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Absorption Coefficients of Air and Nitrogen for the Extreme Ultraviolet*

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A method involving the use of two photomultiplier tubes as detectors has been developed for absorption studies in the extreme ultraviolet. The monochromator was a modified grazing-incidence spectrograph. A capillary discharge tube was employed as a source. Absorption coefficients for dry air and nitrogen were measured in the range 150A–1000A. The total oscillator strength of nitrogen for the transitions appropriate for this range was computed to be 3.2.

INTRODUCTION

DURING an investigation of photometric methods for gas absorption measurements in the spectral region below 1000A some absolute absorption coefficients of air and nitrogen were determined. These gases were studied because of the importance of knowledge of absorption coefficients for the interpretation of solar ultraviolet spectra obtained in rocket instruments. Only one paper[1] presenting air absorption data and two[2,3] concerned with nitrogen absorption were found after a careful survey of the literature. These did not cover the whole of the range included here.

DESCRIPTION OF TECHNIQUE AND APPARATUS

An attempt was made to overcome some of the difficulties common to the kind of photometry used in the vacuum ultraviolet. In order to eliminate the uncertainties of film calibration, photomultiplier tubes (1P28) coated with sodium salycilate were used as detectors.

TABLE I. Measured absolute absorption coefficients (in cm^{-1}) for dry air and for dry nitrogen at various wavelengths in the extreme ultraviolet. K_f and K_n refer to the coefficients determined by using as the path lengths the distances from the slit to the far cell and to the near cell, respectively. K_r is a coefficient computed on the basis of absorption of the gas between the two cells.

λ	K_f		K_n		K_r		K_{Av}	
(angstroms)	N_2	Air	N_2	Air	N_2	Air	N_2	Air
150	81	159					81±40	159±60
202	70	155					70±30	155±50
279	112	162					112±20	162±30
303	125	143					125±30	143±30
374	147	208					147±50	208±50
434	195	225					195±20	225±25
507	268	368	273	402	277	418	273±15	396±30
525		407		390	460	510	460±100	460±100
552	296		298		308		301±15	
554	471	405	254	235	640	585		
580	357	354	346	342	349	339	351±20	345±30
598	313	368					323±40	368±40
608	310	323	341	349	340	340	330±20	335±20
625	416	413	415	387	417	463	413±20	416±20
685	342	359					342±50	359±50
702	353	359					353±40	350±40
760	367	350					367±30	350±30
790	278	298	283	310	382	343	281±15	317±30
835	54	86					54±10	86±10
990	126	142					162±35	142±30

An effort was also made to eliminate the effect of intensity fluctuations found in ultraviolet light sources commonly used. A Lyman-type source was finally employed. This source consisted of a capillary tube through which a 0.5-mf condenser charged to approximately 10 kv was discharged at one-second intervals. A mixture of hydrogen and a small amount of air at a pressure of about 200 microns was allowed to flow through the tube. Many spectral lines of ionized oxygen, nitrogen, and silicon as well as continuous radiation, were obtained from below 150A to the visible. A special mounting for a grazing incidence spectrograph was constructed. The setup is shown in Fig. 1. The arrangement has the advantage of utilizing two detectors simultaneously (which are pointed toward the grating for all positions) and of providing a linear wavelength scale. The source slit was 25 microns wide and the monochromating slit was chosen to include about a two-angstrom band width. The grating used was a one-meter concave replica with 15 000 rulings per inch set at a grazing angle of 10°.

Two detectors were used for the following reasons. First, it was possible to check the linearity of the detectors. This was accomplished by varying the light intensity of the source and observing the constancy of the ratio of the outputs of the detectors. It was found that the detectors were linear for the intensity range used. The second objective of this arrangement was to provide a method of absorption measurement that was independent of fluctuation in the source intensity. The absorption coefficient calculated from the ratio of outputs of the detectors was not a function of the source intensity as long as noise and scattered light were not appreciable.

Absorption coefficients were determined by measuring the outputs of the two detectors as a function of the chamber pressure. The detector outputs were first read after a high vacuum was attained in the chamber. Gas was admitted into the chamber until some absorption could be detected. The detector outputs were recorded after the pressure became constant. This process was repeated with increasing steps in pressure until nearly complete absorption was obtained. The

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[2] Weissler, Lee, and Mohn, J. Opt. Soc. Am. **42**, 84–90 (1952).

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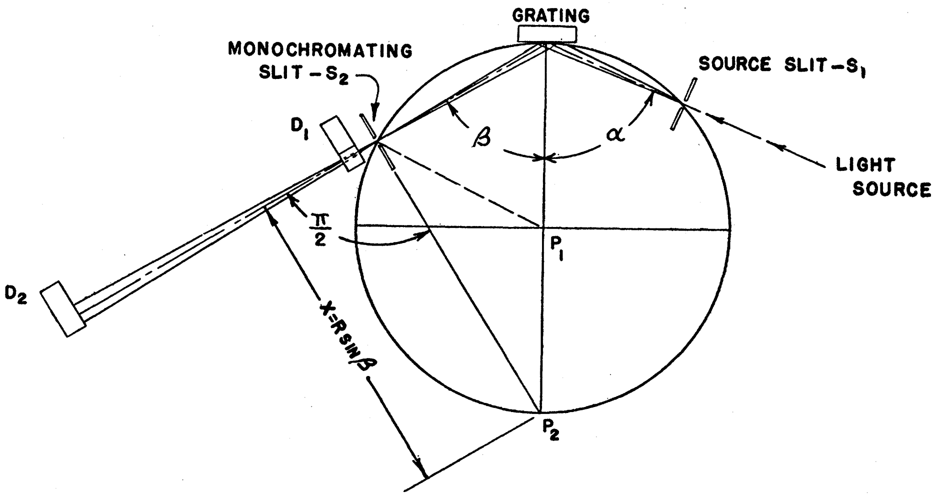

Fig. 1. The monochromator used for measuring the absorption coefficients. The light from a capillary discharge strikes the grating at grazing incidence and is focused along the Rowland circle. The monochromating slit directs the light in a narrow wave band to two coated photomultiplier tubes, D_1 and D_2. (D_1 is above D_2). The two-tube method enables one to eliminate errors arising because of source intensity fluctuations.

chamber was then pumped to high vacuum and the zero reading obtained again. Five readings were taken for each point.

The following method was used to record the light intensity data. The output pulses from the two detectors were individually integrated and used to deflect an oscilloscope. The detector nearest the grating deflected the beam horizontally while the one farthest away deflected the beam vertically. The screen was photographed and the film read later with a measuring eyepiece. All the equipment was operated from a regulated ac supply.

A calibrated Pirani gauge was used for pressure measurements and a liquid nitrogen trap on the gas inlet supply line was used to dry the gases.

Both the output of the two detectors individually and the ratio of the outputs were plotted on semi-logarithmic paper for each spectral region used. In all cases a straight line could be fitted to these points in accordance with Beer's Law. This law, in the form

$$I = I_0 \exp\left(-\frac{PT_0Kx}{P_0T}\right),$$

was used to calculate the usual linear absorption coefficient K in cm^{-1}. Here K is the reciprocal of the path length (referred to conditions of normal temperature and pressure) required to reduce the intensity to $1/e$ of the original intensity; x is the path length for the detector in question (or the path difference when the ratio of the two detectors is used). Three absorption coefficients were obtained. These were the two values determined from the detectors taken individually and the one value determined from the ratio of the detector outputs.

RESULTS AND DISCUSSION

Table I lists the results of these measurements. In some cases the far detector alone was used. As this detector could "see" only the illuminated part of the grating it had a better signal to scattered light ratio. There was too much scattered light recorded by the near detector in the region below 500A to make the benefits of the two detector method worth while. In only one case did the indicated coefficient from the two detectors fall outside the estimated accuracy. This is in the vicinity of 554A. This was found to be due to a rapid variation in the absorption with wavelength and a slight misalignment of the far detector.

Figure 2 shows the measured points for nitrogen plotted on a frequency scale. The limits of the Hopfield-Rydberg series and the Worley-Jenkins-Rydberg series are indicated. As one expects continuous absorption at the frequencies above these limits, the total oscillator strength f for these transitions was computed from the formula

$$\int K d\bar{\nu} = \frac{\pi N e^2}{mc^2} f.$$

Here $\bar{\nu}$ is the wave number. Since the measurements represent the average K over a short wavelength band (several lines were usually included together with

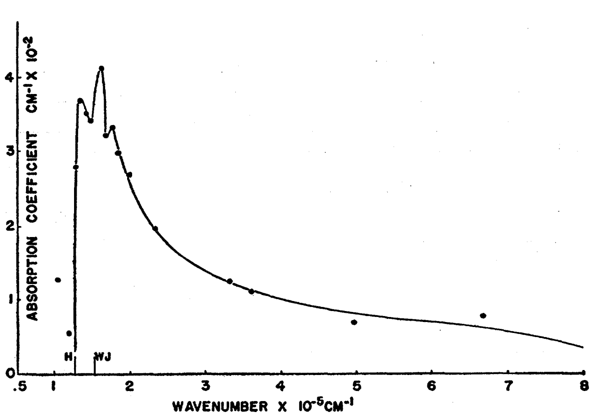

Fig. 2. Absorption ceofficient of dry N_2 as a function of wave number. The observed points are connected by a smooth curve for the purpose of estimating the oscillator strength f.

continuous radiation in each setting), the integral was evaluated by measuring the area under the line connecting the points. In this way the value of f was found to be 3.2. Wulf and Deming[4] predicted a total oscillator strength of 3.27 for these two transitions. They do not consider their value to be accurate because the calculations were made on the basis of dispersion measurements down to only 1900A.

ACKNOWLEDGMENTS

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Mobilities of Atomic and Molecular Ions in the Noble Gases*

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A method is described for measuring the mobilities of ions of near-thermal energy. A pulse of ions is generated in a discharge region and passes through a grid into a drift region where a uniform electric field causes the ions to move to a collector electrode. The mobilities are determined from measurements of the transit time of the ions in crossing the drift space. The experimental mobility values for thermal energy ions moving in their parent gases at 300°K and a gas density of 2.69×10^{19} atoms/cc are $\mu_0=10.5$ cm^2/volt-sec (He$^+$), 20.3 (He$_2^+$), 4.0 (Ne$^+$), 6.5 (Ne$_2^+$), 1.60 (A$^+$), 2.65 (A$_2^+$), 0.90 (Kr$^+$), 1.21 (Kr$_2^+$), 0.58 (Xe$^+$), and 0.79 (Xe$_2^+$). These values are in good agreement with available theoretical results. Our measurements join smoothly at higher ion energies with the measurements made by Hornbeck and by Varney except in the case of A$_2^+$. In addition, our results indicate that earlier measurements at near-thermal energy by Tyndall and collaborators refer to the molecular ions in helium and neon, and to the atomic ions in krypton and xenon.

I. INTRODUCTION

THE mobilities of ions in gases have been the subject of numerous investigations during the last fifty years. The continuing interest in this topic arises from improvements in both the experimental and theoretical situations. Prior to 1930, impurities in the gas samples used led to conflicting results concerning the experimentally determined values of the mobilities.[1] Theoretical calculations of that period followed classical treatments based on ion-atom interactions of electrostatic origins.[2]

During the 1930's, major advances were made in both the experimental and theoretical investigations. Improvements in gas handling techniques and the development of new methods for measuring ionic mobilities[3] resulted in reliable, reproducible data. It was then found that, in cases other than ions moving in their parent gas, good agreement was often obtained between experiment and theory. The inclusion in the theory of charge exchange as part of the ion-atom interaction permitted the accurate calculation of the mobility of a positive ion in its parent gas for the particular case of He$^+$ in helium.[4] Unfortunately, in this one case in which the new theory could be tested, the measured mobility was roughly twice the theoretical value. As a result it was concluded that the theoretical treatment had overestimated the effect of the charge exchange interaction on the ionic mobility.

The next significant changes in our understanding of ionic mobilities occurred during the post-war period. The recently developed electronic timing and microwave techniques were used in new types of apparatus for studying the behavior of ions in gases. The data obtained from these experiments[5,6] gave a mobility for He$^+$ in helium which agreed with the theoretical value, but therefore disagreed with the previous measurements. It had been suggested by Meyerott[7] that the earlier measurements applied to the molecular helium ion, He$_2^+$, moving in helium. The existence of stable diatomic ions of noble gases, e.g. He$_2^+$, had been experi-

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