AD 436116

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

STRUCTURE BEYOND THE IONIZATION LIMIT IN INELASTIC ELECTRON SCATTERING IN THE RARE GASES*

C.E. KUYATT* and J. AROL SIMPSON

National Bureau of Standards, Washington, D.C., U.S.A.

Abstract

The intensity of inelastic scattering of electrons with 500 to 1000 eV primary energy by rare gases has been examined in an electron spectrometer with a resolution of ~0.7eV. At energies beyond the first ionization limit, structures localized in energy are detected. The structures in argon, neon, krypton, and xenon occur in a region a few eV below the L_1', M_1', N_1', and O_1' ionization edges respectively, and probably correspond to discrete autoionizing states of the inner electron involved. The structure in helium has been discussed recently by Fano, and arises from interference between a two-electron autoionizing state and a continuum. Because energy losses corresponding to extreme ultraviolet transitions are easily accessible, electron scattering provides a versatile method for the study of effects far out in the continuum.

The intensity of the inelastic scattering of 500-1000 eV electrons by rare gases has been examined in an electron spectrometer with a resolution of ~0.7 eV. A highly schematic diagram of the apparatus is shown in Fig. 1. An electron gun forms an intense highly-collimated electron beam which passes through the gas to be studied. The path length in the gas is about 40 cm, and the gas pressure is in the range 1 to 5 x 10^{-4} Torr. Those electrons scattered into a small solid angle about the direction of the electron beam are energy analysed and recorded either with an X-Y recorder or point-by-point on punched paper tape.

Attention was concentrated on the location of structure in the continuous region of the spectrum above the first ionization potential; consequently no attempt was made to accurately locate and identify the discrete loss peaks below the first ionization potential, as done by Arai[1] and by Geiger[2] for all the rare gases. Arai[3] has also examined the spectrum of the rare gases above the first ionization potential, but because of a relatively high pressure in his scattering chamber, small peaks in the continuum were observed which corresponded to twice the energy loss of the strong discrete loss peaks. These multiple loss peaks tended to obscure structure in the continuum, particularly for the heavier rare gases. In the work reported here, use of a sufficiently low gas pressure assured that multiple loss peaks were completely negligible. The structure observed must be attributed to single scattering events.

Fig. 2 shows the inelastic scattering intensity observed in helium with 500 eV electrons. A prominent asymmetric peak is observed at an energy loss of 60.0 eV, and a small peak at 63.5 eV. These peaks have been previously observed in electron scattering by Whiddington and co-workers[4] and by Silverman and Lassettre,[5] but have only recently been observed in ultraviolet (U-V) absorption by Madden and Codling.[6] The position of the first two U-V absorption lines and the limit of the series (He II, 2s) are shown in Fig. 2. The asymmetric line shape has been explained by Fano[7] as resulting from an interaction between a doubly excited state ($2s2p\,^1P$) and a continuum (1s,εp).

The inelastic scattering found in neon is shown in Fig. 3. Definite structure is observed near the L_1 ionization edge at 48.47 eV,[8] and is well correlated with the series of U-V absorption lines converging to the L_1 edge, as observed by Madden and Codling and shown on the figure. The line at 44.9 eV, shown dashed, is weak and not part of the series.

The results for argon are shown in Fig. 4. A prominent dip in the scattering intensity occurs at about 26.5 eV, and is again well correlated with the series of U-V absorption lines converging to the M_1 edge at 29.24 eV,[8] as observed by Madden and Codling, and shown on the figure. In this case the U-V measurements show that the interaction between the discrete state and the continuum results in a <u>decrease</u> in U-V absorption in the neighborhood of the line.

Fig. 5 shows the scattering intensity in krypton. A peak in the continuum is observed at about 23.7 eV and is probably due to a pre-ionization line in the series converging to the N_1 ionization edge at 27.51 eV.[9] This line has not previously been observed in either electron scattering or U-V absorption.

The results for xenon are shown in Fig. 6. Two small peaks in the continuum are observed at about 21.3 and 22.7 eV and are probably due to preionization lines in the series converging to the O_1 ionisation edge at 23.40 eV.[10] Although the peaks are small, they appear in all runs on xenon. The peaks are not instrumental since they did not occur in runs on other gases. These lines have not previously been observed in either electron scattering or U-V absorption.

Because energy losses corresponding to extreme ultraviolet transitions are easily accessible, electron scattering provides a versatile method for the study of effects far out in the continuum. New structures in the rare gas continua have already been observed. Recent improvements in apparatus and measurement technique are expected to give increased accuracy in determining the location and shape of these structures.

The authors wish to thank Dr. L. Marton, former Chief of the Electron Physics Section, for suggesting this investigation and for valuable suggestions during the design of the apparatus. The project would not have been possible without the aid and encouragement of Dr. L. M. Branscomb, former Chief of the Atomic Physics Division. It is a pleasure to acknowledge helpful discussions on theoretical aspects of the measurements with Dr. U. Fano and J. W. Cooper. Thanks are due to J. D. Steele for assistance with the experimental work, and to Dr. R. Madden for the communication of some of his results on ultraviolet absorption in advance of publication.

BIBLIOGRAPHY

1. S. Arai, Sci. Rep. Tôhoku Univ. I, <u>42</u> (1958) 51.
2. J. Geiger, Dissertation, Techn. Univ. Berlin, 1962.
3. S. Arai, Sci. Rep. Tôhoku Univ. I, <u>42</u> (1958) 123.
4. R. Whiddington and H. Priestly, Proc. Leeds Phil. Soc. <u>3</u> Pt. 2 (1935) 82; Proc. Roy. Soc. (London) A <u>145</u> (1934) 462; S.B. Coles and R. Whiddington, Proc. Leeds Phil. Soc. <u>3</u> (1937) 257; W. Swift and R. Whiddington, ibid. <u>3</u> (1937) 262.

*This research is a part of Project DEFENDER, sponsored by the Advanced Research Projects Agency, Department of Defense.

5. S. Silverman and E. N. Lassettre, Scientific Report No. 9 to Air Force Cambridge Research Center under Contract AF 19 (122)-642, Ohio State Univ. Research Foundation, Columbus, Ohio, 1957.
6. R. Madden and K. Codling, Phys. Rev. Letters, 10, 516 (1963).
7. U. Fano, Phys. Rev. 124 (1961) 1866.
8. C. M. Sitterly, Atomic Energy Levels, National Bureau of Standards Circular No. 467, Vol. I.(U.S. Government Printing Office, Washington, D.C., 1949).
9. C. M. Sitterly, Atomic Energy Levels, National Bureau of Standards Circular No. 467, Vol. II. (U.S. Goverment Printing Office, Washington, D.C., 1952).
10. C. M. Sitterly, Atomic Energy Levels, National Bureau of Standards Circular No. 467, Vol. III. (U.S. Goverment Printing Office, Washington, D.C., 1958).

Figure 1 - Schematic diagram of the experimental apparatus.

Figure 2 - Inelastic scattering of 500 eV electrons in helium. Intensity was measured in the forward direction. The two peaks on the left are caused by excitation of the $1s2p\ ^1P$ and $1s3p\ ^1P$ levels. Excitation of doubly excited states is shown in the inset. The position of the first two ultraviolet absorption lines observed by Madden and Codling are shown by vertical lines, together with the series limit (He II 2s and 2p).

Figure 3 - Inelastic scattering of 500 eV electrons in neon. Intensity was measured in the forward direction. The two peaks on the left are caused by excitation of discrete levels below the first ionization limit. A portion of the continuum is shown on an enlarged scale. Peaks caused by autoionizing states are evident, and agree well in position with ultraviolet absorption lines observed by Madden and Codling, which are shown by vertical lines. The series limit (Ne II $2s2p^6\ ^2S_{\frac{1}{2}}$) at 48.47 eV is also shown.

Figure 4 - Inelastic scattering of 500 eV electrons in argon. Intensity was measured in the forward direction. The three peaks on the left are caused by excitation of discrete levels below the first ionization limit. The prominent decrease in intensity in the continuum at an energy loss of about 26.5 eV agrees well in position with the first of a series of ultraviolet absorption lines observed by Madden and Codling, which are evidenced by a decrease in absorption. The first two of these lines and the corresponding series limit (A II, $3s3p^6\ ^2S_{\frac{1}{2}}$) at 29.24 eV are shown by vertical lines.

Figure 5 - Inelastic scattering of 500 eV electron in krypton. Intensity was measured in the forward direction. Portions of the curve are shown magnified. The three peaks on the left are caused by excitation of discrete levels below the first ionization limit. An increase in intensity observed in the continuum at an energy loss of about 23.7 eV is probably caused by the first of a series of autoionizing lines converging to the N_1 ionization edge (Kr II, $4s4p^6\ ^2S_{\frac{1}{2}}$) at 27.51 eV.

Figure 6 - Inelastic scattering of 500 eV electrons in xenon. Intensity was measured in the forward direction. The four peaks on the left are caused by excitation of discrete levels below the first ionization limit. There appears to be a peak associated with the excitation of discrete (autoionizing) lines between the first two ionization limits. Two definite but small peaks at energy losses of about 21.3 and 22.7 eV in the continuum are shown in the inset. These are probably caused by the first two of a series of autoionizing lines converging to the O_1 ionization edge (Xe II, $5s5p^6\ ^2S_{\frac{1}{2}}$) at 23.40 eV.

DISCUSSION

Question by S. BOROWITZ (U.S.A.) :

Is there any possibility that the structure observed is due to collective states of the ions ?

Answer by C. E. KUYATT (U.S.A.) :

Since I have no knowledge of the properties of collective states, if they exist, I cannot answer the question directly. However, the structures observed are in excellent agreement with ultra-violet measurements in Helium, Neon and Argon which are interpreted conventionally. The structures in Krypton and Xenon fit into the same pattern.

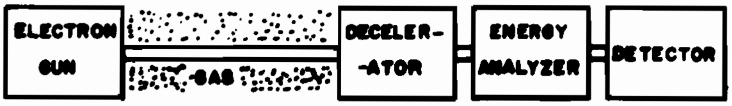
Question by H. HERING (FRANCE) :

What has been the reason you choose high energy electrons, when lower energy ones would have shown, in addition, metastable states ?

Answer by C. E. KUYATT (U.S.A.) :

Another purpose of the experiment is to determine the oscillator strength of atoms and molecules from the intensity of inelastic electron scattering. This requires an electron energy high enough for the Born approximation to be valid. In addition, the use of higher electron energies produces more excitation of states far in the continuum which were examined in this experiment.

Figure 1



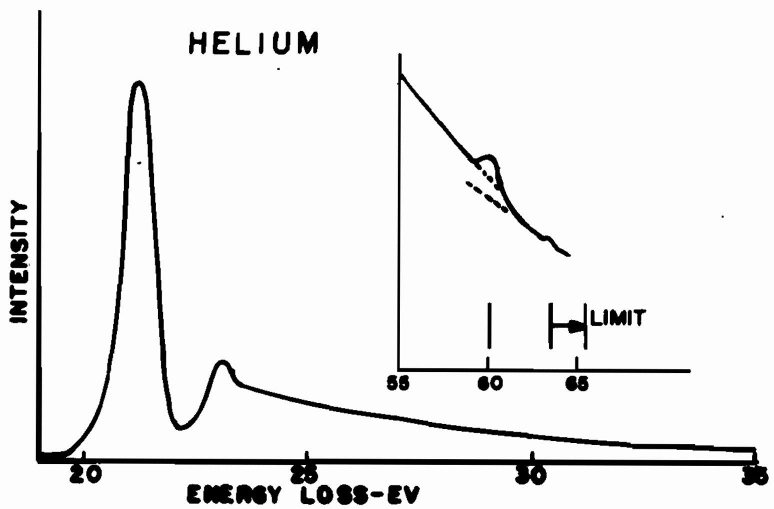
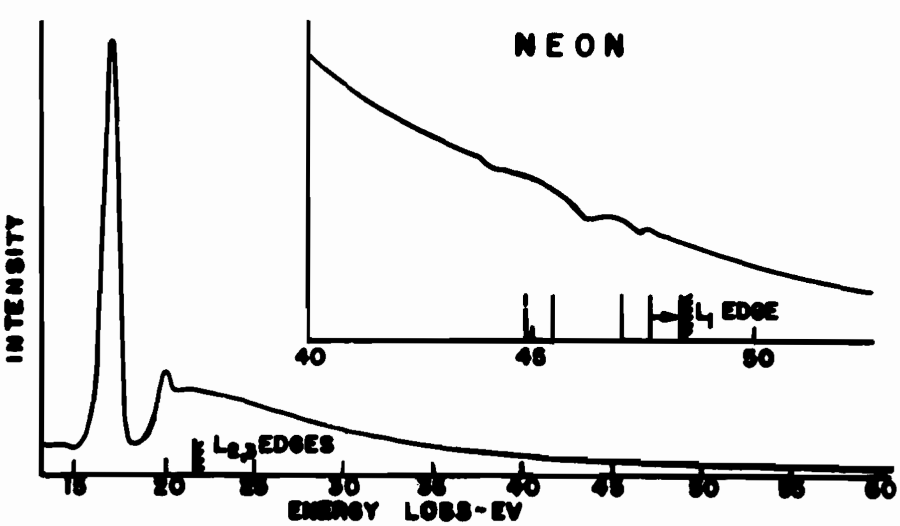


Figure 2

Figure 3



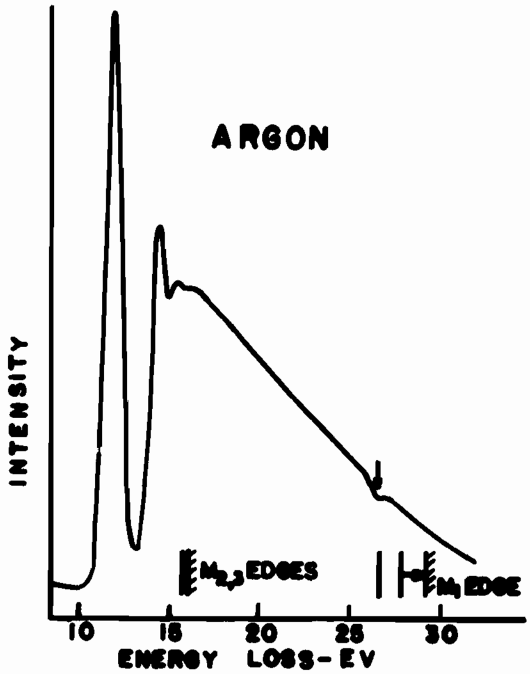


Figure 4

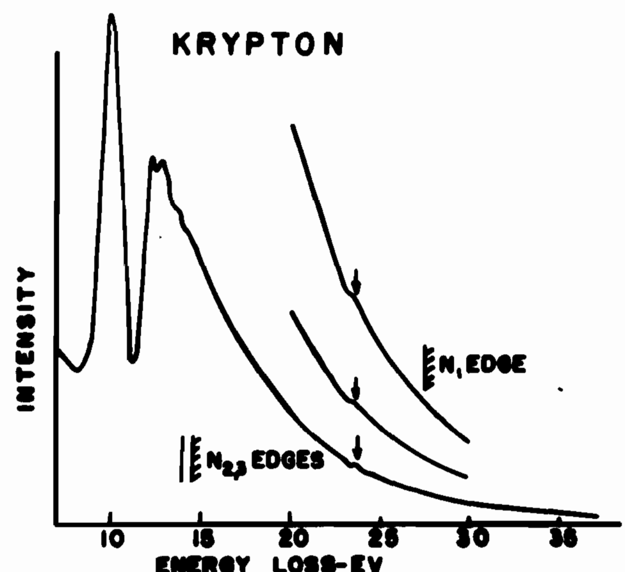


Figure 5

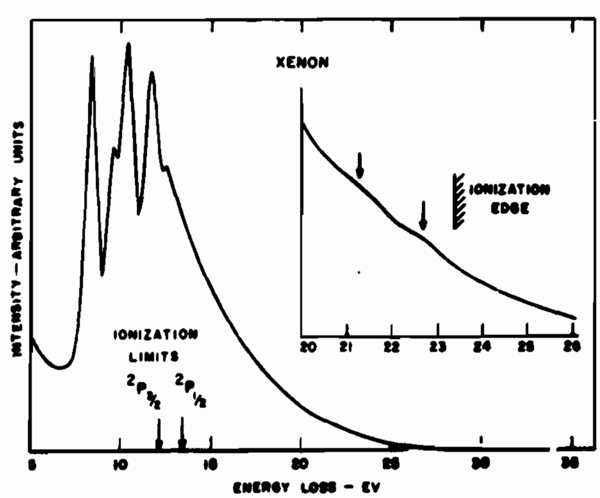


Figure 6