Comment on "Measurement of the Ratio of Double-to-Single Photoionization of Helium at 2.8 keV Using Synchrotron Radiation"

Recently Levin and co-workers [1,2] and Bartlett *et al.* [3] have measured the ratio $R \equiv \sigma^{2+}/\sigma^{+}$ of cross sections for double ionization to single ionization of helium by photons at increasing energies approaching 12 keV. The results were compared to several theoretical calculations of helium photoionization [4], and are in approximate agreement that the limit of high (but nonrelativistic) energies is $R = 0.017$.

In this Comment we point out that, in addition to photoionization, the atomic Compton effect is important to consider in interpreting these experiments. This follows from the strong energy dependence of the photoionization cross section ($\sigma_{\rm PI}^{+} \approx [h\nu/(1\ {\rm keV})]^{-3.5} 480$ b), which falls rapidly compared to the roughly constant Compton scattering cross section ($\sigma_{\rm CS} \approx 1$ b). At energies higher than $h\nu \approx 6$ keV, more He^{+} ions are produced by Compton scattering than by photoionization. In view of these Compton processes, the observed branching ratio can be written as

$$R_{\rm obs} = (\sigma_{\rm PI}^{2+} + \sigma_{\rm CS}^{2+})/(\sigma_{\rm PI}^{+} + \sigma_{\rm CS}^{+}) . \quad (1)$$

Here the single and double photoionization terms $\sigma_{\rm PI}^{+}$ and $\sigma_{\rm PI}^{2+} \approx 0.017\sigma_{\rm PI}^{+}$ are reasonably well understood at high energies. The cross section $\sigma_{\rm CS}^{+}$ for producing He^{+} ions by the Compton effect is also understood theoretically and has been tabulated in Refs. [5,6]. (Here we estimate that the "incoherent" Compton scattering cross section will be close to the ionization contribution $\sigma_{\rm CS}^{+}$ above 3 or 4 keV.) However, the cross section for producing He^{2+} by the Compton effect has not been previously considered. A calculation has now appeared [7]. One of our goals for this Comment is to draw attention to the need for theoretical calculations of the two-electron Compton process: $h\nu + {\rm He} \rightarrow h\nu' + {\rm He}^{2+} + e + e$.

Even without an estimate of the term $\sigma_{\rm CS}^{2+}$, some definite conclusions can be reached. Clearly the new measurements of Levin *et al.* [2] in the energy range 8.2–11.6 keV are dominated by Compton scattering rather than by photoionization. At the highest energy studied, the measured branching ratio $R_{\rm obs}$ should probably be interpreted as a measurement of $R_{\rm CS}$, since $\sigma_{\rm CS}^{+} \approx 10\sigma_{\rm PI}^{+}$ at that energy [6]. Thus, the agreement between experiment [1–3] and theory [4] may be fortuitous above 5 keV. The lower energy measurements of Refs. [1–3] are still correctly interpreted as measurements of $R_{\rm PI}$, since $\sigma_{\rm PI}^{+} \approx 7\sigma_{\rm CS}^{+}$ at 4 keV. Nevertheless, a Compton effect correction should be applied to the data, as it could be about a 15% effect there. Compton scattering presumably excites only one electron initially; thus the term $\sigma_{\rm CS}^{2+}$ should be negligible at photon energies below 5 keV because insufficient energy is gained to ionize both electrons. (A shakeoff-type model suggests that $R_{\rm CS}$ eventually approaches the same limiting constant as $R_{\rm PI}$ at very high energies. The energy of a Compton-produced electron would seem to be too low to validate this model in the 8–12 keV range.)

The Compton and photoionization contributions can be distinguished experimentally by measuring the ejected electron energy distribution or by observing the Compton scattered photon in coincidence with an ion or electron. Compton processes should produce no electrons faster than about 600 eV, even for photon energies of 12 keV, whereas almost every photoionization event at these energies produces a photoelectron with energy close to $h\nu$.

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