accurate. For ν_2^1 the following differences are used:

$$\nu_0(001\text{–}000)-\nu_0(001\text{–}01^10)=2630.303-2061.278=569.025\ \text{cm}^{-1},$$
$$\nu_0(11^10\text{–}000)-\nu_0(11^10\text{–}01^10)=2497.143-1928.096=569.047\ \text{cm}^{-1},$$
$$\nu_0(01^11\text{–}000)-\nu_0(01^11\text{–}01^10)=3183.670-2614.623=569.047\ \text{cm}^{-1}.$$

The average value is 569.039 ± 0.011 cm^{-1}.

The value of $2\nu_2^0$ is given by

$$\nu_0(02^00\text{–}000)=\nu_0(02^01\text{–}01^10)-\nu_0(02^01\text{–}02^00)+\nu_0(01^10\text{–}000)=3160.08-2599.140+569.039=1129.98\ \text{cm}^{-1},$$

and for $2\nu_2^2$

$$\nu_0(02^20\text{–}000)=\nu_0(02^21\text{–}01^10)-\nu_0(02^21\text{–}02^20)+\nu_0(01^10\text{–}000)=3167.90-2599.000+569.039=1137.94\ \text{cm}^{-1}.$$

In these cases the uncertainty is believed to be not greater than ±0.15 cm^{-1}.

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Photoionization Cross Sections of Helium

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The photoionization cross sections of helium have been measured from threshold down to 260 Å. At the spectral head the cross section is found to be 7.3×10^{-18} cm^2. The experimental results are compared to available theoretical data. The oscillator strength for transitions into the ionization continuum have been estimated from threshold to 0.01 Å using the present and previously published data. A continuum f value of 1.54 is obtained. Applying the Thomas–Kuhn sum rule one therefore obtains the total oscillator strength for all discrete transitions as $f=0.46$.

INTRODUCTION

THE photoionization cross sections of helium were first calculated by Vinti[1] and Wheeler[2] in 1933 using a hydrogen approximation. In this approximation the inner electron is regarded as moving in a field of charge two while the outer electron, excited into the continuum, is assumed to be in a field of charge one. Later, calculations were performed by many investigators[3–10]; these calculations included the use of the more sophisticated Hartree and Hartree–Fock wavefunctions.

Available experimental cross sections[11–13] agreed with the theoretical values within their experimental errors. It was not possible, however, to say which theoretical approach was the most satisfactory. The present work has endeavored to reduce the scatter in the experimental points and to improve the over-all accuracy of the cross section measurements so a choice can be made between the various calculations.

All previous experimental cross section measurements have used photographic plates as detectors of radiant energy; all depended on the irradiance remaining constant while the exposures were made, first with the absorption cell empty and then with it filled with helium. The difficulties and errors inherent in the above method were avoided in the present work by using two ionization chambers in series as detectors of the incident energy. This is the first time this method has been applied to helium.

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EXPERIMENTAL PROCEDURE

Absorption coefficients were measured by the double-ion-chamber technique.[14] Briefly, the essentials are that the two collector plates must be identical in length, and the exit slit of the vacuum monochromator must be held at a positive potential to drive all ions formed in the vicinity of the slit over to the first collector plate. A guard ring at the end of the ion chamber provided a uniform field at the end of the second plate.

Figure 1 shows the experimental arrangement with the ion chamber mounted on the exit arm of the monochromator. The light source consisted of a high voltage condensed spark discharge through a ceramic capillary. This produced a line spectrum characteristic of the gas used, which in this case was argon at approximately 0.1 Torr.

The absorption coefficient k is given by $k=(1/x)\times\ln(i_1/i_2)$, where x is the length of one collector plate reduced to STP and i_1 and i_2 are the respective ion currents to the two collector plates. The major advantages of this technique are (a) that the ion currents i_1 and i_2 are measured simultaneously and thus there is no demand that the source intensity remain constant and (b) since the gas itself is the detector of the incident energy it is insensitive to scattered energy of wavelengths longer than its ionization threshold (504 Å).

Helium obtained from the Matheson Company with a quoted purity of 99.9% was further purified by passage through a liquid-nitrogen-cooled charcoal trap.

To minimize sources of error, the two micromicroammeters used to measure i_1 and i_2 were calibrated to an accuracy of 1%. Probably the major single error occurs in measuring the absolute gas pressure. This error was estimated to be ±3%. A McLeod gauge was used in all pressure measurements to avoid cumulative errors due to the calibration of secondary pressure-sensitive devices. However, a thermocouple pressure gauge was used to ensure that the pressure of the gas remained constant during a run.

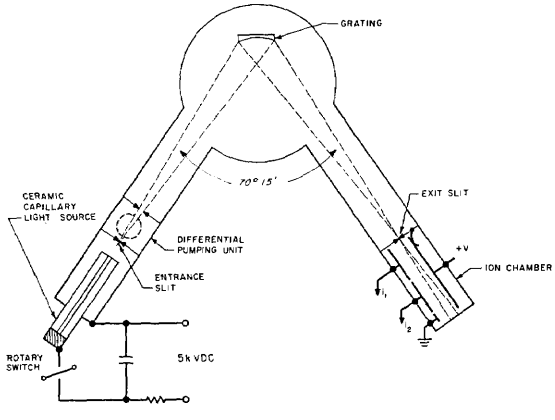

FIG. 1. Experimental arrangement of light source, vacuum monochromator, and absorption cell. The absorption cell is in fact a double ion chamber.

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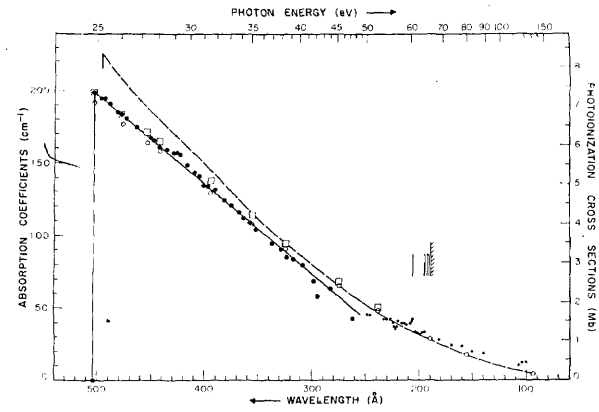

FIG. 2. Experimental photoionization cross sections of helium compared to theoretical values. The vertical lines indicate the position of discrete absorption lines observed by Madden and Codling. Squares, Stewart & Webb (dipole length); open circles, Stewart & Webb (dipole velocity); large dots, present data; small dots, Lowry & Tomboulian. Broken curve, Cooper; solid curve, present data.

The absolute values of the absorption coefficients thus determined are estimated to have a maximum error spread of ±5%. The error in the spectral shape of the absorption curves is dependent only on the error in $\ln(i_1/i_2)$. This is estimated to be within ±3%.

RESULTS

The photoionization cross sections are shown in Fig. 2. They represent the average of four different determinations with the gas pressure varying from 0.5 to 1.0 Torr. The scatter of points lie within ±2.5% of the average curve, with the exception of the last few points at the shortest wavelengths where the spread is somewhat greater.

The vertical lines in Fig. 2 represent the positions of absorption lines discovered by Madden and Codling[15] using the continuum radiation from a 180-MeV synchrotron. They account for the series as due to a double electron excitation process of the type $1s^2-2s,np$ and $1s^2-2p,ns$. The first member of the series, appearing at approximately 260 Å, is common to the two series and represents the transition $1s^2\,{}^1S_0-2s,\ 2p\,{}^1P^0$. Only one series was observed.

The data are compared with the theoretical calculations of Cooper,[10] who used a one electron model, and to that of Stewart and Webb[9] using the Hartree–Fock wavefunction. The experimental points of Lowry and Tomboulian[16] are included to extend the range of comparison down to 100 Å. The recent work of Stewart and Webb is felt to be the most sophisticated available cal-

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culation of the helium cross sections. They have computed the cross sections using the Coulomb, Hartree, and Hartree–Fock approximations and for each approximation they quote values using the dipole length, velocity, and acceleration formulations. We have selected the values obtained by the Hartree–Fock approximation as the ones which best fit our experimental data. It can be seen that the dipole length formulation is the best fit at the spectral head but at the shorter wavelengths the velocity formulation appears superior. This is in agreement with the conclusion reached by Stewart and Webb.

We should mention that the selected cross-section values of Dalgarno and Stewart[6] are very close to those calculated by Stewart and Webb. The selected values were obtained from the data of Stewart and Wilkinson[8] for energies up to 1 Ry, and Huang's[4] acceleration values for energies greater than 1 Ry; these values were then adjusted to provide good agreement with the various sum rules involving the oscillator strengths.

The experimental oscillator strength f for excitation into the continuum was obtained by use of the relation

$$f=\frac{mc^2}{e^2\pi n_0}\int k(\nu)d\nu, \qquad (1)$$

where k, the absorption coefficient, and ν, the wavenumber, are expressed in reciprocal centimeters and m, e, and c have their usual meaning. n_0 is Loschmidt's number. The numerical value of $(mc^2)/(e^2\pi n_0)$ is 4.19×10^{-8}.

The integral was evaluated graphically from the ionization threshold to 0.01 Å using the data in Fig. 2, the experimental k-values compiled by Allen,[17] and the semiempirical values calculated by Henke[18] and Victoreen.[19] A value of $f=1.54$ was obtained. Since the contribution between 0.01 and 4.0 Å amounts to only 0.0001, the contribution below 0.01 is assumed to be negligible. The Thomas–Kuhn sum rule requires that the total oscillator strength be equal to the number of electrons in the atom, that is $=2$ for helium. Thus, the contribution to the oscillator strength due to discrete structure must be $=0.46$. Theoretical values for the discrete transitions have been calculated by several investigators.[1–7,20–22] A value of 0.45 was obtained by both Dalgarno and Stewart,[6] and by Salpeter and Zaidi.[7] The calculations included the f values for the doubly excited transitions as well as those for the resonance series. Since Dalgarno and Stewart quote f values only for $n=2$ to 6, the remainder of the sum for $n=7$ to ∞ was obtained from their earlier paper.[5]

TABLE I. Helium f values for the transition 1^1S-n^1P as obtained from the relation $f=C/n^3$.

n	Dalgarno and Stewart[a]	Present data $f=C/n^3$
2	0.270	0.229
3	0.0746	0.0679
4	0.0304	0.0286
5	0.01530	0.0147
6	0.00878	0.00848
7		0.00505
8		0.00359
9		0.00251
10		0.00183

[a] See Ref. 6.

Discrete transitions for large n have f values given, approximately, by $f=C/n^3$,[23] where n is the principal quantum number and C is given by twice the value of $df/d\epsilon$ evaluated at the series limit ($k=217\ df/d\epsilon\ \mathrm{cm}^{-1}$); ϵ being the kinetic energy of the released photoelectron, measured in Rydbergs. Using the present experimental data we find $C=1.83$. Table I compares the theoretical f values calculated by Dalgarno and Stewart with the values obtained from the above relation. As n increases we find the two results in good agreement.

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