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HIGH-ENERGY PARTICLE DATA

Volume II

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HIGH-ENERGY PARTICLE DATA

Volume II

John H. Atkinson, Jr., and Beverly Hill Willis

June 1957

Printed for the U. S. Atomic Energy Commission

HIGH-ENERGY PARTICLE DATA

Volume II

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Radiation Laboratory
University of California
Berkeley, California

June 1957

INTRODUCTION

This section of the original Beverly Hill Willis report, greatly expanded, has been placed in a separate volume to facilitate its use as a handbook for accelerator experiments. The range-energy curves have been corrected, and curves for K, Σ, and Ξ particles and for emulsion data have been added. Range-momentum curves corresponding to the range-energy curves have been added, for momentum is often the parameter of direct concern to the experimenter. A miscellaneous collection of supplemental data useful to the experimenter has been added.

The basic sources of the range-energy curves are the proton range-energy tables given in Aron's thesis,[1] except for the emulsion data, which come from Barkas.[2] The curves for other particles were made from the proton masters by shifting the range and energy scales by a factor M_x/M_p. If $M_x/M_p = q$, a new particle with kinetic energy K_x will have a range that is q times the range of a proton of kinetic energy $K = K_x/q$. If the particle is multiply charged, an additional vertical shift by a factor of z^2 is required. A range graph for any new charged particle may be made in this way, by simply laying over the curve printed herein a sheet of similarly ruled paper and tracing the curve onto the new sheet in the required position. For example, to make the deuteron graph: shift the left index (1×10^n) of the proton curve to the right under the new paper so that it lies beneath 2×10^n, and up to 2×10^n on the new paper; then trace the deuteron curve. For a lighter-particle example, to make the K-meson graph: shift the left index (1×10^n) of the new paper to the right to $(938/493 = 1.89) \cdot 10^n$ and up to 1.89×10^n on the proton curve, and draw the K-meson curve. The electron curves in aluminum were calculated from Feather's Rule, and the curves for electrons in emulsion are from extrapolations of experimental data and are of approximately 3% accuracy. The range-momentum curves for protons were plotted by converting the abscissa from energy to momentum with the graphs of Volume I, and then

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[1] Walter A. Aron, The Passage of Charged Particles through Matter (Thesis), UCRL-1325, May 1951.

[2] Walter H. Barkas, Preliminary Calculations, Range-Energy Curve for Protons in G.5 Emulsion of Density 3.815 g/cm^3, UCRL-3384, April 1956.

shifting for other particles as above. The range-energy curves have been corrected in this revision, chiefly by the use of later data. (Aron's thesis was used rather than his earlier report.) The chief differences from the earlier work occur for carbon (.5%) and hydrogen (6%). It should be recognized that there are accuracy limitations in the graphing process, and in the shifting and sliding procedure used to draw the curves for particles other than protons (0.5%), as well as limitations in the theory and in the original data.

Mass absorption coefficients for photons of 10 kev to 10 Bev have been plotted. Data for the section for 10 kev to 100 Mev are from ORNL-503.[3] Both experimental and calculated points from several sources were used from 100 Mev to 10 Bev, and some liberty was taken in fitting a smooth curve.

The radiation length and geometric cross section are given by straightforward calculation. The plot of range-momentum index and range-energy index was provided by Rosenfeld and Tripp of UCRL. The dE/dx plot is from values of Aron.[1] The remaining writeups and tables are as attributed on the material (except for the generally known constants and values that are included for convenience). The values of numerical constants are generally from a recent compilation by Dumond and Cohen.

--JHA

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[3] Unclassified extract from classified report by Ralph Zirkind, ORNL-503, June 1950.

ACKNOWLEDGMENTS

Members of many physics groups at the Radiation Laboratory have helped greatly in the compilation of this essentially eclectic report. Drs. Robert W. Kenney, Arthur H. Rosenfeld, Frank T. Solmitz, and M. Lynn Stevenson have been generous with their direction and suggestions. Many of the additions are at the suggestion of Dr. Luis W. Alvarez. Finally, I wish to thank Mr. Charles V. Stableford for his preliminary work and Mr. Ellis H. Myers for his beautiful drafting.

This work was done under the auspices of the U. S. Atomic Energy Commission.

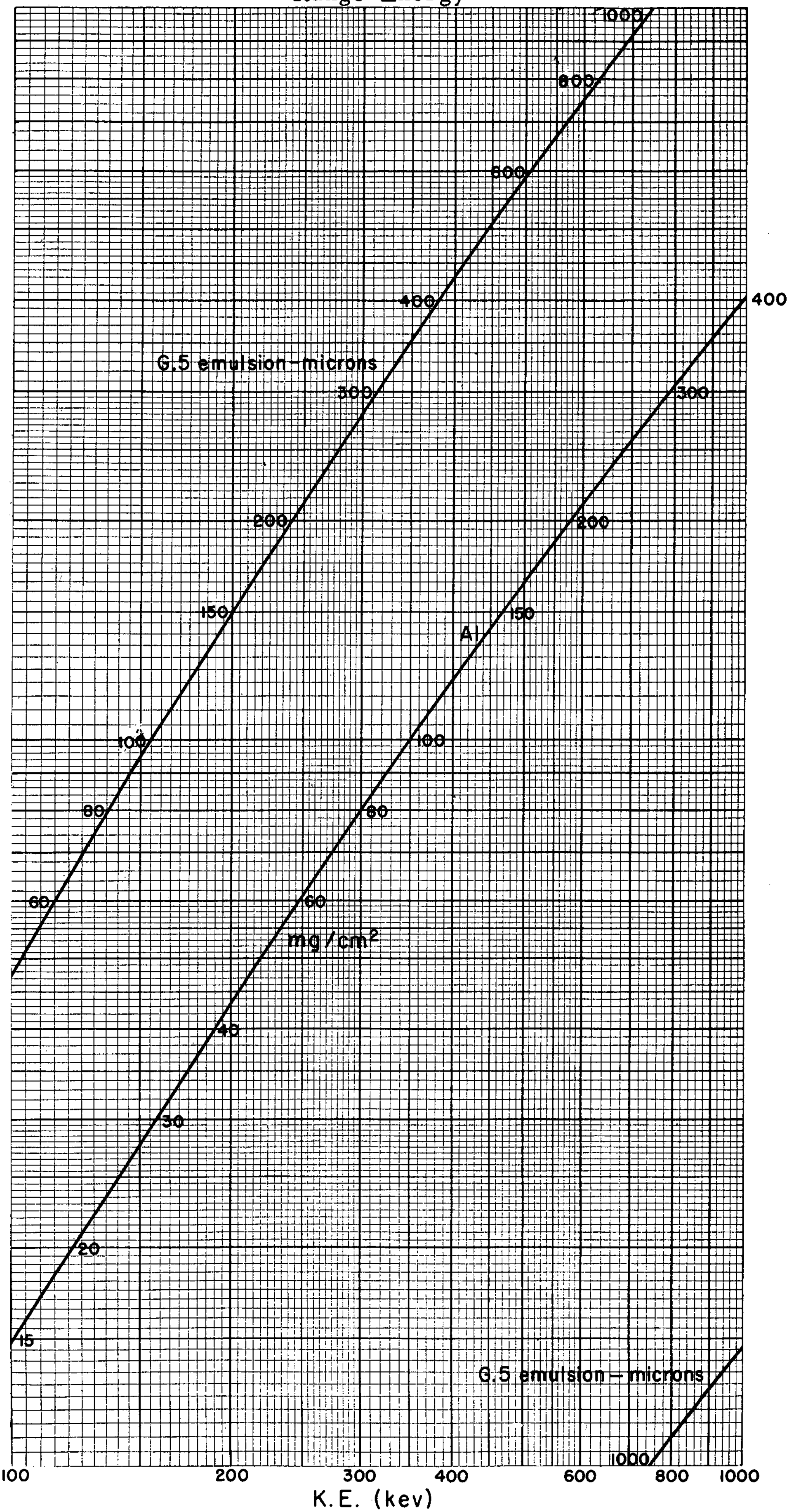
---JHA

ELECTRONS

100 kev to 1 Mev

Range-Energy

M = 0.5110 Mev
  = m

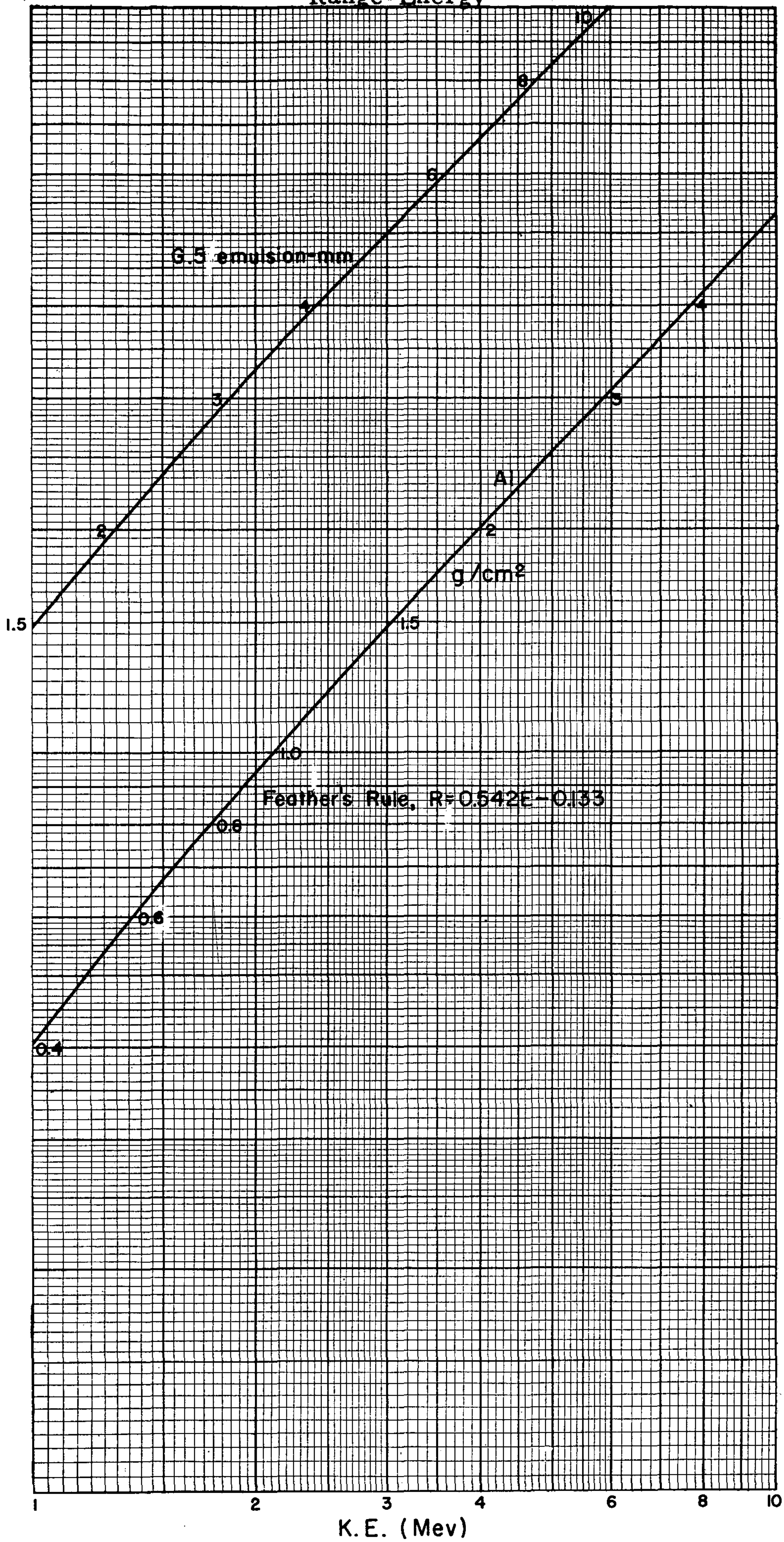


0 0 1 0 1 2 0 4 1 4 5

ELECTRONS 1 to 10 Mev

Range-Energy

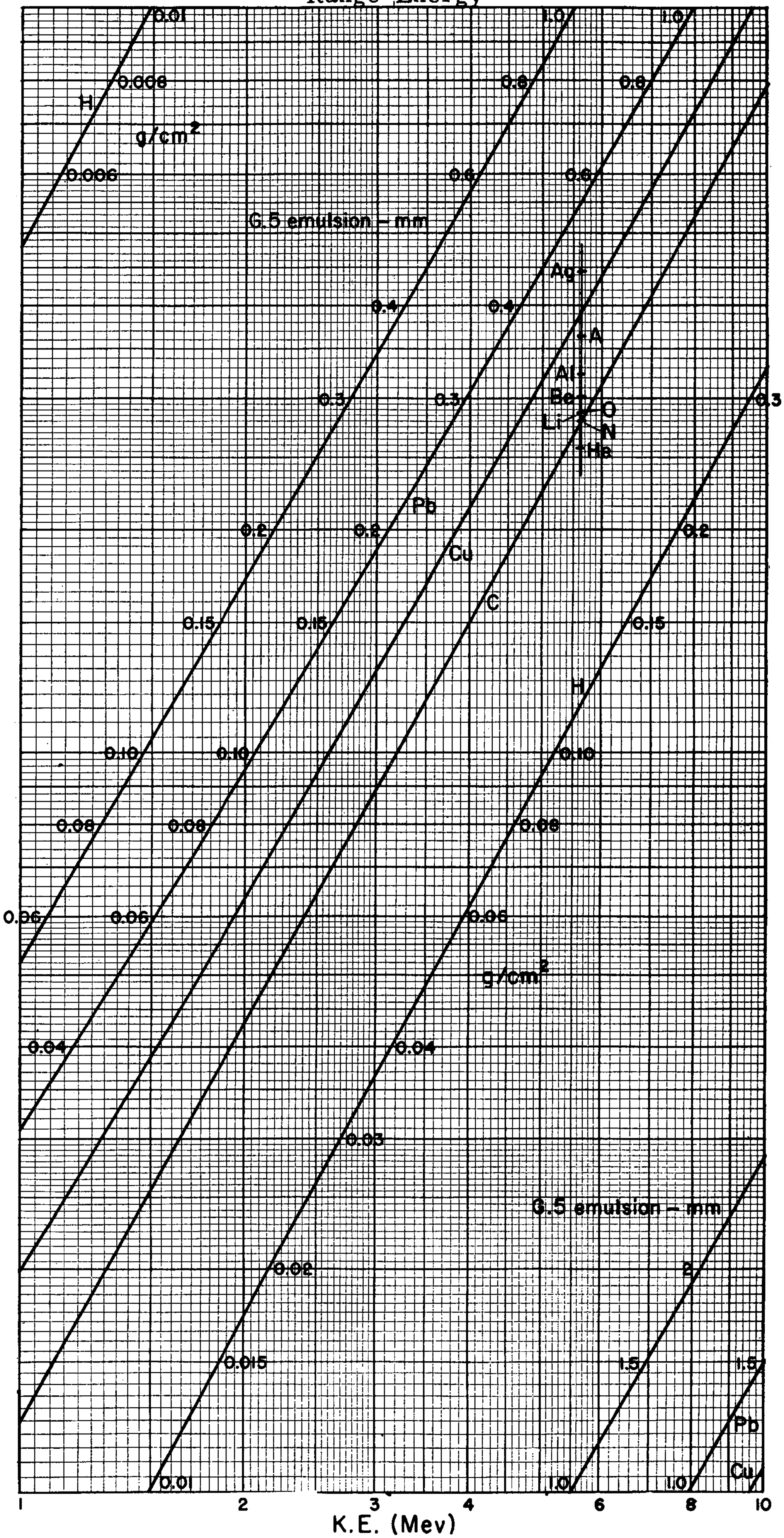
M = 0.51098 Mev
= m



μ MESONS 1 to 10 Mev

Range-Energy

M = 105.7 Mev
= 206.86 m

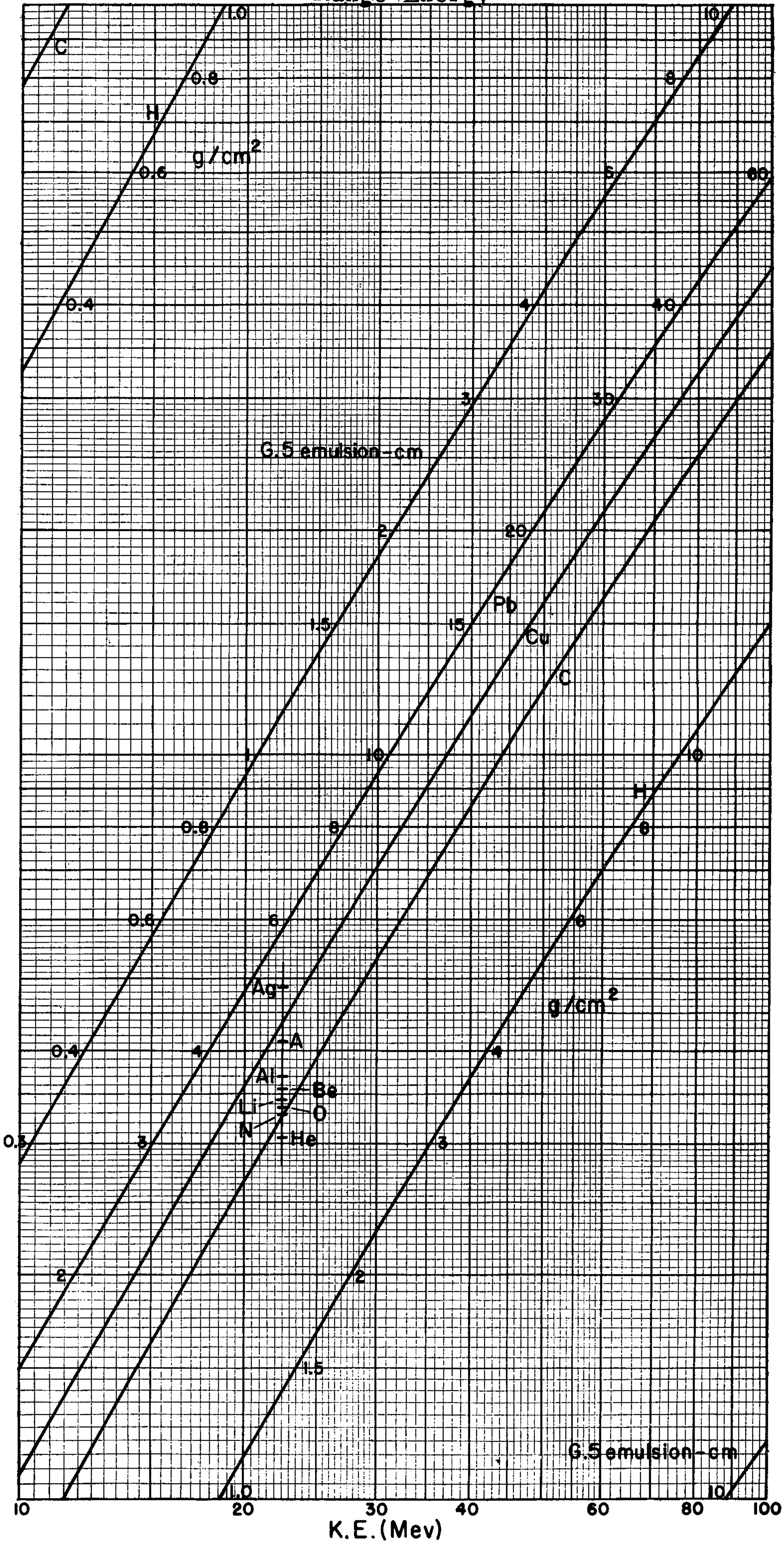


0 0 1 0 1 2 0 4 1 4 7

μ MESONS
Range-Energy

10 to 100 Mev

M = 105.7 Mev
= 206.86 m

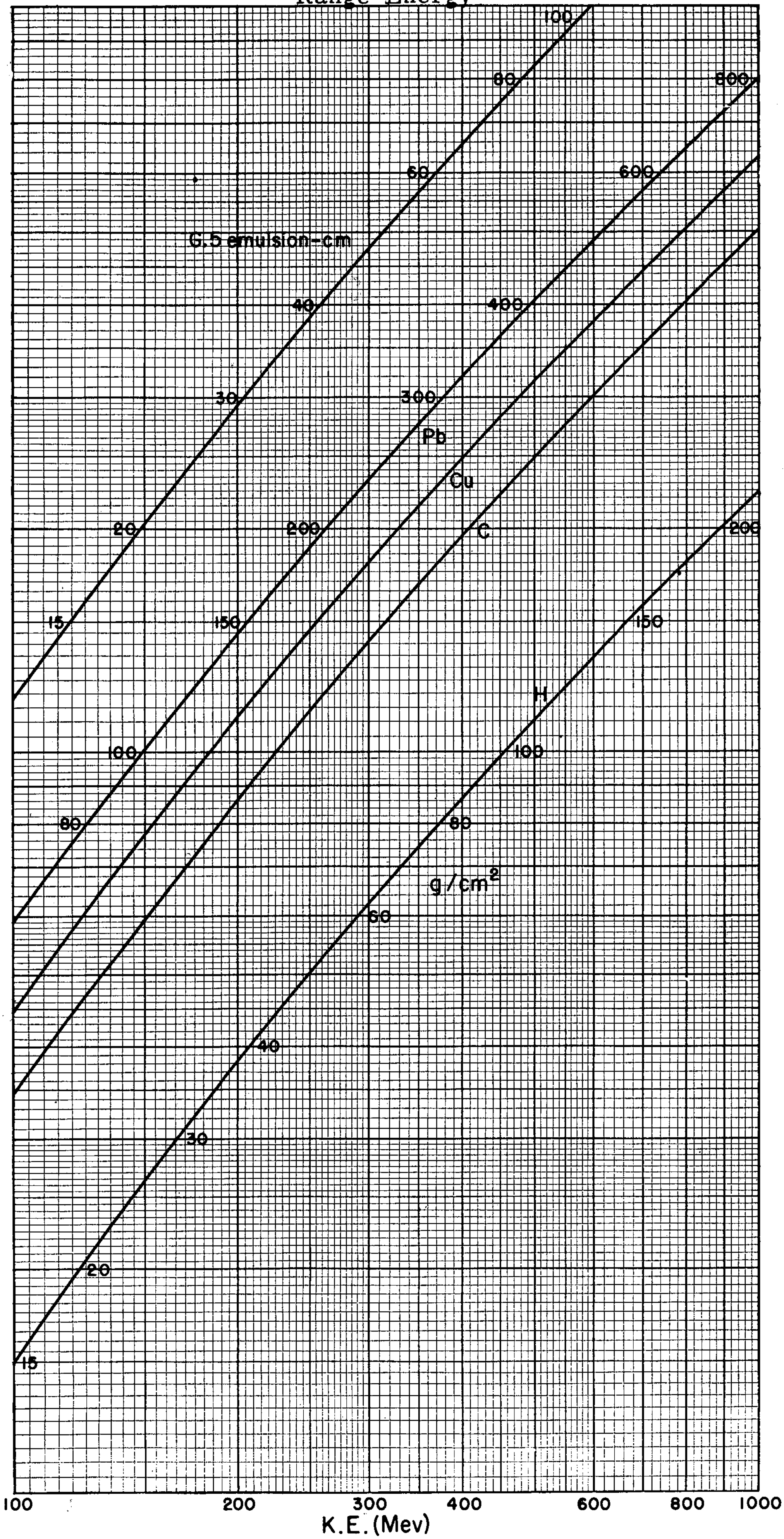


μ MESONS

Range-Energy

100 Mev to 1 Bev

M = 105.7 Mev
= 206.86 m

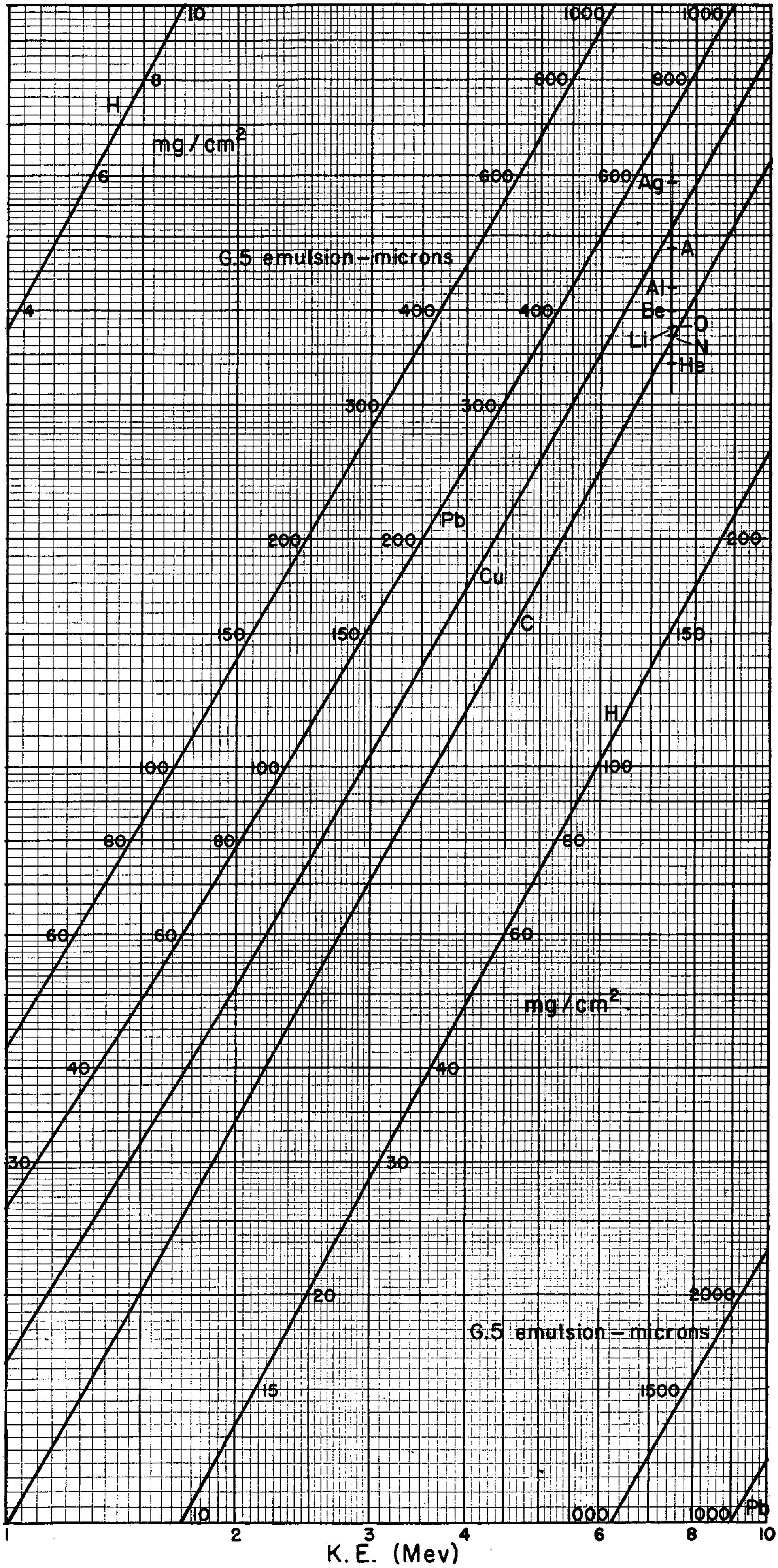


π MESONS 1 to 10 Mev

00101204149

Range-Energy

M = 139.6 Mev
= 273.27 m

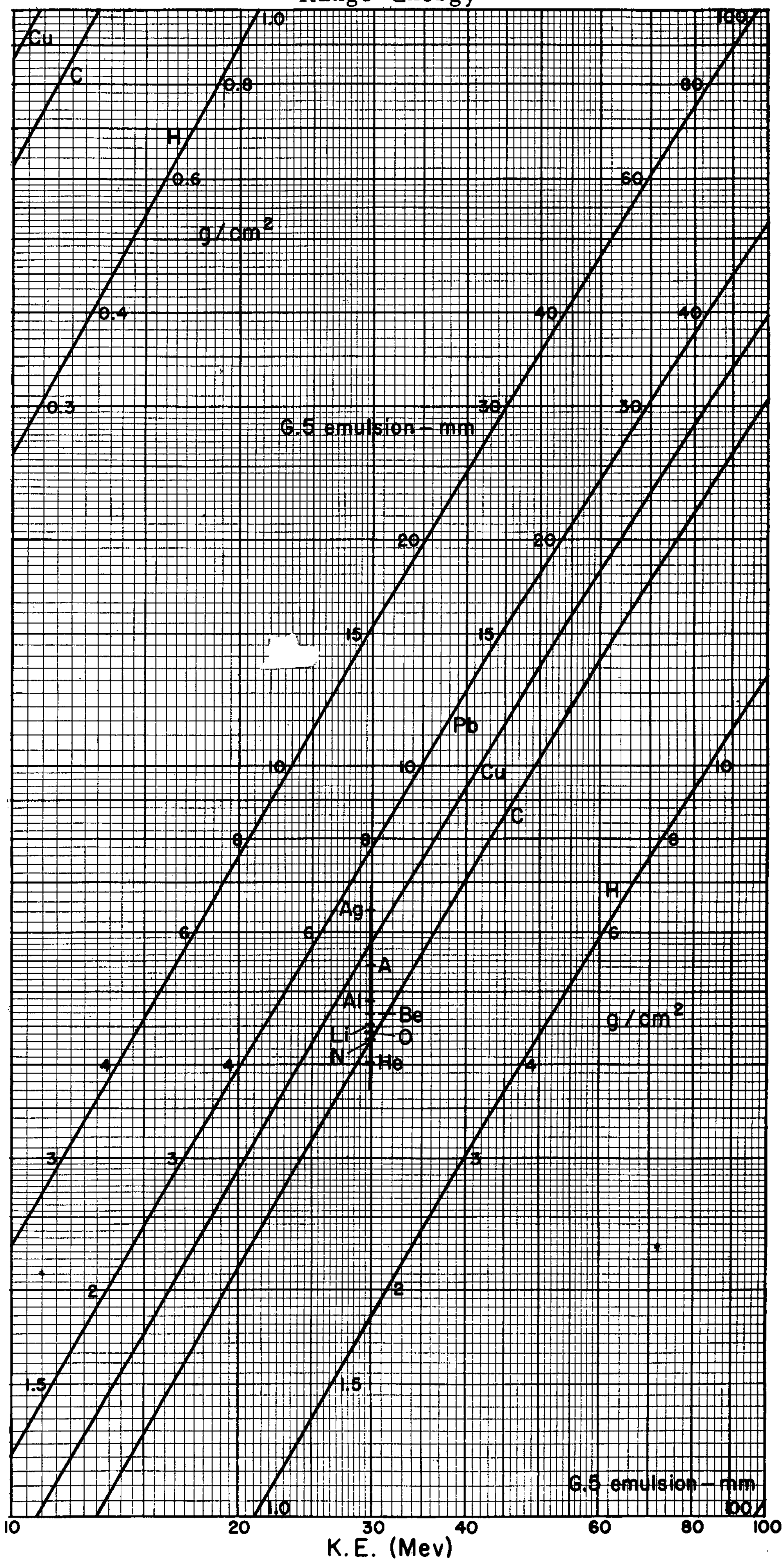


π MESONS

Range-Energy

10 to 100 Mev

M = 139.6 Mev
= 273.27 m



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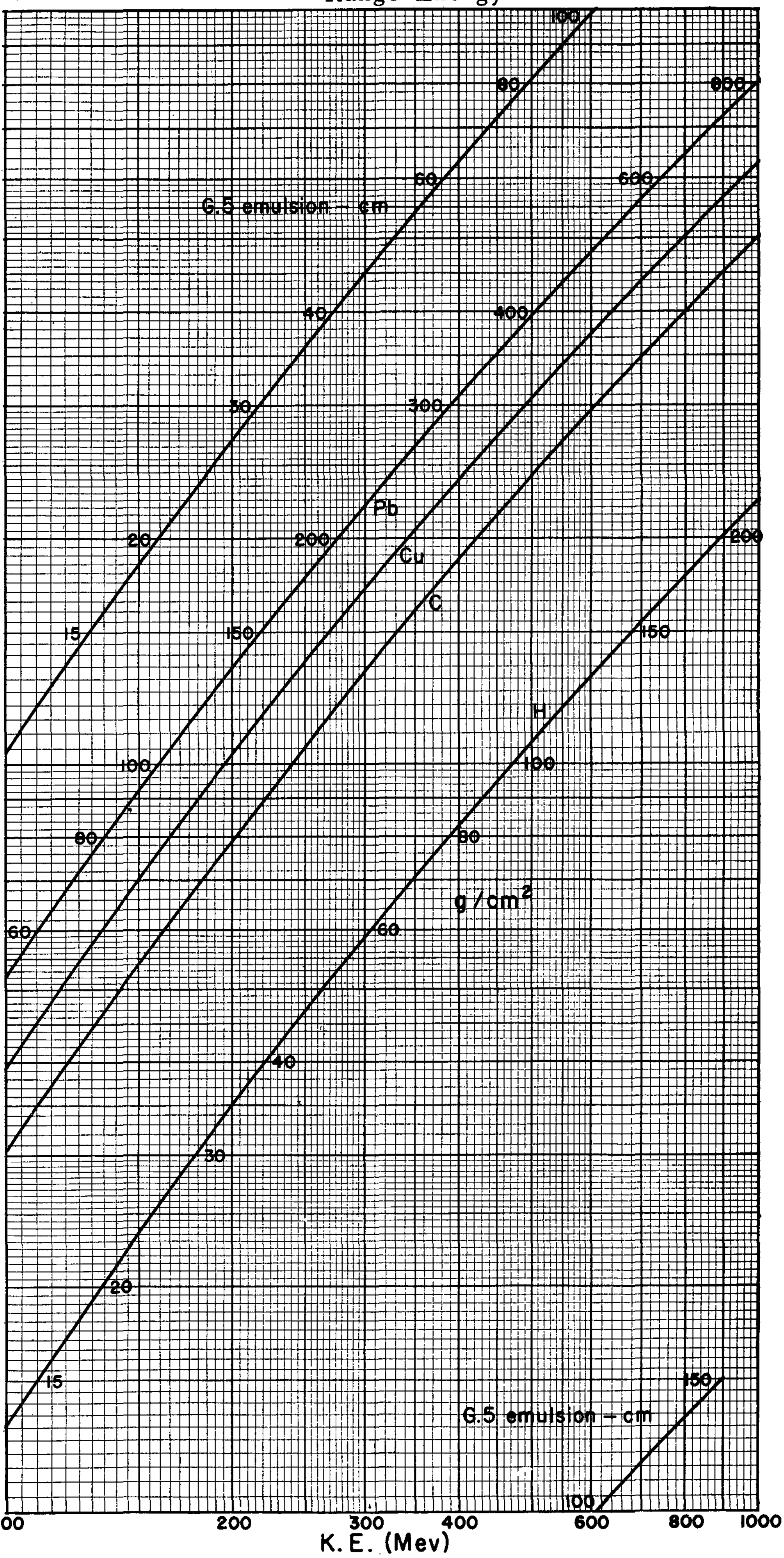
π MESONS Range-Energy

100 Mev to 1 Bev

M = 139.6 Mev
  = 273.27 m

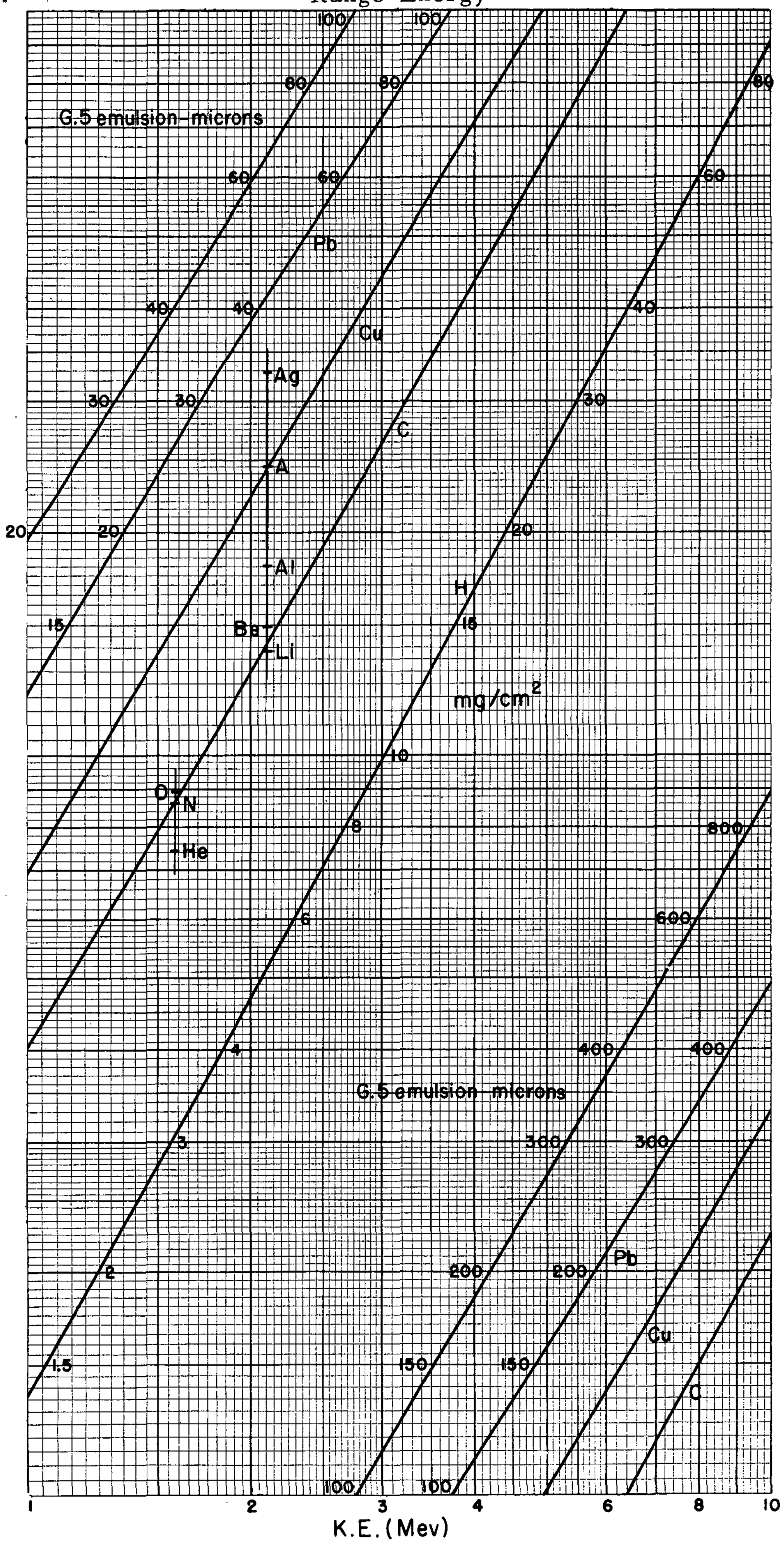


K MESONS

Range-Energy

1 to 10 Mev

M = 494.0 Mev
= 966.71 m



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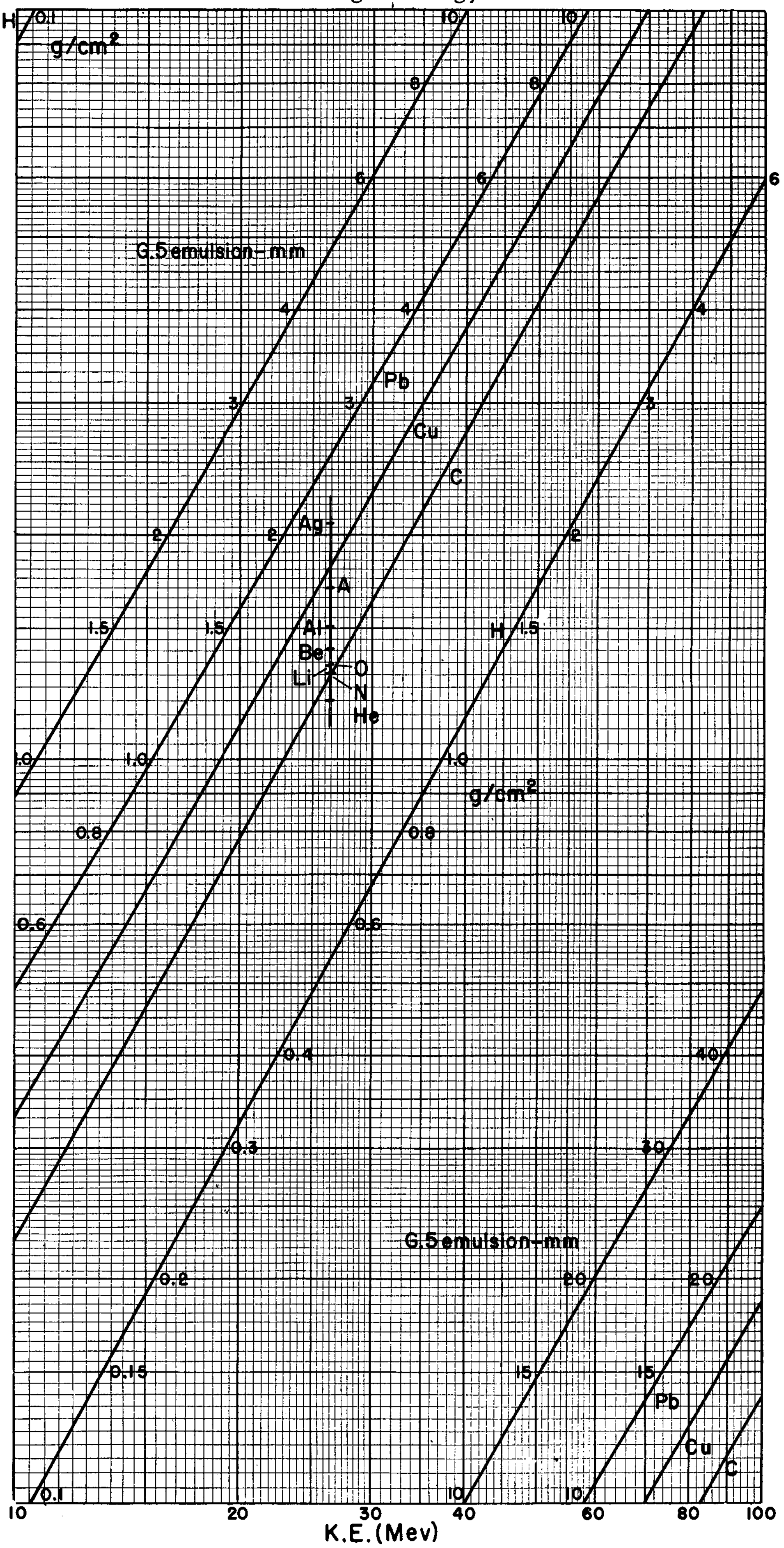
Range-Energy

M = 494.0 Mev
= 966.71 m



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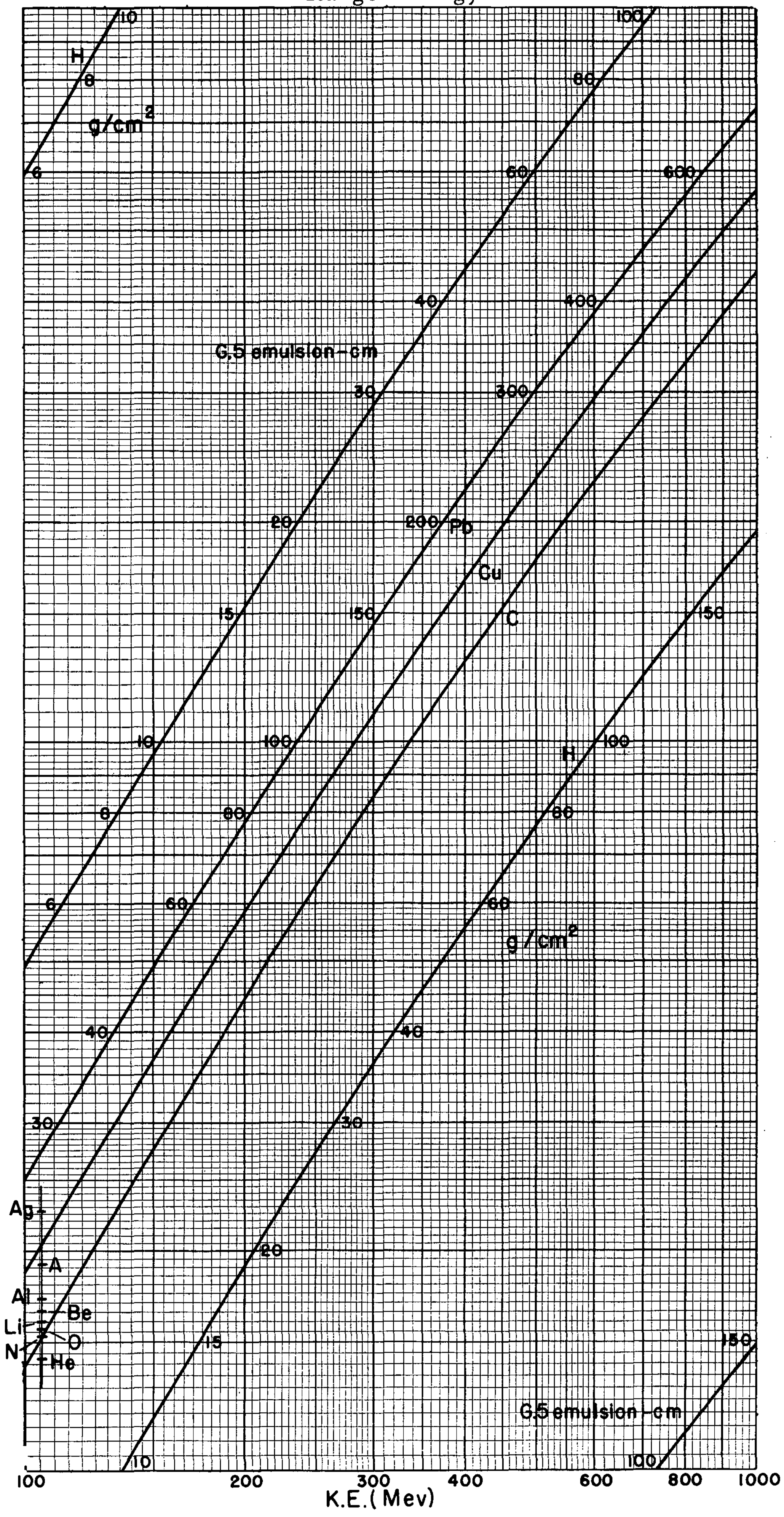
K MESONS

100 Mev to 1 Bev

Range-Energy

M = 494.0 Mev
= 966.71 m

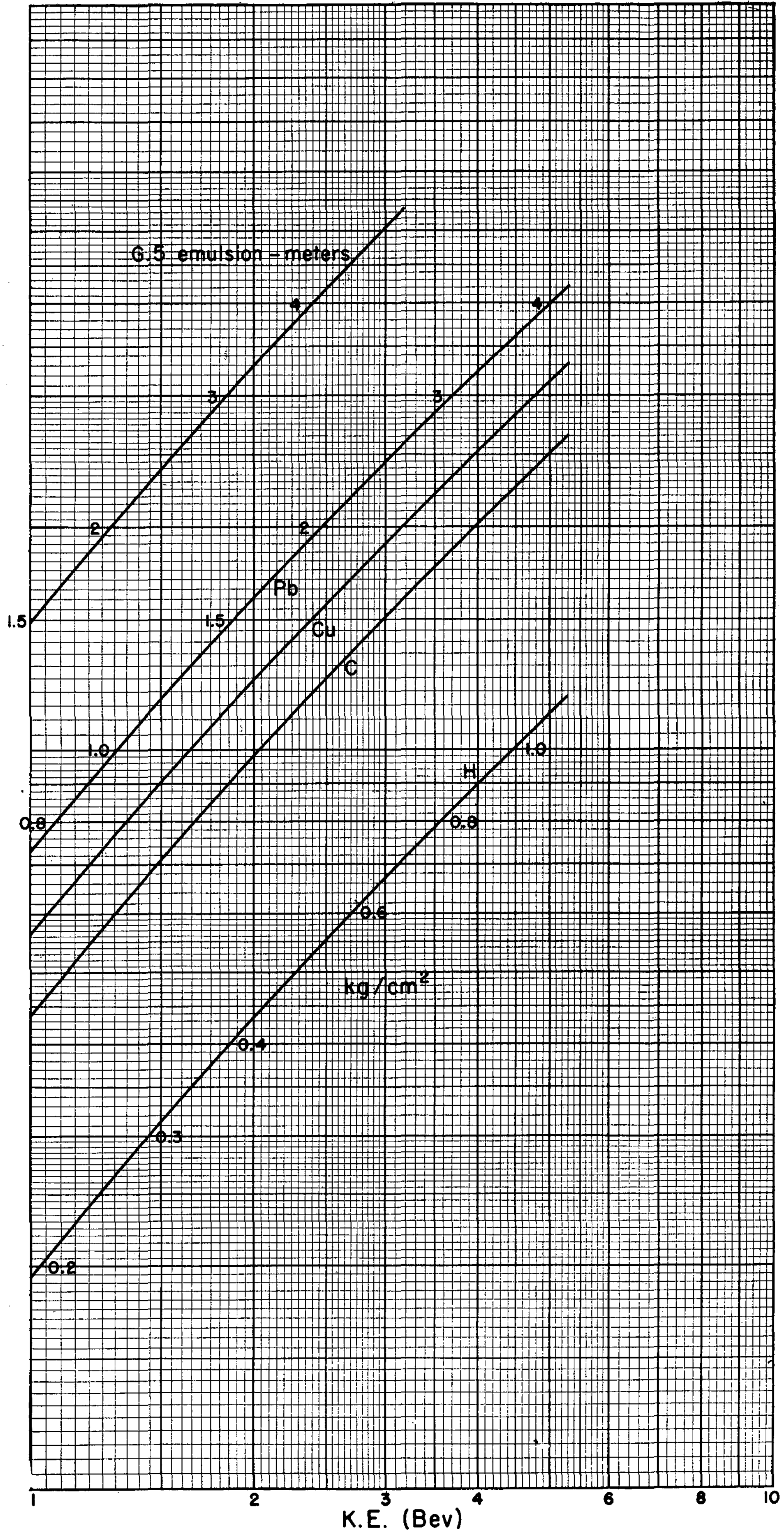


K MESONS

1 to 5.3 Bev

Range-Energy

M = 494.0 Mev
= 966.71 m



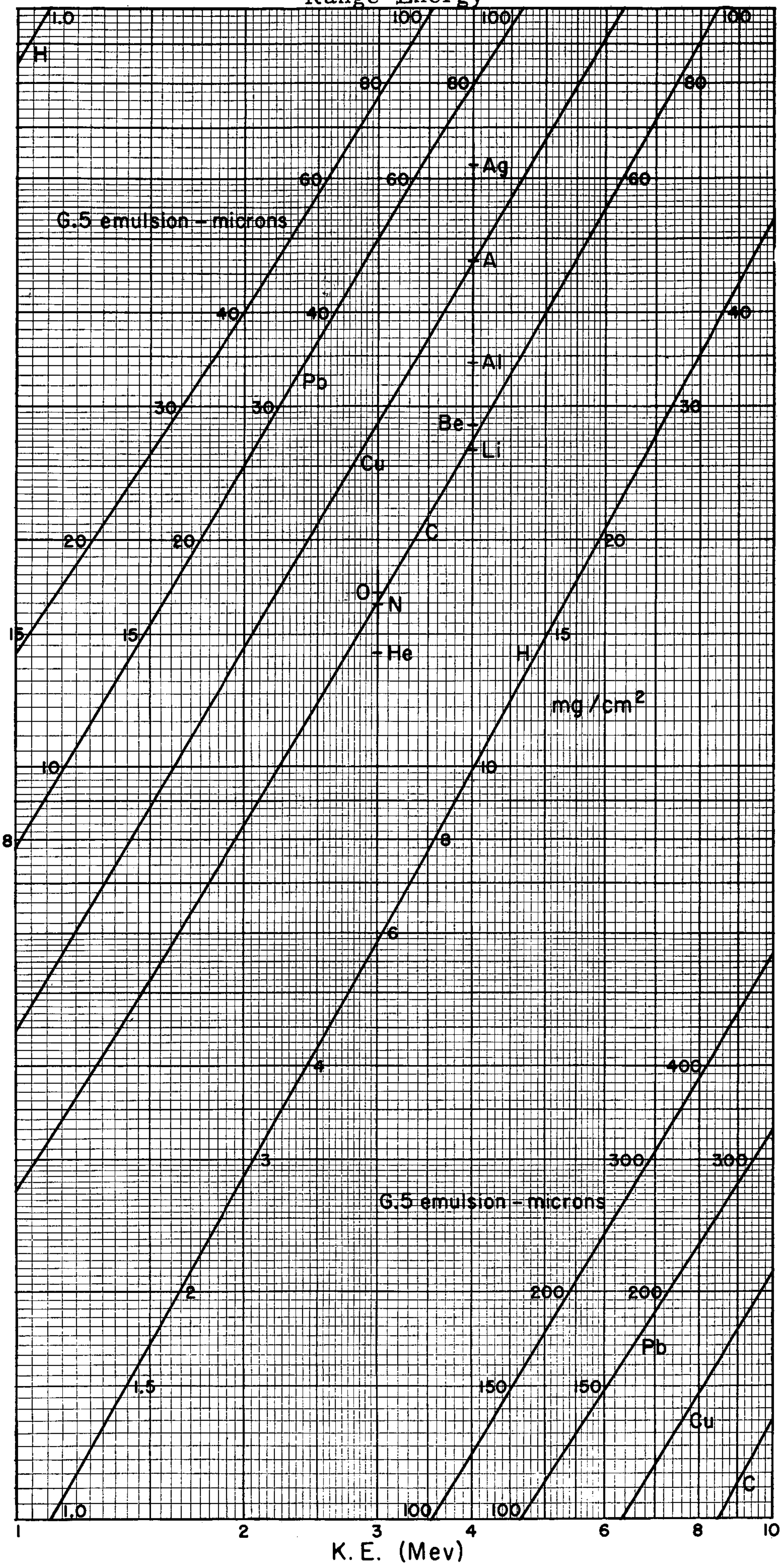
0 0 1 0 1 2 0 4 1 5 6

PROTONS

Range-Energy

1 to 10 Mev

M = 938.23 Mev
= 1836.1 m



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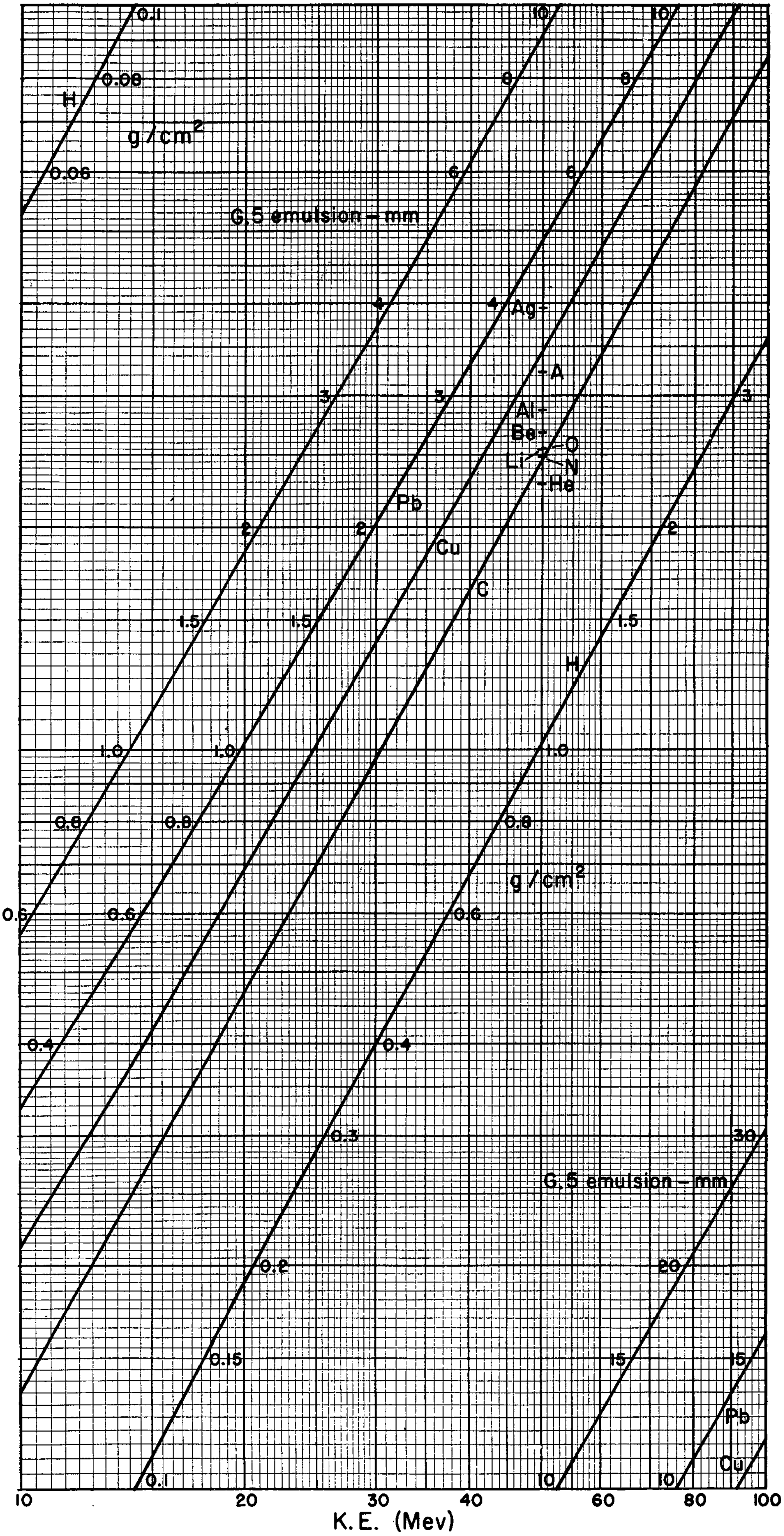
PROTONS

10 to 100 Mev

Range-Energy

M = 938.23 Mev
= 1836.1 m



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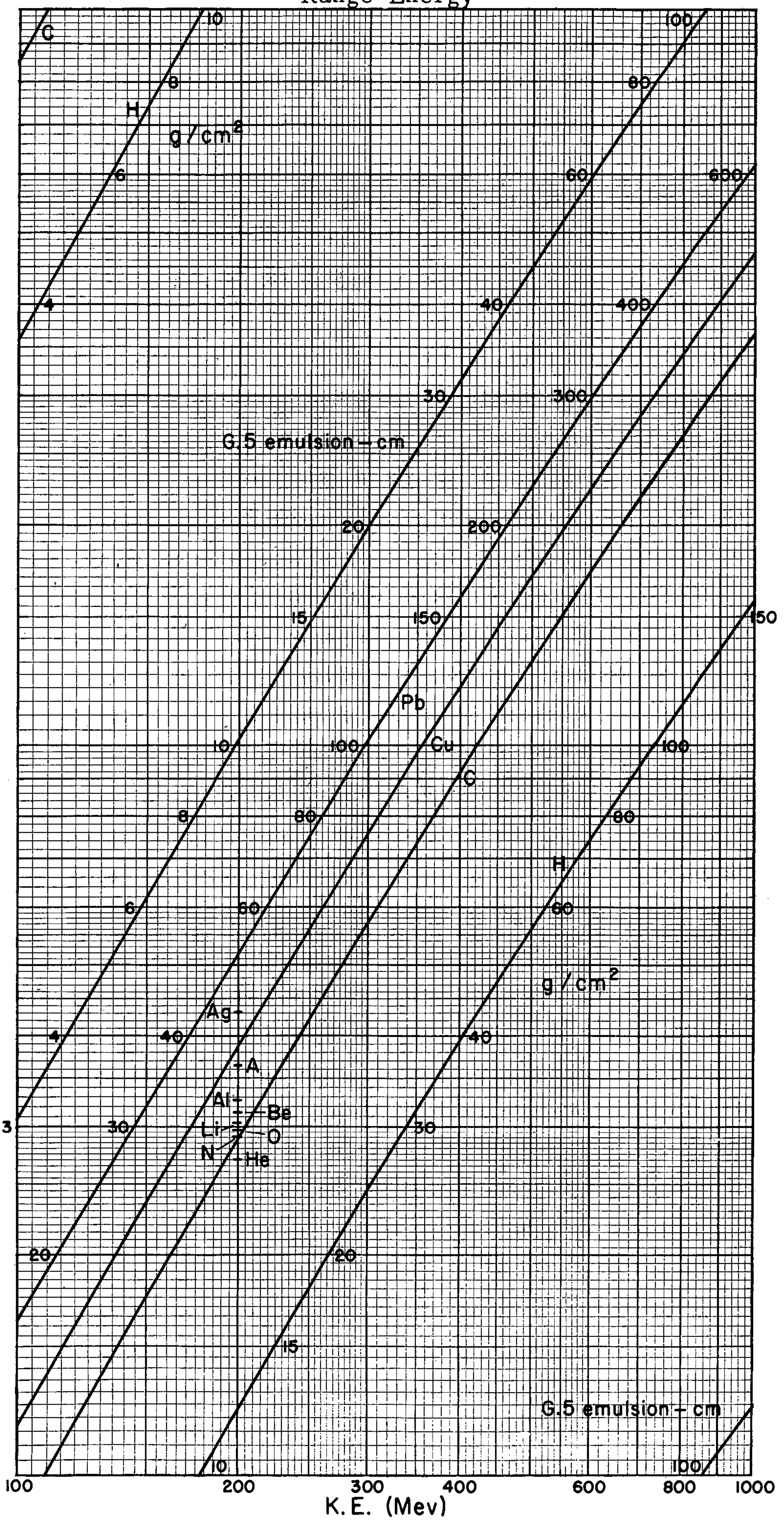
PROTONS

100 Mev to 1 Bev

Range-Energy

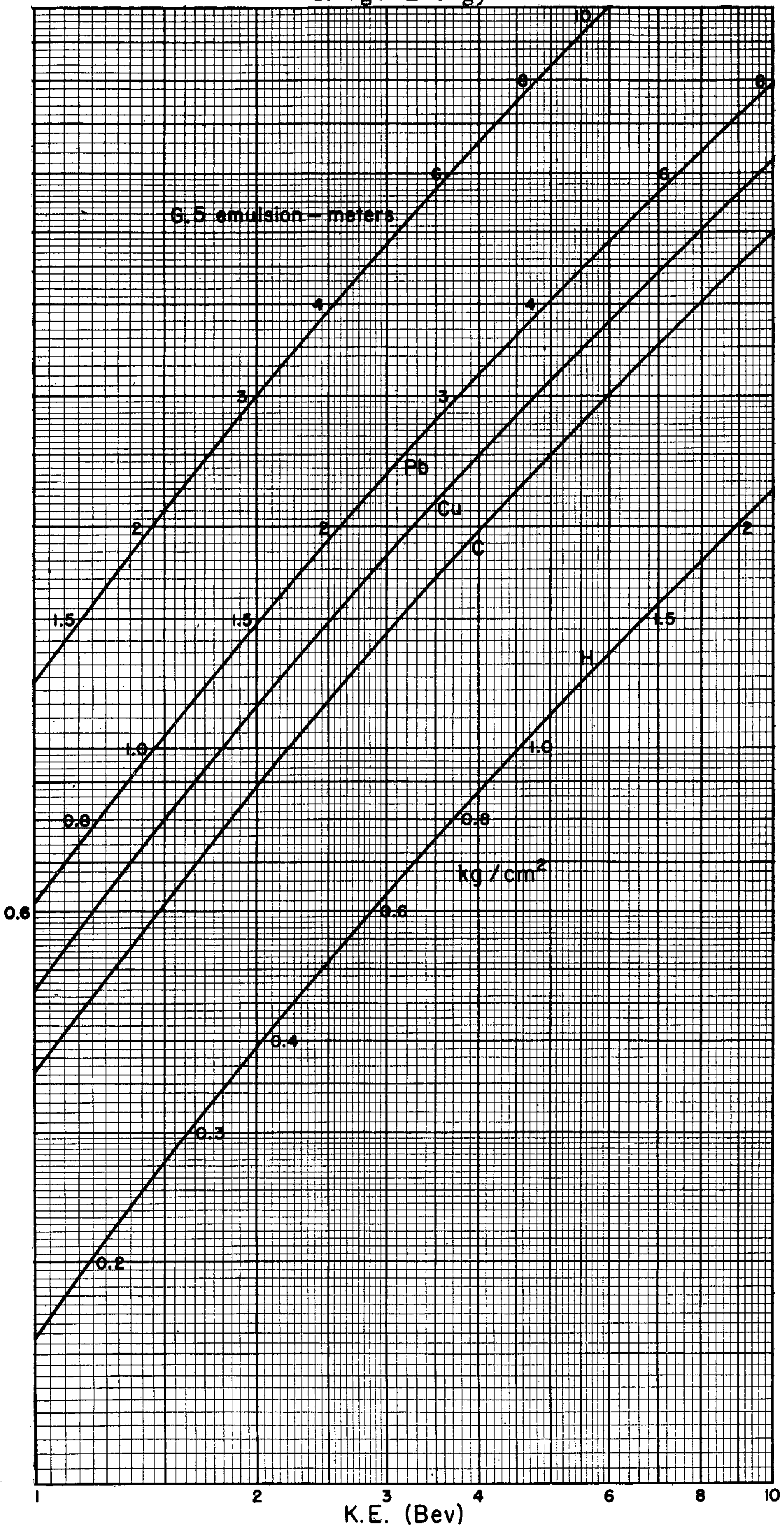
M = 938.23 Mev
= 1836.1 m



PROTONS **1 to 10 Bev**

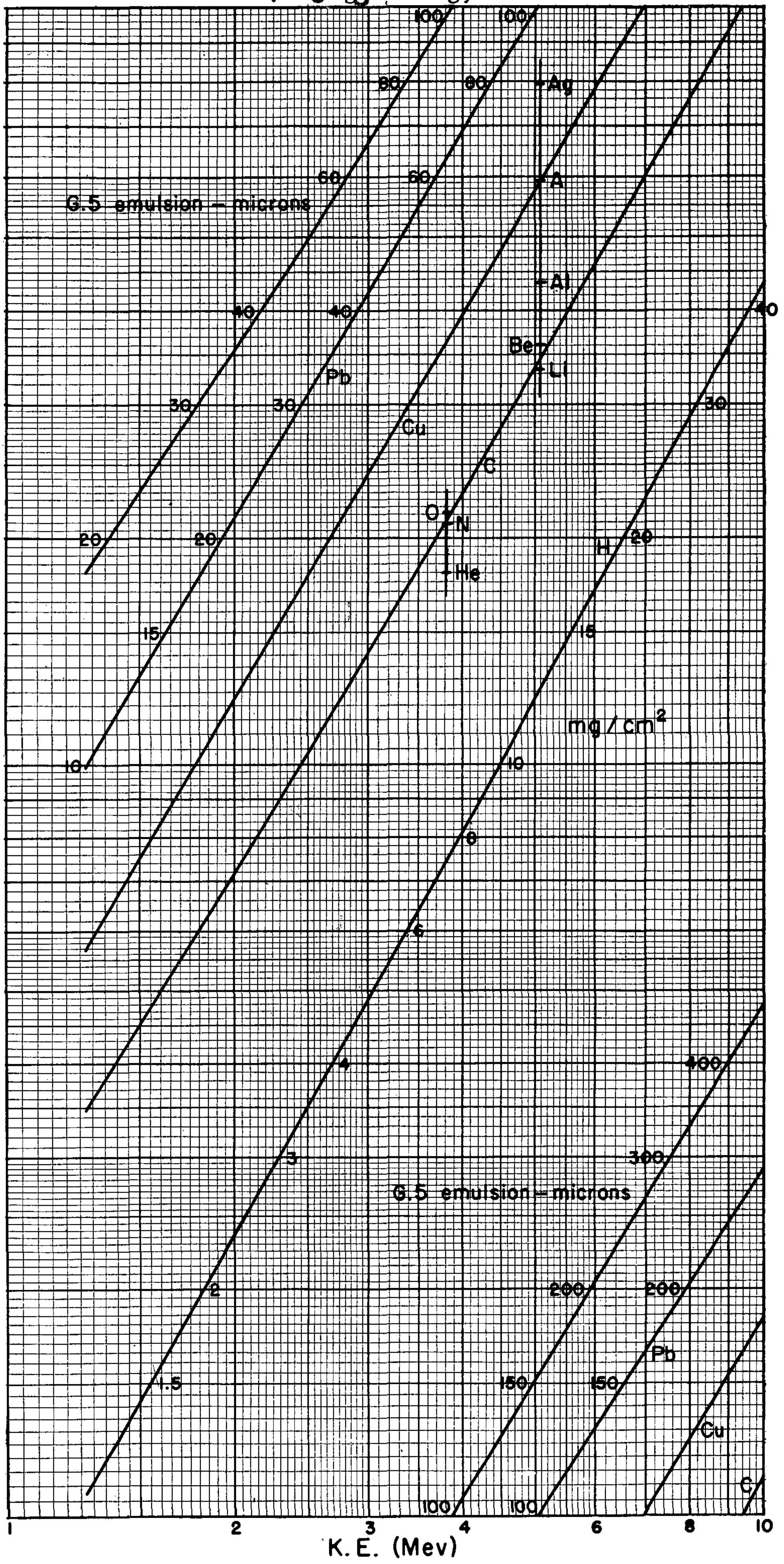
Range-Energy

M = 938.23 Mev
= 1836.1 m



Σ_{av} HYPERONS Range-Energy 1.3 to 10 Mev

M = 1194.1 Mev
= 2336.83 m

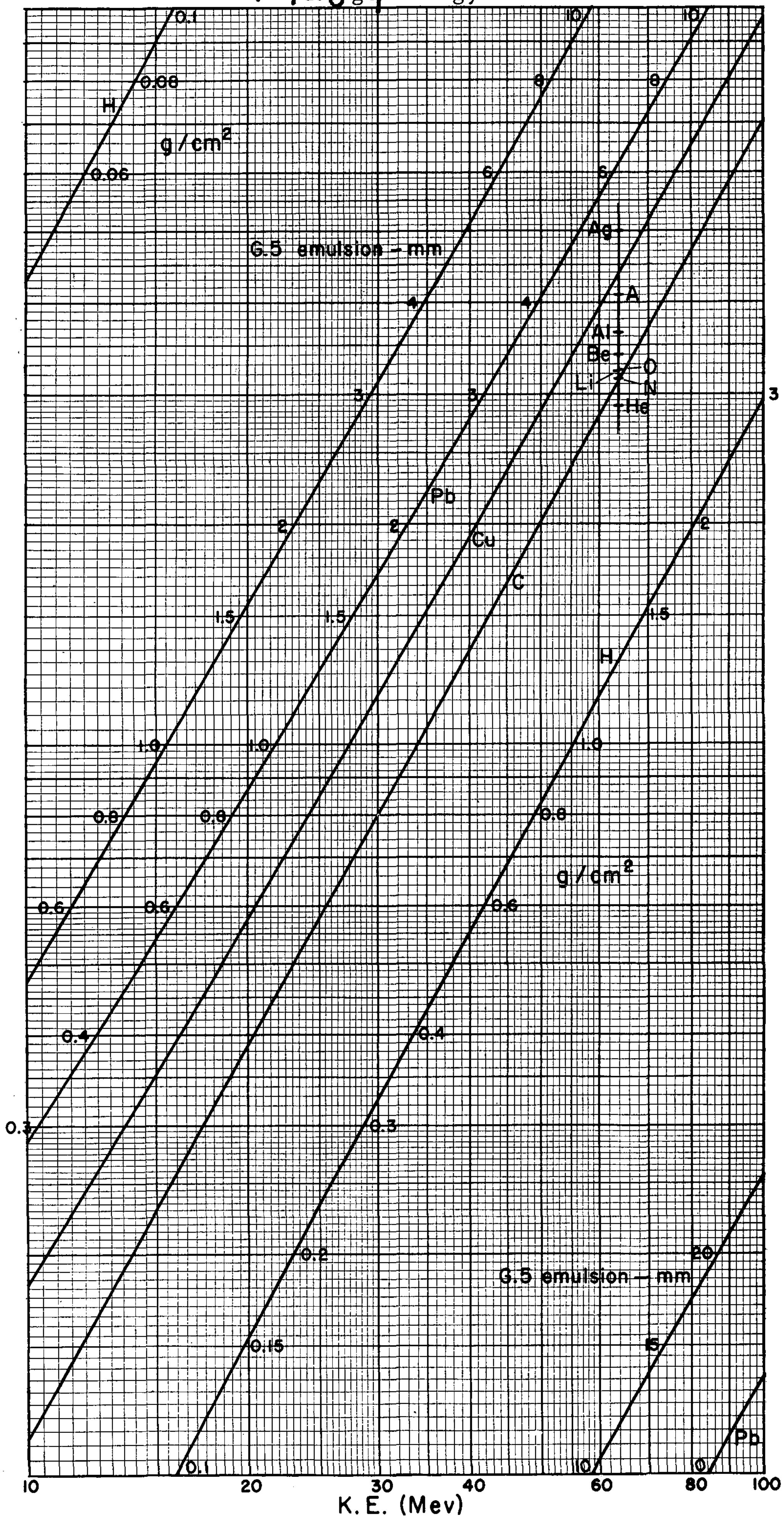


Σ_{av} HYPERONS

10 to 100 Mev

Range-Energy

M = 1194.1 Mev
= 2336.83 m



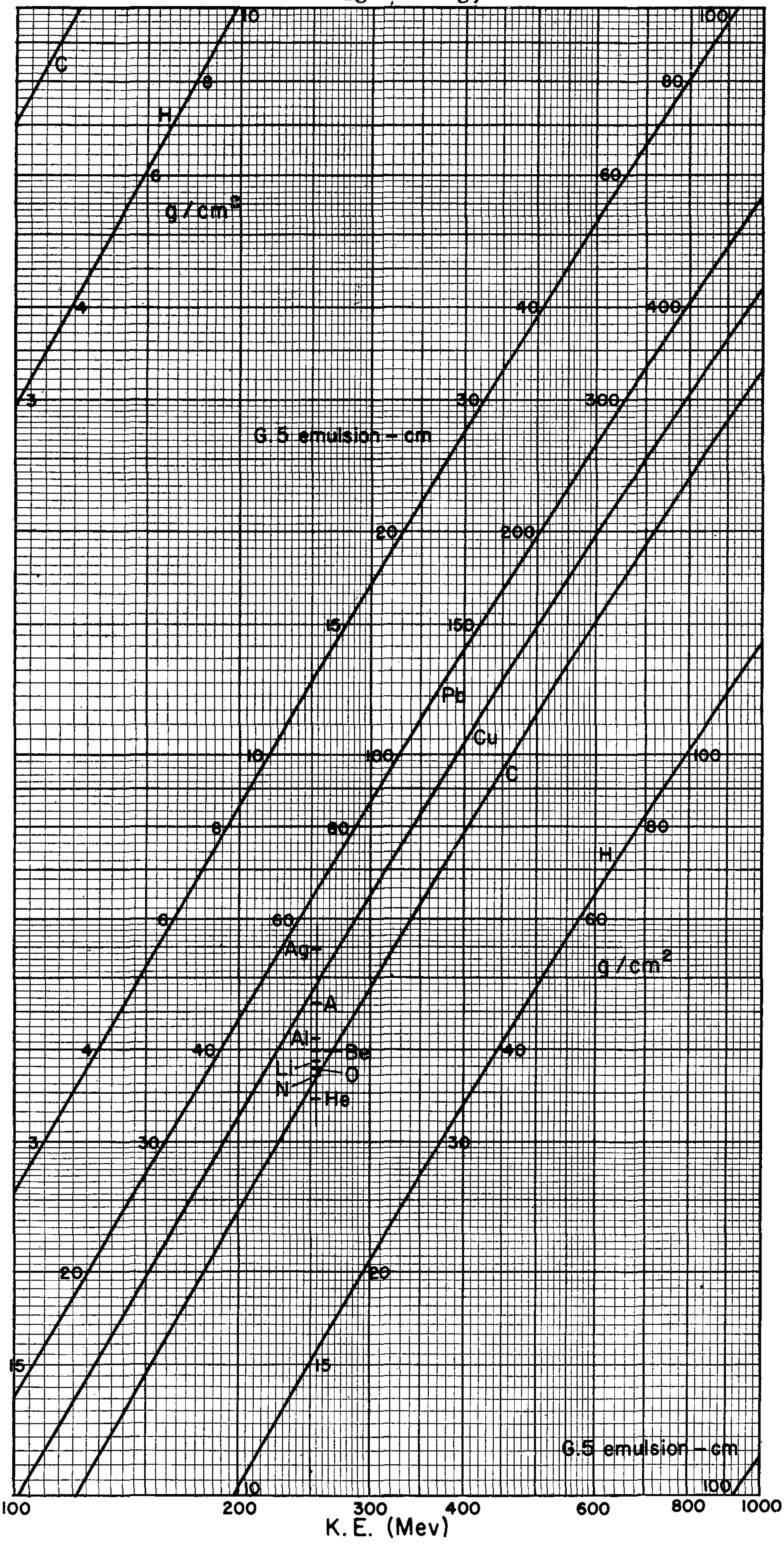
0 0 1 0 1 2 0 4 1 6 2

Σ_{av} HYPERONS

100 Mev to 1 Bev

Range-Energy

M = 1194.1 Mev
≈ 2336.83 m



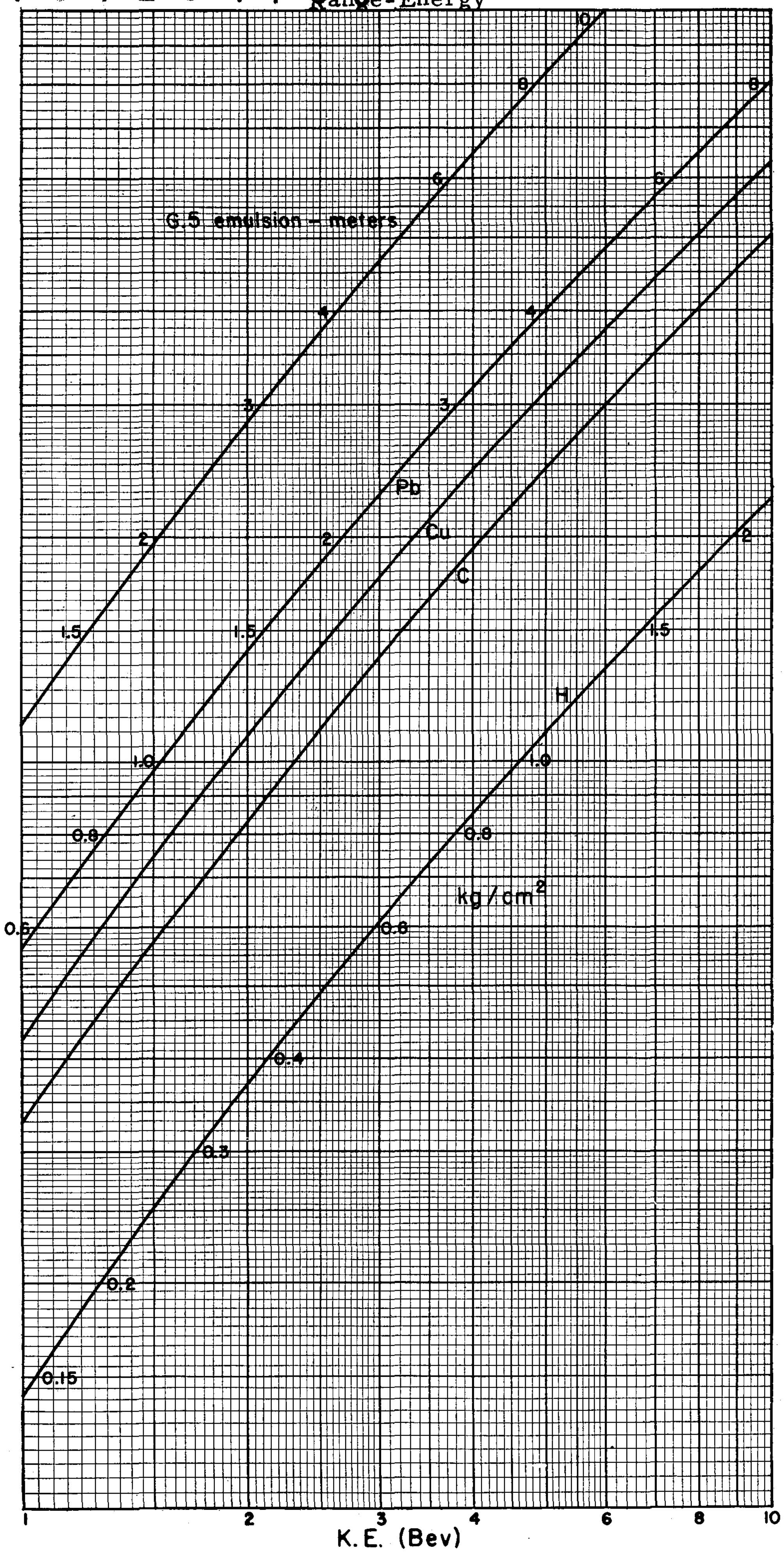
0 0 1 2 0 4 1 6 7

Σ_{av} HYPERONS

1 to 10 Bev

Range-Energy

M = 1194.1 Mev
  = 2336.83 m



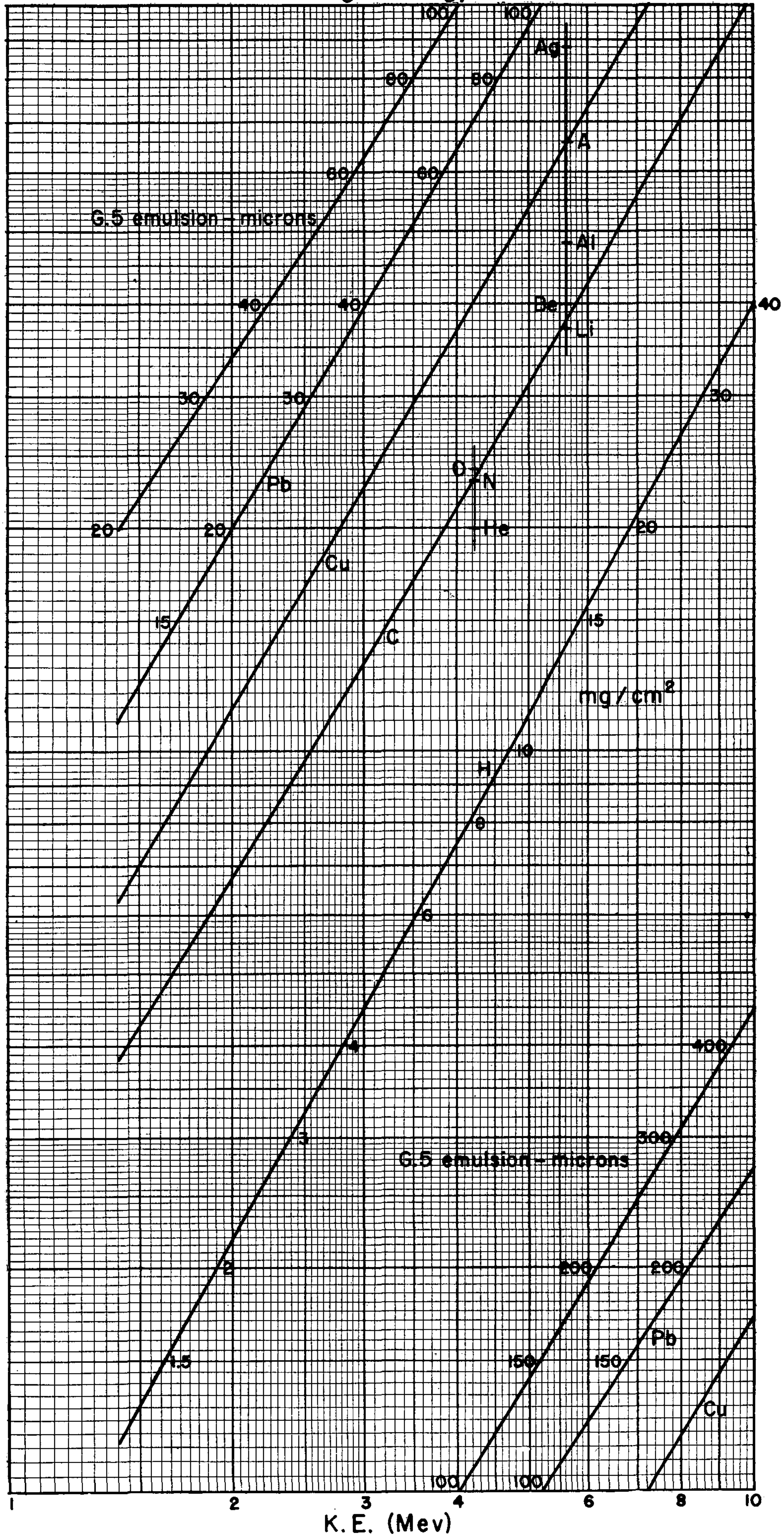
0 0 F 0 1 2 0 4 1 6 4

Ξ HYPERONS

1.4 to 10 Mev

M = 1321.0 Mev
= 2585.28 m

Range-Energy

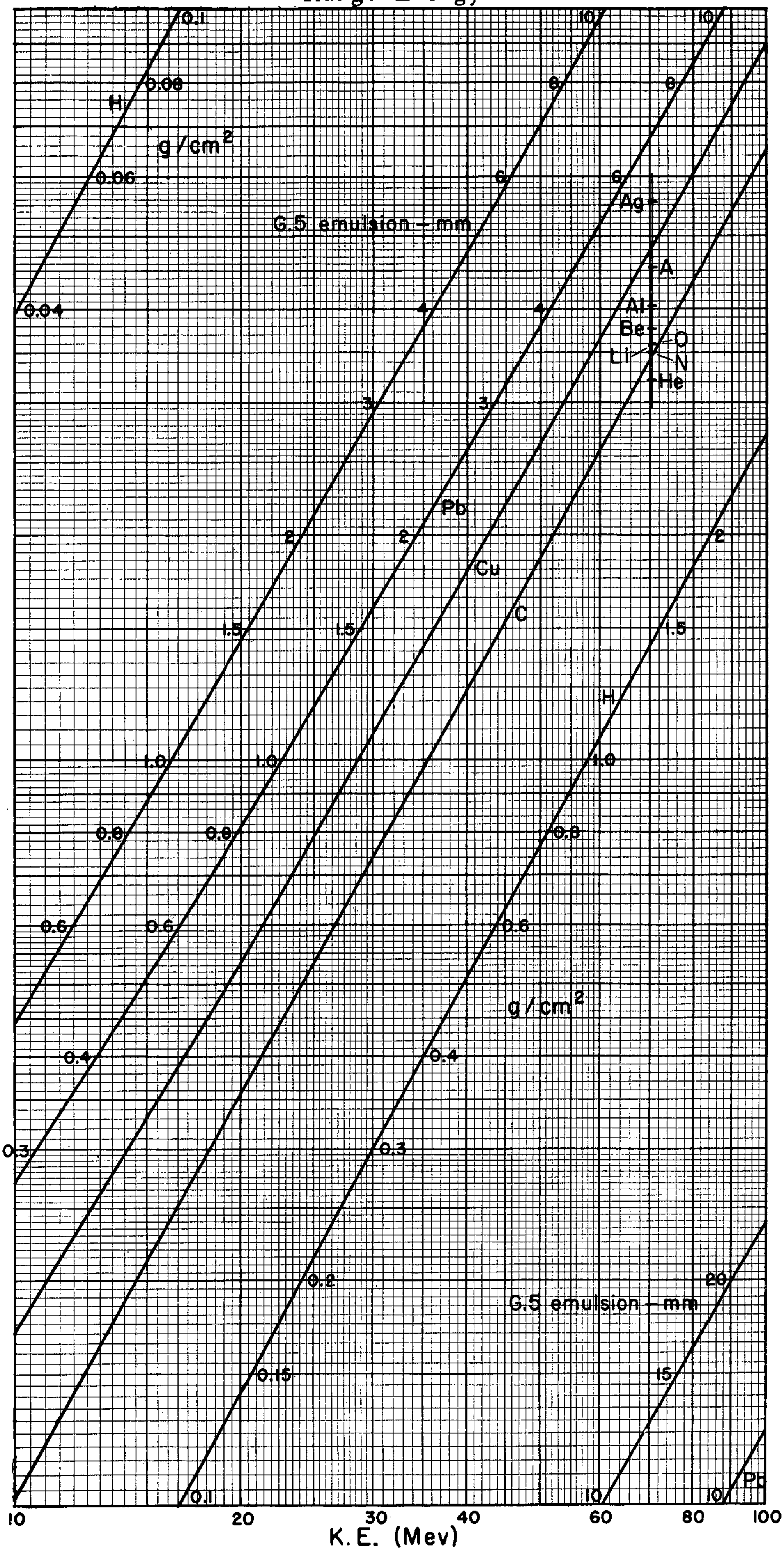


HYPERONS

10 to 100 Mev

Range-Energy

M = 1321.0 Mev
= 2585.28 m

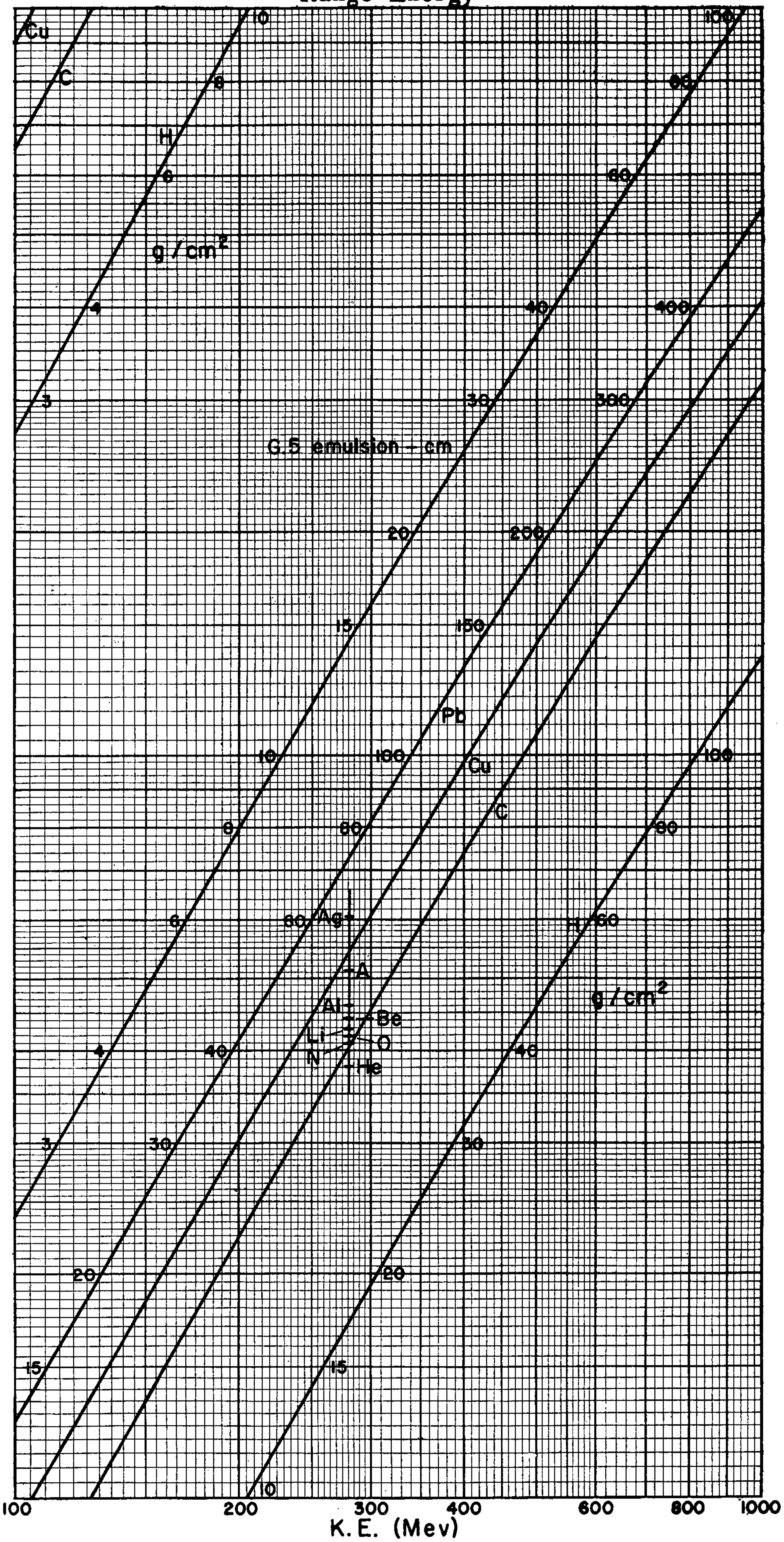


HYPERONS

100 Mev to 1 Bev

Range-Energy

M = 1321.0 Mev
= 2585.28 m



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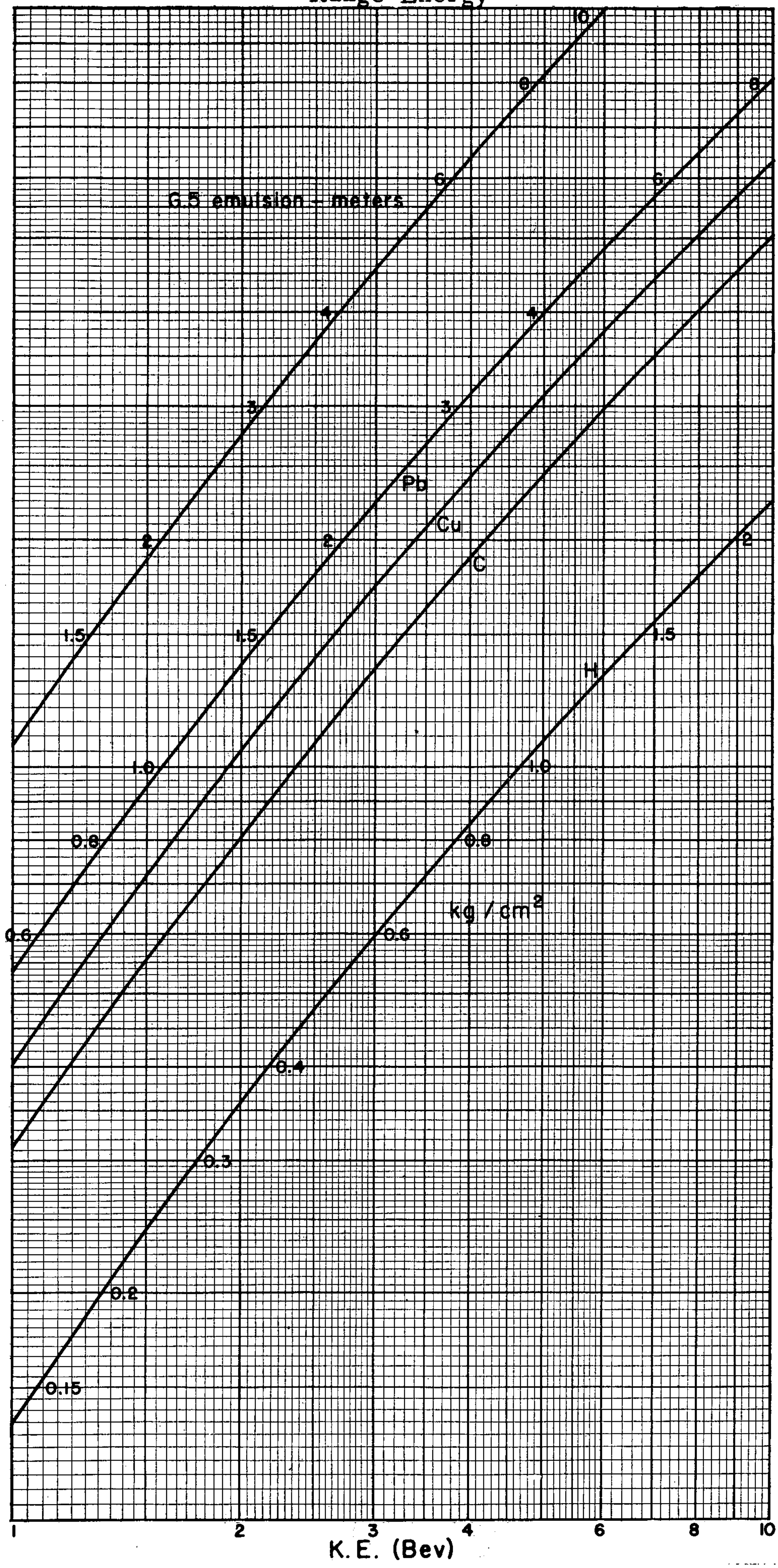
Ξ HYPERONS Range-Energy 1 to 10 Bev

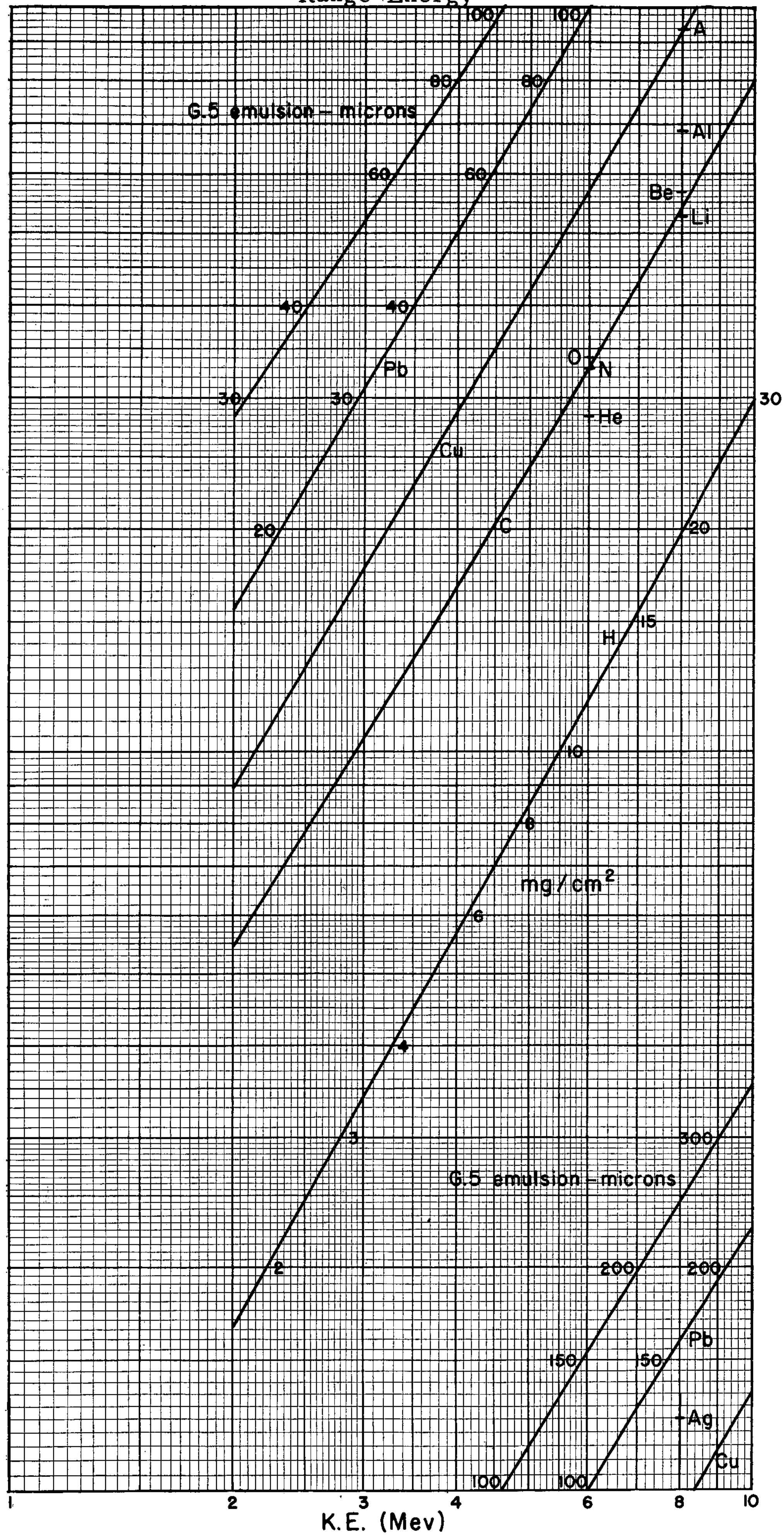
M = 1321.0 Mev
= 2585.28 m



DEUTERONS

Range-Energy

M = 1875.5 Mev
= 3670.45 m



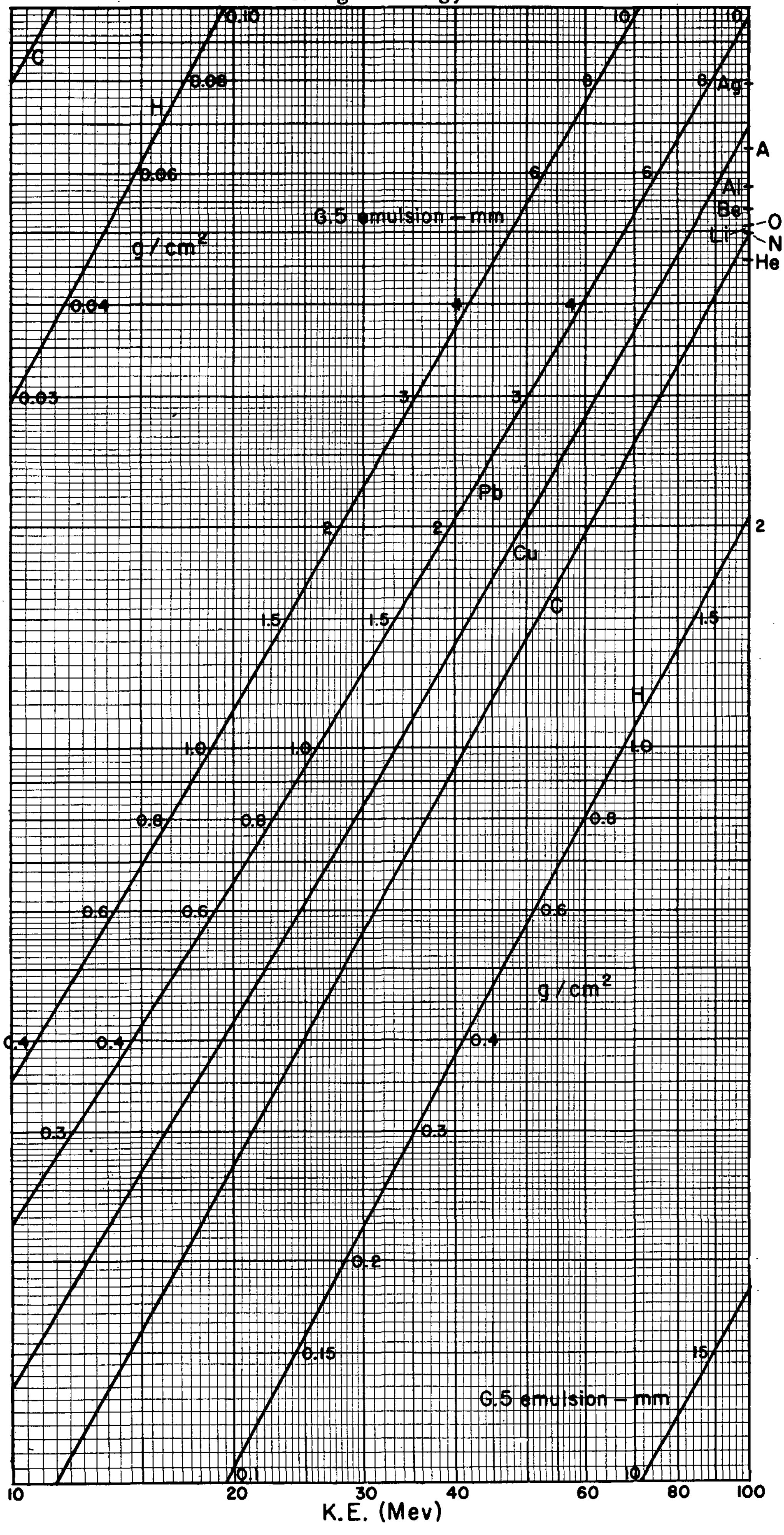
0 0 1 0 1 2 0 4 1 6 9

DEUTERONS

10 to 100 Mev

Range-Energy

M = 1875.5 Mev
= 3670.45 m



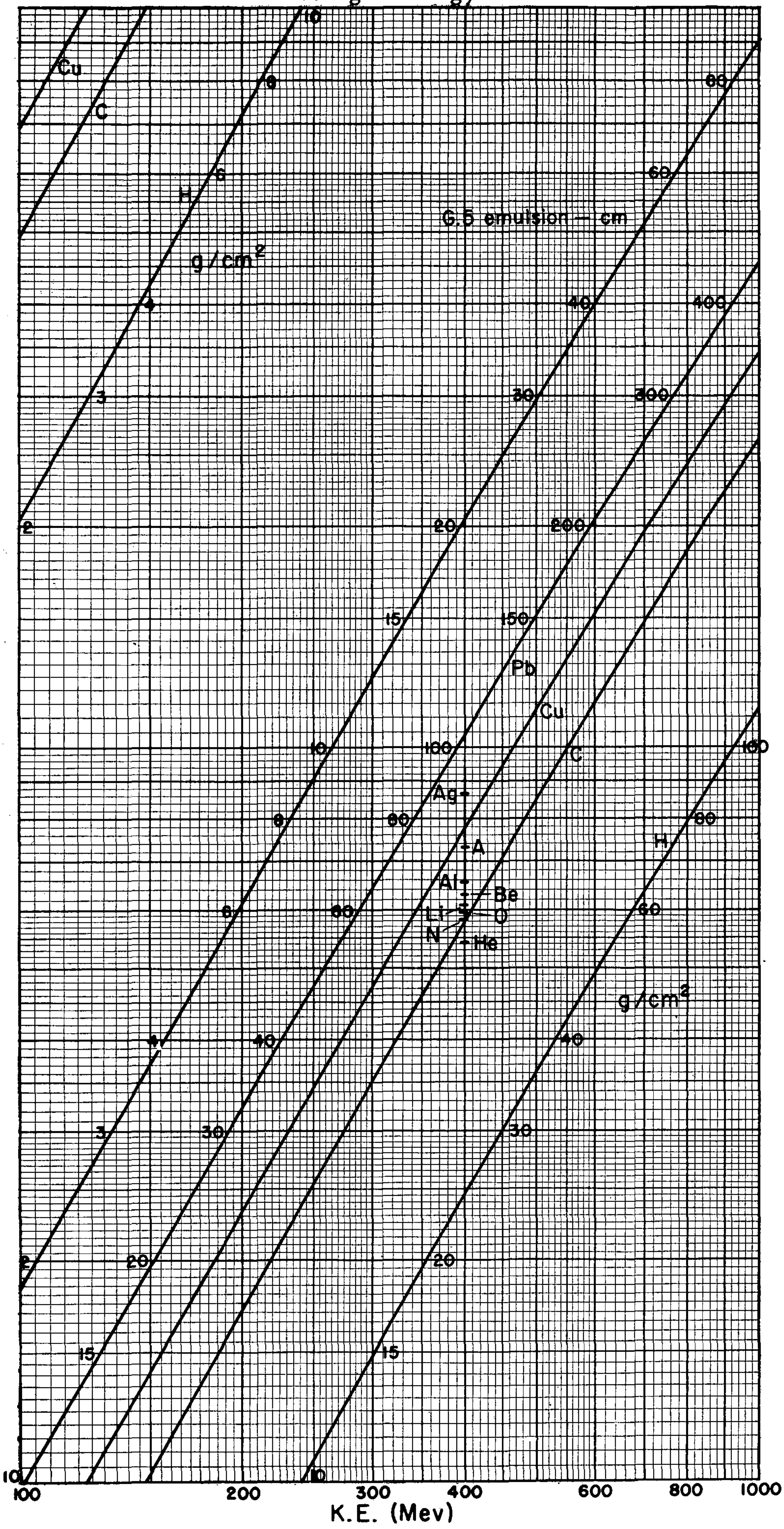
0 0 1 0 1 2 0 4 1 7 0

DEUTERONS

Range-Energy

100 Mev to 1 Bev

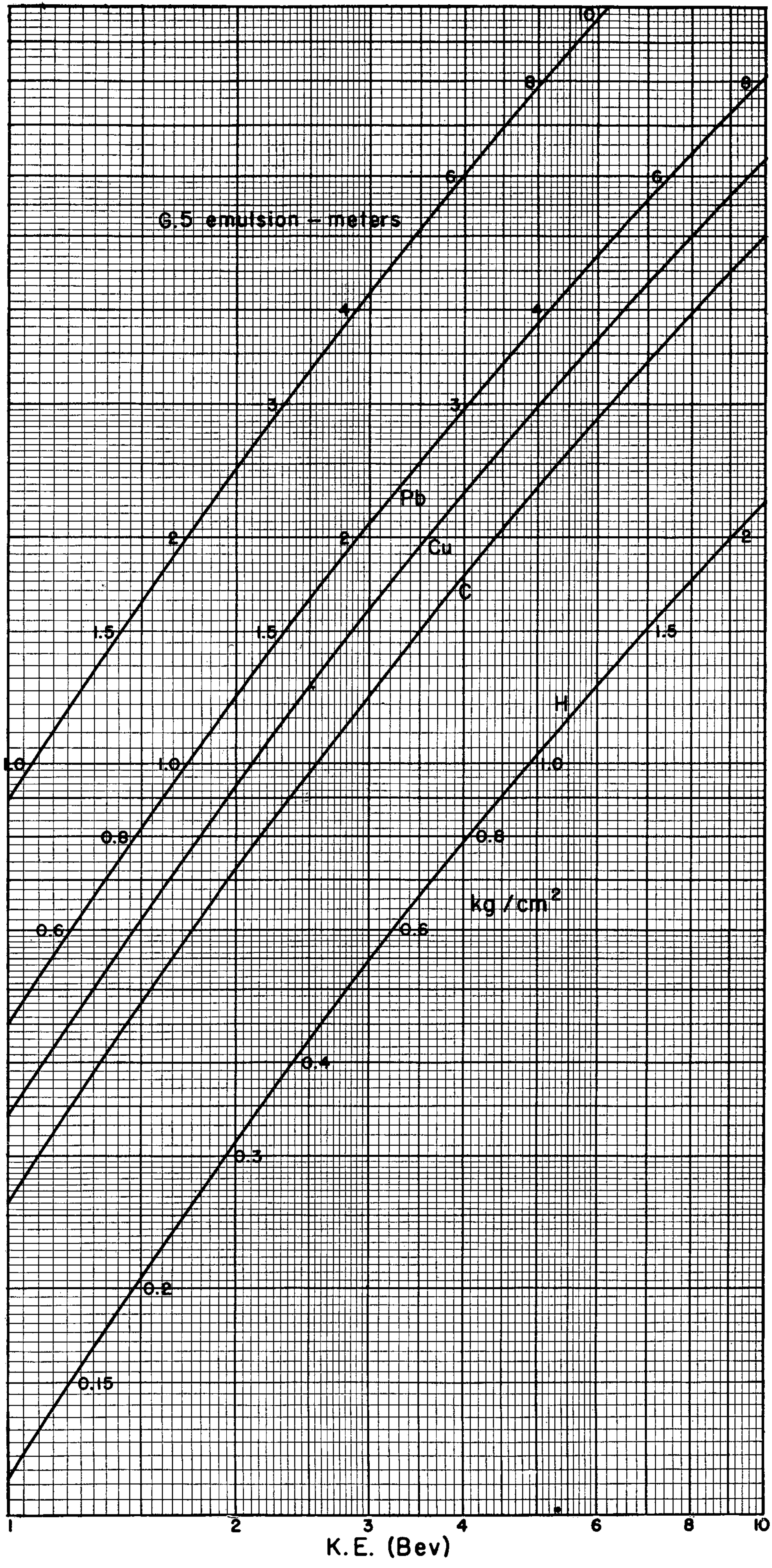
M = 1875.5 Mev
= 3670.45 m



DEUTERONS Range-Energy

1 to 10 Bev

M = 1875.5 Mev
= 3670.45 m

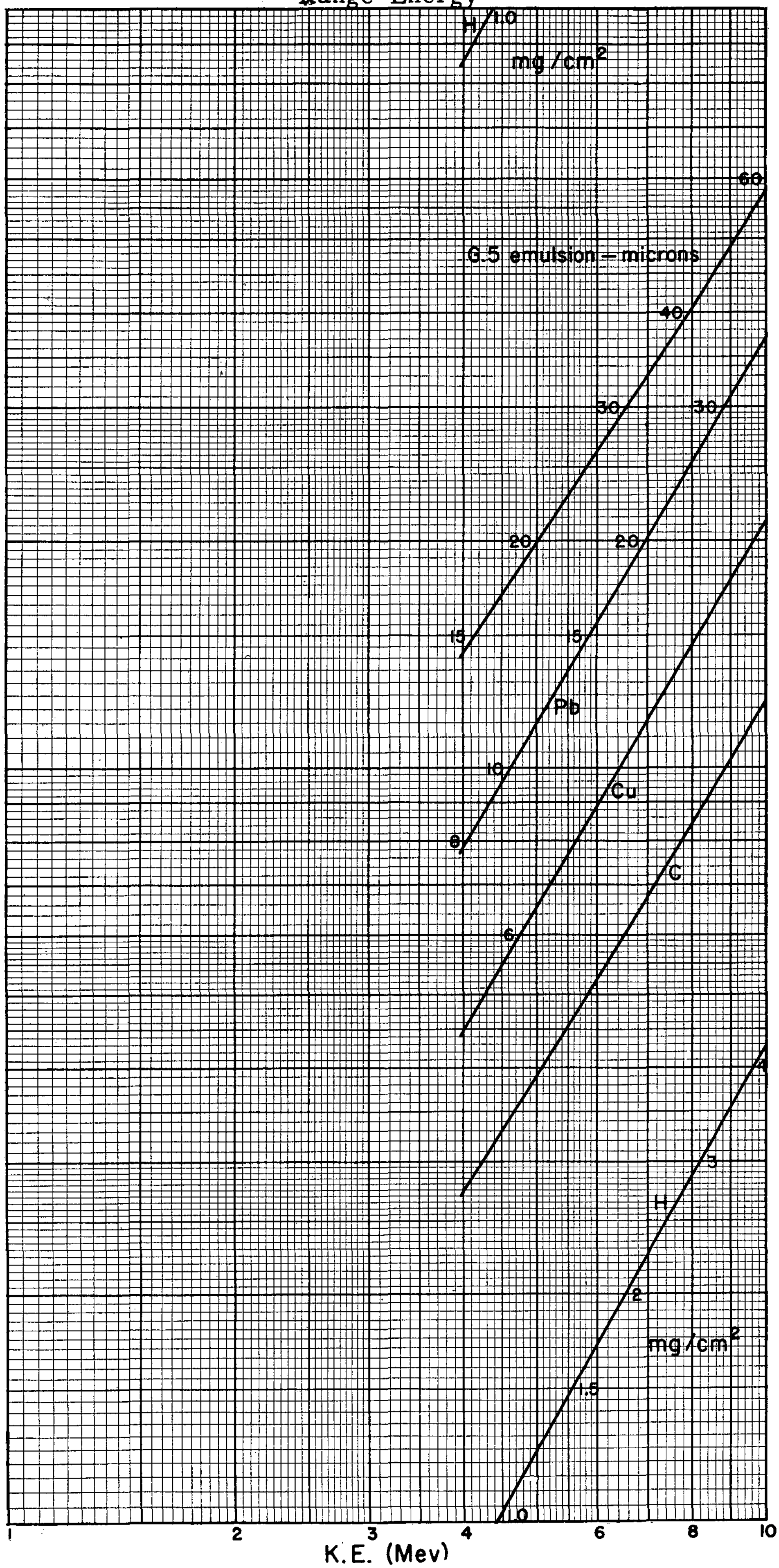


ALPHA PARTICLES

4 to 10 Mev

Range-Energy

M = 3727.3 Mev
= 7294.47 m



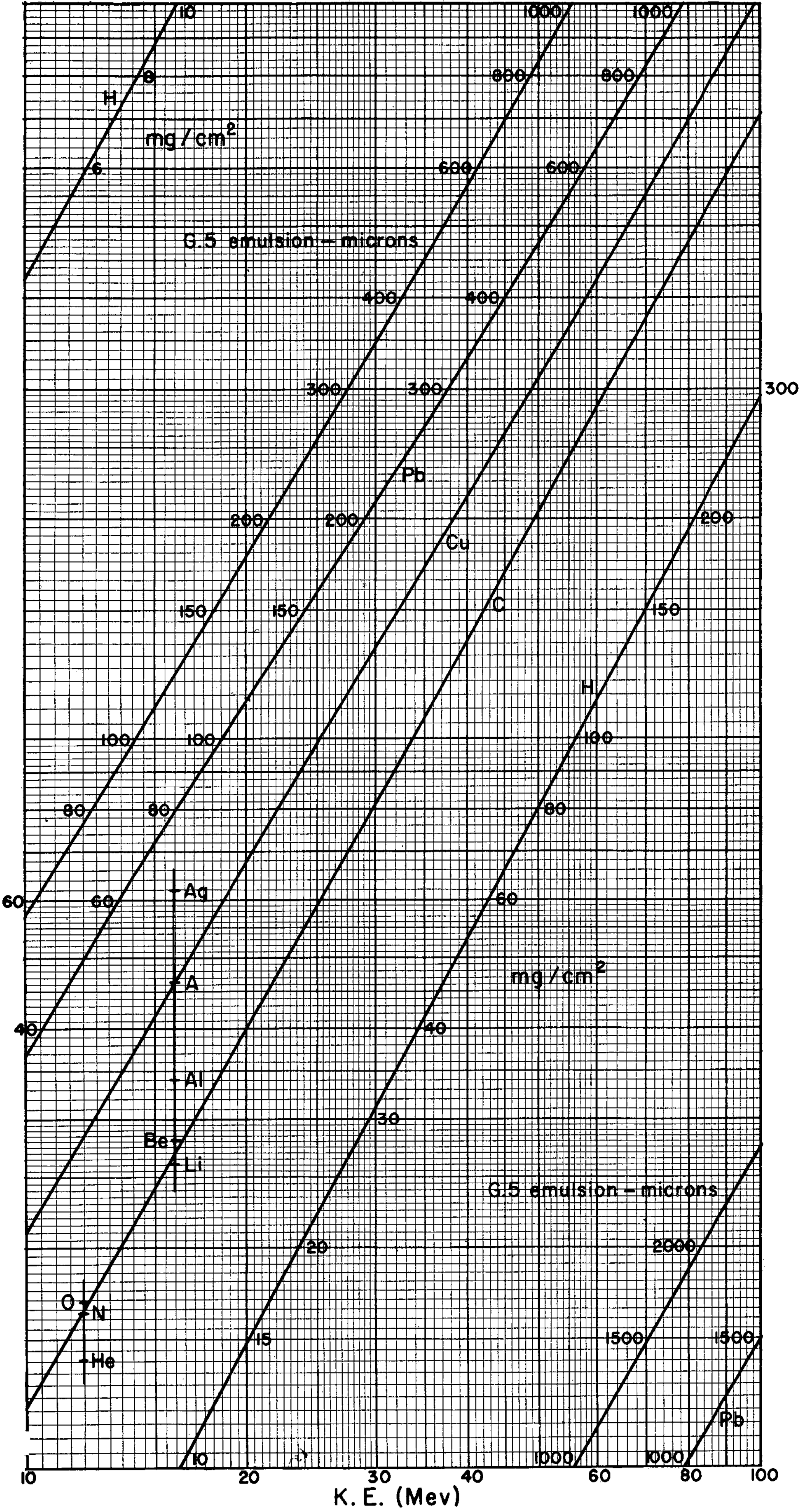
0 0 1 0 1 2 0 4 1 7 3

ALPHA PARTICLES

10 to 100 Mev

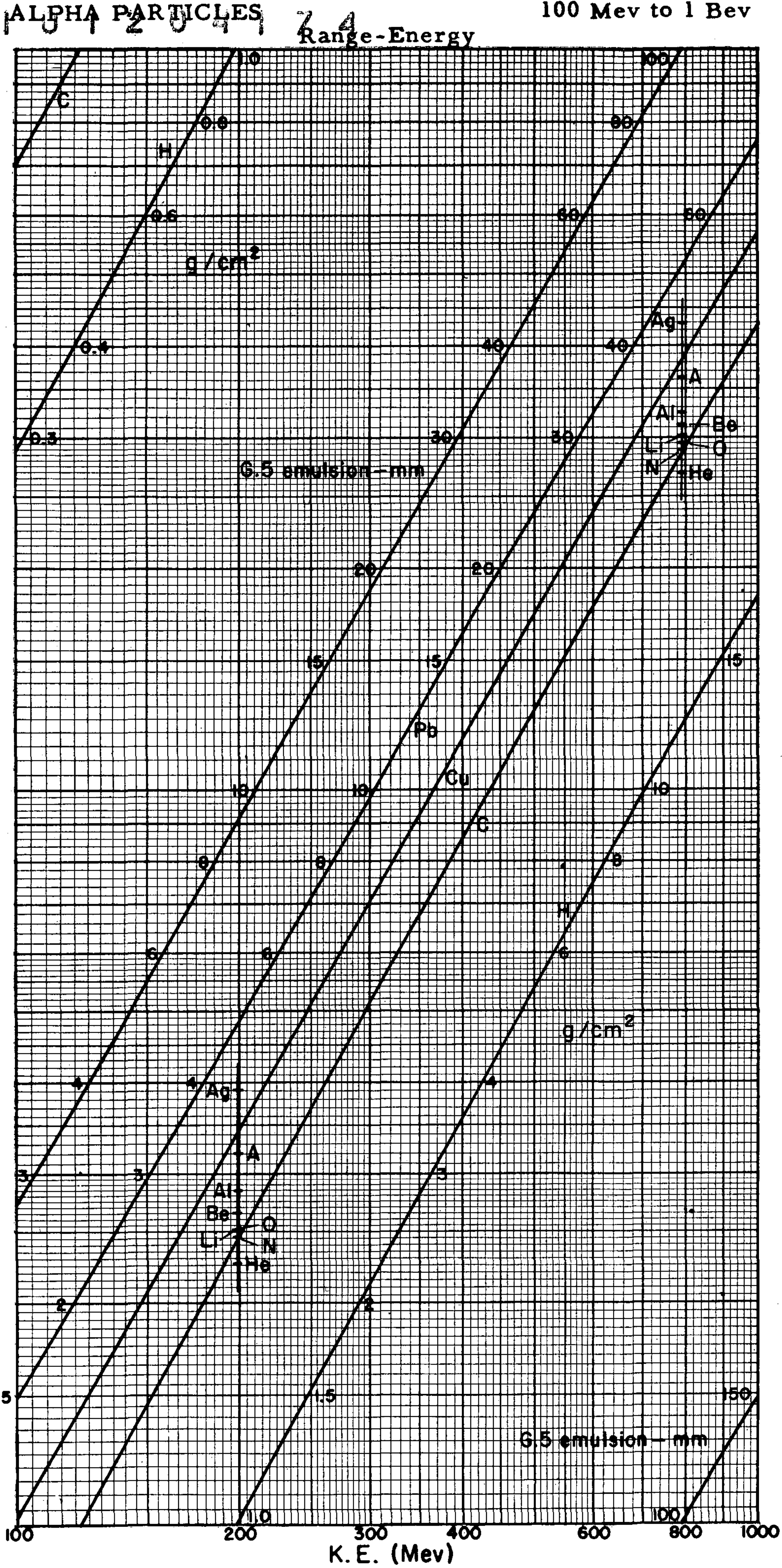
Range-Energy

M = 3727.3 Mev
= 7294.47 m



0 0 1 0 1 2 0 4 1 7 4

M = 3727.3 Mev
= 7294.47 m

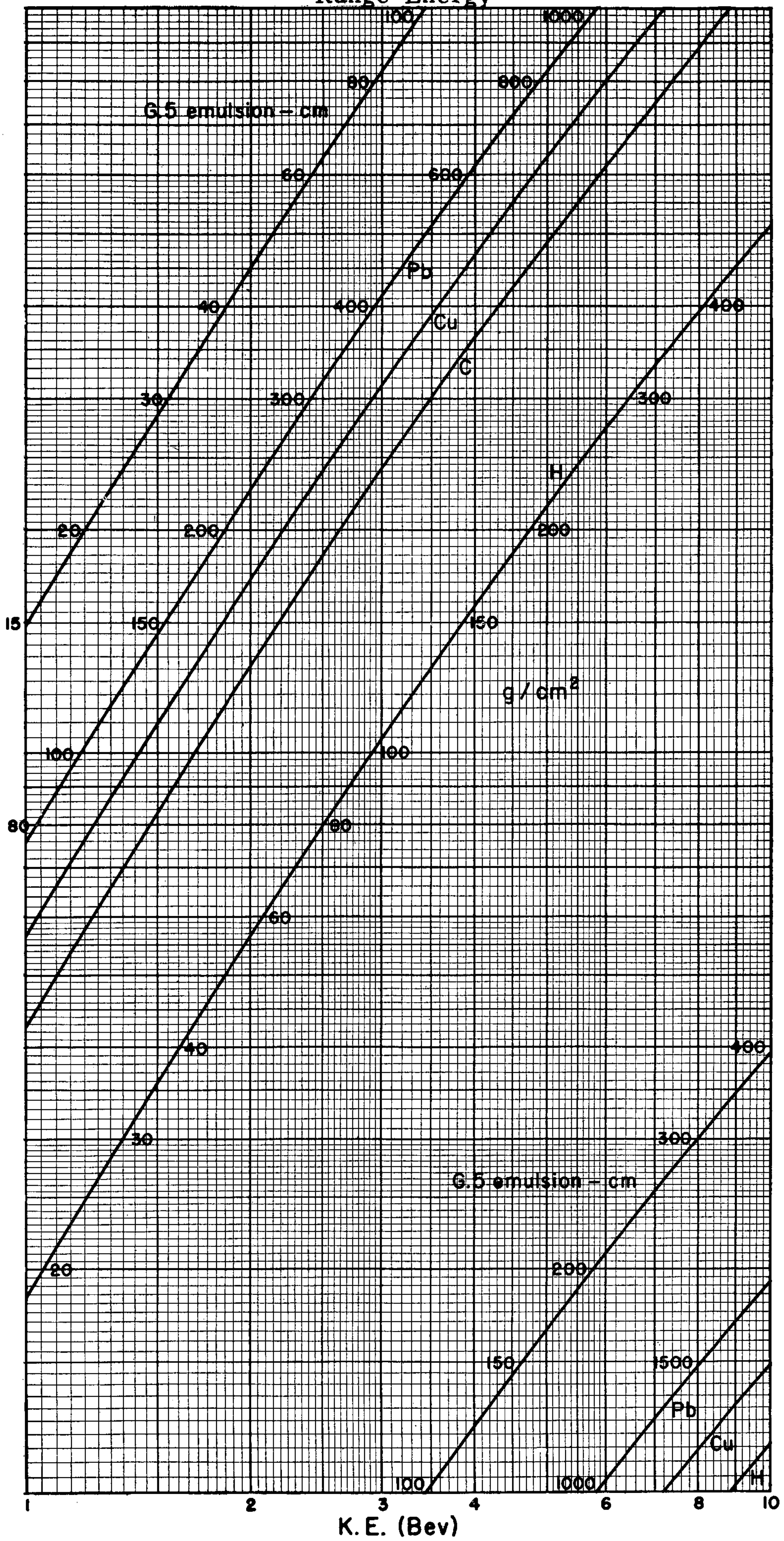


0 0 1 0 1 2 0 4 1 7 5

ALPHA PARTICLES

Range-Energy

M = 3727.3 Mev
= 7294.47 m

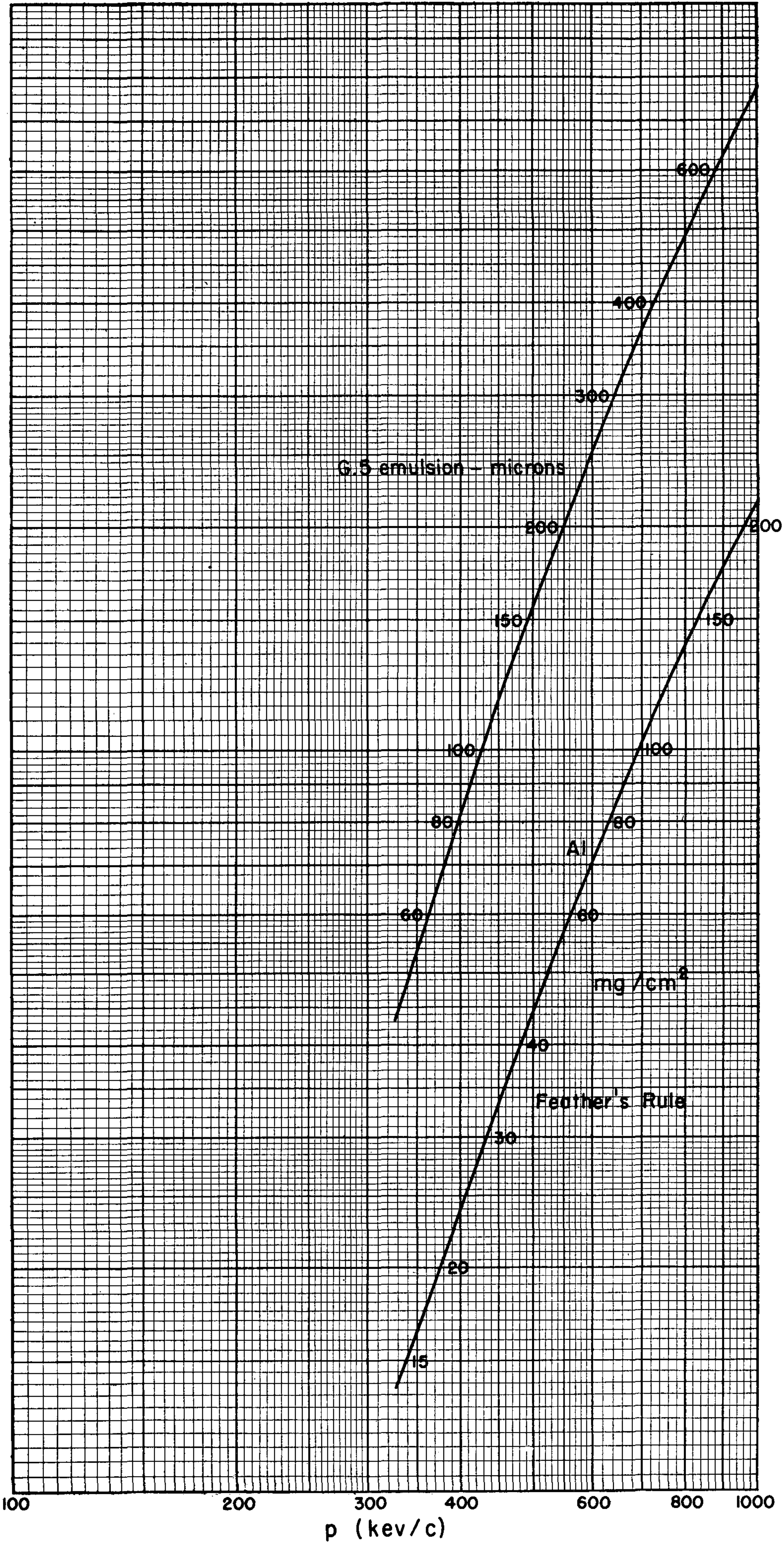


ELECTRONS 330 kev/c to 1 Mev/c

0 0 1 0 1 2 0 4 1 7 6

Range-Momentum

M = 0.51098 Mev
= m



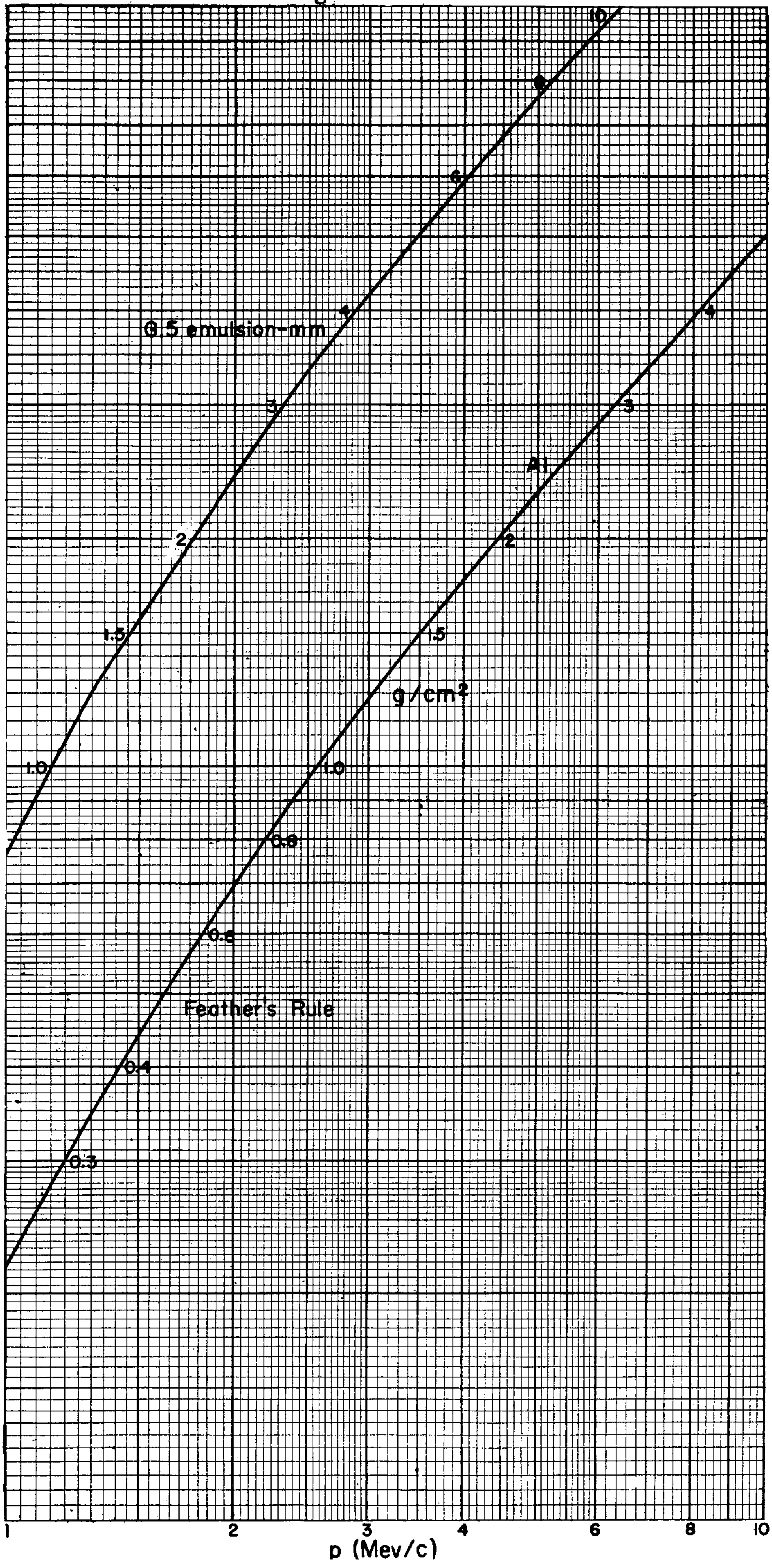
0 0 1 0 1 2 0 4 1 7 7

ELECTRONS

1 to 10 Mev/c

Range-Momentum

M = 0.51098 Mev
= m



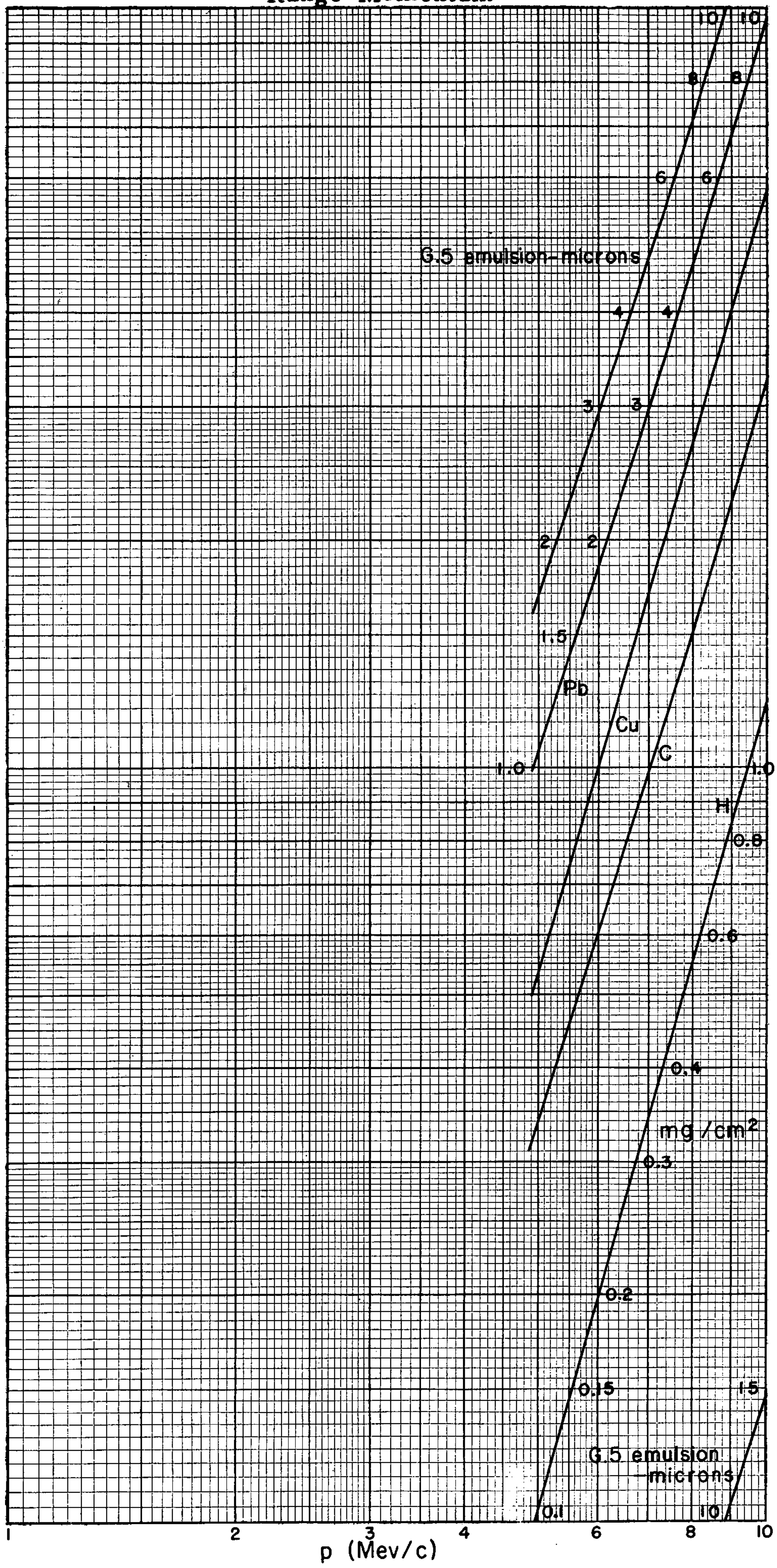
0 0 1 0 1 2 0 4 1 7 8

μ MESONS

5 to 10 Mev/c

Range-Momentum

M = 105.7 Mev
= 206.86 m

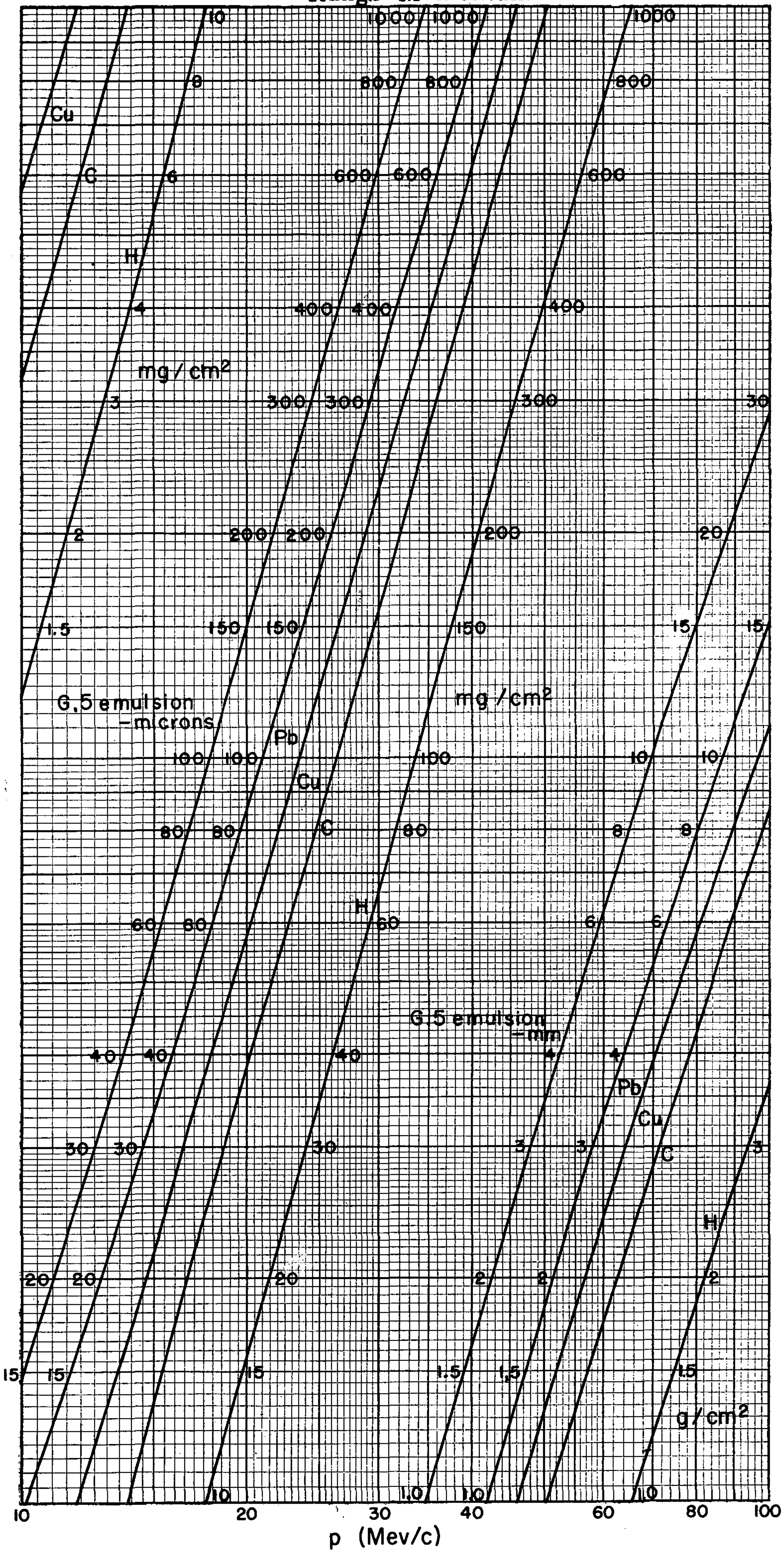


MESONS

10 to 100 Mev/c

Range-Momentum

M = 105.7 Mev
= 206.86 m

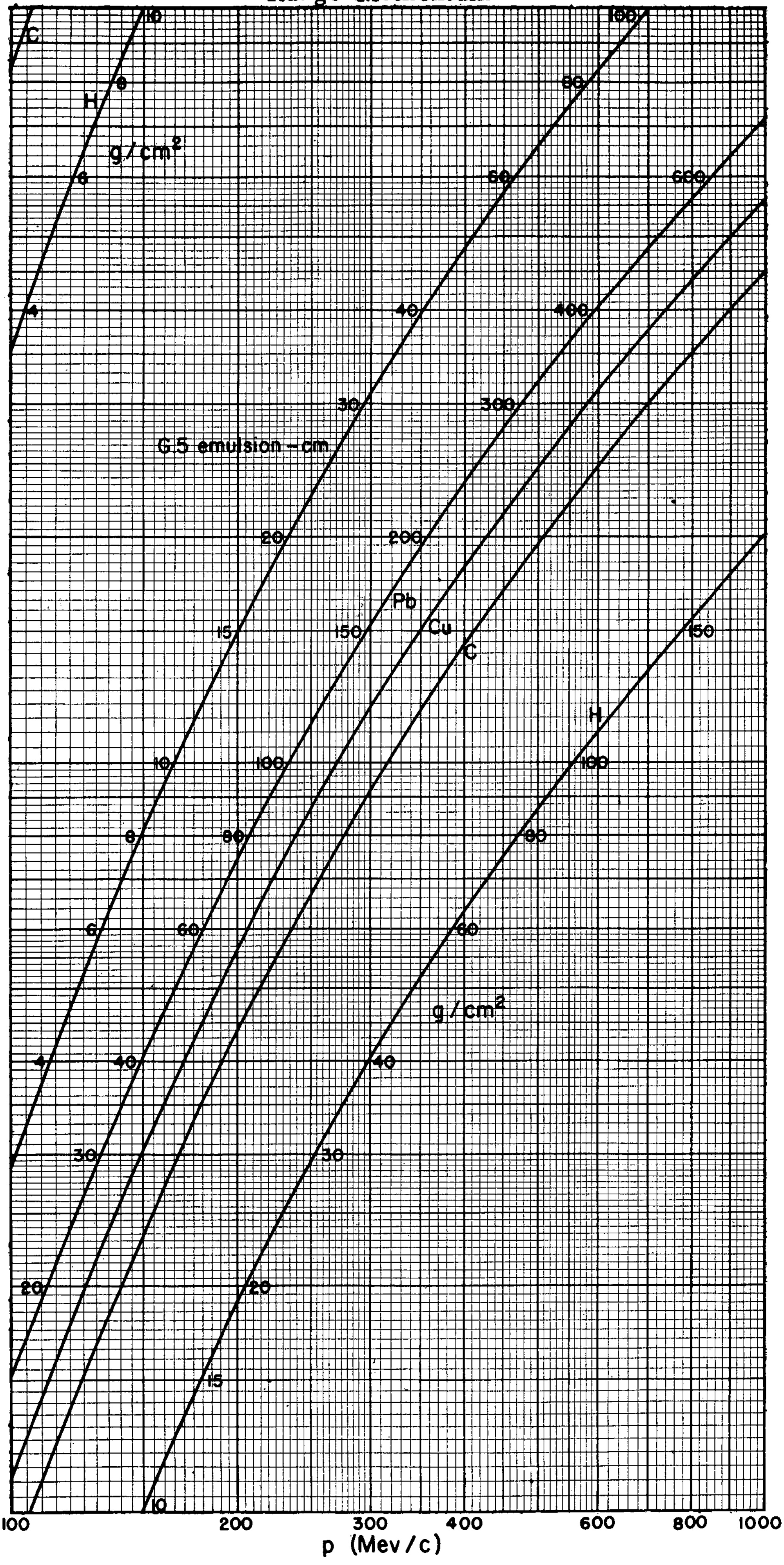


μ MESONS

100 Mev/c to 1 Bev/c

Range-Momentum

M = 105.7 Mev
= 206.86 m



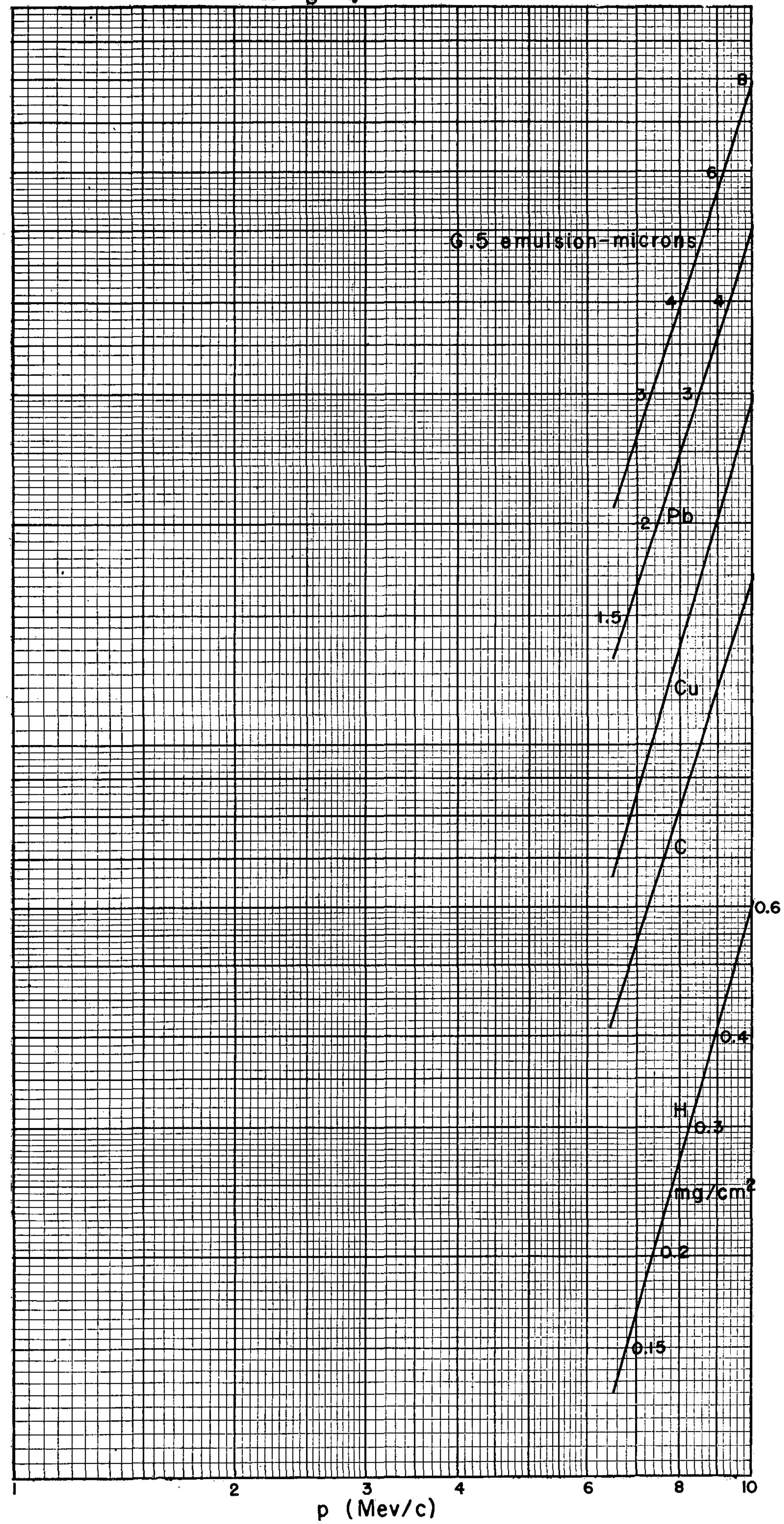
0 0 1 0 1 2 0 4 1 8 1

π MESONS

Range-Momentum

6.5 to 10 Mev/c

M = 139.6 Mev
= 273.27 m



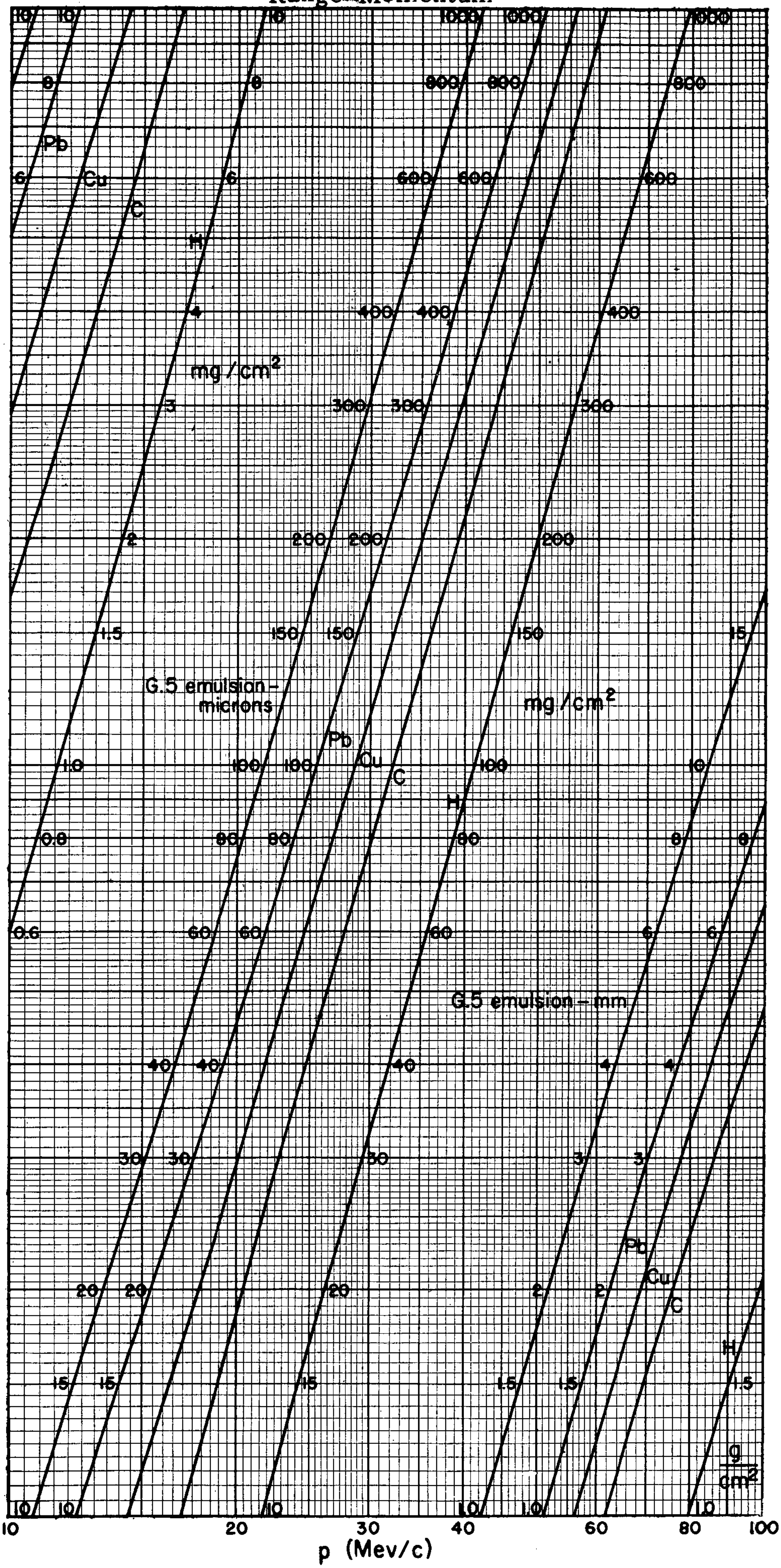
0 0 1 0 1 2 0 4 1 8 2

π MESONS

Range-Momentum

10 to 100 Mev/c

M = 139.6 Mev
= 273.27 m



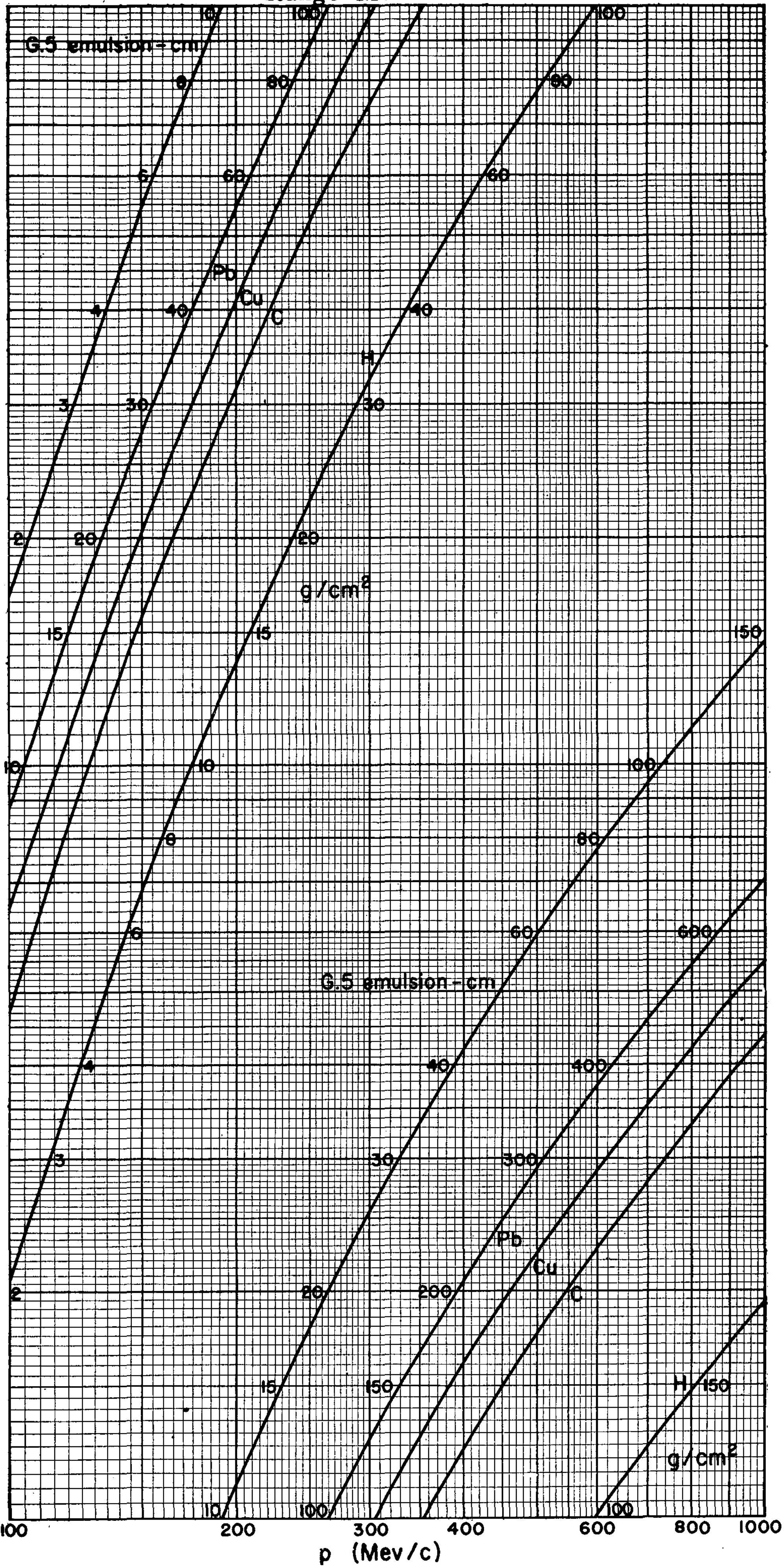
0 0 1 0 1 2 0 4 1 8 3

π MESONS

100 Mev/c to 1 Bev/c

Range-Momentum

M = 139.6 Mev
= 273.27 m



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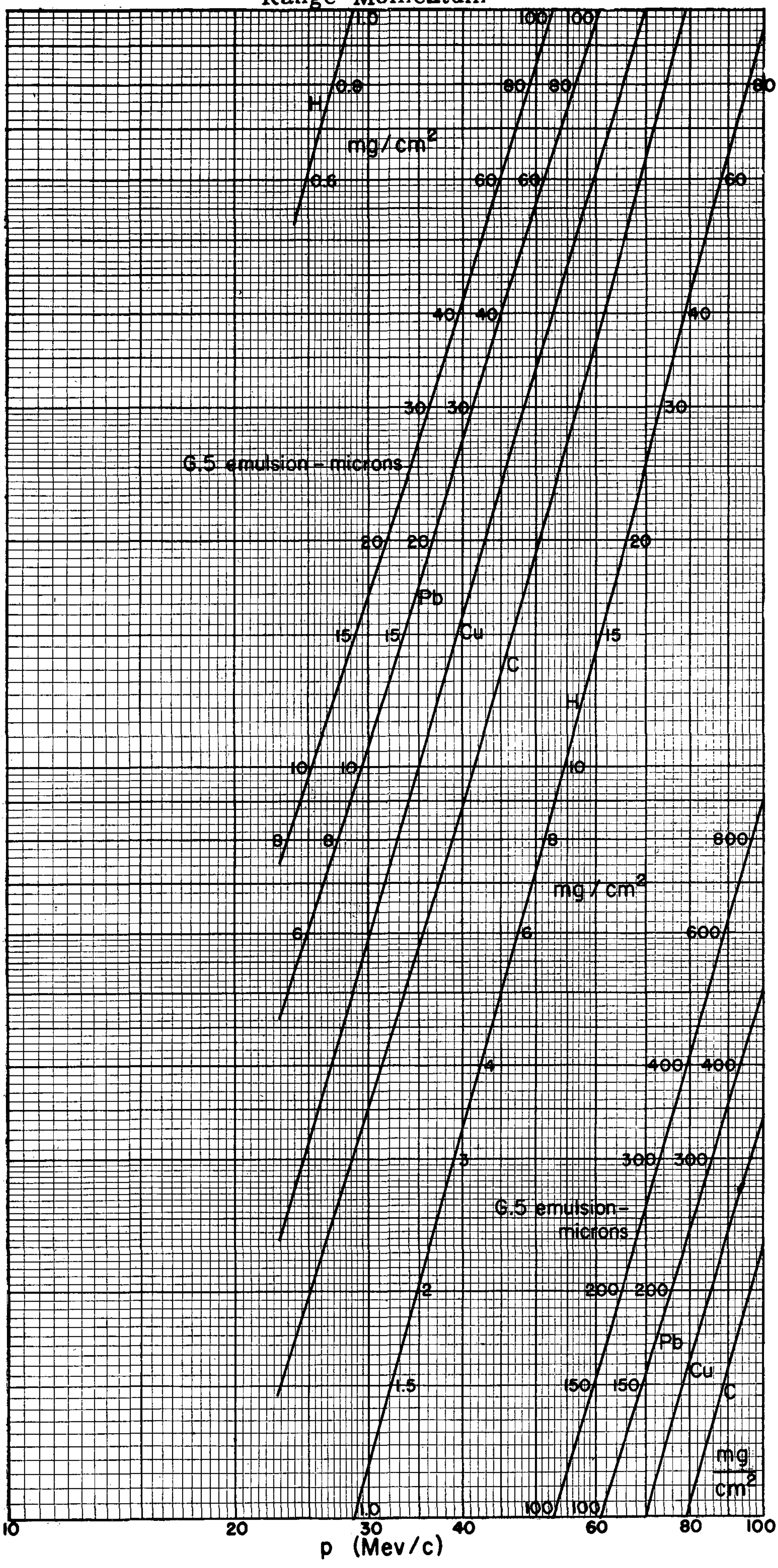
K MESONS 23 to 100 Mev/c

Range-Momentum

M = 494.0 Mev
= 966.71 m



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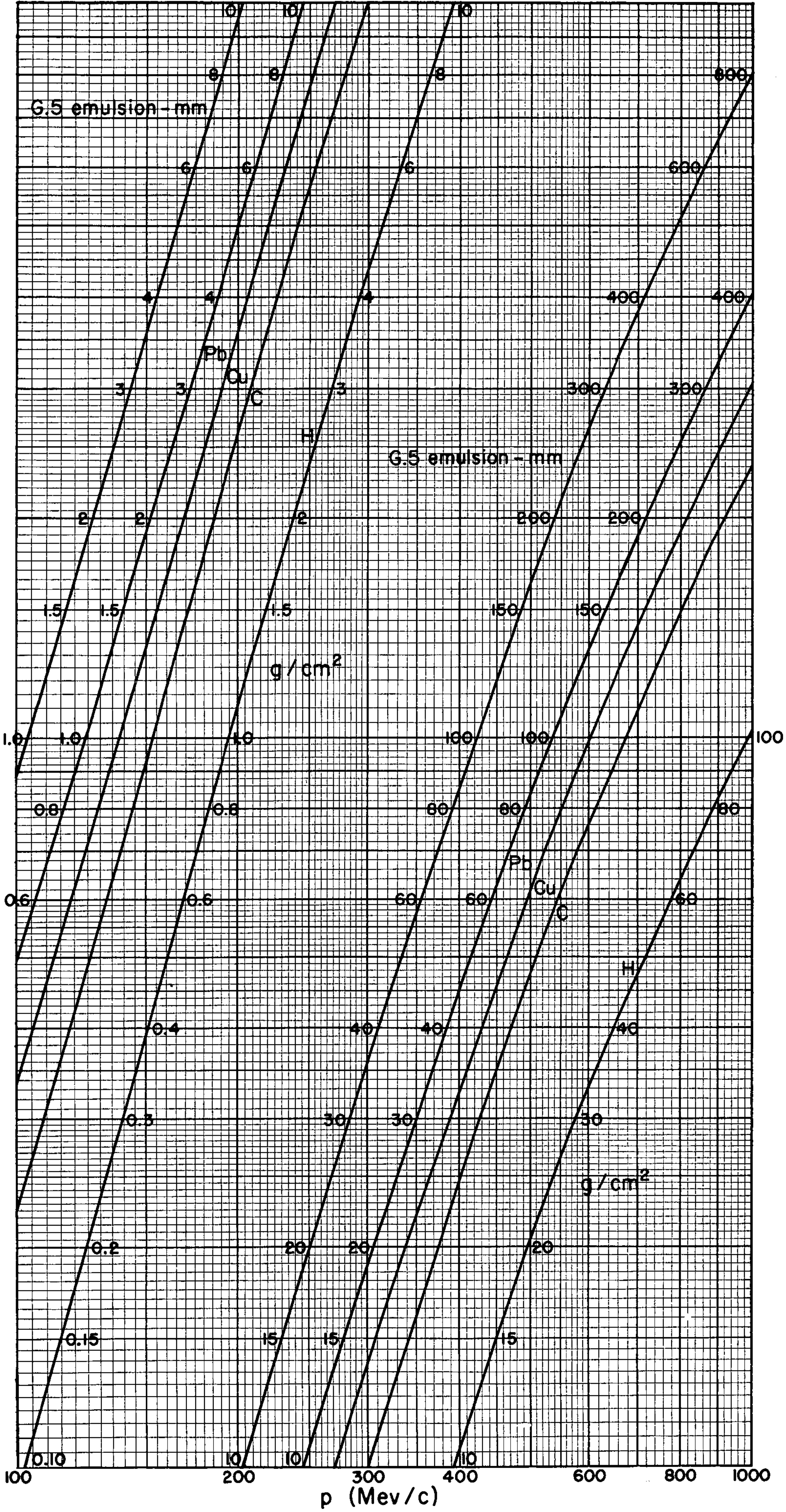
K MESONS

100 Mev/c to 1 Bev/c

Range-Momentum

M = 494.0 Mev
= 966.71 m



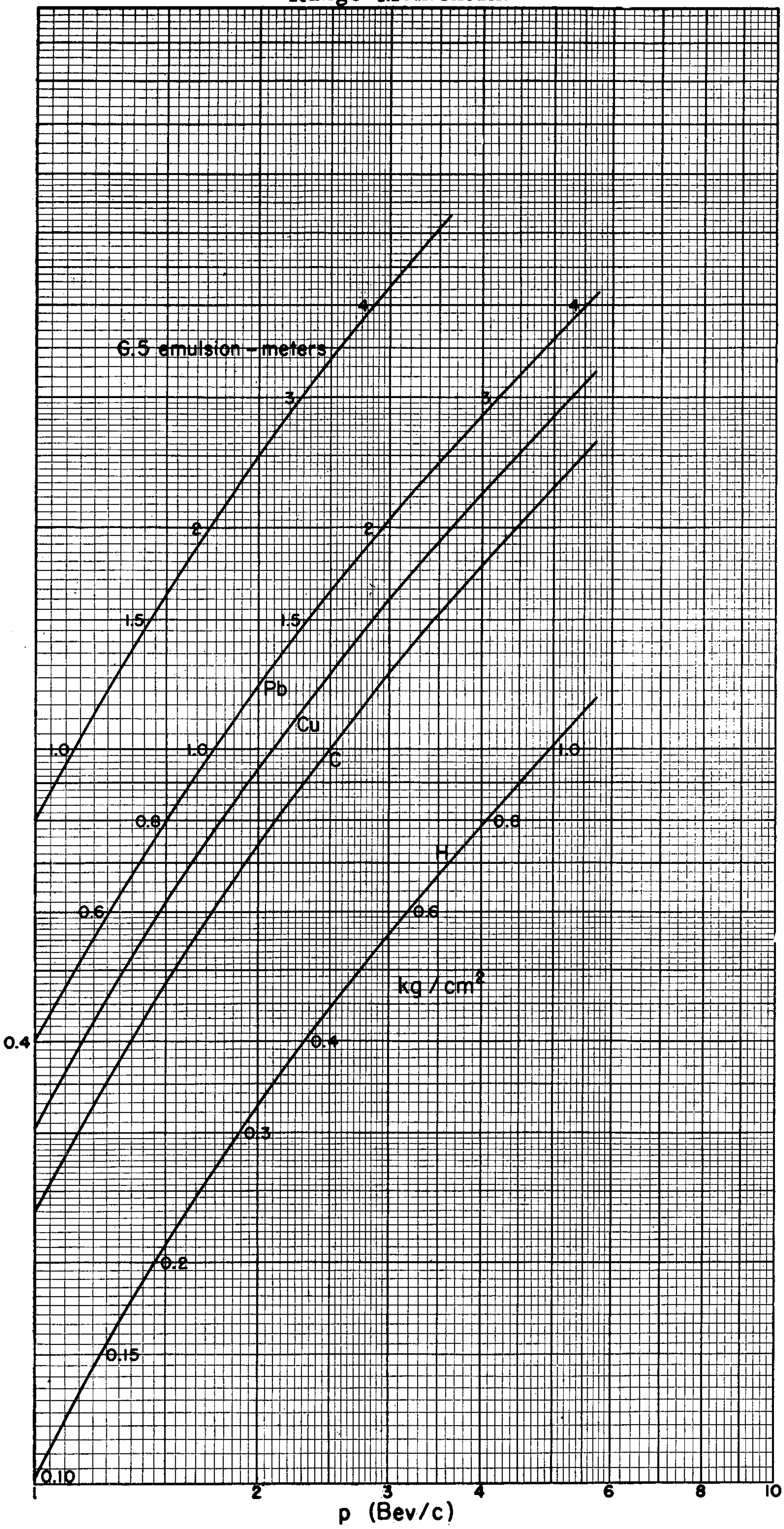
0 0 1 0 1 2 0 4 1 8 6

K MESONS

1 to 5.7 Bev/c

Range-Momentum

M = 494.0 Mev
= 966.71 m



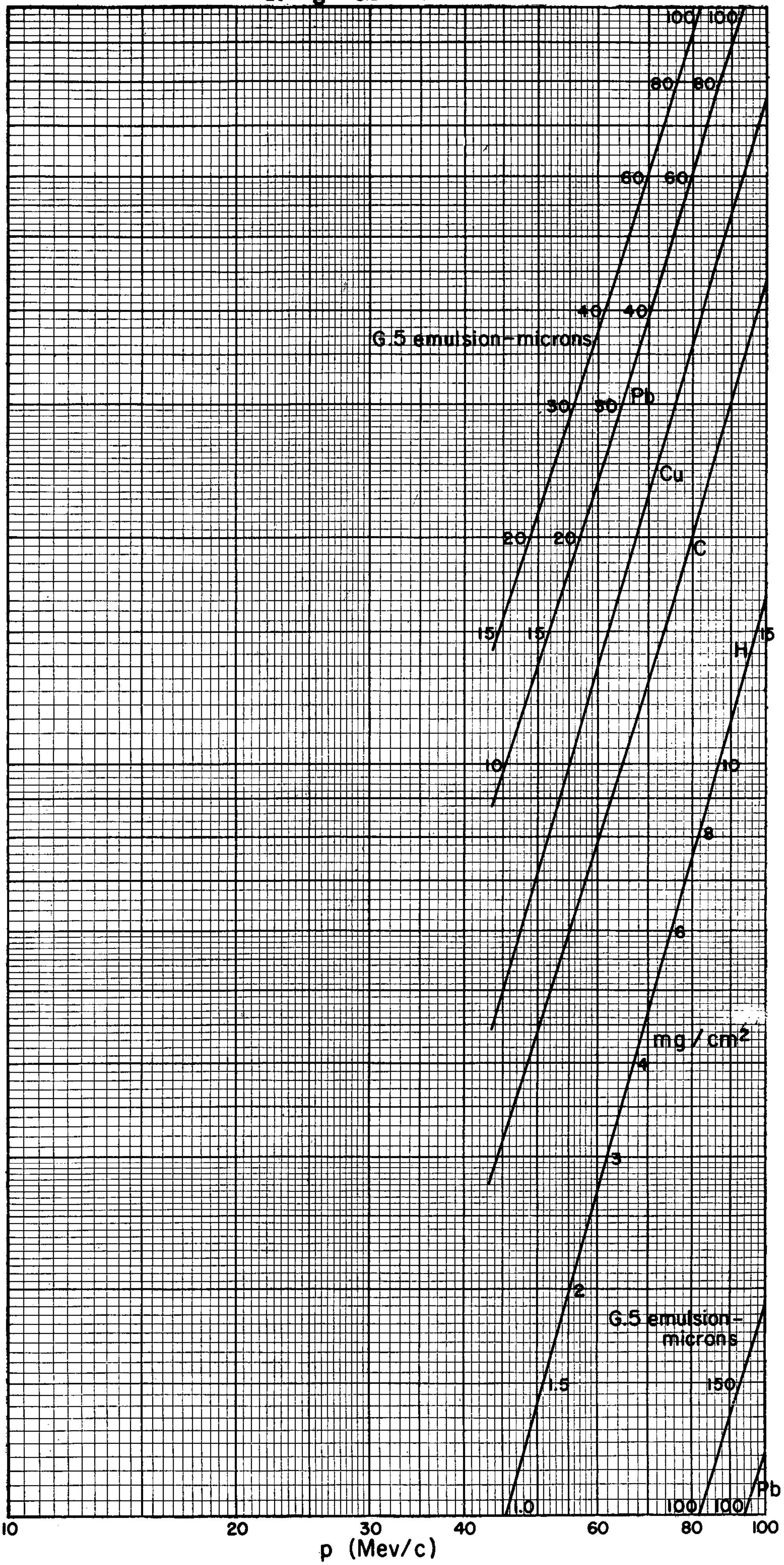
0 0 1 0 1 2 0 4 1 8 7

PROTONS

43 to 100 Mev/c

Range-Momentum

M = 938.23 Mev
= 1836.1 m

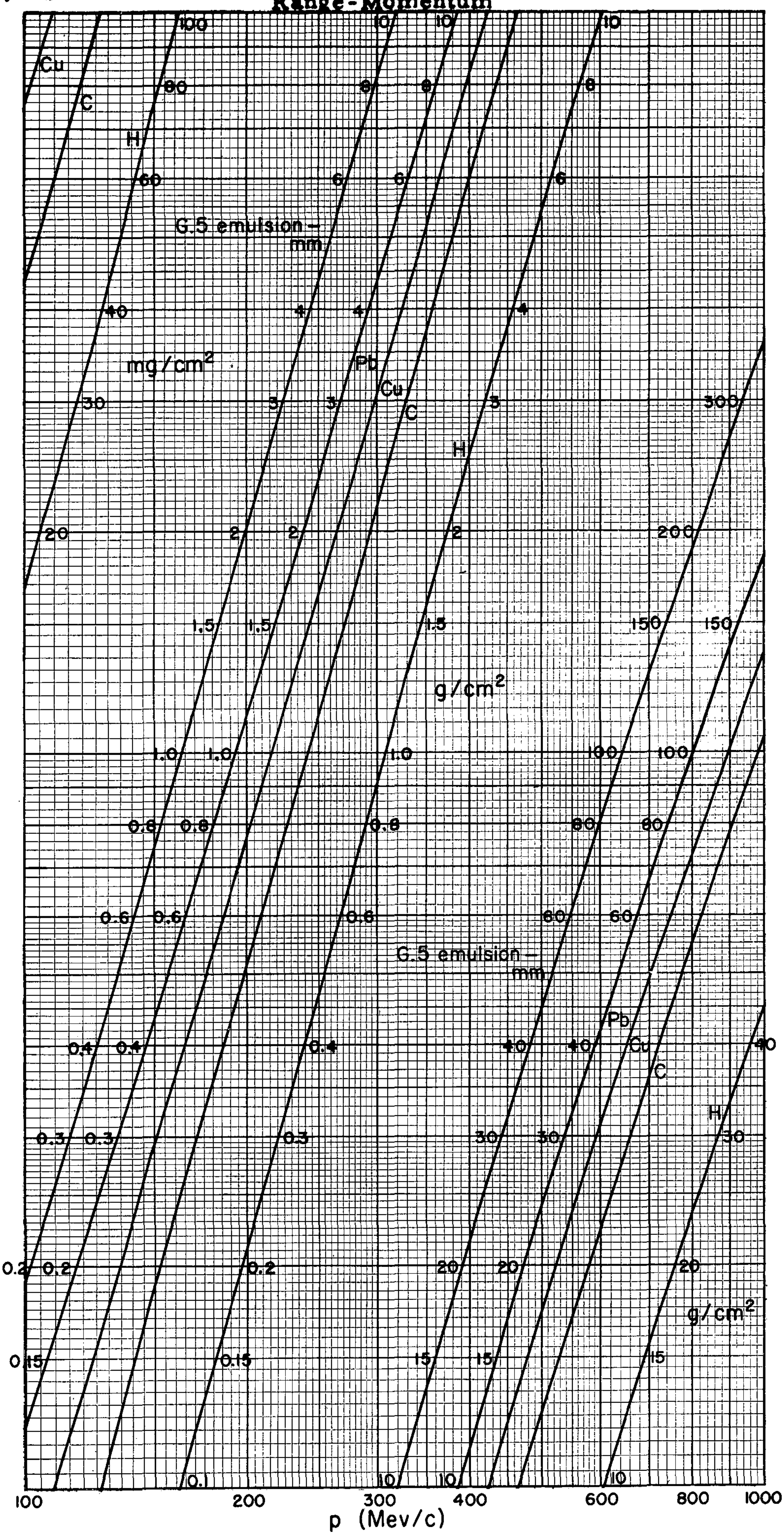


PROTONS

100 Mev/c to 1 Bev/c

Range-Momentum

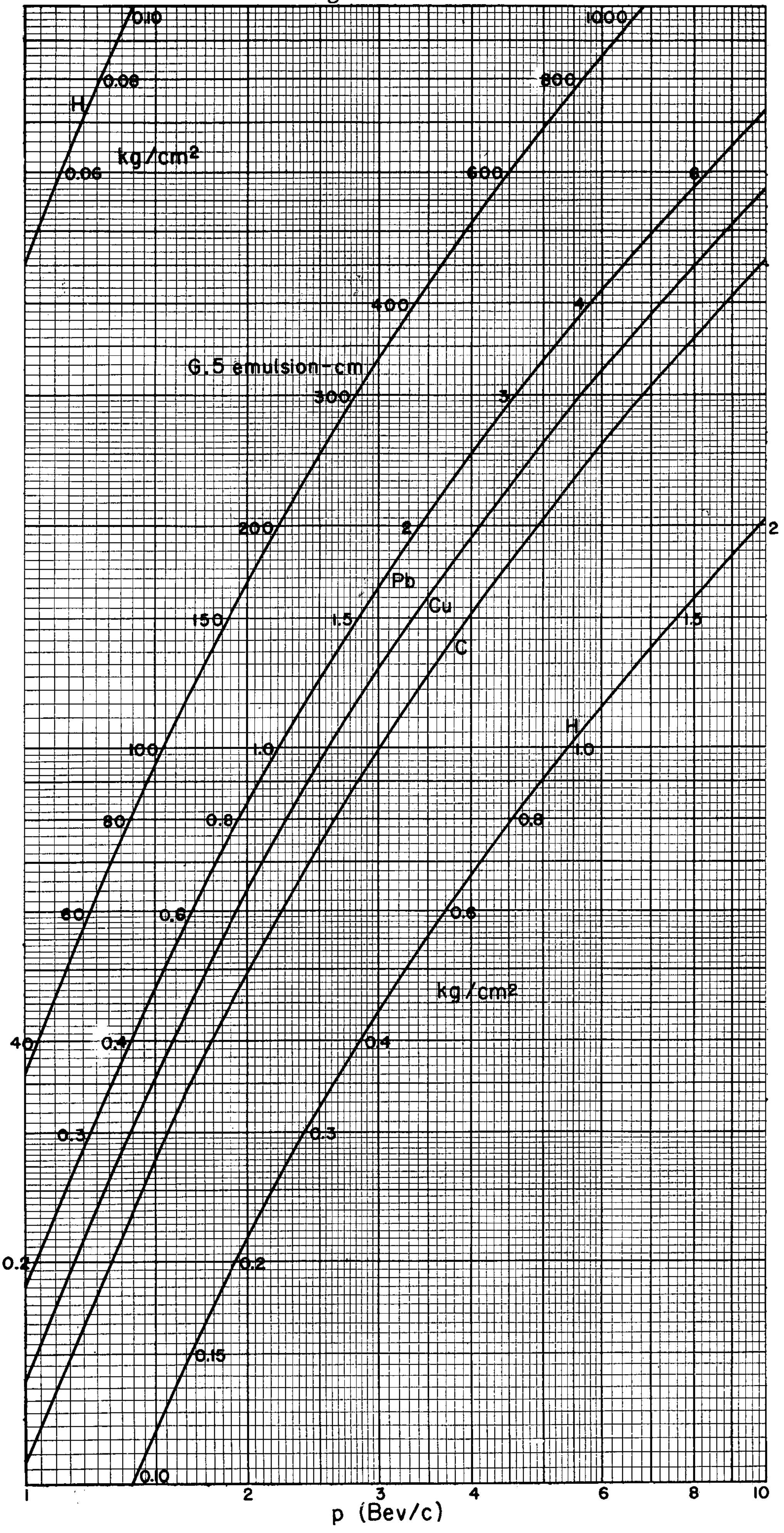
M = 938.23 Mev
= 1836.1 m



PROTONS
Range-Momentum

1 to 10 Bev/c

M = 938.23 Mev
= 1836.1 m

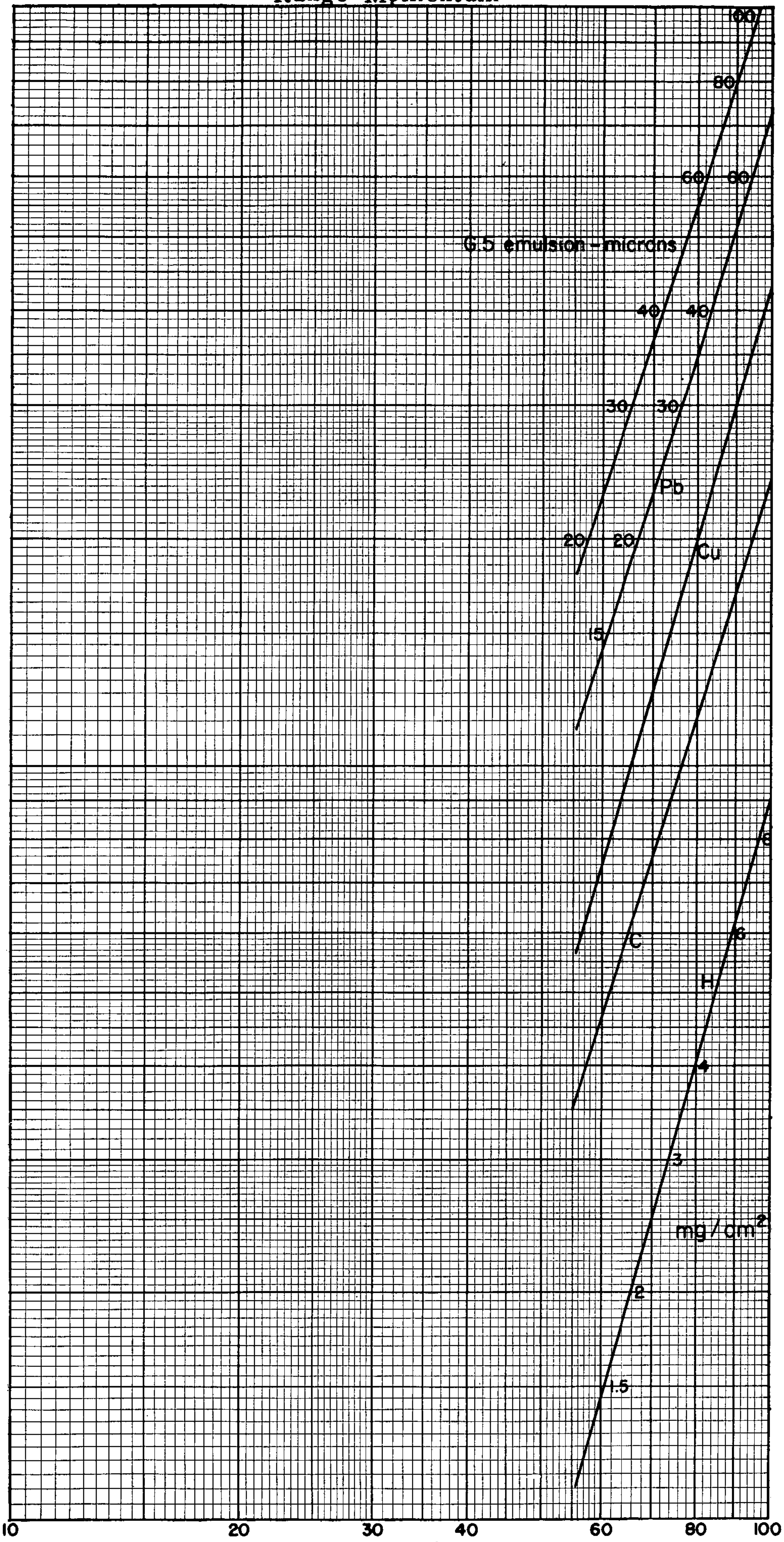


Σ_{av} HYPERONS

55 to 100 Mev/c

Range-Momentum

M = 1194.1 Mev
= 2336.83 m

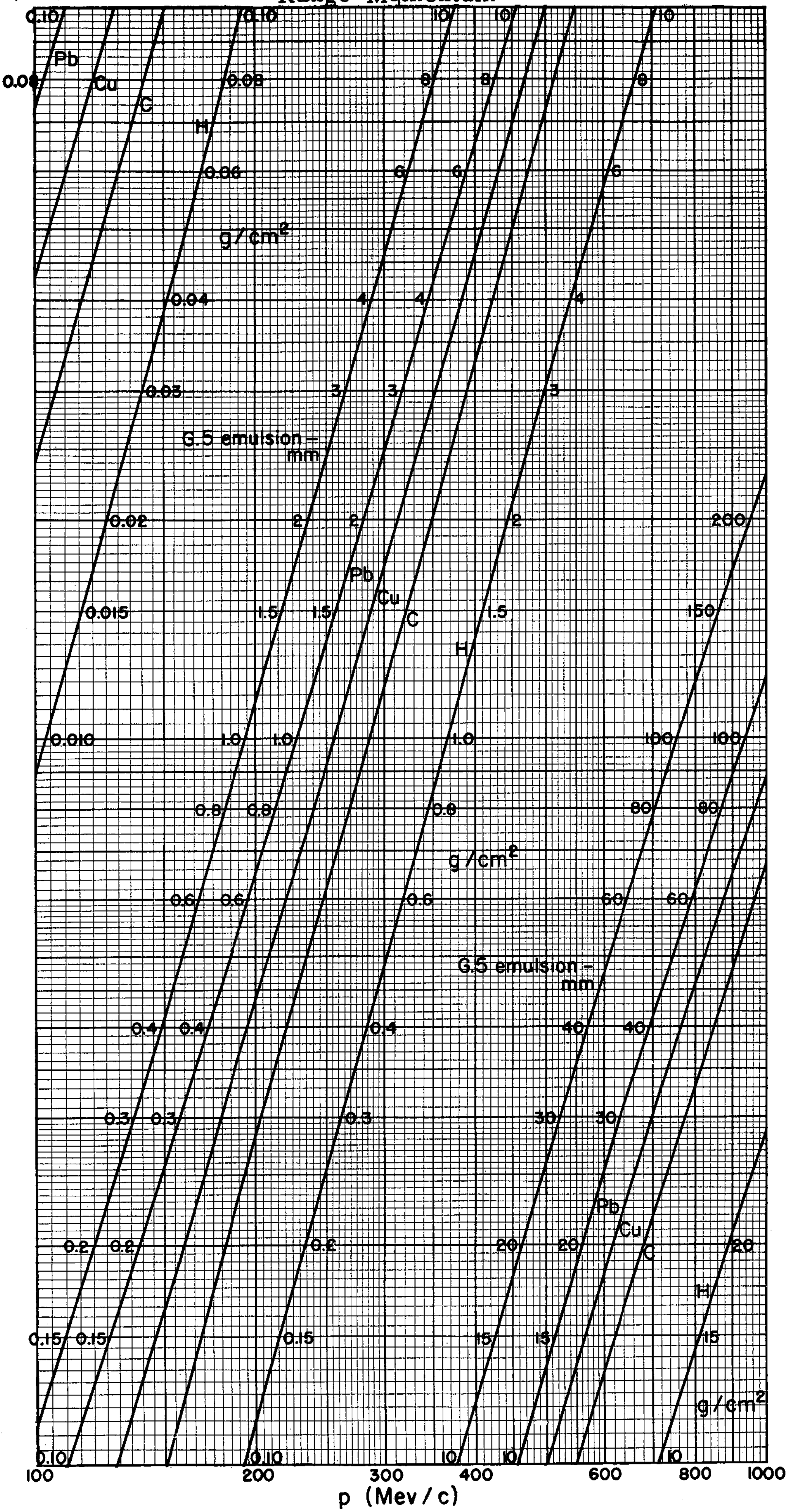


0 0 1 2 0 4 1 9 1

Σ_{av} HYPERONS Range-Momentum

100 Mev/c to 1 Bev/c

M = 1194.1 Mev
= 2336.83 m

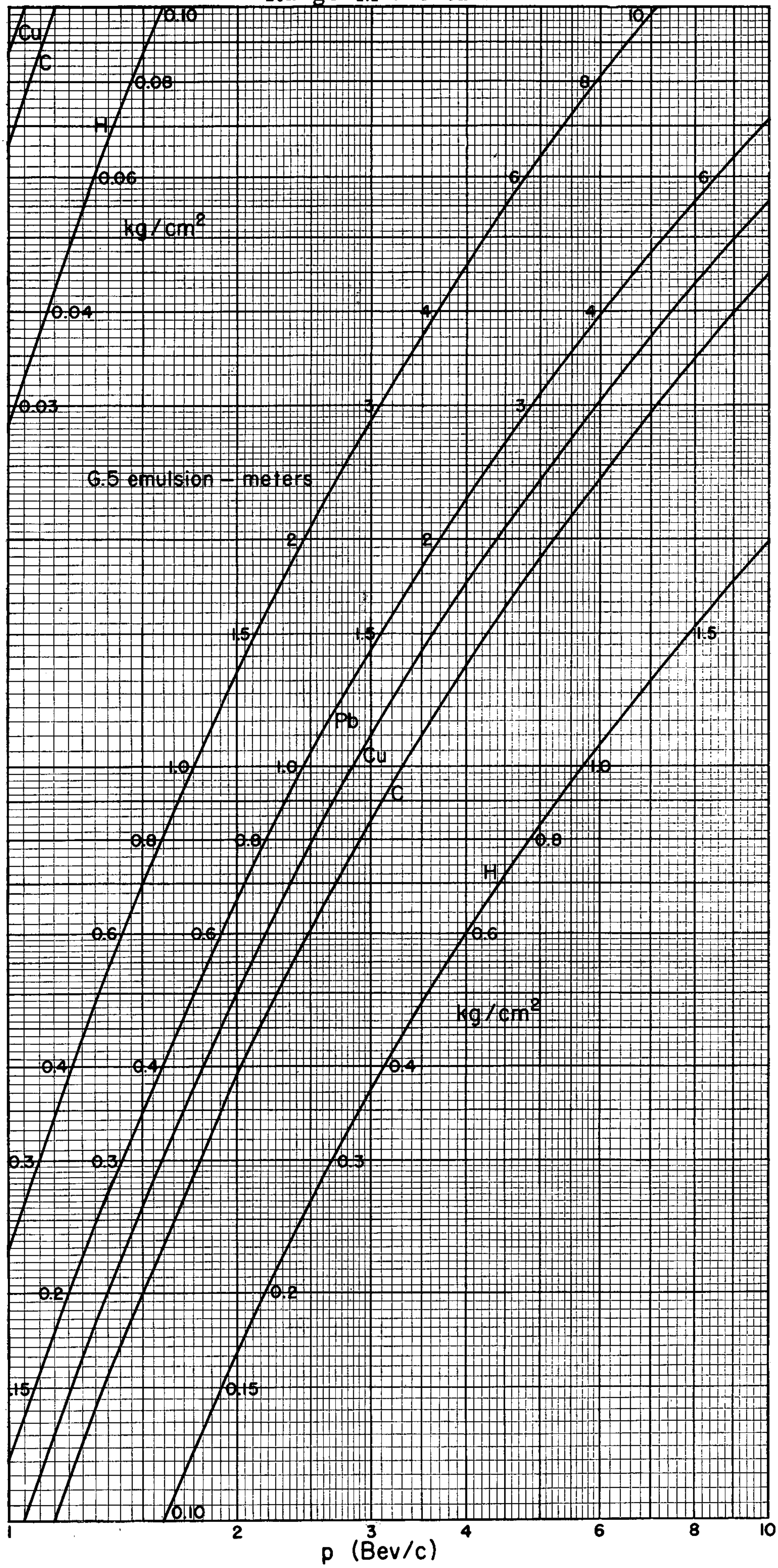


0 0 0 0 1 2 0 4 1 9 2

Σ_{av} HYPERONS
Range-Momentum

1 to 10 Bev/c

M = 1194.1 Mev
= 2336.83 m



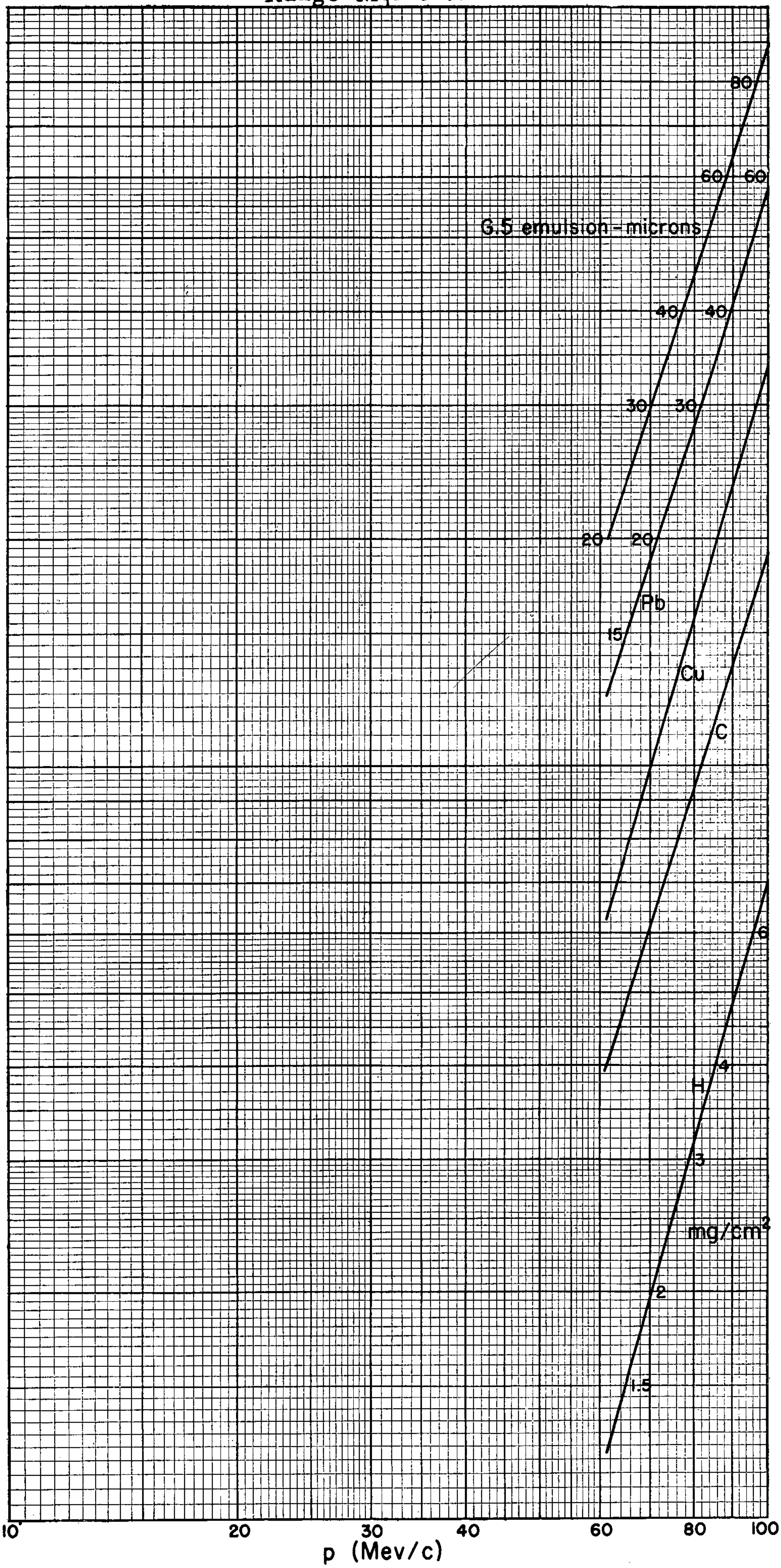
0 0 1 0 1 2 0 4 1 9 3

Ξ HYPERONS

Range-Momentum

61 to 100 Mev/c

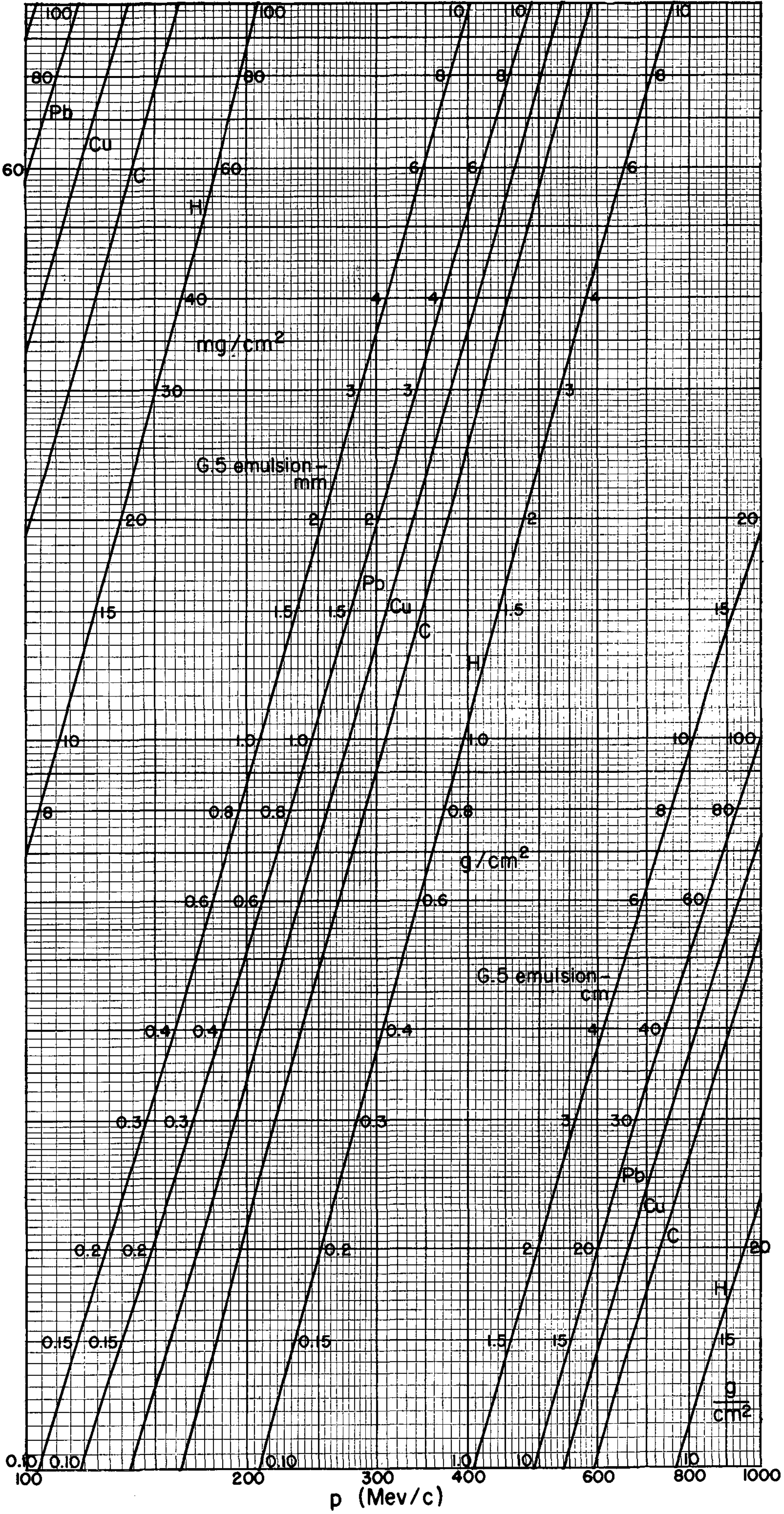
M = 1321.0 Mev
  = 2585.28 m



0 0 1 0 1 2 0 4 1 2 4

Ξ HYPERONS Range Momentum 100 Mev/c to 1 Bev/c

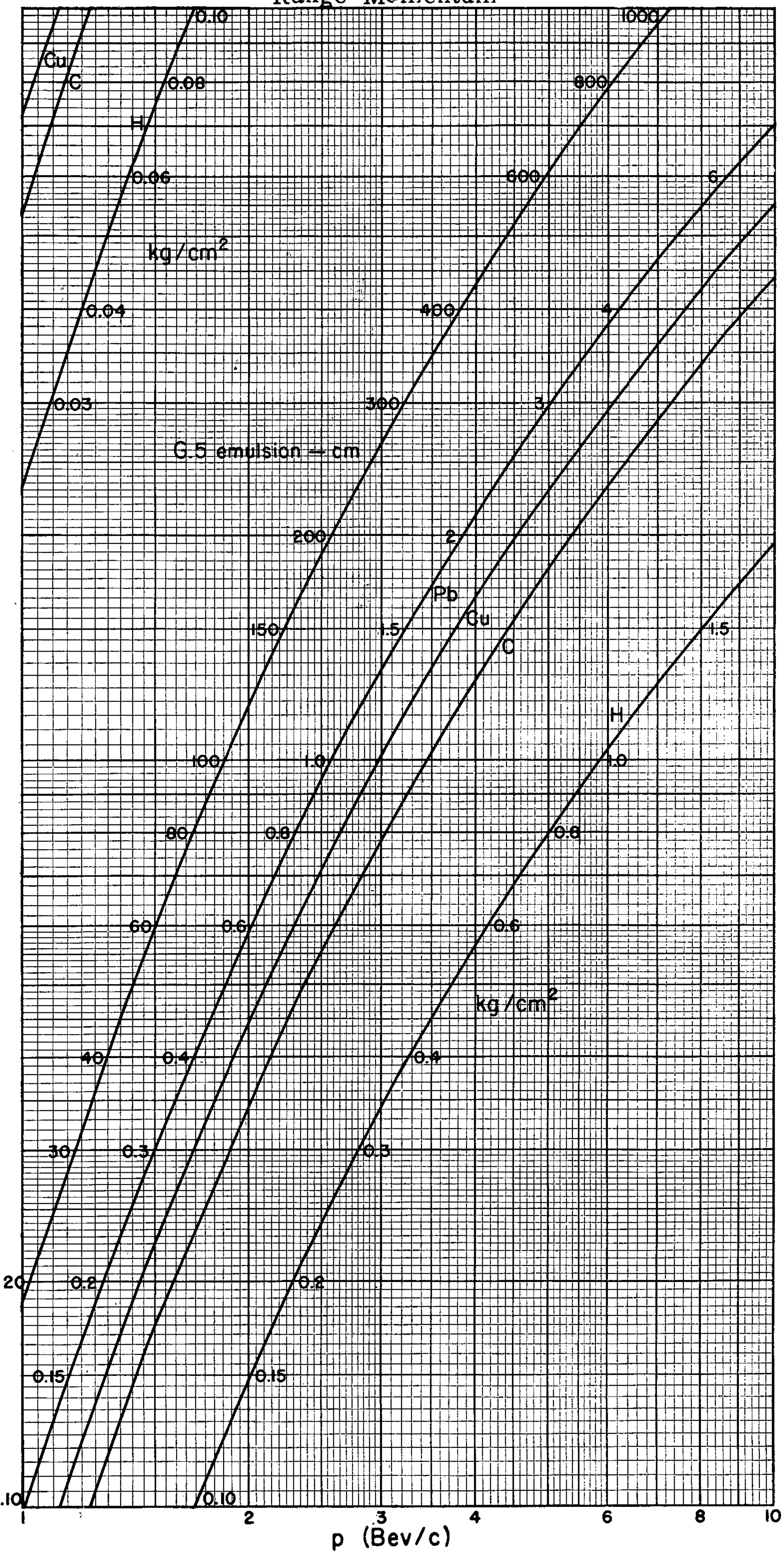
M = 1321.0 Mev
= 2585.28 m



Ξ HYPERONS Range-Momentum

1 to 10 Bev/c

M = 1321.0 Mev
= 2585.28 m

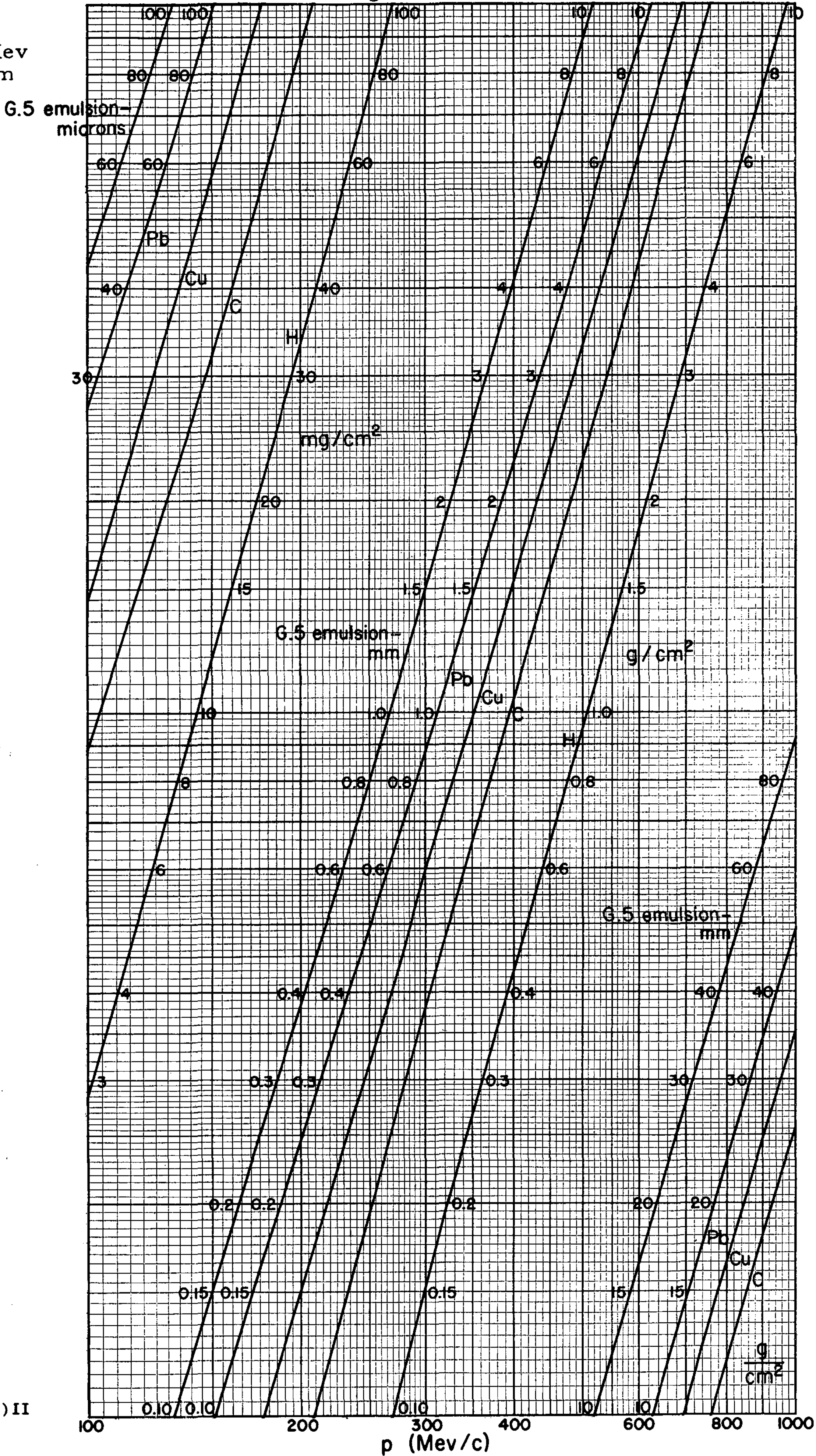


DEUTERONS

100 Mev/c to 1 Bev/c

Range-Momentum

M = 1875.5 Mev
= 3670.45 m



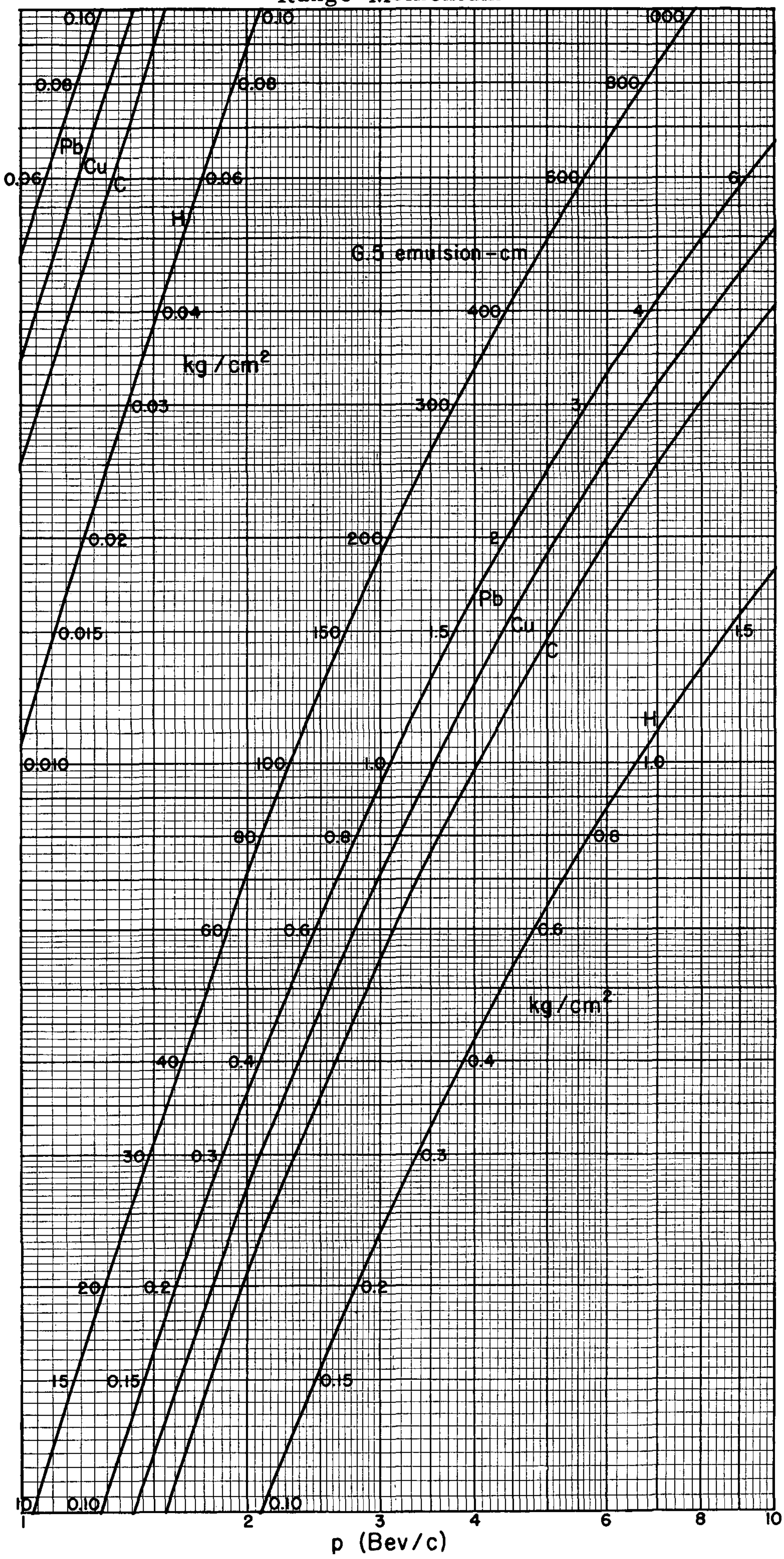
0 0 1 0 1 2 0 4 1 9 7

DEUTERONS

1 to 10 Bev/c

Range-Momentum

M = 1875.5 Mev
= 3670.45 m

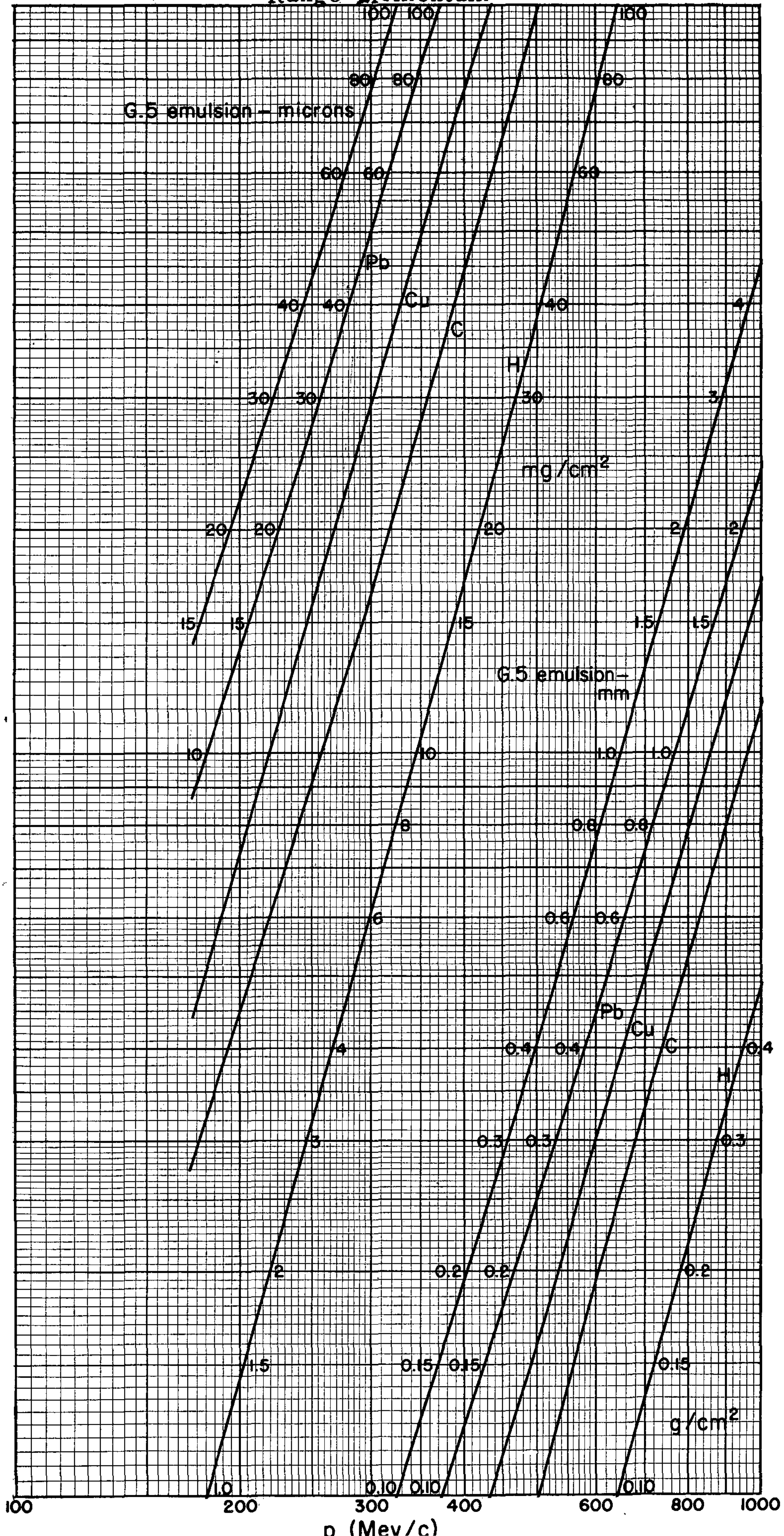


ALPHA PARTICLES

175 Mev/c to 1 Bev/c

M = 3727.3 Mev
= 7294.47 m

Range-Momentum

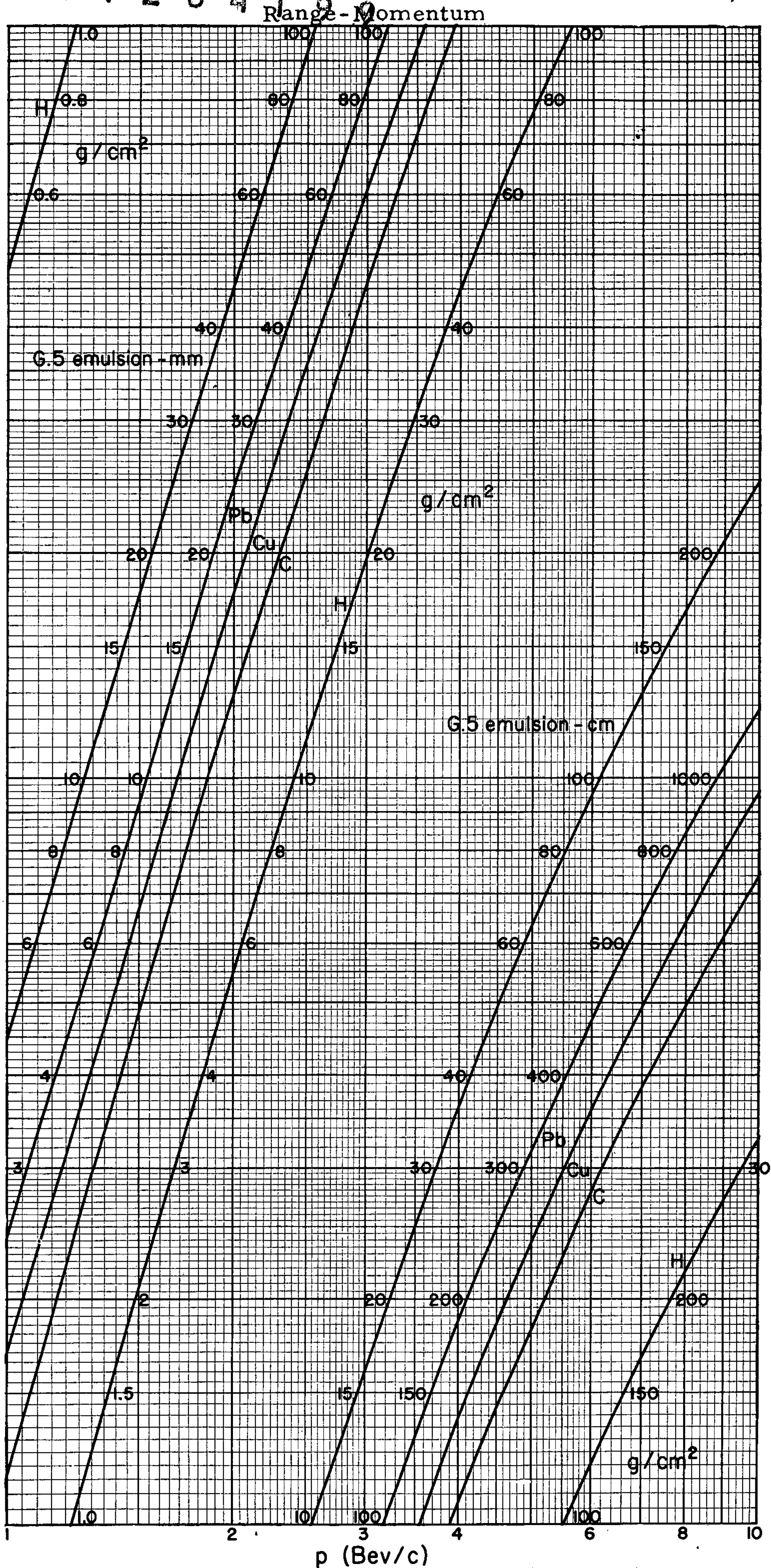


0 0 2 0 4 1 2 9

ALPHA PARTICLES

1 to 10 Bev/c

M = 3727.3 Mev
  = 7294.47 m

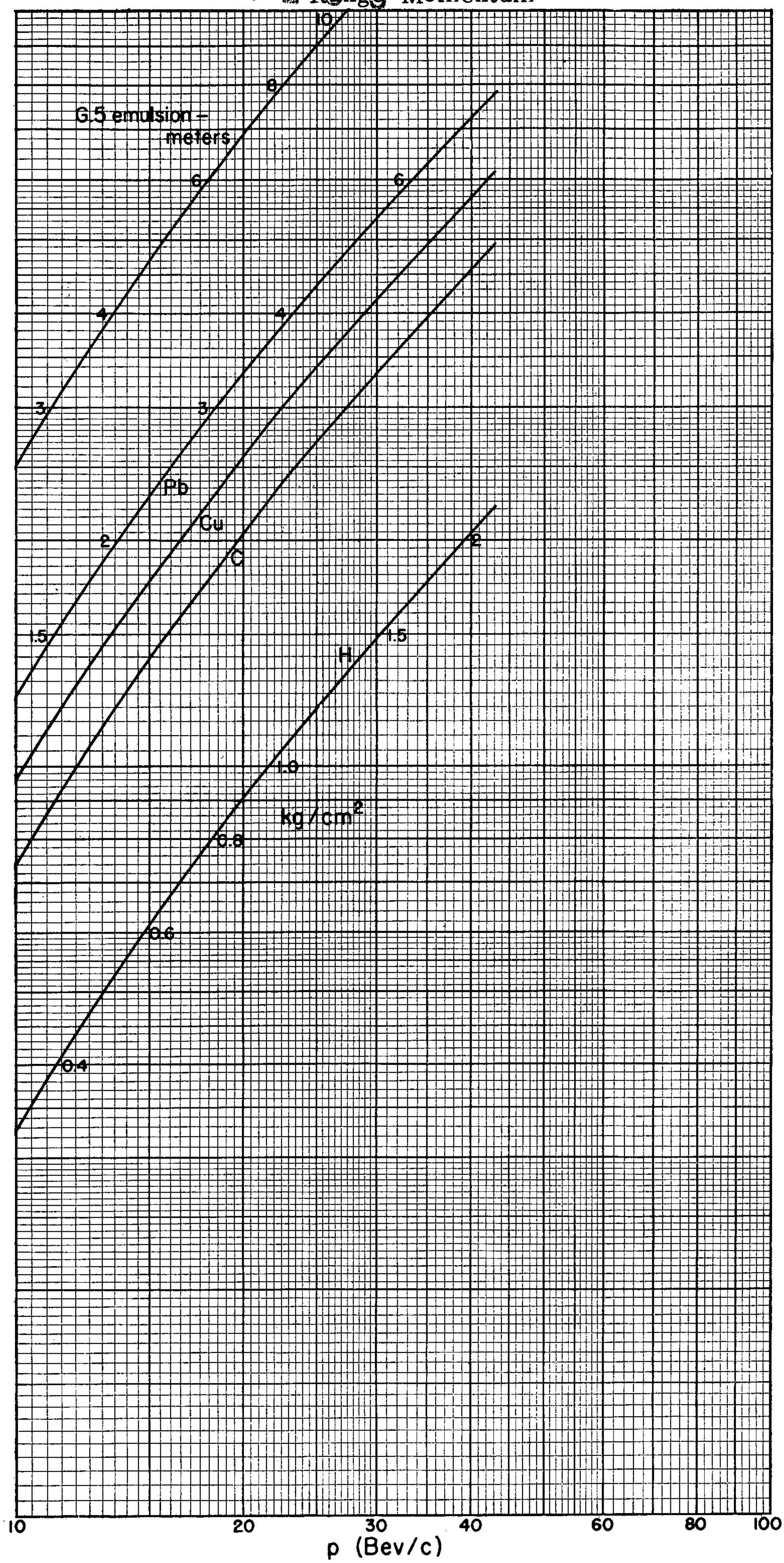


ALPHA PARTICLES

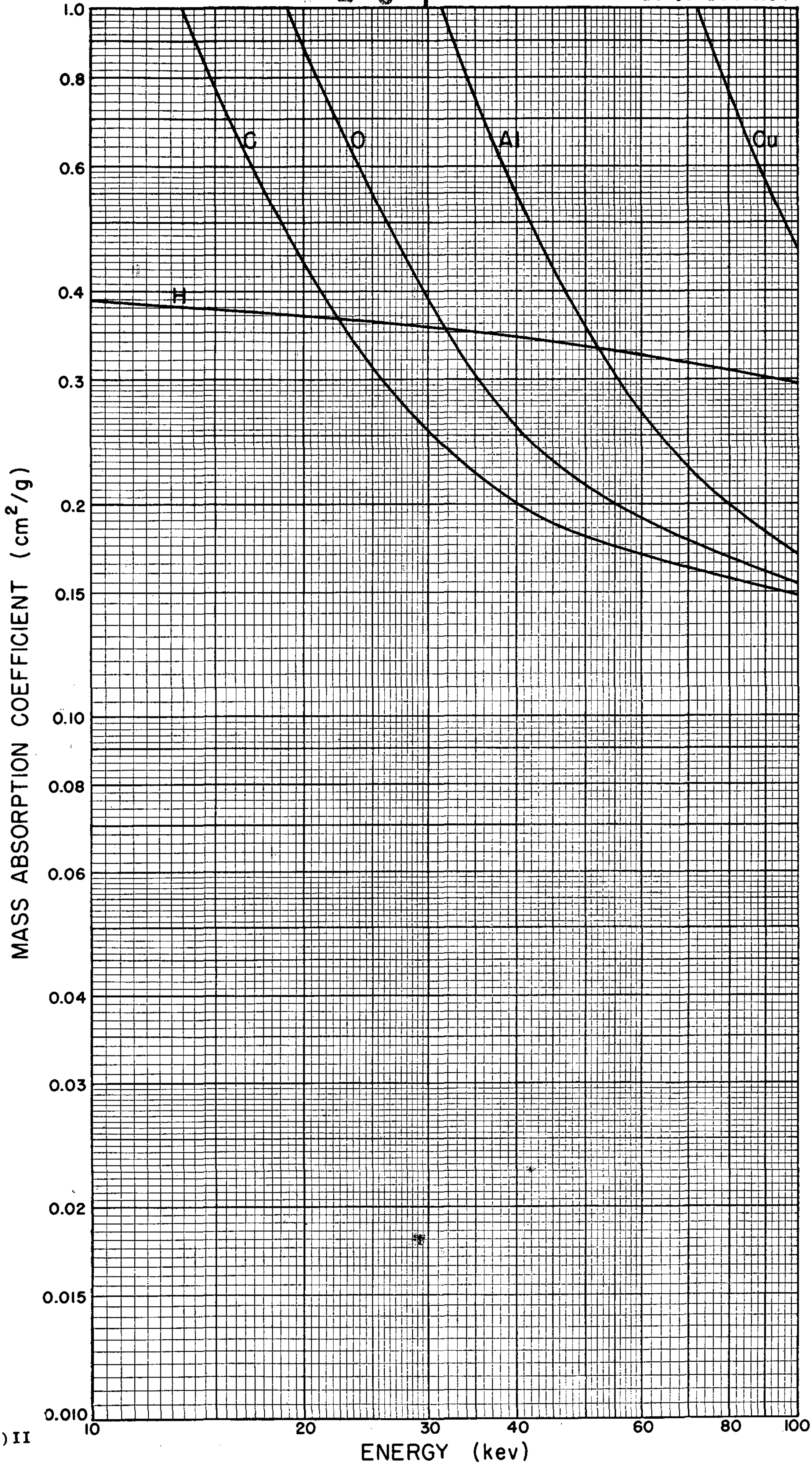
10 to 43 Bev/c

Range-Momentum

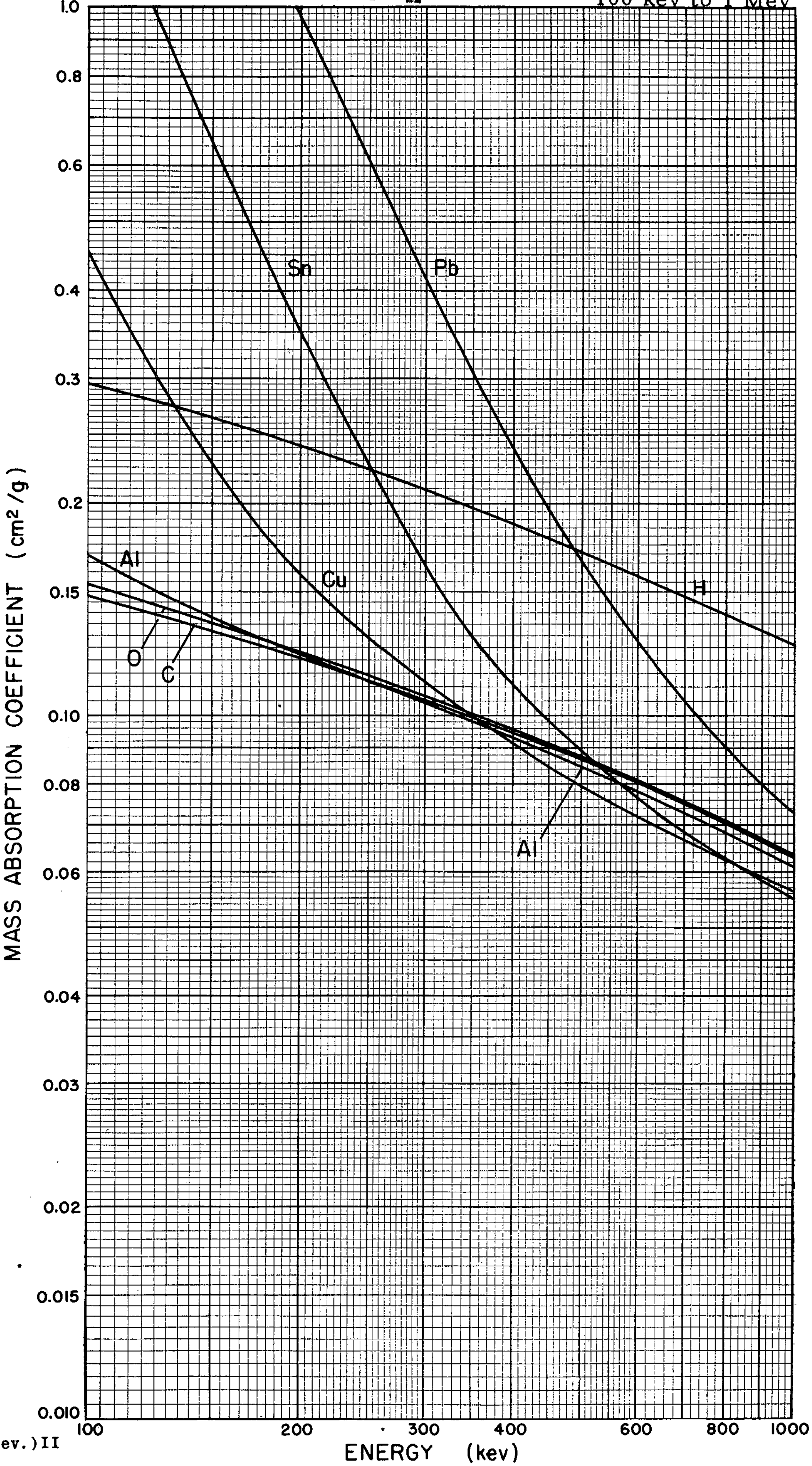
M = 3727.3 Mev
  = 7294.47 m



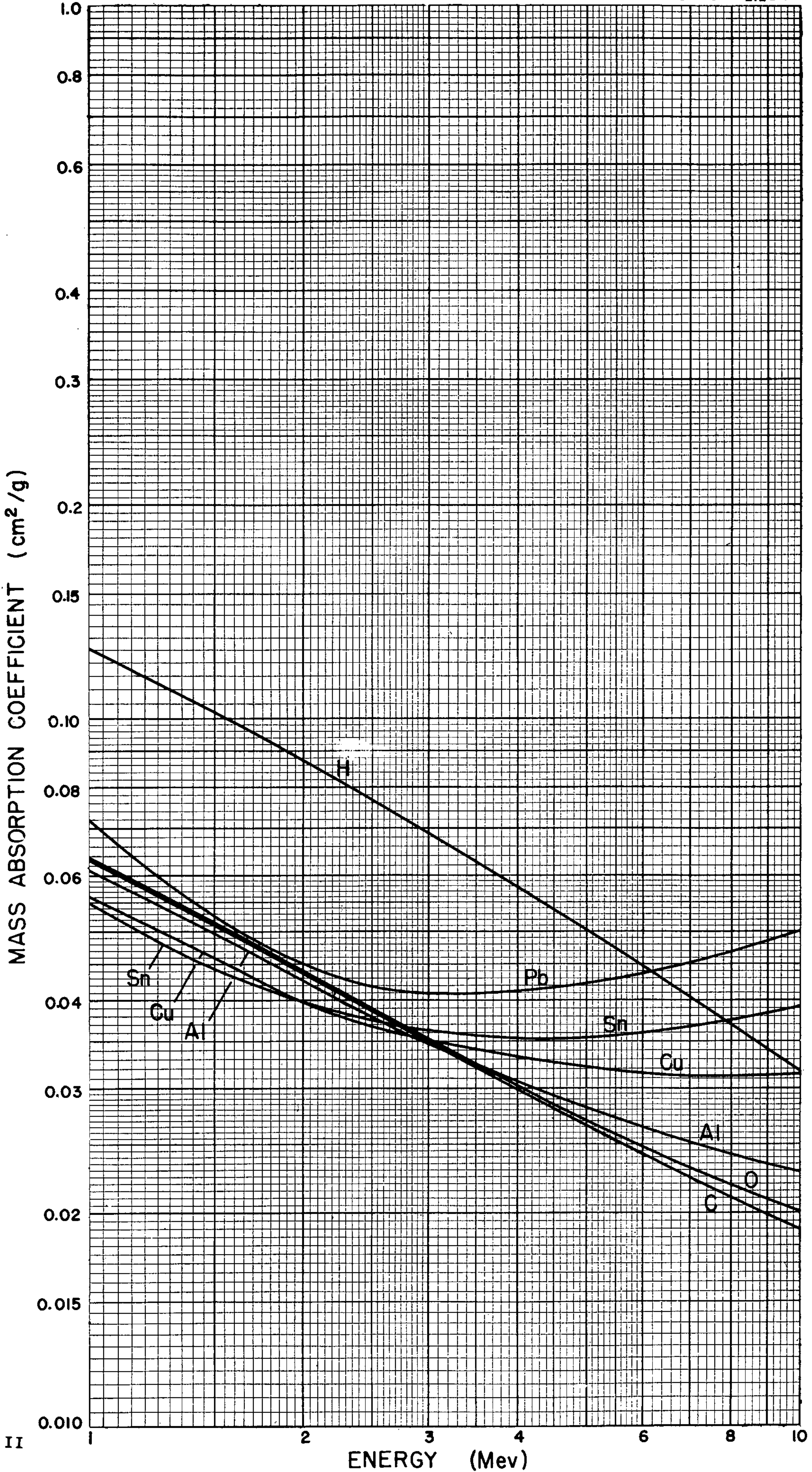
PHOTON MASS-ABSORPTION COEFFICIENT VS. ENERGY
10 to 100 kev



PHOTON MASS-ABSORPTION COEFFICIENT VS. ENERGY
100 kev to 1 Mev

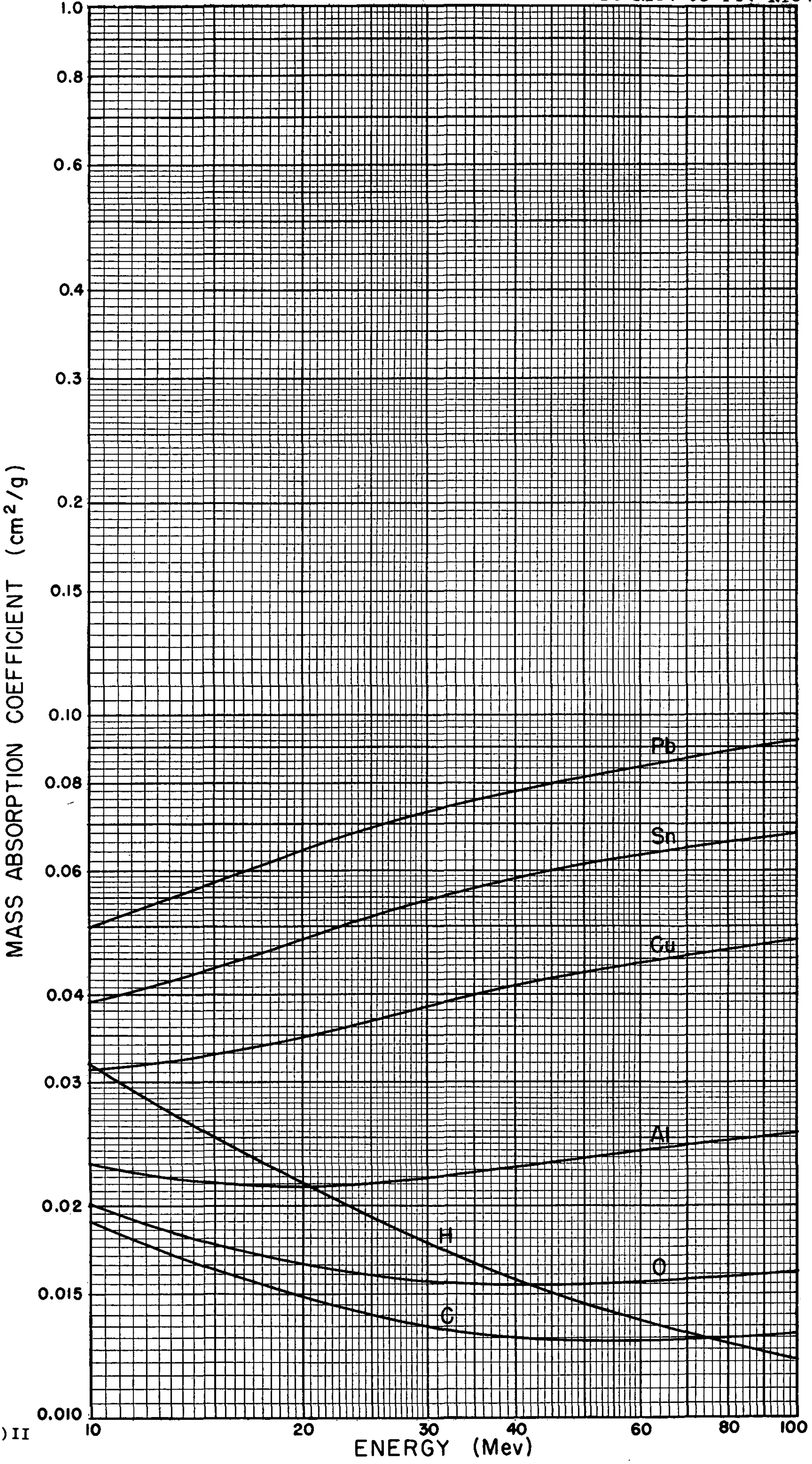


PHOTON MASS-ABSORPTION COEFFICIENT VS. ENERGY
1 to 10 Mev

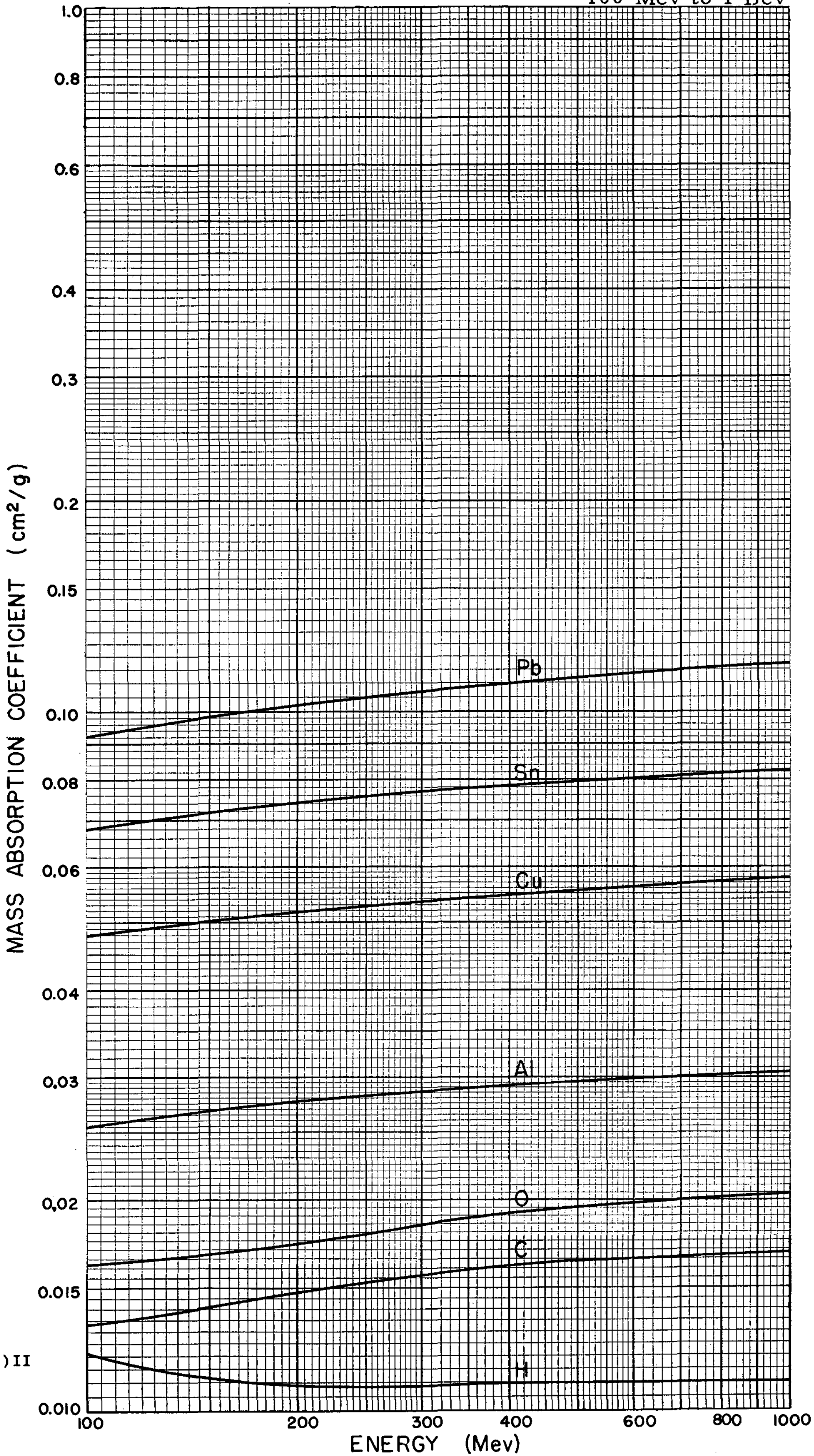


PHOTON MASS-ABSORPTION COEFFICIENT VS. ENERGY

10 Mev to 100 Mev

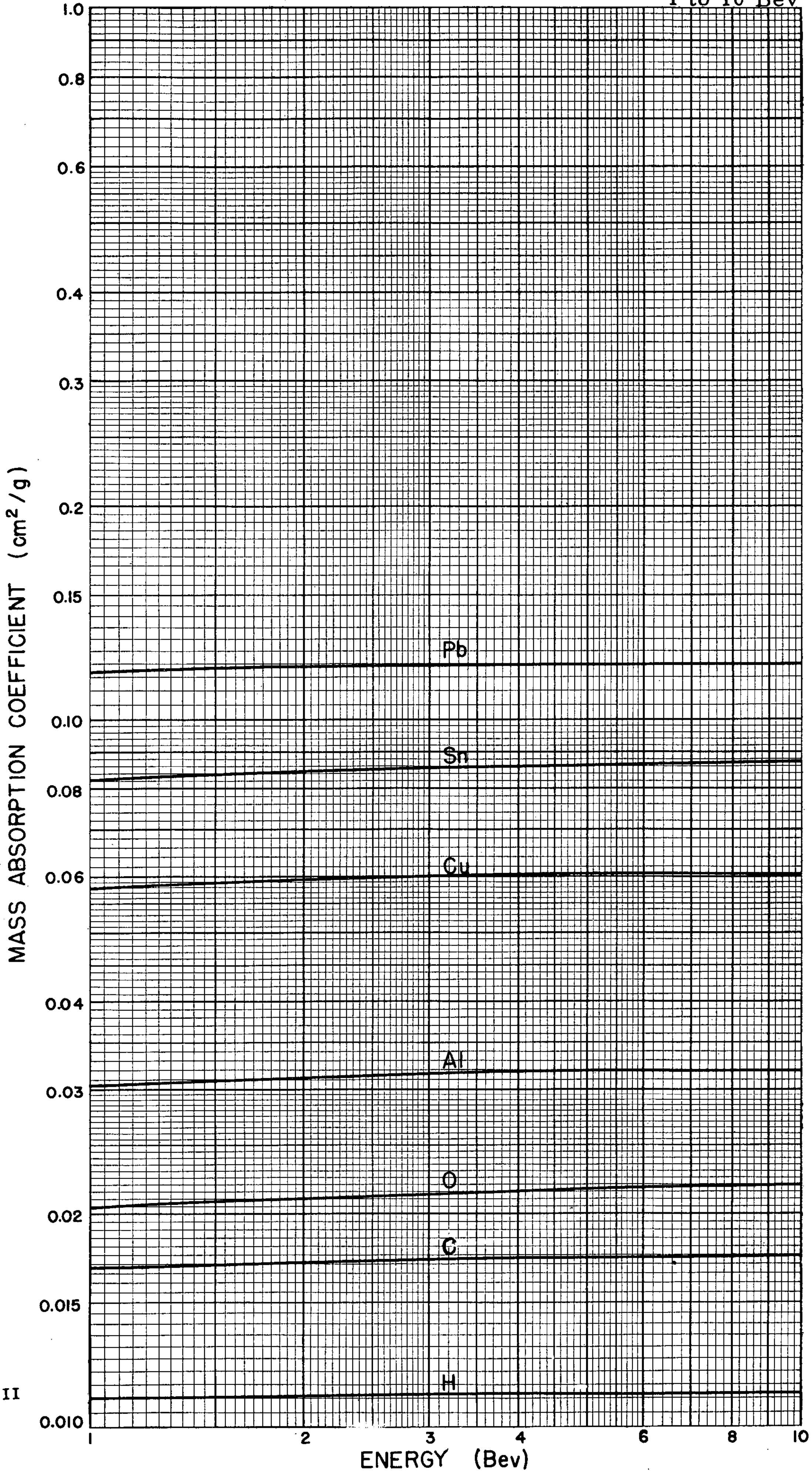


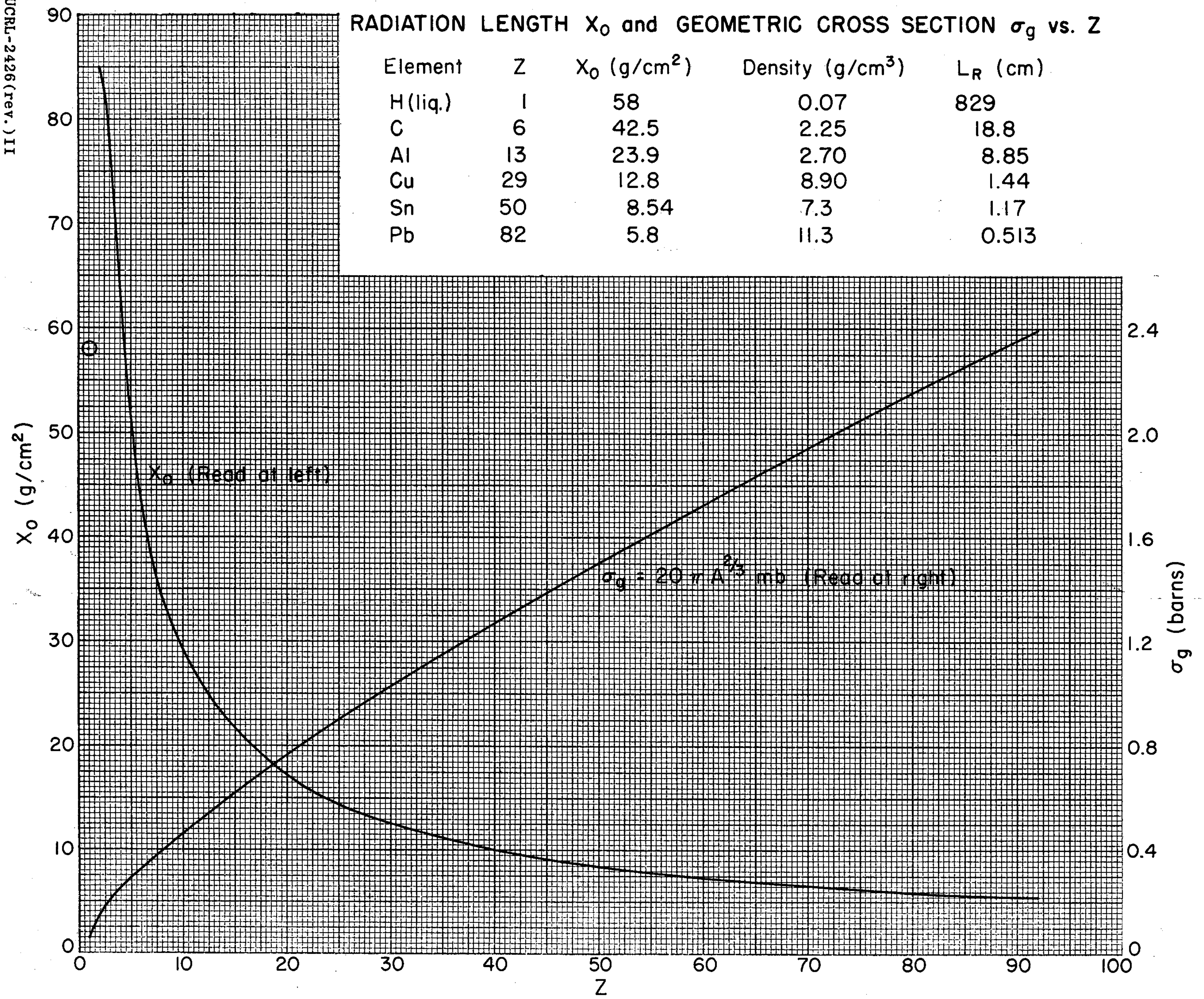
PHOTON MASS-ABSORPTION COEFFICIENT VS. ENERGY
100 Mev to 1 Bev



PHOTON MASS-ABSORPTION COEFFICIENT VS. ENERGY

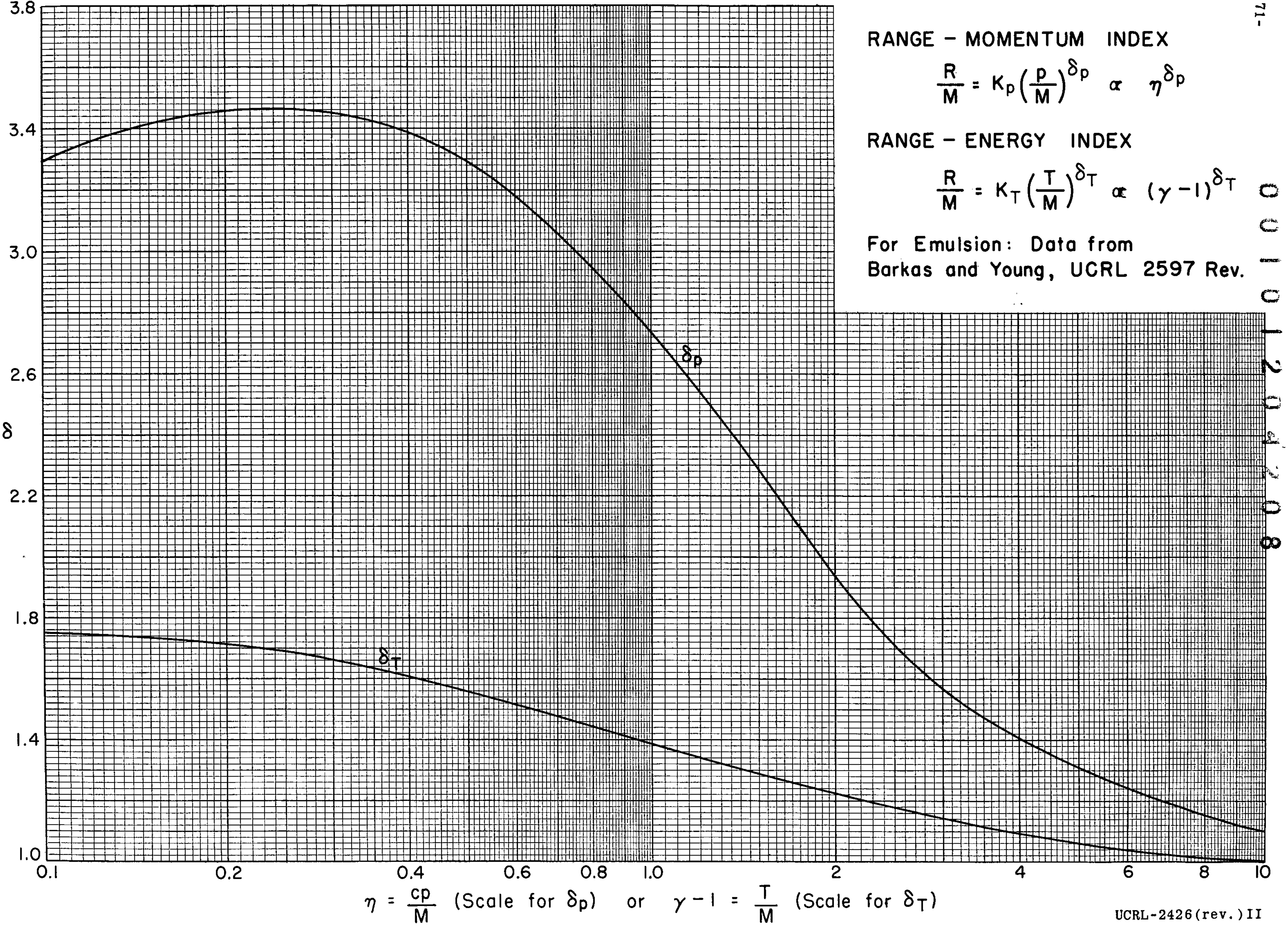
1 to 10 Bev

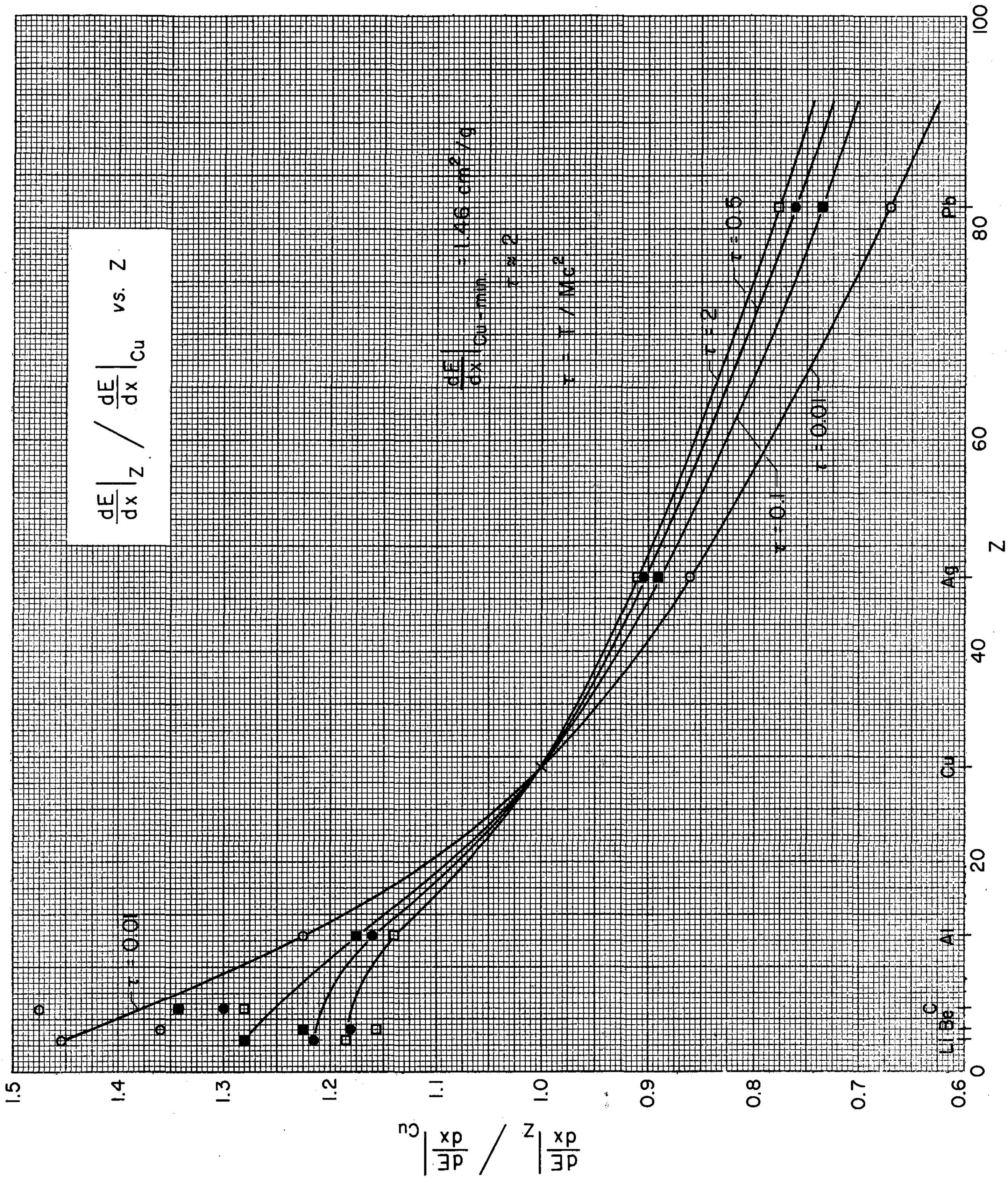


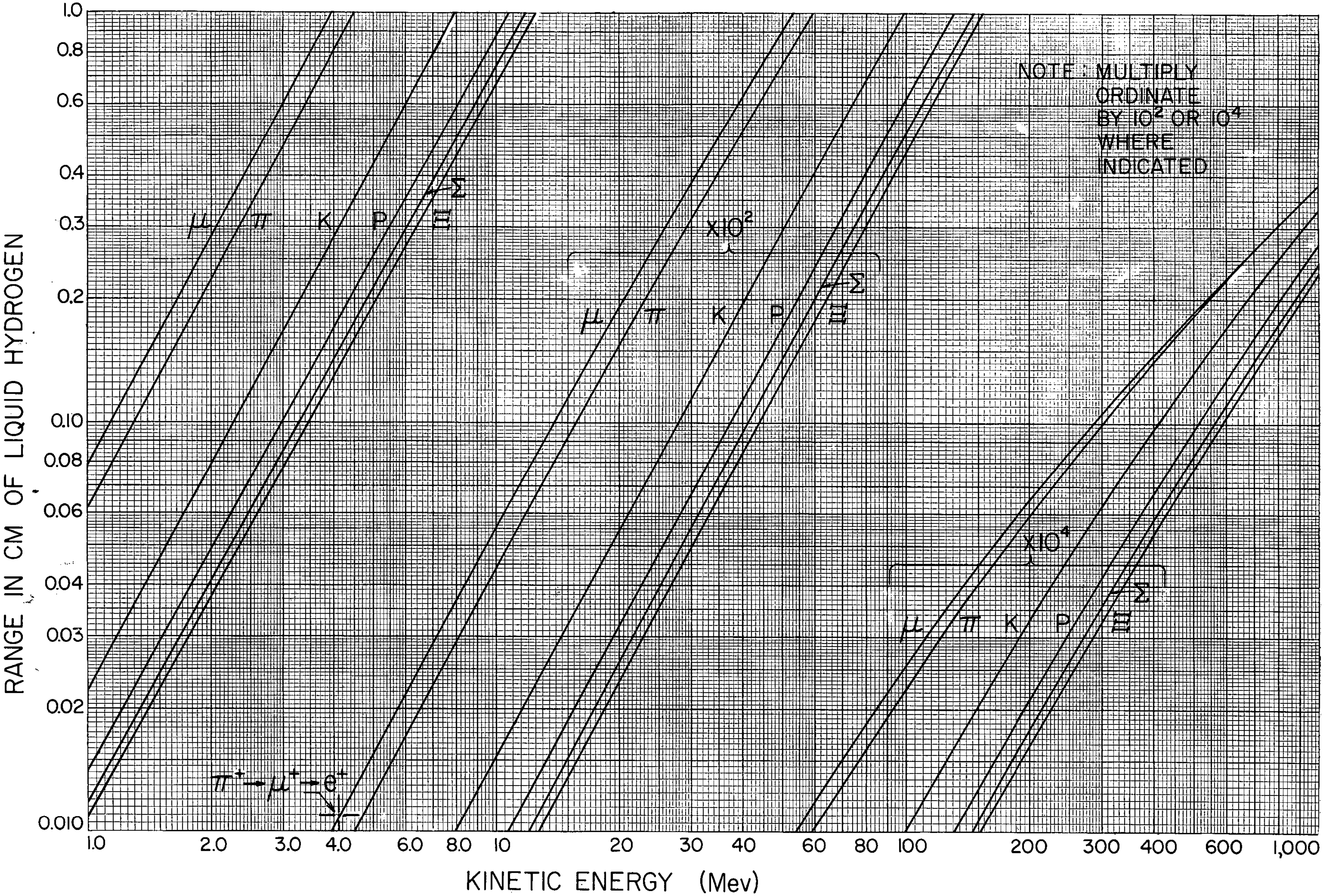


RADIATION LENGTH X_0 and GEOMETRIC CROSS SECTION σ_g vs. Z

Element	Z	X_0 (g/cm^2)	Density (g/cm^3)	L_R (cm)
H (liq.)	1	58	0.07	829
C	6	42.5	2.25	18.8
Al	13	23.9	2.70	8.85
Cu	29	12.8	8.90	1.44
Sn	50	8.54	7.3	1.17
Pb	82	5.8	11.3	0.513


RANGE – MOMENTUM INDEX
$\frac{R}{M} = K_p\left(\frac{p}{M}\right)^{\delta_p} \propto \eta^{\delta_p}$
RANGE – ENERGY INDEX
$\frac{R}{M} = K_T\left(\frac{T}{M}\right)^{\delta_T} \propto (\gamma-1)^{\delta_T}$
For Emulsion: Data from
Barkas and Young, UCRL 2597 Rev.
δ_p
δ_T
δ
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
$\eta = \frac{cp}{M}$ (Scale for δ_p) or $\gamma - 1 = \frac{T}{M}$ (Scale for δ_T)


$\frac{dE}{dx}\Big|_Z \Big/ \frac{dE}{dx}\Big|_{Cu}$ vs. Z
$\frac{dE}{dx}\Big|_{Cu\text{-min.}} = 1.46\ \text{cm}^2/\text{g}$
$\tau \approx 2$
$\tau = T / Mc^2$
$\tau = 2$
$\tau = 0.5$
$\tau = 0.1$
$\tau = 0.01$
$\tau = 0.01$
Li
Be
C
Al
Cu
Ag
Pb
0
20
40
60
80
100
Z
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
$\frac{dE}{dx}\Big|_Z \Big/ \frac{dE}{dx}\Big|_{Cu}$

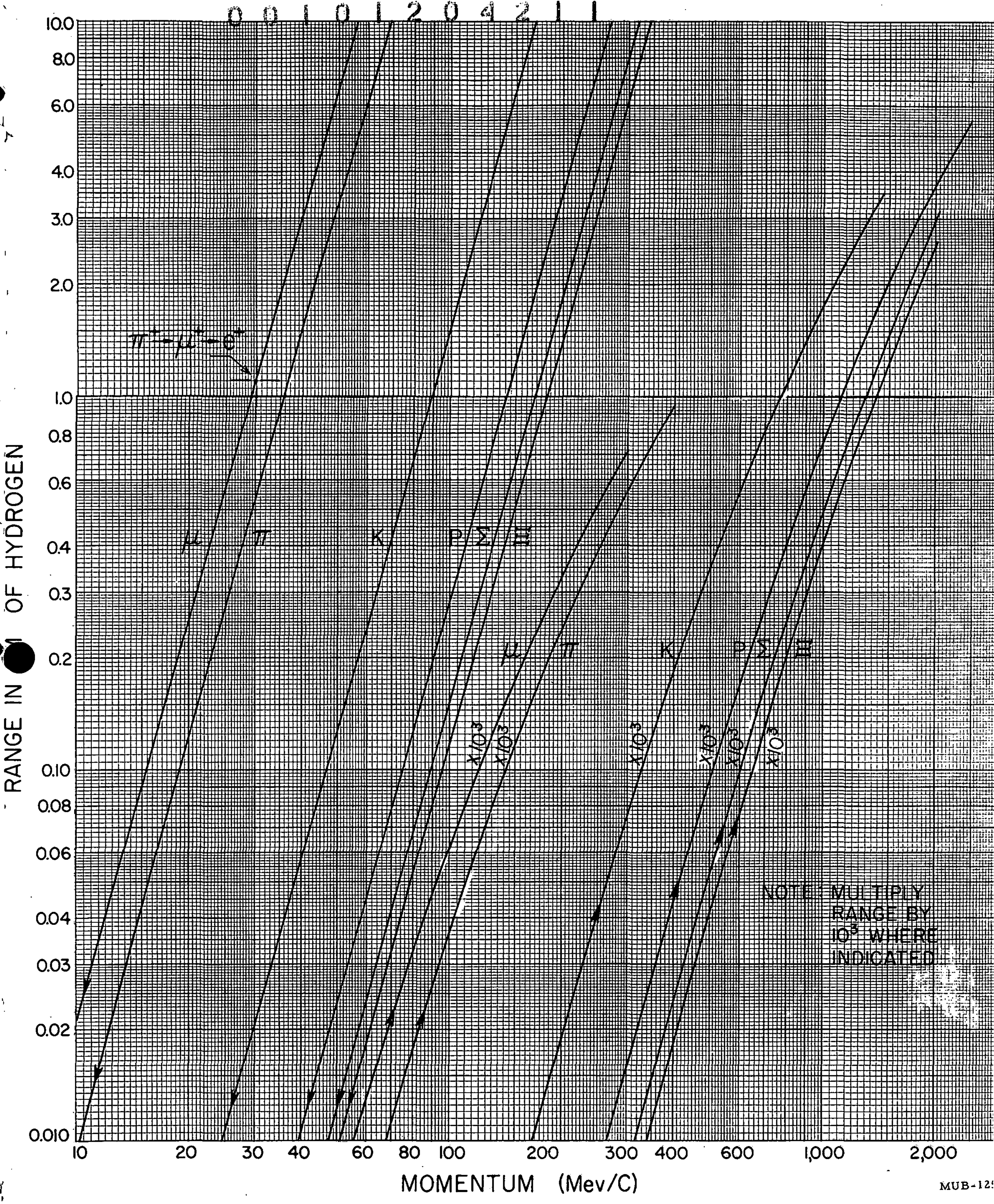


Range-energy curves for liquid hydrogen bubble chamber, based on experimentally determined range of 1.103±.003 cm for μ^+ from π^+ decay. Liquid hydrogen conditions: T = 27.6 ±.1° K; P = 48±5 psia; $\rho = (5.86 \pm .06)\ 10^{-2}\ g/cm^3$. Mass ratios used: $M_\mu/M_p = 0.1127$; $M_\pi/M_p = 0.1488$; $M_k/M_p = 0.526$; $M_\Sigma/M_p = 1.270$; $M_\Xi/M_p = 1.408$.

(by Glenwood Clark and William Diehl)

MUB-124

0010120421 1



MUB-12

Range-momentum curves for liquid hydrogen bubble chamber, based on experimentally determined range of 1.103±.003 cm for μ^+ from decay of π^+. Within arrowheads (↔) curves are straight lines corresponding to $p \propto R^{0.278}$. Liquid hydrogen conditions: $T = 27.6 \pm .1^\circ$ K, $P = 48.5 \pm 5$ psia, $\rho = (5.86 \pm .06) 10^{-2}$ g/cm^3. Mass ratios used: $M_\mu / M_p = 0.1127$; $M_\pi / M_p = 0.1488$; $M_k / M_p = 0.526$; $M_\Sigma / M_p = 1.270$; $M_\Xi / M_p = 1.408$.

(by Glenwood Clark and William Diehl)

Mnemonic Device for Relativistic Kinematic Formulas

Frank S. Crawford, Jr.

In order to obtain slide-rule accuracy for kinetic energies, using a slide rule, one should use formulae expressed in terms of kinetic energies, because if one uses the total energy, the rest mass often uses up the first few significant figures.

The following mnemonic device enables one to write down the exact relativistic (R) formula, if one remembers the nonrelativistic (NR) one:

(a) Write the correct NR formula.

(b) To the rest energy of each moving particle add one-half of the total kinetic energy in the center-of-mass (c. m.) system.

Example 1:

A particle of rest mass m_1 and lab kinetic energy $T_1{}^0$ is incident on a stationary particle of rest mass m_2. What is the total kinetic energy T in the c.m. system? (Let c = 1.)

$$\text{(a) NR:} \quad T = T_1{}^0 \left(\frac{m_2}{m_2 + m_1} \right);$$

$$\text{(b) R:} \quad T = T_1{}^0 \left(\frac{m_2}{m_2 + m_1 + (T/2)} \right).$$

To solve this quadratic expression numerically for T, it is easier and faster to consider this as a recursion formula, and use a slide rule, than to rewrite and solve by radicals. For example, a 600-Mev proton on a proton gives

$$T_{(n+1)} = 600 \left(\frac{938}{938 + 938 + T_{(n)}/2} \right) = (0),\ \underset{\substack{\uparrow \\ \text{NR}}}{300},\ 278,\ \underset{\substack{\uparrow \\ \text{R}}}{279},\ 279,\ \cdots \text{ Mev.}$$

Example 2:

Two particles, of rest mass m_1 and m_2, share the kinetic energy $T = T_1 + T_2$ in their c.m. system. How do they divide up T?

$$\text{(a) NR:} \quad T_1 = T \left(\frac{m_2}{m_2 + m_1} \right);$$

$$\text{(b) R:} \quad T_1 = T \left(\frac{m_2 + T/2}{m_2 + T/2 + m_1 + T/2} \right) = T \left(\frac{m_2 + T/2}{m_1 + m_2 + T} \right)$$

For instance, what is the kinetic energy of the μ meson (rest mass 106 Mev) in the decay of a π meson (rest mass 140 Mev) $\pi \rightarrow \mu + \nu$?

$$T_\mu = 34 \, \frac{(0 + 34/2)}{(0 + 106 + 34)} = 4.13 \text{ Mev.}$$

Example 3:

A single particle m_1 moves relative to the lab origin, where an infinite mass is located (so that the lab and c.m. systems are equivalent). Express the particle's kinetic energy in terms of its momentum and rest energy.

(a) NR: $T = \frac{p^2}{2m}$;

(b) R: $T = \frac{p^2}{2(m + (T/2))}$.

This example exposes the underlying root of the "mnemonic," in the exact relativistic formulae. We added an infinite mass at the origin so that we could use the "mnemonic" without modifying the phrase "in the c.m. system." One could perhaps say that the infinite mass provides the inertial frame in which special relativity is true.

Some Simple Rules of Relativistic Kinematics

Frank T. Solmitz

I. Energy-Angular Distributions

In many problems in particle physics one has to transform an energy-angular distribution from one frame of reference to another (say, from the laboratory system to the center-of-mass system of a reaction). This transformation is given simply by

$$\frac{1}{P}\frac{d^2n}{dW\,d\Omega} = \frac{1}{P'}\frac{d^2n}{dW'\,d\Omega'} ,$$

where P, W, and Ω are the momentum, total energy, and solid angle in one frame and the corresponding primed quantities refer to the other frame. In other words, P dW dΩ is Lorentz-invariant.

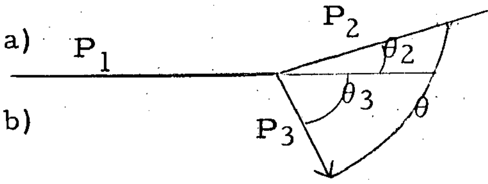
II. Two-Body Decays

Consider Particle 1 decaying into Particles 2 and 3, with respective masses and momenta M_1, M_2, M_3, P_1, P_2, P_3; let the angle between the directions of Particles 2 and 1 be θ_2, and that between 3 and 1 be θ_3, and let $\theta \equiv \theta_2 + \theta_3$. Given two of the momenta and one angle, or both angles and one momentum, one can identify the type of decay process with the help of kinematics tables and graphs (see, for example, Howard S. White, Identification Curves for Heavy-Meson and Hyperon Decays, UCRL-3514, Sept. 1956). However, one can often rule out certain possible identifications, even if only two quantitites are measured, by the use of simple inequalities:

$$P_2 \sin\theta_2 = P_3 \sin\theta_3 \leqslant P_{c.m.} , \qquad (a)$$

$$P_1 \sin\theta_2 = P_3 \sin\theta \leqslant (M_1/M_2)\, P_{c.m.} , \qquad (b)$$

$$P_1 \sin\theta_3 = P_2 \sin\theta \leqslant (M_1/M_3)\, P_{c.m.} , \qquad (c)$$



Here $P_{c.m.}$ denotes the momentum of Particle 2 (or 3) in the rest frame of Particle 1:

$$P_{c.m.} = \frac{1}{2M_1}\left[(M_1 + M_2 + M_3)(M_1 - M_2 - M_3)(M_1 + M_2 - M_3)(M_1 - M_2 + M_3)\right]^{1/}$$

Equation (a) is a consequence of the invariance of the momentum components transverse to the direction of flight of Particle 1. Similarly, Eq. (b) follows from consideration of the momentum components transverse to the direction of flight of Particle 2, and from noting that the momentum of Particle 1 (or 3) in the rest frame of Particle 2 is $(M_1/M_2)\, P_{c.m.}$

Similar restrictions govern three-body decays.

Solid Angle Subtended by a Finite Rectangular Counter

Frank S. Crawford, Jr.

A geometry problem that arises in particle detection is the calculation of the solid angle Ω subtended by a "finite" detector at a source of particles. For a rectangular detector and a point source, a simple formula can be obtained for the integrated solid angle. First consider the special case in which the point source P is located a distance c perpendicularly above a corner of a rectangle of length a and width b (see Fig. 1). Then we have

$$\tan \Omega = \frac{ab}{r^2_{\text{eff}}} ,$$

where ab = area of rectangle,

$r_{\text{eff}} = \sqrt{cd}$ = geometric mean of smallest and largest distances from P to the rectangle,

$d = \sqrt{c^2 + a^2 + b^2}$.

Thus the finite solid-angle formula is obtained from that of an infinitesimal detector by replacing r^2 by r^2_{eff}, and Ω by $\tan \Omega$.

The above holds only for the special case in which the perpendicular from P to the plane of the detector intersects one corner of the detector. We can now use this result to obtain the solid angle subtended by a rectangle oriented arbitrarily with respect to P. Let σ be the intersection with the plane of the rectangle of the perpendicular from P to the plane of the rectangle. If σ lies inside the rectangle (Fig. 2), it implies the four subrectangles A, B, C, and D; we simply apply the formula to them and add the results. If σ lies outside the rectangle (Fig. 3), then we apply the formula to the four rectangles A + B + C + D, B + C, C + D, and C, and find the desired quantity from A = (A + B + C + D) - (C + D) - (B + C) + C.

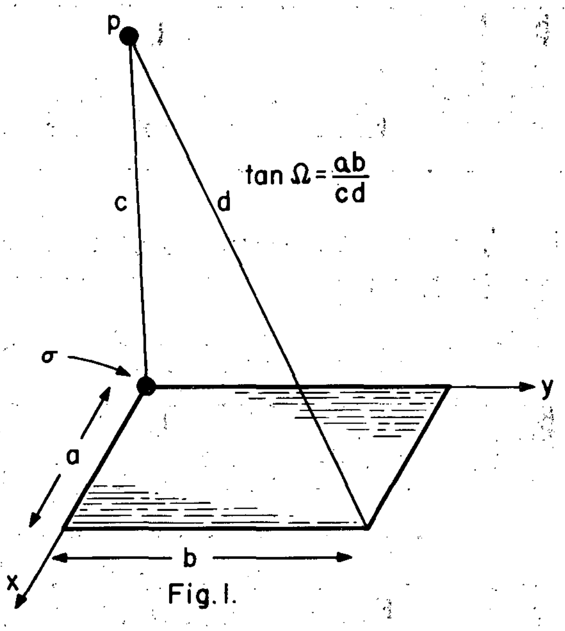
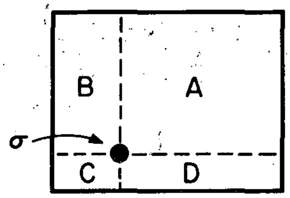


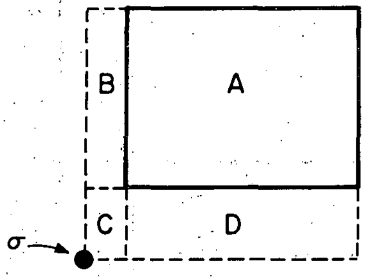
Fig. I.



$$\Omega = \Omega_A + \Omega_B + \Omega_C + \Omega_D$$

Fig. 2.

Fig. 3.



$$\Omega = \Omega_{A+B+C+D} - \Omega_{B+C} - \Omega_{C+D} + \Omega_C$$

MU-4773

NORMALIZED EMULSION QUANTITIES TABULATED AS FUNCTIONS OF THE PARTICLE VELOCITY

September 1954

1 Velocity	2 Proton Kinetic Energy	3 Kinetic Energy	4 Momentum and Magnetic Curvature	5 Multiple Scattering	6 Maximum Energy of δ-Ray	7 Energy Loss Rate	8 Residual Range	9 Percentage Straggling	10 Delta-Ray Density	11 Residual Proper Time	12 Restricted Energy Loss Rate and Grain Density	13 Range-Energy Index
$\beta = v/c$	$\tau = T/M$	$\gamma - 1 = T/E_o$	$\beta\gamma = pc/E_o$	$\beta^2\gamma = p\beta c/E_o$	$\epsilon_1 = 1.022(\gamma^2 - 1)$	$\iota = I/z^2$	$\lambda = z^2 R'/M$	$\phi = 100\sigma/\lambda$	$\nu = N/z^2$	$\theta = z^2 t/M$	$\iota' = I'/z^2$	$\eta = \lambda\iota/\tau$
			$= \frac{z' B\rho}{3335.64E_o}$	$= \frac{Kz}{\langle n \rangle E_o}\left(\frac{s}{100}\right)^{1/2}$				$= \frac{100\sqrt{M}\,S}{R'}$			$= \frac{I'_o}{z^2} \ln \frac{n_o}{n_o - n}$	
	Mev				Mev	Mev/cm	cm		cm^{-1}	Sec	$Mev.cm^2/g$	
0.0461342	1.000	0.001065886	0.0461843	0.00213063	0.002174	508.1	14.0×10^{-4}	2.11	0	1.5×10^{-12}	115.	0.711
0.0651921	2.000	0.002131771	0.0653310	0.00425907	0.004362	331.0	39.1	1.94	0	3.0	70.7	0.647
0.0797800	3.000	0.003197656	0.0800352	0.00638521	0.006547	252.0	74.1	1.79	0	4.6	53.3	0.622
0.0920477	4.000	0.004263542	0.0924401	0.00850890	0.008733	206.7	118.2	1.71	0	6.3	42.5	0.612
0.1028308	5.000	0.005329428	0.1033788	0.01063054	0.01092	176.4	170.8	1.66	1	8.1	35.6	0 603
0.1125564	6.000	0.006395313	0.1132762	0.01274996	0.01311	154.4	231.8	1.63	4	9.9	31.0	0.596
0.1214786	7.000	0.007461198	0.1223849	0.01486715	0.01531	138.0	300.0	1.60	7	11.9	27.3	0.591
0.1297633	8.000	0.008527084	0.1308698	0.01698209	0.01750	125.1	376.3	1.57	10	13.9	24.6	0.588
0.1375260	9.000	0.009592970	0.1388453	0.01909484	0.01970	114.6	459.9	1.55	17	15.9	22.4	0.586
0.1448508	10.00	0.01065886	0.1463947	0.02120539	0.02190	105.9	550.7	1.53	30	18.1	20.5	0.583
0.1616290	12.50	0.01332357	0.1637824	0.02647201	0.02741	89.02	813.1	1.49	60	23.6	17.5	0.579
0.1767080	15.00	0.01598828	0.1795333	0.03172497	0.03294	77.85	1110.	1.46	79	29.4	15.0	0.576
0.1904929	17.50	0.01865300	0.1940462	0.03694144	0.03846	69.19	1451.	1.44	89	35.5	13.4	0.574
0.2032481	20.00	0.02131771	0.2075809	0.04219045	0.04404	62.46	1831.	1.42	96	41.9	12.0	0.572
0.2263568	25.00	0.02664714	0.2323886	0.05260273	0.05519	52.61	2708.	1.38	98	55.1	10.0	0.570
0.2470048	30.00	0.03197657	0.2549032	0.06296230	0.06641	45.71	3730.	1.36	89	69.0	8.77	0.568
0.2657732	35.00	0.03730599	0.2756881	0.07327052	0.07768	40.58	4894.	1.34	83	83.6	7.714	0.567
0.2830403	40.00	0.04263542	0.2951078	0.08352739	0.08900	36.63	6192.	1.32	77	98.7	6.905	0.567
0.2990724	45.00	0.04796485	0.3134173	0.09373446	0.1004	33.47	7622.	1.30	72	114.	6.268	0.567
0.3140626	50.00	0.05329428	0.3308003	0.1038920	0.1118	30.88	9179.	1.29	67	130.	5.751	0.567
0.3414745	60.00	0.06395313	0.3633129	0.1240621	0.1349	26.89	1.267×10^{0}	1.27	61	164.	4.960	0.568
0.3661180	70.00	0.07461198	0.3934348	0.1440435	0.1582	23.96	1.661	1.25	57	198.	4.387	0.569
0.3885468	80.00	0.08527084	0.4216786	0.1638419	0.1817	21.70	2.100	1.23	53	234.	3.947	0.570
0.4091497	90.00	0.09592970	0.4483993	0.1834624	0.2055	19.91	2.582	1.22	49	271.	3.608	0.571
0.4282122	100.0	0.1065886	0.4738548	0.2029104	0.2295	18.45	3.104	1.21	47	309.	3.322	0.573
0.4704457	125.0	0.1332357	0.5331258	0.2508067	0.2905	15.77	4.574	1.18	38	406.	2.814	0.577
0.5066429	150.0	0.1598828	0.5876464	0.2977269	0.3529	13.92	6.270	1.16	30	507.	2.471	0.582
0.5382367	175.0	0.1865300	0.6386340	0.3437363	0.4168	12.59	8.161	1.14	27	610.	2.220	0.587
0.5661795	200.0	0.2131771	0.6868760	0.3888951	0.4822	11.56	10.24	1.13	25	714.	2.031	0.592

0.6136279	250.0	0.2664719	0.7771422	0.4768762	0.6172	10.12	14.73	1.10	23	925.	1.763	0.595
0.6525911	300.0	0.3197657	0.8612673	0.5620554	0.7581	9.136	19.92	1.08	21	1.14×10^{-9}	1.581	0.607
0.7130746	400.0	0.4263542	1.017097	0.7252660	1.057	7.914	31.76	1.05	19	1.55	1.359	0.625
0.7579264	500.0	0.5329428	1.161858	0.8806026	1.380	7.190	45.12	1.02	17	1.96	1.224	0.643
0.7924550	600.0	0.6395313	1.299255	1.029600	1.725	6.721	58.65	1.00	16	2.35	1.139	0.660
0.8197662	700.0	0.7461198	1.431410	1.173421	2.094	6.400	74.02	0.987	14	2.72	1.078	0.677
0.8418252	800.0	0.8527084	1.559657	1.312959	2.486	6.170	90.14	0.972	13	3.08	1.037	0.695
0.8599447	900.0	0.9592970	1.684887	1.448910	2.901	5.988	106.8	0.963	12	3.42	1.000	0.712
0.8750382	1000.0	1.065886	1.807729	1.581832	3.340	5.876	124.3	0.952	12	3.74	0.9788	0.728
0.8877610	1100.0	1.172474	1.928638	1.712169	3.801	5.782	141.5	0.943	12	4.04	0.9601	0.742
0.8985960	1200.0	1.279063	2.047957	1.840291	4.286	5.709	158.4	0.935	12	4.34	0.9452	0.754
0.9079065	1300.0	1.385651	2.165948	1.966478	4.795	5.654	175.7	0.929	11	4.62	0.9333	0.768
0.9159705	1400.0	1.492240	2.282818	2.090994	5.326	5.612	193.9	0.923	11	4.88	0.9231	0.780
0.9230046	1500.0	1.598828	2.398730	2.214039	5.880	5.581	212.2	0.918	11	5.14	0.9132	0.790
0.9291795	1600.0	1.705417	2.513818	2.335788	6.458	5.558	230.8	0.913	10	5.38	0.9084	0.802
0.9346305	1700.0	1.812005	2.628186	2.456383	7.059	5.541	248.4	0.910	10	5.62	0.9028	0.810
0.9394701	1800.0	1.918594	2.741932	2.575963	7.684	5.530	266.2	0.907	10	5.84	0.8984	0.818
0.9437855	1900.0	2.025182	2.855123	2.694624	8.331	5.523	283.9	0.904	10	6.06	0.8948	0.825
0.9476510	2000.0	2.131771	2.967826	2.812463	9.002	5.519	302.0	0.904	10	6.26	0.8918	0.833
0.9511276	2100.0	2.238360	3.080093	2.929562	9.696	5.516	320.4	0.903	10	6.46	0.8895	0.840
0.9542662	2200.0	2.344948	3.191971	3.045990	10.41	5.513	338.1	0.903	10	6.66	0.8874	0.847
0.9571096	2300.0	2.451537	3.303499	3.161810	11.15	5.509	355.8	0.902	10	6.84	0.8857	0.852
0.9596940	2400.0	2.558125	3.414711	3.277078	11.92	5.506	373.8	0.903	10	7.02	0.8843	0.858
0.9620502	2500.0	2.664714	3.525639	3.391842	12.70	5.507	391.9	0.903	10	7.20	0.8834	0.863
0.9642043	2600.0	2.771302	3.636306	3.506141	13.51	5.508	410.0	0.904	10	7.37	0.8827	0.869
0.9661791	2700.0	2.877891	3.746737	3.620019	14.35	5.509	428.0	0.904	10	7.53	0.8821	0.873
0.9679939	2800.0	2.984479	3.856951	3.733505	15.20	5.511	446.1	0.906	10	7.69	0.8816	0.878
0.9696657	2900.0	3.091068	3.966968	3.846633	16.08	5.513	464.1	0.909	10	7.82	0.8814	0.882
0.9712092	3000.0	3.197657	4.076803	3.959428	16.99	5.515	482.2	0.913	10	7.99	0.8814	0.886
0.9817868	4000.0	4.263542	5.167676	5.073556	27.29	5.551	662.0	0.935	9	9.30	0.8841	0.919
0.9874404	5000.0	5.329428	6.249932	6.171436	39.92	5.610	839.9	0.963	9	10.3	0.8900	0.945
0.9908155	6000.0	6.395313	7.327391	7.260092	54.87	5.677	1.021×10^{3}	0.990	9	11.2	0.8964	0.966
0.9929914	7000.0	7.461199	8.401897	8.343012	72.14	5.740	1.203	1.02	9	12.0	0.9026	0.986
0.9944760	8000.0	8.527084	9.474457	9.422120	91.74	5.799	1.382	1.05	9	12.6	0.9082	0.998
0.9955342	9000.0	9.592970	10.54566	10.49857	113.7	5.853	1.544	1.08	9	13.2	0.9133	1.00
0.9963148	10000.	10.65886	11.61589	11.57308	137.9	5.902	1.708	1.11	9	13.7	0.9180	1.01
0.9989956	20000.	21.31771	22.29529	22.27290	508.0	6.211	3.360	1.38	9	17.1	0.9473	1.04
0.9995401	30000.	31.97657	32.96140	32.94624	1110.0	6.389	4.94	1.62	9	19.0	0.9616	1.05

---Walter H. Barkas

Range-energy relation for emulsion of specific gravity 3.815

Walter H. Barkas
(March 26, 1957)

τ (Mev)	Range (cm)	τ (Mev)	Range (cm)	τ (Mev)	Range (cm)	τ (Mev)	Range (cm)
0.2	0.00018	20.0	0.1858	300	20.14	1000	124.2
0.4	0.00041	22.5	0.2283	320	22.37	1200	158.7
0.6	0.00070	25.0	0.2744	340	24.67	1400	194.1
0.8	0.00105	27.5	0.3243	360	27.04	1600	229.9
1.0	0.00144	30.0	0.3777	380	29.48	1800	266.1
1.2	0.00187	32.5	0.4347	400	31.98	2000	302.4
1.4	0.00234	35.0	0.4952	420	34.53	2200	338.8
1.6	0.00286	37.5	0.5591	440	37.14	2400	375.3
1.8	0.00343	40.0	0.6264	460	39.81	2600	411.7
2.0	0.00404	42.5	0.6970	480	42.52	2800	448.0
2.5	0.00574	45	0.7709	500	45.28	3000	484.2
3.0	0.00767	50	0.9275	520	48.08	3200	520.4
3.5	0.00983	55	1.097	540	50.93	3400	556.4
4.0	0.01223	60	1.278	560	53.81	3600	592.3
4.5	0.01484	65	1.471	580	56.73	3800	628.1
5.0	0.01765	70	1.675	600	59.69	4000	663.7
5.5	0.02065	75	1.891	620	62.68	4200	699.2
6.0	0.02384	80	2.117	640	65.71	4400	734.6
6.5	0.02724	85	2.353	660	68.76	4600	769.9
7.0	0.03082	90	2.600	680	71.84	4800	805.0
7.5	0.03460	100	3.124	700	74.96	5000	840.0
8.0	0.03857	110	3.686	720	78.09	6000	1013
8.5	0.04272	120	4.286	740	81.26	7000	1184
9.0	0.04706	130	4.923	760	84.44	8000	1352
9.5	0.05157	140	5.594	780	87.65	9000	1518
10	0.05626	150	6.298	800	90.88	10000	1682
11	0.06628	160	7.034	820	94.13	11000	1844
12	0.07696	170	7.800	840	97.40	12000	2005
13	0.08825	180	8.596	860	100.7	13000	2164
14	0.1002	190	9.421	880	104.0	14000	2323
15	0.1129	200	10.27	900	107.3	15000	2479
16	0.1262	220	12.06	920	110.7	20000	3249
17	0.1402	240	13.95	940	114.0	25000	4000
18	0.1548	260	15.92	960	117.4	30000	4735
19	0.1700	280	17.99	980	120.8	35000	5459

Density and Chemical Constitution of Various Materials

Substance	Formula	Density	Condition
Hydrogen	H_2	0.070 g/cm^3	liquid--21°K
	H_2	0.08988 g/ℓ	gas--a 0°C, 760 mm
Polyethylene	H_8C_4	0.92 g/cm^3	
Polystyrene	H_8C_8	1.054-1.070 g/cm^3	
Lucite	$H_8C_5O_2$	1.16-1.20 g/cm^3	
Glass (crown)	SiO_2, 67.0%	2.243 g/cm^3	
	Na_2O, 12.0%		
	K_2O, 5.0%		
	B_2O_3, 3.5%		
	BaO, 10.6%		
	ZnO, 1.5%		
	As_2O_3, 0.4%		
Plastic Scintillator		~1.05	(see polystyrene)
	97% polystyrene		
	3% terphenyl		
	0.03% tetraphenyl butadiene		
Sodium Iodide	NaI	3.667 g/cm^3	
Fluor Chemical (Carbon)	$C_8F_{16}O$	1.76 g/cm^3	

Index of Refraction of Various Materials for Sodium D Lines

		Reference
Hydrogen (liquid, -252.83°C)	1.0974	CR[a]
Nitrogen (liquid, -190°C)	1.2053	CR
Xenon (gas)	1.000703	Landolt-Börnstein
(liquid)		
Propane (liquid, -42.2°C)	1.3397	Egloff
Pentane (liquid, 15.7°C)	1.358	Handbook of Physics
Water	1.3335	CR
Lucite	1.49-1.51	CR
Glass (crown)	1.51714	CR
Quartz (fused)	1.45845	CR
Fluor Chemical	1.276	
Lead Glass ($\rho = 3.89$)	1.649	Brabant
Polystyrene	1.592-1.597	CR

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[a] Handbook of Chemistry and Physics, Charles D. Hodgman, Ed. (Chemical Rubber Publishing Co., Cleveland).

Masses and Lifetimes of Elementary Particles

	Particle	Spin	Mass (Errors represent standard deviation) (Mev)		Mass difference (Mev)	Mean life (sec)		Decay rate (number per second)
Photons	γ	1	0.00			stable		0.0
Leptons and antileptons	$\nu, \bar{\nu}$	1/2	0.00			stable		0.0
	e^-, e^+	1/2	0.510976	*		stable		0.0
	μ^-, μ^+	1/2	105.70±0.06	*		$(2.22\pm0.02)\times10^{-6}$	*	0.45×10^{6}
Mesons	$\pi^\pm$	0	139.63±0.06	*	4.6 *	$(2.56\pm0.05)\times10^{-8}$	*	0.39×10^{8}
	π^0	0	135.04±0.16	*		$(0.0<\tau<0.4)\times10^{-15}$	(O)	$>2.5\times10^{15}$
	$K^\pm$	0	494.0 ±0.14	(a)	1 ± 5	$(1.224\pm.013)\times10^{-8}$	(b)	0.815×10^{8}
						K_1: $(0.95\pm.08)\times10^{-10}$	(P)	1.05×10^{10}
	K^0	0	493 ±5	(Th)		K_2: $(3<\tau<100)\times10^{-8}$	(L)(P)	$(>0.01, <0.3)\times10^{8}$
Baryons†	p	1/2	938.213±0.01	*		stable		0.0
	n	1/2	939.506±0.01	*		$(1.04\pm0.13)\times10^{3}$	*	0.96×10^{-3}
	Λ	1/2 ?	1115.0 ±0.16	(c)		$(2.77\pm0.15)\times10^{-10}$	(d)	0.36×10^{10}
	Σ^+	1/2 ?	1189.3 ±0.3	(W)	7.20±0.1	$(0.78\pm.074)\times10^{-10}$	(e)	1.28×10^{10}
	Σ^-	1/2 ?	1196.5 ±0.5	(W)	8.3^{+3}_{-2}	$(1.58\pm.17)\times10^{-10}$	(f)	0.64×10^{10}
	Σ^0	1/2 ?	1188.2^{+3}_{-2}	(g)		$(<1)\times10^{-11}$	(A)	$<10\times10^{10}$
	Ξ^-	?	1321 ±3.5	*		$(4.6<\tau<200)\times10^{-10}$	(Tr)	$(>0.005, <0.2)\times10^{10}$
	Ξ^0	?	?			?		

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*From compilations by Cohen, Crowe, and DuMond, Nuovo cimento 5, 541 (1957), and "Fundamental Constants of Physics," to be published by Interscience, New York, 1957. They include all data available before January 1, 1957.

†Antibaryons have the same spin, mass, and mean life as baryons.

(AHR, May 1957)

(A) Alvarez, Bradner, Falk-Vairant, Gow, Rosenfeld, Solmitz, and Tripp, K^- Interactions in Hydrogen, UCRL-3775, May 1957.
(L) Lande, Booth, Impeduglia, Lederman, and Chinowsky, Phys. Rev. 103, 1901 (1956).
(O) Orear, Harris, and Taylor, Bull. Am. Phys. Soc. 1126 (1957).
(P) Plano, Samios, Schwartz, and Steinberger, Phys. Rev. (to be published) 1957.
(Th) Thompson, Burwell, and Huggett, Supplemento 3 Nuovo cimento 4, 286 (1956).
(Tr) G.H. Trilling and G. Neugebauer, Phys. Rev. 104, 1688 (1956).
(W) R. S. White, compilation of all emulsion data available from all laboratories, prepared for 7th Rochester Conference (private communication).

(a) $M_{K\pm} = 3M_{\pi\pm} + Q_\tau$, where Q_τ is the weighted average from Heckman, Smith, and Barkas, Nuovo cimento 4, 51 (56); from Roy Haddock, Nuovo cimento 4, 240 (56); and from Bacchella, Berthelot, et al., Nuovo cimento 4, 1529 (56). We have assumed that the K^- is the antiparticle of the K^+ and shares the same mass and lifetime. The present experimental mass of the K^- is consistent with this assumption, namely 493.4 ± 0.5 Mev (White, 1957).

(b) Weighted average of
1.227 ± 0.015 (Alvarez, Crawford, Good, and Stevenson, Phys. Rev. (to be published)).
1.211 ±0.026 (V. Fitch and R. Motley, Phys. Rev. 101, 496 (1956); Phys. Rev. 105, 265 (1957); and private communication.) The quoted errors are statistical only.

(c) Weighted average of
1114.82 ± 0.18 *
1115.74 ± 0.4 (R. Armenteros, report at 7th Rochester Conference, private communication).

(d) Weighted average of
1.9 ± 0.4 (Graves, Brown, Glaser, and Perl, Bull. Am. Phys. Soc. 2, 221 (1957)).
2.77 ± 0.2 (Eisler, Plano, Samios, Steinberger, and Schwartz, Bull. Am. Phys. Soc. 2, 221 (1957)).
3.1 ± 0.5 (A)
3.25 ± 0.33 *

(e) Weighted average of
0.95 ± 0.30 (Graves, Brown, Glaser, and Perl, Bull. Am. Phys. Soc. 2, 221 (1957)).
0.69 ± 0.1 (A)
0.89 ± 0.12 (compilation of all emulsion data available from all laboratories, prepared for 7th Rochester Conference by G. Snow (private communication)).

(f) Weighted average of
1.5 ± 0.35 (Eisler, Plano, Samios, Steinberger, and Schwartz, Bull. Am. Phys. Soc. 2, 221 (1957)).
1.6 ± 0.2 (A)

(g) Combined result from Alvarez et al., K^- Interactions in Hydrogen, UCRL-3583, Nov. 1956, and a private communication from M. Schwartz and R. Plano giving $Q = 73.5 \pm 3.5$ for $\Sigma^0 \rightarrow \Lambda + \gamma + Q$. We have assumed that the K^- is the antiparticle of the K^+ and shares the same mean life. The present experimental mean life is consistent with this assumption, namely $\tau_{K^-} = 1.25 \pm 0.11$ (W. H. Barkas, Seventh Rochester Conference).

Kinematics of Meson Decays

Decay mode	Momentum, p $(\text{Mev}/c)^a$	Total energy $w = T + mc^2$ $(\text{Mev})^a$	Available kinetic energy, Q (Mev)
$e^{\pm}$ (mass = 0.510976 Mev)			
$\mu^{\pm}$ (mass = 105.70 ± .06 Mev) $\mu^{\pm} \rightarrow e^{\pm} + \nu + \bar{\nu}$	$p^m = 52.85$	$w_e^m = 52.85$	105.19
$\pi^{\pm}$ (mass = 139.63 ± .06 Mev) $\pi^{\pm} \rightarrow \mu^{\pm} + \nu$	$p = 29.81$	$w_\mu = 109.82$	33.93
π^0 (mass = 135.04 ± .16 Mev) $\pi^0 \rightarrow \gamma + \gamma$	$p = 67.52$	$w_\gamma = 67.52$	135.04
K^+ (mass = 494.0 ± 0.14 Mev) $K_{\pi 2} \rightarrow \pi^+ + \pi^0$	$p = 205.3$	$w_{\pi^+} = 248.25$	219.33
$K_\tau \rightarrow \pi^+ + \pi^+ + \pi^-$	$p_\pi^m = 125.5$	$w_\pi^m + 187.8$	75.11
$K_{\tau'} \rightarrow \pi^+ + \pi^0 + \pi^0$	$p_{\pi^+}^m = 133.1$ $p_{\pi^0}^m = 132.3$	$w_{\pi^+}^m = 192.9$ $w_{\pi^0}^m = 189.0$	84.29
$K_{\mu 2} \rightarrow \mu^+ + \nu$	$p = 235.7$	$w_\mu = 258.3$	388.3
$K_{\mu 3} \rightarrow \mu^+ + \pi^0 + \nu$	$p_\mu^m = 215.2$ $p_\pi^m = 215.3$	$w_{\mu^+}^m = 239.8$ $w_{\pi^0}^m = 254.1$	253.26
$K_{\mu 3} \rightarrow e^+ + \pi^0 + \nu$	$p_e^m = 228.5$ $p_\pi^m = 228.5$	$w_{e^+}^m = 228.5$ $w_{\pi^0}^m = 265.4$	358.45

Kinematics of Meson Decays (cont'd)

Decay mode	Momentum, p (Mev/c)[a]	Total energy, $w = T + mc^2$ (Mev)[a]	Available kinetic energy, Q (Mev)
$K_{e2} \rightarrow e^+ + \nu$	$p = 247.0$	$w_{e^+} = 247.0$	493.49
$K_{\pi\gamma} \rightarrow \pi^+ + \gamma$	$p = 227.2$	$w_{\pi^+} = 266.7$	354.37
K^0 (mass = 493 ± 5 Mev)			
$K^0 \rightarrow \pi^+ + \pi^-$	$p = 203.1$	$w = 246.5$	213.7
$\rightarrow \pi^0 + \pi^0$	$p = 206.2$	$w = 246.5$	222.9
$\rightarrow \pi^+ + \pi^- + \pi^0$	$p^m_{\pi^\pm} = 128.4$	$w^m_{\pi^\pm} = 189.7$	78.7
$\rightarrow \mu^\pm + \pi^\mp + \nu$	$p^m_\mu = 213.2$	$w^m_\mu = 238.0$	247.7
	$p^m_\pi = 213.2$	$w^m_\pi = 254.9$	
$\rightarrow e^\pm + \pi^\mp + \nu$	$p^m_\pi = 226.6$	$w^m_\pi = 266.2$	352.9
	$p^m_e = 226.6$	$w^m_e = 226.7$	

[a] The momentum and total energy are given in the rest frame of the decaying particle. In three-body decays, the maximum momentum and energy possible for each of the products is given, as indicated by the superscript m.

Kinematics of Baryon Decays

Decay mode	Momentum, p (Mev/c)	Total energy, $w = T + mc^2$ (Mev)	Available kinetic energy, Q (Mev)
p (mass = 938.21 ± 0.01 Mev) n (mass = 939.51 ± 0.01 Mev)			
Λ (mass = 1115.0 ± .16 Mev)			
$\Lambda \rightarrow p + \pi^-$	99.6	$w_p = 943.5$ $w_\pi = 171.5$	37.2
$\Lambda \rightarrow n + \pi^0$	103.1	$w_n = 945.1$ $w_\pi = 169.9$	40.5
Σ^0 (mass = $1188.5 {}^{+3}_{-2}$ Mev)			
$\Sigma^0 \rightarrow \Lambda + \gamma$	71.2	$w = 1117.3$	73.5
Σ^+ (mass = 1189.3 ± .3 Mev)			
$\Sigma^+ \rightarrow p + \pi^0$	189.0	$w_p = 957.1$ $w_\pi = 232.2$	116.1
$\Sigma^+ \rightarrow n + \pi^+$	185.0	$w_n = 957.5$ $w_\pi = 231.8$	110.2
Σ^- (mass = 1196.50 ± .5 Mev)			
$\Sigma^- \rightarrow n + \pi^-$	192.2	$w_n = 959.0$ $w_\pi = 237.5$	117.4
Ξ^- (mass = 1321 ± 3.5 Mev)			
$\Xi^- \rightarrow \Lambda + \pi^-$	139.4	$w = 1123.6$ $w_\pi = 197.3$	66.4

Compton Wavelengths ($1/2\pi$) of Elementary Particles

$\bar{\lambda} = \frac{\hbar}{mc}$

$e = 3.8615 \times 10^{-11}$ cm

$\mu = 1.8667 \times 10^{-13}$ cm

$\pi = 1.4131 \times 10^{-13}$ cm

$K = 3.998 \times 10^{-14}$ cm

$p = 2.1031 \times 10^{-14}$ cm

$n = 2.1002 \times 10^{-14}$ cm

Bibliography of Available Dynamics Calculations

$\gamma + p$, $\gamma + d$, $\pi - \mu$ decay

John H. Malmberg and L. J. Koester, Jr., Tables of Nuclear Reaction Kinematics at Relativistic Energies, Univ. of Illinois, AECU-3353, July 1953.

$\pi + p \rightarrow \pi + p$ (0 to 200 Mev

H. L. Anderson and D. G. Wilson, Pion-Proton Scattering Tables, Univ. of Chicago, Institute for Nuclear Studies, May 1954.

$\pi + p \rightarrow \pi + p$ (300 Mev to 6 Bev)

James A. Baker and John Killeen, Pion-Proton Scattering Tables, UCRL-2843, Jan. 1955.

$K + p \rightarrow K + p$ (10 Mev to 6 Bev)

James A. Baker and Kent Curtis, Tables of K-Meson Scattering by Protons, UCRL-3274, Jan. 1956.

Constants and Conversion Factors

Constants

Avogadro's Number: $N = (6.02486 \pm 0.00016) \times 10^{23}\ (\text{g mole})^{-1}$

Gas Constant: $R_0 = (8.31696 \pm 0.00034) \times 10^{7}\ \text{erg mole}^{-1}\ \text{deg}^{-1}\text{C}$

$= 5.19142 \times 10^{13}\ \text{Mev mole}^{-1}\ \text{deg}^{-1}\text{C}$

Standard Volume of a Perfect gas:

$V_0 = (22.4207 \pm 0.0006) \times 10^{3}\ \text{cm}^{3}\ \text{atmos mole}^{-1}$

Bohr radius: $a_0 = \frac{\hbar^2}{(me^2)} = (5.29172 \pm 0.00002) \times 10^{-9}$ cm

Electron radius (classical):

$r_0 = \frac{e^2}{(mc^2)} = (2.81785 \pm 0.00004) \times 10^{-13}$ cm

Fine-structure constant: $\alpha = \frac{1}{137.0373 \pm 0.0006}$

Planck's Constant: $\hbar = (1.05443 \pm 0.00004) \times 10^{-27}$ erg sec

$= 6.5817 \times 10^{-22}$ Mev sec

Boltzmann's Constant:

$k = \frac{R_0}{N} = (1.38044 \pm 0.00007) \times 10^{-16}\ \text{ergs deg}^{-1}$

$= (8.6167 \pm 0.0004) \times 10^{-5}\ \text{ev deg}^{-1}$

Conversion Factors:

11 kilogauss feet $= 100\ \frac{\text{Mev}}{c}$

15 kilogauss feet $= 137\ \frac{\text{Mev}}{c}$

1 electron volt $= (1.60206 \pm 0.00003) \times 10^{-12}$ erg