

### Auger Ejection of Electrons from Tungsten by Noble Gas Ions

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 (Received June 5, 1956)

Previously published data on Auger ejection from tungsten include the effect of a two percent admixture of metastable ions in the ion beam for A, Kr, and Xe. Data on yield and kinetic energy distribution of electrons ejected by the normal singly-charged ion only are presented in this paper.

THE results of a study of electron ejection from atomically clean tungsten have already been published.<sup>1,2</sup> During the course of this publication it was found that the ion beam in the case of A<sup>+</sup>, Kr<sup>+</sup>, and Xe<sup>+</sup> contained a very small fraction (about 2%) of ions which were excited in metastable states. The detection of these ions and related problems are discussed extensively in the accompanying paper.<sup>3</sup> It is the purpose here merely to present data on tungsten which have been obtained with an ion beam which is entirely in the ground state. These data include electron yield ( $\gamma_i$ ) as a function of ion kinetic energy (Fig. 1), and energy distributions of the ejected electrons (Figs. 2 and 3). Figures 1 and 3 replace Figs. 4 and 7 of reference 1, respectively. The differences between these figures occur only in the data for A, Kr, and Xe and are

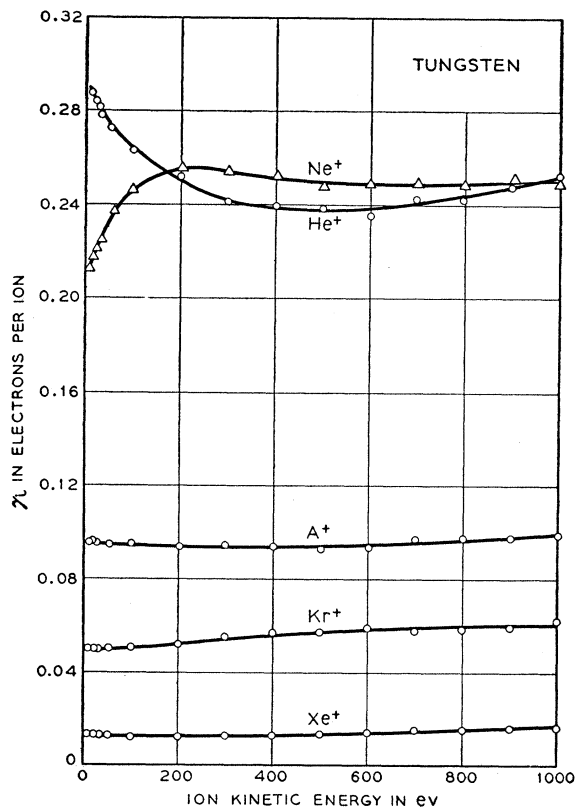


FIG. 1. Total electron yield versus ion kinetic energy for singly-charged ions of the noble gases incident on atomically clean tungsten. Ions are all in the ground state.

<sup>1</sup> H. D. Hagstrum, Phys. Rev. 96, 325 (1954).  
<sup>2</sup> H. D. Hagstrum, Phys. Rev. 96, 336 (1954).  
<sup>3</sup> H. D. Hagstrum, Phys. Rev. 103, 309 (1956), preceding paper.

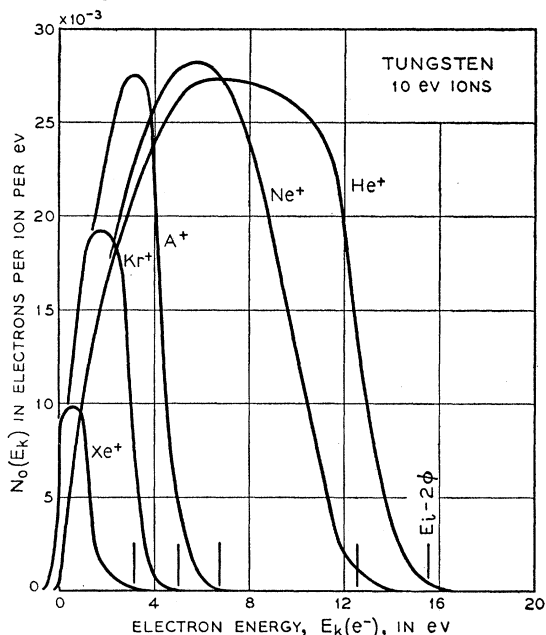


FIG. 2. Energy distribution functions for electrons ejected from atomically clean tungsten by singly-charged ions of 10-eV incident kinetic energy, all of which are in the ground state. The vertical lines on the abscissa scale indicate the energies  $E_i - 2\phi$ .

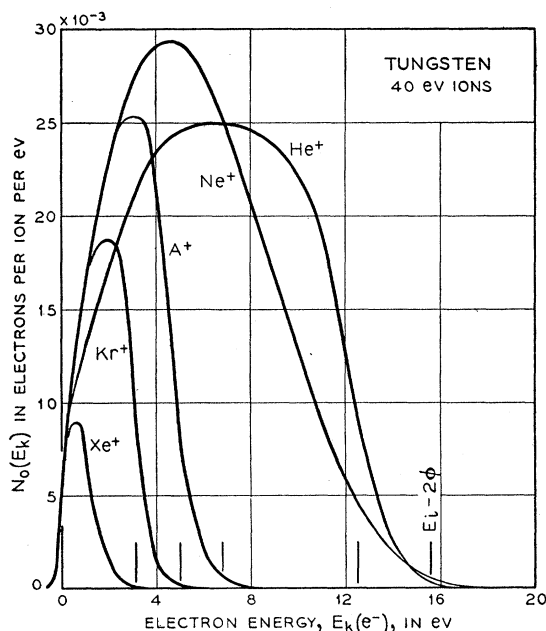


FIG. 3. Energy distribution functions for electrons ejected from tungsten by 40-eV noble gas ions, all of which are unexcited. Vertical lines on the abscissa scale indicate the energies  $E_i - 2\phi$ .

small. Data were also taken for 10-ev ions, and these are shown in Fig. 2. Comparison of Figs. 2 and 3 shows clearly the anomalous behavior of  $\text{Ne}^+$ . At the lowest ion energies  $\text{Ne}^+$  is Auger-neutralized and the upper energy limit of the  $N_0$  function is approximately  $E_i - 2\phi$  as for the other ions. As ion energy increases, a portion of the  $\text{Ne}^+$  ions are resonance-neutralized and de-excited in a process of Auger de-excitation

which has a higher yield (Fig. 1) and a larger kinetic energy maximum. Thus, for 40-ev ions (Fig. 3), the  $E_i - 2\phi$  limit is clearly violated in the case of neon. These and related matters have already been discussed extensively in Sec. XI of reference 2.

The data presented here were taken under the same conditions of gas purity, vacuum conditions, and surface cleanliness of the target as in the previous work.<sup>1</sup>

## Magnetic Susceptibility of $\alpha\text{MnS}^\dagger$

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(Received June 28, 1956)

The magnetic susceptibility of a powder sample of  $\alpha\text{MnS}$  was measured from 90°K to 800°K by an absolute Gouy method. The Néel temperature was found to be 154°K. There was no evidence of thermal hysteresis and the susceptibility was independent of field strength over a range of fields between 2000 and 3000 oersteds. Two sets of Weiss-Curie constants fitted the data above the Néel temperature. Between the Néel temperature and 300°K, values of  $\theta = 490^\circ\text{K}$  and  $C_M = 4.40$  were calculated. Above 400°K, the respective values were 380°K and 3.90. It is suggested that the persistence of short-range ordering effects to temperatures well above the Néel temperature affects the value of these constants and that the values above 400°K are probably more representative.

### INTRODUCTION

THE magnetic properties of  $\alpha\text{MnS}$  (manganous sulfide, green, NaCl structure) have been studied by several investigators. Mehmed and Haraldsen<sup>1</sup> determined the susceptibility at several fixed temperatures between 90°K and 478°K. Bhatnagar<sup>2</sup> made a similar study between room temperature and 510°K. Squire<sup>3</sup> established that  $\alpha\text{MnS}$  was antiferromagnetic with a Néel temperature of about 145°K. A subsequent investigation by Bizette<sup>4</sup> indicated a Néel temperature of 165°K. Anderson<sup>5</sup> observed two anomalies in the specific heat, one at 139°K and the other at 145°K, which have been correlated with the antiferromagnetic transition. Serres<sup>6</sup> measured the susceptibility from room temperature to 773°K.

For an antiferromagnetic substance the relationship,  $\chi_M = C_M / (T + \theta)$ , where  $\theta > 0$ , describes the molar susceptibility above the Néel temperature; so, from the data in this temperature region, it is possible to calculate the values of  $\theta$  and  $C_M$ . Values obtained by the various investigators are given in Table I. Other members of the manganese chalcogenide series have

been investigated and found to be antiferromagnetic. MnSe and MnTe are somewhat unusual in that they show some thermal hysteresis effects in the vicinity of the Néel temperature.<sup>7-9</sup> In addition, field-dependent effects have been observed with MnSe.<sup>8,10</sup> So far, no such unorthodox behavior has been noted in the case of MnS.

The purpose of this investigation was to make susceptibility measurements on a sample of MnS of known composition by an absolute method at several field strengths and over a wide enough temperature range to permit location of the Néel temperature and calcula-

TABLE I. Comparison of data obtained by different investigators for  $\alpha\text{MnS}$ .

Investigator	Temperature range (°K)	Néel temperature (°K)	$\theta$ (°K)	$C_M$	$\mu_B$
Mehmed and Haraldsen <sup>a</sup>	90-477	...	411	3.8	5.5
Serres <sup>b</sup>	293-773	...	459	3.45	5.27
Bhatnagar <sup>c</sup>	307-510	...	495	4.45	5.99
Bizette <sup>d</sup>	90-300	165	528	4.30	5.89
Squire <sup>e</sup>	90-300	145	...	...	...
Banewicz and Lindsay	90-400	154	490	4.40	5.96
	400-800	...	380	3.90	5.61

<sup>a</sup> See reference 1.

<sup>b</sup> See reference 6.

<sup>c</sup> See reference 2.

<sup>d</sup> See reference 4.

<sup>e</sup> See reference 3.

<sup>7</sup> H. Bizette and B. Tsai, *Compt. rend.* **212**, 75 (1941).

<sup>8</sup> R. Lindsay, *Phys. Rev.* **84**, 569 (1951).

<sup>9</sup> Uchida, Kondoh, and Fukuoka, *J. Phys. Soc. Japan* **11**, 27 (1956).

<sup>10</sup> H. Haraldsen and W. Klemm, *Z. anorg. u. allgem. Chem.* **220**, 183 (1934).

<sup>†</sup> Supported in part by a Frederick Gardner Cottrell grant from The Research Corporation.

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<sup>1</sup> F. Mehmed and H. Haraldsen, *Z. anorg. u. allgem. Chem.* **235**, 193 (1938).

<sup>2</sup> S. S. Bhatnagar, *J. Indian Chem. Soc.* **16**, 313 (1939).

<sup>3</sup> C. F. Squire, *Phys. Rev.* **56**, 922 (1939).

<sup>4</sup> H. Bizette, *Ann. phys.* (12), **1**, 295 (1946).

<sup>5</sup> C. T. Anderson, *J. Am. Chem. Soc.* **53**, 476 (1931).

<sup>6</sup> A. Serres, *J. phys. radium* **8**, 146 (1947).