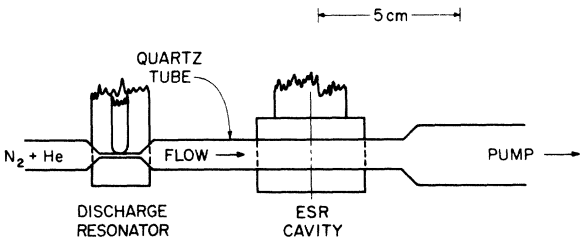

FIG. 2. Diagram of gas-flow system.

signals were obtained when the partial pressures measured 25 cm downstream from the ESR cavity were 0.13 Torr of nitrogen and 3.2 Torr of helium. No signals could be observed in pure nitrogen afterglows.

The g factors were determined from the central line of each of the spectra to be 0.8002 $\pm$ 0.0004 for the $^2D_{3/2}$ level and 1.2005 $\pm$ 0.006 for the $^2D_{5/2}$ level, in agreement with the theoretical Landé g factors $\frac{4}{5}$ and 6/5. Each of the spectra exhibits three groups of lines, due to the magnetic hyperfine splitting caused by nitrogen's nuclear spin of one. The measured separations of the three groups are 58.5 G for the $^2D_{3/2}$ spectrum and 68 G for the $^2D_{5/2}$ spectrum. Theoretical separations, based on the central-field approximation[2] and accurate analytical wave functions,[3] are calculated to be 69 G for both spectra, in fair agreement with the measured values. The splittings within the three hyperfine-structure groups of each spectrum result from the second-order Zeeman interactions between the two fine-structure levels. The measured splittings agree within 10% with those calculated from second-order perturbation theory,[2] using the known level separation of 8 cm^{-1}. A more detailed analysis of the spectra, including the effects of electric-quadrupole hyperfine structure, deviations from LS coupling, configuration interaction, and relativistic corrections, will be published elsewhere.

Measurements of the ^4S ground state concentration showed that approximately 5% of the nitrogen atoms were in the ^2D levels. The relative intensities of the $^2D_{3/2}$ and $^2D_{5/2}$ spectra showed these levels to be approximately in thermal equilibrium.

Further experiments are under way to measure the spectra more accurately, to measure the linewidth as a function of pressure, and to look for other metastable levels (a preliminary scan did not reveal the presence of the ^2P levels of nitrogen).

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ELECTRON–H-ATOM ELASTIC-SCATTERING RESONANCES*

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The competition between compound nucleus formation and Rutherford scattering is reflected in the characteristic resonance shape of the cross section for nucleon-nucleus scattering. Such interaction has received considerable experimental and theoretical study, and as a result is well understood. Although the possibility of atomic analogs has long been recognized, it is only within the past few years that much attention has been given to them. The one analog thus far studied extensively is that involving the temporary formation of an excited atomic or molecular negative ion which is observed through resonance structure in the cross-section curves for elastic and inelastic scattering of electrons.

In this Letter we report resonances in the e-H scattering signal observed essentially at 90 deg to the plane of intersection between a modulated beam of H atoms and a beam of energy-analyzed electrons. The experimental configuration[1] is shown in Fig. 1. As can be seen in Fig. 2, there are two resonances defined below 10 eV. If we define the center of a resonance as half-way between the maximum and minimum, the first is centered near 9.45

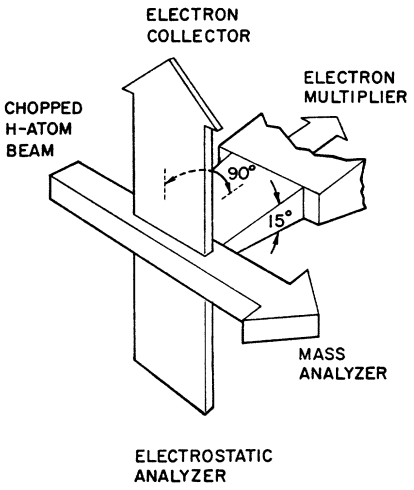

FIG. 1. Sketch of the experimental arrangement used for the hydrogen resonance studies.

eV and the second near 9.68 eV. Above 10 eV, there is a complex structure which no doubt is associated with a number of resonances just below the first excitation threshold of the H atom and, at 10.20 eV, the threshold itself.

The existence and placement of resonances in the e-H system were first predicted theoretically,[2] to be followed by two experimental reports of such structure prior to the present paper. The first was made by Schulz[3] who, through an experimental tour de force, was able to detect but not resolve the resonance pattern in an electron-transmission experiment. The center of mass of his reported structure is 9.7 ± 0.5, which is in good agreement with the center of all the structure shown in this report.

The second report was recently made for the

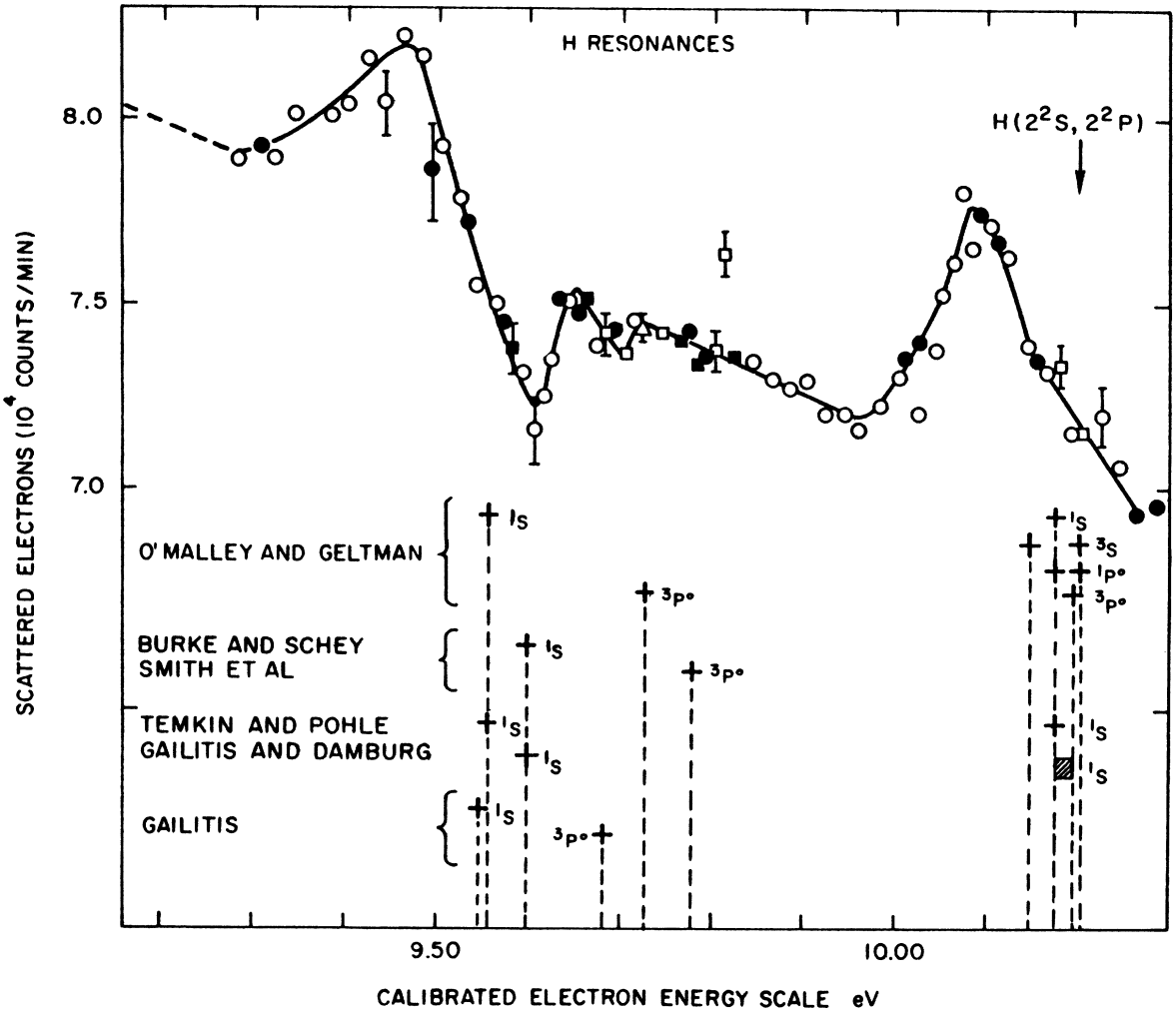

FIG. 2. Resonance structure observed in atomic H. The data points are often the average of several runs and check points. The code used in the graph follows: ●, one datum; ○, 2 data; ■, 3 data; □, 4 data; and △, 5 data. The calibration of the energy scale is good to +0.04 and −0.01 eV. Below the data, plus signs indicate the calculated positions of H^- levels and resonances in the e-H scattering system.

first ^1S resonance by Kleinpoppen and Raible.[4] Although, in essence, their experiment is the same as our own, the agreement in resonance shape and position is not good, although our results lie at the lower limit of the uncertainty in their energy measurement. The reason for the discrepancy is not completely clear, since they used two energy standards: the first He resonance at 19.285 ± 0.025 eV,[5] and "the onset of the first inelastic excitation threshold of atomic hydrogen at 10.20 eV which causes a decrease in the intensity of the scattered electrons." One explanation is that the decrease in the scatter signal above 10.1 eV in Fig. 2 was mistaken by them for the first inelastic threshold, and that their reference to the He resonance is in error. If the position of their reported decrease above 10 eV is made to correspond with ours, then the position of the destructive interference portion of the resonance (the minimum) is found to be in excellent agreement.

The energy scale shown in Fig. 2 has also been calibrated by two independent methods which agree to within 0.01 eV. The total uncertainty which we associate with this placement is +0.04 and −0.01 eV. The first and primary energy reference used was the ionization potential of the H atom, taken as 13.60 eV. Before and after each group of measurements, an ionization efficiency curve for H^+ was taken. In each case, the intercept between the linear extrapolation of the straight portion of the ionization efficiency curve and the electron energy axis was fixed at 13.60 eV. Because there is some question concerning the linearity of the H-atom ionization efficiency curve near threshold,[1] our upper limit to the uncertainty, i.e., +0.04 eV, is large.

The second energy reference used was the position of the minimum in the first scattering resonance in He. These results are shown in Fig. 3. The position of this resonance is well established[5-7] near 19.30 eV.

Normally, two Marmet-Clarke-Kerwin (MCK) type 127-deg electrostatic electron-energy analyzers make up the core of our electron spectrometer.[1] One monochromator produces the analyzed beam of electrons, and the second, among other duties, measures the energy distribution. In these experiments, however, the rotating table normally used for the second monochromator was used instead to mount the total electron collector. It was found that the

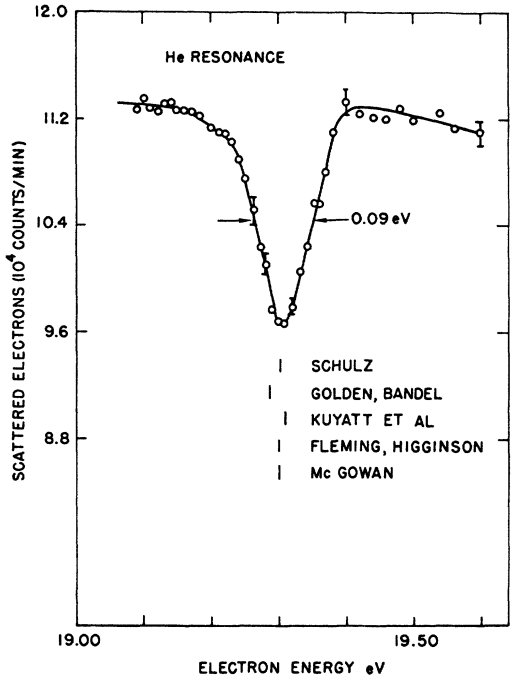

FIG. 3. Resonance structure observed in atomic He. The position of the resonance minimum is fixed at 19.30 eV, thus calibrating the electron energy scale for the H scattering experiments. The experimental breadth of the resonance is used to estimate the electron energy distribution. The energy distribution is judged to be between 0.08 and 0.09 eV.

magnitude of the scatter background depended markedly upon the placement of this collector. Consequently, the prime determination of the energy distribution of the electrons used for this report comes from our measurement of the breadth at half-depth of the He resonance.

The measured breadth of the He resonance (refer to Fig. 3) is 0.09 eV, which includes, with the electron energy distribution, the natural resonance breadth, judged to be 0.01 eV by Simpson and Fano.[8] Depending upon how these distributions are actually folded together, our energy distribution at half-height must lie between 0.08 and 0.09 eV. Normally, our distribution can be reduced to a range between 0.03 and 0.06 eV, but under the high primary-current conditions in this experiment—approximately 8×10^{-8} A—this is judged to be impossible.

Counting techniques are used in these experiments, and the errors shown in Fig. 2 are simply the statistical errors associated with the data accumulated from a number of runs. For the H-

atom data, the number of signal counts was normally 12% of the number of counts resulting from scatter from the background gas and from the surfaces of the gun.[9] The latter contribution to the background was well in excess of the former. Although the position and the shape of the resonance structure are judged by us to be good within the errors quoted, the ratio of the size of the resonance structure relative to the total scatter signal is likely to be a lower limit, affected by as much as 10% H_2 in the H beam and by a small but as yet undertermined component of modulated background. This latter contribution should not exceed 10% of the total signal. Tests were made to be sure that structure in our e-H curve was not a result of residual H_2 in the H beam.

The shape of the first resonance is clearly defined and is characteristically resonant.[10] The shape and magnitude of the second[11] (and subsequent resonances) are partially obscured by the energy distribution and the statistical errors. The position for all the structure observed is in good agreement with the positions of the energy levels of the compound atom H^- predicted by O'Malley and Geltman[12] and the recent elastic scattering calculations of Gailitis.[13] These values, together with the positions of resonance from scattering calculations by others, are shown on the graph and are given in reference 2. It is suggested by O'Malley and Geltman that their configuration calculations should represent an upper limit to the position of the levels in the compound atom and that at most, their calculations may be high by 0.05 eV because of the approximate nature of their variational wave function. The scattering calculations by Gailitis fall in this range and appear to be the most accurate.

It is with pleasure that we acknowledge continuing and fruitful discussion with Dr. A. Temkin, Dr. R. Mariott, Dr. M. A. Fineman, and Dr. R. F. Stebbings, and the members of the Atomic Physics group at General Atomic.

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