communicated during the construction of the apparatus[8] and the experimental data is satisfactory. The differences might be due to uncertainties of the experimental resonance cross sections or to the possible existence of a $6^2S_{1/2}$ autoionization transition[9] near 1300 Å. According to the measurement the value $P = -50\%$ [where $Q_S' = 0$, Eq. (4)] is at the wave number $64\,400 \pm 600$ cm^{-1}. Since from Eq. (2) $\epsilon_0 = -q_0$ for $Q_S' = 0$, Eq. (3) together with the measurement yields $\Gamma_0 q_0 = 5500 \pm 1200$ cm^{-1} for the $6^2P_{1/2}$ autoionization transition.

We have shown that polarized electrons can be obtained from autoionizing transitions and that the polarization can be utilized for the analysis of the autoionization resonances. It is worth noting that the intensity distribution $I(\lambda)$ of the ionizing light (depending on the light source and the absorption coefficients of the optical devices) does not have to be known for the measurement of the wavelength-dependent $P(\lambda)$, since the electron polarization is obtained from the ratio of the electron intensities in the two counters of the Mott detector.

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Measurements of Photon Polarization and Angular Correlations for He^+ - He Collisions Coincidence Technique Using an Ion-Photon

G. Vassilev, G. Rahmat, J. Slevin,* and J. Baudon

Laboratoire de Collisions Atomiques,† Université Paris-Sud, 91405 Orsay, France

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The polarization of photons from the transition $3^3P \rightarrow 2^3S$ and the angular distribution of radiation from the decay $2^1P \rightarrow 1^1S$ emitted in He^+ +He collisions at an incident energy of 150 eV and an ion scattering angle of 13.5° were measured by detecting the scattered ions and photons in delayed coincidence. From these measurements we conclude that the 3^3P excitation takes place through a Σ-Σ radial coupling, and the 2^1P excitation predominantly through a Σ-Π rotational coupling, probably at large internuclear separation.

The interpretation of excitation processes in ion-atom collisions at moderate energies (a few hundred eV) is based on a molecular description of the colliding-particle system. In most cases, the primary excitation mechanism consists in an interaction between ground and excited molecular states, which occurs at a rather small internuclear distance (a few bohrs). In general, many coherent scattering amplitudes, corresponding to several output channels, are produced at the same time by the collision and these amplitudes can interfere at large or infinite internuclear distances. Thus, in spite of the fact that the primary excitation mechanisms are now generally well understood, transition probabilities—or inelastic differential cross sections—for excitation to *one* specific atomic level are often difficult to determine because of these "secondary" interactions occurring at large distances. For the particular case of the excitation of a ^1P state of helium, in a He^+-He collision, for a specific scattering angle (the ion is assumed to remain in the ^1S state), different and coherent amplitudes $a_m(\theta, \Phi)$ are obtained for the different magnetic sublevels $m = -1, 0, +1$, with the symmetry relation $a_1 = -a_{-1}$ (see Macek and Jaecks[1]). As the collision time at moderate energies (10^{-15} sec) is much shorter than the lifetime of the excited

states, the two colliding particles can be considered to be far apart when the radiative decay occurs. Since each particular magnetic sublevel corresponds to a definite polarization of the light emitted in the transition $^1P \rightarrow {}^1S$, an analysis of this light provides information on magnetic-sublevel excitations. Measurements of the polarization have already been made for high-energy collisions and at low and moderate energies,[2-5] by measuring the intensity at 90° from the incident beam direction through a polarizer placed either parallel or perpendicular to that direction. However, since these polarization measurements were made without regard to the ions, the results are necessarily averaged over all ion scattering angles and information is lost in this averaging process. It is then clear that when the (polarized) photons are detected in coincidence with ions scattered in a *particular* direction, new information on the elementary collision process is obtained. Thus, if the final direction of the molecular axis is taken as the quantization axis for atomic states, each magnetic sublevel corresponds to a molecular state of definite Λ symmetry ($\Lambda = 1$ for $m = \pm 1$ and $\Lambda = 0$ for $m = 0$). A measurement of the differential polarization of the coincident light or alternatively its angular distribution yields values of the relative probabilities for the excitation of a given P state via Π or Σ molecular states, which are proportional to $|a_\Pi|^2$ and $|a_\Sigma|^2$ or $|a_{\pm 1}|^2$ and $|a_0|^2$, and in addition the relative phase φ between a_Π and a_Σ. For ^3P states the situation is more complicated because of the fine structure. While for such a light atom the spin is not expected to play any role in the collision itself, the spin-orbit interaction acts on the excited state causing $\vec{L}$ and $\vec{S}$ to precess around their resultant $\vec{J}$, and leads to a reduction in the polarization. However, this effect is quite independent of the collision process itself and can be evaluated *a priori*. Macek and Jaecks[1] have treated this problem in detail. It is the purpose of the present paper to report preliminary measurements of photon polarizations and angular correlations for 2^1P and 3^3P excitations in He^+-He collisions using an ion-photon coincidence technique.

Two experimental methods, already used for electron-atom collisions,[6,7] have been applied to analyze the coincidence light. In the first, photons are detected in a direction perpendicular to the collision plane, through a filter and a linear polarizer, and the number of ion-photon coincidences is measured as a function of the polarizer orientation. In the second method, the spatial distribution of emitted photons (in coincidence with ions scattered at a given angle) is measured by rotating the photon detector around the collision volume. The ion-photon angular-correlation curve gives the same information as a measurement of the polarization.

In order to use the first method, the coincidence apparatus described previously[8] has been slightly modified (see Fig. 1): (i) A UV-HN PB polaroid has been inserted between the interference filter and the photomultiplier, and (ii) the scattered ions have been detected only within an azimuthal angular range of $\pm 20°$. The parabolic mirror, that was used to gather photons from a large solid angle (about π sr), has not been removed for the present measurement: Its effect on the polarization has been calculated, and moreover it can be shown to be rather small when the optical device has a symmetry axis perpendicular to the reference collision plane. This experimental method is convenient for visible or near-uv light; it has been used for the 3^3P-2^3S line ($\lambda = 3889$ Å). The results obtained at an energy of 150 eV and a scattering angle of 13.5° (in the laboratory frame) are shown in Fig. 2. The coincidence number, calibrated with respect to the total number of scattered ions counted during the experimental run, is plotted as a function of

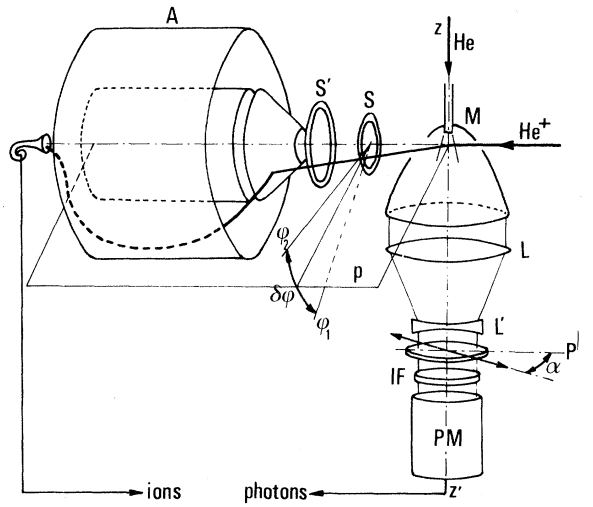

FIG. 1. Experimental setup for the determination of the linear polarization of the coincidence light. M is the parabolic mirror, LL' the quartz lenses, P the polarizer, IF the interference filter; the ion scattering direction is defined by slits SS'; A is the electrostatic analyzer; p is the collision plane, perpendicular to $z'z$.

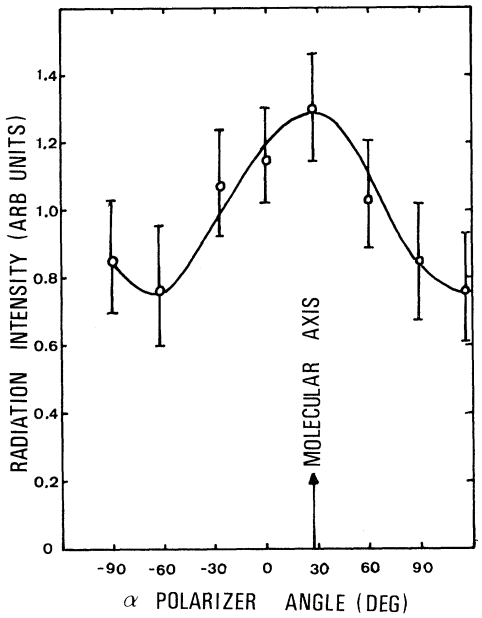

FIG. 2. Ion-photon coincidence rate as a function of the angle of the polarizer. $\alpha = 0$ corresponds to the incident beam direction. The error bars represent 1 standard deviation in the counting statistics. Full curve is a fit of a sinusoid of period π.

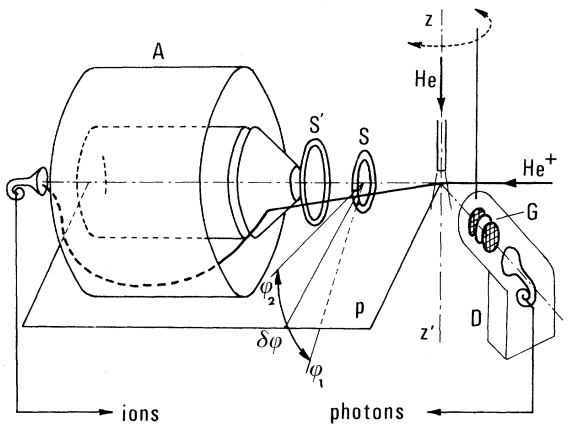

FIG. 3. Experimental arrangement for angular-correlation measurements on the 2^1P-1^1S resonance line ($\lambda = 584$ Å). The optics of Fig. 1 is replaced by the uv detector D (electron multiplier); grids G prevent the detection of charged particles. The rotation axis of D is $z'z$; it is perpendicular to collision plane p.

the polarizer direction α. Each datum point represents typically 24 h of integration and a real coincidence rate of about 2 counts/h. It is seen that a maximum of intensity is observed when the polarizer is parallel to the final molecular axis ($\alpha = 27°$). This can occur either when the scattering amplitude a_Π vanishes, or when the relative phase φ of a_Π with respect to a_Σ is $\pm\frac{1}{2}\pi$ rad. If it is assumed that a_Π is negligible, and depolarization effects due to the spin-orbit coupling, to the mirror, and to Earth's magnetic field are taken into account, then the predicted ratio of intensities at $\alpha = -63°$ and $\alpha = +27°$ is 0.57. The observed ratio is 0.6 ± 0.2. This means that, in the present case, the excitation of the 3^3P state presumably takes place only via a Σ-Σ radial coupling. This conclusion is consistent with qualitative theoretical predictions[9] but it must be remembered that those predictions concern the primary excitation mechanism at small internuclear distance, and that secondary couplings at large distance could change the Σ and Π contributions. Preliminary measurements on the 3^1P level actually show that the polarization is very different from the previous one, in spite of the fact that singlet and triplet $3P$ states are considered as identical in a simple correlation diagram.

The second method, based on angular-correlation measurements, has been used to study the 2^1P-1^1S resonance line of helium ($\lambda = 584$ Å). For this experiment (Fig. 3) the parabolic mirror has been removed and the uv photons are detected by a Channeltron electron multiplier (Mullard 419 BL) which could be rotated around the collision volume. No wavelength selection was necessary in this case since the energy resolution of the analyzer was sufficient to separate $n = 2$ from $n \geq 3$ excitations. Thus ion-photon coincidences necessarily correspond to 2^1P excitation. Two grids biased at negative and positive voltages prevent charged particles from reaching the Channeltron aperture. However, fast or metastable atoms are detected within the angular range 0°–90° with respect to the incident beam direction. This makes the measurement more difficult, because of the increase in the accidental-coincidence rate, but it does not affect the true-coincidence number. It was verified directly that the target density was sufficiently low that pressure-dependent effects, such as resonance trapping of the 584-Å radiation, did not affect the experimental data. Figure 4 shows angular-correlation curves for an impact energy of 150 eV and a scattering angle of 13.5°. Integration times for each datum point are typically 24 h and the real coincidence rate is of the order of 2 to 10 counts/h. The experimental points have been obtained with two different azimuthal angu-

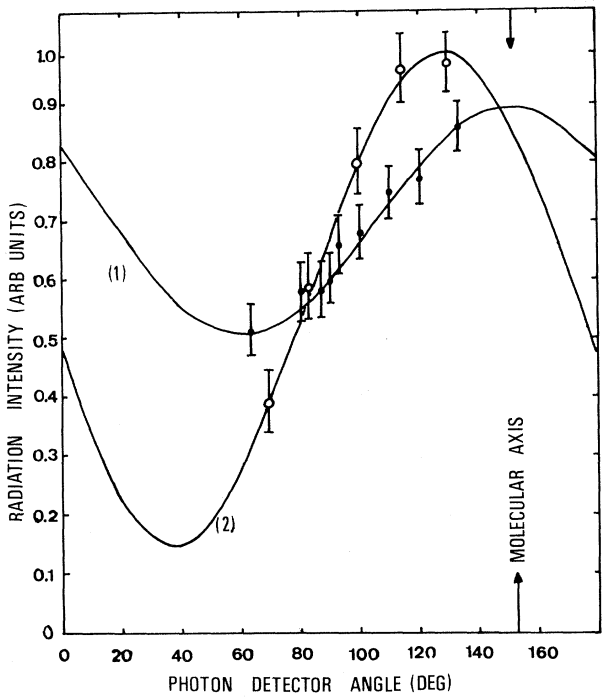

FIG. 4. Ion-photon angular correlation for an incident energy of $E = 150$ eV and scattering angle 13.5°. Error bars represent 1 standard deviation in the counting statistics. Filled circles, $\delta\varphi_i = 90°$; open circles, $\delta\varphi_i = 30°$. Curves (1) and (2) are least-squares fits to the data. The final molecular axis is at 153°, and the incident beam direction is at 0°.

lar spreads $\delta\varphi_i$ of the scattered ions. Each of the two curves, (1) and (2), represents a computer least-squares fit of the angular-correlation function,[10] integrated over the photon-detector aperture and the ion azimuthal angle $\delta\varphi_i$, to the experimental data points. Notice that, as expected, the angular distribution corresponding to the larger range of $\delta\varphi_i$ [curve (1)] is flatter (i.e., the polarization is reduced) than for curve (2). Within the experimental error, the maxima of both curves lie along the final molecular axis, and it is estimated that $|a_\Sigma|^2 \lesssim 10^{-1}|a_\Pi|^2$; i.e., the final molecular state is mainly a Π state. This conclusion may seem rather surprising, because it is known that, at such a small energy, the primary excitation essentially takes place *via* a Σ_g-Σ_g coupling. However this Σ_g-excited-state potential curve lies very close to the Π_g curve leading to He(2^1P), along a rather large range of internuclear distance. Thus a secondary Σ_g-Π_g coupling could explain the observed predominance of $|a_\Pi|$.

For 2^1P excitations, the amplitude of $|a_\Sigma|$ was not sufficiently great to permit us to determine a statistically significant value for the relative phase φ between a_Σ and a_Π. For the case of the 3^3P excitation, the reverse was true, i.e., $|a_\Sigma| \gg |a_\Pi|$, and again a reliable value of φ could not be estimated. Work is continuing on both 2^1P and 3^3P excitations at different energies and scattering angles.

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*Permanent address: Department of Physics, University of Stirling, Stirling, Scotland. Collaboration made possible by a Royal Society Fellowship.

†Equipe de recherche du Centre National de la Recherche Scientifique.

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