shell electrons are available to fill an inner hole, and this requires a charge state $q \gtrsim +26$. Thus, the existence of L-shell REC would tend to support the idea that close collisions often result in the removal of a large number of outer-shell electrons rather than several inner-shell electrons.

The agreement between predicted and observed values of the REC line positions is best at high projectile energy. At lower energies, the measured feature occurs at an energy somewhat lower than expected from our simple model. A significant correction may arise due to the noticeable degradation of beam energy in thick targets. Better understanding of position, width, and production cross sections of REC features requires the development of more sophisticated theoretical models.

Further experimental work is in progress to establish the angular distribution and polarization of the REC radiation. Gaseous targets will also be investigated to determine how the capture process is changed when the target electrons are distributed in sharply defined states of widely differing energy. Results from these experiments will test specific predictions of the present model.

Provided that the model is thoroughly established, REC can become an important diagnostic process in the interpretation of data from such diverse fields as astrophysics and solid-state physics. In addition, when the bromine data presented here are considered, it is clear that the REC process must also be included in the general discussion of x-ray spectra from heavy-ion collisions. REC lines could easily be blended with spectral features attributed to other processes, for example, combined atom effects, fusion products, and trace impurities in the beam or target.

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†Center for Space Research, Massachusetts Institute of Technology, Cambridge, Mass. 02139.

‡Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Mass. 02139.

§The MIT authors also hold guest appointments at Brookhaven National Laboratory.

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K-Shell Fluorescence Yield for Metallic Lithium and Other Light Elements*

K. Feser
Sektion Physik der Universität München, München, Germany
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The K-shell fluorescence yield ω_K for metallic lithium was determined from intensity measurements of the K emission band excited in fluorescence with the synchrotron radiation of the 7.5-GeV DESY electron synchrotron. The value obtained for lithium is $\omega_K = (1.06 \pm 0.53) \times 10^{-4}$. Recently determined values of ω_K for Be, B, and C are tabulated. The value of ω_K for C previously published by the author was incorrect; the corrected value is $\omega_K = (13.0 \pm 3.9) \times 10^{-4}$.

The fluorescence yield of lithium has not yet been measured, although this element is deserving of special attention. A free lithium atom from which a K-shell electron is removed cannot show an Auger effect and therefore the fluorescence yield should be 1. However, following a K-shell ionization in solid lithium or the transfer of a K-shell electron of a free lithium atom to a high bound state, an Auger effect is possible and the fluorescence yield should be less than 1. This would mean that the fluorescence yield depends upon the configuration of the atom and the character of the chemical binding. Such conclusions are supported by the results of recent measurements on carbon by Toburen.[1] We have measured the fluorescence yield of metallic lithium and

our results are also consistent with these conclusions.

The fluorescence yield of metallic lithium was determined in a manner described in a previous paper.[2] The probe was irradiated with the synchrotron radiation of the 7.5-GeV DESY electron synchrotron and the emitted Li K-emission band was recorded with a 2-m concave grating spectrometer. The lithium was evaporated *in situ* onto a glass substrate. A turbomolecular pump provided an oil-free vacuum of 1.5×10^{-5} Torr during evaporation and a pressure of less than 1.5×10^{-6} Torr during the measurements. Layers of at least 0.05 mm thickness, which can be regarded as infinitely thick for Li K photons, were deposited several times between the measurements. The number of the evaporated layers had no influence upon the intensity of the Li K band. For the evaluation of the fluorescence yield only such measurements were used as were made within a time of 10 min after evaporation, since the layers oxidized slowly, as could be shown unambigously by successive recordings of the spectrum. The K-emission band of freshly evaporated lithium was in good agreement with that reported by Bedo and Tomboulian,[3] but as soon as 30 min after evaporation two peaks which are predominant in the spectrum of Li_2O could be detected on the high-energy side of the Li K band.

The fluorescence yield was evaluated by use of the formula[2]

$$I_{max}=N_K\omega_K g_S R_G f_E Y_D, \qquad (1)$$

where I_{max} is the counting rate measured in the maximum of the K-emission band; $N_K\omega_K g_S$ is the number K photons entering the spectrometer entrance slit per minute; g_S is the geometry factor, i.e., the solid angle seen by the spectrometer divided by 4π; R_G is the reflecting power of the grating; f_E is a factor giving the proportion of the peak intensity to the total intensity of the emission band; and Y_D is the quantum yield of the detector.

I_{max} (33.5 counts/min; peak-to-background ratio, 20 to 1) was measured with an error of 7%. The synchrotron was run at 3 GeV and 10.2 mA. The factor N_K was calculated from the intensity distribution $I(\lambda)$ of the synchrotron radiation and the absorption coefficient $\mu(\lambda)$ of lithium using the formula

$$N_K=\frac{\mu_H-\mu_L}{\mu_H}\int_0^{\lambda_{K\,\mathrm{edge}}}\frac{I(\lambda)\tan\beta\,d\lambda}{\tan\beta+\mu(\lambda_K)/\mu(\lambda)}, \qquad (2)$$

where μ_H and μ_L are the absorption coefficients just below and above the wavelength of the K edge ($\lambda_{K\,\mathrm{edge}}$); λ_K is the wavelength of the maximum of the K-emission band; and $\beta=22.9°$ is the take-off angle of the fluorescence radiation with respect to the target surface. $I(\lambda)$ is the intensity of the synchrotron radiation falling onto the target surface seen by the spectrometer and can be calculated from theory.[4] The current of the synchrotron was known with an accuracy of 10%. The absorption coefficients of lithium below 80 Å were taken from calculations of Henke, White, and Lundberg[5] and McGuire[6]; for wavelengths above 80 Å experimental data of Baker and Tomboulian[7] and Haensel *et al.*[8] were used. Since the values of Haensel *et al.*[8] are given only in relative units, an absolute scale was determined by matching this set of data at the wavelength 100 Å to the corresponding mean value $\mu=8\times10^4$ cm^{-1} resulting from the measurements of Baker and Tomboulian[7] and the calculations of McGuire.[6] The two experimental sets of data agree then fairly well for wavelengths up to the K edge, while they differ markedly in the region of the K-emission band, yielding $\mu(\lambda_K)=7.5\times10^4$ cm^{-1} and $\mu(\lambda_K)\,1.2\times10^5$ cm^{-1}, respectively. N_K was calculated for both these values and the result differed by a factor of 2. For the evaluation of ω_K we took the mean reciprocal value, corresponding to $N_K=1.57\times10^{13}$ photons/min. The geometry factor $g_S=9.48\times10^{-6}$ was calculated numerically; the error can be neglect-

TABLE I: Fluorescence yield for Li to C in units of 10^{-4}.

Source	Lithium	Beryllium	Boron	Carbon
Present work	1.06 ± 0.53	···	···	13.0 ± 3.9[a]
McGuire, Ref. 15 (theory)	···	···	5.6	26
Feser, Ref. 2	···	3.6 ± 1.08	5.7 ± 1.7	8.8 ± 2.6
Dick and Lucas, Ref. 13	···	3.04 ± 0.61	7.1 ± 1.84	11.3 ± 2.4
Hink and Paschke, Ref. 14	···	···	···	35 ± 3.5
Toburen, Ref. 1	···	···	···	15.4^{+8}_{-4}

[a]Corrected value, see text.

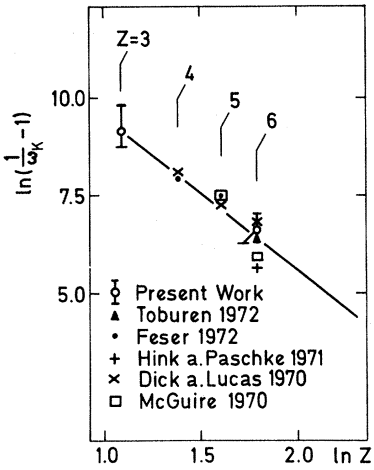

FIG. 1. Plot of the K-shell fluorescence yield ω_K (after Byrne and Howarth, Ref. 16) for Li and C (present work) and Be to C (see Refs. 1, 2, 13–15). Straight line, approximation after Kostroun, Chen, and Crasemann, Ref. 17.

ed. The reflecting power of the grating (Bausch and Lomb; radius of curvature, 1999.5 mm; 600 lines/mm; blaze angle, 3°31′; Au coating) was measured by Neddermeyer[9] just below and above the wavelength of 230 Å (the maximum of the K-emission band of lithium), and his results give $R_G = 0.215 \pm 0.04$. The factor $f_E = 0.141$ was determined with negligible error from the known shape of the emission band. The yield of the detector, a parallel-plate continuous-dynode electron multiplier[10] with Au cathodes, has been determined earlier to be $Y_D = 9\%$ for an angle of incidence of 20° and $\lambda = 44$ Å by comparison with a flow proportional counter of known absolute efficiency. This value agrees well with photoelectric yield measurements of Au cathodes reported by Savinov, Lukirskii, and Shepelev[11] which can be extrapolated to $\lambda = 230$ Å, yielding a value of $Y_D = 0.07 \pm 0.02$ for an angle of incidence of 20°. Inserting these values in Eq. (1) it is found that $\omega_K(\mathrm{Li}) = (1.06 \pm 0.53) \times 10^{-4}$.

In Table I the value of lithium is listed together with a corrected value for carbon (graphite). The value of carbon given earlier[2] is incorrect because the synchrotron was run during the measurements on carbon[12] at 4 GeV, while the calculations had been performed for an energy of 6 GeV. The values of B and Be in this work[2] remain unchanged. Included in Table I are all recent measurements of the fluorescence yield for Be to C[1,2,13,14] and a theoretical calculation by McGuire[15] for B and C.

In Fig. 1 these fluorescence yields are plotted in a manner as proposed by Byrne and Howarth[16] and it can be seen that the values of ω_K for elements with atomic number $Z = 3 \cdots 6$ lie close to the straight-line approximation of ω_K calculated for higher-Z elements by Kostroun, Chen, and Crasemann.[17] This is remarkable especially in the case of lithium.

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