file of the lamp. Since the light is perpendicular to the beam direction, there is no Doppler effect and the resolution of the instrument is the natural linewidth of the transition – about Mc/sec for the cesium D_1 line,[8] but perhaps much less for other transitions. We are currently investigating the ultimate sensitivity and the useful frequency range for an atomic-beam apparatus used in this way.

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OPTICAL EXCITATION WITH VERY LOW ENERGY IONS*

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We have observed radiation due to the impact of very slow helium ions on the rare gases and on some molecular gases.[1] The dependence of the cross section for this process on the kinetic energy of the He^+ beam shows unexpected features down to the lowest energies studied (5 eV). For example, there is a sharp peak at 10 eV for the production of uv photons in Xe. The absolute cross sections are typically of the order of 10^{-16} cm^2 and in some cases are almost an order of magnitude larger. In at least one case the radiation has been shown to result from charge exchange with simultaneous excitation. Previous studies of optical excitation by ion impact have been performed at much higher energies and have not revealed the structure at the lower energies.[2] Energy balance considerations show that the reactions studied here involve the transfer of a large fraction of the kinetic energy into internal electronic energy. The excitation clearly involves nonadiabatic nonradiative transitions between the levels of the molecular-ion complex formed during the collision. The low-energy peaks in the cross section imply that the molecular energy levels are shifted in energy during the collision until they nearly cross.[3] Aside from their intrinsic interest, these results may have important bearing on plasma, laser, and atmospheric phenomena.

The apparatus consists of an electrostatically focused electron-bombardment ion source, a differential pumping chamber for pressure reduction, and a collision chamber. The photons produced in the collision region are detected with either a broad-band windowless EMI 9603 particle multiplier which responds from about 200 Å to about 1200 Å, a broad-band LiF-window EMR 541-*F* "solar-blind" photomultiplier which responds from 1050 to 3500 Å, or a 0.5-m Jarrell-Ash Ebert grating monochromator with quartz optics and a photodetector with an *S*-13 spectral response. The EMI and EMR tubes are mounted in the collision chamber with their photocathodes located about 5 cm from the ion beam. Counting techniques were used to record individual photon events with each of the detectors. The electron bombarding energy in the ion source is typically 350 eV. The ion beam passes through a microwave cavity which may be excited at 14 kMc/sec (the Lamb shift in He^+) to quench ions in the metastable $2\,^2S_{1/2}$ state. The ion current in the collision chamber varies from 5×10^{-9} A at a beam energy of 10 eV to 2×10^{-7} A at 500-eV beam energy. The energy spread in the ion beam is less than 0.5 eV at a beam energy of 10 eV.

Photon counts are recorded in each of the three spectral regions when the helium ions enter the collision chamber with a target gas present. Retarding-potential experiments were performed to show that the radiation does not arise from stray electrons in the beam. The ultraviolet photon signals were found to vary linearly with the pressure of the target gas, and it was therefore possible to interpret the results in terms of a cross section for the production of the observed photons. The absolute values for these cross sections, of course, depend on our knowledge of the photoelectric efficiency of the detectors and may be in error by as much as a factor of 10.

The apparent cross sections obtained with the EMI and EMR phototubes are shown in Fig. 1(a) and Fig. 1(b), respectively. In obtaining these curves, it was assumed that the EMI and EMR tubes had quantum efficiencies of 10 and 5%, respectively. It is unlikely that the actual efficiencies are higher than these values. Lower efficiencies would, of course, imply even larger cross sections. The most striking feature of the cross-section curves is the appearance of distinct maxima and energy onsets at very low energies. Neon is unique among the gases studied in that it does not exhibit a maximum in either spectral region and that the absolute value for its excitation cross section is about two orders of magnitude smaller than those observed with the other gases.

Resolved spectral lines have been detected in the visible region of the spectrum with argon, krypton, and xenon target gases. No lines were observed in neon. The absence of observable lines in neon may result from a smaller cross section and limited detection sensitivity. In the case of argon, 15 lines were observed between about 4200 and 5500 Å [see Fig. 2(a)]. The absence of observable lines beyond these limits may result from the long-wavelength cutoff in the S-13 photocathode and the short-wavelength decrease in the grating blaze efficiency. It was necessary to use slit widths of about 2 mm to obtain adequate photon signals. The resulting spectral resolution was about 20 Å.

All of the lines observed with argon can be attributed to transitions in Ar II, and four complete multiplets have been observed [Fig. 2(a)]. Attempts to fit the observed spectrum with Ar I lines were unsuccessful.[4] These observations indicate that the radiation arises from charge exchange with simultaneous excitation:

$$He^+ + Ar \rightarrow He + Ar^{+*}. \quad (1)$$

Identification of the radiation from the collisions of He^+ with Ne, Kr, and Xe is now in progress.

The dependence of the excitation probability for the Ar II line at 4764.9 Å ($4p\ ^2P^0-4s\ ^2P$) on the kinetic energy of the helium ion is shown in Fig. 2(b). These data were obtained with a narrow-band interference filter and an S-20 photomultiplier. The curve shown in Fig. 2(b) has a sharp maximum at a helium-ion energy of about 22 eV and a threshold at 13.9 eV as obtained by extrapolation. The energy in the center of mass at threshold is 12.6 eV.

It is striking that the cross sections for optical excitation in Ar, Kr, and Xe are of the same order of magnitude as the total cross sections for charge exchange.[5,6] This suggests that, in these cases, charge exchange at low energies proceeds to a large extent through excited states. In all cases except Xe this requires that several volts of kinetic energy be transferred to internal electronic energy; in particular, in Ar the excitation of the 4764.9Å line requires that 11.1 eV be transferred. Our problem is to understand how this much energy can be transferred at low impact energies.

It is well known that in the simplest approximation, a system will have maximum probability for transition in a collision when the following equality is satisfied:[7]

$$(\Delta E/h)(a/v_m) \cong 1. \quad (2)$$

Here ΔE is the difference in internal energy between the two states of the system, a is taken as the impact parameter, and v_m is the relative velocity of the colliding particles. The probability for excitation decreases very rapidly as the velocity is made smaller than v_m. In the present case the cross sections are of the order of 10^{-16} cm^2, and we may take $a \cong 10^{-8}$ cm. At infinite internuclear separation, the change in energy in the $(HeAr)^+$ system for the excitation of the 4764.9Å line in 11.1 eV. The corresponding velocity for maximum cross section as predicted by Eq. (2) is $v_m = 2.5 \times 10^7$ cm/sec, and the corresponding He^+ ion energy is about 2.5 keV. On the basis of this estimate we would expect a very small cross section at low energies. Arguments of this type have generally been used to indicate that optical excitation with ions can only

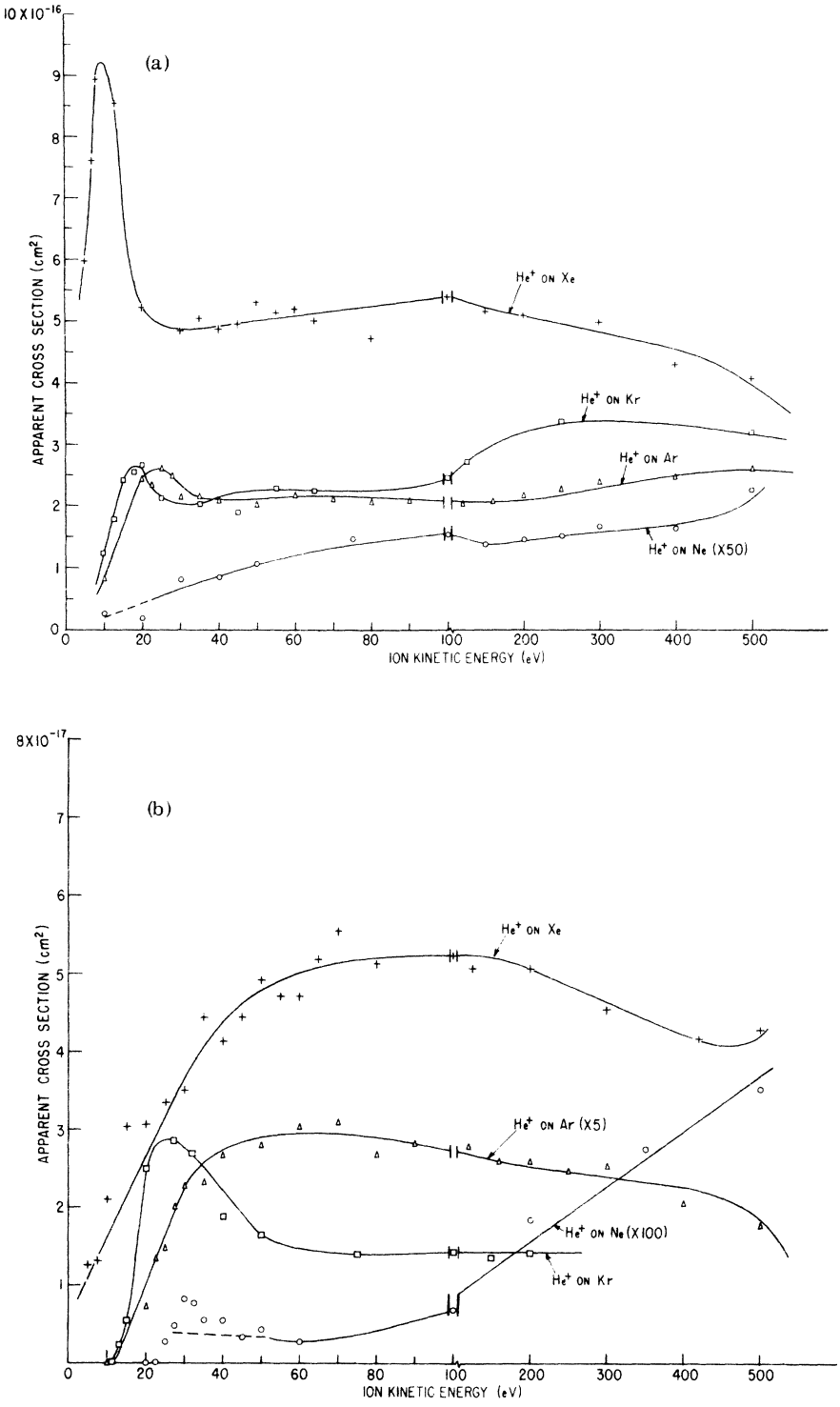

FIG. 1. (a) Kinetic-energy dependence of the cross sections for the production of photons by He^+ impact on the rare gases in the wavelength range from about 200 to 1200 Å. Note that the cross section for neon has been multiplied by a factor of 50. (b) Kinetic-energy dependence of the cross sections for the production of photons by He^+ impact on the rare gases in the wavelength range 1050 to 3500 Å. Note that the cross sections for argon and neon are multiplied by factors of 5 and 100, respectively.

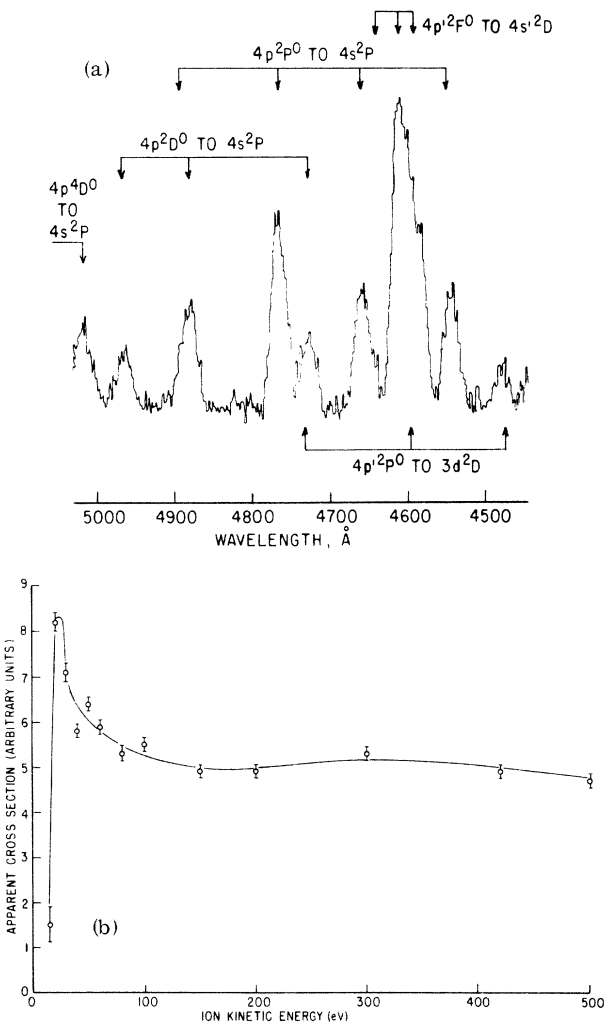

FIG. 2. (a) Spectrum of light emitted in the impact of He^+ on argon. Wavelength assignments correspond to transitions in the Ar^+ spectrum. (b) Kinetic-energy dependence of the cross section for the production of 4764.9Å line ($4p\ ^2P^0$–$4s\ ^2P$) by He^+ impact on Ar.

occur at relatively high energies. This conclusion is, of course, contrary to our observations.

Our results can be reconciled with the predictions of Eq. (2) by noting that in general the energy levels of the molecular complex are strongly dependent on the internuclear separation (R). Thus both the internal energy defect (ΔE), the relative velocity (v), and the distance (a) over which the interaction occurs are functions of R. Our results indicate that the levels involved in the collision which results in optical excitation approach each other in energy as R decreases. We can estimate the energy defect at the point of impact by fitting the low-energy portion of the excitation function shown in Fig. 2(b) for the argon 4764.9Å line to the probability function developed by Landau and Zener.[3] In this way we find that $\Delta E \cong 0.2$ eV at the point of impact.[8]

The above discussion provides a very simple qualitative explanation of our observations. In the case of neon the optically excited states are so far removed in energy [see Fig. (3)] from the initial state of the system (He^+Ne) that the molecular interactions are not sufficient to bring the initial and final states to within a few volts of each other, and therefore the probability for excitation is very small at low energies. In the case of xenon the initial state (He^+Xe) is almost degenerate with the excited states of ($HeXe^{+*}$), and we can satisfy the condition given by Eq. (1) at low velocities without invoking molecular interactions. Argon and krypton are intermediate cases, and we can use our observations to establish that pseudocrossings occur between at least some of the excited states, ($HeAr^{+*}$) and ($HeKr^{+*}$), and the initial states, (He^+Ar) and (He^+Kr), respectively.

We have observed very similar effects in the molecular gases N_2, O_2, H_2, and CO. In the case of CO we used beams of both He^+ and N_2^+ for excitation. The relative band intensities observed with He^+ and N_2^+ excitation of CO^+ were found to be strikingly different. Our observations on CO with N_2^+ excitation are in agreement with the results obtained by Utterback and Broida.[9]

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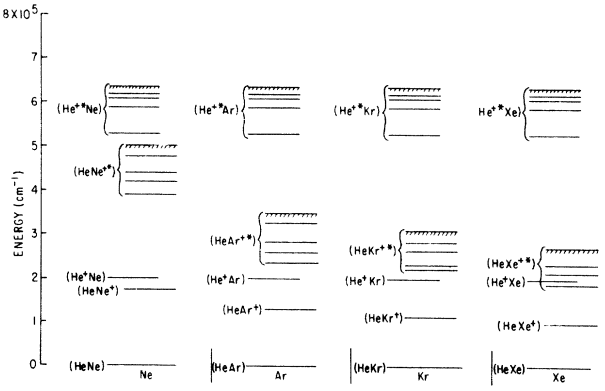

FIG. 3. Relevant energy levels for separated ($R \to \infty$) rare-gas molecular systems..

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SPIN POLARIZATION OF SLOW ELECTRONS BY ELASTIC RESONANCE SCATTERING FROM NEON*

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The generation of intense beams of polarized electrons is of considerable interest at the present time. Two significant advances have recently been made in this field, namely, the ejection of polarized photoelectrons from a polarized atomic beam,[1,2] and Mott scattering of electrons from the screened Coulomb charges of beams of mercury and gold atoms in the keV energy range,[3,4] based on the theory of Mohr,[5] Bunyan,[6] and others.[7] We wish to point out here that a perhaps even more powerful method for the production of intense beams of polarized electrons is a direct consequence of the recent discovery by Simpson and his co-workers[8] of a doublet structure in the resonance for elastic scattering of electrons by neon atoms at 16 eV (0.6 eV below the first excitation level), based on earlier work by Schulz,[9] Simpson,[10] and others,[11] and interpreted by Fano.[12] The questions raised by these experiments are also of more general interest in connection with the nature of autoionizing atomic energy states.[13-15]

The resonance observed by Simpson[8] in the total cross section for the scattering of electrons from neon consists of a small decrease in cross section, followed by two successive peaks, of which the first is approximately twice as pronounced at the second. The two peaks are separated by 0.095 eV, corresponding closely to the $P_{1/2}$-$P_{3/2}$ fine-structure splitting in the ground state of Ne^+. In view of these facts, the resonances have been interpreted by Simpson and Fano[12] as corresponding to the formation of metastable compound states with the configuration $(1s^2 2s^2 2p^5 3s^2)P_{1/2,3/2}$, that is, states of the Ne^- ion formed by adding a $3s$ electron to the lowest excited state of neon. There is little doubt that this interpretation is correct in view of the energy location, separation, and relative statistical weights of the two states. Under these circumstances, interference between resonance and potential scattering in the presence of fine-structure splitting will give rise to almost complete polarization of electrons scattered through 90° at certain energies, as in the polarization of neu-