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We have observed a broad  $P$ -wave resonance at about 50 eV primary energy in the angular distribution of electrons scattered after excitation of the  $2^3S$  state of helium. The resonance has a width of about 15 eV and affects the differential excitation cross section by more than 3 orders of magnitude. It is suggested that this resonance is associated with the temporary formation of triply excited states of the negative helium ion.

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## Observation of a Broad Resonance in the $2^3S$ Excitation of Helium by Electron Impact\*

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We have observed a broad  $P$ -wave resonance at about 50 eV primary energy in the angular distribution of electrons scattered after excitation of the  $2^3S$  state of helium. The resonance has a width of about 15 eV and affects the differential excitation cross section by more than 3 orders of magnitude. It is suggested that this resonance is associated with the temporary formation of triply excited states of the negative helium ion.

Narrow resonances in the  $2^3S$  excitation cross section of helium just above threshold have previously been reported by Schulz and Philbrick<sup>1</sup> at an angle of  $72^\circ$ , and by Ehrhardt and Willmann<sup>2</sup> at angles between  $7^\circ$  and  $110^\circ$ . These resonances were also observed in the forward scattered electron current after excitation of the  $2^3S$  state by Chamberlain and Heideman<sup>3</sup> and are associated with the formation of resonant states of doubly excited  $\text{He}^-$ .

Structure in the transmitted electron current at 57.1 and 58.2 eV, reported by Kuyatt, Simpson, and Mielszarek,<sup>4</sup> was interpreted by Fano and Cooper<sup>5</sup> as associated with the temporary formation of the triply excited states of  $\text{He}^-$ ,  $(2s^22p)^2P$  and  $(2s2p^2)^2D$ . Simpson, Menendez, and Mielszarek<sup>6</sup> investigated the angular dependence of

narrow resonances in the  $2^3S$  excitation due to these states.

All of the above resonances are extremely narrow, less than 100 meV, and give rise to small changes in the excitation cross section. In the present work a resonance has been observed with a width of about 15 eV, due to which the excitation cross section varies by more than 3 orders of magnitude.

The present apparatus is described in detail elsewhere.<sup>7</sup> Briefly, an electron gun produced a  $1-5 \mu\text{A}$  beam of electrons with full width at half-maximum of 150 meV that interacted with the static target gas which was at a pressure of 1 mTorr. Electrons ejected at an angle  $\theta$  with respect to the primary beam, with energy loss corresponding to excitation of the  $2^3S$  state of

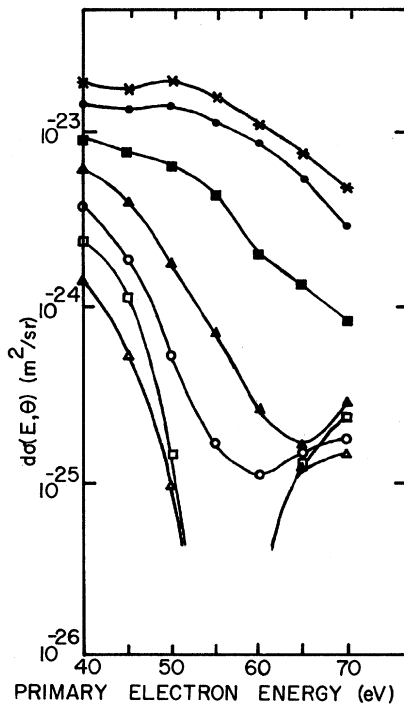


FIG. 1. Differential cross sections for electron excitation of the  $2^3S$  state of He as a function of primary energy for angles between  $25^\circ$  and  $80^\circ$ . Asterisks,  $25^\circ$ ; closed circles,  $30^\circ$ ; closed squares,  $40^\circ$ ; closed triangles,  $50^\circ$ ; open circles,  $60^\circ$ ; open squares,  $70^\circ$ ; open triangles,  $80^\circ$ . The minima in the  $70^\circ$  and  $80^\circ$  curves are less than  $4 \times 10^{-26} \text{ m}^2/\text{sr}$ .

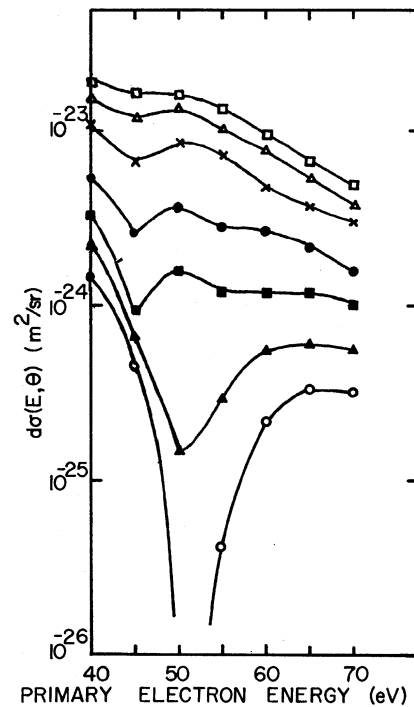


FIG. 2. Differential cross section for electron excitation of the  $2^3S$  state of He as a function of primary energy for angles between  $90^\circ$  and  $150^\circ$ . Open circles,  $90^\circ$ ; closed triangles,  $100^\circ$ ; closed squares,  $110^\circ$ ; closed circles,  $120^\circ$ ; crosses,  $130^\circ$ ; open triangles,  $140^\circ$ ; open square,  $150^\circ$ . The minimum in the  $90^\circ$  curves is less than  $5 \times 10^{-27} \text{ m}^2/\text{sr}$ .

helium, were selected by a parallel-plate analyzer with an energy resolution of 0.35%, and detected by a channel electron multiplier. The angle  $\theta$  was varied by rotating the electron gun with respect to the analyzer entrance slits.

Figures 1 and 2 show the measured cross sections for excitation of the  $2^3S$  state of helium as a function of primary energy  $E$  for fourteen angles between  $25^\circ$  and  $150^\circ$ . The cross sections were placed on an absolute basis by normalization to the 50-eV data of Ref. 7. The uncertainty in the absolute value of the cross sections is less than  $\pm 30\%$ , and the internal consistency is better than  $\pm 10\%$ . An upper limit of  $4 \times 10^{-26} \text{ m}^2/\text{sr}$  has been placed on the cross sections at 55 and 60 eV at both  $70^\circ$  and  $80^\circ$ , and  $5 \times 10^{-27} \text{ m}^2/\text{sr}$  at 50 eV and  $90^\circ$ .

Figure 3 shows the total excitation cross section for the  $2^3S$  state of helium, obtained by integration of the data shown in Figs. 1 and 2. The maximum in the total cross section occurs at the same energy as the minima in the differential cross sections, indicating that the process pro-

ducing the minima cannot be one of simple interference, but rather the effect of a broad resonance.

The differential cross section can be approximated by

$$d\sigma(E, \theta) = (1/E) \left| \sum_L (2L+1) T_L(E) P_L(\cos\theta) \right|^2,$$

where  $T_L$  is the transition matrix for excitation of the  $2^3S$  state of helium from the ground state, containing both real and imaginary elements for each  $L$  value. Fitting this equation to the experimental data at each energy, Macek and Wooten<sup>8</sup> have extracted the elements of the  $T$  matrix for the first four partial waves with a  $\chi^2$  of about 1 per point. Further analysis is required, but the preliminary results indicate that the  $S$ ,  $D$ , and  $F$  waves are fairly constant with the  $S$ - and  $D$ -wave contributions destructively interfering at  $90^\circ$ , while the  $P$ -wave amplitude and phase vary rapidly in this energy range, identifying the major effect as a broad  $P$ -wave resonance.

The width of the resonance indicates that it is not due to the temporary formation of the two

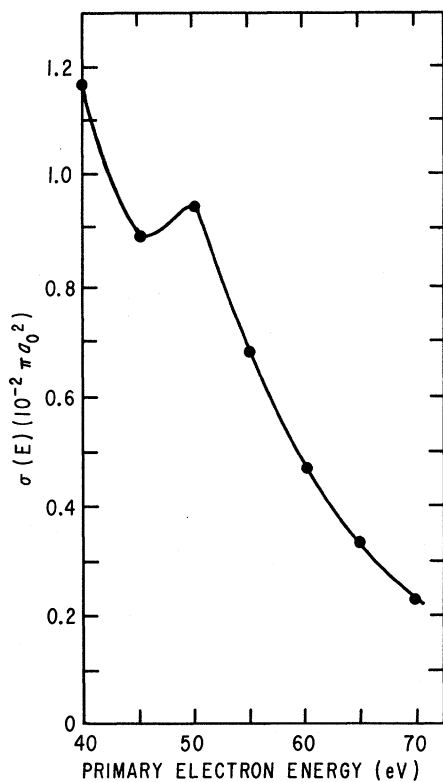


FIG. 3. Total cross section for electron excitation of the  $2^3S$  state of He as a function of primary electron energy.

previously observed states of  $\text{He}^-$ , ( $2s^22p$ ) and ( $2s2p^2$ ), but possibly to the compound states,  $2s(2snp \pm 2pns)$ . While these states correspond

to narrow resonances in Li, they need not correspond to narrow resonances in the isoelectronic sequence of  $\text{He}^-$ . In a comparison of He and  $\text{H}^-$  resonances, it has been found<sup>9</sup> that the (+) series of narrow resonances in He corresponds to a single broad resonance in the isoelectronic sequence of  $\text{H}^-$ . Measurements of the cross sections differential in primary energy and angle for excitation of all the singly excited states of helium over larger energy domain are in progress.

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<sup>1</sup>G. J. Schulz and J. W. Philbrick, Phys. Rev. Lett. **13**, 477 (1964).

<sup>2</sup>H. Ehrhardt and K. Willmann, Z. Phys. **203**, 1 (1967).

<sup>3</sup>G. E. Chamberlain and H. G. M. Heideman, Phys. Rev. Lett. **15**, 337 (1965).

<sup>4</sup>C. E. Kuyatt, J. A. Simpson, and S. R. Mielczarek, Phys. Rev. **138**, A385 (1965).

<sup>5</sup>U. Fano and J. W. Cooper, Phys. Rev. **138**, A400 (1965).

<sup>6</sup>J. A. Simpson, M. G. Menendez, and S. R. Mielczarek, Phys. Rev. **150**, 76 (1966).

<sup>7</sup>G. B. Crooks, Ph. D. thesis, University of Nebraska, 1972 (unpublished).

<sup>8</sup>J. Macek, private communication.

<sup>9</sup>J. Macek and P. G. Burke, Proc. Phys. Soc., London **92**, 351 (1967).