

CROSS SECTION AND POLARIZATION OF THE H_{α} LINE BY ELECTRON IMPACT EXCITATION

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The modulated cross-beam technique has been used to measure the excitation function and the polarization of the Balmer- α line of atomic hydrogen excited by electron impact. Normalization of the H_{α} excitation function to the Born approximation above 300 eV provides cross sections in the energy range from the threshold up to 350 eV. The polarization of the H_{α} line shows an abrupt decrease, which is contrary to the "normal" behavior of increasing polarization up to the threshold observed for the alkali atom resonance line.

In this paper we report on studies which provide Balmer- α cross sections by normalization to the Born approximation at high energies. The excitation of the Balmer- α line by electron impact has already been reported in previous papers.^{1,2}

We define the cross section of the Balmer- α line, excited from the ground state, as follows: $\sigma(1S, H_{\alpha}) = \sigma(1S, 3S) + 0.12\sigma(1S, 3P) + \sigma(1S, 3D)$. This is the sum of the cross sections for the excitation of the 3S state, of the 3P state multiplied by the branching ratio of the 3P-2S transition, and of the 3D state. In order to measure the excitation function and polarization, we utilized the modulated crossed-beam technique. The atomic-beam technique used was similar to that of Hils, Kleinpoppen, and Koschmieder.³ The electron beam of a Pierce-type electron gun with an energy spread of about 0.5 eV was crossed by the collimated atomic H beam produced by thermal dissociation in a multichannel tungsten oven.

One of the main problems in the measurement of the H_{α} excitation process was separation of background from the H_{α} signal. By modulating the intensity of the H beam by a mechanical chopper, one should be able to separate the signals of the H_{α} line excitation from background signals. However, the oven is a very intense source of visible light; since it had to be heated to a temperature of approximately 2700°K, a lot of background light is scattered into the multiplier used for the detection of the H_{α} intensity. In order to reduce the modulated background signal of the oven light, the blades of the mechanical chopper were made of glass. The special mechanical chopper reduced the modulated signal from the oven by

a factor of at least 20. With this technique the H_{α} excitation signal was proportional to the difference of the lock-in signal with and without the current of the electron gun. We separated the H_{α} line from other lines by an interference filter with a half width of about 100 Å. The polarization defined in the usual way (related to the direction of the incoming electrons) was measured by means of a polaroid filter.

Figure 1 shows the results for the H_{α} polarization as a function of the electron energy. The errors quoted are twice the rms error plus a small estimated error arising from the entrance aperture of the observed light detector. This new polarization measurement agrees with the earlier one,² but now the polarization data obtained closer to the threshold energy show an abrupt decrease which is contrary to that "normal" behavior of increasing polarization up to the threshold as observed for the alkali atom resonance lines.^{4,5}

Figure 2 shows the cross section $\sigma(1S, H_{\alpha})$ for the H_{α} line. This cross section was obtained

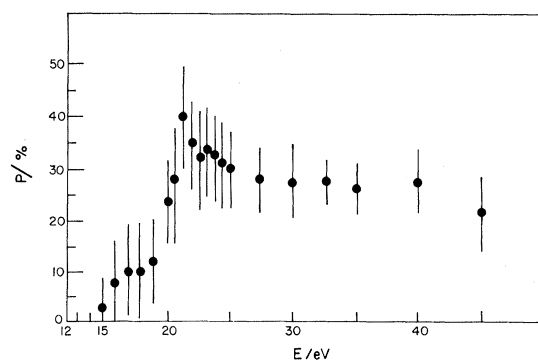


FIG. 1. Polarization of the hydrogen Balmer line H_{α} as a function of the electron energy (the error bars include $2 \times$ rms error plus an estimated systematic error).

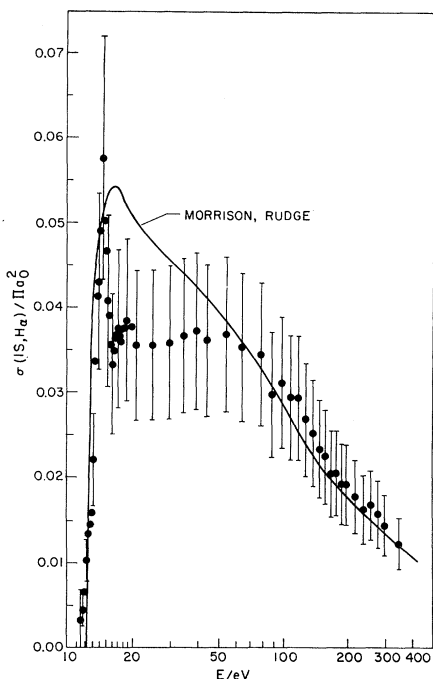


FIG. 2. Cross section $\sigma(1S, H_{\alpha})$ of atomic hydrogen as a function of the electron energy ($3 \times$ rms error plus estimated systematic error). The solid curve represents the theoretical results of Morrison and Rudge (Ref. 7).

by a normalization procedure in which the measured excitation function has been normalized to the Born approximation at higher energy. The justification for the procedure is as follows: Fite et al.⁶ have shown that the shape of the Born cross-section curve for the $2P$ excitation agrees with the shape of the experimental $2P$ excitation function above 250 eV. According to the Born approximation, the cross section for the excitation of the $2S$ state should behave as $\sigma(1S, 2S) \sim 1/E$ or $\sigma(1S, 2S)E = \text{const.}$ It follows from Fig. 4 of the work of Hils, Kleinpoppen, and Koschmieder³ that above 300 eV all points of the product $\sigma(1S, 2S)E$, plotted versus energy, can be fitted to a horizontal line within the single rms error. The indication is that the Born approximation should be valid for the $2S$ excitation above 300 eV. On this basis, normalization of the H_{α} excitation function to the Born approximation has been carried out at energies above 300 eV.

The H_{α} cross section must also be corrected for the cascading contribution from higher lying states. It has been estimated that the cascade contribution results mostly from the transition of the higher nP states to the $3S$ state. Other possible cascade processes to the states

$3P$ and $3D$ cause contributions smaller than 5%. The cascade contribution from the transitions of the higher nP states to the $3S$ state has been estimated in the following way: The branching ratio of the transitions from the nP states to the $3S$ state are nearly constant. At higher energies the Born cross sections for the nP states are proportional to the dipole matrix elements squared. At lower energies the cross sections for the nP states have been assumed to have the same shape as the measured cross section of the $2P$ state. Taking into account all these facts, one can correct for the cascade contributions according to the expression $\sigma_c(1S, H_{\alpha}) = \sigma(1S, H_{\alpha}) + 0.1\sigma(S, 4P)$, where $\sigma_c(1S, H_{\alpha})$ denotes the cross section for the H_{α} excitation, including the cascade processes from the nP - $3S$ transitions. The estimated cascading contribution of $0.1\sigma(S, 4P)$ causes a difference of about 5-20% between $\sigma(1S, H_{\alpha})$ and $\sigma_c(1S, H_{\alpha})$ in the energy range where cascading is possible.

The cross section shown in Fig. 2 represents $\sigma(1S, H_{\alpha})$ where the cascading contribution of $0.1\sigma(S, 4P)$ has been eliminated. The total error of about 25% of each point is to be considered as an upper limit. The total error includes three times the rms error, an error from the normalization procedure, and an error from neglecting the smaller cascading contributions discussed above.

The data for the $\sigma(1S, H_{\alpha})$ cross section have been corrected to the observed H_{α} polarization. Since the smaller polarization at higher energies (above 100 eV) has not been measured, an additional error results which has been estimated and taken into account. The curve in Fig. 2 shows theoretical results of the H_{α} cross section calculated by Morrison and Rudge,⁷ which are based upon the theory of Rudge.⁸ Six-state close-coupling calculations⁹ for the $n = 1 \rightarrow 3$ transitions yield $\sigma(1S, H_{\alpha})$ cross sections which are considerably higher than our reported data.

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DIRECT MEASUREMENTS OF PREDISSOCIATION PROBABILITIES IN CH AND CD MOLECULES*

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Quantitative measurements of nonradiative decay rates in the $C^2\Sigma^+$ state of CH and CD molecules are presented via absolute phase shift versus frequency data and are interpreted as direct measures of predissociation probabilities. The C -state decay rates measured in CH are approximately three times larger than those in CD and comparison with absorption oscillator strength measurements shows that the predissociation probabilities of the rotational levels observed in CH range from approximately 3×10^7 to $1.6 \times 10^8 \text{ sec}^{-1}$, i.e., approximately 3 to 18 times the radiative transition probability.

The visible and near ultraviolet emission spectra of CH and CD have been known for some time,¹ and the transitions in CH have been identified in solar, stellar, and interstellar absorption.² Einstein transition rates, A , have recently been measured for two of the three known emission systems in CH, viz., for $A^2\Delta-X^2\Pi$ and $B^2\Sigma^- - X^2\Pi$.^{3,4} Herbig⁵ has deduced an approximate absorption oscillator strength for the $C^2\Sigma^+ - X^2\Pi$ transition at 3144 Å relative to the $A-X$ and $B-X$ transitions from the observed equivalent widths of the interstellar CH lines in the spectrum of ζ Ophiuchi. Linevsky⁶ has recently reported the first laboratory measurement of a relative f value for the $C-X$ system, using a King furnace; his value of $f(C-X)/f(A-X) = 1.26$, if put on an absolute scale using Fink and Welge's⁴ $A-X$ transition probability, leads to a radiative lifetime of 115 nsec for the C state. The corresponding value derived from Herbig's estimate would be 430 nsec.⁷

In recent flash-photolysis experiments with CH_2N_2 and CD_2N_2 Herzberg⁸ noted that although $C-X$ fluorescence is observed in the spectrum of the deuterated compound, it is absent or weaker by a factor of at least 5 in the normal compound. He has interpreted this intensity difference between the two isotopes as evidence for a weak predissociation affecting the C state

of CH even though the $C-X$ transition of CH is regularly seen in emission in discharges and flames, where it is, however, much weaker than the $A-X$ and $B-X$ emissions in both CH and CD. No anomalies have been reported in the rotational intensity distribution of the $C-X$ emission.^{1,9}

We have measured the decay rate of the $C^2\Sigma^+$, $v'=0$ level in CH and in CD at low pressures using the phase shift apparatus of Lawrence^{10,11} in which emission spectra are excited by an rf-modulated beam of low-energy electrons. We have found a substantially more rapid decay than is consistent with the lifetime for purely radiative decay expected from the absorption measurements of either Linevsky or Herbig.

CH_4 of high chemical purity and CD_4 of high isotopic purity¹² were used for electron-beam excitation of the $C-X$ emission of CH and CD and the phase shifts were determined using the Ne-II multiplet at 1908-1935 Å as an absolute phase reference.¹¹ Electron energies of 100 V were used for these measurements, after careful investigation had shown no dependence of the phase shifts on electron energy in the range from 90 to 200 V and no dependence on pressure in the excitation region over a workable range from about 1 to 11 μ. With equal pressures of the parent molecules in the