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Differential Measurement of the He 3^3P Excitation, in He^+-He Collisions, by Using an Ion-Photon Coincidence Method

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In order to determine the differential cross section for excitation of a given radiative level, in ion-atom collisions, the scattered ions are detected at a given angle, in coincidence with the photons emitted by the excited target atoms. The method has been applied to the He^+-He collision at laboratory energies of 200, 300, and 350 eV in the angular range 5-18 deg, for the 3^3P level of He. At 200 and 300 eV, the differential cross sections exhibit an interference pattern which is characteristic of a curve crossing. The behavior is more complicated at 350 eV because, we believe, more than two molecular states are involved.

Excitation processes occuring in the mean energy range (few hundred eV) of ion-atom collisions are generally explained by transitions which occur in the neighborhood of a crossing point of nonadiabatic-potential curves of the molecular-ion–atom system. The usual experimental study of such processes consists of analyzing the energy of the scattered ions at given angles and impact energies. However this method provides, in most cases, somewhat ambiguous data because of the lack in energy resolution, which makes it impossible to isolate a given excited level, especially if a high–quantum-number excited level is considered. In the present experiment this difficulty has been overcome by detecting the photons emitted by the excited atom in coincidence with the ions scattered at a given angle θ.[1] Then the overall energy resolution is that provided by the optical analysis and is much better than the resolution of an electrostatic analyzer.

A rather similar technique has been recently used by Jaecks, Crandall, and McKnight[2] to investigate differential cross sections of capture into excited states in H^+-He collisions. This method has been applied to the excitation of the 3^3P level in He in He^+-He collisions at impact energies of 200, 300, and 350 eV. The apparatus has been described elsewhere[3] and only its main features are reported here. A He^+ ion beam is crossed at right angles by a He atomic beam, and the collision volume is located at the focal point of a parabolic mirror which gathers 70% of the emitted photons. The wavelength of the investigated line (3^3P-2^3S, $\lambda = 3889$ Å) is selected by an interference filter, and the photons are counted by a low-noise photomultiplier. Two circular movable slits select a given scattering angle and, in order to reduce the accidental coincidence rate, an ion-energy analysis is performed by a cylindrical-mirror–type electrostatic analyzer; the emerging ions are then counted by a tubular particle multiplier. The delay time Δt between a photon-channel pulse and the subsequent ion-channel pulse is converted into pulse height by a time-to-amplitude converter; the heights of the output pulses are analyzed in a multichannel analyzer. The final result is a "coincidence spectrum" (Fig. 1) on which the count numbers are plotted as a function of Δt. A maximum count number can be observed for the delay time Δt_0 corresponding to an ion

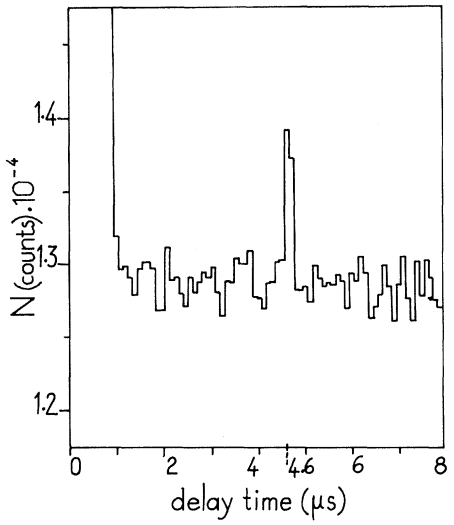

FIG. 1. Coincidence spectrum obtained at $E=350$ eV, $\theta=7$ deg. A maximum count number (real coincidences) is observed at the delay time $\Delta t_0=4.6$ μsec. (The increasing count rate from accidental coincidences toward zero time delay is due to electronics.) The running time is about 12 h and the signal-to-noise ratio is 17.

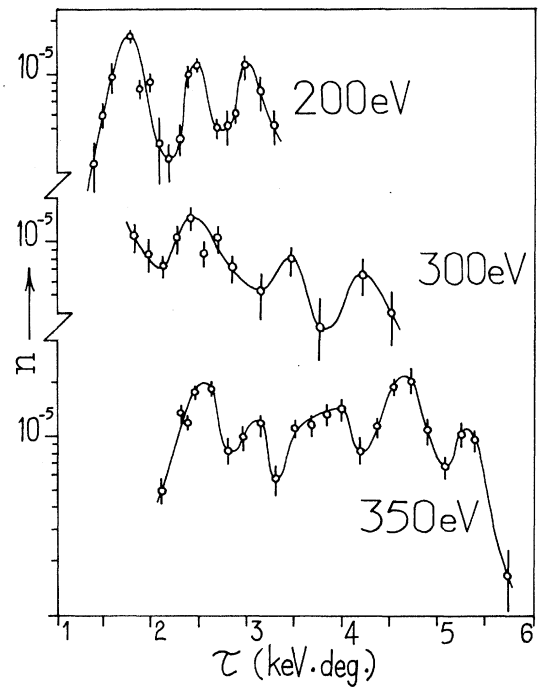

FIG. 2. Ratio $n=N_c/N(h\nu)$ as a function of $\tau=E\theta$, for laboratory impact energies of 200, 300, and 350 eV. As explained in text, $n(\tau)$ has about the same behavior as the excitation differential cross section. The threshold of the excitation can be located (from the 200-eV curve) at about $\tau_0=1600$ eV deg.

and a photon produced by the same collision, while accidental coincidences provide a base line surmounted by a statistical noise. In our operating conditions, the time resolution was good enough so that the width of the coincidence peak was about equal to the lifetime of the excited state (0.1 μsec). The running times necessary to obtain a satisfactory signal-to-noise ratio (4 or 5) are several hours (4-10 h). For given energy E and angle θ, the true coincidence number N_c and the total photon number $N(h\nu)$ are measured; the differential cross section σ is then given by

$$\sigma(E,\theta)=n(E,\theta)f(\theta),$$

where $n(E,\theta)=N_c/N(h\nu)$ and $f(\theta)$ is an instrumental factor. This function f has not yet been determined, but it can be expected to vary slowly and monotonically with θ, and then the structures which are observed on the curves $n(\theta)$ can be considered to occur also on $\sigma(\theta)$.

Keeping in mind the double-crossing model proposed by Rosenthal and Foley[4] in order to explain the oscillation in the total excitation cross section Q,[5,3] we have chosen values of the impact energy corresponding either to minima of Q (200 and 300 eV) or to a maximum (350 eV).

Figure 2 shows n as a function of the reduced collisional parameter $\tau=E\theta$. At the energies $E=200$ eV and $E=300$ eV, the differential cross sections exhibit a regular oscillation which is characteristic of a crossing point of the diabatic-potential curves corresponding to the ground state ($A\,^2\Sigma_g$) and to the excited state ($^2\Sigma_g$) of the He_2^+ system, which leads, at infinite internuclear distances, to $He^+ + He(3^3P)$. The results obtained at 200 eV allow the determination of the apparent threshold of the process at about $\tau_0 = 1.6$ keV deg. The internuclear distance R_x of the crossing point has been evaluated at about 1.4 a.u. from the ground-state–potential curve.[7] This value is qualitatively in good agreement with the predicted Σ-Σ crossing given by the energy diagram of the He_2^+ system.[7] If the maxima of n are labeled by the index numbers $N=0, 1, 2, 2, \cdots$ and the minima by $N=\frac{1}{2}, \frac{3}{2}, \cdots$, then the phase shift between the two interfering waves is $\varphi=2\pi N$. As can be observed in Fig. 3, the quantity $NE^{1/2}$ is approximately a linear function of τ, and the phase shift can be written $\varphi \simeq CE^{1/2} \times(\tau-\tau_0)$, where C is a constant. From the semiclassical approximation it can be shown[8] that φ is related to the impact parameter by

$$\Delta b = b_1 - b_2 = \frac{\partial}{\partial \tau}\left[\left(\frac{E}{2\mu}\right)^{1/2}\hbar\varphi\right],$$

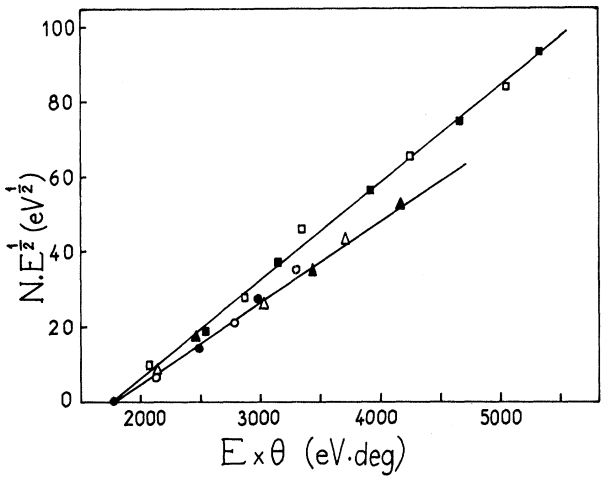

FIG. 3. The quantity $NE^{1/2}$ is plotted as a function of $\tau=E\theta$. N is the index number for the extrema of $n(\tau)$ ($N=0,1,2,\cdots$ for maxima; $\frac{1}{2},\frac{3}{2},\cdots$ for minima). Open symbols are maxima, closed are minima: circles, 200 eV; triangles, 300 eV; squares, 350 eV.

where μ is the reduced mass and b_1 and b_2 are the values of the impact parameter b corresponding to the two scattering potentials for a given scattering angle θ. The linear dependence of $NE^{1/2}$ on τ shows that Δb is approximately independent of τ: $\Delta b \simeq 0.62$ a.u. At 350 eV, the behavior of the differential cross section is more complicated: Oscillations appear also in this case, but they seem to be distorted by another phenomenon. In this case the quantity $NE^{1/2}$ is still a linear function of $\tau-\tau_0$ (see Fig. 3), but the slope $\partial(NE^{1/2})/\partial\tau$ and the values of Δb are slightly larger than for the previous energies. With regard to the diabatic correlation diagram of the He_2^+ system,[9] the mechanisms causing the two curve crossings can be considered as possible mechanisms for the He ($1s3p$, ^3P) excitation, corresponding to two electrons being elevated from the $(1s\sigma_g)(2p\sigma_u)^2\,^2\Sigma_g$ antibonding input channel to $(1s\sigma_g)^2(4d\sigma_g)\,^2\Sigma_g$ and $(1s\sigma_g)$-$(4d\pi_g)^2\,^2\Pi_g$.

In an attempt to clarify the parts played by short-range and long-range crossings, we are currently investigating the "companion" level ($3p$, ^1P).

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"Polarization-Free" Vacuum-Ultraviolet Excitation of Helium by Electrons

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"Polarization-free" excitation cross sections for the 1^1S–n^1P transitions of He have been measured from threshold to 2 keV using a crossed-beam technique. Results have been made absolute using the accurately known oscillator strengths. Maxima in the cross sections for the n^1P levels occurred around 100 eV and were found to be 106×10^{-19} cm^2 (2^1P), 31×10^{-19} cm^2 (3^1P), and 13×10^{-19} cm^2 (4^1P).

Previous measurements of optical excitation functions in the vacuum ultraviolet have suffered from two major disadvantages. In many instances signal intensities have been so low that investigators have had to work at pressures where absorption or imprisonment of resonance radiation is occurring. Secondly, the difficulty of dealing with polarization effects in this spectral region has meant that excitation functions have been presented whose shapes may have been radically altered by the polarizing effect of the detecting spectrograph. In the present experiment these difficulties have been avoided in the following way.