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CHANGES IN THE REFRACTIVE INDEX OF HELIUM PRODUCED BY A GLOW DISCHARGE

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Abstract

Interferometer method of measuring the concentration of ions and excited atoms in a glow discharge.—According to the Lorentz theory, the presence of atoms in a state *s* should change the index of refraction of the discharge for light of wave-length $(\lambda=\lambda_s+\delta\lambda_s)$ by an amount $\delta n=(N_s e^2/8\pi^2c^2m)(\lambda^3_s/\delta\lambda_s)$, where N_s is the concentration of excited atoms. Kramer's theory leads to a somewhat different relation. To measure δn, a Michelson interferometer was used into one arm of which was introduced a cylindrical discharge tube with a filament cathode in a side arm, and a ring anode, so that the light passed along the positive column. In the tests made with He, an iron arc was used as source, and the light from the half silvered mirror was focussed on the slit of a spectrograph. When the glow discharge was started (30 to 40 m-amp.), shifts to .2 to .5 fringe were observed for about 15 Fe lines. In each case the shift was positive or negative according as the wave-length was greater or less than that of a neighboring He line. The results are not quantitative as yet but prove the practicability of the method.

PREVIOUS methods of determining the concentration of ions in gaseous discharges[1] may introduce electrical disturbances arising from the presence of exploring electrodes which, in some cases, cause doubt about the accuracy of the results. Furthermore, these methods are powerless to detect or to measure the concentration of excited atoms or molecules, which often play an important rôle.[2] For these reasons the following optical method has been devised to measure these concentrations and the preliminary tests prove it to be capable of practical application. The method is based on measurement of the refractivity of the gas in the spectral region close to emission or absorption lines in its spectrum, and the interpretation of these measurements by current theories of optical dispersion. The possibility of making such measurements was demonstrated by Ladenburg and Loria.[3]

The apparatus (Fig. 1) consisted of a discharge tube 6 inches (15.2 cm) long, placed in one arm of a Michelson interferometer. The tube

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[1] Langmuir and Mott-Smith, Gen. Elec. Rev. **26**, p. 731 (1923); **27**, pp. 444-538 (1924).

[2] Compton, Turner and McCurdy, Phys. Rev. **24**, p. 597 (1924).

[3] Ladenburg and Loria, Verh. d. D. Phys. Ges. **10**, p. 858 (1908).

itself was made with a hot cathode *F* in a side tube and a ring anode *A* through which the light could pass, and with the two optical glass end plates cemented to the ground ends of the tube. By this arrangement the part of the discharge in the arm of the interferometer included only the positive column, which contains the highest concentration of excited atoms.

The success of the experiment depended upon the use of light of practically the same wave-length as that of a line in the spectrum of the positive column. A strong iron arc *S* was used as the source of light for the interferometer. The light, after passing through the interferometer, was bent to a convenient direction by a right angle prism *P* and focussed by a system of lenses on the slit *I* of a monochromatic illuminator of good resolving power. The fringes were then observed by means of a telescope after the light had been resolved by the illuminator. In order to measure the amount of shifting of the fringe system on starting or stoping the discharge, the telescope was replaced by a camera with an equivalent lens system. The displacement of the fringe system due to the change in refractive index on starting the discharge, was recorded with the camera by taking three adjacent exposures, the two outside being with no discharge while the center one was taken with the discharge running. This gave a convenient method of determining the fraction part of a fringe separation by which the system had been moved by the action of the discharge.

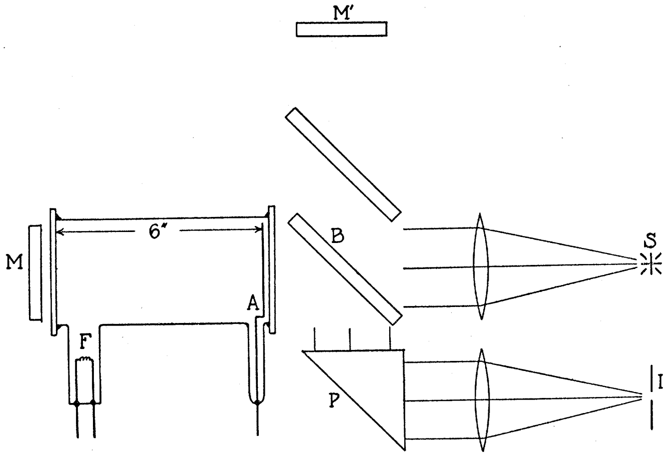

Fig. 1. Diagram of apparatus.

As this method depends on measuring the change in the refractive index of the gas with regard to a certain line when the discharge is started, we will next consider the various formulas which connect the index of refraction with the concentration of atoms in the various states. According to Lorentz's formula, the index of refraction n is connected with the wave-length λ of the light used and concentration N and natural wave-length λ_s of the atoms in the s state by the relation

$$n^2-1=\frac{e^2}{4\pi^2c^2m}\ \frac{N_s\lambda_s^4}{(\lambda^2-\lambda_s^2)}+\text{const.},\tag{1}$$

if λ_s differs from λ by a small quantity. Taking the case of normal incidence of light on the mirrors, the condition for a fringe (darkness) at a given position is

$$2dn=p\lambda$$

where p is an integer and d is the difference of the distances of the two mirrors M and M' from the half-silvered mirror B. Thus the change in n corresponding to a fractional shift f is

$$\delta n=(\lambda/2l)f\tag{2}$$

where l is the length of the tube. Letting $\lambda=\lambda_s+\delta\lambda_s$ we find for N_s in terms of f, λ_s and $\delta\lambda_s$ the expression

$$\mathrm{N}_s=\frac{4\pi^2c^2m}{e^2l}\ \frac{\delta\lambda_s}{\lambda_s}\qquad=10\frac{\delta\lambda_s}{\lambda_s^2}f\tag{3}$$

where $\delta\lambda_s$ is measured in angstroms and λ_s in microns.

According to Kramers,[4] if the atom is in a state s which absorbs energy of frequency $\overset{a}{\nu}_{s_1}\cdots\overset{a}{\nu}_{s_n}$ and emits energy of frequency $\overset{e}{\nu}_{s_1}\cdots\overset{e}{\nu}_{s_n}$ under the influence of external radiation, while $\overset{a}{A}_{s_1}\cdots\overset{a}{A}_{s_n}$ and $\overset{e}{A}_{s_1}\cdots\overset{e}{A}_{s_n}$ represent the probabilities of a transition from the state s to a lower or higher energy level with the emission or absorption of energy respectively, and if N is the total number of atoms and $\overset{a}{\tau}_{s_i}$ and $\overset{e}{\tau}_{s_i}$ represent the life of the excited state s_i for the frequency $\overset{a}{\nu}_{s_i}$ and $\overset{e}{\nu}_{s_i}$, then

$$n^2-1=N\left[A_s^a\tau_s^a\frac{e^2}{4\pi^2c^2m}\ \frac{(\lambda_s^a)^4}{(\lambda^2-(\lambda_s^a)^2)}-A_s^e\tau_s^e\frac{e^2}{4\pi^2c^2m}\ \frac{(\lambda_s^e)^4}{(\lambda^2-(\lambda_s^e)^2)}\right]+\text{const.},$$

where λ_s^a and λ_s^e lie near λ. Since the above type of apparatus measures only the change in refractive index in the neighborhood of a particular line, the frequency λ_s^a must equal λ_s^e and Kramer's equation becomes

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[4] Kramers, Nature, May 10, 1924, p. 273 and Aug. 30, 1924, p. 310.

$$n^2-1=\frac{e^2N}{4\pi^2c^2m}\left[A_s^a\tau_s^a-A_s^e\tau_s^e\right]\frac{\lambda_s^4}{(\lambda^2-\lambda_s^2)}+\text{const.}$$

The quantity $N[A_s^a\tau_s^a-A_s^e\tau_s^e]$ which replaces the concentration N_s of Lorentz's classical formula, represents the average increase per unit time in the number of atoms in the state s due to the absorption and emission of light of frequency ν_s.

In the following table are given the observed fringe shifts for the various excited states of He, investigated in the visible and violet region of the spectrum by this method. The intensity of the lines are given in the bracket, while the shifts are given as fractions of one fringe spacing. In addition to these, shifts with about eight other lines were observed visually, but not measured. In all cases the shift was positive or negative, according as the light was of wave-length greater or less than that of the neighboring helium line. As no shift could be observed for the lines which were 30 or 40 Angstroms from the nearest line of the helium spectrum, the temperature change on starting the discharge must have been negligible.

TABLE 1

Current in tube	State	He line	Fe line	Shift
30 m-amp	1P − 3D	4921.929 (4)	4920.52 (6)	−.4 fringe
30	1P − 4D	4387.928 (3)	4383.55 (10)	−.3
40	1P − 4D	4387.928 (3)	4404.	.18*
40	1P − 5D	4143.77 (2)	4143.88 (6) 4143.43 (6)	−.5†
35	1P − 2S	5047.736 (2)	5049.8 (5)	−.12

These results prove the practicability of the method and the possibility, with refinements and added data, of testing the existence of negative terms postulated in Kramer's dispersion formula and of using refractivity to measure the distribution of atoms in excited states in a discharge. This further work is now being carried on by one of us (W. H. Mc.).

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* This shift appears to be too large. The observed effect is probably in error.

† This shift might have been either + or − in sign as it was impossible to tell from the photographs in which direction the shift had occurred without taking visual observations.