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Author
Schmieder, Robert W.

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Robert W. Schmieder

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Characteristic X-rays from Xenon Ions Trapped in an Electron Ring*

Robert W. Schmieder

Sandia Laboratories, Livermore, California 94550

and

Lawrence Berkeley Laboratory, Berkeley, California 94720

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Abstract

The detection of xenon K and L X-rays from a magnetically confined ring of relativistic electrons loaded with Xe ions is reported. From the ratio of intensities of L and K X-rays, the ratio of cross-sections for L and K vacancy production in Xe by 7.5 MeV electrons was determined to be $\sigma_L/\sigma_K = 18 \pm 8$.

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I wish to report the detection of characteristic X-rays emitted by Xe ions trapped in a magnetically confined ring of relativistic electrons, and the measurement thereby of the ratio of cross-sections for K and L X-ray production.

The experiment was performed at the Electron Ring Accelerator (ERA) facility at the Lawrence Berkeley Laboratory.[1] A diagram of the apparatus is shown in Figure 1. The electron beam is injected tangentially into the compressor, and a pulsed magnetic field forms it into a ring. The ring is then compressed radially by an increasing magnetic field. Gas in the compressor is collisionally ionized, and the ions are trapped in the strong potential well of the ring. A high resolution Si(Li) X-ray detector,[2] heavily shielded and collimated, views the ion-loaded ring, and detects X-rays produced from collisions of the ring electrons with the ions. The base pressure in the chamber of these experiments was 2×10^{-6} torr. By means of a controlled leak, an overpressure of Xe gas or air could be maintained. In this way, the characteristic emission from Xe could be observed above the background.

The electron beam was injected in a fast pulse with a current of about 300 amps, once every three seconds. A typical ring contained about 10^{12} electrons, and reached a minimum radius of 7.6 cm and maximum energy of 7.5 MeV about 275 microseconds after injection, then grew radially again until being lost on the walls at 600-700 microseconds. Pulses from the X-ray detector were fed to a 400 channel pulse-height analyzer, which was gated to accumulate only during a small time interval around maximum compression, during which the ring was within the field of view of the detector.

Figure 2(a) shows a spectrum obtained with enough Xe to read a total pressure of 4×10^{-6} torr. The peaks are identified as the L, K_{α} and K_{β} X-rays of Xe, on the basis of their energies and the fact that there are no other elements that could both produce similar X-rays and be present in the chamber in significant amounts. When the Xe was pumped out and air admitted to a total pressure of 4×10^{-6} torr, the spectrum of Figure 2(b) was obtained. This spectrum shows no evidence of the Xe X-rays, and further exhibits a monotonically decreasing rate toward higher energies consistent with its probable origin as electron-gas bremsstrahlung. The energy calibration for these spectra was made with Fe^{55} and Am^{241} sources; Figure 2(c) shows their spectra.

Table I lists the measured energies of the K_{α}, K_{β} peaks, and the known energies[3] of K_{α}, K_{β} transitions of Xe^{+1} (i.e., a single K shell vacancy only). The good agreement confirms our expectation that in this experiment, in which neutral Xe gas was constantly supplied to the ring, practically all the observed X-rays would come from very low stages of ionization. The K_{β}/K_{α} intensity ratio is 0.23 ± 0.03, in agreement with the value 0.231 listed in Ref. 5.

The widths of the peaks are somewhat larger than the detector resolution, probably due to irregular transients associated with electrical and radiation noise in the compressor environment or to satellite lines. There is almost certainly no significant doppler shift or broadening of these lines, since the RMS velocity of the trapped ions was less than 10^{9} cm/sec[4].

The ratio of cross sections for producing L and K shell vacancies can be found using the following formula:

$$\frac{\sigma_L}{\sigma_K} = \frac{(N_L/N_K)(\eta_K/\eta_L)(\epsilon_K/\epsilon_L)\omega_K - (n_1\nu_1+n_2\nu_2+n_3\nu_3)}{(\nu_1+\nu_2+2\nu_3)/4}$$

where N_L, N_K are the total counts (less background) under the L and K peaks; η_K, η_L are the detector absorptions (0.3 cm Si); ϵ_K, ϵ_L are the transmissions of the window materials (0.013 cm Mylar + 5.1 cm Air + 0.0025 cm Be + 10^{-6} cm Au + 4 x 10^{-5} cm Si); ω_K is the K shell fluorescent yield; n_i is the number of L_i subshell vacancies resulting from the filling of a K shell vacancy; and ν_i is the L_i subshell flourescent yield.

Using $N_L = 348$, $N_K = 212$ (measured), $\eta_K = 0.62$, $\eta_L = 1.0$, $\epsilon_K = 0.99$, $\epsilon_L = 0.51$ (calculated), $\omega_K = 0.9$, $n_1 = 0.0489$, $n_2 = 0.304$, $n_3 = 0.548$, $\nu_1 = 0.104$, $\nu_2 = 0.108$, $\nu_3 = 0.097$ (ref. 5), the above formula gives

$$\frac{\sigma_L}{\sigma_K} = 18 \pm 8 \quad (90\% \text{ confidence})$$

Classical theory of Gryznski[6] predicts $\sigma_L/\sigma_K = 37$, while calculations by Salop,[7] using a Bethe-Born approximation and including excitation as well as direct continuum ionization give 23. Multiple vacancy creation would be expected to increase the L shell yield more than the K shell yield, hence decrease the inferred value of σ_L/σ_K. Since the experimental result is already lower than the theory, multiple vacancy creation probably is insignificant in these experiments.

I wish to acknowledge the interest and hospitality of Denis Keefe in making the ERA facility available, and the contributions of Jeb Rechen and Arthur Salop in developing the experiments. John Meneghetti and Jim Hinkson rendered special technical help.

References and Footnotes

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TABLE I

ENERGY (keV)

	Xe^{+1}	Observed*
K_α	29.70	29.46 ± 0.46
K_β	33.64	33.38 ± 0.68

* Errors represent 90% confidence

Figure Captions

Figure 1 - Schematic of the experimental apparatus. Not shown are coils for producing the magnetic field perpendicular to the plane of the ring. The field of view of the detector was a short segment of the ring moving away from the detector, thus avoiding the forward cone of electron-gas bremsstrahlung.

Figure 2 - X-ray spectra obtained with (a) Xe leaked into the compressor; (b) air leaked into the chamber at the same pressure as (a); (c) Fe^{55} and Am^{241} calibration sources (log scale).

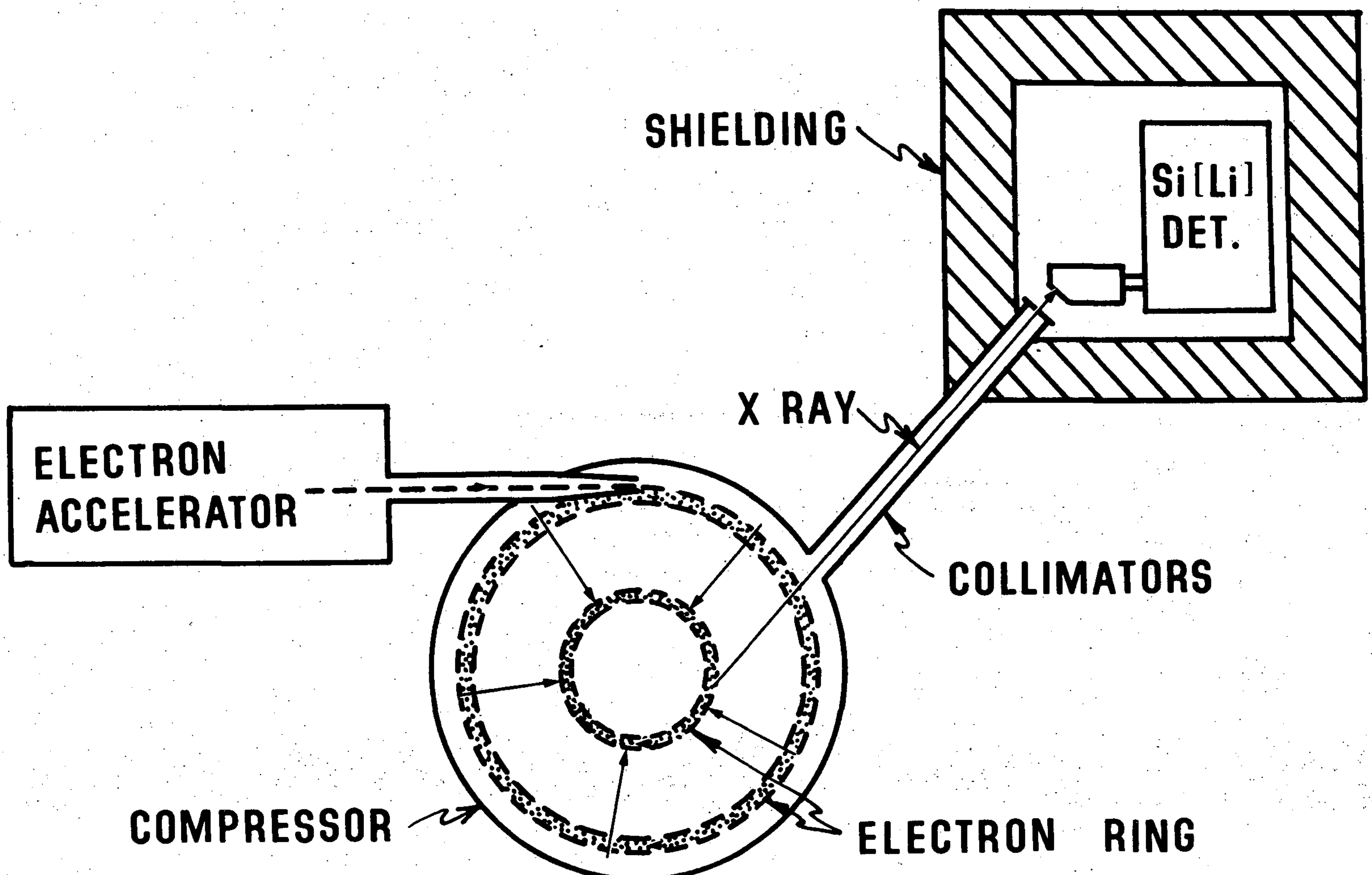

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FIGURE 1

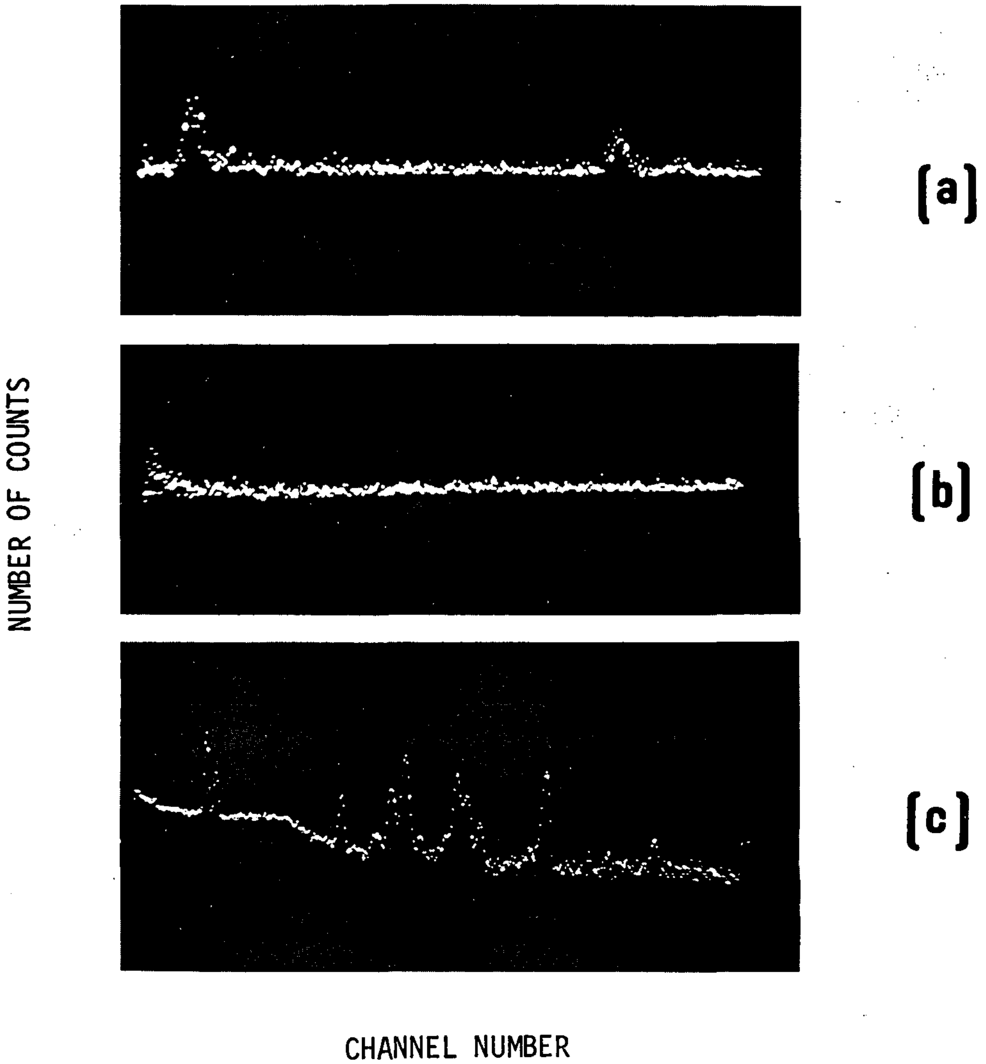

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FIGURE 2

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720