J. Sci. I. R. Iran

Vol. 6 No. 4
Autumn 1995

EXPERIMENTAL INVESTIGATION OF THE POPULATION DENSITIES OF LOWER EXCITED STATES OF NEON*

A. Zendehnam

Department of Physics, Teacher's Training University of Arak,
Arak, Islamic Republic of Iran

Abstract

Many studies employing various methods have been carried out into the number densities of excited atoms in electrical discharges with inert gases [1,2,3], but the ranges of the discharge current and gas pressure is very limited in them all. In this work, the population densities of 3S, 3S' of neon have been investigated using the atomic absorption method. Since the discharge current and gas pressure have marked effects on the variation of these densities, the pressure range of 0.1-15 m. bar and currents up to 30 mA have been used.

Introduction

To investigate the relationship between the intensity of a given spectral line emitted from a d.c. glow discharge and the discharge current for various gas pressures, a study of the population densities at a level lower than that line and their variations is required to give some information, since step-wise excitation in glow discharges play important roles [4].

Scans of emission profiles of NeI spectral lines with lower level $3S(3/2)^{\circ}_{2}$, which is a metastable state, showed a self-reversal effect (Fig. 1), so the population densities of 3S, 3S' levels of neon were investigated, and the results obtained are in good agreement with the results of other works [6-9].

Experimental Section

Demountable glass or silica discharge tubes were connected to a high vacuum system capable of achieving pressures of order of 10^{-8} m.bar to give high purity conditions.

Light from a microwave electrodeless discharge lamp (E.D.L.) was sent through the positive column of neon glow discharge, and then by use of a scanning Fabry-Perot interferometer (F.P.I.), in the optical set-up (see Fig. 2), emission (i=0 discharge off) and absorption (i= 1,5,... mA discharge current) profiles were recorded (Fig. 3).

Discharge tubes were filled with research grade neon and also a getter was used to maintain purity, otherwise the

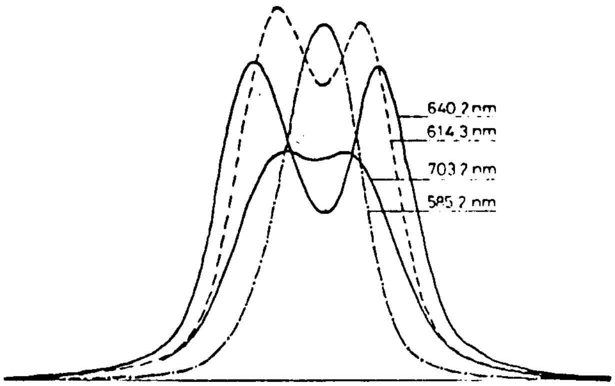

Figure 1. F.P.I. scans of some of NeI lines at P=2 mbar

Keywords: Glow discharge; Inert gases; Population of metastable atoms

---

*Part of this paper was presented at the annual Iranian physics conference (1369, Boo-Ali University, Hamadan).

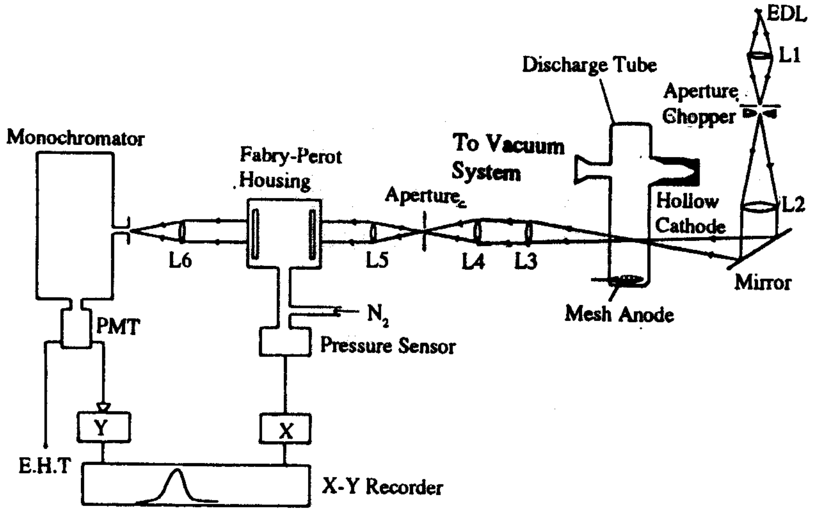

Figure 2. Optical arrangements for absorption measurements

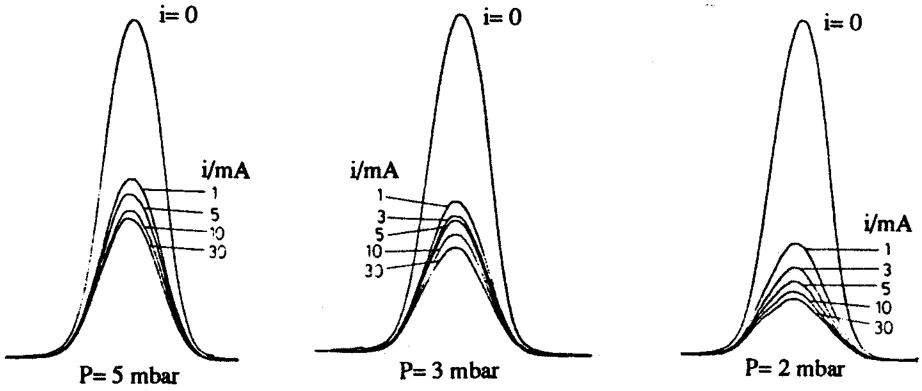

Figure 3. Transmitted profiles of 630.5 nm for various pressures

presence of impurities could cause variation on spectral and electrical characteristics of discharge. To check the reproducibility of the obtained results, each time the voltage-current (V-i) relationships and the electrical field strength (X) were measured [7, 10].

The instrument function of interferometer was determined by recording the profile of neon line 632.8 nm emitted by a mode-stabilizer laser [11]. Because the instrument function was very narrow compared with line profile, correction was not required, since it could cause 2-4% errors.

Theory

Several methods for calculation of the number densities of the excited atoms are described by Mitchell and Zemansky [12]. The method used in this work is similar to that employed by Jarrett and Franken [13]. The absorption coefficient can be calculated by measuring the intensity of primary source and transmitted light. Then by use of equation (1) K(ν) is determined.

$$K(\nu)= L^{-1} \ln[I_0(\nu)/I(\nu)] \qquad (1)$$

Where

K(ν)= The absorption coefficient
L = The absorption path length
$I_0(\nu)$ = The intensity of primary source

I (ν) = The intensity of transmitted light

When a continuous spectrum is passed through a gas and transmitted light is measured as a function of frequency (or wavenumber) the following equation is valid [12].

$$\int K(\nu)\,d\nu = \frac{\lambda_0^2 \cdot g_2}{8\pi \cdot g_1} \cdot \frac{N}{\tau} \qquad (2)$$

Where

λ_0= The central wavelength of spectral line
g_1, g_2= The statistical weight of lower and upper levels
τ= The life time
N= The population density of lower level

To calculate N it is enough to determine the integral of absorption coefficient and by having knowledge about τ, g_1, g_2 of the levels involved, the number density of a given state can be obtained for a given spectral line.

Results and Discussion

The population densities of four levels 3S$(3/2)_2^0$, 3S$(3/2)_1^0$, 3S'$(1/2)_0^0$ and 3S'$(1/2)_1^0$ (Fig. 4) were calculated by graphical integration. The curves of the variations of these densities (N) against the discharge current were plotted (Fig. 5). The graphs for 3S'$(3/2)_2^0$ and 3S'$(1/2)_0^0$, which are the metastable levels, showed a saturation behaviour when the discharge current passed a certain value, which could be due to the increase in loss rate of the metastable atoms at higher currents. In Figure 6, variation of the number density of 3S $(3/2)_2^0$ with respect to gas pressure for various currents is shown. As is illustrated, around a pressure of 2 m.bar the population density reaches a maximum value and then diminishes as pressure increases. This is due to the fact that at low pressures (less than 2m.bar in this work) the metastable atoms are lost in collisions with the walls of the discharge, and at higher pressures (above 2 m.bar in this condition) the metastable atoms population decreases due to interaction with each other and other atoms.

As can be seen in Figure 4, the population of 3S' $(1/2)_0^0$ level, which is a metastable state, is less than the number density of 3S $(3/2)_1^0$ which is a radiative level, this is because of excitation from 3S $(3/2)_2^0$ and also de-excitation from 3S' $(1/2)_0^0$ to that level. Since there is a very small energy gap between these four excited levels,

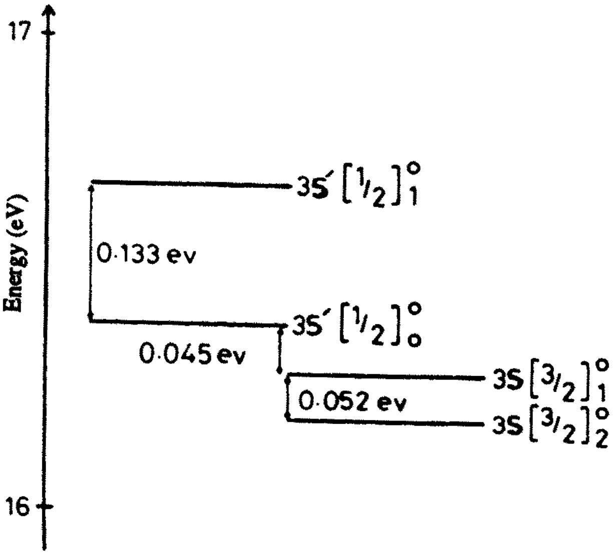

Figure 4. Simple diagram of first excited states of neon

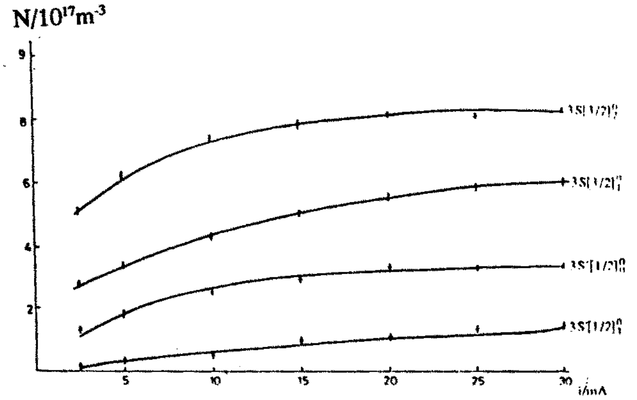

Figure 5. Variation of population densities of the lower excited states of neon at P= 2 mbar

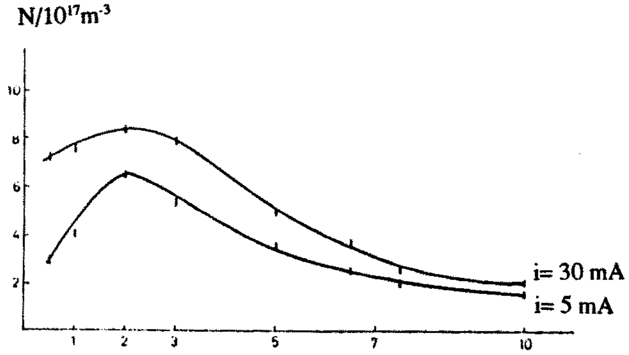

Figure 6. Variation of population density of the 3S$(3/2)_2^0$ level with pressure for various currents

the probability of excitation and de-excitation between them is very high.

Adding a small amount of argon to neon discharge caused a marked reduction in the population density of the neon metastable atoms, which is due to Penning effects that can take place following mechanisms.

$$Ne_m + Ar \text{ --------- } Ar^+ + Ne + e + E \qquad (4)$$

$$Ne_m + Ar \text{ --------- } Ar^* + Ne + E \qquad (5)$$

Where

Ne_m = The neon metastable atom
Ar = The argon atom
Ar^+ = The argon ion
Ne = The neon atom
Ar^* = The excited argon atom
e = Secondary electron
E = Energy

Therefore, by having a good knowledge about the population of these levels and how they vary with discharge current and gas pressure, the importance of probability of two-step excitations to 3P levels of neon spectral lines via these intermediate states can be considered for investigation of the intensity relationships with the discharge current under various conditions.

Summary

By observing the self-reversal effect in scanning emission profiles of neon spectral line, which is good evidence of high population in the metastable states, the following points can be made:

(a) Plots of the number densities of the metastable levels show a saturation trend after a certain amount of discharge current.

(b) Around neon pressure of 2 m.bar the highest population was obtained which is due to variation of collisional mechanisms.

(c) Because these four states 3S, 3S' are very close to each other, the probability of excitation and de-excitation between them is very high, so their population is changing all the time.

(d) These four levels 3S, 3S', together can be taken as a thick state for step-wise excitation to upper levels.

(e) Adding a small amount of argon or some impurities to neon discharge has a marked effect on the number densities of the metastable states, thus affecting the intensity-current (I-i) relationships and in general it could vary the optical, spectral and electrical characteristics of the discharge.

References

1. Soldatov, A.N, Evtushko, G.S. and Muraveu, I.I. *Opt. Spect.*, **34**, (2), 6-8, (1973).
2. Smits, R.M.M. and Prins, M. *Physica*, **80C**, 571-584, (1975).
3. Howard, C., Pillow, M.E., Steers, E.B.M. and Ward, D.W. *Analyst*, **108**, 145-152, (1983).
4. Light, C.E., Steers, E.B.M. and Zendehnam, A. 21st, C.S.I. Garmisch, West Germany, (1985).
5. Mityureva, A.A. and Penkin, N.P. *Opt. Spect.*, **38**, (2), 229-230, (1975).
6. Van Veldhuizen, E.M. Ph. D thesis, University of Technology of Eindhoven, (1983).
7. Howard, C. and Steers, E.B.M. *Analyst*, **108**, (1983).
8. Van Veldhuizen, E.M., Ph. D. thesis. University of Technology of Eindhoven, (1983).
9. Light, C.E., Ph. D. thesis. University of North London, (1987).
10. Steers, E.B.M. and Zendehnam, A. XVIII Int. Conf. on Phenomena in Ionised cases, Swansea, England, (1987).
11. Zendehnam, A. Ph. D thesis. Polytechnic of North London, (1987).
12. Mitchell and Zemansky. Resonance radiation and excited atoms. Cambridge Univ. Press, (1971).
13. Jarrett, S.M. and Franken, P.A. *J. Opt. Soc. Amer.*, **35**, 1603, (1965).