cence due to $Cs + H_2(v=3,4) \rightarrow Cs^* + H_2(v')$. When investigating N_2 instead of H_2 their signal strength is 10 to 15 times weaker. This is explained by our finding of the strongly nonresonant N_2 excitation in the primary process.

We hope to stimulate some new theoretical effort connected with these processes. Further experimental work along these lines including studies of polarization effects[14] is in progress in our laboratory.

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Auger-Electron Ejections from Xenon $N_{4,5}OO$ and Krypton $M_{4,5}NN$ Processes by Electron Impact near Threshold

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Kinetic energies of Auger electrons from xenon $N_{4,5}OO$ and krypton $M_{4,5}NN$ processes have been calibrated using a new procedure, and are found to be 0.20 ± 0.03 eV higher than those determined by other authors. A clear asymmetry has been observed on the profile of each line, and the peak position shifts steadily to higher energy, when the impact energy is lowered to within 20 eV above threshold.

Remarkable energy shifts have been reported by Hicks *et al.*[1] in electron-ejection spectra due to autoionization of helium excited by electron impact near threshold. This phenomenon has been interpreted using a model of the post-collision interaction between the ejected electron and the scattered electron. An analogous effect is also expected to occur in the process of Auger-electron ejection, though the ejected electron may interact with both the scattered electron and ionized one from the inner shell. In the present paper, we report on the features in the spectra of Auger electrons due to electron impact as the impact energy is lowered near to threshold.

The present investigation concerns the $N_{4,5}OO$ Auger spectra of xenon and the $M_{4,5}NN$ Auger spectra of krypton. Auger spectra of xenon (*NOO*) have been studied by Werme and co-workers[2] and those of krypton (*MNN*) by the same authors and Mehlhorn, Schmitz, and Stalherm.[3] Many of these Auger lines have been assigned, and their energies were determined with the accuracy of 0.1 eV.

A crossed-beam apparatus was used for the present experiment. The Auger spectra were excited by electron impact. A rotatable electron gun produces a beam of electrons with an energy half-width of approximately 0.4 eV and a current of about 15 μA. The electron beam intersects at right angles with an atomic beam and the small interaction region is viewed by a fixed entrance aperture of an analyzer which consists of an electrostatic lens and a hemispherical electrostatic deflector, the mean radius of which is 50 mm.

The analyzer was operated in a constant-resolution mode, which was used in preceding works by the authors.[4] The potential difference between the inner and outer spheres of the deflector was fixed to make electrons of a certain energy, about 2 eV in this work, pass through the deflector. The voltage to decelerate an electron before entering the deflector was scanned at the electron lens. Pulses from a channel electron multiplier which was placed behind the deflector were accumulated into a multichannel analyzer by means of a multiscanning scaling technique. Linearity and accuracy of the scanning voltage against the channel number were determined within 0.1% and 0.01 eV, respectively, with a digital voltmeter. An energy resolution of about 50-meV full width at half-maximum was steadily provided in the ejection spectra.

The energy calibrations of the xenon $N_{4,5}OO$ and krypton $M_{4,5}NN$ Auger spectra were achieved by comparing the Auger peaks with the well-known autoionization lines from helium which was mixed with the sample gases. In practice, we took the $(2s2p)^3P$ and the $(2s2p)^1P$ autoionizing lines of helium as standards and assumed the kinetic energies of these peaks to be 33.71 eV and 35.54 eV, which were given from the state energies 58.29 eV and 60.12 eV diminished by the ionization energy 24.58 eV, respectively. In spite of the slight difference between the state energy and the peak energy caused by the asymmetric shape of these spectra, the uncertainty of the assumed values is believed to be less than 0.02 eV. It has also been known that shifts in the kinetic energies of the electrons from these states because of threshold effects are negligibly small when the electron impact energy is higher than 75 eV. The accuracy of the energy values of the discrete peaks in the Auger-electron spectra determined in this work has been evaluated to be about ± 0.03 eV.

Auger-electron spectra of xenon ($N_{4,5}OO$) by electron impact at various impact energies are shown in Fig. 1. The ejection angle is 150° with respect to the primary beam direction. Impact energy is shown on the left-hand side of each spectrum. The length of the vertical line shown in each spectrum indicates the distance to the base line.

Two important features were derived from these spectra; one of them is a distinct difference in energy values of Auger electrons determined by the present method from those by former authors,[2,3] the other is a sort of threshold effect which appears when the impact energy is lowered. The spectrum at an impact energy of 500 eV is seen to be similar to that of former works, except for peaks due to autoionization of helium. It is found, however, that the energy of each Auger line is larger in value than that of former works by 0.20 ± 0.03 eV. In the former study, the xenon $N_{4,5}OO$ Auger spectra were calibrated against the $N_5O_1O_{2,3}$ ($^1P_1$) and the $N_5O_{2,3}O_{2,3}$ ($^1D_2$) lines. The energies of these lines were calculated from optical data of the xenon N_5 ionization energy[5] and the energies of the doubly ionized atoms in the states $O_1O_{2,3}$ ($^1P_1$) and $O_{2,3}O_{2,3}$ ($^1D_2$).[6] In comparison with this method, the energy calibration mode in the present study is more direct and must be more accurate.

The most significant feature derived from Fig.

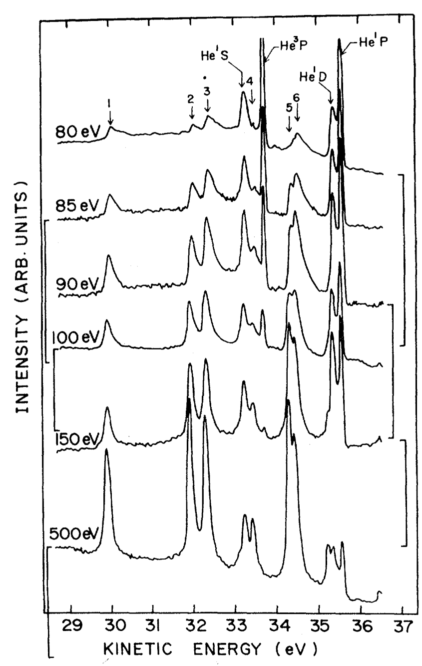

FIG. 1. Xenon $N_{4,5}OO$ Auger-electron spectra at various impact energies. Helium is mixed for energy calibration.

TABLE I. Kinetic energies (eV) of xenon $N_{4,5}OO$ Auger electrons at various impact energies.

Impact energy (eV) \ Line number / Assignment[a]	1 $N_5O_{2,3}O_{2,3}(^1S_0)$	2 $N_4O_{2,3}O_{2,3}(^1S_0)$	3 $N_5O_{2,3}O_{2,3}(^1D_2)$	4 $N_5O_{2,3}O_{2,3}(^3P_2)$	5 $N_4O_{2,3}O_{2,3}(^1D_2)$	6 $N_5O_{2,3}O_{2,3}(^3P_0)$
78	30.08		32.50			
80	30.05	32.06	32.39			34.54
85	30.03	32.01	32.38	33.53	34.38	34.53
90	29.98	31.99	32.36	33.48	34.37	34.48
100	29.94	31.93	32.32	33.46	34.33	34.46
150	29.95	31.94	32.32	33.45	34.32	34.44
500	29.91	31.90	32.28	33.42	34.28	34.40
3000–5000[a]	29.73	31.71	32.09	33.21	34.07	34.21
ΔE[b]	0.18	0.19	0.19	0.21	0.21	0.19

[a]From Ref. 2

[b]ΔE indicates the difference in energy value (eV) determined in the present work from that by other authors.

1 is that the line profiles of Auger-electron spectra appear to become noticeably asymmetric and show tails toward the high-energy side, and that the widths of the peaks appear to spread with decreasing impact energy: from 150 meV at high impact energy to 220 meV at minimum impact energy.

The peaks in the Auger spectra steadily shift to higher energies as the impact energy is lowered. Kinetic energies of the xenon $N_{45}OO$ Auger peaks at various impact energies are shown in Table I. This phenomenon found in Auger-electron ejection may be a similar one to that in the near-threshold excitation of autoionizing states by electron impact. Analogously to the case of autoionization, this effect may be qualitatively explained by considering the post-collision Coulomb interaction between the Auger electron and the slowly receding electrons. Auger-electron ejection by electron impact, however, may produce two kinds of slowly moving electrons, that is, inelastically scattered electrons and directly ionized electrons from the N shell. When the impact energy of the incident electron is lowered to near the threshold for xenon N_4, N_5 ionization, the energy of either the scattered electron or the directly ionized one may become very low, because the two electrons will share the excess energy with each other. For example, if the impact energy is 10 eV larger than the threshold for Xe N_5 ionization (69.52 eV),[5] the electrons having an energy of 9.5 eV and 0.5 eV will travel a mean distance of about 90 Å and 20 Å, at the moment of transition, because the typical Auger transition time is about 5×10^{-14} sec. The resulting Coulomb interaction between the Auger electrons and the other two kinds of electrons is approximately 0.2 eV and 0.7 eV, respectively. This interaction results in the shift of the peak and the tailing toward high-energy side.

Figure 2 shows the krypton $M_{45}NN$ Auger spectra at various impact energies. Just as the case with xenon, it is found that even at high impact energies, where any threshold effect cannot be possible, the position of each krypton Auger line in

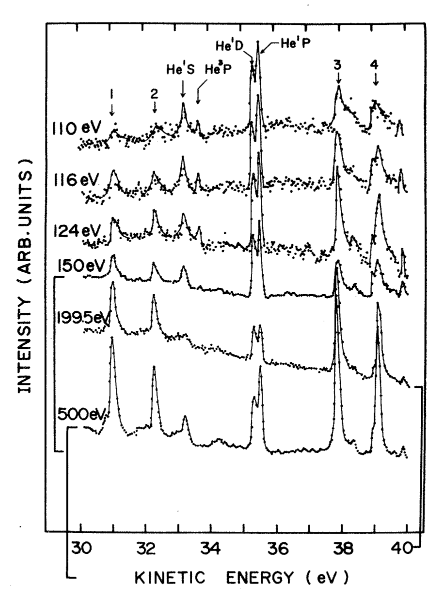

FIG. 2. Krypton $M_{4,5}NN$ Auger-electron spectra at various impact energies.

TABLE II. Kinetic energies (eV) of krypton $M_{4,5}NN$ Auger electrons at various impact energies.

Impact energy (eV) \ Line number, Assignment[a]	1 $M_5N_1N_{2,3}(^1P_1)$	2 $M_4N_1N_{2,3}(^1P_1)$	3 $M_5N_1N_{2,3}(^1P_1)$	4 $M_4N_1N_{2,3}(^1P_1)$
110	31.19	32.50	38.00	
116	31.14	32.41	37.94	39.19
119.3	31.11	32.38	37.94	39.18
124	31.10	32.35	37.88	39.16
128.9	31.09	32.34	37.93	39.12
150	31.09	32.35	37.92	39.12
199.5	31.09	32.34	37.87	39.10
500	31.08	32.33	37.87	39.08
WBS[b]	30.89	32.14	37.67	38.91
MSS[c]	30.91	32.15	37.67	38.91
ΔE[d]	0.19	0.19	0.20	0.17
	0.17	0.18	0.20	0.17

[a]From Ref. 7.
[b]From Ref. 2.
[c]From Ref. 3.
[d]See footnote b in Table I.

the spectra must be shifted equally to the high-energy side by 0.20 (± 0.03) eV as compared with the results of the former investigators. The asymmetric line profile with prominent tailing toward higher energy and the shift of each Auger peak to the high-energy side are also recognized. The energy values of the krypton $M_{4,5}NN$ Auger peaks at various incident energies are presented in Table II.

The interpretation of these substantial differences in energy value between those calculated from optically determined energy levels[5,6] and present results remains to be done. Although these threshold effects in Auger-electron ejection by electron impact are more complicated than those in autoionization, they must be an important example of processes which are associated with the electron correlation problems.

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