AUTOIONIZATION OF GASES BY ION IMPACT

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INTRODUCTION

There has recently been considerable interest in quasistationary atomic states with energies above the first ionization limit. Such states are due either to multiple excitation or to single excitation of inner shell electrons. Transitions to these states can be produced by photon, electron, or heavy particle bombardment. The latter two can excite forbidden transitions as well as optically allowed ones.

Measurements can be made of the energies of these states by measuring the energy losses of the incident particles such as has been done by Simpson¹ with electron bombardment. In the case of photon bombardment the energies are measured by determining the wavelengths of the lines in the absorption spectra as in the work of Madden and Codling.²

Another possibility for measurement of the energy levels presents itself in the cases where autoionization from the excited states takes place. This is the measurement of the energies of the characteristic lines in the energy spectrum of electrons emitted by a gas being bombarded. The energies of the excited states are the energies of the emitted electrons plus the ionization potential, provided the transition is back to the ground state of the resulting ion. If the transition is to another excited state identification becomes more difficult. Berry³ was the first to identify such structure in the energy spectra of electrons as due to autoionization. Moe and Petsch⁴ have also observed structure in their electron spectra. In previously published work from the laboratory⁵ a number of lines in the spectrum of helium were identified. The work reported here involves higher resolution measurements in helium and an extension to neon, argon, krypton, and xenon gases. A number of previously unreported levels have been discovered.

II. EXPERIMENTAL METHOD

The apparatus used was originally designed to make measurements of the angular and energy dependence of the cross sections for ejection of electrons by protons in gases and has been adapted to the present work. Fig. 1 shows a schematic of the apparatus. The bombarding particles were usually protons for hydrogen molecular

ions of 50 to 75 keV energy. The emitted electrons were energy analyzed by a parallel plate electrostatic analyzer and detected by an electron multiplier. After amplification the pulses from the detector go to a count rate meter. The output of this meter was divided by the beam current before going to the Y-axis of the recorder, the division being performed by a Philbrick MU/DV analog divider. The electrostatic analyzer was swept over the energy range desired with a slowly varying voltage which was also fed to the X-axis of the recorder. In earlier work the output pulses were counted on a scaler. Electrons ejected at an angle $\theta = 160^\circ$ were used since the ordinary cross section for ionization is quite small in that direction and the peaks should thus be more prominent assuming the autoionization electrons to be emitted isotropically. The resolution of the analyzer could be varied by changing slits. In most of our work the resolution was about $\frac{1}{2}$ eV.

III. EXPERIMENTAL RESULTS

Exploratory work has been done in all of the gases mentioned with the result that many new levels have been found. The energies of the more prominent lines in helium and neon are listed in Table I with their identification where known. More intensive work has been done in helium gas with the result that two new series have been identified and the energies of the terms measured.⁶ These are the $(2sns)^1S$ and the $(2snp)^3P$ series. Recently theoretical calculations of the energies of the various resonances in helium have become available⁷ and are included in the table. The agreement with our measured values is excellent. The $(2s2p)^1P$ level is one for which the energy had been calculated theoretically³ but the line had not previously been observed.

A number of peaks appear in the neon spectrum. Two series from inner shell excitation have been identified but much work remains to be done.

Lines detected in argon include ones with ejection energies at 3.0, 3.7, 4.4, 6.5, 7.2, 7.6, 9.6, 10.8, 11.6, 12.3, 14.3, 15.4, 16.2, and 17.2 eV. The resonance at 6.5 eV is an especially strong one but it has not yet been identified. In addition to these lines at fairly low energies we have detected structure in the 200 eV

region from argon. See Fig. 2. These peaks are undoubtedly the Auger electron peaks predicted by Fano and Lichten⁹ in their electron promotion theory of Ar^+-Ar collisions.

The krypton spectrum is also rich in structure with lines appearing at 6.6, 7.8, 8.5, 9.2, 9.6, 10.1, 10.9, 11.6, 12.4, and 13.2 eV ejection energies. The xenon spectrum has not yet yielded any prominent lines but only preliminary work has been done as yet.

IV. CONCLUSIONS

The technique of observing the energy spectrum of electrons from gases being bombarded by ions has already proved to be very fruitful in the discovery of new energy levels. Since this method is still largely unexplored there are many possibilities for future research.

The autoionization electrons are presumable emitted isotropically but this has not been verified and work should be done on the angular dependence of various lines.

Berry's work³ has all been at very low energies (below about 3 keV) and with heavier ions that we have used. His spectra show evidence of only a very few of the lines which we see at higher energies using lighter ions. The reason for this could probably be seen by bombarding with various ions and by studying the energy region between 3 and 75 keV.

The helium spectrum has been quite well studied and the energy level scheme understood. This is not the case for the heavier gases where only a few of the lines have been identified. There is room for much research in classification and identification of lines and series in neon, argon, krypton, and xenon.

There is a possibility of autoionization from higher levels such as the $sp,33$ level into the $2s$ continuum of helium as well as to the $1s$ continuum. This ought to be investigated.

Measurements of line widths using heavier and slower ions could be used to determine the lifetimes of the states.

Observations should be made in the 200 ev region for Ar^+ on Ar collisions to further verify the existence of Auger processes in connection with the theory of Fano and Lichten.⁹

TABLE I

Ejection energy	Excitation energy	Identification	Calculated energy
<u>Helium</u>			
3.24 eV	57.82 eV	$(2s^2)^1S$	57.87 eV
33.76	58.34	$(2s2p)^3P$	58.36
35.42	60.0	$(2p^2)^1D$	
35.52	60.1	$(2s2p)^1P$	60.27
37.57	62.15	$(2p^2)^1P$	62.15
38.20	62.78	$sp, 23^-$	62.77
38.37	62.95	$(2s3s)^1S$	62.99
38.50	63.08	$(2s3p)^3P$	63.14
39.07	63.65	$sp, 23^+$	63.69
39.64	64.22	$(2s4s)^1S$	64.22
		$(2s4p)^3P$	64.26
		$(2s5s)^1S$	64.70
40.13	64.71	$(2s5p)^3P$	64.71
<u>Neon</u>			
15.4			
19.0			
20.4			
21.7		$(2s2p^63s)^1S$	
22.2			
23.7		$(2s2p^63p)^1P$	
24.7		$(2s2p^64s)^1S$	
25.2		$(2s2p^64p)^1P$	
25.3		$(2s2p^65s)^1S$	
25.8		$(2s2p^65p)^1P$	
26.7			

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Fig 1

H⁺ COUNTS

H₂⁺ COUNTS