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EXPERIMENT ON THE RESONANCE IN THE ELASTIC SCATTERING OF ELECTRONS BY ATOMIC HYDROGEN*

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This Letter reports experimental evidence for a resonance in the elastic scattering of electrons by atomic hydrogen, below the onset of excitation of the electronic states of hydrogen. Burke and Schey[1] predicted the existence of such a resonance in atomic hydrogen and several theoretical papers[2-7] have appeared recently which confirm and refine these considerations.

The first experimental confirmation that such resonances occur was obtained in helium[8] where a large resonance (larger than 14% of the elastic cross section) occurs in the elastic cross section at 19.30 ± 0.05 eV, i.e., 0.5 eV below the onset of the first electronic state. Following the finding of this resonance in helium, an attempt was made to find the corresponding resonance in atomic hydrogen using the same technique (double electrostatic analyzer). For various technical reasons, this attempt was fruitless.

It has been shown recently[9,10] that an enhancement of any resonance in the elastic cross section occurs in a transmission experiment in which an electron beam is transmitted through the gas at higher pressures such that electrons make many collisions along the way and in which only the unscattered electrons are measured. This enhancement technique has been verified experimentally[10] for the 19.30-eV resonance in helium by showing that the ratio of the transmitted current on resonance to that off resonance increases as the number of collisions which electrons make in the scattering chamber increases. It is this technique which is used in the present experiment.

Figure 1 shows the experimental arrangement. The gas, from a high-pressure lecture tank, passes through a Pyrex bulb where it is dissociated by a steady microwave discharge. A fixed-frequency 1000-watt magnetron (Raytheon

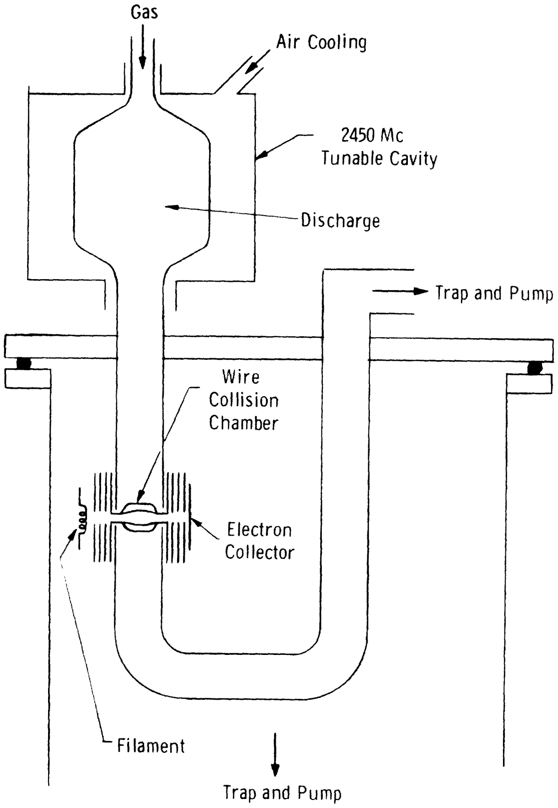

FIG. 1. Schematic diagram of apparatus used for detection of the resonance in atomic hydrogen.

No. QK390) supplies about 150-250 watts at 2450 Mc/sec to a tunable cavity operated in the TM_{010} mode. The gas flows from the discharge through 12-mm diameter Pyrex tubing, cleaned carefully with chromic acid before assembly, and baked at about 400°C after assembly. The gas stream is crossed by the electron beam about 20 cm downstream from the discharge, then passes through a liquid nitrogen trap and a large (6-liter/sec) fore pump. The pressure in the collision region is approximately 0.3 Torr.

The electron beam enters and leaves the glass tube (i.e., the collision chamber) through short metal cylinders which shield it from the glass walls. The gas escaping from the collision region through these holes is pumped by a 300-liter/sec mercury diffusion pump backed with a liquid nitrogen trap. The collision chamber is formed by five wires, 0.1 mm in diameter; this is an attempt to arrive at a compromise between two conflicting requirements, namely, that atomic hydrogen be prevented from hitting metal surfaces where it readily recombines and that a well-defined potential be established in the collision chamber.

The principle of the transmission experiment has been recently described.[10] Briefly, the electron beam is retarded at the entrance retarding plate to limit the energy spread; it is then accelerated into the wire collision chamber, transmitted through the exit retarding plate, and finally collected. The exit retarding plate transmits only that portion of the electron beam which has not undergone scattering, so that the exponential relationship between the transmitted current and the incident current holds; thus enhancement of the resonance results. A magnetic field of about 200 gauss aligns the electron beam.

The resonances in helium and neon are sufficiently well established to permit their use in calibrations of the energy scale. Experiments in pure helium or neon with the discharge operating show the expected transmission curves[10] (half-width of the helium resonance ~0.3 eV) and this is taken as proof that the present transmission tube operates properly although many compromises with good electron-beam techniques had to be made in order to preserve the atomic-hydrogen flow.[11]

The present apparatus is equipped for mixing three gases: H_2, H_2O, and a rare gas (He or Ne). The water vapor serves two purposes, namely, to enhance the formation of atomic hydrogen and to balance the falling elastic cross section in both atomic and molecular hydrogen.[12] The rare gas is used for establishing the correct energy scale, by observing the resonance in helium or neon in a mixture with H_2 and H_2O, i.e., in the same mixture and under identical conditions under which the hydrogen resonance is observed.

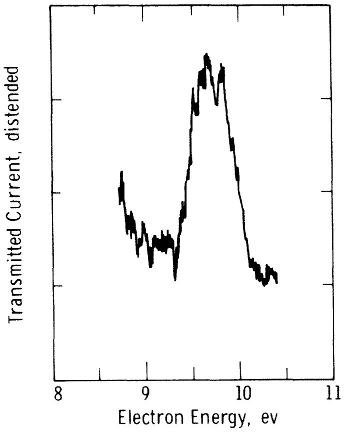

FIG. 2. Transmitted current vs electron energy. The rise in transmitted current, centered around 9.7 ±0.15 eV, indicates that the elastic cross section has a dip at that energy. The width of the resonance is broader than the width of the helium resonance taken under identical conditions in the same apparatus. This indicates that the lifetime of the compound state in hydrogen is shorter than that of He or that structure exists that could not be resolved. The latter viewpoint is favored at the present time.

Figure 2 shows the transmitted current vs electron energy, as it is obtained on an X-Y recorder. Curves similar to that shown in Fig. 2 have been obtained in the following gas mixtures[13]: H_2+H_2O; H_2+Ne; H_2+H_2O+He; H_2+H_2O+Ne. The maximum deviation of the position of the resonance on the energy scale from the value given in Fig. 2 is ±0.15 eV and this is considered to be the confidence error of the energy scale. The magnitude of the resonance is difficult to estimate because the degree of dissociation of the H_2 is unknown.

The rise in transmitted current shown in Fig. 2 is reminiscent of a similar rise observed in the transmission experiment for helium. However, comparison of the width of the helium resonance taken under identical conditions shows that the width of the atomic-hydrogen resonance is approximately double that of helium; it is possible that structure (e.g., a double resonance) is hidden in the curve of Fig. 2 which could not be resolved because of limited energy resolution (~0.3 eV). The curve of Fig. 2 is interpreted as indicating a drop in the elastic cross section centered in the vicinity of 9.7 ± 0.15 eV and resulting from one or more compound states, probably in the ^3P and ^1S configurations.[1,2]

The position of the hydrogen resonance on the energy scale is in very good agreement with theoretical predictions, which range from 9.6 to 9.8 eV.

Because of the difficulty of the present experiment the author had to seek advice on many aspects of the experiment. He is indebted to A. O. McCoubrey, R. F. C. Vessot, and F. Kaufman for advice on handling of atomic hydrogen; to B. R. McAvoy, J. L. Pack, and J. L. Moruzzi for advice on and loan of high-power microwave equipment; to A. V. Phelps and P. J. Chantry for frequent discussions; and to W. J. Uhlig, J. Kearney, and H. T. Garstka for technical assistance.

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[1] P. G. Burke and H. M. Schey, Phys. Rev. 126, 147 (1962). Their value for the energy at resonance is 9.61 eV, with a width of 0.109 eV. The state involved is the ^1S state.

[2] P. G. Burke and K. Smith, in Atomic Collision Processes, edited by M. R. C. McDowell (John Wiley & Sons, Inc., New York, 1964). They calculate the energy at resonance resulting from the $(2s2p)\,^3P$ state to be 9.78 eV, width 0.009 eV. They also calculate resonances resulting from $(1s2s)\,^1S$ and $(1s2p)\,^1P$ configurations at much lower energies.

[3] M. Gailitis and R. Damburg, Proc. Phys. Soc. (London) 82, 192 (1963), find the minimum of the cross section at 9.6 eV (singlet) and 9.8 eV (no exchange).

[4] M. H. Mittleman, Phys. Rev. Letters 10, 145 (1962), finds the minimum in the cross section at 9.8 eV.

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[6] A. Temkin and R. Pohle, Phys. Rev. Letters 10, 22 (1963), find the minimum in the cross section just below 9.7 eV.

[7] A. Herzenberg, K. L. Kwok, and F. Mandl, Proc. Phys. Soc. (London) 84, 345 (1964), discuss the ^1S level at 9.61 eV.

[8] G. J. Schulz, Phys. Rev. Letters 10, 104 (1963).

[9] R. J. Fleming and G. S. Higginson, Proc. Phys. Soc. (London) 81, 974 (1963); see also J. A. Simpson and U. Fano, Phys. Rev. Letters 11, 158 (1963).

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

[11] In addition to the usual problems encountered in calibrating energy scales, the charging of the glass and the existence of a residual plasma in the region in which the electron beam traverses the gas stream may play a role in establishing the potential in that region.

[12] The elastic cross section in both molecular and atomic hydrogen decreases with electron energy; thus the transmitted current vs electron energy under our operating conditions is a steeply rising function. On such a curve it would be very difficult to observe a resonance. Fortunately, the elastic cross section of H_2O increases with energy in the 9- to 10-eV range and thus it is possible to alter the slope of the transmitted current vs electron energy by admixing various amounts of H_2O to H_2.

[13] In a mixture of H_2 and H_2O it is difficult to establish the proper energy scale. In a mixture of H_2 and Ne, the rare gas serves both as a buffer gas for enhanced dissociation and as a calibrating gas.

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

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In all of the fairly numerous attempts to date to formulate a consistent field theory possessing a broken symmetry, Goldstone's remarkable theorem[1] has played an important role. This theorem, briefly stated, asserts that if there exists a conserved operator Q_i such that

$$[Q_i, A_j(x)] = \sum_k t_{ijk} A_k(x),$$

and if it is possible consistently to take $\sum_k t_{ijk} \times \langle 0|A_k|0\rangle \neq 0$, then $A_j(x)$ has a zero-mass particle in its spectrum. It has more recently been observed that the assumed Lorentz invariance essential to the proof[2] may allow one the hope of avoiding such massless particles through the introduction of vector gauge fields and the consequent breakdown of manifest covariance.[3] This, of course, represents a departure from the assumptions of the theorem, and a limitation on its applicability which in no way reflects on the general validity of the proof.

In this note we shall show, within the framework of a simple soluble field theory, that it is possible consistently to break a symmetry (in the sense that $\sum_k t_{ijk}\langle 0|A_k|0\rangle \neq 0$) without requiring that $A(x)$ excite a zero-mass particle. While this result might suggest a general procedure for the elimination of unwanted massless bosons, it will be seen that this has been accomplished by giving up the global conservation law usually