Projectile-Charge Dependence of Quasifree-Electron Bremsstrahlung

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Recently[1,2], we have observed a new continuum x-ray component coming from a kind of radiative ionization process[3] in bombardments of Be, C, and Al targets with 6-40 MeV protons. This new continuum x-ray component was definitely characterized by the relative kinetic energy $T_r = \frac{1}{2} m_e v_p^2$ between an orbital electron of the target atom and the projectile, where m_e is the electron mass and v_p is the projectile velocity. This new component of continuum x rays has been well explained[1] in terms of bremsstrahlung produced by the orbital electron scattered in the projectile-Coulomb field. We call these continuum x rays quasifree electron bremsstrahlung (QFEB). As observed in radiative electron capture, an effect of velocity distribution of the orbital electron[2] is also expected on the spectral shape of QFEB. A simple theory[2] of QFEB predicts that the cross section at the end-point of QFEB strongly depends on the atomic number of projectile. The projectile-charge dependence[4] is therefore expected on the spectral shape.

Beams of 20.21-MeV/amu protons and 20.23-MeV/amu $^3He^{2+}$ ions bombarded a Be target of 4.67-mg/cm^2 thickness, which was set at 45° with respect to the beam. By taking account of the energy spread in the target, the mean beam energies were estimated to be 20.14 MeV/amu for protons and $^3He^{2+}$ ions. The x rays have been measured with an ORTEC Si(Li) detector in the direction 90° to the beam. Differential cross sections for the continuum x-ray production are shown in Fig. 1 as a function of the x-ray energy $\hbar\omega$. The cross sections are multiplied by the x-ray energy and divided by square of the projectile charge. In the vicinity of $\hbar\omega = T_r$ a difference is seen between the spectra for proton and for $^3He^{2+}$ impact, whereas the spectra are in good agreement in the other region.

Figure 2 shows the difference between the cross sections for $^3He^{2+}$-ion and proton impact $[\hbar\omega(\frac{1}{4}\sigma_h(\hbar\omega) - \sigma_p(\hbar\omega))]$ obtained from the experiment and from the theoretical calculations of QFEB and REC.[5] It is found in this figure that the experimental value makes a peak at $\hbar\omega \approx T_r$. Peaks in the region of $\hbar\omega \approx 7$ keV are due to the K x rays from the impurity elements. The dotted line and the dashed line in Fig. 2 show the difference $\hbar\omega(\sigma_h^{QFEB}(h\omega)/4 - \sigma_p^{QFEB}(\hbar\omega))$ calculated in terms of an impulse approximation[4], respectively, for the 1s electrons of Be target and for the 2s electrons, and the dot and dashed line is the difference in cross section for REC between the two kinds of projectile — $\hbar\omega(\sigma_h^{REC}(\hbar\omega)/4 - \sigma_p^{REC}(\hbar\omega))$ — calculated in terms of the impulse approximation developed by Kleber and Jakubassa.[5] The solid line shows the sum of these differences in the cross sections for QFEB and REC. It is seen that the calculations based on the impulse approximation for QFEB and REC can quite well explain the present experimental results.

It is thus concluded that, as has been observed in the x-ray spectrum of REC[6], velocity distribution of the orbital electron gives a large effect on the difference of the cross sections for QFEB between proton and $^3He^{2+}$-ion impact and also that the contribution of REC is clearly found even for proton and $^3He^{2+}$-ion impact, though REC process has well been studied in the case of heavy ion impact.

References

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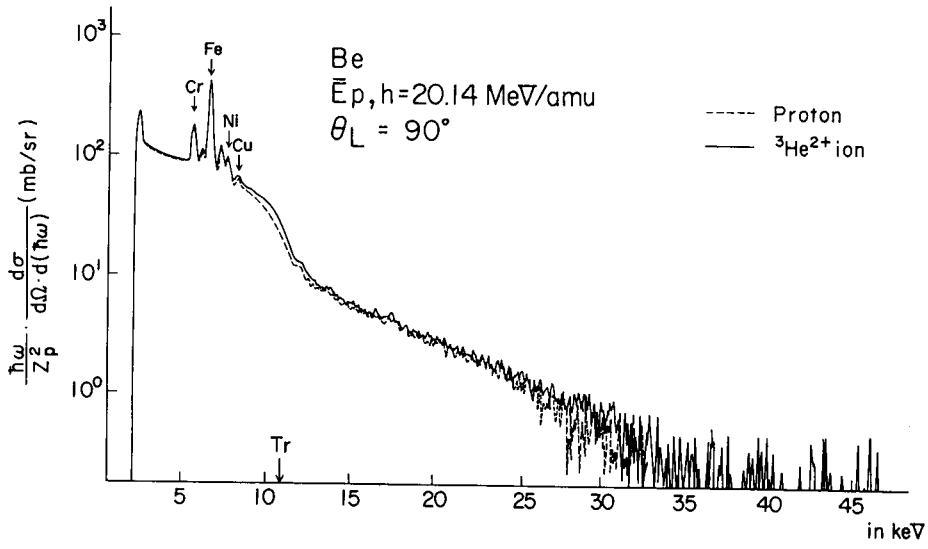

Fig. 1. X-ray spectra for the Be target bombarded with 20.11 MeV/amu protons (dashed line) and 20.33 MeV/amu $^3He^{2+}$ ions (solid line), measured in the direction 90° with respect to the incident beam. The ordinate shows the differential cross sections multiplied by the x-ray energy and divided by square of the projectile charge.

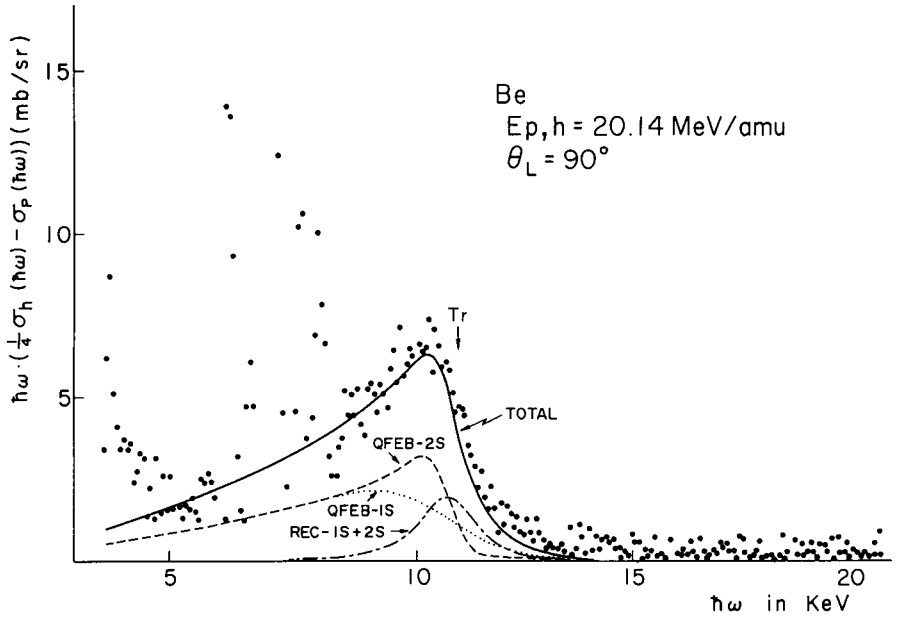

Fig. 2. The difference in cross sections for $^3He^{2+}$-ion and proton impact: $\hbar\omega(\sigma_h(\hbar\omega)/4 - \sigma_p(\hbar\omega))$. The dotted line is the theoretical value for QFEB calculated for the 1s electron of Be target estimated from Eq. (1) and the dashed line is for the 2s electrons. The dot and dashed line is the difference in cross sections for REC process calculated from the formula of Kleber and Jakubassa.[5] The solid line is the sum of the differences calculated for QFEB and REC.