ionization τ. The decay of this state in the region $r < R_c$ will have a velocity dependence given by $\exp(-R_c/v\tau)$ for small impact parameters, an idea discussed by Bates.[13] This interpretation explains the velocity-dependent term in Eq. (1) if we identify $v_0 = 2R_c/\tau$.

Work is presently in progress to extend these results to higher energies (40 keV), and to different target gases; it will be published at a later date, together with a more complete description of the apparatus and experimental procedures.

We would like to thank the following people for their helpful discussions and encouragement: Joel Gerstein, Arvid Herzenberg, Robert Junker, William Lichten, Donald Lorents, Ronald Olson, Arnold Russek, and George Temmer.

†Work supported in part by the National Science Foundation.

[1] J. F. Williams, Phys. Rev. 154, 9 (1967); see also J. S. Risley, A. K. Edwards, and R. Geballe, in *Seventh International Conference on the Physics of Electronic and Atomic Collisions. Abstracts of Papers,* edited by J. B. Hasted (North-Holland, Amsterdam, 1971), p. 1047; E. P. Andreev, V. A. Ankudinov, V. M. Dukelsky, and A. L. Orbeli, in *Sixth International Conference on the Physics of Electronic and Atomic Collisions. Abstracts of Papers* (Massachusetts Institute of Technology Press, Cambridge, Mass., 1969), p. 800.

[2] W. C. Keever, G. J. Lockwood, H. F. Helbig, and E. Everhart, Phys. Rev. 166, 68 (1968).

[3] D. C. Lorents and G. M. Conklin, to be published.

[4] R. Francois, D. Dhuicq, and M. Barat, in *Seventh International Conference on the Physics of Electronic and Atomic Collisions. Abstracts of Papers,* edited by J. B. Hasted (North-Holland, Amsterdam, 1971), p. 135.

[5] G. P. Lawrence, R. K. Beauchamp, and J. L. McKibben, Nucl. Instrum. Methods 32, 357 (1965). Development of our source is due in no small part to the generous assistance of Bob Peterson and Ralph Waldhauser.

[6] Model No. 4028 Channeltron electron multiplier. Available from Bendix Corp., Electro-Optics Division, P. O. Box 635, 175 Green Road, Ann Arbor, Mich. 48107.

[7] P. R. Jones, P. Costigan, and G. Van Dyk, Phys. Rev. 129, 211 (1963).

[8] C. N. Burrows, A. J. Lieber, and V. T. Zaviantseff, Rev. Sci. Instrum. 38, 1477 (1967).

[9] G. J. Lockwood, H. F. Helbig, and E. Everhart, Phys. Rev. 132, 2078 (1963).

[10] F. T. Smith, R. P. Marchi, W. Aberth, D. C. Lorents, and O. Heinz, Phys. Rev. 161, 31 (1967).

[11] Risley, Edwards, and Geballe and Andreev *et al.*, Ref. 1.

[12] G. W. F. Drake, Phys. Rev. Lett. 24, 126 (1970).

[13] D. R. Bates, in *Atomic and Molecular Processes,* edited by D. R. Bates (Academic, New York, 1962), pp. 613–615.

K-Shell Fluorescence Yield for Beryllium, Boron, and Carbon*

K. Feser
Sektion Physik der Universität München, München, Germany
(Received 25 February 1972)

The *K*-shell fluorescence yield ω_K for Be, B, and C was determined from intensity measurements of the *K* emission bands excited in fluorescence with the synchrotron radiation of the 7.5-GeV DESY electron synchrotron. The following values for ω_K were obtained: beryllium, 3.6×10^{-4}; boron, 5.7×10^{-4}; carbon (graphite), 8.8×10^{-4}; the mean error being ±30%. These results and those of previous measurements are discussed.

Several papers[1-4] dealing with the fluorescence yield of elements with atomic number $Z < 10$ have been published recently. The values obtained by different authors are not in good agreement, and therefore further measurements seemed to be necessary.

A new method was used to determine the *K*-shell fluorescence yield ω_K of Be, B, and C. Synchrotron radiation from the 7.5-GeV DESY electron synchrotron fell onto the target at an angle of incidence of about 70°, and the fluorescence radiation, taken off at an angle of 90° with respect to the primary beam, entered a 2-m concave grating spectrometer. For the evaluation of ω_K, the photon flux of the fluorescer was determined as follows. Let $N_K\omega_K$ be the number of *K* photons emitted per second per steradian by the fluorescer in the direction of the spectrometer entrance slit. Then N_K can be calculated by integrating the absolute intensity of the synchrotron radiation over the wavelength, taking into account the absorption coefficients of the target materials

TABLE I. Fluorescence yield for Be, B, and C in units of 10^{-4}.

Source	Beryllium	Boron	Carbon
McGuire, Ref. 1 (theory)	···	5.6	26
Present work	(3.6 ±30)%	(5.7 ±30)%	(8.8±30)%
Dick and Lucas, Ref. 2	(3.04±20)%	(7.10±40)%	(11.3±20)%
Hink and Paschke, Ref. 3	···	···	(35 ±10)%
Crone, Ref. 15	···	···	(9 ±45)%

for the primary photons and the fluorescence radiation with the use of a formula which is similar to that given by Dick and Lucas.[2] The absolute intensity of the synchrotron radiation, whose wavelength distribution is well known,[5,6] was determined with an error of ± 10% from beam-current measurements.[7,8] Considering the uncertainty of the absorption coefficients,[9-11] the mean error of N_K amounts to ± 22%. The fluorescence yield ω_K was calculated from the data for intensity measurements of the K emission bands[12] using the formula[13]

$$I_{max} = N_K \omega_K L, \tag{1}$$

where I_{max} is the counting rate measured in the maximum of the K emission band in question, and L is a quantity which is determined by the characteristics of the spectrometer and may be written

$$L = g_S R_G f_E Y_D, \tag{2}$$

where g_S is the geometry factor, i.e., the fraction of the emitted intensity of the fluorescer which is accepted by the spectrometer; 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.[14]

The value of L was obtained by calculating g_S and measuring R_G, f_E, and Y_D; and the resulting value was checked by intensity measurements of the K radiations of C and Be excited by electron impact. The absolute intensities N_{eff} (emitted K photons per electron per steradian) of the x-ray sources were calculated using the K x-ray quantum yield coefficients determined by Campbell.[4] A comparison of the measured peak intensities I_{max}' of the spectra excited by electron impact with the values calculated from the quantity L and the absolute intensities N_{eff} with use of the equation

$$I_{max}' = N_{eff} L \tag{3}$$

gave an agreement within a few percent, thus confirming the reliability of the determined value of L.

The values obtained for the fluorescence yield are listed in Table I together with all values determined so far experimentally for Be, B, and C and theoretical calculations of McGuire[1] for B and C. Our value for B is in agreement with McGuire's calculation, while for our value of C this is not the case.

The experimental values of Dick and Lucas[2] for Be, B, and C and of Crone[15] for C are within the error bars of our results, while Hink and Paschke's[3] value for C is closer to McGuire's calculation.

In Fig. 1 the K-shell fluorescence yield for elements of $Z = 4 \cdots 47$ is shown in a plot after Byrne and Howarth.[16] The straight line representing the equation

$$\ln(1/\omega_K - 1) = -3.94 \ln Z + 13.5 \tag{4}$$

has been taken from a calculation of Kostroun,

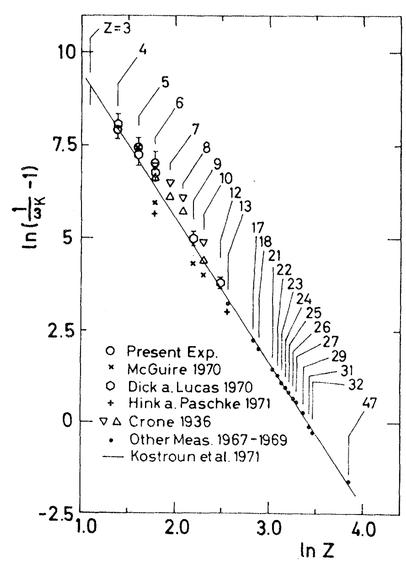

FIG. 1. Plot of the K-shell fluorescence yield ω_K (after Byrne and Howarth, Ref. 16), for Be to C (present work) and Be to Ag (see Refs. 1–3, 15, 18–23). Straight line, approximation after Kostroun, Chen, and Crasemann, Ref. 17.

Chen, and Crasemann[17] and fits best the theoretical data of these authors for $15 < Z < 70$. The values of Crone[15] for C, N, and O were determined relative to neon for which a theoretical value ($\omega_K = 8.1\times10^{-3}$) was used. A better value for neon seems to be that lying on the straight line ($\omega_K = 1.2\times10^{-2}$) in Fig. 1. Relative to this value Crone's results are $\omega_K = 1.3\times10^{-3}$, 2.2×10^{-3}, and 3.2×10^{-3} for C, N, and O, respectively, which fit the straight line more closely than the original values. The values for $Z = 13\cdots47$ from more recent and reliable measurements[18-23] fit this line best. Our results and those of Dick and Lucas[2] are close enough to the straight line so that one may say that Eq. (4) is a good approximation for the dependence of the K-shell fluorescence yield upon the atomic number at least down to $Z = 4$.

Thanks are due to J. Müller for help during the measurements and the synchrotron radiation group at DESY for their hospitality.

*Work supported by the Deutsche Forschungsgemeinschaft.

[1]E. J. McGuire, Phys. Rev. A 2, 273 (1970).
[2]C. E. Dick and A. C. Lucas, Phys. Rev. A 2, 580 (1970).
[3]W. Hink and H. Paschke, Phys. Rev. A 4, 507 (1971).
[4]A. J. Campbell, Proc. Roy. Soc., Ser. A 274, 319 (1963).
[5]R. Haensel and C. Kunz, Z. Angew. Phys. 23, 276 (1967).
[6]R. P. Godwin, in *Springer Tracts in Modern Physics, Ergebnisse der exacten Naturwissenschaft,* edited by G. Höhler (Springer, Berlin, 1969), Vol. 51, p. 1.
[7]R. Haensel and B. Sonntag, J. Appl. Phys. 38, 3031 (1967).
[8]D. Lemke and D. Labs, Appl. Opt. 6, 1043 (1967).
[9]B. L. Henke, R. White, and B. Lindberg, J. Appl. Phys. 28, 98 (1957).
[10]V. A. Fomichev and I. I. Zhukova, Opt. Spectrosk. 24, 284 (1968) [Opt. Spectrosc. (USSR) 24, 147 (1968)].
[11]R. Haensel, G. Keitel, B. Sonntag, C. Kunz, and P. Schreiber, Phys. Status Solidi (a) 2, 85 (1970).
[12]K. Feser, J. Müller, G. Wiech, and A. Faessler, J. Phys. (Paris), Colloq. 32, C4-331 (1971).
[13]K. Feser, thesis, Universität München, 1971 (unpublished).
[14]K. Feser, Rev. Sci. Instrum. 42, 888 (1971).
[15]W. Crone, Ann. Phys. (Leipzig) 27, 405 (1936).
[16]J. Byrne and N. Howarth, J. Phys. B: Proc. Phys. Soc., London 3, 280 (1970).
[17]V. O. Kostroun, M. H. Chen, and B. Crasemann, Phys. Rev. A 3, 533 (1971).
[18]L. E. Bailey and J. B. Swedlund, Phys. Rev. 158, 6 (1967).
[19]W. Bambynek, Z. Phys. 206, 66 (1967).
[20]W. Bambynek and D. Reher, Z. Phys. 214, 374 (1968).
[21]H. U. Freund, H. Genz, J. B. Siberts, and R. W. Fink, Nucl. Phys. A138, 200 (1969).
[22]J. Pahor, A. Kodre, M. Hribar, and A. Moljk, Z. Phys. 221, 490 (1969).
[23]C. Foin, A. Gidson, and J. Oms, Nucl. Phys. A113, 241 (1968).

rf Plasma Heating in a Mirror Machine at Frequencies near the Ion Cyclotron Frequency and its Harmonics*

D. G. Swanson and R. W. Clark
Electronics Research Center, The University of Texas at Austin, Austin, Texas 78712

and

P. Korn, S. Robertson, and C. B. Wharton
Laboratory of Plasma Studies, Cornell University, Ithaca, New York 14850
(Received 12 October 1971)

By applying 75 kW of pulsed rf power to a decaying hydrogen plasma following turbulent heating, we have maintained a plasma density of 10^{12} to 5×10^{12} cm^{-3} for the 600-μsec duration of the rf pulse. Neutral energy analyzer measurements of ion temperature indicate $T_i \sim 100$ eV, while diamagnetic loop measurements indicate 100 eV $< T_e + T_i <$ 200 eV. Probe measurements made using different equipment show discrete changes in the amplitude of the rf signals near the harmonics of the ion cyclotron frequency.

The purpose of the study reported here was to explore rf plasma heating at frequencies near the ion cyclotron frequency and its harmonics. Previous experiments reporting rf heating at harmonics of the ion cyclotron frequency either have been cursory with few details reported,[1] or were performed in a cold, low-density plasma with low rf power.[2] The results of this experiment show that it is possible to add energy to a collisionless plasma at densities as high as 5×10^{12}