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The Zeeman Effect of N II

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The Zeeman effect of N II has been studied at field strengths of about 36,000 gauss. By using helium as residual gas with a small nitrogen impurity, the spectrum has been strongly excited, especially in the visible region. Edlén's corrections to Freeman's classification have been verified. Except in a few important cases, g values are LS within experimental error. The exceptions are considered in detail.

THE spectrum of N II was first well classified by Fowler and Freeman[1] and later extended by Freeman[2] who found quintet combinations in addition to the singlets and triplets and singlet-triplet intercombinations found by Fowler and Freeman. In the meantime, some work by Pretty[3] had disclosed some new singlet levels, but Edlén[4] has shown that Pretty's interpretation of his results is probably incorrect. Thus, the $3p\,^1P_1$ and $3p\,^1D_2$ assigned by Freeman were interchanged by Edlén.

Studies of the Zeeman effect of N II indicate that Edlén's interpretation is the correct one. The Zeeman effect of N II was first studied by Croze[5] over twenty years ago. The patterns were, in general, unresolved, and were therefore of very little use in helping to classify the spectrum or to study perturbations in the classified spectrum. The present investigation was carried out along with other work in our systematic study of the Zeeman effect.

The atomic spectra of N are not usually excited with any great intensity in the spark discharge in air or in partial vacuum. But when a discharge takes place between metal electrodes in an atmosphere of helium with a small percentage of nitrogen, the spectrum of N II is very strongly excited. This would indicate that the N_2 molecule when ionized by electron impact dissociates into two N^+ ions. In the present investigation, the discharge took place between gold or gold and copper electrodes. The upper electrode was a piece of No. 20 gold wire held in a brass rod and the lower electrode was a gold or copper wire wrapped on a brass disk which rotated about an axis so that its periphery was at the center of the magnetic field. The interaction of the current in the upper electrode and the magnetic field causes the arc to be intermittent, the greater the current the longer the period during which the arc remains lit.

The exposures varied from a few hours up to 48 hours, and the arc current averaged about 0.7 ampere. Most of the measurements were made from an exposure between gold and copper electrodes which lasted about 38 hours and was spread over a period of about four days. The temperature of the grating was carefully controlled by an ether thermostat and no effects due to changing temperature could be observed on some of the finely resolved patterns of copper and gold.

About fifty lines in the spectrum of N II were measured in a field of about 36,000 gauss and the results are tabulated in Table I. Typical Zeeman patterns are shown in Fig. 1.

The lines are arranged in multiplets and the g values have been calculated using the resolved patterns first, and then using the g values thus obtained from the same multiplet (wherever

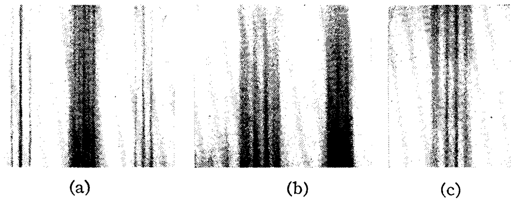
(a) (b) (c)

FIG. 1. Typical Zeeman patterns of N II. (a) λ5045, (b) λλ5010.6 and 5007.3, (c) λ4994.3.

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[1] Fowler and Freeman, Proc. Roy. Soc. **A114**, 662 (1927).

[2] Freeman, Proc. Roy. Soc. **A124**, 654 (1929).

[3] Pretty, Proc. Phys. Soc. London **41**, 442 (1929).

[4] Edlén, Nov. Acta Reg. Soc. Sci. Upsala, Sev. **IV**, 9, No. 6.

[5] Croze, Ann. de physique **1**, 35 (1914).

TABLE I. *Zeeman pattern and g values for lines in the spectrum of N II.*

λ	CLASSIFICATION[4]	ZEEMAN PATTERN	g_1	g_2
3994.995	$3s\ {}^1P_1 - 3p\ {}^1D_2$	(0) 0.980	1.052	1.004
4432.71	$3d\ {}^3P_2 - 4f\ {}^3D_3$	(0) 1.096	1.50	1.30
4447.035	$3p\ {}^1P_1 - 3d\ {}^1D_2$	(0) 0.976	1.005	0.986
4530.37	$3d\ {}^1F_3 - 4f\ {}^1G_4$?	(0) 1.017	—	—
4601.490	$3s\ {}^3P_1 - 3p\ {}^3P_2$	(0) 1.514	1.457	1.495
4607.167	${}^3P_0 - {}^3P_1$	(0) 1.530	—	1.530
4613.884	${}^3P_1 - {}^3P_1$	(0) 1.500	1.465	1.535
4621.405	${}^3P_1 - {}^3P_0$	(0) 1.457	1.457	—
4630.551	${}^3P_2 - {}^3P_2$	(0) 1.502	1.509	1.495
4643.106	${}^3P_2 - {}^3P_1$	(0) 1.475	1.493	1.530
4779.710	$3p\ {}^3D_1 - 3d\ {}^3D_1$	(0) 0.495	0.495	0.495
4778.126	${}^3D_2 - {}^3D_2$	(0) 1.140	1.167	1.113
4803.272	${}^3D_3 - {}^3D_3$	(0) 1.333	1.333	1.333
4895.20	$2p'\ {}^1D_2 - 3p\ {}^1P_1$	(0) 0.971	0.985	1.013
4987.377	$3p\ {}^3S_1 - 3d\ {}^3P_0$	(0) 2.018	2.018	—
4994.358	$- {}^3P_1$	(0.495) 1.505 2.009	2.010	1.505
5007.316	$- {}^3P_2$	(0) (0.490) 1.012 1.514 2.00	2.008	1.514
5001.469	$3p\ {}^3D_2 - 3d\ {}^3F_3$	(0) 0.976	1.166	1.071
5005.140	${}^3D_3 - {}^3F_4$	(0) 1.125	1.333	1.250
5025.665	${}^3D_3 - {}^3F_3$	(–) (0.747)—	1.333	1.086
5012.026	$3s'\ {}^5P_3 - 3p^1\ {}^5P_3$	(0) 1.664	1.664	1.664
5002.692	$3s\ {}^3P_0 - 3p\ {}^3S_1$	(0) 2.022	—	2.022
5010.620	${}^3P_1$	(–) 1.460 2.016	1.460	2.016
5045.098	${}^3P_2$	(0) (0.515) 1.000 1.495 —	1.505	2.015
5175.89	$3p'\ {}^5D_3 - 3d'\ {}^5F_4$	(0) 1.087	—	—
5179.50	${}^5D_4 - {}^5F_5$	(0) 1.073	—	—
5452.12	$3p\ {}^3P_0 - 3d\ {}^3P_1$	(0) 1.478	—	1.478
5454.26	${}^3P_1 - {}^3P_0$	(0) 1.528	1.528	—
5462.62	${}^3P_1 - {}^3P_1$	(0) 1.508	1.533	1.483
5478.13	${}^3P_1 - {}^3P_2$	(0) 1.486	1.528	1.500
5480.10	${}^3P_2 - {}^3P_1$	(0) 1.502	1.495	1.481
5495.70	${}^3P_2 - {}^3P_2$	(0) 1.496	1.492	1.500
5535.39	$3s'\ {}^5P_{3,\,1} - 3p'\ {}^5D_{4,\,1}$	(0) 1.079	—	—
5666.64	$3s\ {}^3P_1 - 3p\ {}^3D_2$	(0) (0.282) 0.888 1.167 —	1.448	1.167
5676.02	${}^3P_0 - {}^3D_1$	(0) 0.487	—	.487
5679.56	${}^3P_2 - {}^3D_3$	(0) 1.104	1.532	1.319
5686.21	${}^3P_1 - {}^3D_1$	0.501 (0.935) 1.444	1.442	.501
5747.29	$3s\ {}^1P_1 - 3p\ {}^3D_2$	(0) 1.216	1.056	1.163
5927.82	$3p\ {}^3P_0 - 3d\ {}^3D_1$	(0) 0.493	—	.493
5931.79	${}^3P_1 - {}^3D_2$	(0) 0.910	1.53	1.115
5941.67	${}^3P_2 - {}^3D_3$	(0) 1.143	1.509	1.325
6167.82	$\begin{cases} 3d\ {}^1P_1 - 4p\ {}^1S_0 \\ 3d\ {}^3F_4 - 4p\ {}^3D_3 \end{cases}$	(0) 1.146	1.250	1.319
6170.16	${}^3F_2 - {}^3D_1$	(0) 0.777	0.682	0.50
6173.40	${}^3F_3 - {}^3D_2$	(0) 0.913 ?	1.086	1.259
6284.30	$3p\ {}^1D_2 - 3d\ {}^1P_1$	(0) 0.987	1.000	1.026
6379.63	$3s\ {}^3P_1 - 3p\ {}^1P_1$	(0.450) —	1.455	1.005
6482.07	$3s\ {}^1P_1 - 3p\ {}^1P_1$	(0) 1.026	1.047	1.005

possible), the g values from the unresolved patterns were determined.[6]

The g values thus obtained are summarized in Tables II, III, IV. The results shown are weighted averages.

TABLE II. *Configurations* $1s^22s^22p3s$.

TERM	g(obs)	$g(LS)$	g (Houston)[7]	
$3s\ {}^3P_2$	1.502	1.500	1.500	
$3s\ {}^1P_1$	1.051	1.000	1.055	
${}^3P_1$	1.455	1.500	1.445	
	2.506	2.500	2.500	Σg
$3s\ {}^3P_0$	—	—	—	

TABLE III. *Configuration* $1s^22s^22p3p$.

TERM	g(obs)	$g(LS)$	
$3p\ {}^1S_0$	—	—	
${}^3P_0$	—	—	
$3p\ {}^1P_1$	1.005	1.000	
${}^3S_1$	2.015	2.000	
${}^3P_1$	1.530	1.500	
${}^3D_1$	0.494	0.500	
	5.044	5.000	Σg
$3p\ {}^1D_2$	1.002	1.000	
${}^3P_2$	1.497	1.500	
${}^3D_2$	1.166	1.167	
	3.665	3.667	Σg
$3p\ {}^3D_3$	1.330	1.333	

TABLE IV. *Configuration* $1s^22s^22p3d$.

TERM	g(obs)	$g(LS)$	
$3d\ {}^3P_0$	—	—	
$3d\ {}^1P_1$	1.026	1.000	
${}^3P_1$	1.487	1.500	
${}^3D_1$	0.494	0.500	
	3.007	3.000	Σg
$3d\ {}^1D_2$	0.986	1.000	
${}^3P_2$	1.504	1.500	
${}^3D_2$	1.114	1.167	
${}^3F_2$	—	0.667	
		4.333	Σg
$3d\ {}^1F_3$	—	1.000	
${}^3D_3$	1.329	1.333	
${}^3F_3$	1.079	1.083	
		3.417	Σg
$3d\ {}^3F_4$	1.250	1.250	

In our previous work, we have stated that the g values obtained have an accuracy of about one-half percent. In the present work, due to the lack of sharpness of the lines, we must increase the limit of error, and suggest that this accuracy is not better than one percent. An inspection of the

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[6] See e.g., Shenstone and Blair, Phil. Mag. 8, 765 (1929).

tables shows that wherever it is possible to give g sums, that they show an accuracy of considerably better than 1 percent, but we believe this result to be entirely fortuitous.

The configuration $1s^22s^22p3s$ is compared with Houston's[7] calculations for this configuration and the two levels with $j=1$ show considerable deviation from LS coupling and gratifying agreement between theory and observation.

Of particular interest in connection with the configuration $1s^22s^22p3p$, is the line λ6379, which has a pattern belonging definitely to a transition in which $\Delta j=0$, thus showing that Fowler and Freeman's and Pretty's designation of the level $3p\,{}^1P_1$ (called by them $3p\,{}^1D_2$) is incorrect, as pointed out by Edlén, on the basis of selection rules.

The configurations $1s^22s^22p3p$ and $1s^22s^22p3d$ show a large perturbation of the middle term of the middle triplet. $3p\,{}^3P_1$ has a g value of 1.530 and $3d\,{}^3D_2$ has a g value of 1.114, the LS g values being 1.500 and 1.167, respectively. Both of these results are too far different from the LS values to be accounted for on the basis of experimental error. No other levels of the configurations are close enough to produce perturbations of so large a magnitude. Nevertheless there are perturbations in both cases, as is evidenced by the fact that the $3p\,{}^3P$ separations are in the ratio 1.65 : 1 instead of 2 : 1; and the $3d\,{}^3D$ separations are in the ratio 2.52 : 2 instead of 3 : 2 for LS coupling. In addition to this, it has been pointed out by Condon and Shortley[8] that the intermultiplet separations are also considerably different from the LS values for the $2p$ and $3p$ configuration for the whole isoelectronic sequence C I, N II, O III, being in the ratio of 2.27 : 2 instead of 3 : 2 for $P-D/D-S$. They attribute this to interaction between the $2p$ and $3p$ configurations. There could also be configuration interaction between either of these configurations and the configuration $1s^22p^4$; and between the $3d$ configuration and $1s^22s2p^3$. Perturbations of this type are electrostatic, however, and their effects on g values would come as a result of their spoiling the electrostatic parameters which would in turn perturb the LS ratios and thus secondarily affect the g values.

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[7] Houston, Phys. Rev. **33**, 297 (1929).

[8] Condon and Shortley, *Theory of Atomic Spectra* (Cambridge University Press, 1935).

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The Refractive Index of Water for Electromagnetic Waves Eight to Twenty-Four Centimeters in Length

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Wave-lengths were measured in air and water for continuous waves produced by magnetron and positive grid oscillators. Although high in absolute value, the index of refraction thus determined shows a decrease with increasing frequency, indicating a start of the drop toward the infrared value.

INTRODUCTION

EARLY attempts[1, 2] with electromagnetic waves from spark sources have been made to detect experimentally the beginning of the dispersion region where the index of refraction of water drops from the long wave value of $\mu=\sqrt{\epsilon}=9$ toward the infrared value of $\mu=1.33$. This paper reports an investigation in the interval of wave-lengths from eight to twenty-four centimeters, making use of the improved stability obtainable with the magnetron and positive grid oscillators as sources of short electromagnetic waves.

Debye[3] and Bernal and Fowler[4] give some theoretical discussion indicating probable dispersion in this region.

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[1] Nichols and Tear, Nat. Acad. of Sci. Proc. **9**, 211 (1923).

[2] Glagolewa-Arkadiewa, Nature **113**, 640 (1924).

[3] Debye, *Polar Molecules* (Chemical Catalog Company, 1929), p. 85.

[4] Bernal and Fowler, J. Chem. Phys. **1**, 515 (1933).

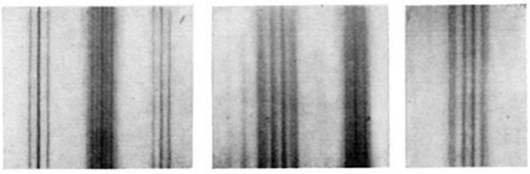
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FIG. 1. Typical Zeeman patterns of N II. (a) λ5045, (b) λλ5010.6 and 5007.3, (c) λ4994.3.