Excitation of the He II λ4686 Å Line by Electron Impact*

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Absolute cross sections for the excitation of the He II λ4686 Å line by electron impact on helium have been measured as a function of electron energy from threshold to 400 eV. A rough comparison of the results is made with expected cross sections from the calculations of Dalgarno and McDowell. Excitation of the He I λ4713 Å line ($4\,^3S \rightarrow 2\,^3P$ transition) was also measured and the results compared with those of other investigators.

I. APPARATUS

An electron collision chamber very similar to that previously described[1] was used in this experiment. This particular apparatus is different in that it does not use differential pumping; it uses the electron gun from a 3AP1 cathode-ray tube; and it is constructed of brass. The current was measured in a deep Faraday cup while the pressure was measured by a trapped McLeod gauge. Helium was leaked into the collision area via a liquid-air-cooled charcoal trap.

The spectrometer described in Ref. 1 was used for spectral analysis. Calibration of the spectrometer was checked against that of another spectrometer calibrated in this laboratory. The procedure used in calibrating this latter spectrometer has been previously described.[2]

II. RESULTS AND DISCUSSION

Cross sections for the production of the He II λ4686 Å emission were determined. This emission results from the simultaneous ionization and excitation of the helium atom. This particular line represents the $n=4 \rightarrow n=3$ transition in the helium ion. Measurements were also made on the He I λ4713 Å line ($4\,^3S \rightarrow 2\,^3P$ transition). These latter measurements were made principally to compare our calibration with the work of other investigators.

Measurements were made at pressures of about 10 μ Hg. It was determined that both lines were linear with both pressure and current in this region. This indicates single collision excitation.

Our definition of cross section is usual and follows from the equation, $P=\sigma\rho F$, where P is the number of photons/sec emitted from a cubic centimeter, σ is the cross section, ρ is the atomic gas density, and F is the electron flux.

Figure 1 displays our results for the λ4713 Å line. Our results agree within experimental error with the maximum cross-section measurements of Stewart and Gabathuler.[3] Their measurement of 2.19×10^{-19} cm^2 for the maximum appears quite satisfactory. Gabriel and Heddle[4] have also made measurements at 108 eV. They quote an observed $4\,^3S$ level excitation cross section of 4.4×10^{-20} cm^2, which implies a $4\,^3S \rightarrow 2\,^3P$ line cross section of 2.6×10^{-20} cm^2 using their tabulated transition probabilities. Our measurements normalized to the peak value of Stewart and Gabathuler indicate a line cross section of only 1.2×10^{-20} cm^2 at 108 eV. This seems to indicate that the value quoted by Gabriel and Heddle may be too large by nearly a factor of 2 for this particular line. The shape of our excitation curve seems to agree well with that of Heddle,[4,5] the ratio of the peak excitation to the excitation at 108 eV being about the same.

Figure 2 displays the results for the λ4686-Å emission. Dalgarno and McDowell[6] have calculated cross sections for the simultaneous ionization and excitation of helium

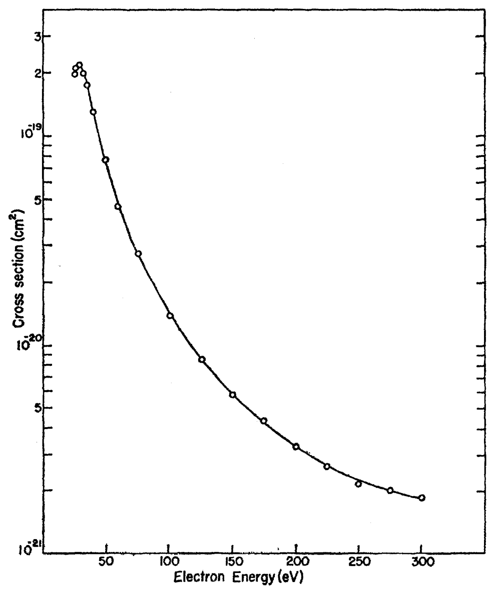

FIG. 1. Excitation cross sections for the He I λ4713 Å line as a function of electron energy.

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by electron impact using the Born approximation. They include excitation to the $4p$ and $4d$ levels. Their estimated uncertainty is a factor of 5.

In order to compare our experimental results with their calculations, we choose to roughly estimate the cross section for populating the $n=4$ level of the helium ion from our measured cross section for the production of $n=4 \rightarrow n=3$ emission.

Let $R_1=\sigma(4s)/\sigma(4p)$, $R_2=\sigma(4d)/\sigma(4p)$, and $R_3=\sigma(4f)/\sigma(4p)$ where the σ's are the indicated cross sections for populating the various $n=4$ states. Thus, $\sigma(n=4)=\sigma(4p)[1+R_1+R_2+R_3]$. Neglecting cascade from higher states, the equilibrium number of ions in the $4p$ states is $N(4p)=T_{4p}\sigma(4p)\rho F$, where T_{4p} is the mean radiative lifetime of the $4p$ state. Similar expressions will exist for the $4s$, $4d$, and $4f$ states. The rate at which λ4686 Å photons are emitted, $P(4\rightarrow 3)$, is

$$P(4\rightarrow 3)=\sigma(4\rightarrow 3)\rho F=N(4s)A_1+N(4p)[A_2+A_3]+N(4d)A_4+N(4f)A_5,$$

where A_1, A_2, A_3, A_4, A_5 are the $4s\rightarrow 3p$, $4p\rightarrow 3s$, $4p\rightarrow 3d$, $4d\rightarrow 3p$, $4f\rightarrow 3d$ transition probabilities, respectively. It follows then that

$$\sigma(n=4)=\sigma(4\rightarrow 3)\times\left[\frac{1+R_1+R_2+R_3}{R_1T_{4s}A_1+T_{4p}[A_2+A_3]+R_2T_{4d}A_4+R_3}\right].$$

Hydrogen lifetimes and transition probabilities are sufficient here since the product of these quantities is used in this calculation.

Obtaining an accurate factor to multiply our line cross section, $\sigma(4\rightarrow 3)$, would require knowledge of the ratios R_1, R_2, and R_3. The calculations of Dalgarno and McDowell give only R_2. However, one can reasonably assume that $R_3<R_1<1$. Excitation to the $4p$ state is optically allowed, while excitation to the $4s$ and $4f$ are optically forbidden, as is the $4d$ state. It would be expected then that the $4p$ cross section would in general be the largest. R_2 seems to have values between $\frac{1}{4}$ to $\frac{1}{5}$ in the energy range of the calculations of Dalgarno and McDowell (109 to 544 eV). We estimate that $\sigma(n=4)$ will be given roughly by multiplying our line cross section by a factor of about 5. This should be easily within a factor of 2 of the proper value. We estimate from Dalgarno and McDowell that they would obtain a cross section of the order of 5×10^{-21} cm^2 for $\sigma(n=4)$ if $\sigma(4s)$ and $\sigma(4f)$ were included at 200 eV. This is an order of magnitude smaller than expected from our experimental estimate of 4×10^{-20} cm^2. If our results

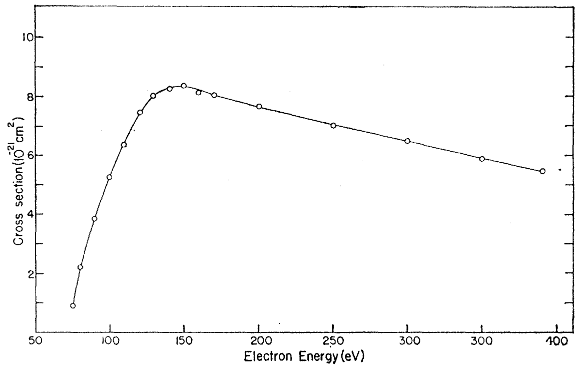

FIG. 2. Excitation cross sections for the He II λ4686 Å line as a function of electron energy.

and arguments are valid, this would indicate that a more suitable wave function should be chosen for such calculations.

It is of some interest to compare the excitation of this line by electron impact with the excitation by proton impact where both particles have the same velocity. It appears that this line exhibits a cross section of about 2×10^{-20} cm^2 under 200-keV proton impact[7] while our measurements indicate a cross section of about 5.3×10^{-21} cm^2 under 100-eV electron impact which is four times smaller than the proton impact figure. At these high proton velocities the charge transfer reaction, $H^+ + He \rightarrow H + He^+$, is small compared with simple ionization. Further, according to Mapleton's calculations,[8,9] at 200 keV, charge transfer resulting in excited states of the helium ion is an order of magnitude smaller than simultaneous ionization and excitation. Therefore, we should be close to comparing the same excitation process for the two cases, namely simultaneous ionization and excitation. At this velocity the gross ionization cross section for proton impact is only about twice that for electron impact.[10] Thus, it would appear that proton impact is more effective in exciting the ion than is the electron impact. The experimental uncertainties are quite large, however.

The derived cross section for excitation by electron impact to the $n=4$ state is roughly 0.1%, the total ionization cross section in the energy range above 100 eV.

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