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Absolute Cross Sections for Simultaneous Ionization and Excitation of N_2 by Electron Impact*

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Cross sections for the excitation of the (0,0) band of the N_2^+ first negative and the (4,1) band of the N_2^+ Meinel system by electron impact on nitrogen have been measured. The maximum effective cross sections for the (0,0) first negative and for the (4,1) Meinel band are 1.68×10^{-17} and 6.76×10^{-19} cm^2, respectively. The maximum cross section for both systems occurs in the energy range 90–110 eV.

INTRODUCTION

A KNOWLEDGE of the electron-impact excitation functions of nitrogen band spectra, besides being of interest in itself, is of importance in auroral and gas-discharge phenomena. Experiments are in progress in several laboratories[1–3] to determine these excitation functions; in our laboratory we are studying the absolute excitation cross sections of importance in the visible and near-infrared region band systems. We present here some results of absolute excitation cross sections obtained for the N_2^+ first negative and Meinel-band systems.

EXPERIMENTAL ARRANGEMENTS

The radiation studied was produced by a well-defined electron beam. Our experimental arrangement of the electron gun and collision chamber is shown in Fig. 1(a), where C is a directly heated cathode and G, A_1, and A_2 are three cylindrical electrodes for acceleration and focusing. The electron gun chamber was mounted directly over the mouth of a high-speed diffusion pump and was operated at a background pressure of about 10^{-6} Torr so that the gun should be free from contamination. A refrigerated baffle was used to avoid backstreaming of pump oil into the system. The electrons were injected into the collision chamber C_1 through an orifice of 3.2-mm diam. The collision chamber C_1 was a 12.7-cm-long aluminum cylinder of 4.7-cm diam, the inside of which was coated with acquadag to prevent the reflection of light from its wall. A small magnetic field (up to 50 G) in the beam direction was used for additional collimation. The injected beam was collected in a Faraday cup placed at the other end of the chamber and shielded by shields S_1 and S_2. The apertures of these two shields were 4.8 mm. The collision chamber, and shields S_1 and S_2 were kept at ground potential. The Faraday cage was biased 100 to 200 eV positive with respect to the collision chamber. Shields S_1 and S_2 avoid the penetration of fields into the collision chamber. Electron currents were monitored at the collision chamber C_1 and at both shields, S_1 and S_2. The current at collision chamber C_1 was two orders of magnitude less than the actual beam current during the observation, while the currents measured at S_1 and S_2 were less than 0.2% of the beam current. The experiment was carried out at pressure near 2×10^{-4} Torr and the energy of the electrons was varied from 70 eV to 2.5 keV. In this energy range the total sum of the

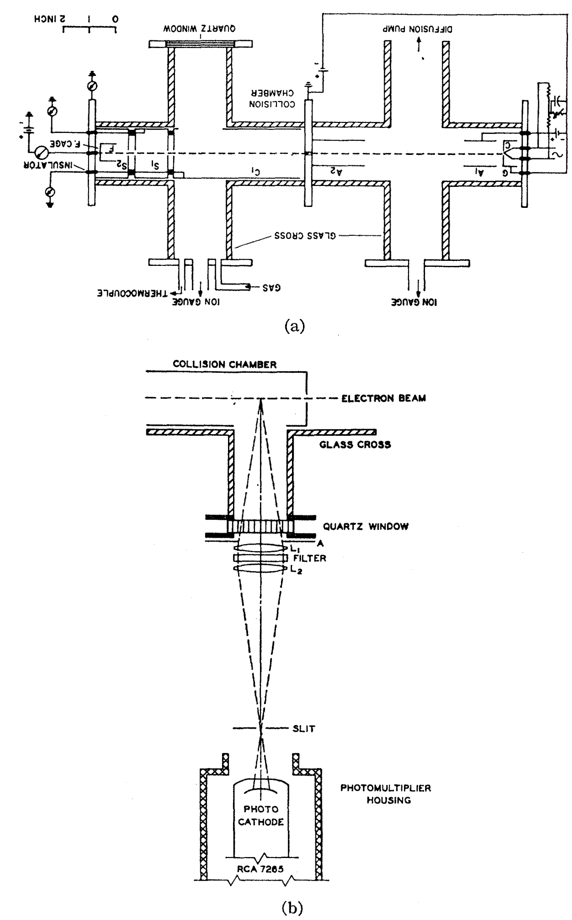

FIG. 1. (a) Schematic view of the apparatus used for measuring excitation cross section. (b) Collimator system.

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[2] S. Hayakawa, T. Kumazaki, H. Nishimura, and M. Otsuka, Rept. Ionosphere Space Res. (Japan) **19**, 311 (1965).

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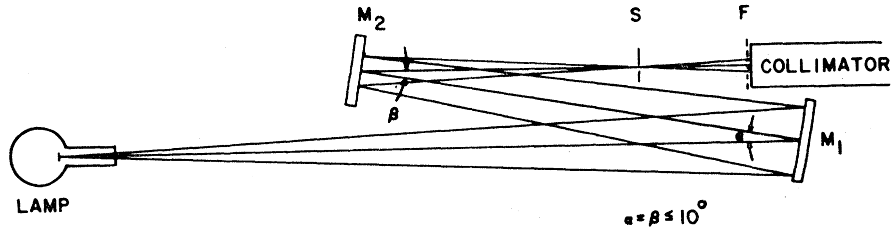
FIG. 2. Calibration system of the photomultiplier tube.



current at C_1, S_1, and S_2 was always less than 1.5% of the actual beam current.

The radiation was viewed at right angles to the beam direction through a quartz window and an interference filter. The light was monitored with an RCA 7265 photomultiplier tube. The details of the collimator system are shown in Fig. 1(b). Beam current and output of the photomultiplier were measured by 600-A Keithley electrometers (electrometer tube grid current less than 5×10^{-14} A).

CALIBRATION OF THE PHOTOMULTIPLIER TUBE

The photomultiplier-tube output was calibrated against a standard tungsten lamp. The calibration was performed as described by the instructions for using NBS standards of spectral radiance.[4] A diagram of the calibration system is given in Fig. 2. The spherical mirror M_1 was placed at a distance of 1 m (equal to its radius of curvature) from the lamp filament. The plane mirror M_2 was set approximately 60 cm from the spherical mirror facing it at an angle of less than 10°. The light from the standard lamp on the spherical mirror (fully illuminated) was within a cone of 5° and all angles of reflection were kept within 10°. The image (unit magnification) of the standard lamp filament was focused at slit S having an area of 1.58 mm². The central part of the filament was observed through the slit. The collimator assembly, including the quartz window, was placed at a distance from the slit S equal to the distance between the electron beam and the quartz window. The distance from the slit to the collimator aperture was 14.6 cm (equal to the focal length of the lens L_1 of the collimator). An extra Kodak filter whose transmission factor was determined in the laboratory was placed before the quartz window to avoid excessive current in the photomultiplier output. The light from the slit S passed unobstructed through the aperture and slit of the collimator assembly. The solid angle of the radiation recorded by the photomultiplier was determined by the diameter of the spherical mirror which was fully illuminated by the light from the standard lamp, and its distance from the filament. The possibility of polarization in the standard-lamp radiation due to reflection at two mirrors was checked, revealing no polarization. The same area of the photocathode was illuminated during calibration and in measurements. The spectral response of the standard lamp and reflectivity of the aluminized mirrors were supplied by the National Bureau of Standards.

RESULTS

All measurements were made in the region where light intensity was proportional to both electron current and gas pressure. Absolute pressure calibration was effected using a high-vacuum McLeod gauge Model GM 110 manufactured by Consolidated Vacuum Corporation.

Cross sections obtained for the (0,0) band (λ3914 Å) of the N_2^+ first negative and the (4,1) band (λ7081 Å) of the Meinel-band system are shown in Fig. 3. Each of our points represents an average of approximately 10 data points. The relative scatter in our cross section was within ±5% under a wide range of conditions. Cross sections were measured with and without magnetic fields. No variation in the cross section with the magnetic field was observed, indicating that magnetic field had no undesirable effects on the excitation. For the λ3914 Å (0,0) first negative band, the maximum cross section is 1.68×10^{-17} cm² at 100-eV electron energy. For the (4,1) Meinel band, it is 6.76×10^{-19} cm² at 90–100-eV electron energy. These absolute values are believed to be accurate to better than ±20%. Correc-

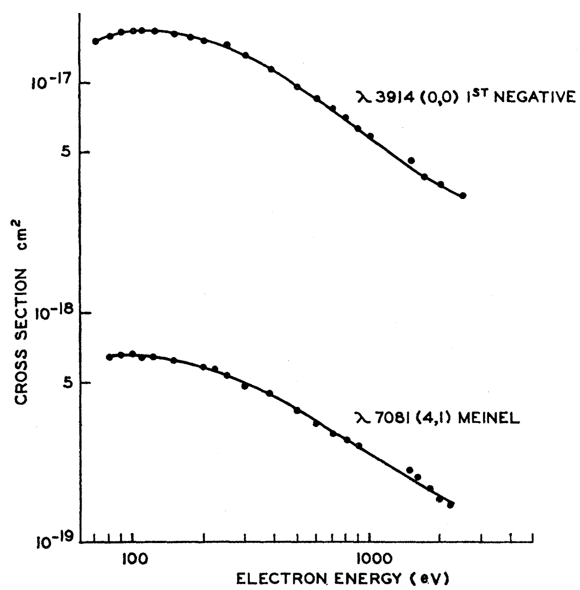


FIG. 3. Excitation cross section of λ3914 Å (0,0) band of the first negative and the λ7081 Å (4,1) band of the Meinel system of N_2^+ by electron impact.

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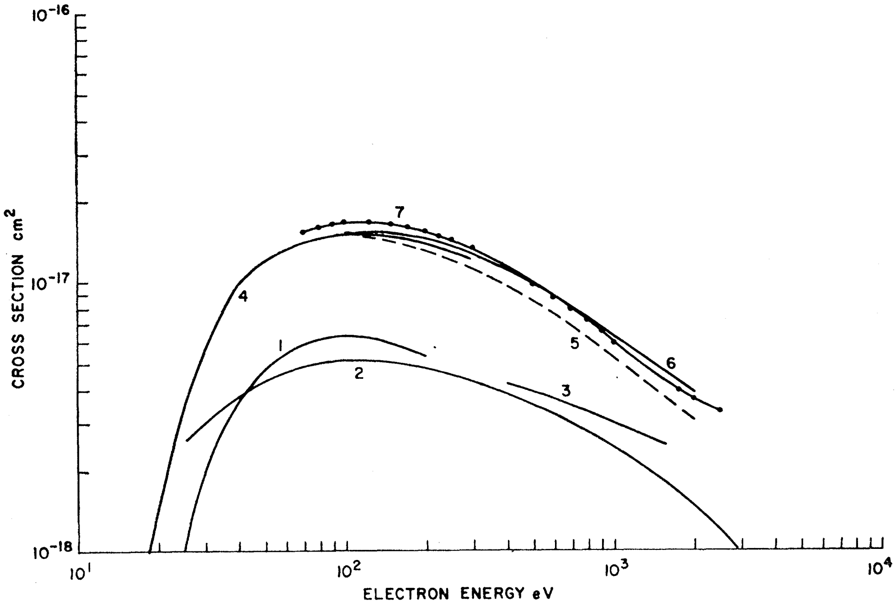

FIG. 4. Electron excitation of the λ3914 Å (0,0) N_2^+ band: (1) Stewart (Ref. 7); (2) Sheridan *et al.* (Ref. 9); (3) Hayakawa and Nishimura (Ref. 8); (4) McConkey and Latimer (Ref. 1); (5) Holland (Ref. 11); (6) McConkey *et al.* (Ref. 10); (7) present results.

tion is made for the contamination of the (0,0) band due to the (1,1) band of the N_2^+ first negative system. From the synthetic spectra of these bands and the transmission curve of the filter, the effective transmission (filter factor) of both bands through the filter was determined with a computer. Using these filter factors, Einstein A coefficients given by Nicholls,[5] and relative population of V_0 to V_1 levels as 9:1 measured by Sheridan and Clark[6] for proton and electron impact and calculated by Franck-Condon factors, the ratio between intensities of the (1,1) and (0,0) band observed through the filter was obtained. The contribution due to the (1,1) band was about 2% in the measurement of the (0,0) band cross section. The same correction factor was made over the whole energy range assuming that the relative band profile and intensity do not change with the energy (both bands are directly excited by the primary electrons, neglecting secondary effects at low pressure of 10^{-4} mm of Hg in the collision chamber). However, even if there is a change in the relative band intensity with the electron energy, the error will be negligible, since the total intensity of the (1,1) band is only a few percent of that of the (0,0) band [recent measurements of Hayakawa *et al.*[2] indicate that the absolute intensity of the (1,1) band is only 1% of the (0,0) band]. The (4,1) Meinel-band interference filter was transmitting in the region about 7065 Å and its measurement may be blended by the weak (8,6) first positive band.

In our setup the polarization was about 1.5% for the (0,0) N_2^+ first negative band and 2% for the (4,1) Meinel band at 100-eV electron energy. Cross sections quoted are uncorrected for the polarization, since it produces a negligible effect on the angular distribution of the radiation.

Figure 4 compares our results with those of earlier workers[1,7–9] for λ3914 Å excitation by electron impact. It also shows recent measurements by McConkey *et al.*[10] and Holland.[11] Our maximum cross section is slightly higher than those obtained by McConkey *et al.*[10] and Holland.[11] However, at higher energy, the results of McConkey *et al.* are in excellent agreement with our own.

ACKNOWLEDGMENTS

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