results because many simplyifying assumptions have been used to derive the expressions in (13) and evaluate them numerically. In particular, note that S_0 and $S_{\pi/2}$ differ by a factor of 5 or 10, which indicates that the angular distribution is important and should be considered more carefully. Also, it should be mentioned that even though the expressions found in the earlier paper may be a fairly good approximation to K, it does not follow that the result of a double differentiation will yield an equally good approximation to $d^2K/d\theta^2$.

Some data of Thompson and Holmes are shown in Table I. The Young's modulus (which would be the reciprocal of s_{11} if the specimen axis were along a cubic axis of the crystal) is measured before and after pile irradiation. The difference between these is interpreted as the dislocation contribution since by thoroughly pinning the dislocations, the irradiation reduces or eliminates the dislocation motion. The change is of the same order of magnitude as calculated above and in well annealed elastically anisotropic crystals can amount to a percent or two of the elastic constants.

In slightly deformed crystals (such as Thompson and Holmes specimen 1A) the change can amount to 10%. The fact that anisotropic crystals give large dislocation motion for small stresses is also of importance if one considers the dislocation damping, i.e., the internal friction associated with dislocation motion. One expects that for specimens of comparable purity and perfection the logarithmic decrement at low strain amplitudes increases as the elastic anisotropy increases. Although a quantitative comparison is difficult, the present data do indicate a trend of this kind.[12]

[12] A. Granato and K. Lucke, J. Appl. Phys. **27**, 791 (1956).

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Relative Measurement of the Photodetachment Cross Section for H^-

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The spectral dependence of the photodetachment cross section for the negative ion of atomic hydrogen has been measured in the range from 4000 A to 13 000 A with approximately 300-A resolution. Measurements were made with twenty-five band pass filters, each measurement taken relative to the value obtained with a control filter at 5280 A. A probable error of about 2% is attached to the relative value obtained for each filter. The results are in significant disagreement with available calculated cross sections.

WE have carried out a careful measurement of the wavelength dependence of the photon absorption cross section of the negative ion of atomic hydrogen. A direct interest in this cross section has arisen from the fact that solar emissivity is controlled by H^-, through bound-free and free-free transitions. A special theoretical interest arises from the fact that the process is a particular case of the quantum-mechanical three-body problem; a wavelength dependence measurement would be useful in checking the success of various theoretical approximation methods.

The H^- photodetachment reaction is

$$H^- + h\nu \rightarrow H + e, \tag{1}$$

and the cross section for this is

$$\sigma \propto \left| \int \psi_b^* D \psi_c d\tau \right|^2. \tag{2}$$

Here D is a dipole length operator, ψ_b is the wave function for the H^- ion, and ψ_c is the wave function describing an outgoing electron in the field of the residual H atom. Approximations to ψ_b have been developed from the Ritz variational principle of minimum energy, using wave functions with various modifications and as many as 24 adjustable parameters[1,2] to calculate the electron binding energy of H^-. These calculations have satisfactorily converged on 0.754 ev, although no accurate experimental check exists. Furthermore, Chandrasekhar[3] has shown that values obtained for the cross section from Eq. (2), or from velocity and acceleration forms derived from Eq. (2), are not very dependent on the number of variational parameters used, above about ten. We can then believe that the H^- ground-state wave functions are quite good; and that internal inconsistencies in values calculated from Eq. (2), and from the velocity and acceleration forms derived from Eq. (2), are due mainly to the limitations of the plane-wave and static central field approximations used for the continuum state, ψ_c. No calculation of the photodetachment cross section presently available goes beyond the static

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[2] J. F. Hart and G. Herzberg, Phys. Rev. **108**, 79 (1957).
[3] S. Chandrasekhar and D. D. Elbert, Astrophys. J. **128**, 633 (1958). See also earlier work referred therein.

central field approximation with subsequent symmetrization of the bound and outgoing parts of the total wave function. The present experiment is intended to be helpful in evaluation of the importance of these limitations in the calculation of ψ_c, since we expect that they should be responsible for any significant differences between calculated and experimental values. The comparison will also be of interest for the calculation of free-free transitions and elastic scattering, since both of these depend on the description of an electron of arbitrary angular momentum in the field of a neutral hydrogen atom by a set of wave functions which includes the symmetrical p-wave description used for photodetachment.

PRINCIPLE OF THE EXPERIMENT

Aside from solar data, the only observational data on optical transitions in H^-, other than photodetachment studies conducted in this laboratory, have been arc and shock tube studies of the H^- emission continuum.[4,5] The more recent of these was effectively a measurement of the slope of the detachment cross section from 4000 to 6000 A.[5] Various photodetachment experiments have been conducted since the detection of the photodetachment process under laboratory conditions was reported in 1954.[6] The measurement of the relative H^- cross section reported in this paper supplements a careful measurement of the absolute integrated cross section carried out in 1955 by Branscomb and Smith.[7] Our measurement of the relative cross section was done on an apparatus evolved from the 1955 version.

Both experiments involved the collection of the entire current of free electrons produced at the intersection of an intense beam of photons with a beam of H^- by the photodetachment process [Eq. (1)]. The current of photodetached electrons j_e is given by

$$j_e = kj_iW\int \sigma(\lambda)T(\lambda)\varphi(\lambda)(\lambda/hc)d\lambda, \qquad (3)$$

where j_i is ion beam current; $\sigma(\lambda)$ is the photodetachment cross section; $T(\lambda)$ is the transmission of the optical system; $\varphi(\lambda)$ and W give the normalized spectral distribution of the light source and the total power in the photon beam, respectively; and k contains geometrical factors and ion beam velocity. The photon wavelength is λ, and hc/λ is the photon energy.

In the 1955 absolute measurement, the light source was a very stable tungsten projection lamp for which the color temperature was carefully measured and $\varphi(\lambda)$ determined from information on the tungsten emissivity. The $T(\lambda)$ of the optical system passed a very wide band of the continuum of the lamp in order to obtain a satisfactory signal-to-noise ratio for j_e. W was measured by an absolute radiometer, and k was known. The absolute value of a theoretically determined cross section can be checked by inserting it into the integral and comparing the value of the integral with the value of j_e/kj_iW determined experimentally.

An attempt was made in 1955 to determine the spectral dependence of $\sigma(\lambda)$ in the visible spectral region by measuring the different values obtained for j_e/kj_iW with the modification of $T(\lambda)$ with sharp cutoff absorption filters, but the method was to insensitive to provide more than a general confirmation of the shape of $\sigma(\lambda)$ obtained in the visible in several theoretical calculations of the cross section.

The point-by-point measurement of $\sigma(\lambda)$ described in this paper requires the use of relatively narrow band filters. We assume that $\sigma(\lambda)$ varies linearly in the interval where the optical transmission, $T_m(\lambda)$, of bandpass filter m is nonzero. Equation (3) is conveniently written

$$(j_e)_m = kj_iW\int \sigma(\lambda)T_m(\lambda)\varphi(\lambda)(\lambda/hc)d\lambda, \qquad (3')$$

and this leads to

$$\sigma(\lambda_{m2}) \propto (j_e)_m/kj_iW_m\lambda_{m1}, \qquad (4)$$

where

$$W_m = W\int T_m(\lambda)\varphi(\lambda)d\lambda \qquad (4')$$

is the total power in the photon beam at the position of the ion beam. λ_{m1} and λ_{m2} are defined by the relation

$$\lambda_{mn} = \int \varphi(\lambda)T_m(\lambda)\lambda^n d\lambda \Big/ \int \varphi(\lambda)T_m(\lambda)\lambda^{n-1}d\lambda.$$

Errors will arise if $\sigma(\lambda)$ is appreciably nonlinear within the transmission band. For all filters used in this work we introduce no significant error by assuming $\lambda_{m2}=\lambda_{m1}$. Henceforth, we refer only to λ_m by which we mean either λ_{m1} or λ_{m2}.

The use of these narrow transmission bands with the tungsten lamp would have been difficult. The stable tungsten lamp was abandoned in favor of a brighter but less stable carbon arc projection lamp. In addition, it was necessary to improve sensitivity of detection of j_e. The fluctuating output of the carbon arc also required the development of a system of monitoring the light intensity and abandonment of the slow absolute radiometer. A method of monitoring the light beam was developed and applied to the measurement of the spectral dependence of the O^- and O_2^- photodetachment cross sections.[8]

[4] W. Lochte-Holtgreven, Naturwissenschaften **38**, 258 (1951).
[5] O. Weber, Z. Physik **152**, 281 (1958).
[6] L. M. Branscomb and W. L. Fite, Phys. Rev. **93**, 651(A) (1954).
[7] L. M. Branscomb and S. J. Smith, Phys. Rev. **98**, 1028 (1955); S. J. Smith and L. M. Branscomb, J. Research Natl. Bur. Standards **55**, 165 (1955).
[8] Branscomb, Burch, Smith, and Geltman, Phys. Rev. **111**, 504 (1958); Burch, Smith, and Branscomb, Phys. Rev. **112**, 171 (1958).

We have applied this method of point-by-point measurement of the photodetachment cross section to the atomic hydrogen negative ion. In view of the special position the atomic hydrogen negative ion occupies, as the simplest and most nearly calculable of the negative ions, we have attempted to obtain a precise and reliable measurement. We have tried to limit experimental errors to be no more than a few percent. The accomplishment of this has required a substantial effort in refinement of the experiment, particularly in the optics and measurement of photon beam intensity. A brief preliminary description of the results has been published.[9]

OPTICAL MONITORING AND RADIOMETRY

The method of monitoring the photon beam is indicated in Fig. 1. A chopped, approximately parallel beam of radiation was passed through a set of interference and absorption filters, through a 1-mm-thick sheet of clear Corex D set at a 45° angle, and was focused into a 1×1.55 cm rectangular image at $\sim f/1.5$ by an aspheric borosilicate crown glass lens. About 8% of the light beam was reflected by the diagonal sheet into a secondary aspheric lens identical to the first, and the entire secondary beam was passed into a small integrating sphere. The radiation intensity in the sphere was measured by a bolometer.

The bolometer signal, W_m', can be expressed as

$$W_m'=k'W\int T'(\lambda)T_m(\lambda)\varphi(\lambda)d\lambda, \qquad (5)$$

where $T'(\lambda)$ gives the spectral selectivity of the monitoring system including the reflectivity of the diagonal sheet, the "whiteness" of the integrating sphere and the "blackness" of the bolometer. The proportionality constant k' contains only geometry and the electrical response of the bolometer. Combining (5) and (4′), we have

$$W_m=\left[W_m'\int T_m(\lambda)\varphi(\lambda)d\lambda\right]\Big/\left[k'\int T'(\lambda)T_m(\lambda)\varphi(\lambda)d\lambda\right]. \qquad (6)$$

In principle, the two integrals in Eq. (6) can be evaluated from a knowledge of the factors occurring in their integrands. In practice, $T'(\lambda)$ could not be determined sufficiently well, since the reflectivities of the diagonal sheet and of the bolometer window are functions of the angle of incidence, and the angular distribution of the incident radiation could not easily be determined.

The calibration method used for the measurement described in this paper consisted of directly comparing

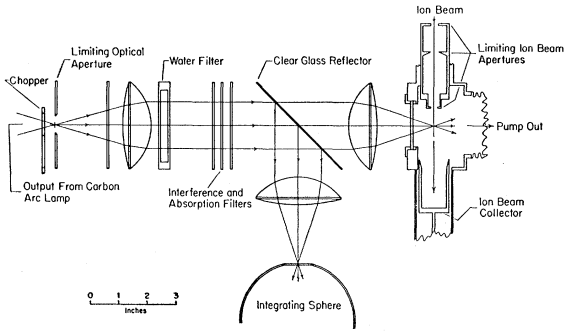

FIG. 1. The arrangement of the photon beam optics and its position relative to the ion beam apparatus is shown schematically.

W_m, the total power in the final focus of the primary beam (at the position of intersection with the ion beam), with the bolometer response, W_m', for each of the m narrow band filters. This calibration was performed with the arc and optics pulled back from the ion beam apparatus. We measured power in the primary beam with a plane calorimeter consisting of a $1\frac{1}{2}$-in.$\times\frac{1}{4}$-in. disk of OFHC copper blackened on the face presented to the photon beam. This carbon-blackened surface, which appeared to be quite uniform, had a measured total reflectivity, at the center, of about $2\frac{1}{2}$%, with an almost negligible wavelength dependence, and a completely negligible specular reflectivity in the spectral range of interest here. This disk was suspended by fine wires in an airtight case and the temperature of the copper receiver was measured by a fine copper-constantan couple attached at the center of the back. The transmission of the fused quartz window of this calorimeter at normal incidence was identical to the transmission of the fused quartz window of the negative ion beam apparatus, and the angular distribution of radiation was the same in the two cases. Therefore, in the spectral range of interest, the calorimeter had a wavelength-independent response to the power in the photon beam, except for a correction for the slight selectivity of the black surface.

Linearity of the calorimeter was demonstrated at fixed wavelengths by varying the power in the primary beam over a wide range. This was accomplished by varying the carbon arc current and by attenuating the beam with screens. The increase in calorimeter temperature was strictly proportional to the average bolometer response for the period of illumination, this ranging from three to twelve seconds. We found no error from nonlinearity of the calorimeter such as might have occurred due to radiation losses from the black surface. Furthermore, we obtained a physically reasonable smooth functional dependence of $W_m'/W_m\cong T'(\lambda_m)$ on λ_m, which required linear calorimeter response since W_m varied by factors of two or three from one filter to the next.

In the calibration runs, a shutter was used to pass the photon beam through a given bandpass filter for a

[9] S. J. Smith and D. S. Burch, Phys. Rev. Letters 2, 165 (1959).

carefully timed interval of from five to twelve seconds. The relative energy absorbed by the calorimeter during this time was determined from the thermocouple response, using an extrapolation procedure to correct for electrical and thermal time constants and for heat loss during illumination. This energy relative to the integrated bolometer response was W_m/W_m'. The time constant associated with the bolometer was negligible.

In order to reduce time-dependent effects (amplifier gain changes, slow geometry changes, etc.) each filter was compared to one filter (designated No. 7) at 5280 A, used for control throughout the calibration and measurement of the cross section. For convenience, filters were run against No. 7 in cycles of three, each cycle of filters being run six times. A representative group of filters was recalibrated after some weeks had elapsed, and these results were directly combined with the results of the first run. Twenty-four mean values of $(W_m/W_m')\div(W_7/W_7')$ were obtained in this way. The standard deviations of the mean values ranged from 0.1% to 0.6%.

BANDPASS FILTERS

The use of Eq. (4) required that the filter transmissions be well defined—limited to a narrow enough spectral region so that the curvature of the cross section in these regions could be ignored. The filter transmissions were carefully examined on a Cary Model 14*M* spectrophotometer.

In the use of Eq. (4) it was assumed that transmission values, T_m, below 1% could be neglected. For four filters, at 5280 A, 7500 A, 8740 A, and 12000 A, the transmissions have been measured with a sensitivity of 0.01%. We find from Eqs. (3) and (5) that there was negligible contribution of the transmission tail (outside the bandpass defined by $>1\%$ transmission), through additional increments of photodetachment and and bolometer response, to the value of the cross section, σ, calculated from Eq. (4).

THE ION BEAM

The ion beam was composed of deuterium negative ions, rather than ions of the first hydrogen isotope, because of the lower velocity and lower sensitivity to magnetic fields at a given kinetic energy. The ions, extracted from a glow discharge in D_2O vapor, had an energy spread of about 25 volts. A 90° sector magnetic field unambiguously separated D^- from other species before the beam passed into the reaction chamber. The ion energy at the reaction region was about 400 ev, and the beam current about 2×10^{-8} ampere.

Apertures limited the ion beam divergence to an angle of $\sim4°$ with the axis. The beam diameter was apertured to $\frac{3}{16}$ in. just before it was illuminated by the photon beam. A measurement of the distribution of ions at the collector showed them well concentrated on axis.

THE REACTION REGION

The geometry of the intersection of the two beams was not so critical in this relative measurement as in the 1955 absolute measurement. With the control filter inserted at every fourth change of bandpass, systematic wavelength-independent changes in geometry and ion beam velocity could be detected and corrected. Only chromatic changes in geometry of the photon beam had to be separately determined. Such effects might include lateral and longitudinal chromatic aberrations, wavelength dependence of the spatial distribution of intensity in the photon beam, and selective reflection of radiation within the reaction chamber.

As indicated in Fig. 1, the ion beam was passed through the image of the limiting optical aperture. Longitudinal chromatic aberrations were determined by studying the image with the aperture illuminated by an auxiliary lamp of low intensity. The longitudinal aberrations were measured over the visible region of the spectrum and extrapolated through the long wavelength (low-dispersion) region of the spectral range of this experiment. The longitudinal chromatic aberrations were corrected during photodetachment experiments by displacing the last lens in such a way that the image remained fixed in space independent of wavelength. It was also shown directly that failure to make this correction would produce a maximum error in photodetachment signal of about 2%.

Lateral chromatic aberrations were studied by making measurements of the size of the image of the limiting aperture, over the visible spectrum. No change in size with wavelength could be observed. The measurement was accurate to within one percent through the middle of the visible and within two percent at the extreme blue end of the spectral range. An allowance for this possible effect was included in the experimental error.

The spectral distribution of the arc was roughly characteristic of a blackbody source at 5400°K and was peaked at about 5300 A. We studied the intensity distribution in the reaction region in detail with thermopiles, by removing the last lens, and obtaining a much magnified image of the limiting optical aperture at a distance of about six feet. The intensity distribution was measured at 4260 A, 5280 A, and 5760 A. These were on the peak and on either side of the peak of the spectral intensity distribution of the arc. The distribution at 4260 A should have been extremely sensitive to temperature gradients. The three intensity distributions were identical within a few percent and could not have caused a significant error in the relative photodetachment measurements.

About 5% of the incoming radiation was incident on the back wall of the reaction chamber, most of the rest permanently escaping through the pump-out aperture. That part of the radiation reflecting within the reaction chamber was divergent and was therefore dispersed.

We could see no possibility of this light being reconcentrated on the ion beam axis. The reaction chamber had about 200 cm² of wall surface area A, consisting mostly of electrolytically deposited nickel. This has a reflectivity R ranging from 0.56 at 4000 A to about 0.75 at 13 000 A. Assuming effectively diffuse reflection, the background intensity would be roughly a fraction $0.05/A(1-R) \leqslant 10^{-3}$ of the intensity in the primary beam, and could cause no significant error.

EXPERIMENTAL PROCEDURE

The measurement of the cross section at wavelength λ_m, the effective wavelength for filter m, consisted of simultaneous measurement of j_e, j_i, and W_m' for use in Eqs. (4) and (5). The photodetached electrons had energies of up to 2 ev and were trapped by the weak magnetic field at the reaction region. A weak electric field parallel to the magnetic field was used to collect them at an electrode which cut across the magnetic field lines. The 450-cps current, j_e, of photodetached electrons was, perhaps, 10^{-14} ampere and was measured with a very sensitive preamplifier, a narrow-band amplifier, a phase-sensitive detector, and a recorder. The time constant of this system was about three seconds. The electronics and other details of the apparatus will be described in a separate publication.[10] The bolometer signal, W_m', was also a 450-cps signal, and was recorded after amplification and rectification. The ion current, j_i, about 2×10^{-8} ampere, was measured with an electrometer.

The ion beam current was recorded continuously. With a given filter m in the optics, the shutter was opened and the ion beam illuminated with chopped light for 30 seconds during which signals j_e and W_m' were obtained. The shutter was closed for 30 seconds while the next bandpass filter in the sequence was installed in preparation for measurement, and for base-line determination. In this manner we cycled through 25 filters, obtaining at least six measurements for each, inserting the control filter, No. 7, for every fourth measurement. We obtained a set of six to twelve values of

$$\sigma'(\lambda_m)/\sigma'(\lambda_7)=[(j_e)_m/j_iW_m']\div[(j_e)_7/j_iW_7'],$$

for each filter m. Equations (4) and (6) were then used to obtain the values of $\sigma(\lambda_m)/\sigma(\lambda_7)$.

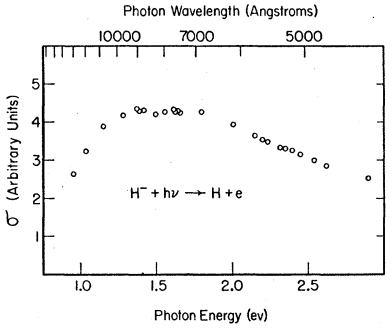

FIG. 2. Our experimental values of the photodetachment cross section for H⁻. Each point is the mean value of from six to twelve measurements with a given bandpass filter combination. Estimated errors are listed in Table I.

[10] S. J. Smith and L. M. Branscomb (to be published).

TABLE I. Relative H⁻ photodetachment cross section, $\sigma(\lambda_m)/\sigma(\lambda_7)$.

Filter m	Effective wavelength λ_m (angstroms)	$\sigma(\lambda_m)/\sigma(\lambda_7)$	Probable error (%)
1	4260	0.76	3
3	4620	0.87	2.5
4	4880	0.91	2
5	5060	0.95	1.5
6	5180	0.98	1.5
7	5280	1.00	
8	5340	1.02	1.2
9	5560	1.05	1.2
10	5620	1.07	1.3
11	5760	1.10	1.4
12	6170	1.19	1.2
13	6890	1.29	1.3
14	7500	1.28	1.8
22	7520	1.29	1.7
23	7640	1.29	2.6
24	7650	1.31	1.6
25x	7940	1.29	1.9
25	8270	1.28	1.9
26	8740	1.31	1.9
28	8960	1.30	1.7
27	9020	1.32	1.6
29	9700	1.26	1.7
32	10770	1.18	2.6
33	12010	0.98	2.7
34	13010	0.79	2.7

RESULTS

The mean of the values of $\sigma(\lambda_m)/\sigma(\lambda_7)$ obtained for each of the twenty-five filters m is plotted at the wavelength λ_m in Fig. 2. The values are also given in Table I. The standard deviations of the mean for the sets of values of $\sigma'(\lambda_m)/\sigma'(\lambda_7)$ ranged from 0.2 to 1.0%. A "probable statistical error" could be determined by combining the statistical errors of the σ' values and the statistical errors in the calibration factors. It appeared desirable to make an additional allowance for possible accumulation of very small chromatic and filter dependent effects such as chromatic aberrations, inhomogeneities in filters, and nonparallel multiple reflections, although no single effect of significant size could be discovered. An additional one percent error was allowed for this in the visible region except for the shortest wavelengths where chromatic effects could be expected to be largest. The allowance was slightly increased in the infrared, where effects are not so conveniently observed, to as much as $2\frac{1}{2}$% at the extreme infrared end of the range. These estimates were directly added to the standard deviations of the mean of the calibration factors, and the resulting errors were combined with the statistical errors in $\sigma'(\lambda_m)/\sigma'(\lambda_7)$ values to obtain the "probable errors" listed in Table I. We feel that these "probable errors," essentially

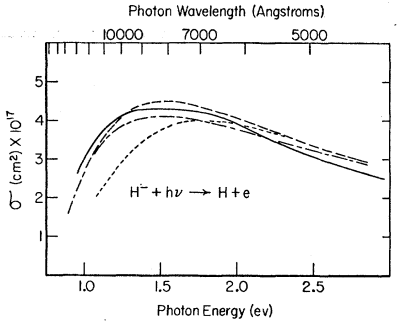

FIG. 3. Our experimental cross section for photodetachment (———) compared with cross sections calculated by Chandrasekhar and Elbert[3] (— — —), Chandrasekhar[12]. (– – – –), and Geltman[13] (— — — —).

estimated, satisfactorily represent the reliability of the measurements.

A twenty-sixth bandpass filter, peaked at 17 000 A, was used to obtain a rough check on the theoretical value of the threshold of the H^- cross section (16 400 A). This filter, labeled No. 38, yielded a small photodetachment signal due to the overlap of the short-wavelength tail of the filter transmission and the H^- cross section. The measured quantities yielded a value of $(j_e)_{38}/j_iW_{38}'$ relative to filter No. 7 which agrees very closely with that small signal predicted from Eq. (3) using reasonable values for $\sigma(\lambda)$ and $\varphi(\lambda)$, and values of $T_{38}(\lambda)$ measured with a sensitivity of 0.01%. The real significance of this measurement is that it does not permit the assumption of any large photodetachment contribution from excited ions, H^{-*}, which would have a photodetachment threshold at a longer wavelength and possibly a large cross section near the detachment threshold for ground-state ions. Our cross section for photodetachment from the ground state of H^- is not in error from this cause by more than ~2% of the maximum value. It seems quite reasonable to assume that there is no H^{-*} in the beam, there being also substantial theoretical indication that H^{-*} is not bound. Unstable ions, such as doubly excited H^{-*}, would not live long enough to pass through the apparatus to the reaction chamber.

DISCUSSION OF RESULTS

This measurement of the H^- photodetachment cross section is relative and is therefore presented on an arbitrary scale in Fig. 2. We have selected a smooth curve, through the points from Fig. 2, which represents our measured relative cross section. The result of the 1955 Branscomb and Smith absolute measurement of the integrated cross section can be used to put this curve on an absolute basis within about 10%. Branscomb and Smith[7] tabulated their values of $\varphi(\lambda)$ and $T(\lambda)$ and provided values necessary to determine the geometrical factor [k of Eq. (3)] for comparison of their experimental photodetachment probabilities j_e/j_i with the value of the integral $kW\int\sigma(\lambda)T(\lambda)\varphi(\lambda)(\lambda/hc)d\lambda$ using any proposed $\sigma(\lambda)$. Using our experimental cross section we obtain a normalizing factor which is used to put our result on an absolute scale as the solid line in Fig. 3.

The dashed line in Fig. 3 represents the most recent theoretical calculation of the H^- photodetachment cross section, by Chandrasekhar and Elbert.[3] They used the Hart and Herzberg 20-parameter ground-state wave function[2] and a Hartree approximation for the continuum wave function, using a momentum form instead of the dipole length matrix element indicated in Eq. (2). Chandrasekhar has given reasons for preferring the momentum form over the length or acceleration forms. This calculation takes incomplete account of exchange, and takes no account of distortion of the residual hydrogen atom.

The experimental curve can be scaled by about 10% in the absolute value of σ, so that it can be adjusted to fit the theoretical curve at either end. No adjustment in the wavelength scale is allowable. The major significant feature of this comparison is a 20% discrepancy in the value of σ across the spectral range of the measurement, from 4000 to 13 000 A. The experimental result appears, also, to be significantly more flat in the vicinity of the maximum than is the theoretical curve. Other details such as minor dips and wobbles appearing in Fig. 2 are within experimental error and cannot be said to be significant.

The 20% discrepancy must be accounted for in terms of the approximations which have been necessary because of the difficulty of the calculation: neglect of distortion and limited treatment of exchange. Chandrasekhar and Elbert have calculated the cross section at one point, 2985 A, using wave functions recently developed by Bransden, Dalgarno, John, and Seaton,[11] which treat exchange fully but still neglect distortion of the residual H atom. They obtain a value about 20% lower than the value based on the Hartree approximation. Since the difference between the new wave functions and the Hartree approximation should decrease with wavelength, this fragmentary theoretical result is consistent with our experiment to the extent that it indicates a cross section dropping faster toward shorter wavelengths than the cross section based on the Hartree approximation. This suggests that a calculation of this nature extended over the appropriate range of wavelengths might be in significantly better agreement with our experiment.

Also shown in Fig. 3 are cross sections calculated by Chandrasekhar[12] using the Hart and Herzberg ground-state function, a plane wave for the free electron, and a dipole length matrix element; and by Geltman[13] whose calculation employed simple wave functions for the bound and continuum states of H^- consistent with the precisely known affinity, and constrained to yield

[11] Bransden, Dalgarno, John, and Seaton, Proc. Phys. Soc. (London) **71**, 877 (1958).
[12] S. Chandrasekhar, Astrophys. J. **128**, 114 (1958).
[13] S. Geltman, Phys. Rev. **104**, 346 (1956).

the same cross section on the basis of the dipole length, momentum, and acceleration matrix elements.

Geltman's spectral dependence is in good agreement with our result at wavelengths longer than 6500 A, but deviates at shorter wavelengths. In his calculation he used a continuum wave function consisting of a symmetrized product for an outgoing electron and a residual hydrogen atom. The hydrogen atom "size" was increased to take some account of distortion of the hydrogen atom and in a manner required to exactly satisfy the two-electron sum rules. Geltman, now at this Laboratory, points out that this distortion, which, for convenience, he took to be the same at all energies, would in fact decrease at higher energies of the outgoing electron. He finds that a cross section calculated on the basis of an undistorted hydrogen atom would be scaled down by a factor of 0.891, which is the square of the overlap integral of the distorted and undistorted hydrogen atom wave functions. If we apply this scaling rather abruptly at wavelengths shorter than 6000 A, the modification would tend to make the spectral dependence of Geltman's cross section very similar to our experimental result. This scaling would preserve equality of his dipole length, velocity, and acceleration matrix elements, but such a cross section would not exactly satisfy the sum rules without some adjustment of the contribution from photodetachment leading to the excited states of the residual hydrogen atom.

Weber[5] has recently measured the emission spectrum in a shock tube, using hydrogen gas. After accounting for observed neutral atom ionization continua and making appropriate subtractions, he is left with a continuum which he attributes to H^-. On the basis of certain simplifying assumptions including local thermodynamic equilibrium and an optically thin gas, we have derived from his results the spectral dependence of the photodetachment cross section from 4000 A to 6000 A, shown in Fig. 4 in comparison with our experimental cross section. The agreement between the slopes is remarkable in view of the difficulties in interpretation of the shock tube experiment, and is confirmation of Weber's assignment of this continuum to radiative formation of H^-.

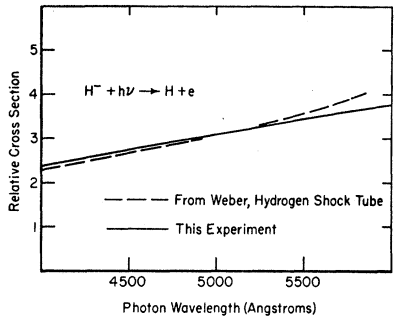

FIG. 4. Comparison of our relative H^- photodetachment cross section and a relative cross section derived from Weber's hydrogen shock tube results, assuming local thermodynamic equilibrium and an optically thin gas.

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