

Lawrence Berkeley National Laboratory

Recent Work

Title

RANGE-ENERGY RELATION FOR HEAVY IONS IK METALS

Permalink

<https://escholarship.org/uc/item/64q024tn>

Author

Hubbard, Edward L.

Publication Date

1960-01-25

UNIVERSITY OF
CALIFORNIA
Ernest O. Lawrence
Radiation
Laboratory

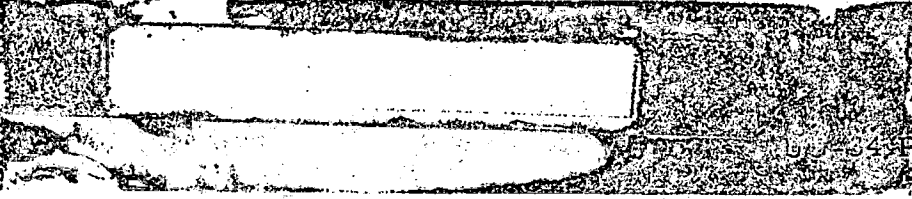
RANGE-ENERGY RELATION
FOR HEAVY IONS IN METALS

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545*

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.



UCRL-9053
Physics and Mathematics
TID-4500 (15th ed.)

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California
Contract No. W-7405-eng-48

RANGE-ENERGY RELATION FOR HEAVY IONS IN METALS

Edward L. Hubbard

January 25, 1960

Printed in USA. Price 75 cents. Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D.C.

RANGE-ENERGY RELATION FOR HEAVY IONS IN METAL

Edward L. Hubbard

Lawrence Radiation Laboratory
University of California
Berkeley, California

January 25, 1960

ABSTRACT

The range-energy relations for C, N, O, Ne, and A ions in Be, Al, Ni, Cu, Ag, and Au have been calculated from the experimental range-energy relation for these ions in emulsion. The calculated curves are compared with experiment in the cases for which experimental data are available.

RANGE-ENERGY RELATION FOR HEAVY IONS IN METALS

Edward L. Hubbard

Lawrence Radiation Laboratory
University of California
Berkeley, California

January 25, 1960

Introduction

Very few measurements have been made of the ranges of heavy ions in metals other than aluminum. To provide experimenters with a set of range-energy curves until more measurements are made, the experimental range-energy relations for heavy ions in emulsions have been used to calculate the ranges in several metals frequently used by experimenters.

Method of Calculation

The range of a heavy ion in a metal is related to the range of an α particle of the same velocity by the equation

$$R_{h, m} = \frac{4 M_h}{M_a Z_h^2} R_{a, m} + R_{ext, m} \quad (1)$$

where

$R_{h, m}$ = range of the heavy ion in a metal,

$R_{a, m}$ = range of an α particle in the metal,

M_h = mass of the heavy ion,

Z_h = nuclear charge of the heavy ion,

$R_{ext, m}$ = a correction that must be added to the first term

in Eq. (1) to account for the increase in range caused primarily by capture and loss of electrons by the ion near the end of its range.

Similarly the range of the heavy ion in nuclear emulsion is related to the range of an α particle in emulsion by

$$R_{h, em} = \frac{4 M_h}{M_a Z_h^2} R_{a, em} + R_{ext, em} \quad (2)$$

where the subscript em refers to emulsion.

Combining Eqs. (1) and (2) gives

$$R_{h, m} = \frac{R_{a, m}}{R_{a, em}} R_{h, em} \frac{1 - \frac{R_{ext, em}}{R_{h, em}}}{1 - \frac{R_{ext, m}}{R_{h, m}}}$$

$$R_{h, m} \approx \frac{R_{a, m}}{R_{a, em}} R_{h, em} (1 - \Delta), \quad (3)$$

where

$$\Delta = \frac{R_{ext, em}}{R_{h, em}} - \frac{R_{ext, m}}{R_{h, m}}$$

Since the average charge of an ion with a given velocity is not a sensitive function of the material it is going through, $\Delta \ll 1$ should be a good approximation.

Equation (3) then simplifies to

$$R_{h, m} = \frac{R_{a, m}}{R_{a, em}} R_{h, em} \quad (4)$$

This expression has been used to calculate the ranges of C, N, O, Ne, and A ions in Al, Ni, Cu, Ag, Au, and Pb. The data of Barkas, Heckman, et al. were used for the ranges of heavy ions in emulsion¹ and of α particles in emulsion.² The ranges used for α particles in metals were those of Whaling.³ Whaling does not quote ranges of α particles in Be. The ranges of heavy ions in Be were calculated from the ranges of protons in Be by using an expression analogous to Eq. (4). The range-energy data used for protons in Be were those of Bichsel, Mozeley, and Aron,⁴ and the ranges in emulsion were taken from Heckman et al. and Barkas et al.²

Results

The range-energy data calculated from Eq. (4) are given in Tables I through VI. The calculated curves for Be, Al, Cu, Ag, and Au are plotted in Figs. 1 through 5. In Figs. 6 through 17 the calculated curves are compared with experiment for those cases for which experimental data are available. The data of Walton and Hubbard, Sikkeland, and Gilmore are from stopping-power experiments done with the heavy-ion accelerator at Berkeley. The stopping-power experiments can be used only to check the shape of the range curves in the high-energy region. The point where the experimental data have been normalized to the calculated curves is indicated by a circle. The data for stopping in Ni from the Yale experiments of Roll and Steigert are treated in the same way. Burcham,⁵ Northcliffe,⁶ and Zucker et al.⁷ also measured stopping power, but their measurements extended to low enough energy that they can be extrapolated to zero to get an absolute value for the range. The data of Oganesian were obtained from a paper by Flerov.⁸ No description of the experiments was given.

Table I

Calculated ranges of C ions						
Energy (Mev)	Range (mg/cm ²)					
	Al	Ni	Cu	Ag	Au	Pb
12.0	3.1	4.6	4.3	5.6	7.6	8.2
24.0	6.2	8.7	8.5	11.0	15.3	15.3
36.0	9.9	13.4	13.4	17.2	23.9	23.3
48.0	14.4	19.0	19.2	24.1	34.4	32.3
60.0	20.0	25.9	26.1	32.5	45.0	43.4
75.0	28.1	35.5	35.9	44.3	41.2	58.6
89.9	37.4	46.7	47.0	57.7	79.1	76.6
104.9	48.0	59.2	60.2	73.2	98.0	96.3
119.9	60.1	73.6	75.0	89.9	121.1	118.7

Table II

Calculated ranges of N ions						
Energy (Mev)	Range (mg/cm ²)					
	Al	Ni	Cu	Ag	Au	Pb
14.0	3.1	4.6	4.2	5.5	7.6	8.1
28.0	5.9	8.3	8.2	10.5	14.7	14.6
42.0	9.3	12.5	12.5	16.1	22.4	21.8
56.0	13.3	17.5	17.7	22.2	30.8	29.8
70.0	18.1	23.5	23.6	29.4	40.8	39.4
87.5	25.2	31.8	32.1	39.7	54.8	52.5
104.9	33.3	41.6	41.9	51.4	70.4	68.2
122.4	42.3	52.2	53.2	64.6	86.5	85.0
139.9	52.8	64.7	65.9	79.1	106.5	104.4

Table III

Calculated ranges of O ions						
Energy (Mev)	Range (mg/cm ²)					
	Al	Ni	Cu	Ag	Au	Pb
16.0	3.1	4.5	4.2	5.5	7.5	8.0
32.0	5.6	7.9	7.8	10.0	14.0	14.0
48.0	8.7	11.8	11.8	15.1	21.0	20.5
63.9	12.3	16.2	16.4	20.6	28.6	27.7
79.9	16.7	21.6	21.8	27.1	37.5	36.3
99.9	23.0	29.1	29.4	36.3	50.1	48.0
119.9	30.3	37.8	38.1	46.7	64.0	62.0
139.9	38.5	47.4	48.3	58.7	78.6	77.2
159.8	47.6	58.3	59.4	71.2	96.0	94.1

Table IV

Calculated range of Ne ions						
Energy (Mev)	Range (mg/cm ²)					
	Al	Ni	Cu	Ag	Au	Pb
20.0	3.0	4.4	4.0	5.3	7.2	7.8
40.0	5.3	7.5	7.4	9.5	13.2	13.2
59.9	8.0	10.9	10.9	14.0	19.4	18.9
79.9	11.2	14.8	14.9	18.8	26.0	25.2
99.9	15.0	19.4	19.5	24.3	33.7	32.5
124.9	20.3	25.7	26.0	32.1	44.2	42.4
149.9	26.4	33.0	33.2	40.8	55.9	54.1
174.8	33.1	40.8	41.5	50.5	67.6	66.4
199.8	40.6	49.8	50.7	60.8	82.0	80.3

Table V

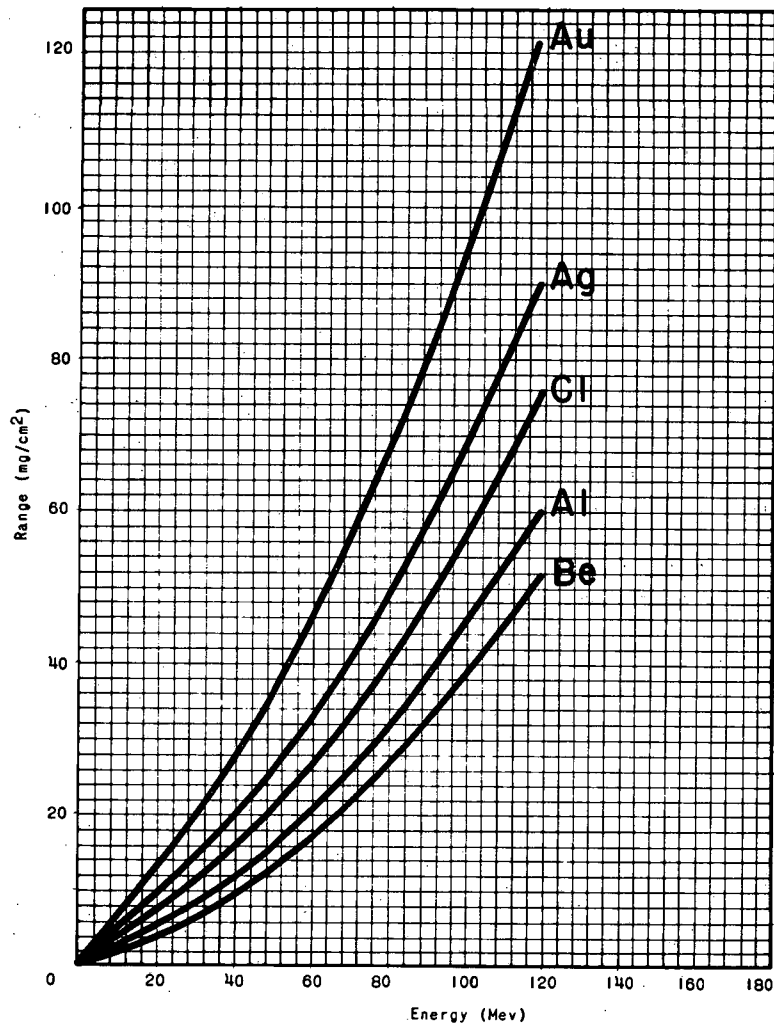
Calculated ranges of A ions							
Energy (Mev)	Range (mg/cm ²)						
	Al	Ni	Cu ⁶⁴	Ag ¹⁰⁷	Au ¹⁹⁷	Pb	
39.9	3.3	4.9	4.5	6.0	8.1	8.7	
79.9	5.4	7.6	7.4	9.6	13.4	13.4	
119.8	7.6	10.3	10.3	13.3	18.5	18.0	
159.7	10.3	13.5	13.6	17.2	23.8	23.0	
199.7	13.2	17.1	17.2	21.4	29.8	28.6	
249.6	17.4	22.0	22.2	27.4	37.8	36.2	
299.5	21.9	27.3	27.5	33.8	46.3	44.6	
349.4	26.8	33.1	33.7	40.9	54.8	53.9	
399.4	32.3	39.5	40.3	48.3	65.1	63.8	

Table VI

Calculated ranges of heavy ions in Be									
C		N		O		Ne		A	
Energy Mev	Range ₂ mg/cm ²	Energy Mev	Range ₂ mg/cm ²	Energy Mev	Range ₂ mg/cm ²	Energy Mev	Range ₂ mg/cm ²	Energy Mev	Range ₂ mg/cm ²
11.9	1.9	13.9	1.9	15.9	1.9	19.8	1.8	39.7	2.1
23.8	4.6	27.8	4.3	31.7	4.2	39.7	3.9	79.4	4.0
35.7	7.8	41.6	7.2	47.6	6.8	59.5	6.3	119.0	6.0
47.6	11.7	55.5	10.7	63.5	10.1	79.4	9.1	158.7	8.4
59.5	16.1	69.4	14.6	79.4	13.7	99.2	12.4	198.4	11.0
71.4	21.6	83.3	19.4	95.2	18.2	119.0	16.1	238.1	13.9
83.3	28.1	97.2	24.9	111.1	22.8	138.9	19.9	277.8	16.9
95.2	35.3	111.0	31.0	127.0	27.9	158.7	24.4	317.4	20.3
107.1	42.8	124.9	37.2	142.8	33.7	178.6	29.2	356.9	23.9
119.0	50.9	139.0	45.0	158.7	40.2	198.4	34.8	396.5	27.7

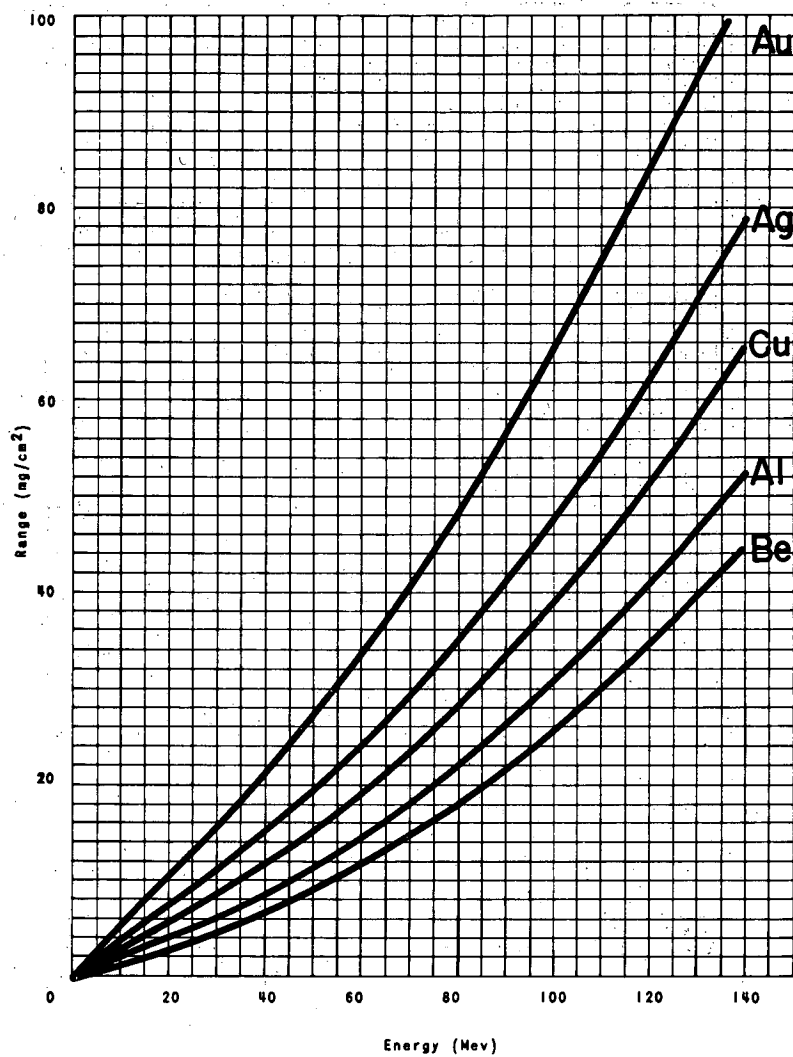
References

1. Heckman, Perkins, Simon, Smith, and Barkas, Range and Energy-Loss Processes of Heavy Ions in Emulsion, Phys. Rev. (to be published).
2. Barkas, Barrett, Cüer, Heckman, Smith, and Ticho, Nuovo cimento 8, 185 (1958); W. H. Barkas, Nuovo cimento 8, 201 (1958).
3. W. Whaling, Encyclopedia of Physics 34, 193 (1958).
4. Bichsel, Mozeley, and Aron, Phys. Rev. 105, 1788 (1957).
5. W. E. Burcham, Proc. Phys. Soc. A 70, 309 (1957).
6. L. C. Northcliffe, Bull. Am. Phys. Soc. II, 4, 44 (1959).
7. Webb, Reynolds, and Zucker, Phys. Rev. 102, 749 (1956); Reynolds, Scott, and Zucker, Phys. Rev. 95, 671 (1954).
8. G. N. Flerov, Peaceful Uses of Atomic Energy, vol 14, P 151, United Nations, Geneva (1958).



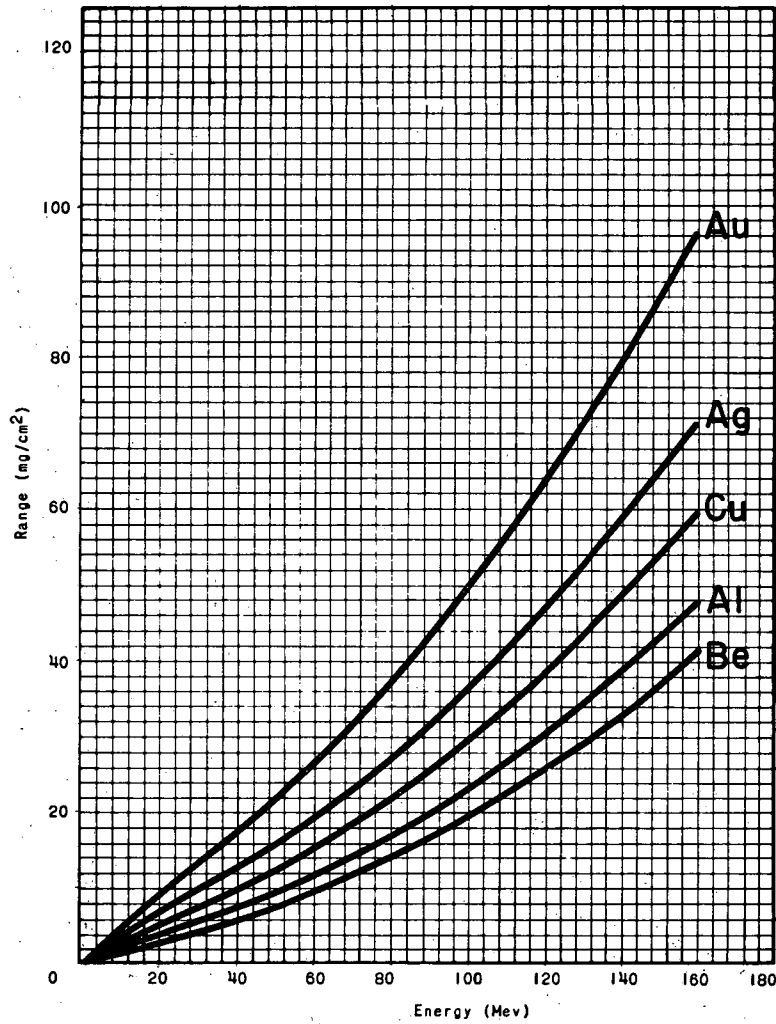
MU-19274

Fig. 1. Calculated range-energy relations for C¹² ions in Be, Al, Cu, Ag, and Au.



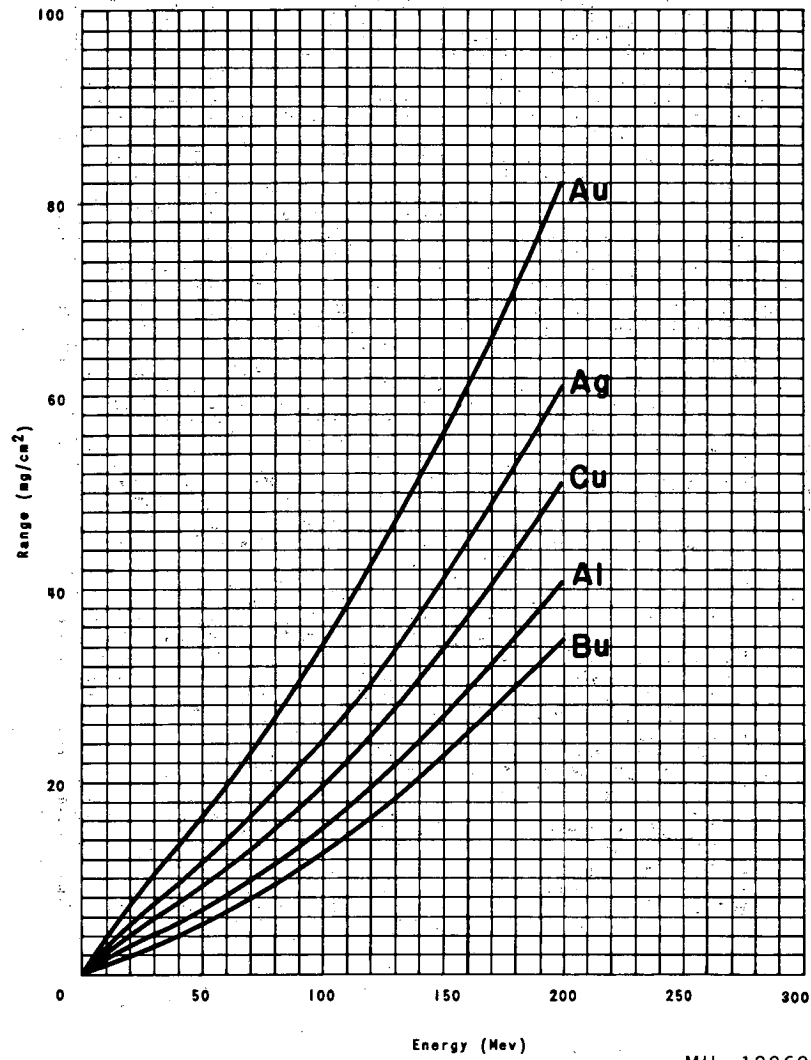
MU-19267

Fig. 2. Calculated range-energy relations for N^{14} ions in Be, Al, Cu, Ag, and Au.



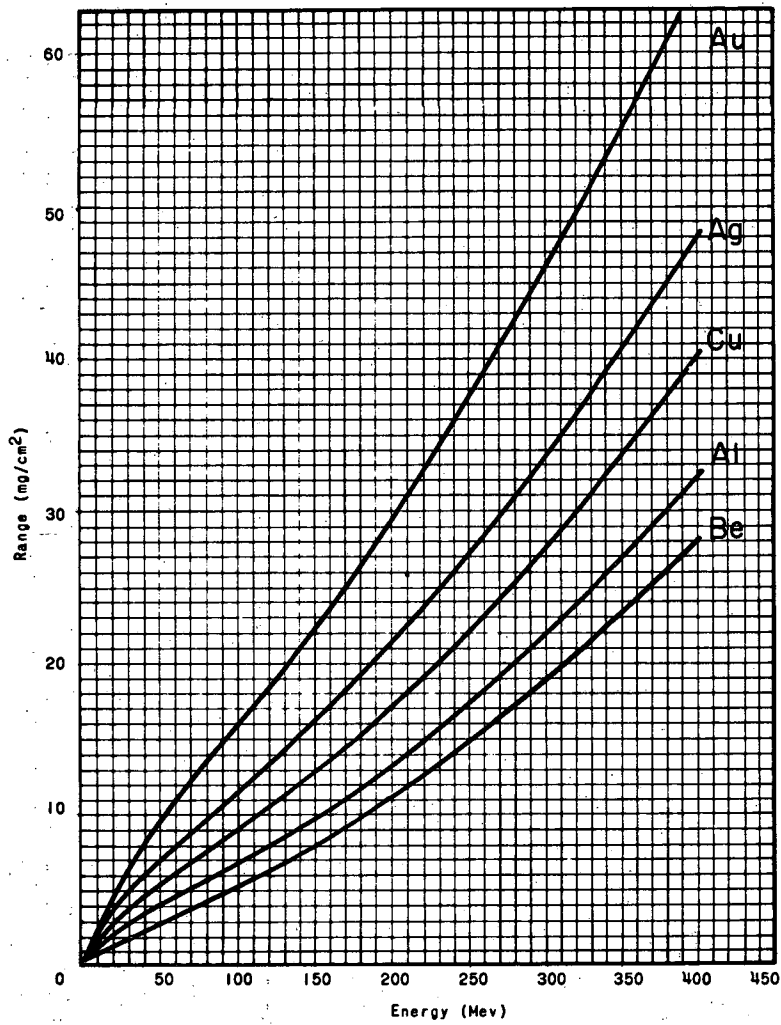
MU-19273

Fig. 3. Calculated range-energy relations for O^{16} ions in Be, Al, Cu, Ag and Au.



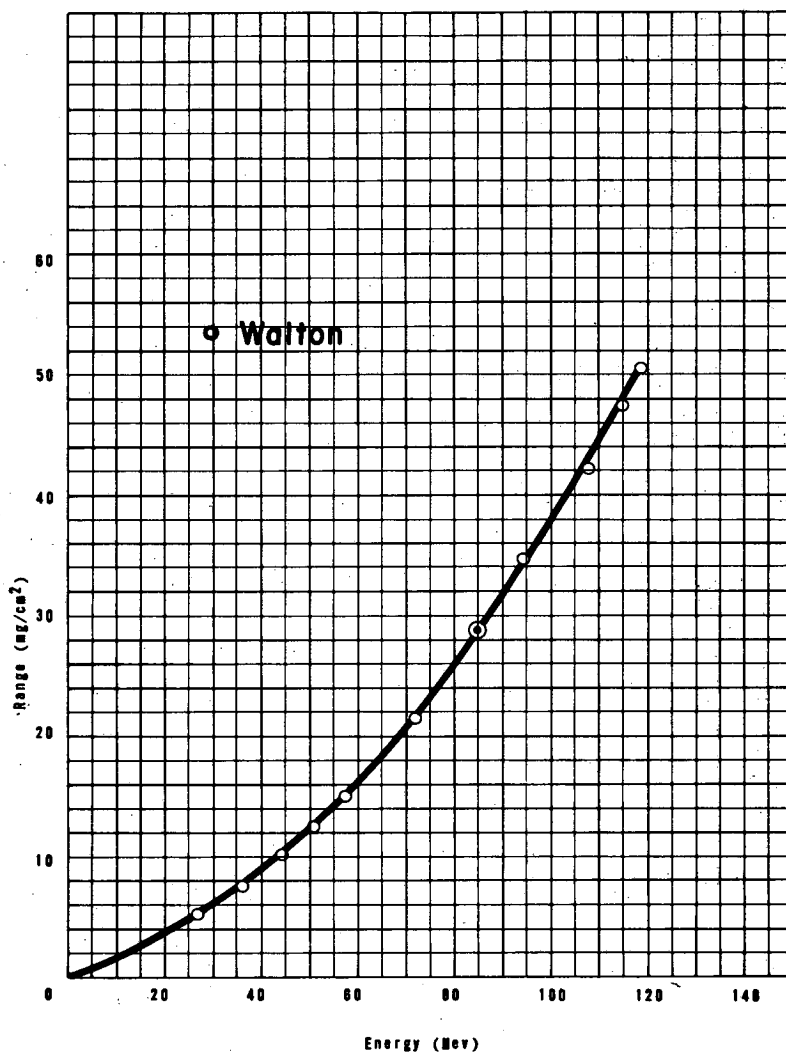
MU-19262

Fig. 4. Calculated range-energy relations for Ne²⁰ ions in Be, Al, Cu, Ag, and Au.



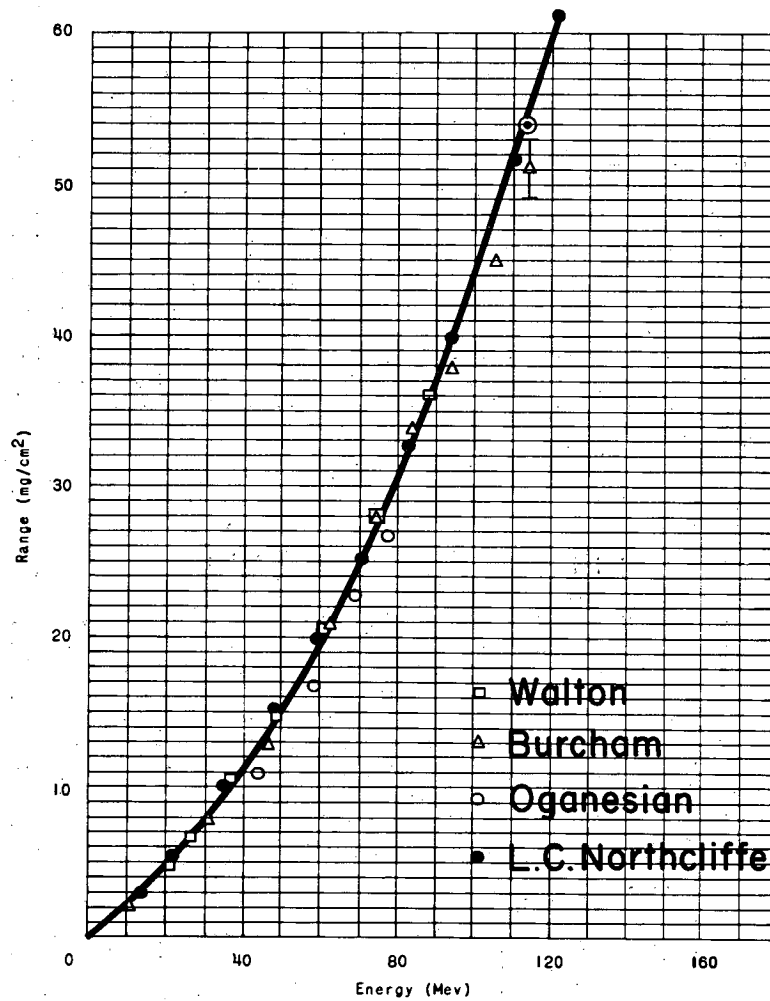
MU-19275

Fig. 5. Calculated range-energy relations for A^{40} ions in Be, Al, Cu, Ag, and Au.



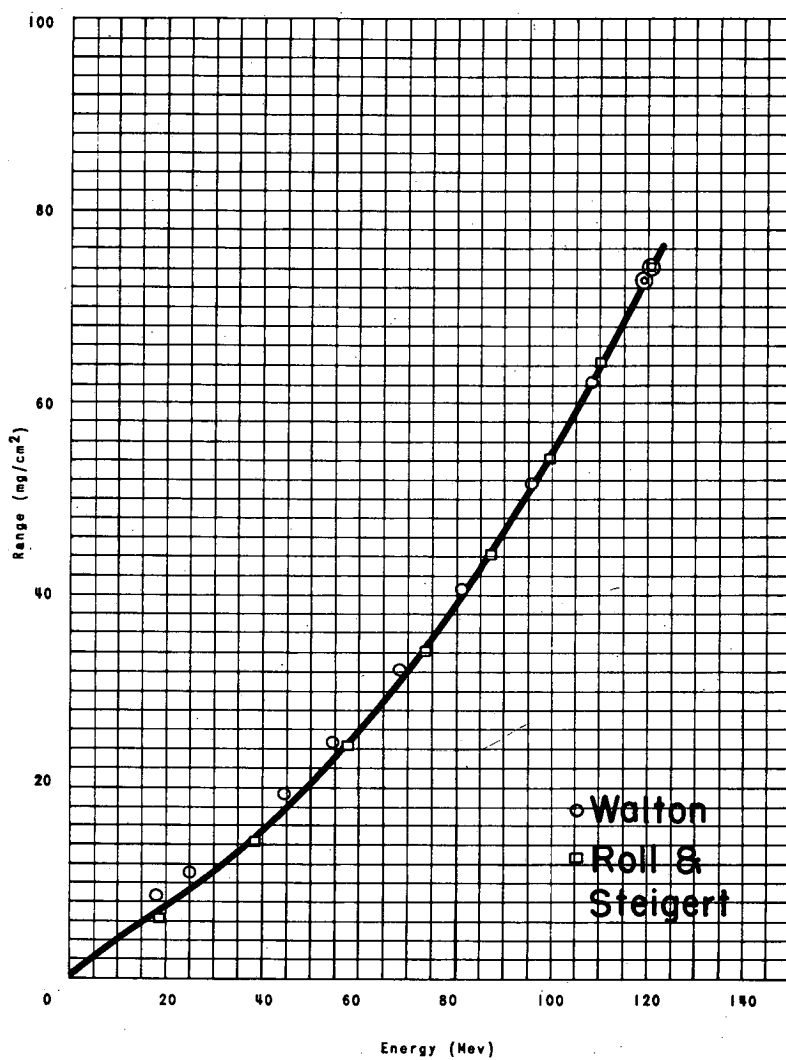
MU-19263

Fig. 6. Range-energy relation for C^{12} ions in beryllium. Solid curve was calculated from emulsion data. Walton's energy-loss data were fitted to the calculated range curve at the point circled.



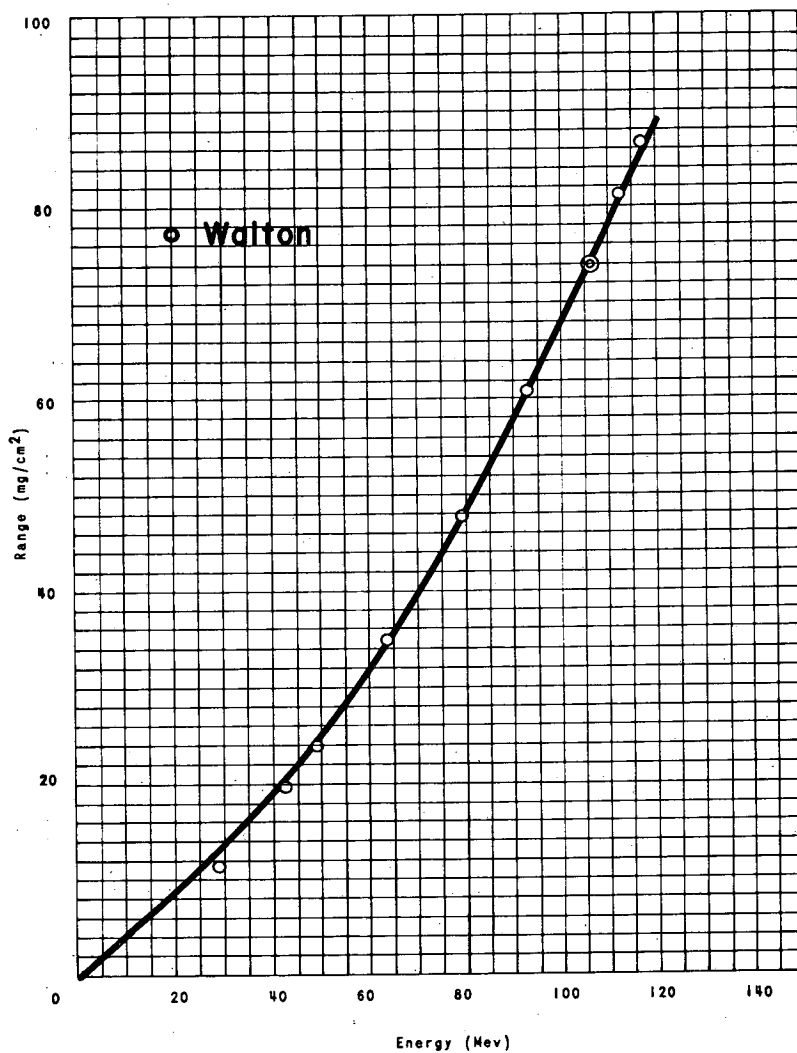
MU-19270

Fig. 7. Range-energy relation for C^{12} ions in aluminum. The solid curve was calculated from Eq. (4). The energy-loss data of Walton were fitted to the calculated range curve at the point circled. The energy-loss data of Northcliffe and Burcham were converted to range data by extrapolating to zero.



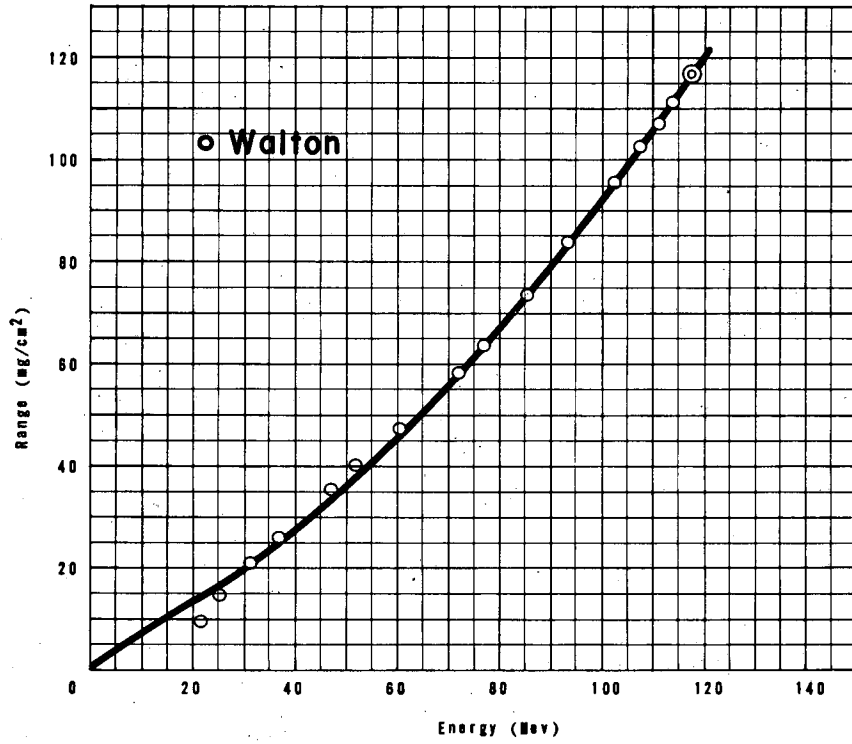
MU-19265

Fig. 8. Range-energy relation for C^{12} ions in nickel. The solid curve was calculated from Eq. (4). Experimental energy-loss data were fitted to the calculated curve at the points circled.



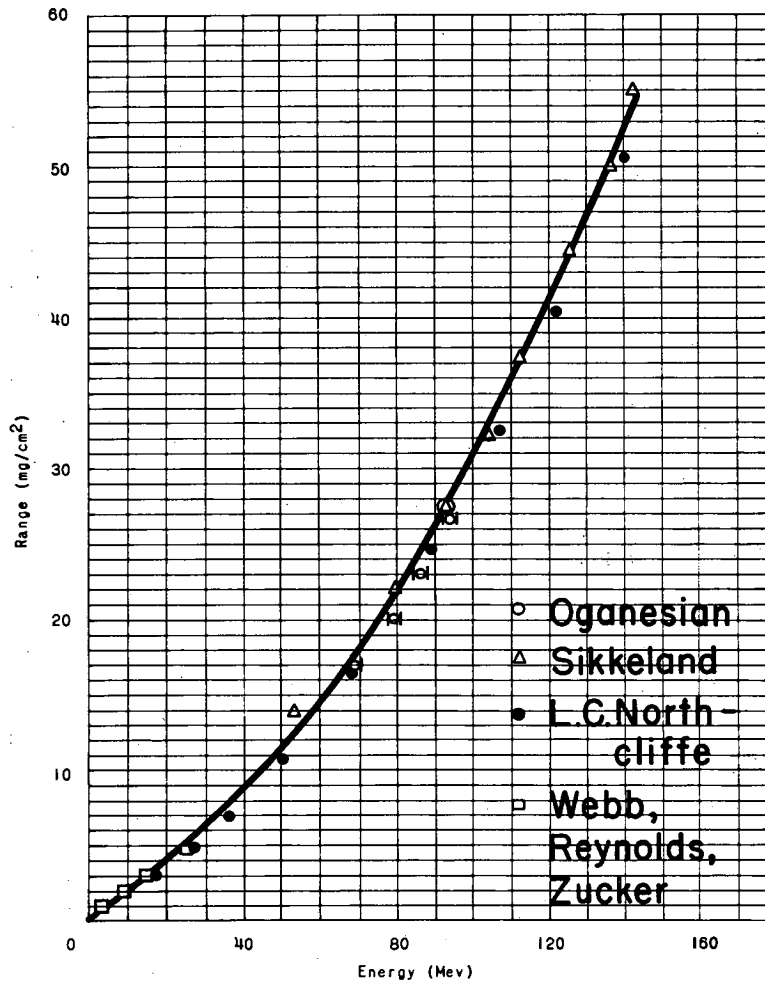
MU-19264

Fig. 9. Range-energy relation for C^{12} ions in silver. The solid curve was calculated from Eq. (4). Walton's energy-loss data were fitted to the calculated range curve at the point circled.



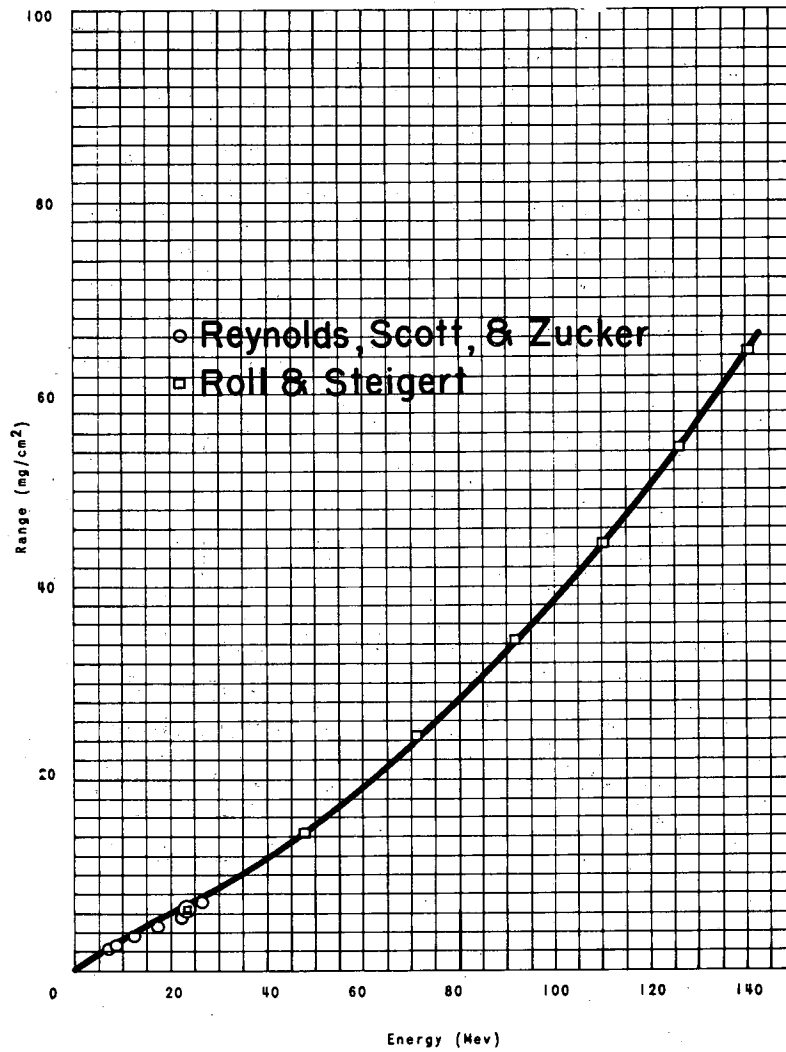
MU-19260

Fig. 10. Range-energy relation for C^{12} ions in gold. The solid curve was calculated from Eq. (4). Walton's energy-loss data were fitted to the calculated range curve at the point circled.



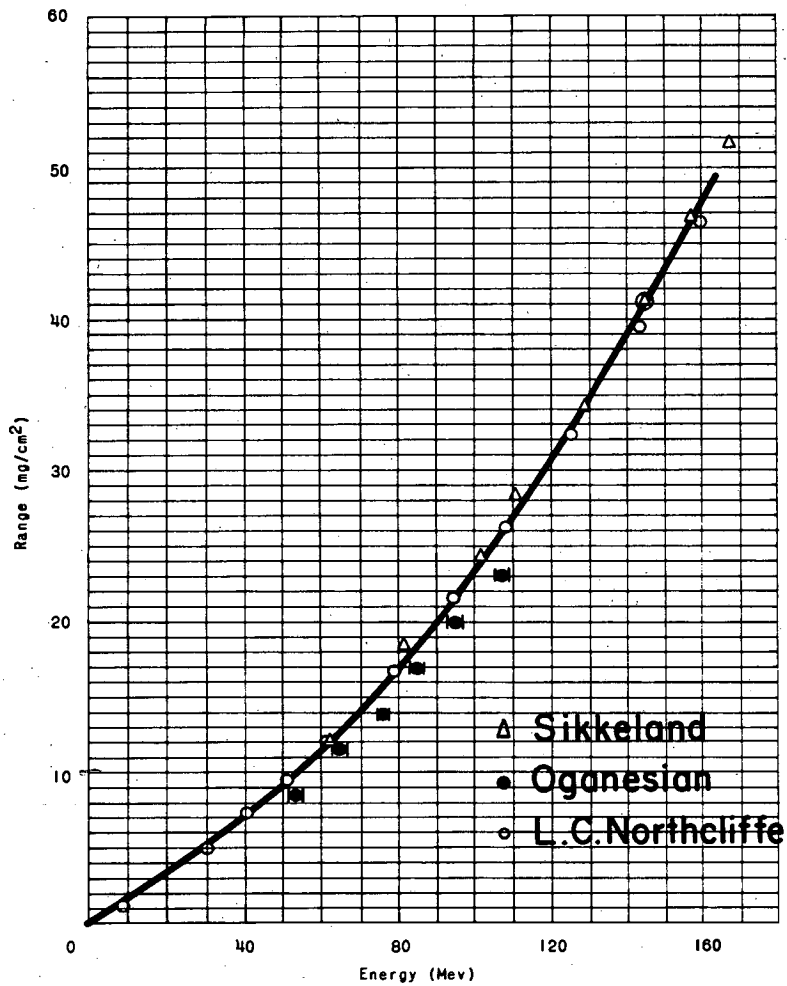
MU-19269

Fig. 11. Range-energy relation for N^{14} ions in aluminum. The solid curve was calculated from Eq. (4). Sikkeland's energy-loss data were fitted to the calculated range curve at the point circled. The energy-loss data of Northcliffe and Zucker et al. was converted to range data by extrapolating to zero.



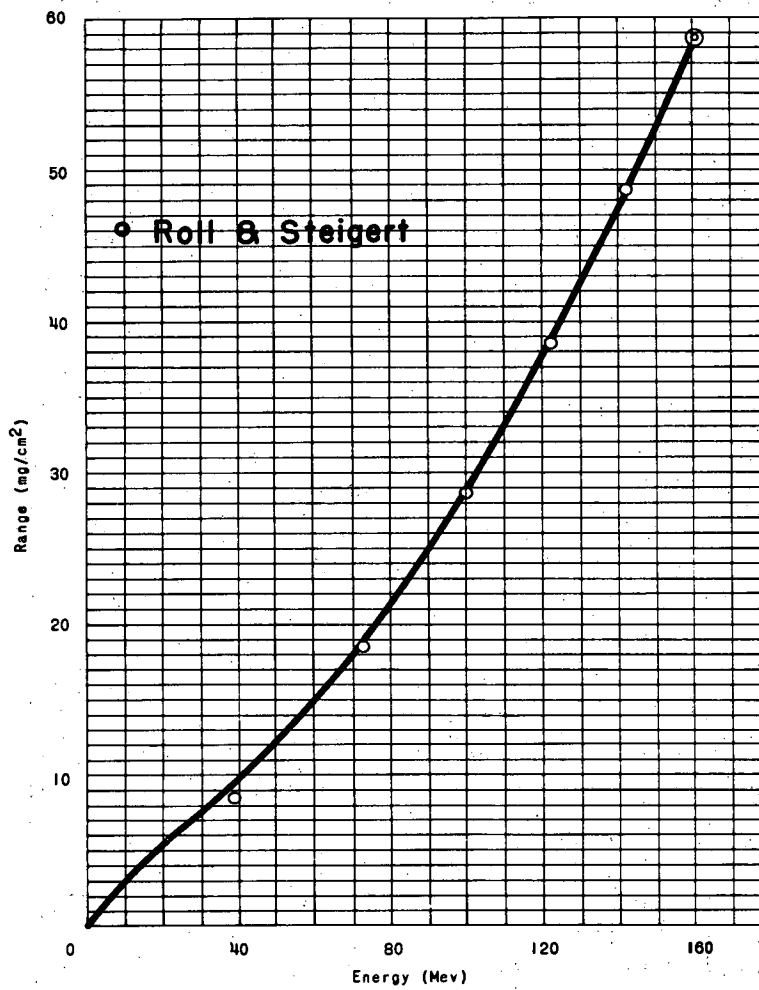
MU-19266

Fig. 12. Range-energy relation for N^{14} ions in nickel. The solid curve was calculated from Eq. (4). The energy-loss data of Zucker et al. were converted to range data by extrapolating to zero. The energy-loss data of Roll and Steigert were fitted to the range curve at the point circled.



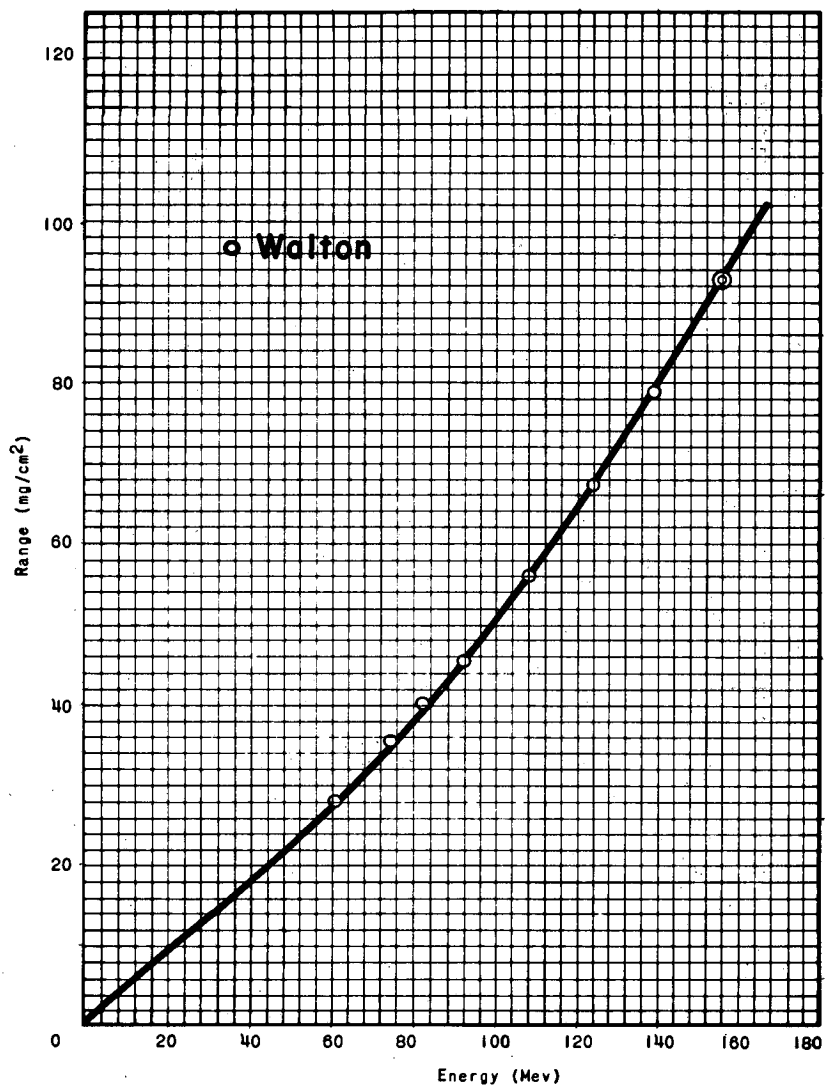
MU-19271

Fig. 13. Range-energy relation for O^{16} ions in aluminum. The solid curve was calculated from Eq. (4). Sikkeland's energy-loss data were fitted to the calculated range curve at the point circled. Northcliffe's energy-loss data were converted into range data by extrapolating to zero.



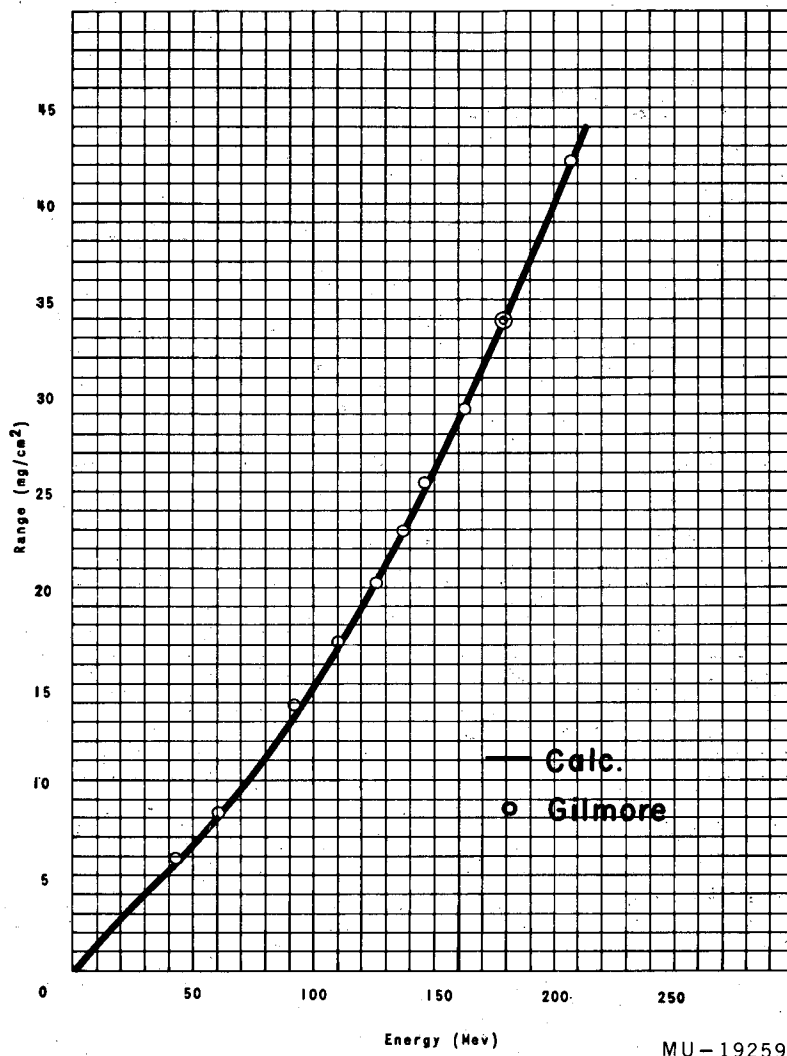
MU-19268

Fig. 14. Range-energy relation for O^{16} ions in nickel. The solid curve was calculated from Eq. (4). The experimental energy-loss data of Roll and Steigert were fitted to the calculated range curve at the point circled.



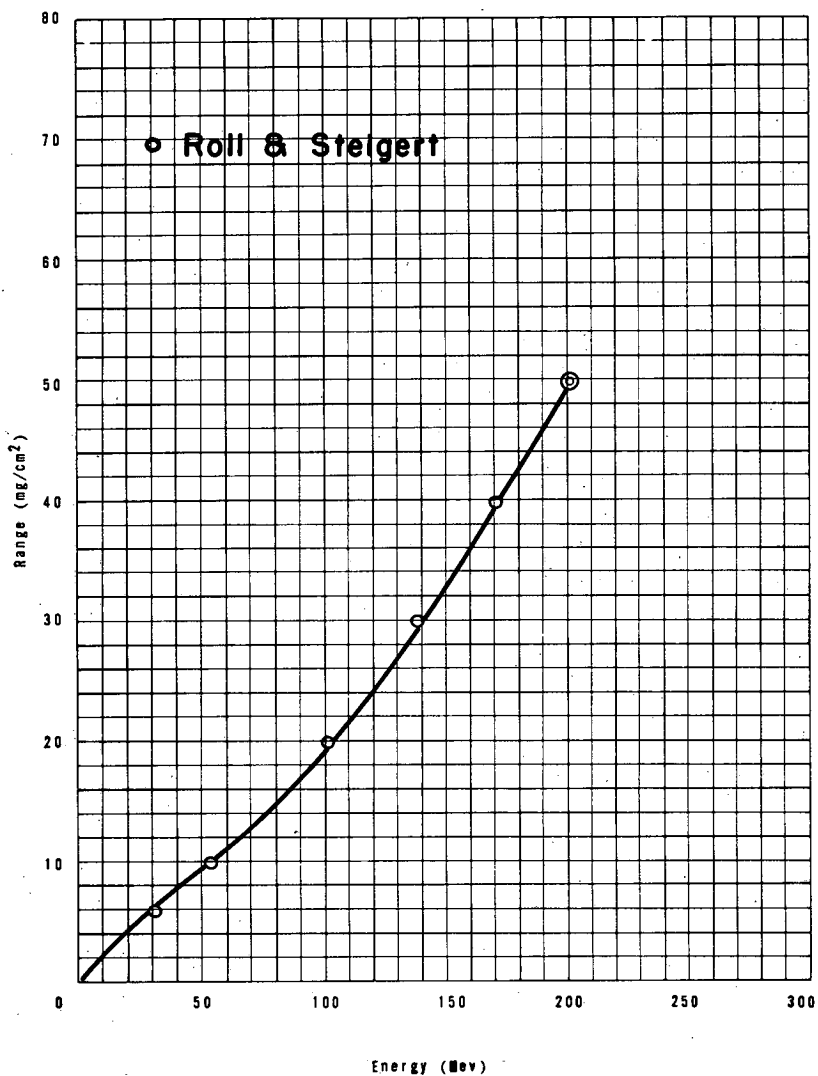
MU-19272

Fig. 15. Range-energy relation for O^{16} ions in gold. The solid curve was calculated from Eq. (4). Walton's experimental energy-loss data were fitted to the calculated range curve at the point circled.



MU-19259

Fig. 16. Range-energy relation for Ne^{20} ions in aluminum. The solid curve was calculated from Eq. (4). Gilmore's energy-loss data were fitted to the calculated range curve at the point circled.



MU-19261

Fig. 17. Range-energy relation for Ne²⁰ ions in nickel. The solid curve was calculated from Eq. (4). The energy-loss data of Roll and Steigert were fitted to the calculated range curve at the point circled.

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.