binding and "angle transformations," as well as large effects due to true meson absorption, Pauli correlations, and ρ-meson exchange. Because of the large contributions from all of these sources, it is imperative that a systematic calculation simultaneously including all of these effects be carried out. This will hopefully clarify the situation considerably.

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Resonances Below the $n = 3$ Doubly Excited States of Helium*

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Some features have been observed for the first time around 69 eV in the electron-impact differential excitation cross section of the bound state $2\,^3S$ of helium, measured in the forward direction. The main feature, which involves a variation of about 2.8×10^{-21} $\mathrm{cm}^2\ \mathrm{sr}^{-1}$ in the cross section, may be assigned to the negative-ion state $3s\,^23p\,(^2P)$ thus lying at about 68.98 ± 0.07 eV; a second feature is observed at about 69.67 ± 0.08 eV. The detection of these resonances has a special interest because the decay of these He^- states involves the three electrons concerned in the collision process.

The $n = 2$ region (around 60 eV) of the doubly excited states of helium was investigated by many techniques which lead to an accurate knowledge of these states.[1] Associated with the first members among them, at least two negative-ion resonances were observed by various electron-impact techniques, as summarized by Schulz[2] and by Hicks *et al.*[3] In the $n = 3$ region (around 70 eV) however, few data are available; Madden and Codling[4] determined the energy values of the optically allowed series $3sn'p\,(^1P)$, but for the other levels some theoretical data and very little experimental data are available.[5] No detection nor theoretical prediction of He^- resonances was reported so far in this region. The energy diagram presented in Fig. 1 summarizes these data for the lower-lying levels of He and He^- in both regions. The features around 69 eV which are reported in the present work bring a new interest on this region and raise questions about configurations of new He^- states with three electrons in the $n = 3$ shell. Furthermore, what is novel in the observations of these He^- states is that their decay into the $2\,^3S$ channel involves all three electrons which participate in the collision.

These features have been observed in the inelastic electron scattering by helium. They appear as a perturbation around 69 eV in the differential excitation cross section of the bound state $1s2s\,(^3S)$, measured in the forward direction.

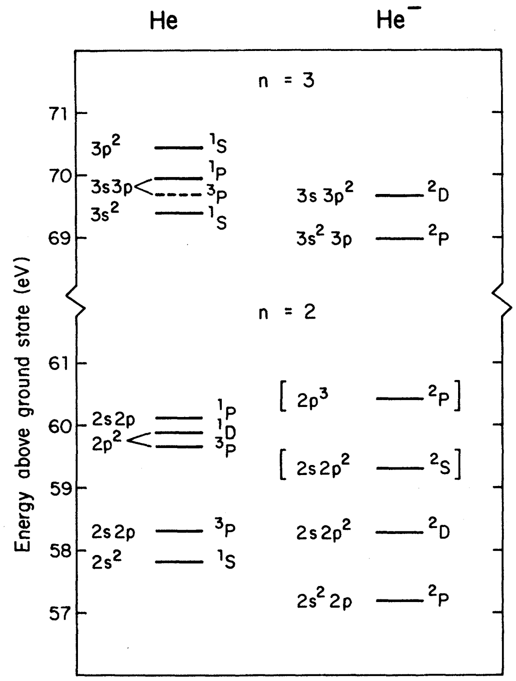

FIG. 1. Energy diagram of the lower-lying levels of He and He$^-$ in the $n=2$ and $n=3$ regions. Other He states are possible in the $n=3$ region, but their positions are unknown; the dashed line representing the $3s3p$ (^3P) state is purely symbolic. The two He$^-$ resonances in the $n=3$ region are possible assignments of the features reported in the present work. The He$^-$ states in brackets are the type-II resonances calculated by Nesbet (Ref. 6) [the ^2S state was observed by Spence (Ref. 7)]; according to the calculations of Ormonde, Kets, and Heideman (Ref. 8), other He$^-$ states are possible in the $n=2$ region, around 60 eV.

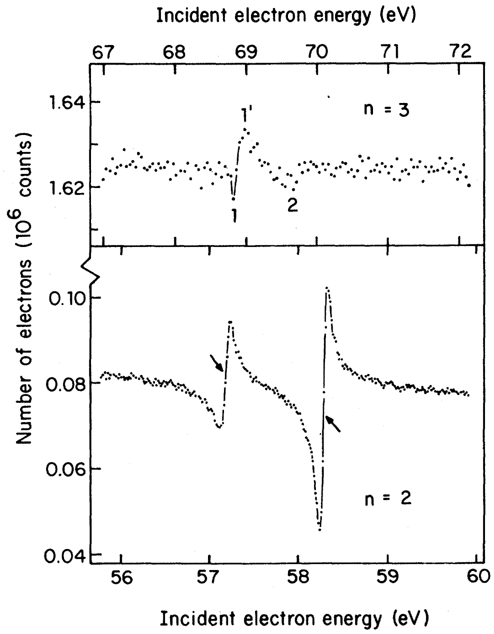

FIG. 2. Measurement of the electron-impact differential excitation cross section of the state $1s2s(^3S)$ in the forward direction ($\theta=2°$), for incident energies corresponding to the $n=2$ and $n=3$ regions. The resonance energies of the states $2s^2 2p(^2P)$ and $2s2p^2(^2D)$, at 57.19 and 58.29 eV, respectively, are indicated by arrows in the $n=2$ curve, which is similar to that presented by Simpson, Menedez, and Mielczarek (Ref. 9). The $n=3$ curve was straightened in order to display the features on a flat background. Each point represents an energy interval of 16 meV in the $n=2$ region, and 40 meV in the $n=3$ region.

This technique of observing resonances in the autoionization region by the detection of their decays in the excitation of bound states was first used by Simpson, Menendez, and Mielczarek,[9] in the $n=2$ region of helium. Its sensitivity was later improved by Roy and Carette[10] and it was applied to the other rare gases[11-13] with success.

The electron spectrometer used in the present work was extensively described elsewhere.[12,14] In short, it involves a 127°-cylindrical monochromator-analyzer tandem, electrostatic lenses, and a collision chamber (scattering length: 3.3 cm). For the present measurements, the overall energy resolution was about 50 meV, and the pressure in the scattering chamber 6×10^{-3} Torr (0.8 Pa). In order to minimize the background due to the primary beam, the analyzer was set at $\theta=2°$; the width at half-intensity of its angular acceptance function is about $\pm 2.5°$. The energy analyzer was tuned at the fixed energy loss of the $2\,^3S$ state (19.82 eV) and the incident electron energy was swept in the suitable range. The measurements for the $n=3$ region extented over a period of three weeks, with frequent electron energy calibrations in order to track energy drifts.

I present in Fig. 2 our measurements of the differential excitation cross section of the $2\,^3S$ state both in the $n=2$ and 3 regions. The vertical scales were corrected for a low background, which was not negligible relative to the weak cross section of the forbidden $2\,^3S$ line (about 19%). Great care was taken to achieve an accurate energy calibration of the $n=2$ resonances in order to have a handy reference point for the $n=3$ region. As in the work of Hicks *et al.*[3] and in a previous paper on krypton,[13] we chose to exploit the double-collision event in the $2\,^1P$ excitation function (21.217 eV) with the $1s\,2s^2(^2S)$ resonance, the peak of which is assumed to be at 19.36 ± 0.01 eV (as determined from the data of Cvejanović, Comer, and Read[15]). By means of the graphical method described by Comer and Read,[16,17] the resonance energies were accurately determined in the excitation functions of three different states ($2\,^3S$, $2\,^1S$, and $2\,^1P$), and the absolute calibration finally gave 57.19 ± 0.03 eV and 58.29 ± 0.03 eV for the He^- states $2s^22p(^2P)$ and $2s2p^2(^2D)$, respectively, with an energy separation of 1.094 ± 0.012 eV. These values, indicated by arrows in Fig. 2, are in good agreement with those obtained by Hicks *et al.*[3]: 57.22 ± 0.04 eV and 58.30 ± 0.04 eV, which are the most accurate presently available. As shown in Fig. 2, the relative strength[9,12] $\Delta\sigma/\sigma$ of these resonances is very high in this channel: about 32% and 71%, respectively, without taking into account the flattening effect of the instrumental convolution. These large cross-section variations show that the $2\,^3S$ channel provides the most sensitive indicator for these coumpound states. By measuring an energy-loss spectrum at about this incident energy in order to determine the ratio of the $2\,^3S$ to $2\,^1P$ differential cross sections, and using absolute data[18] for the $2\,^1P$ cross section, I estimate that these resonances involve cross-section variations of about 1.1 and 2.4×10^{-19} cm^2 sr^{-1}, respectively.

A straightening procedure proposed by Bolduc, Quéméner, and Marmet[19] (fully described by Carbonneau, Boldac, and Marmet[20]) was used to remove the steeply sloping background which obscured the weak feature in the $n=3$ region. The vertical scale given in Fig. 2 for this curve refers to the accumulated counts near the feature 1–1′. It was determined that the features 1–1′ and 2 involve relative changes in the measured cross section of about 1.0% and 0.3%, respectively. From this evidence one infers a cross-section variation of about 2.8 and 0.8×10^{-21} cm^2 sr^{-1}, respectively, for the two resonances. This is far weaker than the cross-section changes for the $n=2$ resonances. If the ratio of the resonance strengths for the two regions is the same in the other observation channels, the $n=3$ resonances may be unobservable by other electron-impact techniques.

According to the energy calibration given above, the energy positions of the features 1, 1′, and 2 are 68.83 ± 0.04, 69.00 ± 0.04, and 69.67 ± 0.04 eV, respectively. For these conditions, the detected electrons leave the scattering chamber with a kinetic energy of about 49 eV. No electron may be ejected from helium with this energy following autoionization, and no other secondary process is likely to occur. According to many calculations[5] the $3s^2(^1S)$ state lies at about 69.4 eV. The feature 1–1′ is then very likely to be a Feshbach resonance corresponding to the state $3s^23p(^2P)$, with an electron affinity of about 0.4 eV, as shown in Fig. 1. The resonance energy is estimated to be 68.98 ± 0.07 eV. The natural energy width Γ is estimated to be about 180 ± 40 meV, assuming that the overall broadening affect[17,21,22] of the energy resolution and the Doppler effect is about 65 meV. The dip 1 followed by the fast rise from 1 to 1′ in Fig. 2 seems quite characteristic of a narrow resonance profile; however the fall on the high-energy side exhibits an unexpected broadening which could indicate the contribution or the overlapping of another resonance in this region. The actual width Γ of the first resonance would then be smaller than the value given above.

The feature 2 appears as a dip in the cross section which seems distinct from the feature 1–1′. In analogy with the $n=2$ region (see Fig. 1), it could be assigned to the state $3s3p^2(^2D)$; its energy position would be 69.67 ± 0.08 eV. The position of the parent state $3s3p\,^1P)$ was determined at 69.92 eV by Dhez and Ederer,[23] but the position of the ^3P term is unknown as shown in Fig. 1. On the other hand, the ^2D state of He^- could also be located at a lower energy, thus being responsible of the broadening on the high-energy side of the feature 1–1′, as suggested previously. Then the dip 2 should be assigned to another He^- resonance, or could be a threshold feature (Wigner cusp[24]) caused be the presence of a He autoionizing state at this position, as the states $3s3p(^3P)$ or $3p^2(^1D)$ whose positions are unknown. These suggestions indicate the need of accurate calculations for the determination of the possible He^- resonances and the He parent states in this region. In addition, the observation of He^- resonances involving three-electron decay calls for further theoretical investigation.

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Simple Form of the Fixed-Scatterer Approximation: An Application to e^--H Scattering

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A tractable form of the fixed-scatterer approximation retaining up to double-scattering terms has been proposed. This formalism can be employed to investigate the elastic as well as inelastic processes at intermediate and high energies. The results for the differential cross section for the elastic scattering and for excitation of the $n=2$ states of H atom in e^--H scattering are found to be very encouraging, computational labor involved for s-s transitions being comparable to that of the first Born calculations.

The fixed-scatterer approximation (FSA) which assumes a stationary configuration of the target enjoys wide application in intermediate- and high-energy scattering. Chase[1] seems to have been the first to have suggested this model. The idea of a fixed-nuclei model (Golden *et al.*[1]) has its origin long before Chase's prescription. Stier[1] and Fisk[1] have applied this model, which is similar to the present one, to investigate the e^--molecule scattering. The Glauber multiple-scattering model[1] is the most commonly used method underlying this assumption. Apart from its application in other fields, Glauber multiple-diffraction theory has been extensively used in investigating atomic collision processes.[2] In addition to the frozen-nucleus assumption, Glauber theory assumes additivity of the phases and neglect of the longitudinal momentum transfer; moreover, it neglects the off-shell contributions. As a consequence of these approximations, the Glauber elastic amplitude gives a logarithmic singularity in the forward direction, and it fails to predict even the qualitative nature of the cross section for the large-angle region. The Glauber model suffers from some other practical difficulties. The results for e^--H scattering are identical to those for e^+-H in the framework of Glauber's method. The simplicity of the Glauber prescription is lost when one is interested in applying his formalism to complex atoms or incorporating exchange effects.

Considering all these points, in the present study I have used the FSA to investigate the scattering problem. I have assumed that triple and higher-order scattering terms are negligible. At high energies, this assumption is always valid. As in the present study, the Glauber approximation also neglects the triple and higher-order scattering terms. The present formalism can distinguish between the results obtained by using electrons and positrons as projectiles.

I will now give a brief outline of the present formalism. In the center-of-mass system, we can write the Schrödinger equation for e^--H scattering processes in the FSA as

$$(E-\epsilon_T-T_1)\psi_{\vec{k}_i}^{+}(\vec{r}_1,\vec{r}_2)=V(\vec{r}_1,\vec{r}_2)\psi_{\vec{k}_i}^{+}(\vec{r}_1,\vec{r}_2). \quad (1)$$