of 3 ppm.

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[1]W. E. Cleland, J. M. Bailey, M. Eckhause, V. W. Hughes, R. M. Mobley, R. Prepost, and J. E. Rothberg, Phys. Rev. Letters 13, 202 (1964).

[2]M. M. Sternheim, Phys. Rev. 130, 211 (1963).

[3]E. N. Fortson, F. G. Major, and H. G. Dehmelt, Bull. Am. Phys. Soc. 9, 626 (1964).

[4]J. A. White, L. Y. Chow, C. Drake, and V. W. Hughes, Phys. Rev. Letters 3, 428 (1959).

[5]R. Novick and E. D. Cummings, Phys. Rev. 171, 822 (1958).

[6]A. M. Sessler and H. M. Foley, Phys. Rev. 98, 6 (1955).

[7]C. L. Pekeris, Phys. Rev. 126, 1470 (1962).

[8]N. M. Kroll and F. Pollock, Phys. Rev. 86, 876 (1952); R. Karplus and A. Klein, Phys. Rev. 85, 972 (1952).

[9]H. A. Bethe and E. E. Salpeter, Quantum Mechanics of One- and Two-Electron Atoms (Academic Press, Inc., New York, 1957), Sec. 44B.

[10]Reference 9, Sec. 35B.

[11]D. E. Zwanziger, Phys. Rev. 121, 1128 (1961).

INELASTIC SCATTERING OF ELECTRONS BY HELIUM*

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Resonances in the inelastic scattering of electrons by helium, first detected by Schulz and Philbrick[1] at a scattering angle of 72°, were recently observed[2] for forward scattering in the energy range of 22.4 to 22.8 eV. These resonances are attributed to short-lived negative-ion states formed from excited levels of the atom.[3] This paper reports the results of extending the forward-scattering measurements to lower and higher energies.

The extension to higher energies has shown that the strongest resonances appear in pairs below each of the levels $n=3$, 4, and 5. This clearly identified double series of resonances had previously appeared only dimly in transmission experiments.[3] The extension to lower energies allowed us to measure the energy dependence of the cross section in the neighborhood of threshold. Comparison of our results for $2\,^3S$ excitation with other experiments[1,3,4] shows that the cross section is anisotropic within the first electron volt above threshold. This, plus the general trend of the $2\,^3S$ cross section, leads us to believe that the cross section within a few electron volts of threshold is almost entirely due to resonance structures. There also appears to be a peak, or steplike rise, within 0.06 eV of threshold in the excitation cross section of both the $2\,^3S$ and $2\,^1S$ levels. We regard these measurements not only as information on e^--He collisions but as a demonstration of new experimental capabilities.

The apparatus has been described previously[2] and essentially consists of an electron monochromator, gas cell, and analyzer which is adjusted to accept electrons that have lost a fixed amount of energy in the gas cell. Slight modifications have improved the collection efficiency for electrons of near zero energy, i.e., for primary energies near threshold, and significantly improved the over-all resolution to ~0.06 eV.

Figure 1 shows the yield curves for electrons which have excited the $n=2$ levels of helium as the primary energy is swept from below threshold to several volts above. The curves are smooth traces of the recorded data with the background of secondary electrons scattered from the walls of the gas cell subtracted out. This background is measured by tuning the analyzer to accept an energy loss that does not correspond to an energy level in helium. Error bars are shown to indicate the noise width of the original data, and each curve is labeled according to the atomic level that is excited. The energy scale is calibrated by assuming a value of 19.30 ± 0.05 eV for the transmission peak in the elastic scattering of electrons by helium.[5]

One of the most prominent features seen in Fig. 1 is the extremely large rise near threshold in the differential cross section for elec-

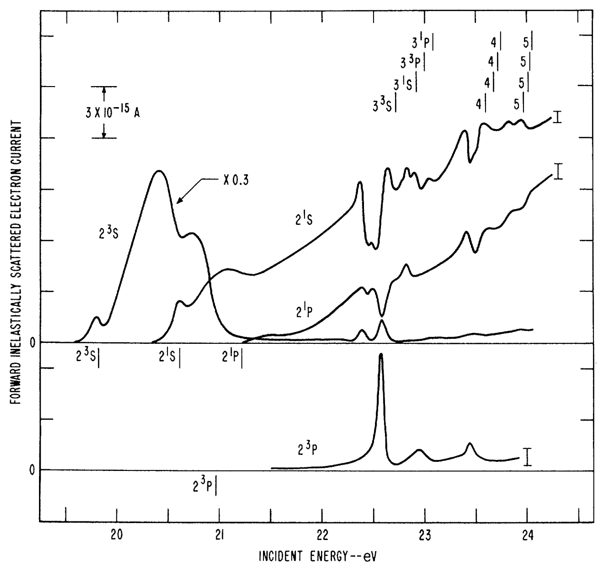

FIG. 1. Forward inelastically scattered electron current versus incident energy in helium.

tron excitation of the $2\,^3S$ state. The ratio of this peak height to the minimum near 22.5 eV is in excess of 100:1, whereas the data of Schulz and Philbrick[1] gives a ratio of about 5:1 for a scattering angle of 72°. Data in addition to those shown in Fig. 1 show a definite steep rise at threshold followed by a break, or dip, in both the $2\,^3S$ and $2\,^1S$ loss curves. The rapid onsets of these curves, obscured by the tailing in Fig. 1, appear to be limited by the resolution of the apparatus, which fact indicates that there is a sharp peak or nearly steplike rise in the $2\,^3S$ and $2\,^1S$ excitation cross section at threshold.

Above the threshold region the grouping of the resonance structures clearly can be associated with negative-ion states formed from the $n=3$, 4, and 5 levels of helium. It is interesting to observe that there appear to be two series of negative-ion states which produce the stronger resonances above 22 eV. A notable exception is that there is no coupling, as far as can be observed in our apparatus, between the He^- state at ~22.4 eV and the $2\,^3P$ state. Preliminary measurements also show resonance structure in the $2\,^3S$, $2\,^1S$, and $2\,^1P$ loss curves due to the negative-ion states at 57.1 and 58.2 eV.[3]

A more detailed discussion of the experiment and the results will be presented elsewhere.

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[1]G. J. Schulz and J. W. Philbrick, Phys. Rev. Letters 13, 477 (1964). Additional resonance structure was also seen in the $2\,^3S$ excitation curve below 22 eV.

[2]G. E. Chamberlain, Phys. Rev. Letters 14, 581 (1965).

[3]C. E. Kuyatt et al., Phys. Rev. 138, A385 (1965).

[4]G. J. Schulz and R. E. Fox, Phys. Rev. 106, 1179 (1957).

[5]G. J. Schulz, Phys. Rev. 136, A650 (1964).

HIGHER ORDER CALCULATION OF THE LAMB SHIFT IN Li^{++}†

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A preliminary result for the measurement of the Lamb shift in $(Li^6)^{++}$ has recently been reported by Fan, Garcia-Munoz, and Sellin,[1] with the intention of testing the dependence of the theoretical calculations on Z, the nuclear charge. The present Letter gives the calculation of the Lamb shift for Li^{++}, including higher order terms not considered by Fan, Garcia-Munoz, and Sellin, as well as careful estimates of the limits of error in the calculation. These higher order terms are especially necessary for the comparison of theory with experiment because the largest ones are the most highly Z-dependent terms known and also because their magnitudes add up to more than the present difference between theory and experiment (although their algebraic sum is an order of magnitude smaller). The detailed error estimates are necessary in order to be able to say to what extent the various terms are actually tested.

The lowest order expression for the Lamb shift (energy difference between the $nS_{1/2}$ and $nP_{1/2}$ states) in a hydrogenic atom is[2]

$$\Delta E_n[\alpha(Z\alpha)^4]=\frac{4\alpha(Z\alpha)^4mc^2}{3\pi n^3}\left\{\left(1-3\frac{m}{M}\right)\left[\ln\frac{1}{(Z\alpha)^2}+\ln\frac{\Delta\epsilon_{nP}}{\Delta\epsilon_{nS}}+\ln\left(1+\frac{m}{M}\right)+\frac{11}{24}+\frac{3}{8}-\frac{1}{5}\right]+\left(1-2\frac{m}{M}\right)\left[\frac{1}{8}\right]\right\}, \quad (1)$$