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MULTICHANNEL RESONANCES IN THE FORWARD SCATTERING OF ELECTRONS BY HELIUM

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This Letter reports the observation of resonances in the forward, inelastic cross section for scattering of electrons by helium. Resonance structure occurs for incident electron energies between 22.4 and 22.8 eV in all four of the open channels. These channels correspond to excitation of the final-state, neutral-helium levels $(1s2s)\,^3S$, $(1s2s)\,^1S$, $(1s2p)\,^3P$, and $(1s2p)\,^1P$. A resonance is caused by interference between the direct excitation of the final state and excitation via an intermediate negative-ion state. The negative-ion states seen here are considered to be formed from the $n=3$ levels of helium (22.7-23.0 eV) since the observed resonances occur just below these helium levels. There is insufficient information to identify the negative ion configurations, but most likely the ones involved are $(1s3s^2)$, $(1s3s3p)$, and $(1s3p^2)$. Together with earlier reports of resonances in total scattering[1,2] and in the inelastic $2\,^3S$ channel at 72°,[3] there now have been observed six different manifestations of these resonances.

The apparatus employed has been described, and used previously in high-resolution elastic and inelastic electron-scattering experiments at incident energies considerably above threshold.[2,4,5] This Letter reports the use of the apparatus in a new mode of operation in which electrons with a fixed energy loss and near zero residual energy are observed after leaving the scattering chamber. The number of electrons collected is obtained as a function of the incident energy. Primary electrons in a narrow energy range are selected from a thermionic source by a hemispherical electrostatic deflecting monochromator and pass into the gas-filled ($\sim 5\times 10^{-2}$ Torr cm) collision chamber. A second hemispherical analyzer is adjusted so that those electrons that have lost a fixed amount of energy pass through it and are collected by a Faraday cup. It is estimated that scattering angles of more than 0.12 radian do not contribute significantly to the detected signal. The apparent energy resolution is 0.15 eV.

Figure 1 shows reproductions of X-Y recorder traces of electron current versus incident energy for fixed energy losses of 19.818 ($2\,^3S$), 20.614 ($2\,^1S$), 20.962 ($2\,^3P$), and 21.216 ($2\,^1P$) eV. Excessively large noise pulses have been deleted. The zeros of scattered electron current in Fig. 1 have been arbitrarily displaced. However, it can be said that the smooth part of the cross section in the triplet curves is no greater than the resonance structure, whereas the smooth part of the singlet cross sections is several times larger than the resonance fea-

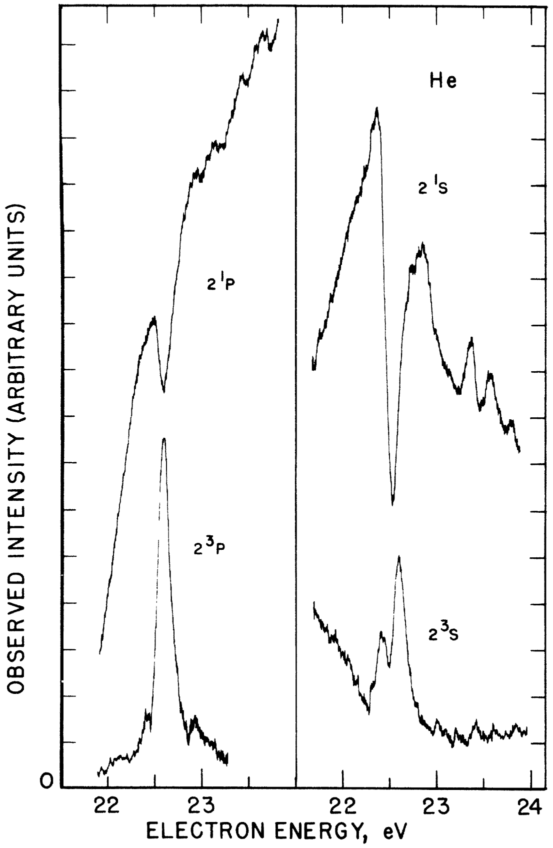

FIG. 1. Forward inelastic electron scattering intensity (zero displaced) versus incident electron energy in helium. The number of electrons that have lost a fixed amount of energy is shown as a function of the incidnet energy. The final-state helium levels are indicated by the labels on the curves.

tures. The energy scale in Fig. 1 is established by observing the 19.31-eV peak due to the helium "window"[2] in the transmitted (zero-energy-loss) electron current. Features of the structure in Fig. 1 are located within ±0.02 eV relative to the 19.31-eV resonance, and within about ±0.05 eV on an absolute energy scale.

The two well-defined peaks in the $2\,^3S$ channel are 0.18 eV apart, and the larger is at 22.60 eV. Successive recorder sweeps show that the peak in the $2\,^3P$ curve occurs at the same energy as the larger $2\,^3S$ peak. The tailing on the high-energy side of the triplet peaks indicates that they have a line shape with positive q.[6] Schulz and Philbrick[3] have observed a peak in the $2\,^3S$ loss curve, for a scattering angle of 72 degrees, near 22.42 eV in agreement with the smaller $2\,^3S$ peak in Fig. 1.

The structure in the singlet losses is more complex. The dominant feature in both curves, namely a rise followed by a sudden dip, is that of a negative-q line shape. The minima occur at 22.53 eV in the $2\,^1S$ curve and 22.60 eV in the $2\,^1P$ curve. It seems likely that the $2\,^1S$ resonance corresponds to the 22.42-eV peak in the $2\,^3S$ channel; but, it is not clear whether the $2\,^1P$ resonance is the same as either of the $2\,^3S$ peaks, or represents yet another resonance state. The $2\,^1S$ peak near 22.8 eV apparently is an additional $n=3$ negative ion state. The $2\,^1S$ resonances above 23.3 eV presumably are associated with negative ion states formed from the $n=4$ levels of helium.

The resonance structure in total scattering observed by Kuyatt, Simpson, and Mielczarek[2] in the range 22.4-22.9 eV corresponds quite closely to the structure in Fig. 1. In fact, there is a sharp minimum in their total cross-section curve at 22.60 eV. Resonance structure in the total scattering cross section should reflect mostly inelastic scattering since the negative-ion states are more closely coupled to the excited states than to the ground state. However, due to the lack of knowledge of the angular distribution of the inelastic resonances, one can say little about the correlation between the maxima and minima of the total and inelastic cross sections.

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