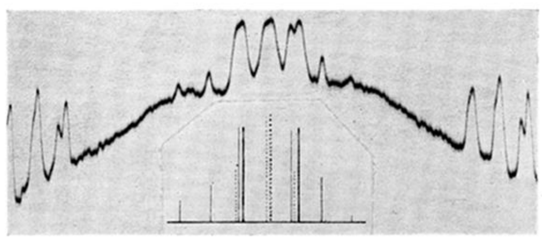

FIG. 1. The Paschen-Back effect of the helium line λ7066.