Angular distribution of electrons elastically scattered from hydrogen atoms. II

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(Received 26 March 1992)

We have measured absolute differential cross sections of atomic hydrogen by electron impact. A modulated crossed-beam method was used. The energy and angular range measured were from 40 to 200 eV and from 12° to 156°, respectively. Atomic hydrogen was generated by a microwave discharge device. The present results were compared with the previous measurement by Williams [J. Phys. B **8**, 1683 (1975); **8**, 2191 (1975)] and a few theoretical results. There is relatively good agreement in the forward scattering, but a signficant discrepancy has been found in the extreme backward direction in this energy region. In general, the present results are larger than the previous measurement and theoretical results by more than a factor of 3 at extreme angles. The present results of the integrated cross sections are in good agreement with the previous measurement and theoretical predictions, even though there are disagreements in the backward scattering due to the very small differential cross sections in the backward angles.

PACS number(s): 34.80.Bm

I. INTRODUCTION

This paper is an extension of a previous paper [1] (designated as I) on the absolute elastic differential cross section (DCS) of atomic hydrogen for higher electron-impact energies. As stated in I, a study of the scattering processes of electrons by the hydrogen atom is of fundamental importance not only for atomic and molecular physics but also for its applications in various fields. However, the status of this fundamental study (including excitation and ionization processes) is far from the goal even though some progress has been made in the theoretical forefront. The experimental situation is worse than the theoretical one.

Williams [2,3] measured the absolute DCS of atomic hydrogen over the energy and angular ranges from 0.5–680 eV and from 10°–140°, respectively. In distinction to experimental results, there are a number of theoretical studies for elastic-scattering cross sections (mostly integrated cross sections) using various approximations (see, for example, *Computer Index to Atomic and Molecular Collision Data* [4]). Fon, Burke and Kingston [5] have used the $1s$-$2p$ pseudostate approximation to calculate the DCS for energies from 1–200 eV. The results of Fon, Burke and Kingston are in good agreement with the experimental results of Williams within the experimental uncertainty. More recently, Kingston and Walters [6] have applied the distorted-wave second Born approximation to the DCS in the energy range from 30 to 680 eV. Their results at 30-eV impact have larger values in the forward direction than other theoretical values and experimental values, and lower values than other theoretical values above 60°. However, their results agree with the experimental values above 60°. Also Lower, McCarthy, and Weigold [7] calculated elastic differential cross sections above 54.4 eV up to 200 eV utilizing a close-coupling optical potential method. It is apparent that there are disagreements in the DCS among the theories and measurements above 20-eV impact.

This paper presents the results of continuing measurements of the absolute elastic DCS and momentum-transfer cross sections of atomic hydrogen by electron impact. The energy extended from the previous measurements were from 40 to 200 eV. It is found that backward-scattering cross sections are stronger than previously measured and calculated.

II. APPARATUS AND PROCEDURE

A detailed description of the apparatus can be found in the previous paper I [1]. Briefly, the apparatus consists of the upper and the lower chamber. The two chambers are pumped differentially to maintain a low background pressure for the measurements in the lower chamber. The apparatus consists of four subsystems: an atomic hydrogen source, a rotatable electron-beam source, a fixed electron detector system on the vacuum chamber wall, and a mass spectrometer. The dissociation rate was measured to be $(56\pm3)\%$.

The incident electron beam of a given energy in the horizontal plane intersects with the vertically collimated and modulated neutral beam in an interaction region. The elastically scattered electrons from the modulated beam at a given angle are detected by the electron channeltron multiplier after energy analysis. This procedure is repeated for different angles and incident energies. It should be noted that before and after the final data of atomic hydrogen were taken, the angular distributions of electrons elastically scattered from helium and molecular hydrogen for each incident energy were measured carefully and confirmed with the previous measurements in order to eliminate all systematic errors, including stray magnetic-field effects and interaction volume effects.

Absolute differential cross sections of atomic hydrogen have been obtained by Eqs. (2) and (3) of the previous paper I. The differential cross sections of the hydrogen

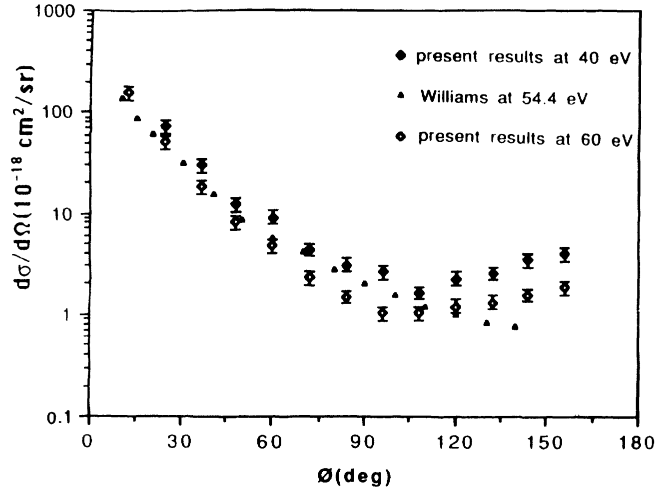

FIG. 1. Angular distribution of elastic cross sections at 40- and 60-eV impact energy along with the measurements of Williams at 54.4 eV.

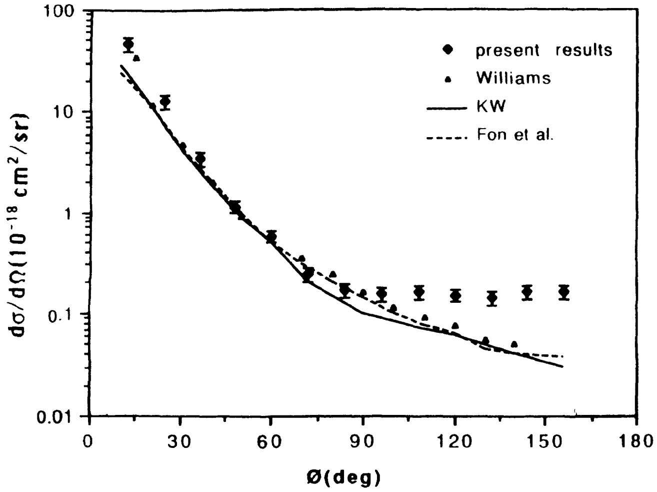

FIG. 3. Same as Fig. 1 except at 200-eV impact energy.

molecule measured by the present author [8] have been used for the normalization.

Three sets of Helmholtz coils reduce stray magnetic fields down to less than 20 mG in all directions near the interaction region. The absolute energy scale has been established by the He resonance dip at 19.3 eV.

III. EXPERIMENTAL RESULTS

We have measured absolute differential cross sections of atomic hydrogen by electron impact utilizing a modulated crossed-beam method. Atomic hydrogen was produced by a microwave discharge device. The final results are shown in Table I.

The standard deviation in data points at each angle is less than 3%; the other uncertainties are 3% in the dissociation rate and 4% in the normalization process against the H_2 elastic cross section. Therefore, the resultant uncertainty for the present results is 15% including the uncertainty of the H_2 cross section (13%).

Figure 1 shows DCS's of 40- and 60-eV impact along with the results of Williams at 54.4 eV. There is a good agreement in the forward-scattering angles but a considerable discrepancy was found in the backward scattering.

Figure 2 shows DCS's of 100-eV impact energy along with the results of Williams, the theoretical results of Fon, Burke, and Kingston, and those of Kingston and Walters. There is a good agreement in the forward-scattering angles within experimental uncertainty but the backward scattering of the present results is larger than all other results by a factor of approximately 3. Figure 3

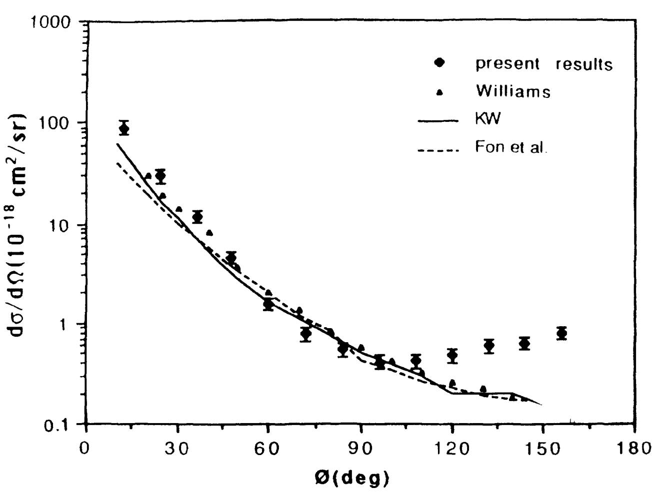

FIG. 2. Same as Fig. 1 except at 100-eV impact energy. Theoretical results by Fon, Burke, and Kingston and those of Kingston and Walters (KW) are included.

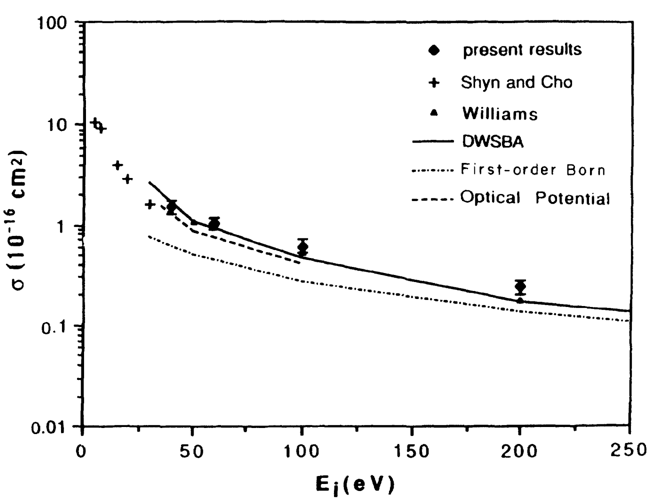

FIG. 4. Integrated cross sections of elastic scattering along with the results of Williams' measurement, the theoretical results of the optical potential method (OP), those of the distorted-wave second-order Born approximation (DWSBA), and those of the first-order Born approximation.

TABLE I. Absolute differential elastic cross sections of atomic hydrogen by electron impact. Numbers in parentheses are extrapolated data points.

E (eV) \ θ (deg)	$d\sigma/d\Omega$ (10^{-18} cm^2/sr) 12	24	36	48	60	72	84	96	108	120	132	144	156	168	σ_i (10^{-16} cm^2)	σ_{mt} (10^{-16} cm^2)
40	156	73	30	19	9.1	4.4	3.1	2.6	2.5	2.6	2.6	3.4	4.0	(4.5)	1.54	0.57
60	157	51	18	8.2	4.7	2.3	1.5	1.0	1.0	1.2	1.3	1.6	1.9	(2.0)	1.04	0.28
100	90	29	12	4.6	1.6	0.78	0.55	0.41	0.42	0.48	0.59	0.64	0.8	(0.9)	0.61	0.13
200	46	13	3.4	1.1	0.58	0.25	0.17	0.16	0.16	0.15	0.14	0.16	0.16	(0.2)	0.24	0.04

shows the same as Fig. 2, except for 200 eV. The same trend holds as shown in Fig. 2.

Figure 4 shows the integrated cross sections along with the results of Williams, the distorted-wave second-order Born approximation (DWSBA), the optical approximation, and the first-order Born approximation. Agreement among the results is very good. As expected, there is disagreement in the integrated cross section for the first-order Born approximation due to the low energies at which the experiments were performed. The reason for agreement in the integrated cross section for the other theories is that there is an agreement in the DCS at forward angles. The DCS's at these angles are the major contributors to the integrated cross section as they are more than 100 times larger than the DCS's at backward angles. It is encouraging to have agreement with theory in the integrated cross section. Since the DCS is a more stringent test of theory, however, the theories may need to be improved to explain the backward scattering.

ACKNOWLEDGMENT

This work was supported by National Science Foundation, Grant No. PHY-9010886.

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