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Authors
Marrus, Richard
Schmieder, Robert W.

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Richard Marrus and Robert W. Schmieder

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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OBSERVATION OF THE MAGNETIC-DIPOLE DECAY OF THE 2^3S_1 STATE OF HELIUM-LIKE Si XIII, S XV, and Ar XVII

Richard Marrus and Robert W. Schmieder

Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley, California 94720

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ABSTRACT

The observation of the magnetic-dipole decay 2^3S_1-1^1S_0 in the helium-like atoms Si XIII, S XV, and Ar XVII is reported. Evidence based on observed energies and other decay characteristics is presented in the text.

The possibility of magnetic dipole decay from the metastable states of hydrogen-like and helium-like atoms was first noted by Breit and Teller.[1] They pointed out that, although the transition rate (A_{M1}) for the decay of the 2s state of hydrogen by this mode would vanish in a nonrelativistic theory, a finite decay rate results if the Dirac theory is employed. More recently, Griem[2] has considered the magnetic dipole decay of the 2^3S_1 state of helium-like atoms and on the basis of the Breit and Teller calculation has estimated

$$A_{M1}(2^3S_1) \approx 3.7 \times 10^{-6}\left(\frac{\omega}{\omega_Z}\right)^3 Z^7(Z + \tfrac{1}{2})\ \mathrm{sec}^{-1}.$$

Here ω_Z = angular frequency of the Lyman α line arising from the hydrogenic ion of the same Z, and ω = angular frequency of the observed transition. On this basis, Griem deduces that the single-photon rate is larger than the two-photon rate by a factor $6Z^{-2} \times 10^3$. There seems, however, to be some disagreement on this point because Drake, Victor, and Dalgarno[3] have stated that the magnetic dipole rate might become competitive with the two-photon rate for $Z > 10$, implying that the two-photon rate is higher for $Z < 10$. Moreover, Schwartz[4] has recently studied the rate $A_{M1}(^3S_1)$ and concluded that, to an accuracy of relative order 1/Z,

$$A_{M1}(2^3S_1) = 1.66 \times 10^{-6}\ Z^{10}\ \ \mathrm{sec}^{-1}.$$

In this letter we report the first observation of the magnetic dipole transition 2^3S_1-1^1S_0 in the helium-like atoms Si XIII, S XV, and Ar XVII. A schematic diagram of our apparatus is shown in Fig. 1. The ions emerge from the Berkeley heavy-ion linear accelerator (Hilac) with an energy of about 10.2 MeV/nucleon. A bending magnet is used to deflect the beam into our apparatus. An energy monitor consisting of a gold scattering foil and a solid-state detector can be interposed to determine the beam energy. The energy spread is found to be ~1%. A series of collimators serves to prevent stray ions from striking the walls in the detector chamber. The beam is well focused and has a diameter of about 0.25 inch in the detector chamber. To obtain ions in the desired charge state, the Hilac beam is passed through a thin metallic foil.[5] There are two foil positions: an upstream position about 4 m from the detector and a downstream position located about 15 cm from the detector. At the beam energies appropriate to this experiment, essentially all the particles leave the foil either fully stripped or as hydrogen- and helium-like ions. The hydrogen-like and helium-like atoms are distributed among the atomic levels, but rapidly decay to the ground and metastable levels with a sizeable fraction of the helium-like atoms appearing in the 2^3S_1 state.[6] It is these atoms which are of interest and give rise to the decay reported here.

The detector is a high-resolution silicon detector with an energy resolution of about 225 eV. It views the beam through a narrow aperture which is adjustable so that the counter can be made to view upstream, downstream, or straight ahead. The output of the counter is fed into an analog-to-digital converter, which in turn is fed into a PDP-7 computer, and the energy spectrum is observed on an oscilloscope and printed out on a CalComp plotter. The detector is calibrated in place by exciting the K x rays of Mn, P, and Ca by fluorescence, using the x rays from an iron-55 source. The K x-ray lines bracket the energies of the x rays observed in these experiments and yield a linear calibration over the region of interest.

The x-ray spectrum in the energy range 500 eV to 7 keV observed with the silicon, sulfur, and argon beams, and the upstream foil in position, is shown in Fig. 2. These peaks are also seen with the downstream foil. To demonstrate that the x rays arise as the result of a decay in flight of a beam atom, we have varied the aperture position in front of the detector so as to observe the Doppler shift of the emitted x ray. The shift can be clearly seen in Fig. 3, and is in good agreement with the beam velocity $\beta = v/c = 0.14$. To guard against the possibility that the decay may arise from a foil atom which is "kicked out" of the foil as the result of a collision with a beam atom, we have shown that the observed peaks are independent of foil material. To avoid processes arising from the collision of a beam atom with an atom in the background gas, a pressure of about 10^{-7} torr is maintained in the detector chamber. Increasing this pressure by a factor of 100 does not change the observed spectra. Finally, we note that when the foil is removed from the beam no x rays are observed in the range 500 eV to 6 keV.

The foregoing observations lead us to the conclusion that the x rays arise from a long-lived decay mode of ions formed when the beam passes through the foil. Our assignment of these x rays to the 2^3S_1-1^1S_0 transition is based on the following:

(a) For each of the three elements the observed x-ray energy is higher than the ionization energy of any atom having three or more electrons. Moreover, the fraction of such atoms present in the beam should be negligible.

(b) The only metastable states of hydrogen-like and helium-like atoms present in the beam are the $2^2S_{1/2}$ state of hydrogen-like atoms and the 2^1S_0 and 2^3S_1 states of helium-like atoms. However, the $2^2S_{1/2}$ state and the 2^1S_0 states are too short-lived to be observed at the detector with the upstream foil. Moreover, the primary mode of decay from these states is predicted to be the two-photon mode, which gives rise to a continuous spectrum, unlike the discrete lines observed here.

(c) The observed energies are in good agreement with a calculation of the 2^3S_1-1^1S_0 energy difference by Knight and Scherr[7] in a 1/Z expansion. The observed energies, corrected for the transverse Doppler effect, are compared with the calculated energies in Table I.

At the present time work is progressing towards identification of the two-photon decay mode from the hydrogen-like and helium-like metastable states. We are also planning measurements of the lifetimes of these modes and measurements of the Lamb shift and fine structure in the n = 2 state of the hydrogen-like atoms.

The success of this experiment is possible only because of the help and encouragement of many people. We are especially grateful to Dick Diamond, Al Ghiorso, Fred Goulding, Doug MacDonald, Frank Stephens, and Jack Walton.

1 G. Breit and E. Teller, Astrophys. J. 91, 215 (1940).

2 H. R. Griem, Astrophys. J. 156, L 103 (1969).

3 G. W. F. Drake, G. A. Victor, and A. Dalgarno, Phys. Rev. 180, 25 (1969).

4 C. Schwartz (University of California, Berkeley), private communication (work to be published). We are grateful to Professor Schwartz for permission to quote his results prior to publication.

5 For an experimental discussion of the charge equilibrium achieved by passage of fast beams through thin foils, see H. H. Heckman, E. L. Hubbard, and W. G. Simon, Phys. Rev. 129, 1240 (1963).

6 For a review of the whole subject of beam foil spectroscopy and prior work on the production of hydrogen-like and helium-like metastable states, see Beam Foil Spectroscopy, Vols. I and II, edited by S. Bashkin (Gordon and Breach, New York, 1968).

7 R. E. Knight and C. E. Scherr, Rev. Mod. Phys. 35, 431 (1963).

FIGURES

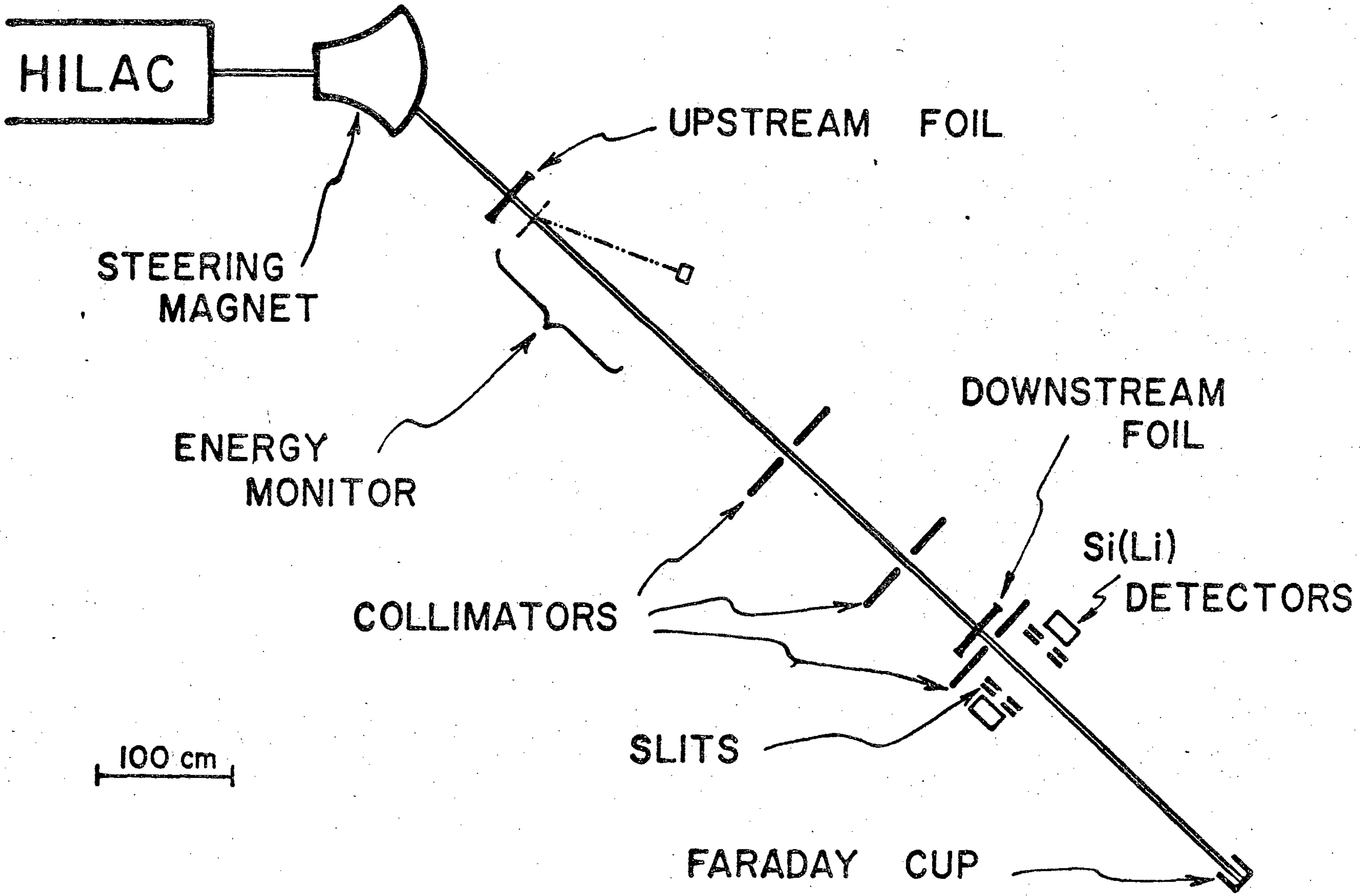
Fig. 1. Schematic of the apparatus.

Fig. 2. Spectra observed in energy interval 500 eV — 7 keV with (a) argon beam, (b) sulfur beam, (c) silicon beam.

Fig. 3. Observation of the argon x ray with the detector looking (a) downstream, (b) straight ahead, (c) upstream. The shift due to the Doppler effect is readily apparent.

Table I. Observed and predicted energies ($2\ ^3S_1 - 1\ ^2S_0$) (keV).

	Si XIII	S XV	Ar XVII
Observed	1.85 (0.10)	2.46 (0.10)	3.13 (0.10)
Predicted[7]	1.84	2.42	3.09



HILAC
UPSTREAM FOIL
STEERING MAGNET
ENERGY MONITOR
DOWNSTREAM FOIL
Si(Li) DETECTORS
COLLIMATORS
SLITS
100 cm
FARADAY CUP

Fig 1

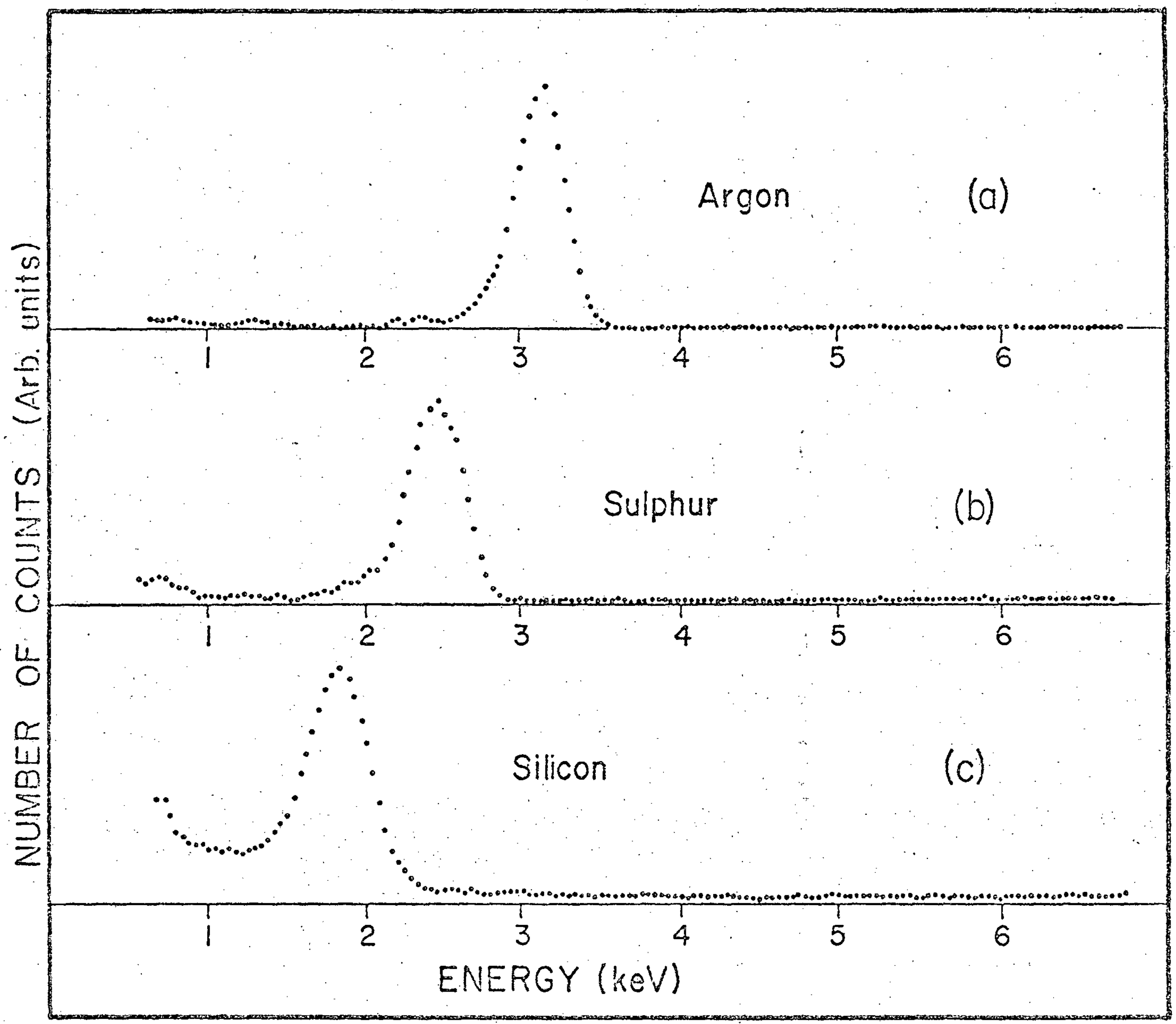
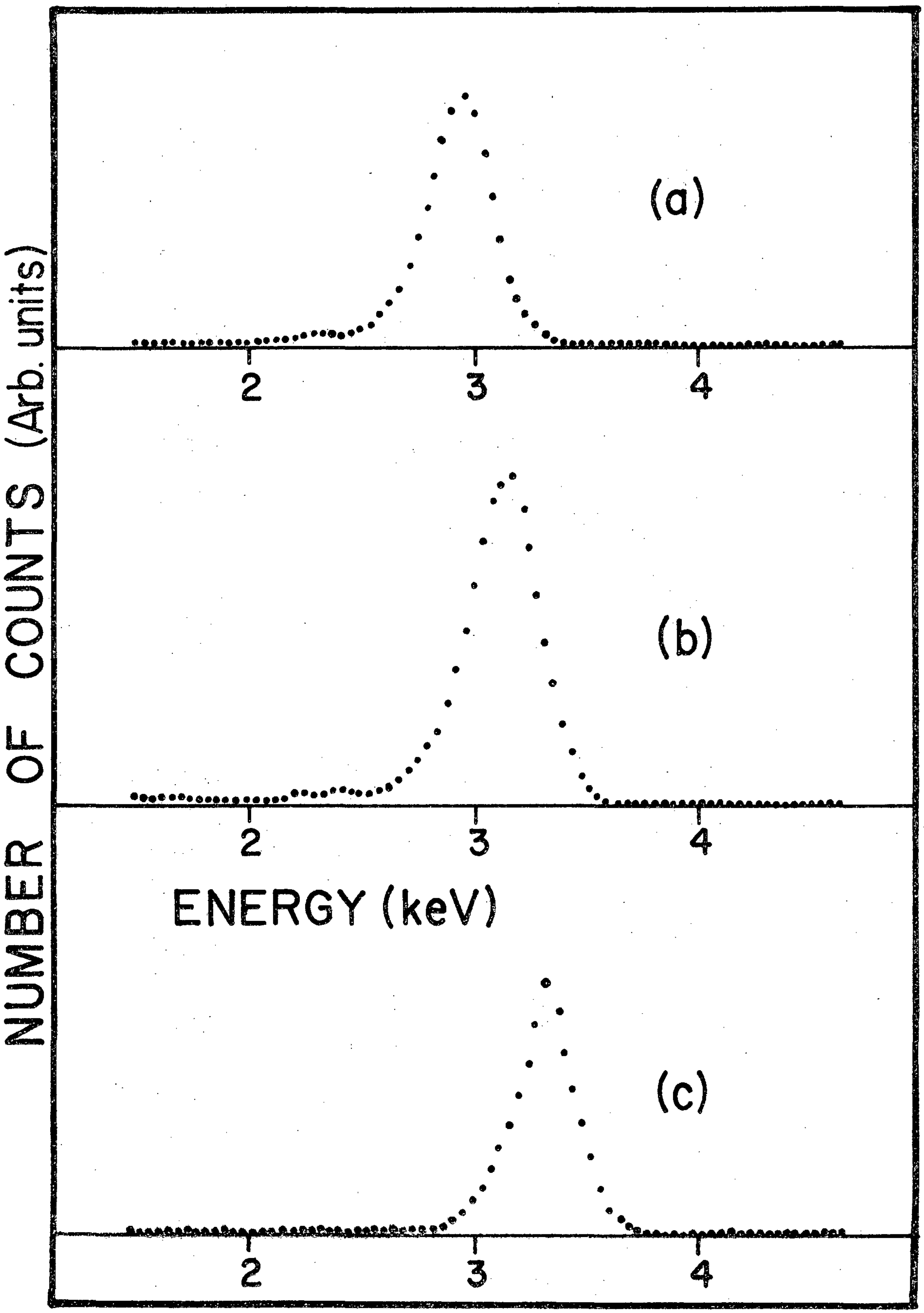

NUMBER OF COUNTS (Arb. units)
Argon
(a)
Sulphur
(b)
Silicon
(c)
1
2
3
4
5
6
ENERGY (keV)

Fig 2


NUMBER OF COUNTS (Arb. units)
(a)
2
3
4
(b)
2
3
4
ENERGY (keV)
(c)
2
3
4

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