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EQUILIBRIUM CHARGE-STATE FRACTIONS OF Li-, Li<sub>0</sub>, AND Li<sup>+</sup> IN Mg, Sr, AND Cs VAPORS

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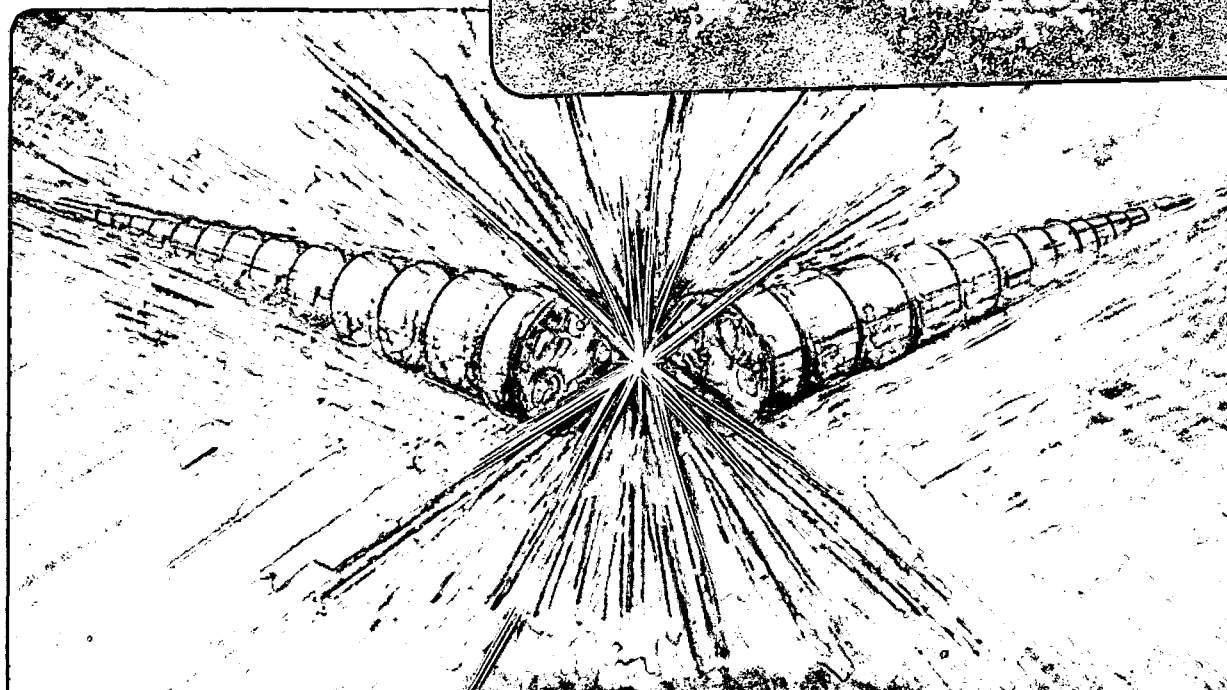
EQUILIBRIUM CHARGE-STATE FRACTIONS OF  $\text{Li}^-$ ,  $\text{Li}^0$ ,  
AND  $\text{Li}^+$  IN Mg, Sr, AND Cs VAPORS

J.R. Mowat, E.E. Fisch, A.S. Schlachter,  
J.W. Stearns, and Y.K. Bae

December 1984

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Equilibrium Charge-State Fractions of  $\text{Li}^-$ ,  $\text{Li}^0$ , and  $\text{Li}^+$   
in Mg, Sr, and Cs Vapors\*

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$\text{Li}^+$  ions, accelerated to energies between 1 and 20 keV, pass through thick vapor targets of Mg, Sr, and Cs. The ions that emerge into a narrow, forward-directed cone are electrostatically separated into three charge-state components:  $\text{Li}^-$ ,  $\text{Li}^0$ , and  $\text{Li}^+$ . The principal results over this energy range are (1) the negative fraction peaks at 5% near 5 keV for a Cs target, and is less than 1% in Mg and Sr targets, (2) for Sr and Cs targets, the beam is greater than 90% neutral, and (3) for a Mg target, the beam does not neutralize at the lowest energies studied, remaining mostly positive between 1 and 10 keV.

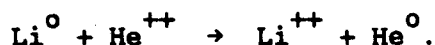
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## I. Introduction

Describing the mechanisms for negative-ion formation in ion-atom collisions at adiabatic energies is an interesting challenge to our present understanding of the dynamics of quasi-molecular systems. Furthermore, the production of negative ion beams is of current practical interest to the Magnetic Fusion Energy program. An important motivation for this work on  $\text{Li}^-$  formation is a recent proposal to measure the spatial distribution of fusion product alpha particles through the double-electron-transfer reaction<sup>1,2</sup>



The most efficient way to produce the high-energy neutral lithium atoms needed for this diagnostic probe is by electron detachment of fast  $\text{Li}^-$ . Other uses of fast Li atoms have been proposed for space applications. The choice of target vapors used in the present experiment was suggested by previous work at LBL on  $\text{D}^-$  formation,<sup>3,4</sup> in which negative-ion equilibrium fractions larger than 30% were found in Cs and Sr targets.

The detection of  $\text{Li}^-$  was first reported in 1947 by Sloane and Love,<sup>5</sup> who bombarded a Ni surface with  $\text{Li}^+$  ions from a lithium thermionic source and analyzed the scattered ions with a mass spectrometer. The measured electron affinity, 0.620(7),<sup>6</sup> agrees with accurate values calculated<sup>7</sup> for the  $1s^2 2s^2$  configuration.  $\text{Li}^-$  is one of only two negative ions known to possess a second bound state; radiation from the core-excited configuration  $1s2s2p^2$  has been observed<sup>8</sup> with a 2.3 ns lifetime. Since that state can autodetach and does not live long enough to be detected in the present experiment, the results presented below refer to production of ground-state  $\text{Li}^-$ .

The formation of negative ions of species heavier than hydrogen by charge transfer has recently been reviewed.<sup>9</sup> This review summarizes data for species as heavy as Cl.

## II. Experimental Arrangement

A schematic diagram of the apparatus is shown in Fig. 1.  ${}^7\text{Li}^+$  ions are formed by surface ionization in an indirectly heated, isotopically purified,  $\beta$ -eucryptite impregnated, porous tungsten plug.<sup>10</sup> A very stable ion current of about  $1\mu\text{A}$  is extracted from a Pierce electrode. The 1 to 20 keV acceleration potential is obtained from a well-regulated dc power supply. After electrostatic focusing and steering the beam is 100-percent square-wave modulated at a 50% duty cycle by a transverse electric field. Magnetic analysis then directs the beam into one of two beam lines where it passes through either a stainless-steel recirculating Cs-vapor heat-pipe target<sup>3</sup> or a differentially pumped iron oven<sup>4</sup> containing Mg or Sr vapor. A chromel-alumel thermocouple is used to measure the temperature at the reservoir. That temperature is used to estimate the target number density from a least-squares fit to temperature-vapor pressure data.<sup>11</sup> Neutral atoms and ions emerging from the target within approximately  $\pm 3.5^\circ$  of the forward direction pass through an electrostatic field which directs the positive and negative components into magnetically suppressed Faraday cups and which allows the neutral component to pass undeviated onto the face of a pyroelectric detector.<sup>12</sup> Both electrostatic and magnetic suppression are used to prevent secondary electrons from the front surface of the pyroelectric detector from reaching the Faraday cups; the small secondary-electron flux could mask the small  $\text{Li}^-$  signal. The two targets are coupled to identical analysis chambers<sup>3,4</sup> which terminate each beam line. Beam components travel approximately 10 cm between the target and the analyzing field. The vacuum, maintained by liquid-nitrogen-trapped oil diffusion pumps, is typically less than  $2 \times 10^{-6}$  Torr in all beam lines and chambers, except inside and immediately adjacent to the targets.

The signals from the two Faraday cups are amplified by electrometers whose outputs are digitized, integrated, and recorded by a microcomputer.

The pyroelectric detector is insensitive to the charge of the particles impinging on its front surface, so it is calibrated by comparing its output to the output of a Faraday cup when the  $\text{Li}^+$  beam is switched back and forth between the two. The output of the pyroelectric detector is rectified and amplified with a lock-in amplifier that is synchronized to the  $\sim 1$ -Hz beam modulator. The output of the lock-in amplifier is also digitized, integrated, and recorded by the computer. Since charge-state fractions are measured, but not the beam intensity incident on the target, transmission through the target is estimated by assuming constant incident  $\text{Li}^+$  intensity.

Typical beam currents reaching the Faraday cups are 200 nA for the Cs heat-pipe target, and 20 nA for the alkaline-earth oven, which requires a more highly collimated beam. At equilibrium thickness the beams are attenuated from these values by 10% to 90% depending upon the beam energy, target geometry, and target material.

### III. Experimental Procedure

Growth curves were taken for each target at the lowest and highest beam energies in order to determine the target thickness required for equilibrium. An example is shown in Fig. 2, for 4-keV  $\text{Li}^+$  in cesium vapor. The target temperature was freely rising (i.e., driven at a constant power level), and the temperature change between points is typically five degrees C. Charge-state fractions are calculated from the integrated signals and from the pyroelectric-detector calibration constant, subject to the condition that the three charge-state fractions sum to unity. The densities that label the



abscissa of Fig. 2 are the densities estimated at the center of the heat pipe target, whose length is about  $5.3 \pm 0.7$  cm.<sup>3</sup> Once the temperature corresponding to equilibrium thickness is determined for a given target and for each of the three charge-state fractions, the target is maintained at the fixed temperature and the fractions are measured as a function of beam energy.

Various systematic checks were performed to verify correct behavior of the apparatus. The measured equilibrium charge-state fractions are found to be insensitive to the polarity of the analyzing field and to small variations in the magnitude of the field. Likewise, the pyroelectric-detector calibration is found to be insensitive to the polarity of the analyzing field, the position of the beam on its 2.2-cm-diameter face, and the position at which the charged beams strike the Faraday cups. The calibration constant is found to vary linearly with beam energy, as expected.

#### IV. Results and Discussion

The equilibrium charge-state fractions  $f_-^\infty$ ,  $f_0^\infty$  and  $f_+^\infty$  were measured for incident  $\text{Li}^+$  ions over the energy range 1 to 20 keV in targets of magnesium ( $Z=12$ ), strontium ( $Z=38$ ) and cesium ( $Z=55$ ) vapor. No previous experiments have measured Li charge-state fractions for this energy range in either Mg or Sr vapor targets. One previous report<sup>13</sup> has results for equilibrium fractions in Cs vapor for energies between 5 and 40 keV, while another<sup>14</sup> reports conversion efficiencies between 2 and 20 keV. Conversion efficiencies cannot be directly compared with equilibrium fractions, since the former are apparatus dependent. Measurements in Na vapor have also been reported.<sup>15</sup> Results for each target are described below and are shown in Figs. 3-5 and in Table 1.

### A. Magnesium-vapor target

The equilibrium fractions for 1 to 20 keV  $\text{Li}^+$  in magnesium vapor are shown in Figure 3. The  $f_0^\infty$  and  $f_+^\infty$  curves join smoothly with the results of an older, higher-energy experiment<sup>16</sup> which did not report measuring a negative component.

Previous studies<sup>17</sup> in a Mg-vapor target suggest that beams of elements from columns 6A and 7A of the periodic table tend to have relatively small neutral equilibrium fractions (< 65%) for energies between 10 and 100 keV, while elements to the left in the periodic table tend to have relatively large neutral fractions (> 70%) for the same energies. The results reported here for Li ( $f_0^\infty < 60\%$ ) do not fit into that trend.

At the highest energies used here, the neutral fraction dominates. In most beam-target systems, the neutral fraction becomes larger as the energy is lowered. An unexpected finding is that the neutral fraction decreases in favor of the positive fraction as the energy is lowered from 20 keV. For energies below about 12 keV and extending to the lowest energy measured to this experiment, the beam does not neutralize to a high degree, and the positive fraction dominates.

The probable reason for this observation is that the electron-capture cross section for  $\text{Li}^+ + \text{Mg} \rightarrow \text{Li} + \text{Mg}^+$  is very small below 10 keV. Such behavior is expected if recent calculations<sup>18</sup> on the similar  $\text{Li}^+ + \text{Ca} \rightarrow \text{Li} + \text{Ca}^+$  system are scaled to the endoergicities  $\Delta E$  of the respective reactions. The  $\Delta E$  for  $\text{Li}^+ + \text{Ca}$  electron capture is 0.72 eV, while that for  $\text{Li}^+ + \text{Mg}$  is 2.26 eV. For  $\text{Li}^+ + \text{Ca}$ , the maximum cross section is realized<sup>18</sup> at  $E \approx 10$  keV. Using the adiabatic criterion<sup>19</sup> which predicts that the velocity at the maximum in the cross section will scale inversely with  $\Delta E$ ,

one is lead to predict the  $\text{Li}^+ + \text{Mg}$  electron-capture cross section will not maximize until the energy is above those studied here. Thus, our observations of a small neutral fraction are in accord with theoretical predictions. It should be noted that the heavier alkaline earths, such as Sr, where  $\Delta E = 0.30$  eV, will necessarily have large electron-capture cross sections at low energies and will not exhibit behavior similar to that of Mg.

An estimate of the electron-detachment cross section  $\sigma_{0+}$  can be made from  $f_0^\infty$  when the electron-capture cross section  $\sigma_{+0}$  is known, if the negative fraction is sufficiently small for a two-component model to be valid. In this model the neutral fraction is

$$f_0^\infty = \sigma_{+0} / (\sigma_{+0} + \sigma_{0+}). \quad (1)$$

Cross sections  $\sigma_{+0}$  for electron capture have recently been measured by Coggiola, Bae, and Peterson.<sup>20</sup> These values combined with present measurements of  $f_0^\infty$  provide an estimate of the electron-detachment cross section  $\sigma_{0+}$ , which lies between  $1.0 \times 10^{-15}$  and  $1.2 \times 10^{-15}$  cm<sup>2</sup> over the energy range 4-10 keV.

#### B. Strontium-vapor target

Figure 4 summarizes the energy dependence of  $f_-^\infty$  and  $f_+^\infty$  in strontium vapor. Previous measurements<sup>4</sup> of the  $\text{D}^-$  charge-state fraction in Sr vapor showed a peak at about 50% for a  $\text{D}^-$  energy near 0.5 keV. Note in the figure that there is a small peak at about 2.5 keV, with a broad shoulder at higher energies. This is qualitatively similar to the  $\text{D}^-$  yield in the same target at the same velocities, although the maximum  $\text{Li}^-$  yield of 1% is very small compared to 50% for  $\text{D}^-$ .

### C. Cesium-vapor target

The largest negative fraction ( $5.4\pm$ ) observed for the three targets studied was for a cesium-vapor target. This result is shown in Fig. 5. The negative fraction also exceeds the positive fraction at energies less than 10 keV. Our observations confirm a trend noted earlier<sup>13</sup> for other alkali-metal projectiles in cesium vapor; the negative-ion fraction peaks at a projectile velocity of about 0.17 a.u. As with the Sr target, but unlike the Mg target, the positive-ion fraction is monotonically decreasing as the energy is reduced.

### D. Scattering

The incident beam is not tightly collimated in this experiment, nor is it continuously monitored, hence little can be said about scattering. The collimation of the beam after the target is designed so that only ions and atoms that scatter into a cone of half-angle approximately  $3.5^\circ$  about the forward direction enter the analysis chamber. For the cesium target the following quantitative statements can be made. At equilibrium, by definition, almost all of the ions undergo more than one collision that is close enough for an electron to be captured or lost. We find that at least  $80\pm$  of the beam reaches the analysis chamber; it thus follows that most of the ions are not scattered by more than  $3.5^\circ$ . For the Mg and Sr targets, because the target collimation is tighter, scattering loss is much greater within the target, and the downbeam collimation does not determine an upper bound for the scattering angle.

### E. Uncertainties

The systematic errors associated with the data in Figs. 3-5 are estimated to be equal to or smaller than the plotting symbols except where noted by error bars. These uncertainties are a measure of the repeatability of the charge-state fractions over a period of time, and arise mainly from variations in the neutral-atom detector. Additional uncertainties occur for very small fractions, where instrument drift and various backgrounds increase the uncertainty of the charge-state-fraction measurements. Typical uncertainty for an equilibrium yield is  $\pm 5\%$ . Charge-state fractions are, of course, determined at equilibrium thickness, so there is no error associated with target temperature measurement or target density determination. The error associated with the ion energy and  $q/m$  is determined by the stability and calibration of the accelerator and magnet power supplies, which are well enough regulated so that those errors are negligible.

## V. Conclusion

The equilibrium charge-state fractions of lithium ions passing through vapors of Mg, Sr, and Cs show quite different trends, as seen in Fig. 6. The maximum negative-ion fraction occurs near 5 keV in Cs vapor, and for energies below 10 keV, the emergent Li beam has a net negative charge. While negative-ion formation is extremely small in a Mg target, interesting behavior is observed, indicating an inhibition of neutralization at low projectile energies, so that the emergent beam has a net positive charge. In contrast to production of  $D^-$  at comparable velocities, very little  $Li^-$  is produced in Sr vapor.

## Acknowledgments

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## References

1. R. W. McCollough, T. V. Goffe, M. B. Shah, M. Lennon, and H. B. Gilbody, *J. Phys. B* 15, 111 (1982).
2. G. A. Murray, J. Stone, M. Mayo, and T. J. Morgan, *Phys. Rev. A* 25, 1805 (1982).
3. A. S. Schlachter, K. R. Stalder, and J. W. Stearns, *Phys. Rev. A* 22, 2494 (1980).
4. R. H. McFarland, A. S. Schlachter, J. W. Stearns, B. Liu, and R. E. Olson, *Phys. Rev. A* 26, 775 (1982).
5. R. H. Sloane and H. M. Love, *Nature* 159, 302 (1947).
6. T. A. Patterson, H. Hotop, A. Kasdan, D. W. Norcross, and W. C. Lineberger, *Phys. Rev. Lett.* 32, 189 (1974).
7. Recent calculations are reviewed by H. Hotop and W. C. Lineberger, *J. Phys. Chem. Ref. Data* 4, 539 (1975).
8. R. L. Brooks, J. E. Hardis, H. G. Berry, L. J. Curtis, K. T. Cheng, and W. Ray, *Phys. Rev. Lett.* 45, 1318 (1980).
9. A. S. Schlachter, in "Production and Neutralization of Negative Ions and Beams," Ed. by K. Prelec, A.I.P. Conf. Series 4111 (1984), p. 300.
10. O. Heinz and R. T. Reaves, *Rev. Sci. Instr.* 39, 1229 (1968).
11. R. R. Hultgren, P.A. Desai, D. T. Hawkins, M. Gleiser, K. K. Kelley, and D. Wagman, Selected Values of the Thermodynamic Properties of the Elements (American Society of Metals, Metal Park, Ohio, 1973).
12. K. H. Berkner, B. R. Meyers, and R. V. Pyle, *Rev. Sci. Instr.* 39, 1204 (1968).
13. P. Tykesson, presented at the 1978 Symposium of Northeastern Accelerator Personnel, Oak Ridge, Tennessee, Oct. 23-25, 1978 (unpublished).
14. E. Steffens, *IEEE Trans. Nucl. Sci.* NS-23, 1145 (1978).

15. J. Heinemeier and P. Hvelplund, Nucl. Instr. Meth. 148, 425 (1978).
16. L. I. Pivovar, L. I. Nikolaichuch, and V. M. Gurov, Sov. Phys. JETP 22, 746 (1966).
17. J. Heinemeier and P. Hvelplund, Nucl. Instr. Meth. 148, 65 (1978).
18. M. Kimura, H. Sato, and R. E. Olson, Phys. Rev. A 28, 2085 (1983).
19. J. B. Hasted and A. R. Lee, Proc. Phys. Soc. 79, 702 (1962).
20. M. J. Coggiola, Y. K. Bae, and J. R. Peterson, submitted to Phys. Rev. A.



Table 1. Equilibrium charge-state fractions  $f_i^\infty$  for Li in Mg, Sr, and Cs vapors (in %). Uncertainty is 5% or less unless otherwise indicated.

| E(keV) | Mg                |                   |                     | Sr                |              |                   | Cs                |              |                   |
|--------|-------------------|-------------------|---------------------|-------------------|--------------|-------------------|-------------------|--------------|-------------------|
|        | $f_+^\infty$      | $f_0^\infty$      | $f_-^\infty$        | $f_+^\infty$      | $f_0^\infty$ | $f_+^\infty$      | $f_+^\infty$      | $f_0^\infty$ | $f_-^\infty$      |
| 1      |                   |                   |                     | 0.19 <sup>c</sup> | 99.5         | 0.34 <sup>c</sup> |                   | 99.3         | 0.62 <sup>b</sup> |
| 1.5    |                   |                   |                     | 0.83 <sup>b</sup> | 98.6         | 0.61 <sup>b</sup> |                   |              |                   |
| 2      |                   |                   |                     | 1.3 <sup>b</sup>  | 97.8         | 0.88 <sup>b</sup> | 0.19 <sup>b</sup> | 98.5         | 1.3 <sup>a</sup>  |
| 3      |                   |                   |                     | 2.5 <sup>b</sup>  | 96.5         | 0.99 <sup>b</sup> | 0.48 <sup>b</sup> | 96.8         | 2.8 <sup>a</sup>  |
| 4      | 87 <sup>a</sup>   | 12.8 <sup>b</sup> | 0.0096 <sup>a</sup> | 3.3 <sup>a</sup>  | 96.0         | 0.76 <sup>a</sup> | 0.85 <sup>b</sup> | 94.5         | 4.6               |
| 5      | 82.4              | 17.6 <sup>a</sup> | 0.0126 <sup>a</sup> | 3.8               | 95.5         | 0.68              | 1.3 <sup>a</sup>  | 93.5         | 5.2               |
| 6      | 74.3              | 25.7              | 0.017               | 4.5               | 94.8         | 0.68              | 1.6               | 93.5         | 4.9               |
| 7      | 67.3              | 32.6              | 0.021               | 5.1 <sup>a</sup>  | 94.2         | 0.68 <sup>a</sup> | 1.9               | 93.7         | 4.4               |
| 8      | 62.8              | 37.2              | 0.025               | 5.6               | 93.7         | 0.68              | 2.2               | 94.1         | 3.7               |
| 9      | 59.1              | 40.8              | 0.027               | 6.2               | 93.1         | 0.66              | 2.5               | 94.4         | 3.1               |
| 10     | 57.3              | 42.6              | 0.030               | 6.7               | 92.7         | 0.61              | 3.0               | 94.4         | 2.6               |
| 11     | 54.8              | 45.2              | 0.032               | 7.2               | 92.2         | 0.56              | 3.4               | 94.4         | 2.2               |
| 12     | 51.8              | 48.1              | 0.034               | 7.8               | 91.7         | 0.49              | 4.0               | 94.2         | 1.8               |
| 13     | 49.0 <sup>a</sup> | 50.0              | 0.036               | 8.3               | 91.2         | 0.44              | 4.6               | 93.8         | 1.56              |
| 14     | 47.8              | 52.2              | 0.038               | 9.2               | 90.4         | 0.39              | 5.2               | 93.4         | 1.36              |
| 15     | 46.1              | 53.9              | 0.041               | 9.8               | 89.9         | 0.34              | 6.0               | 92.8         | 1.22              |
| 16     | 44.7              | 55.3              | 0.044               | 10.3              | 89.4         | 0.32              | 6.7               | 92.2         | 1.09 <sup>a</sup> |
| 17     | 43.5              | 56.5              | 0.047               | 10.8              | 88.9         | 0.29              | 7.4               | 91.6         | 1.05 <sup>a</sup> |
| 18     | 42.2              | 57.7              | 0.050               | 11.3              | 88.4         | 0.28 <sup>a</sup> | 8.2               | 91.8         | 0.97 <sup>b</sup> |
| 19     | 41.4              | 58.5              | 0.054               | 11.8              | 87.9         | 0.27 <sup>a</sup> | 9.0               | 90.1         | 0.91 <sup>b</sup> |
| 20     | 40.7              | 59.2              | 0.058               | 12.4              | 87.4         | 0.26 <sup>a</sup> | 9.7               | 89.4         | 0.84 <sup>b</sup> |

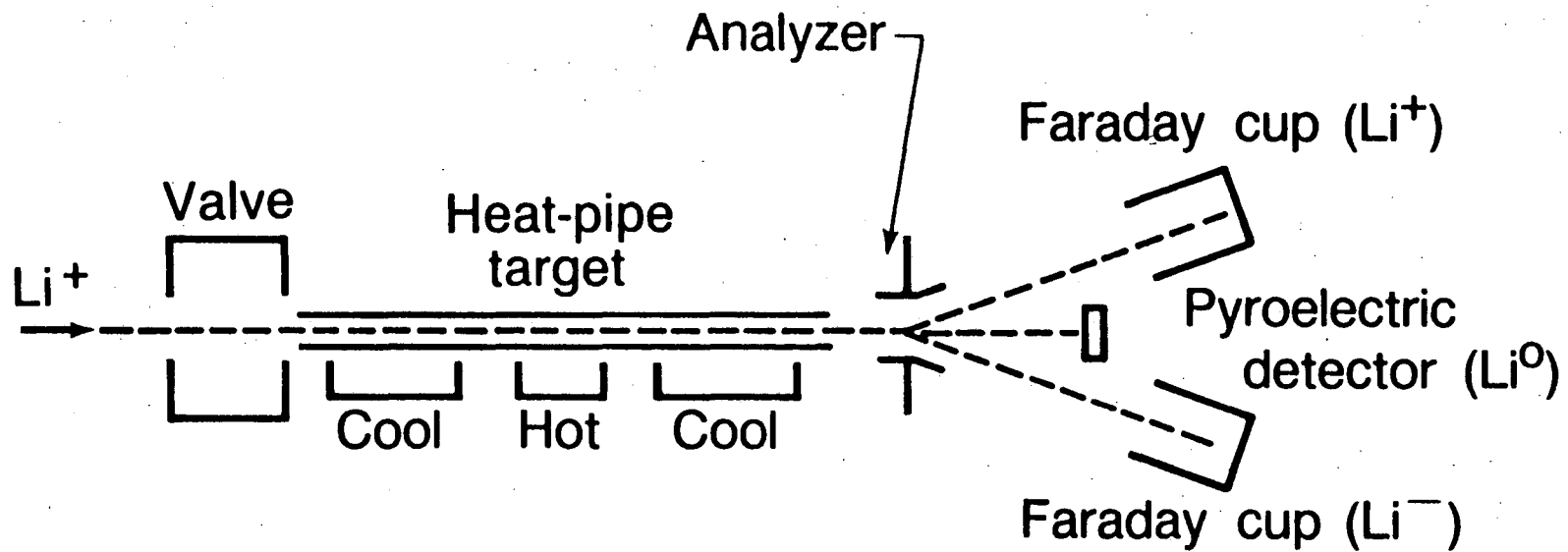
a)  $\pm 10\%$

b)  $\pm 20\%$

c)  $\pm 30\%$

## Figure Captions

- Fig. 1 Schematic diagram of the apparatus
- Fig. 2 Charge-state fractions as a function of target thickness for 4-keV  $\text{Li}^+$  in cesium vapor.
- Fig. 3 Equilibrium charge-state fractions: Li in Mg vapor.
- Fig. 4 Equilibrium charge-state fractions: Li in Sr vapor.
- Fig. 5 Equilibrium Charge-state fractions: Li in Cs vapor.
- Fig. 6 Summary of  $f_{-}^{\infty}$  for Li ions in metal vapors.



10 cm

Figure 1

XBL 7811-12779D

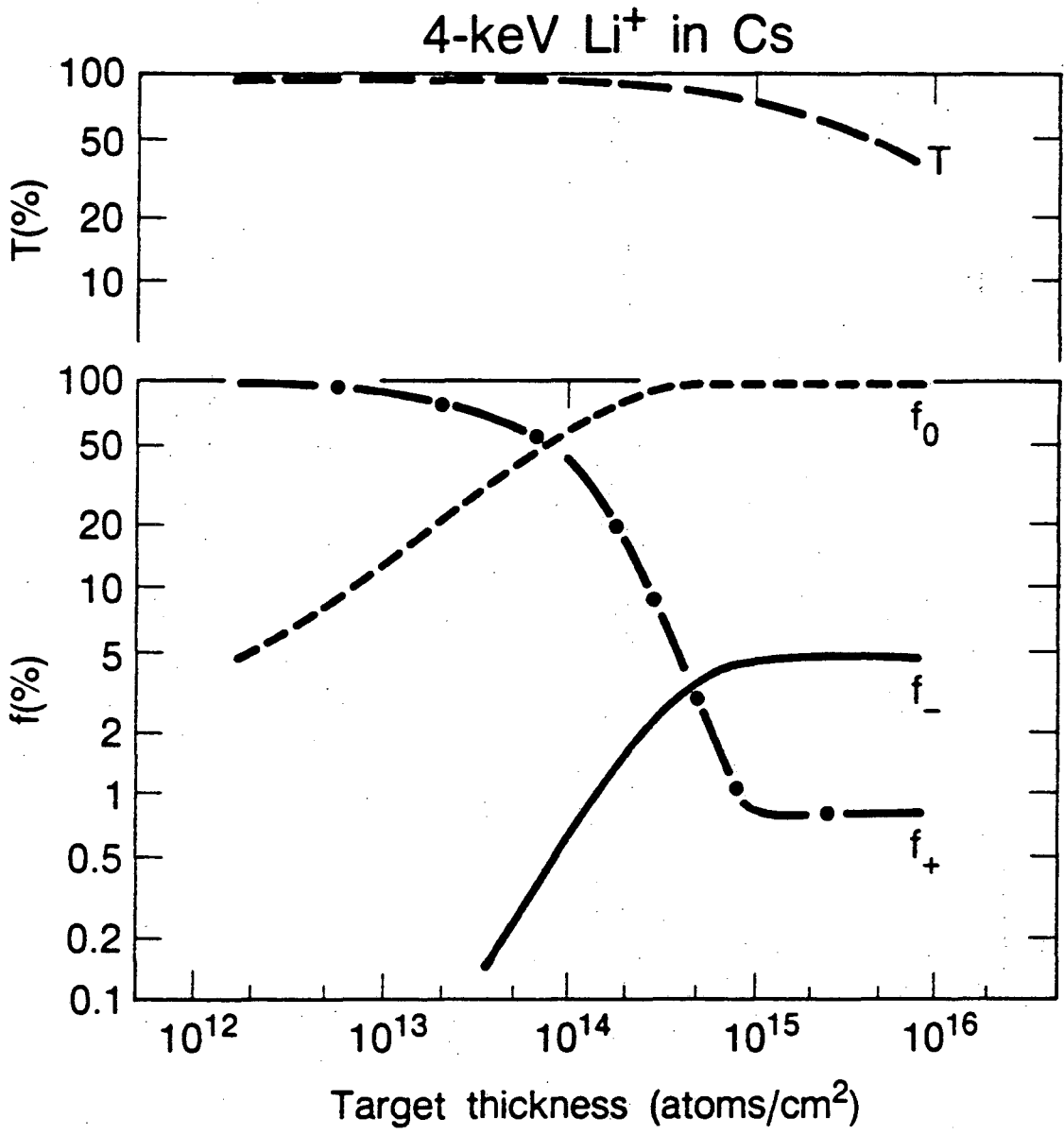


Figure 2

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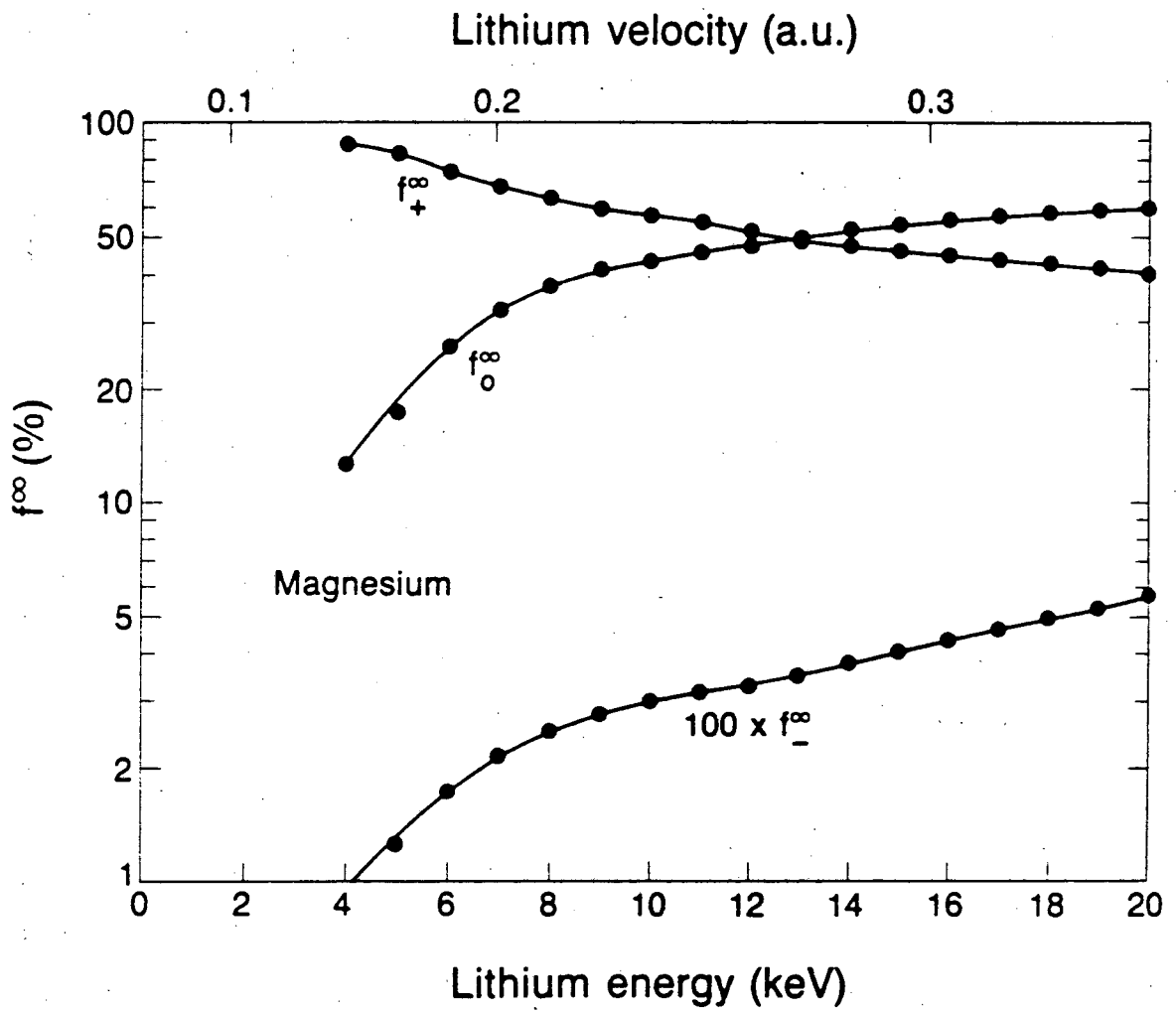


Figure 3

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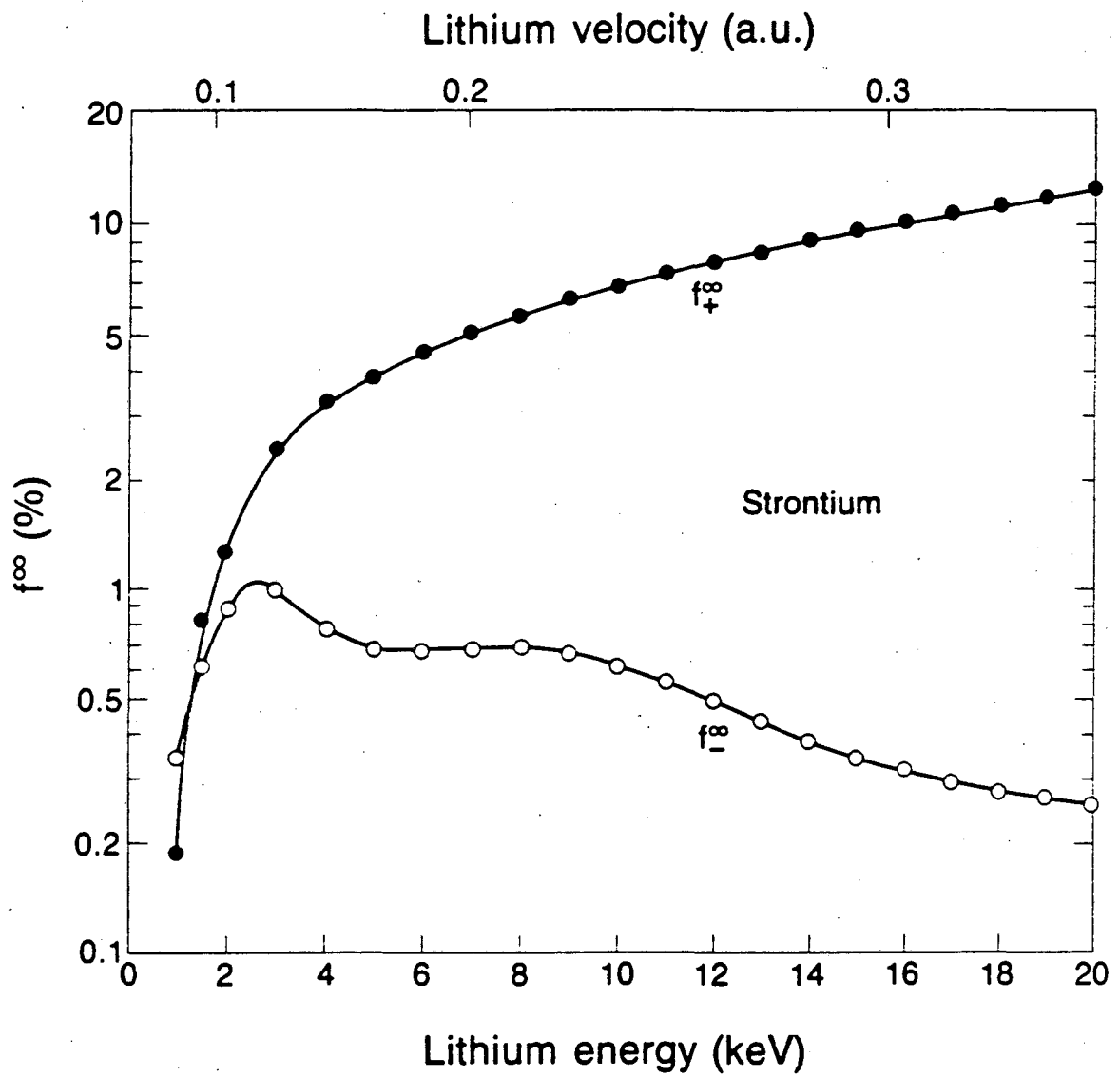


Figure 4

XBL 8410-10883

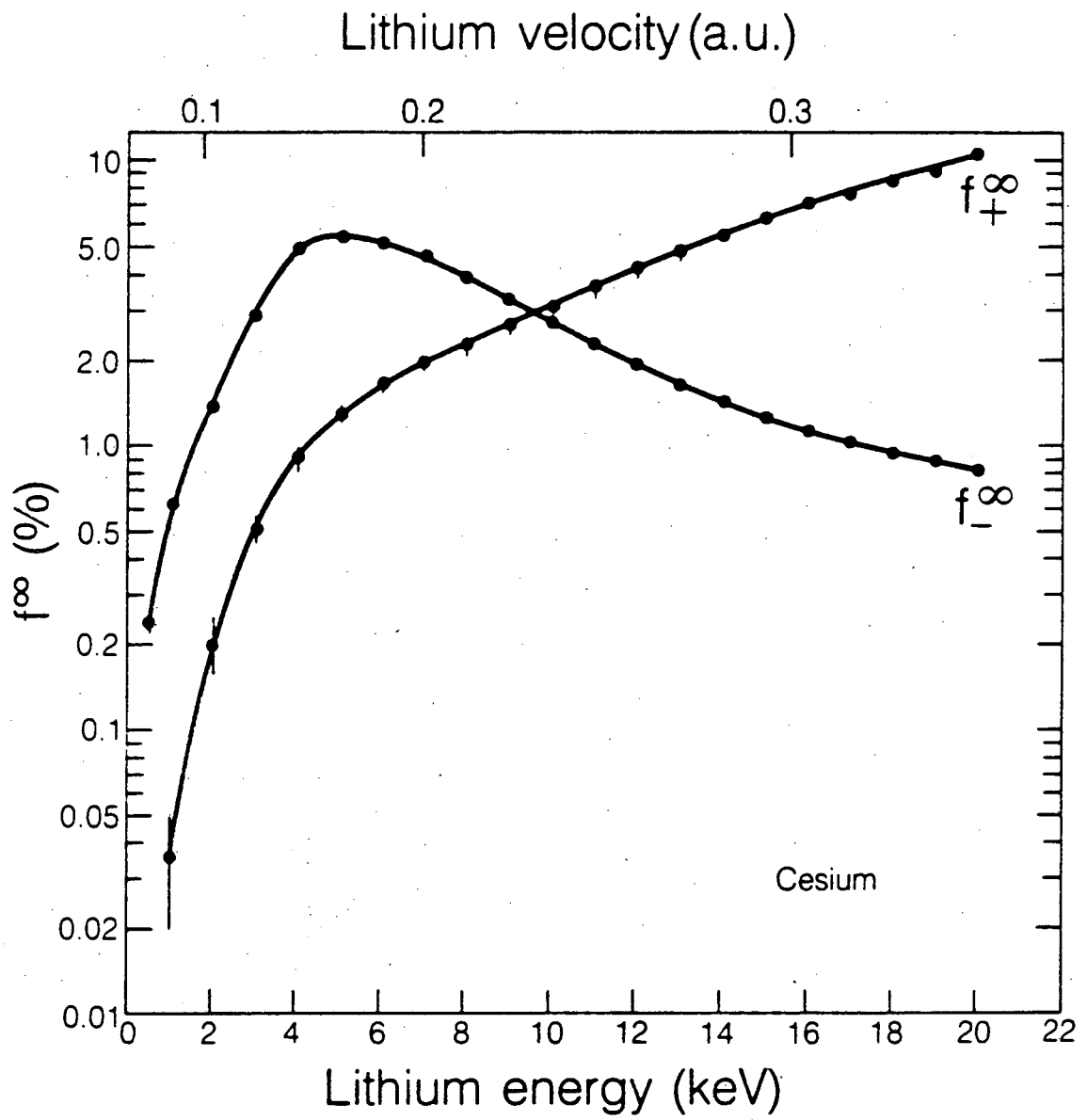


Figure 5

XBL 848-8837

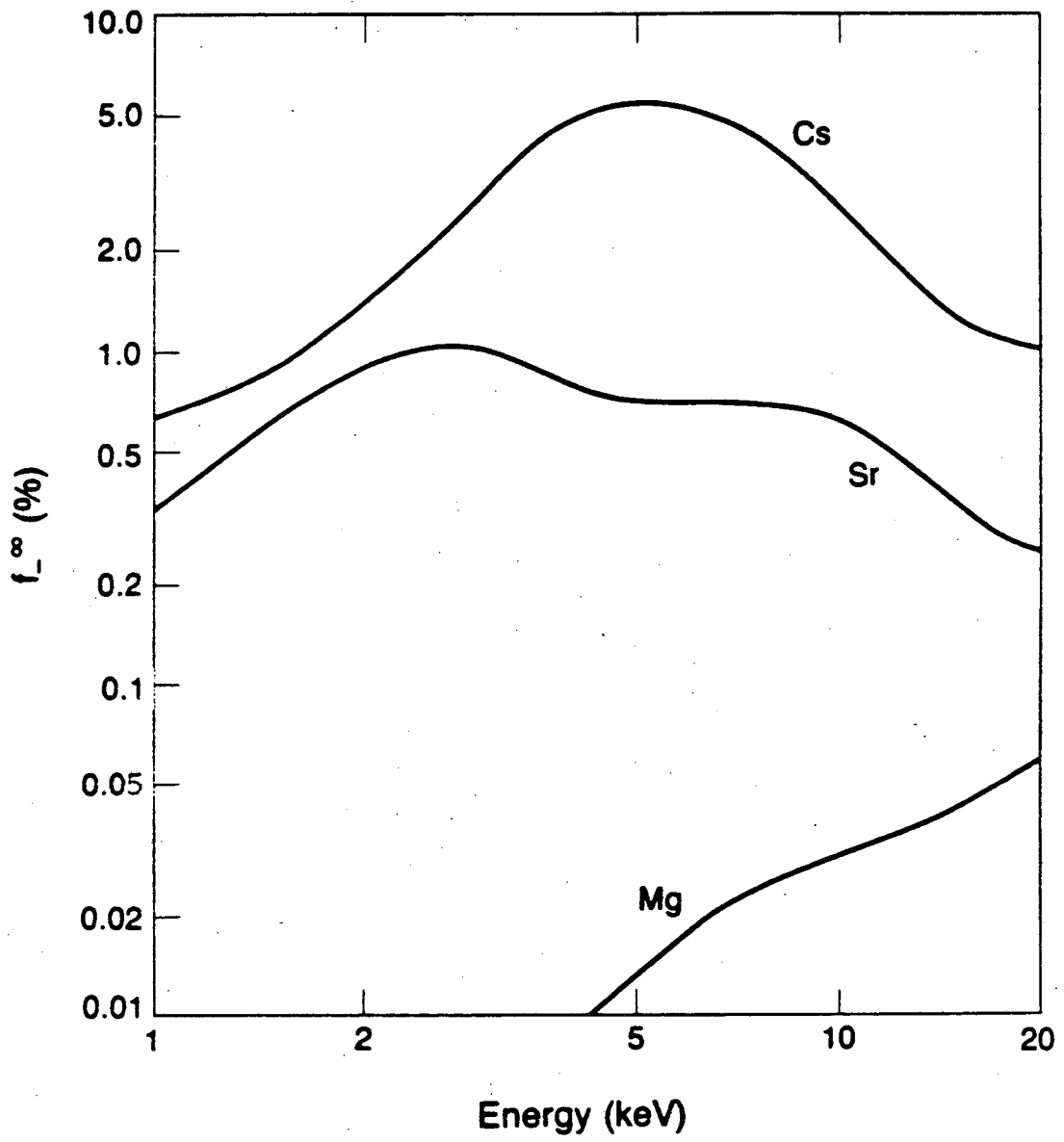


Figure 6

XBL 8410-10948



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