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Vol. II (1966 Rev.)

University of California

Ernest O. Lawrence Radiation Laboratory

HIGH-ENERGY PARTICLE DATA
VOLUME II
RANGE-ENERGY AND dE/dx PLOTS OF CHARGED PARTICLES IN MATTER

Berkeley, California

For Reference
Bldg. 50
Not to be taken from this room

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Research and Development

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UC-34 Physics
TID-4500 (48th Ed.)

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

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HIGH-ENERGY PARTICLE DATA
VOLUME II

RANGE-ENERGY AND dE/dx PLOTS OF CHARGED PARTICLES IN MATTER

W. Peter Trower

July 1, 1966

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HIGH-ENERGY PARTICLE DATA

Volume II

RANGE-ENERGY AND dE/dx PLOTS OF CHARGED PARTICLES IN MATTER

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Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

March 29, 1967

ERRATA

TO: All recipients of UCRL-2426, Vol. II (1966 Rev.) UC-34 Physics

FROM: Technical Information Division

Subject: UCRL-2426, Vol.II (1966 Rev.), High-Energy Particle Data Volume II, Range-Energy and dE/dx Plots of Charged Particles in Matter, W. Peter Trower, July 1, 1966

Some difficulty has been experienced in reading this set of graphs because of the inadvertent omission of the scale on the vertical axis. The vertical scale has two decades; the decade on which the scaling bracket is shown is always assumed to run from 1 to 10, regardless of whether it is in the upper or lower part of the plot.

Pages 5–9

Caption should read "Ranges for H, C, Cu, Pb, and Ilford G-5 emulsion in g/cm^2."

Page 8

Move bracket labeled ($\times 10^1$) up half an inch.

Page 27

New page is attached. Destroy old page which is in error.

Unnumbered

Slip sheet for dE/dx (GRAPHS) should be between pages 45 and 46.

Pages 46–50

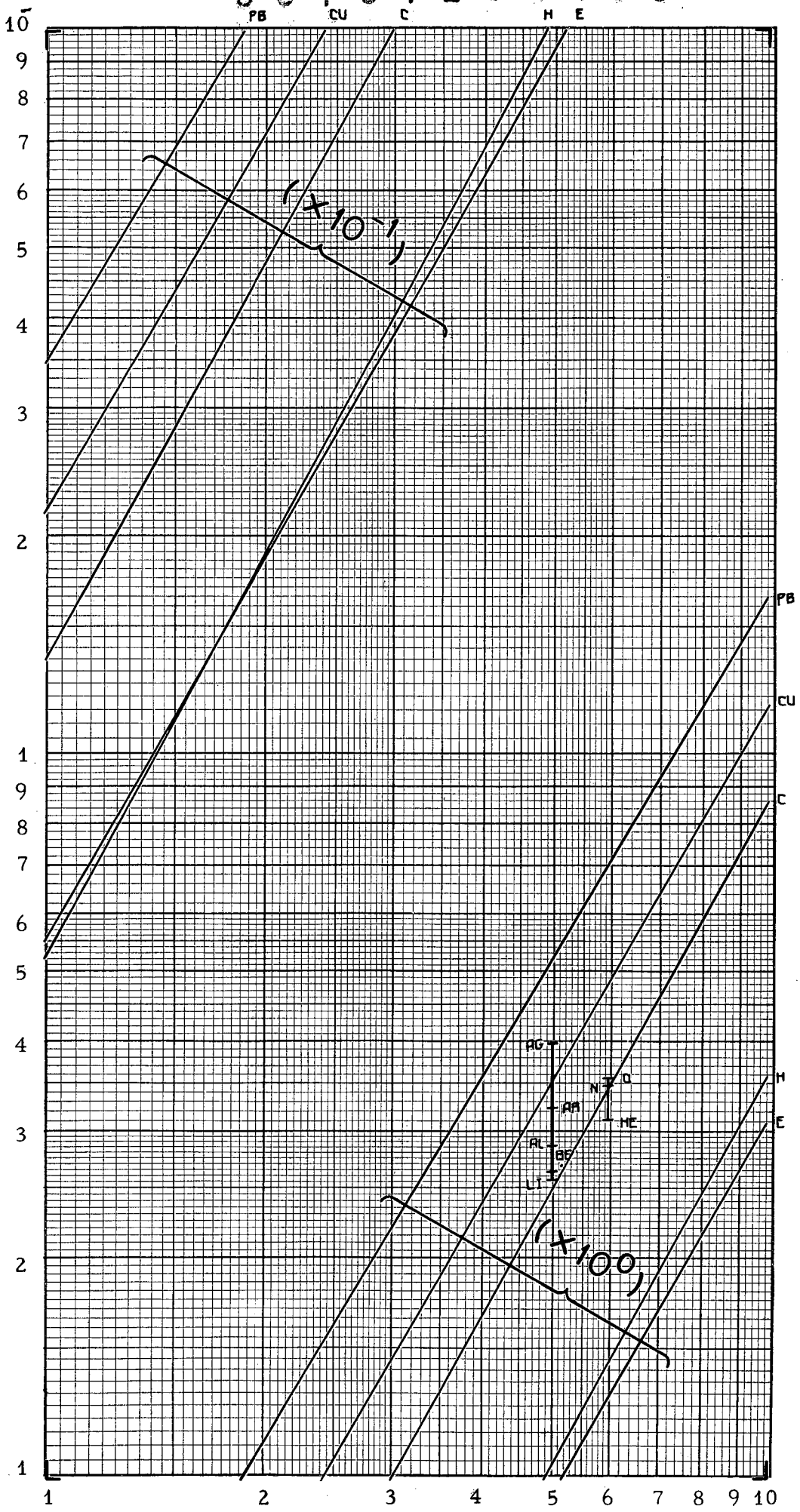
Caption should read "DE/DX of H, C, Cu, Pb and Ilford G-5 emulsion in MeV cm^2/g."

Unnumbered

Slip sheet for Supplemental Data (Graphs and Tables) should be between pages 85 and 86.

Pages 95-98

These pages are out of order and misbound. Pages 95 and 98 should be bound facing each other, as should also pages 96 and 97.



PROTONS

(10 TO 100 MEV)

M = 938.256 MEV

= 1836.1 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.

0 0 1 0 1 2 0 4 4 6 9

HIGH-ENERGY PARTICLE DATA

Volume II

RANGE-ENERGY AND dE/dx PLOTS OF CHARGED PARTICLES IN MATTER

W. Peter Trower*

Lawrence Radiation Laboratory
University of California
Berkeley, California

July 1, 1966

INTRODUCTION

Graphs of range-energy and dE/dx compose most of this report. They are plotted for various incident particles in carbon, copper, emulsion, hydrogen, and lead. Indicated by means of a bar on each plot are aluminum, argon, beryllium, helium, lithium, nitrogen, oxygen, and silver. Included also is a section of supplemental data which contains information such as photon-mass absorption coefficient curves, and particle ranges in the liquid hydrogen bubble chamber.

This report is a revision of part of the 1957 edition of UCRL-2426, Vol. II. All the range-energy plots have been redrawn with a Cal-Comp plotter and with current values of the particle masses. The dE/dx curves are an addition. The data used in generating both types of plots was obtained from the computer program RANGE[1]; this program evaluates the Bethe-Bloch formula, includes the density effect and shell corrections, and uses low-energy proton ranges to initiate the integration of the stopping power to yield range. For electrons, the calculations of Berger and Seltzer[2] are just displayed directly. The data of Barkas is scaled to give the emulsion curves.[3]

The extension of some of these graphs to higher energy was made in order that the user could have at least an estimate, even if it was not experimentally corroborated, of the energy loss and range based upon known effects at lower energies.

The dE/dx in compounds and mixtures can be easily constructed from the graphs by the following technique.[4] If we have a compound M of two elements α and β with atomic weights A_α and A_β and a molecular weight A_M, and if they each have respectively a and b atoms per molecule, then the energy loss of a charged particle in M is given by

$$\left(\frac{dE}{dx}\right)_M = \left(\frac{dE}{dx}\right)_\alpha a \frac{\rho_M A_\alpha}{\rho_\alpha A_M} + \left(\frac{dE}{dx}\right)_\beta b \frac{\rho_M A_\beta}{\rho_\beta A_M} ,$$

where $(dE/dx)_\alpha$ and $(dE/dx)_\beta$ can be obtained from this collection of graphs. The rho's in the above equation are the respective densities.

The supplemental data which comprise the last section of this report have been abridged since much of what used to appear here is now included in another publication.[5] The remaining data have been updated wherever possible. The photon-mass absorption coefficients come from the work of Kirkland,[6] while the table of normalized emulsion quantities appears in a book by Barkas.[7]

0 0 1 0 1 2 0 4 4 7 1

ACKNOWLEDGMENTS

This collection of graphs owes much to its previous authors, Dr. John H. Atkinson and Mrs. Beverly Hill Willis. The present author would like to express his appreciation to Dr. Walter H. Barkas for the use of a table from his book and to his colleagues at the University of Illinois: Mr. Van Bluemel for his general suggestions, and Mr. Howard A. Gordon and Mrs. Myrna Christe Rice for their assistance in the preparation of the Cal-Comp plots.

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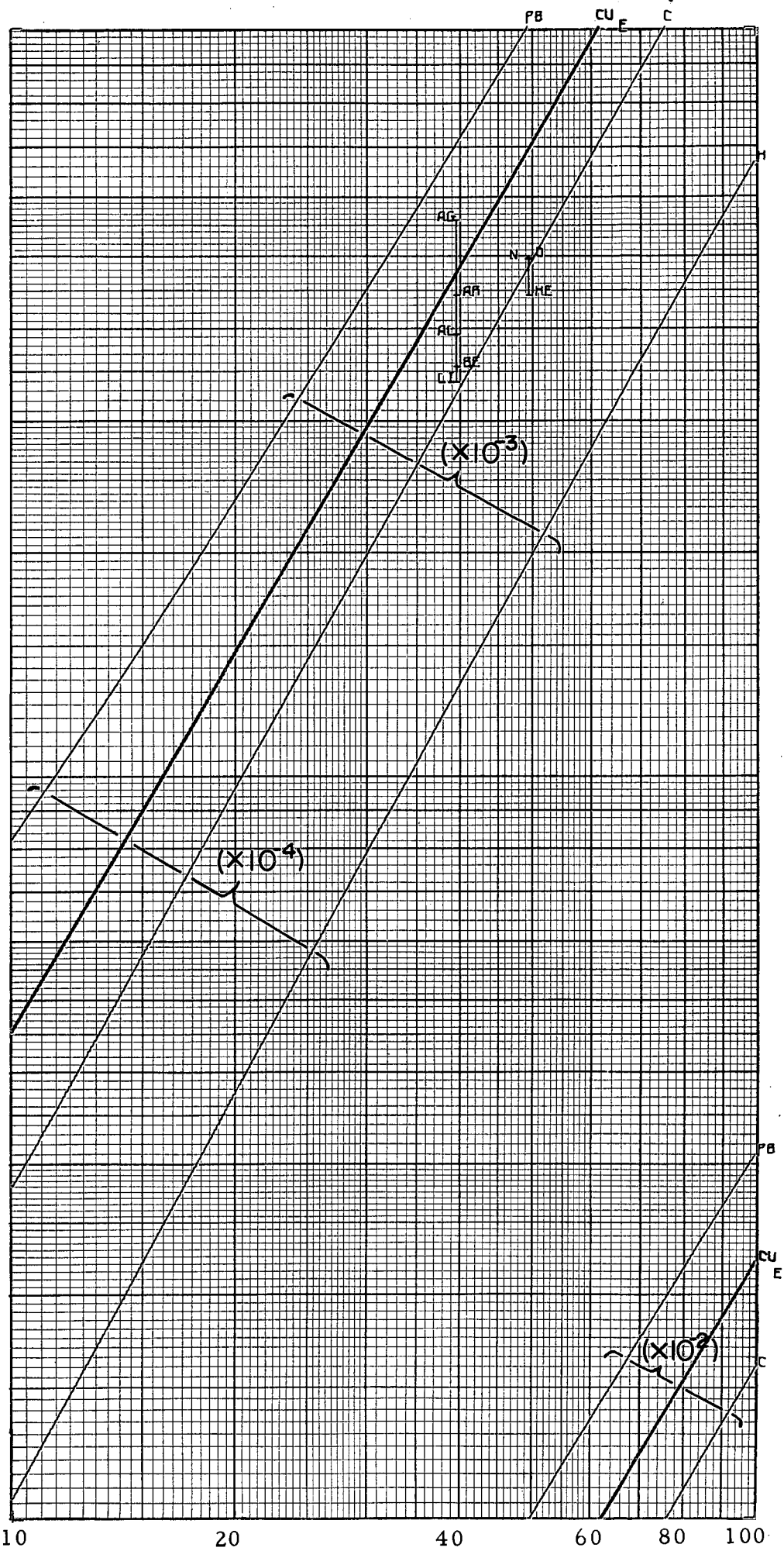
RANGE-ENERGY CURVES
(GRAPHS)



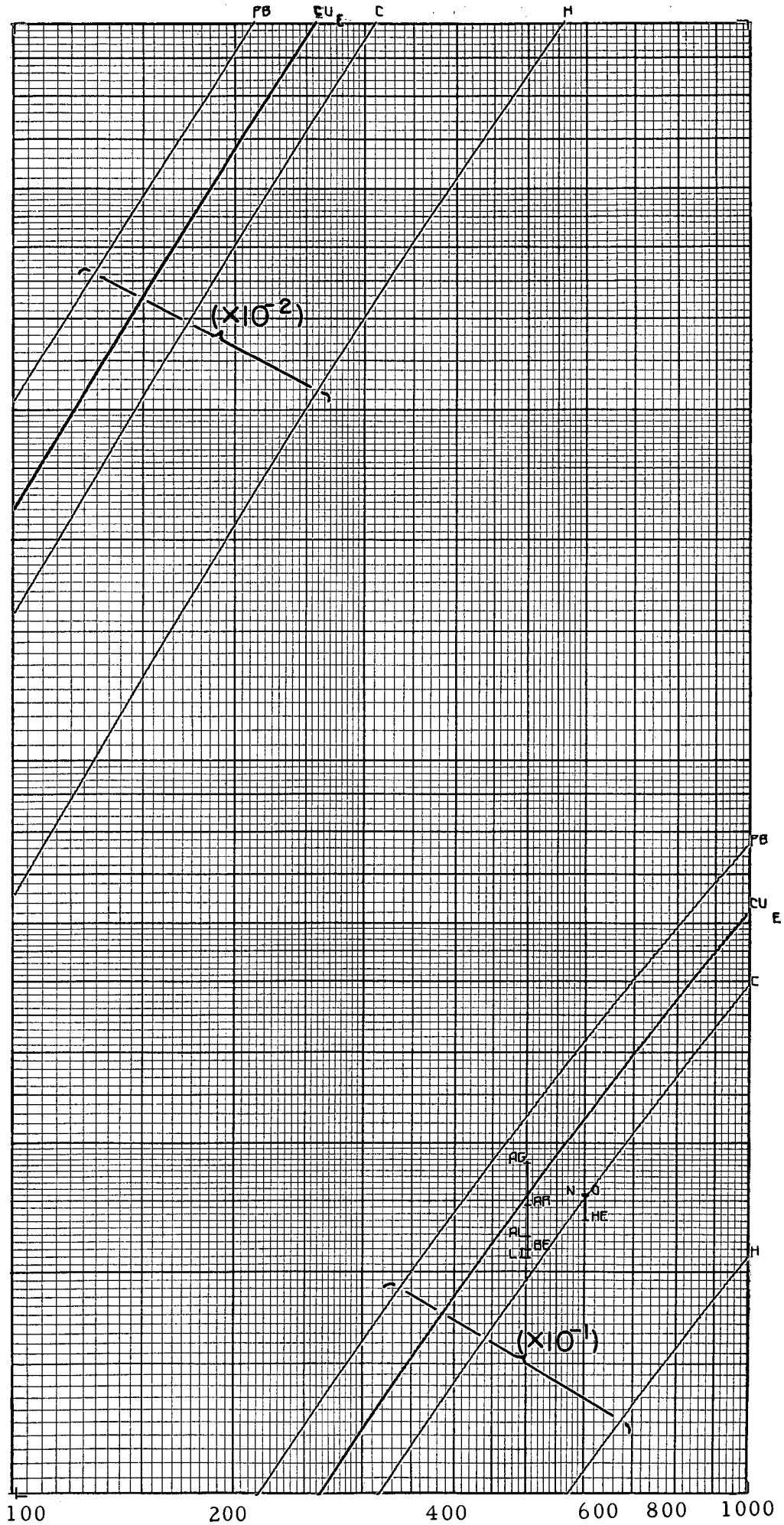
ELECTRONS

(10 TO 100 KEV)

M = 0.511 MEV

= 1 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



RANGE

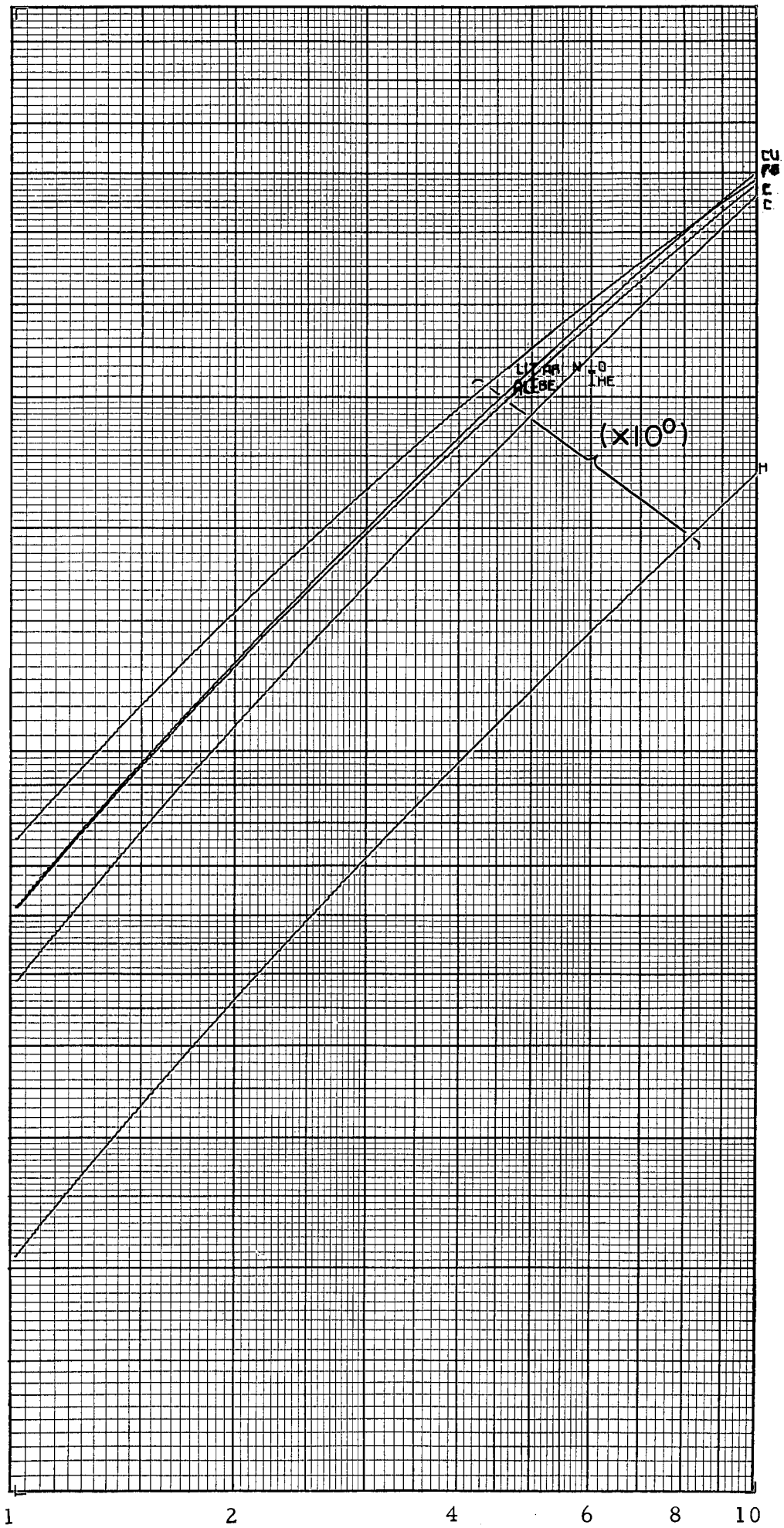
ELECTRONS

(100 TO 1000 KEV)

M = 0.511 MEV

= 1 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



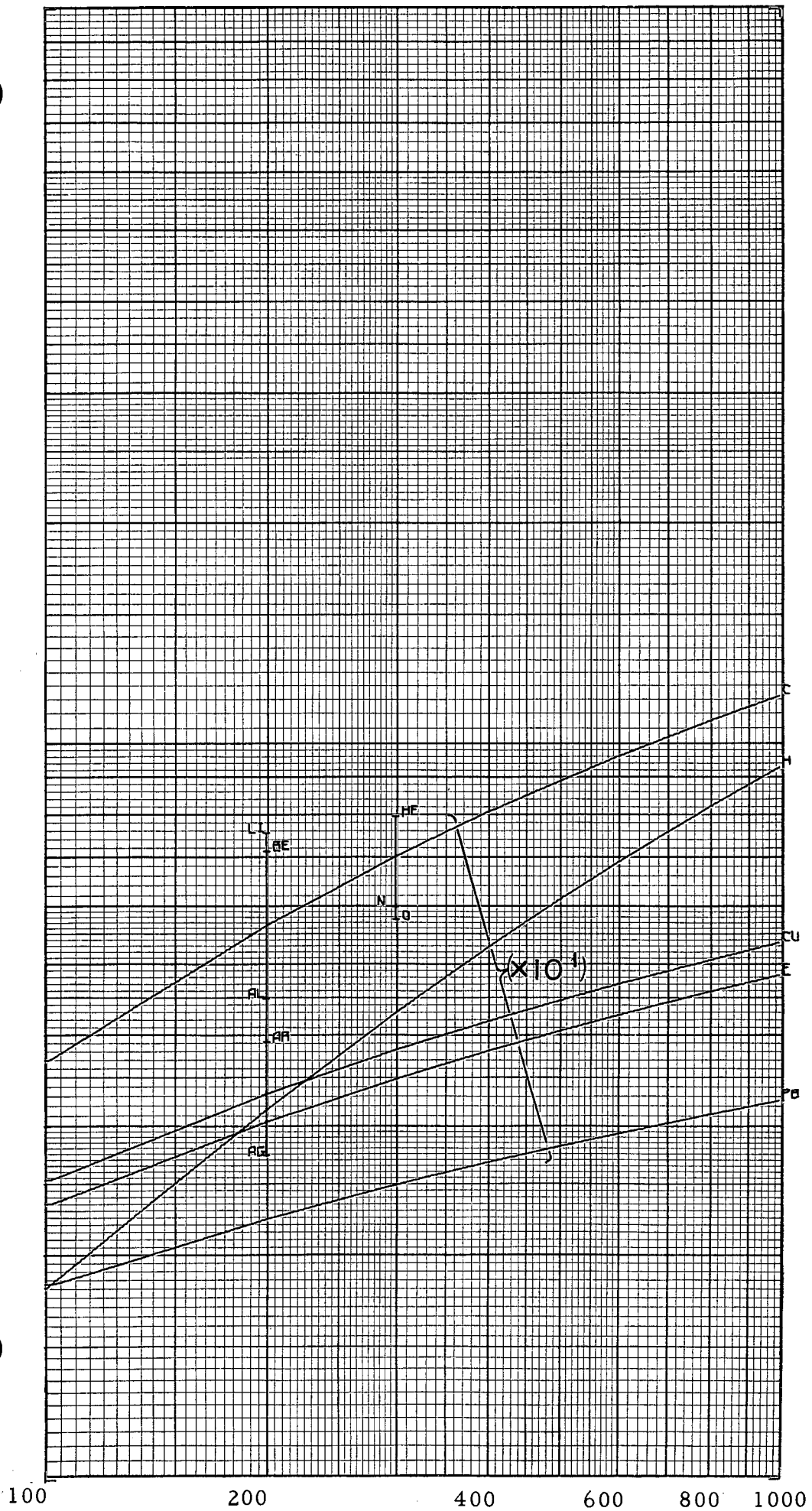
ELECTRONS

(1 TO 10 MEV)

M = 0.511 MEV

= 1 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



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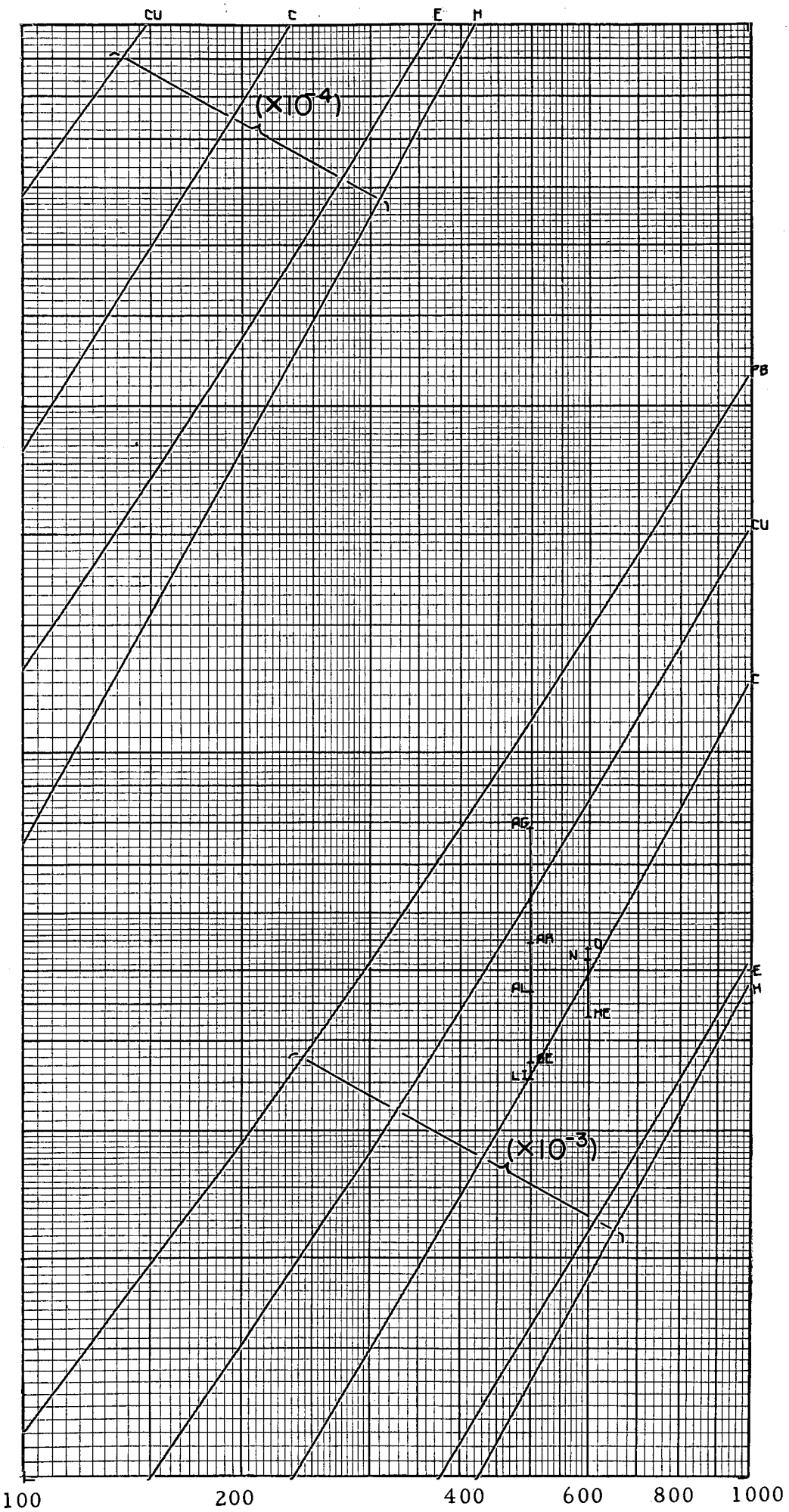
RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



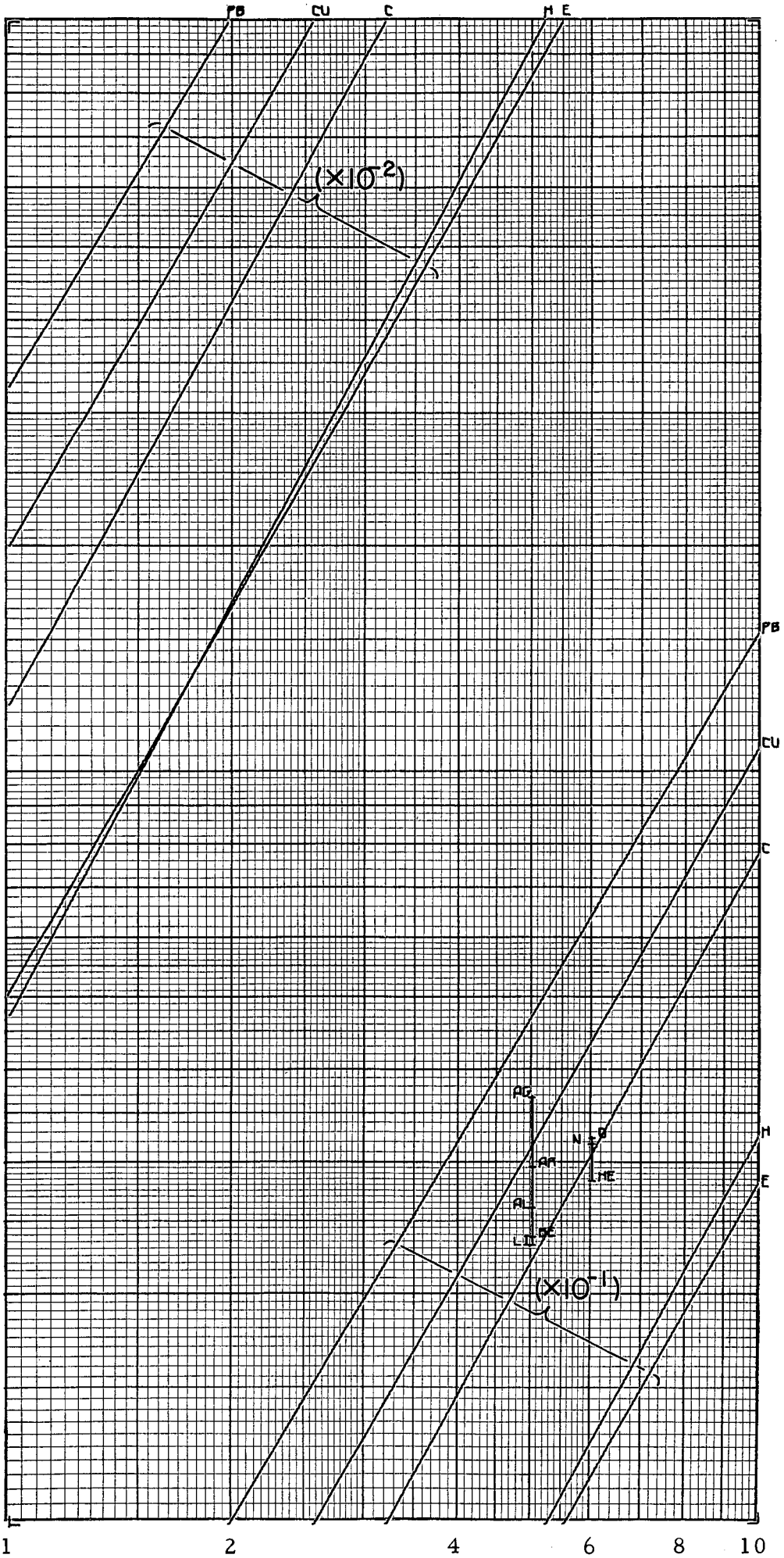
MUONS ±

(100 TO 1000 KEV)

M = 105.654 MEV

= 206.86 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



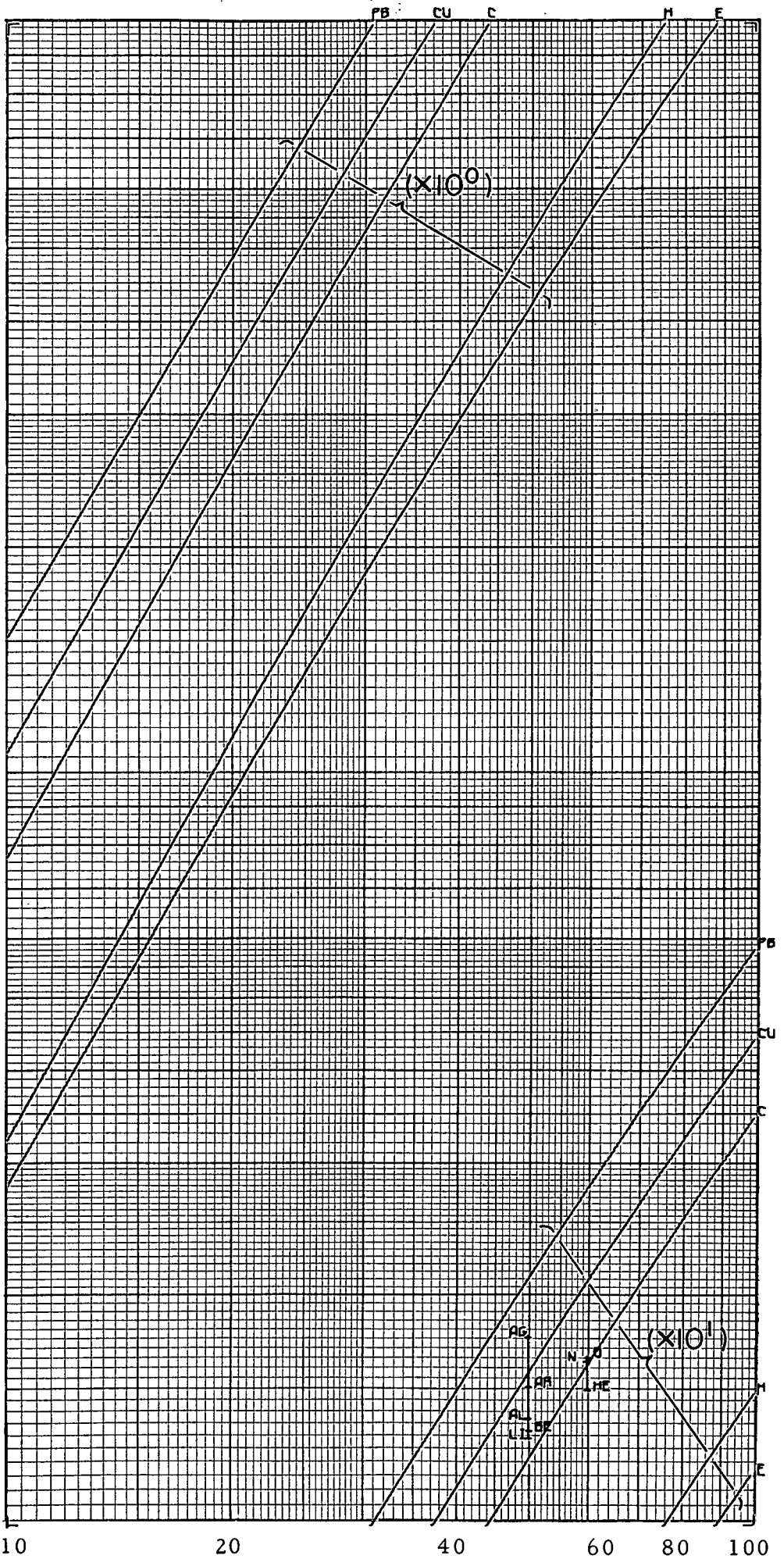
MUONS ±

(1 TO 10 MEV)

M = 105.654 MEV

= 206.86 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



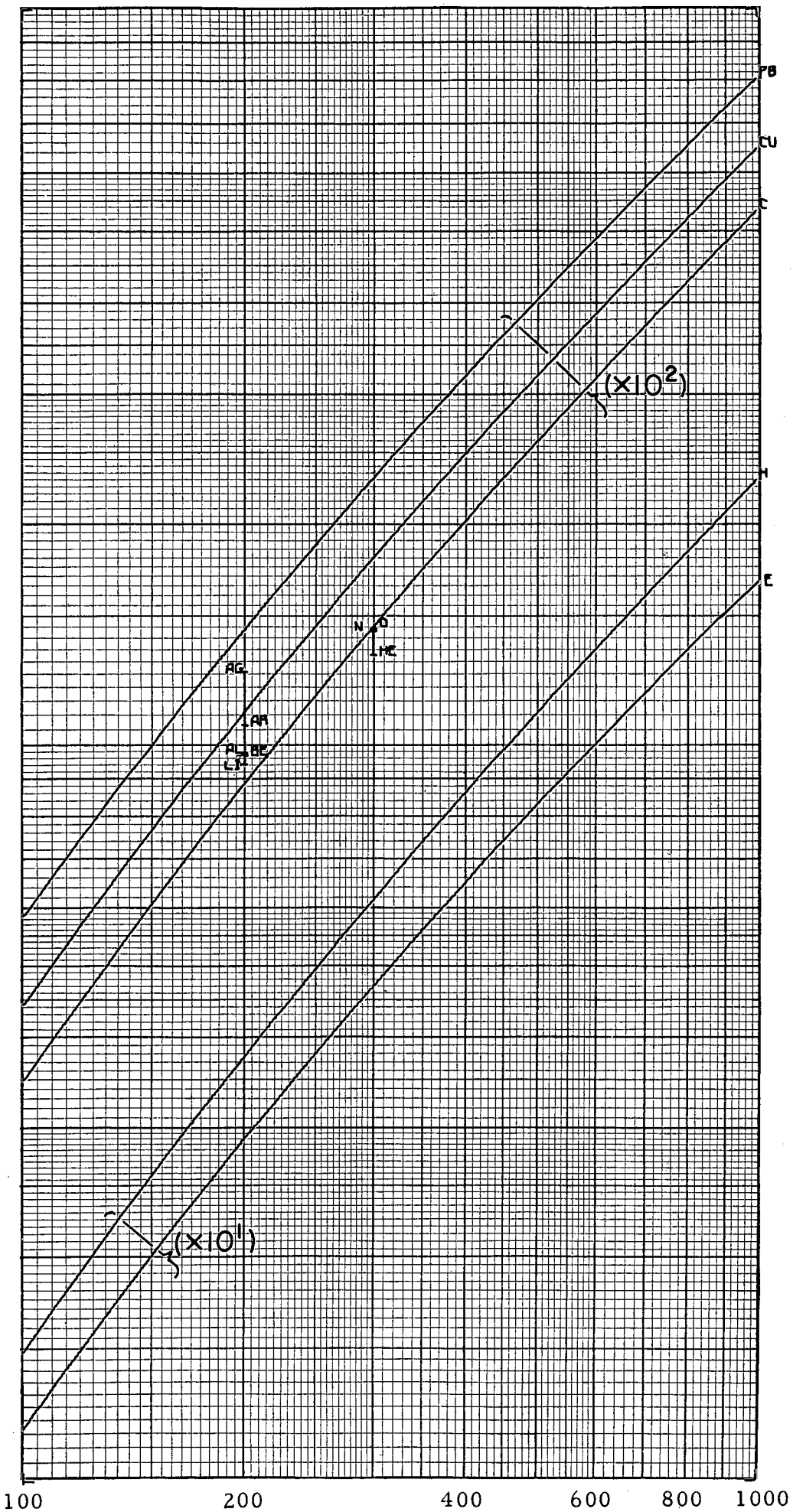
MUONS ±

(10 TO 100 MEV)

M = 105.654 MEV

= 206.86 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



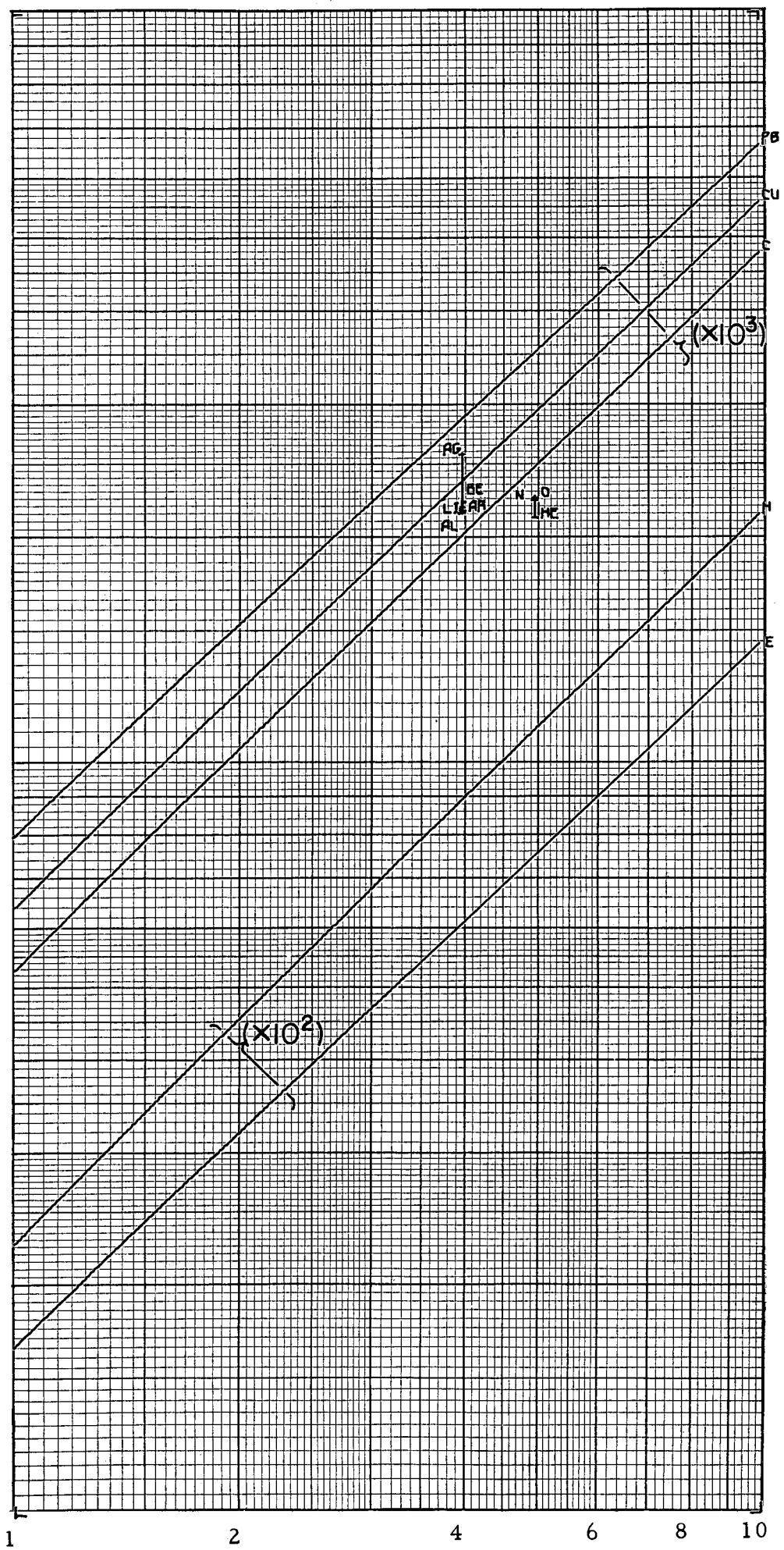
MUONS ±

(100 TO 1000 MEV)

M = 105.654 MEV

= 206.86 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



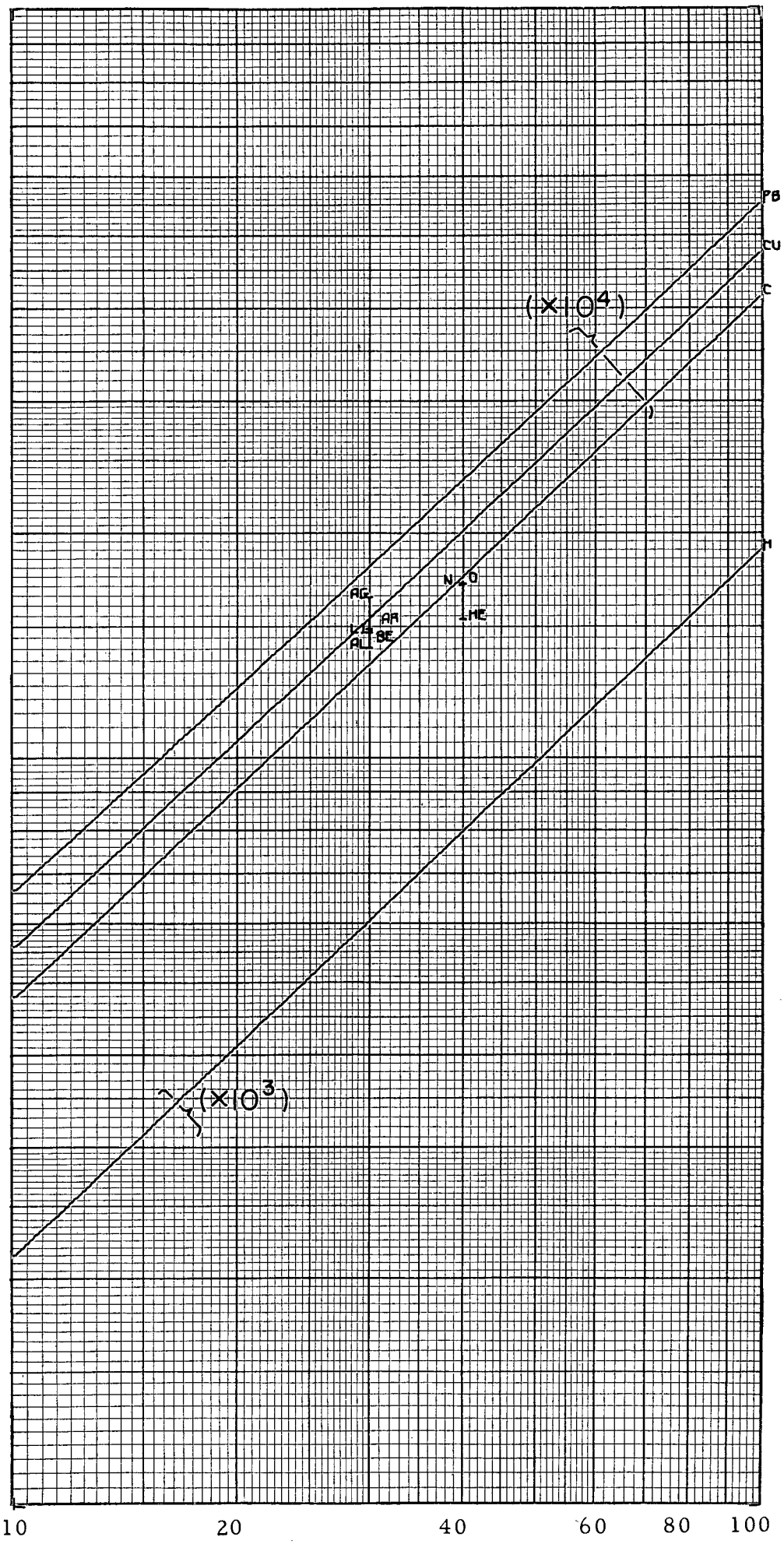
MUONS ±

(1 TO 10 GEV)

M = 105.654 MEV

= 206.86 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



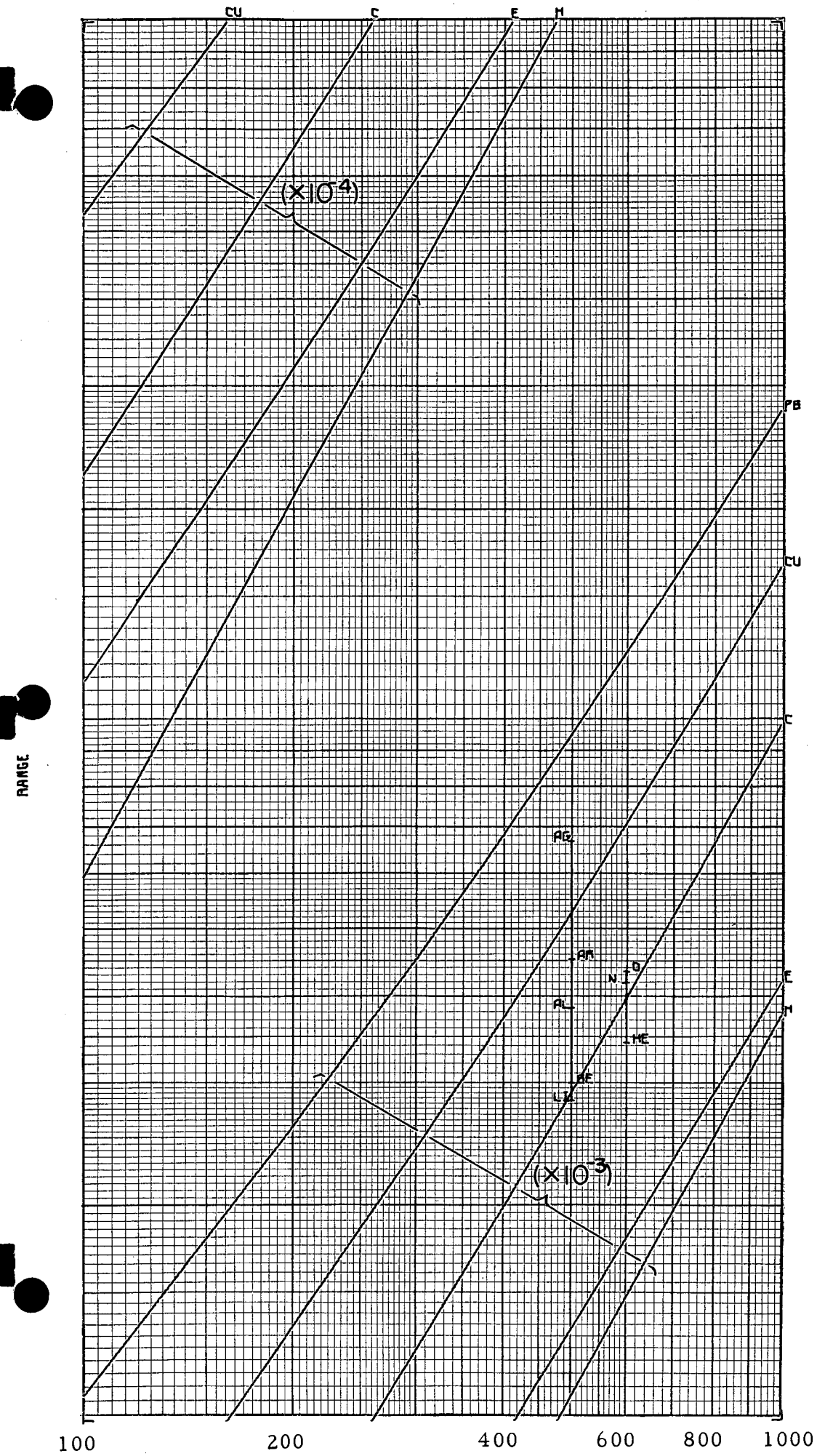
MUONS ±

(10 TO 100 GEV)

M = 105.654 MEV

= 206.86 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



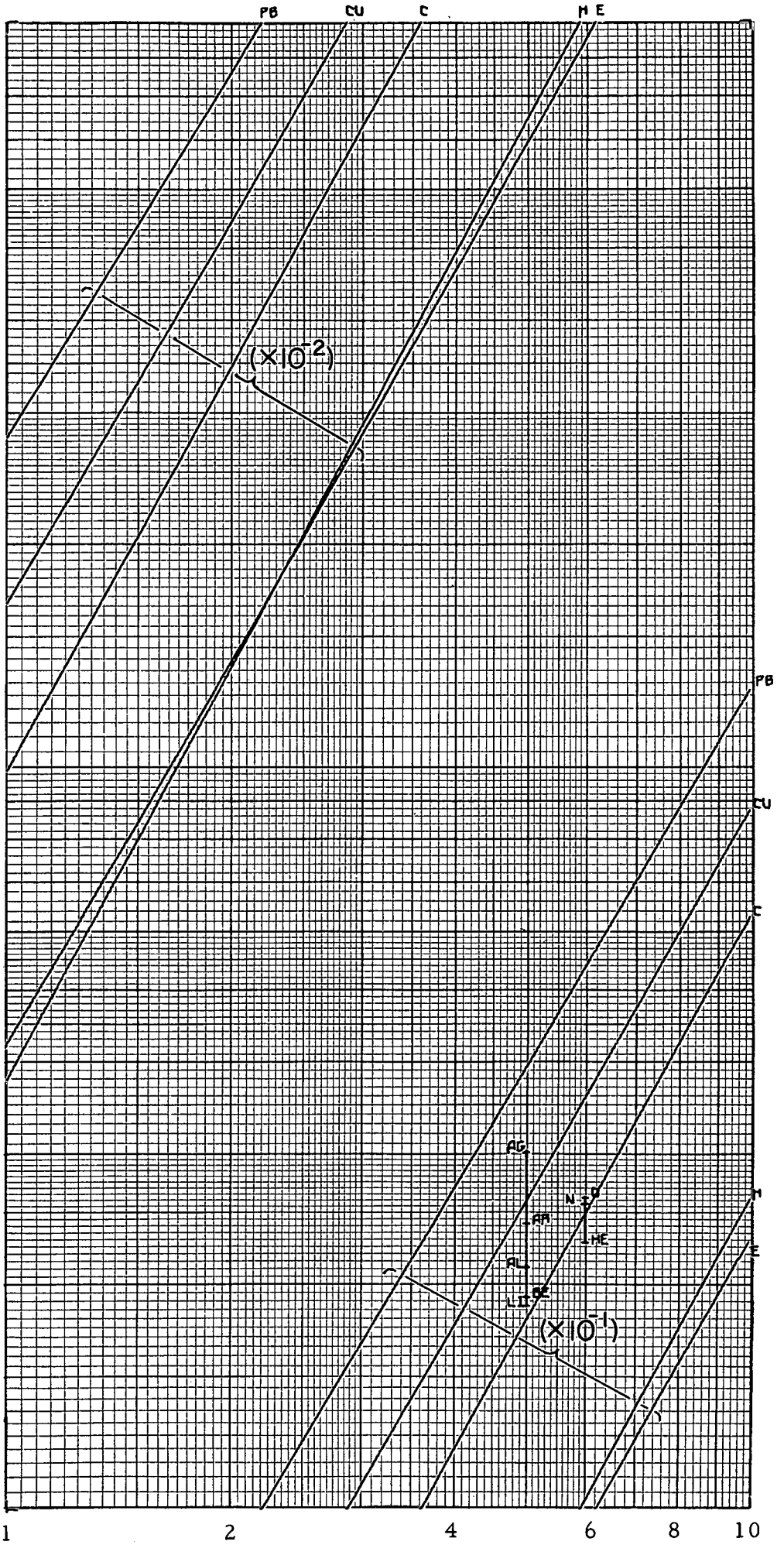
PI± MESONS

(100 TO 1000 KEV)

M = 139.58 MEV

= 273.27 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



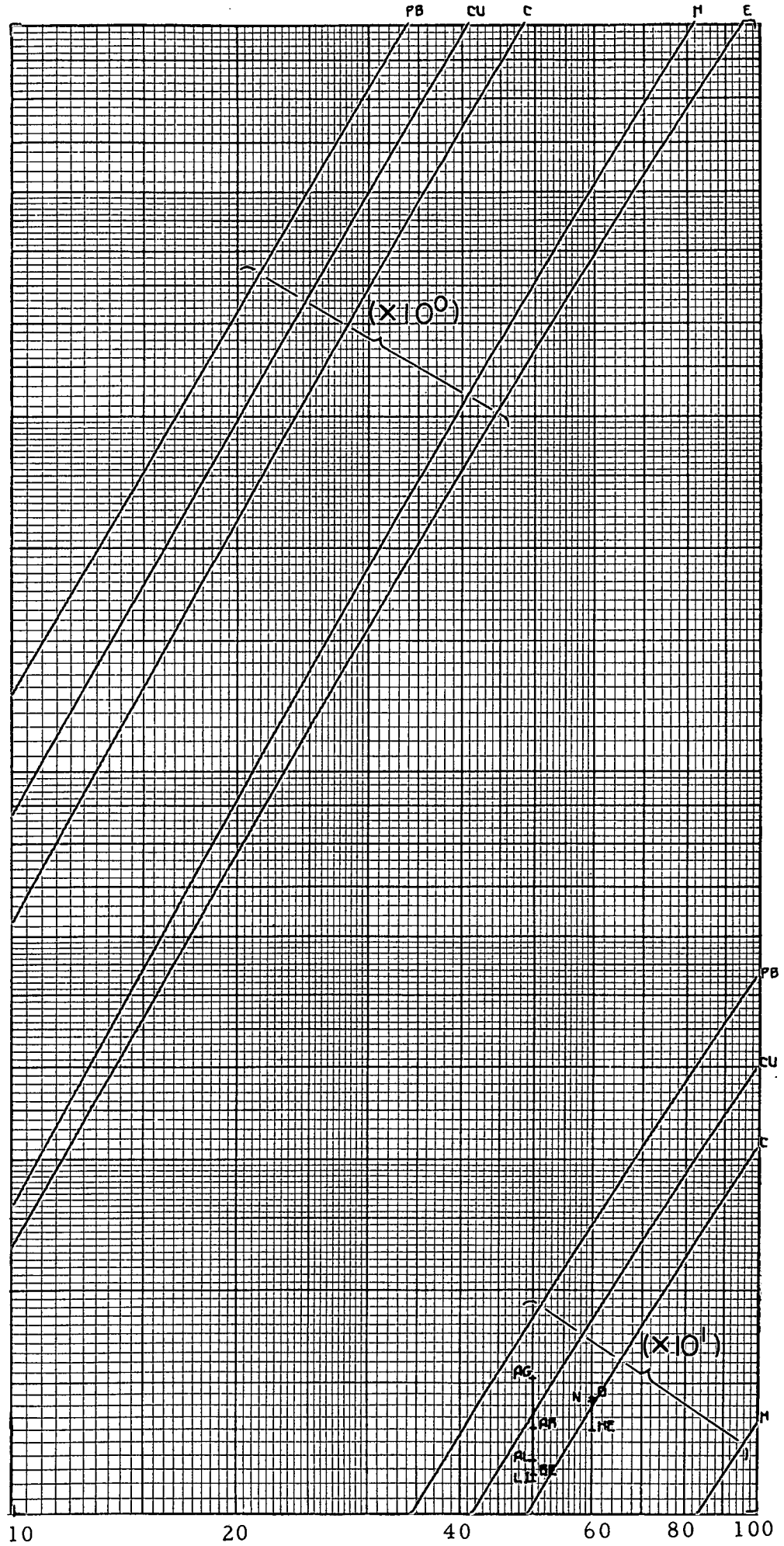
PI± MESONS

(1 TO 10 MEV)

M = 139.58 MEV

= 273.27 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



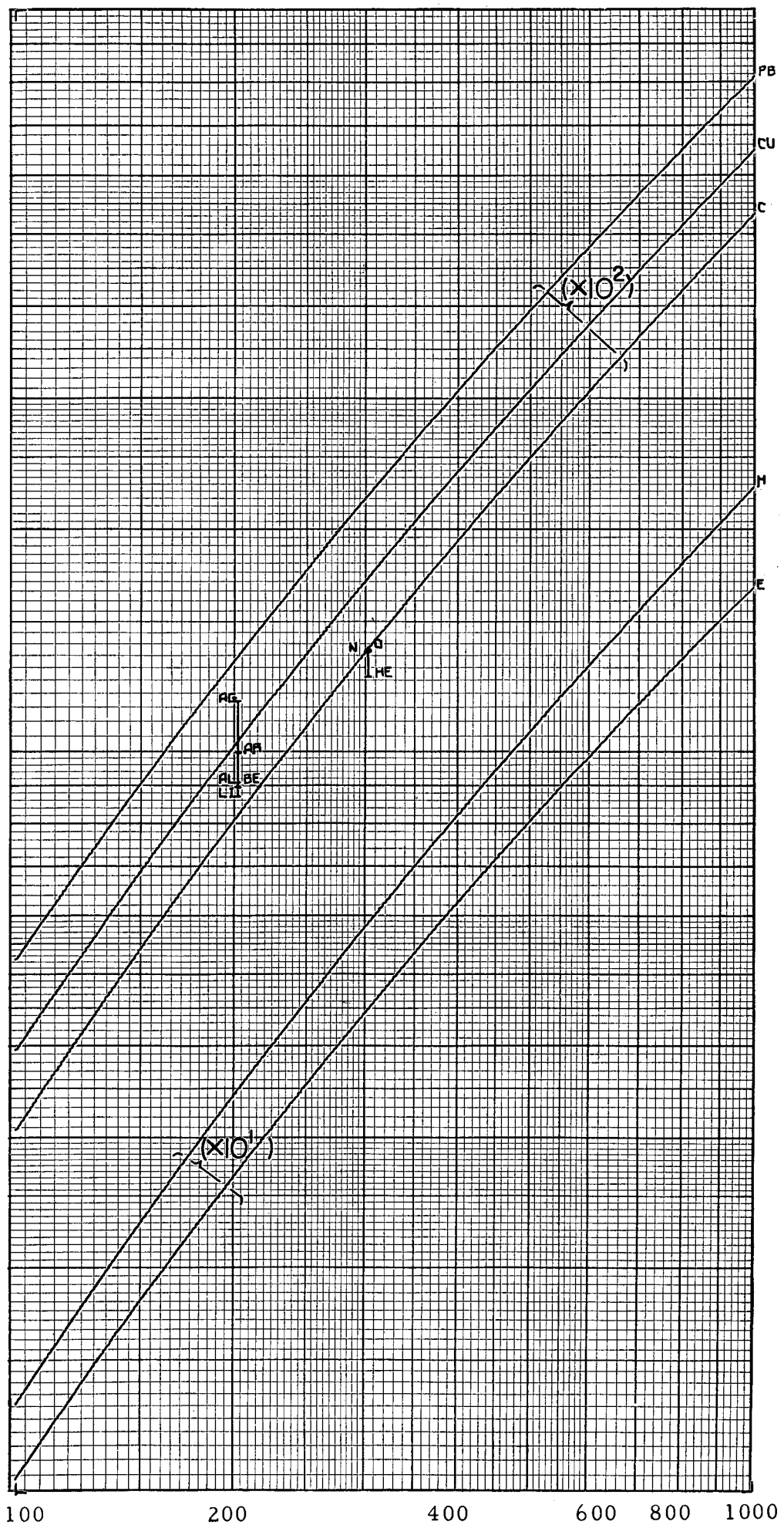
PI± MESONS

(10 TO 100 MEV)

M = 139.58 MEV

= 273.27 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



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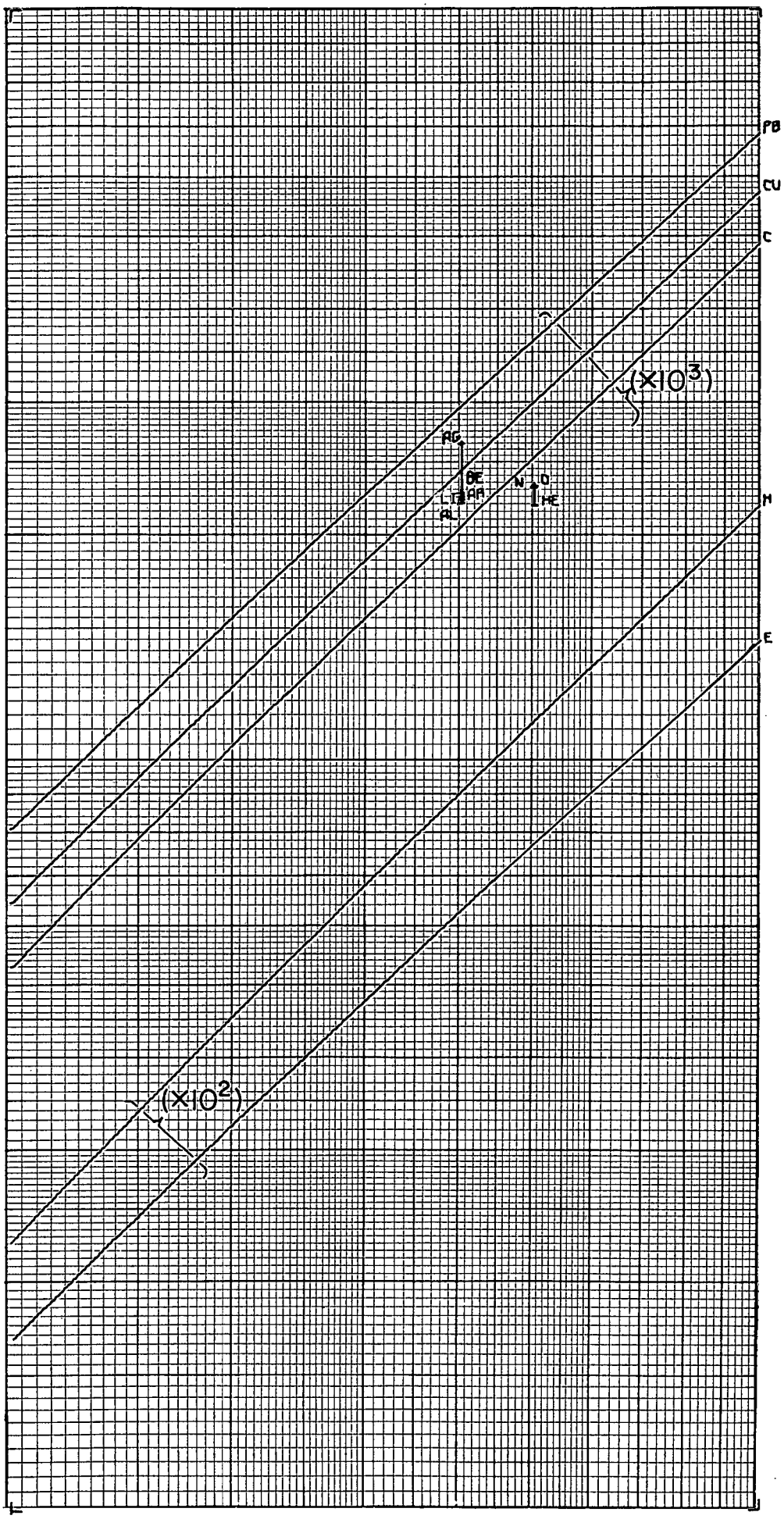

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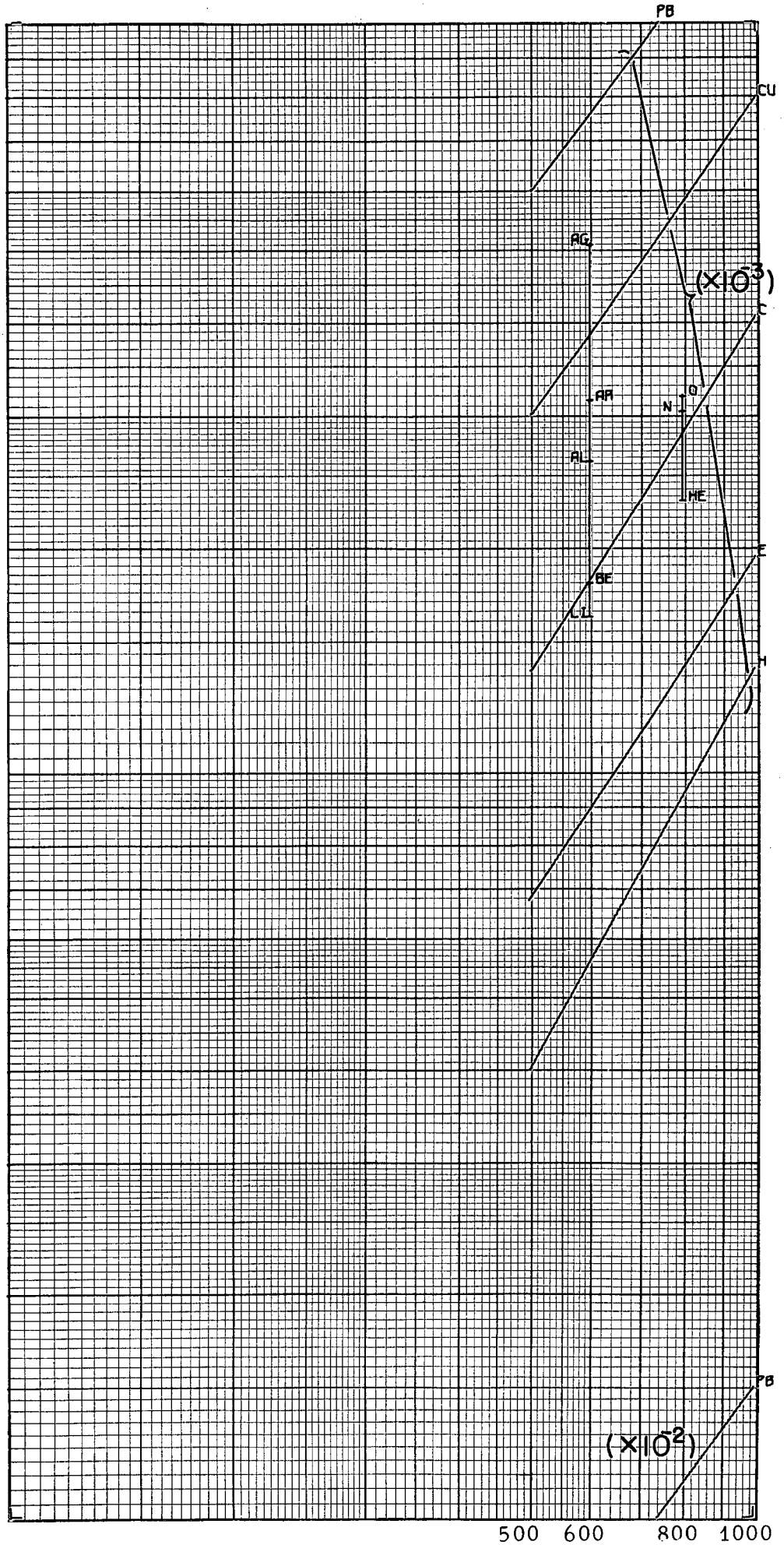


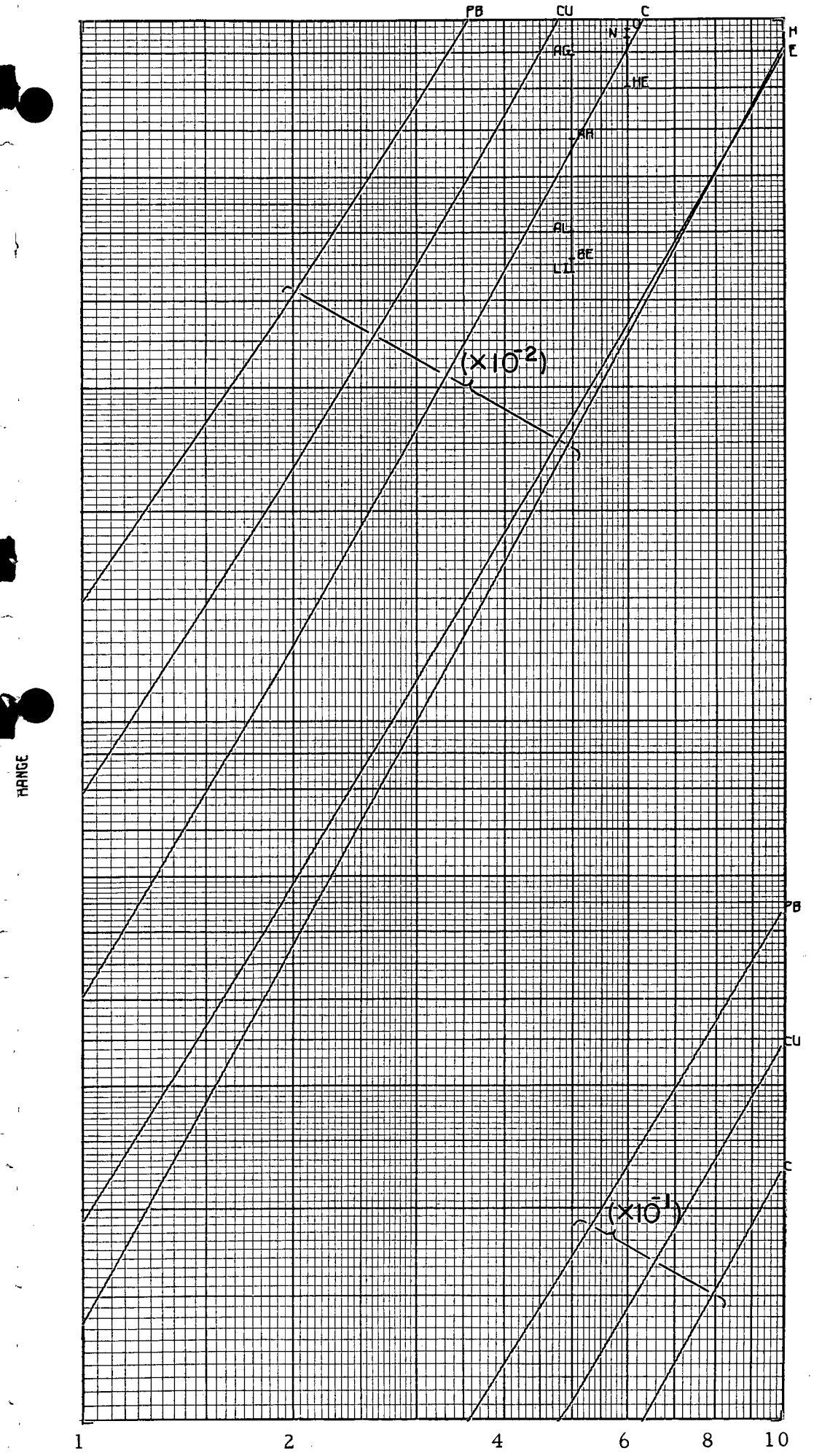
K±MESONS

(500 TO 1000 KEV)

M = 493.78 MEV

= 966.71 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



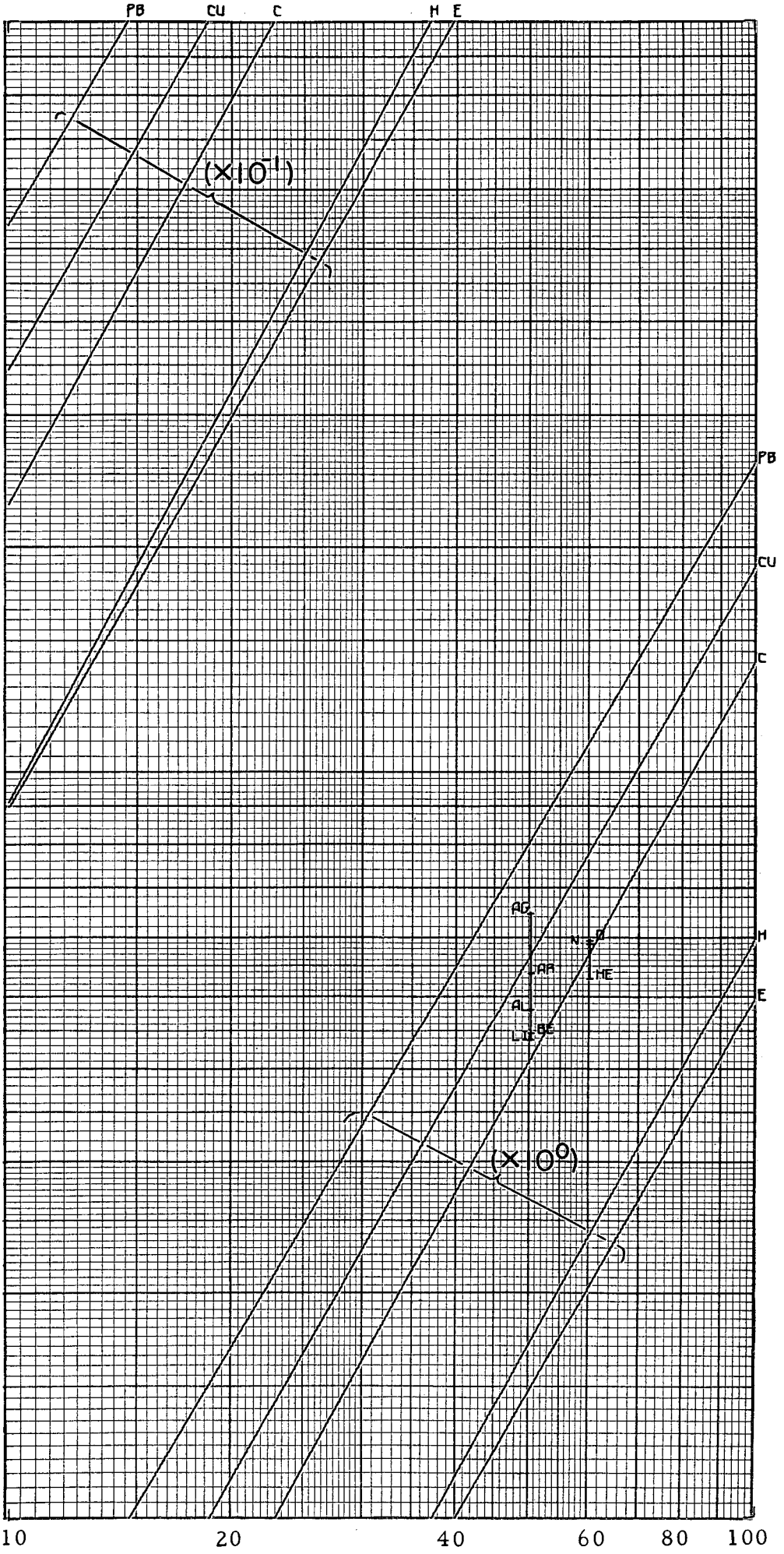
K±MESONS

(1 TO 10 MEV)

M = 493.78 MEV

= 966.71 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



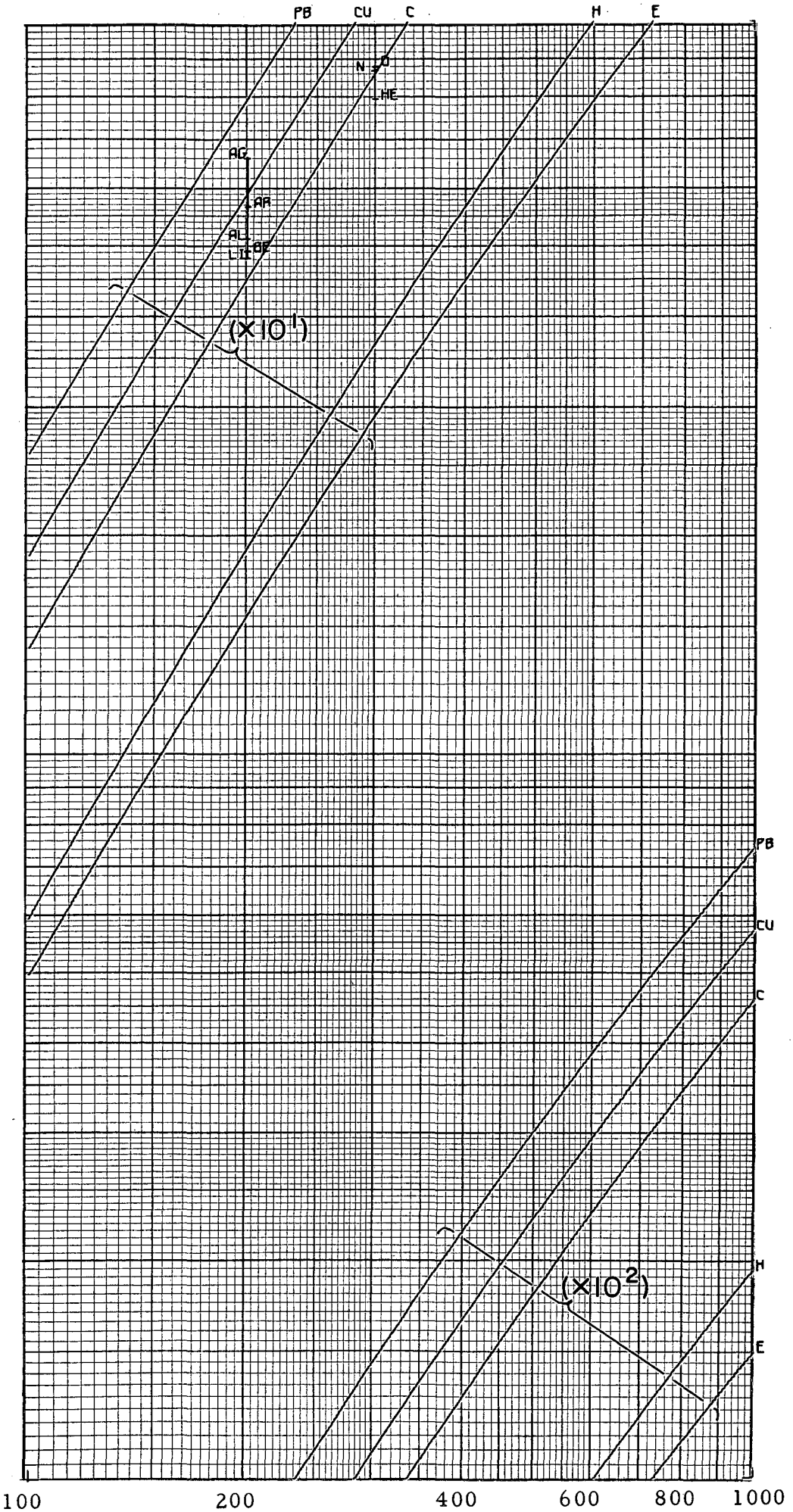
K± MESONS

(10 TO 100 MEV)

M = 493.78 MEV

= 966.71 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



K±MESONS

(100 TO 1000 MEV)

M = 493.70 MEV

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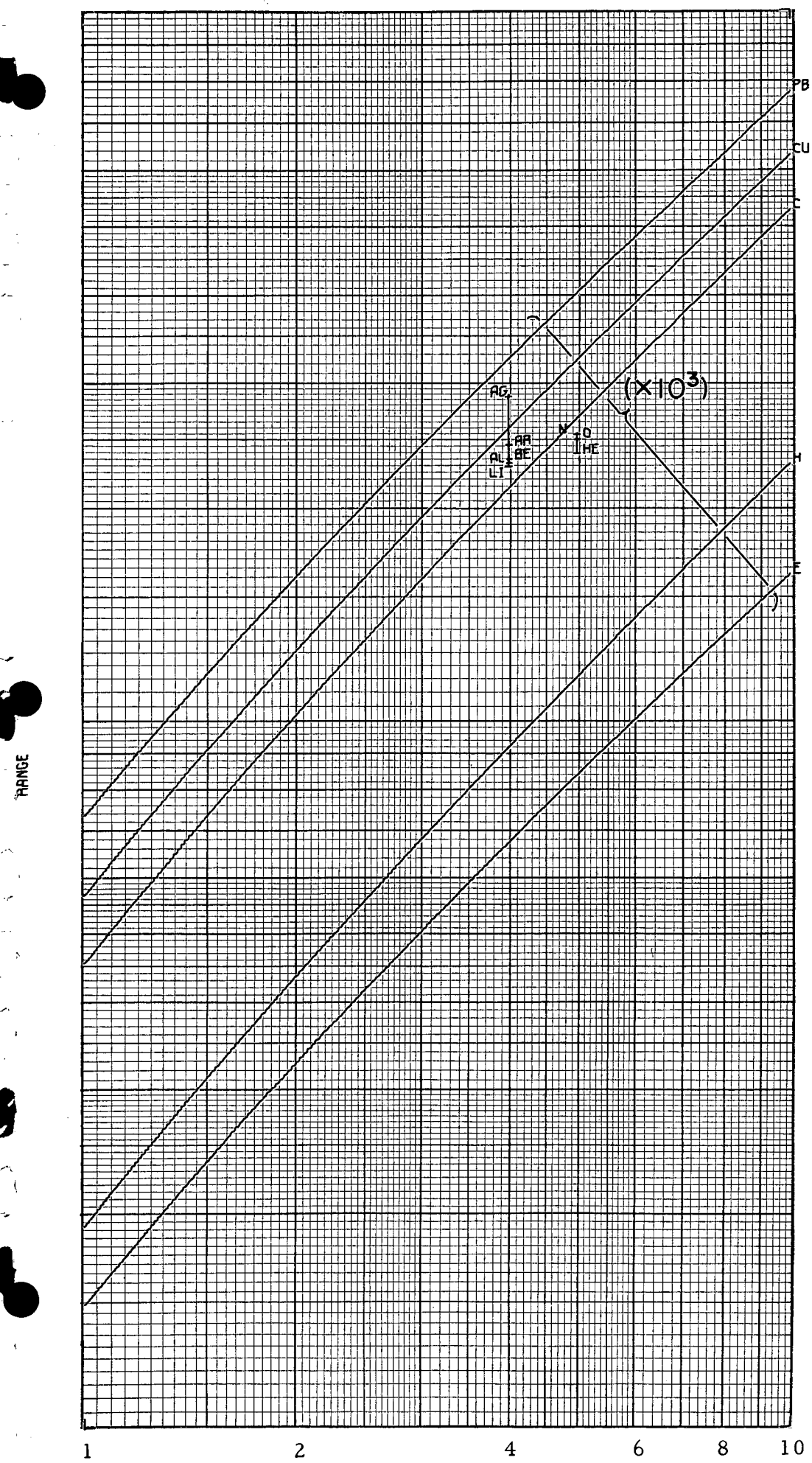
RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



K±MESONS

(1 TO 10 GEV)

M = 493.78 MEV

= 966.71 m

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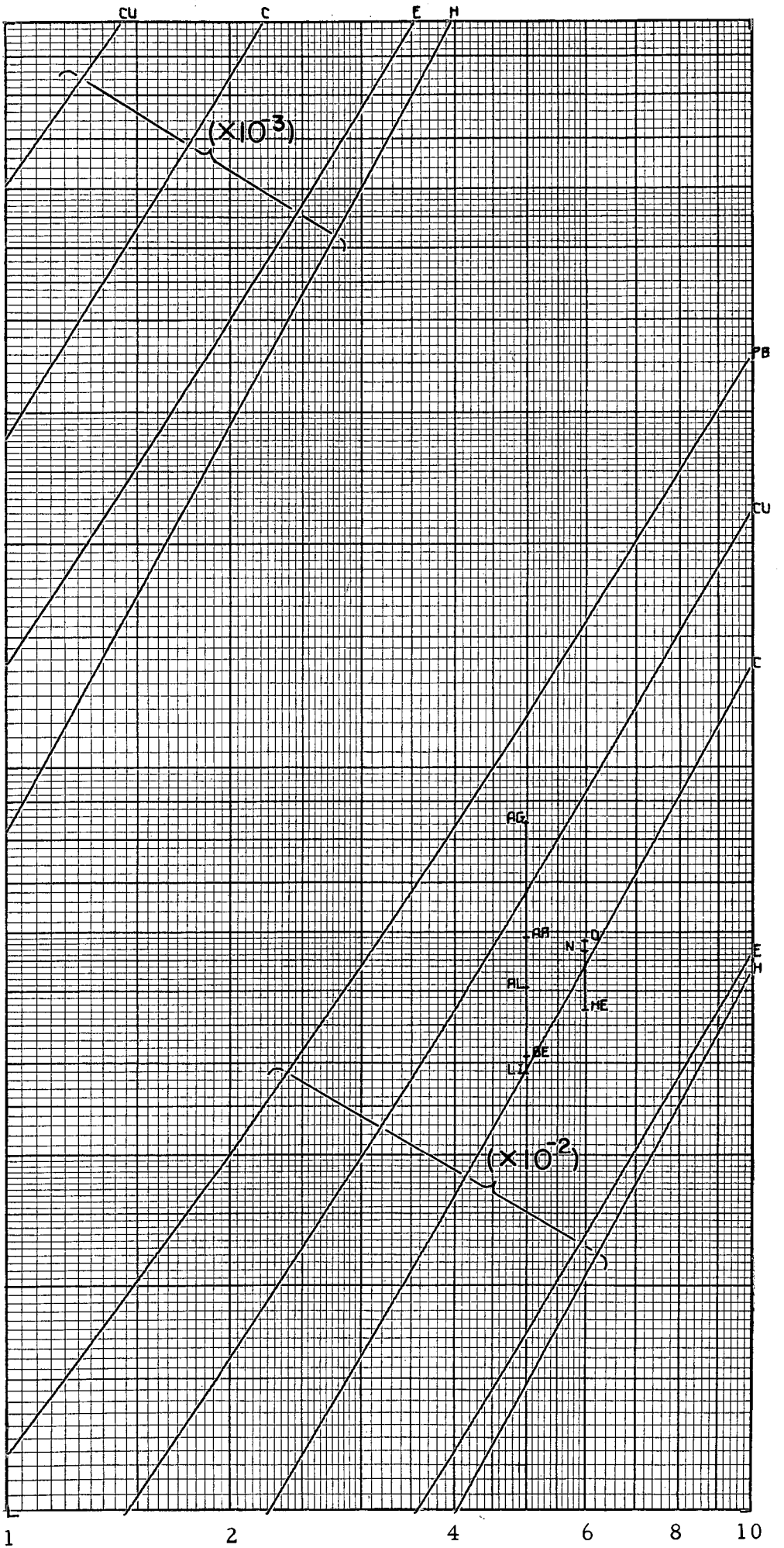

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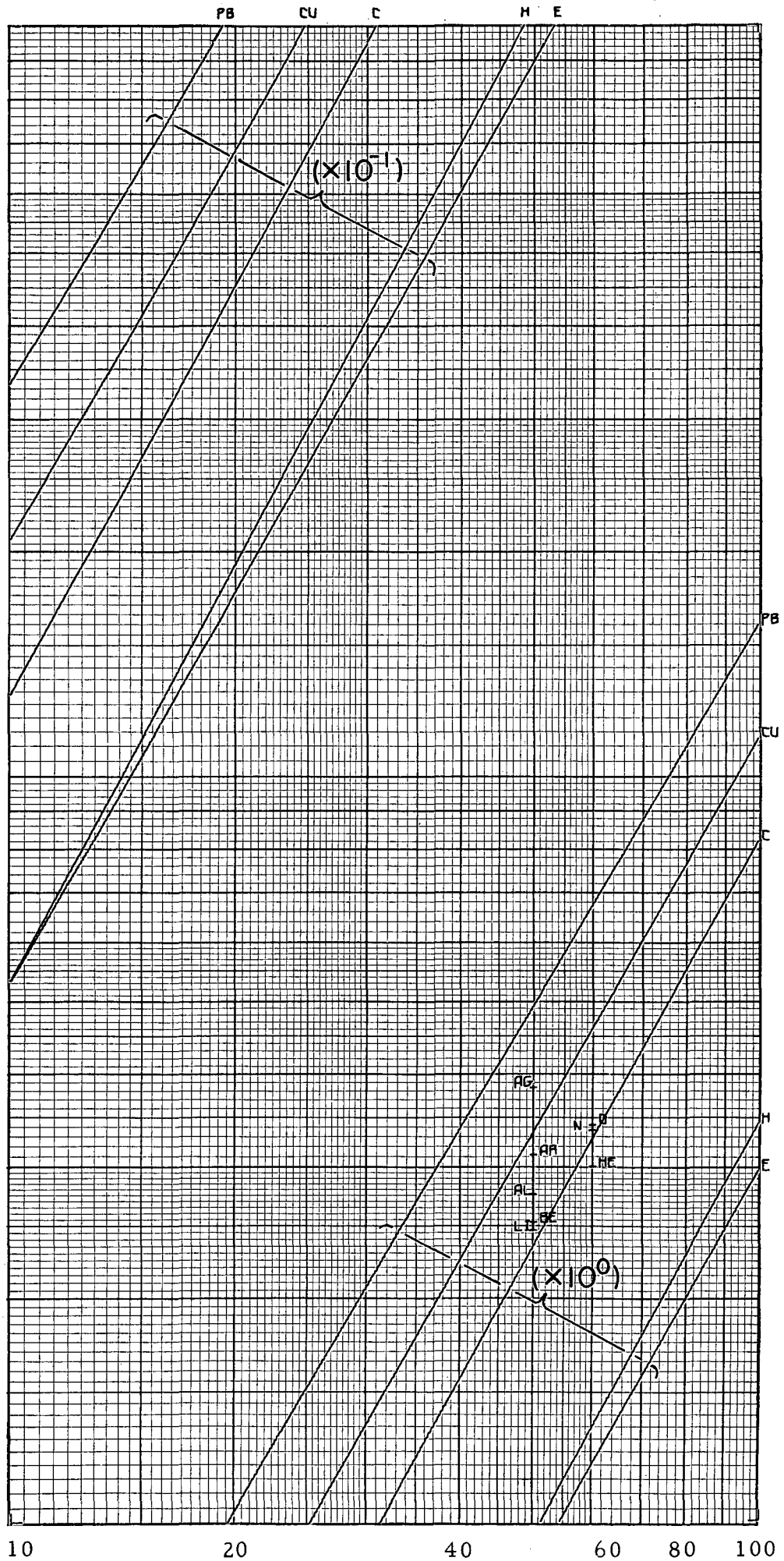

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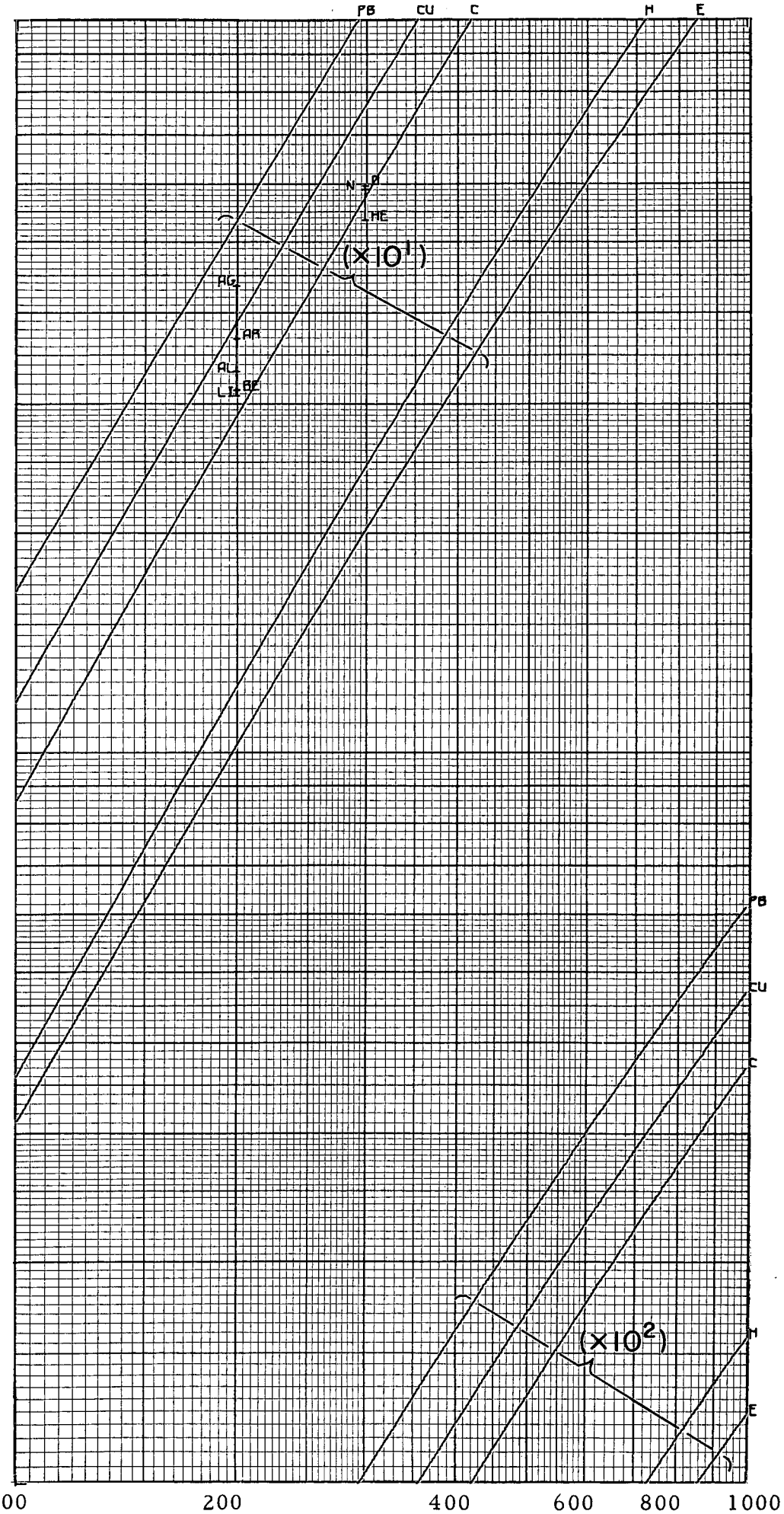

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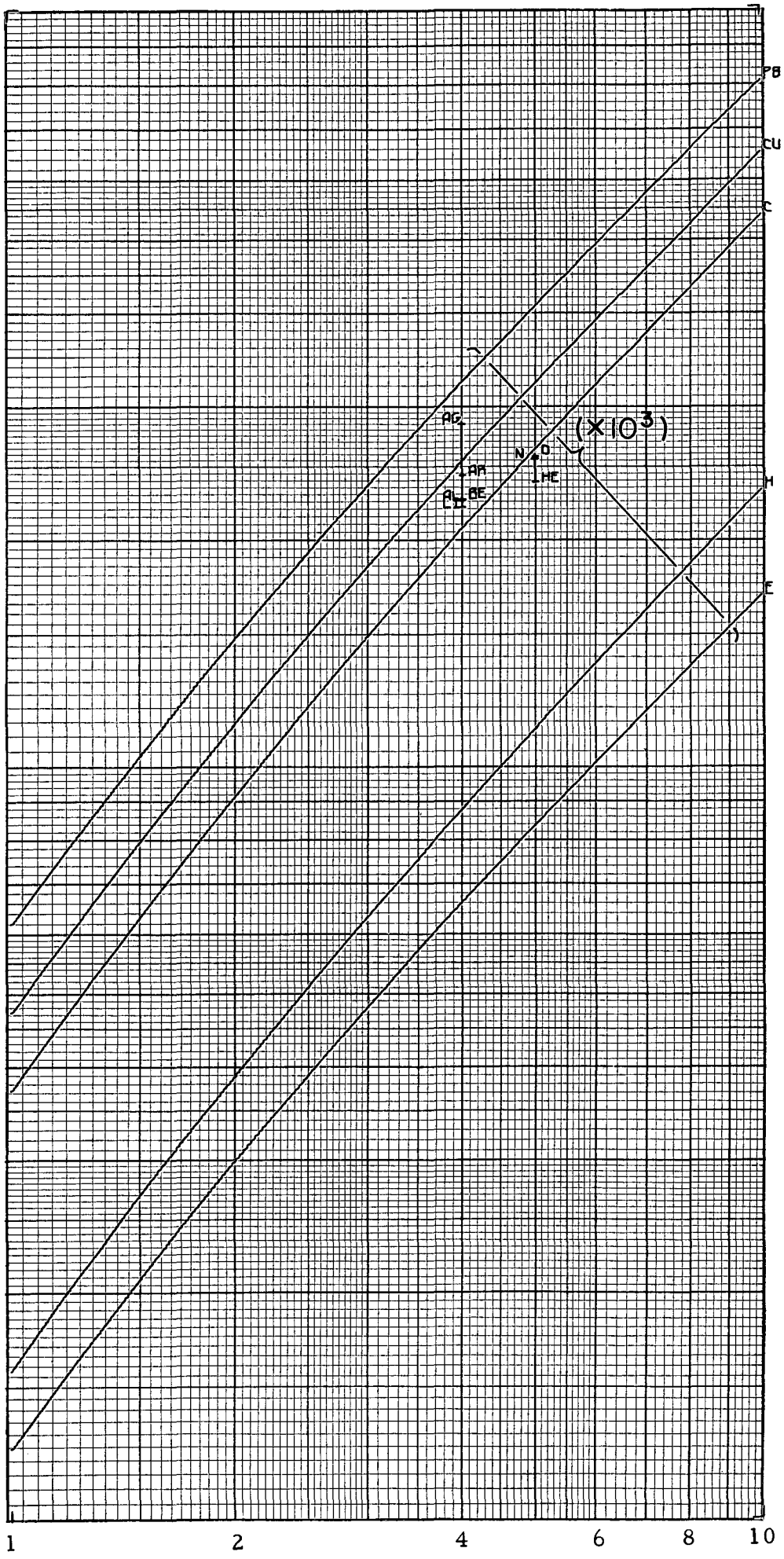

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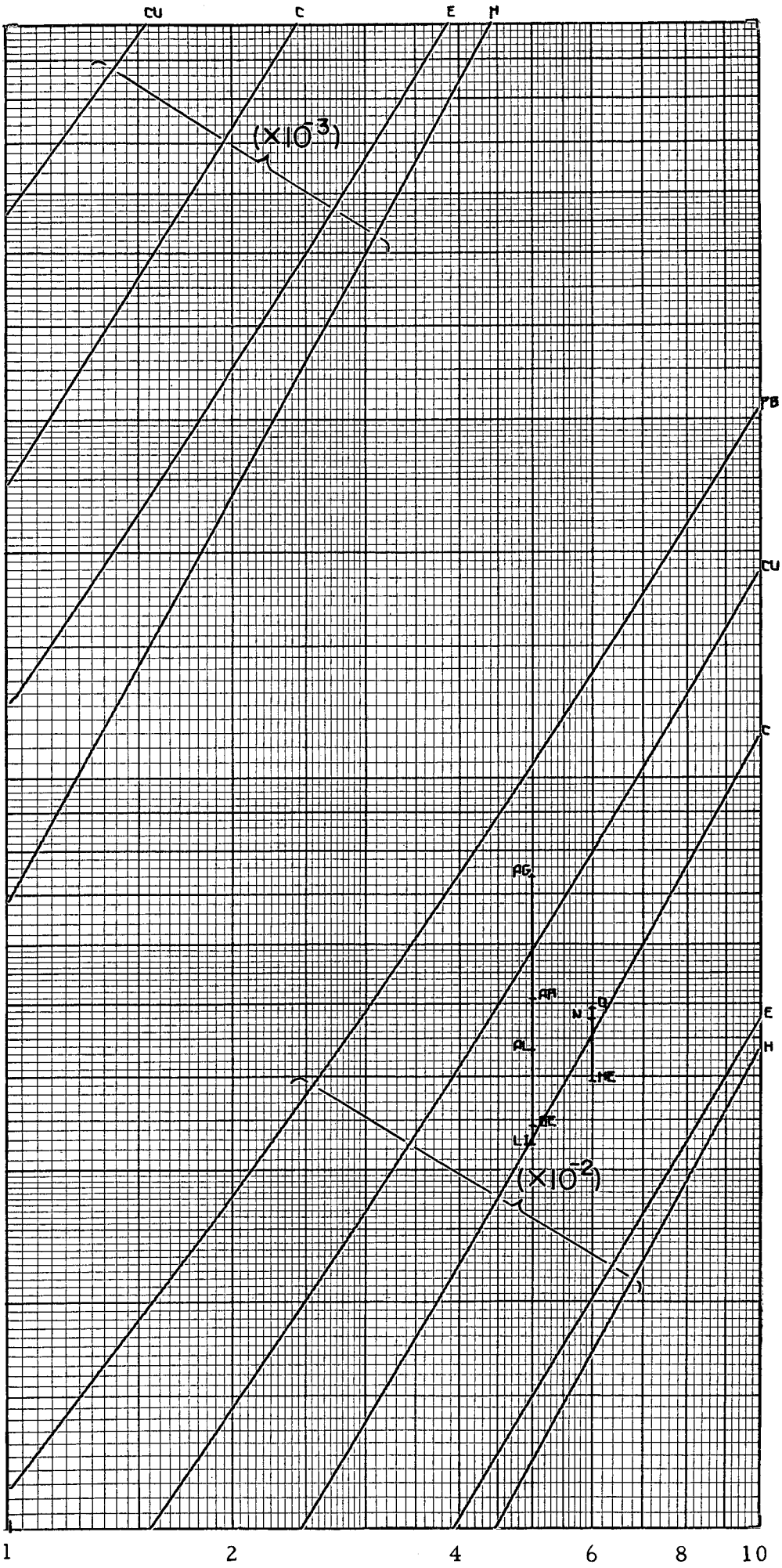


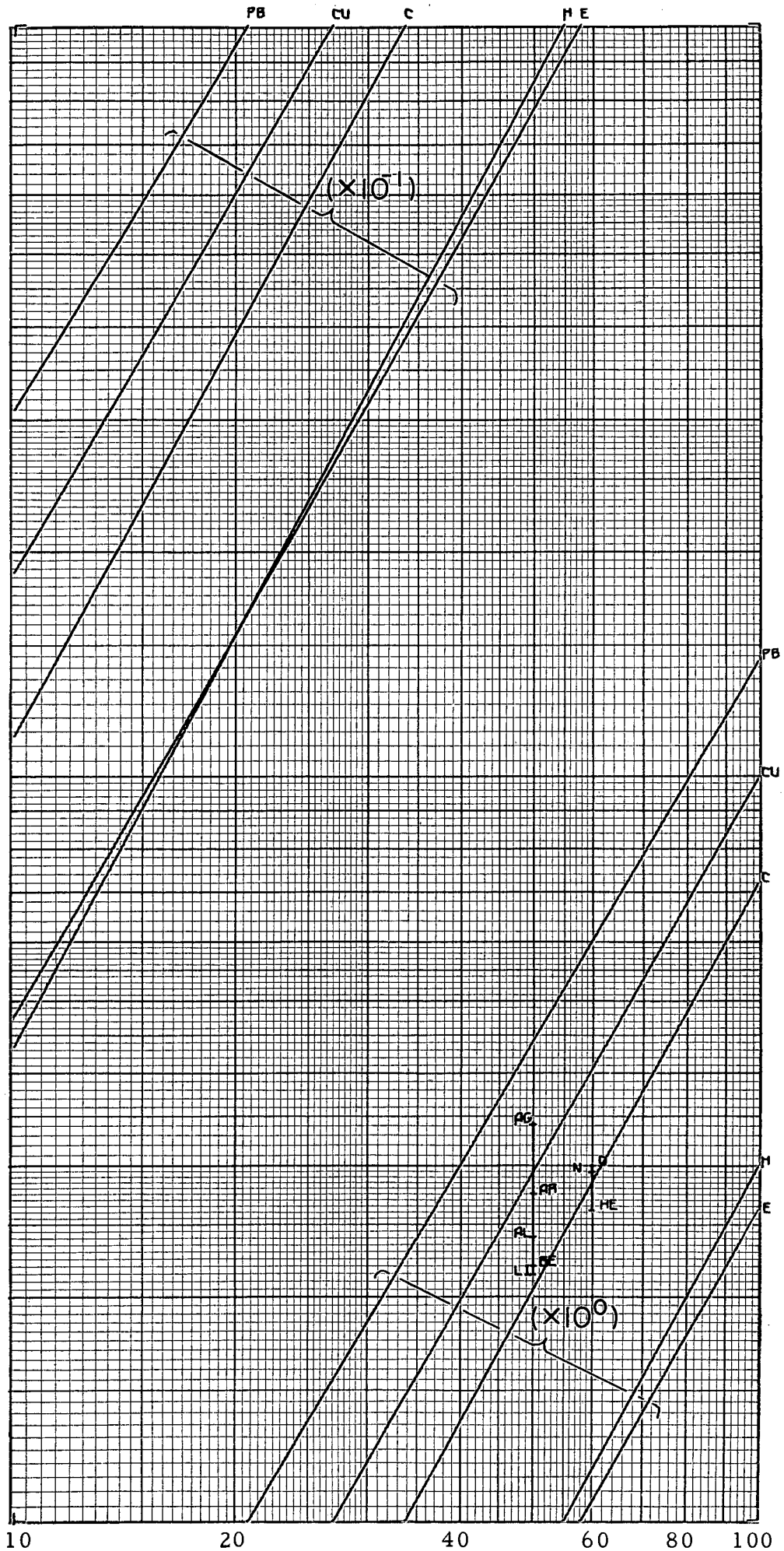
SIGMA+ HYPERONS

(1 TO 10 MEV)

M = 1189.39 BEV

= 2327.6 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



SIGMA+HYPERONS

(10 TO 100 MEV)

M = 1189.39 BEV

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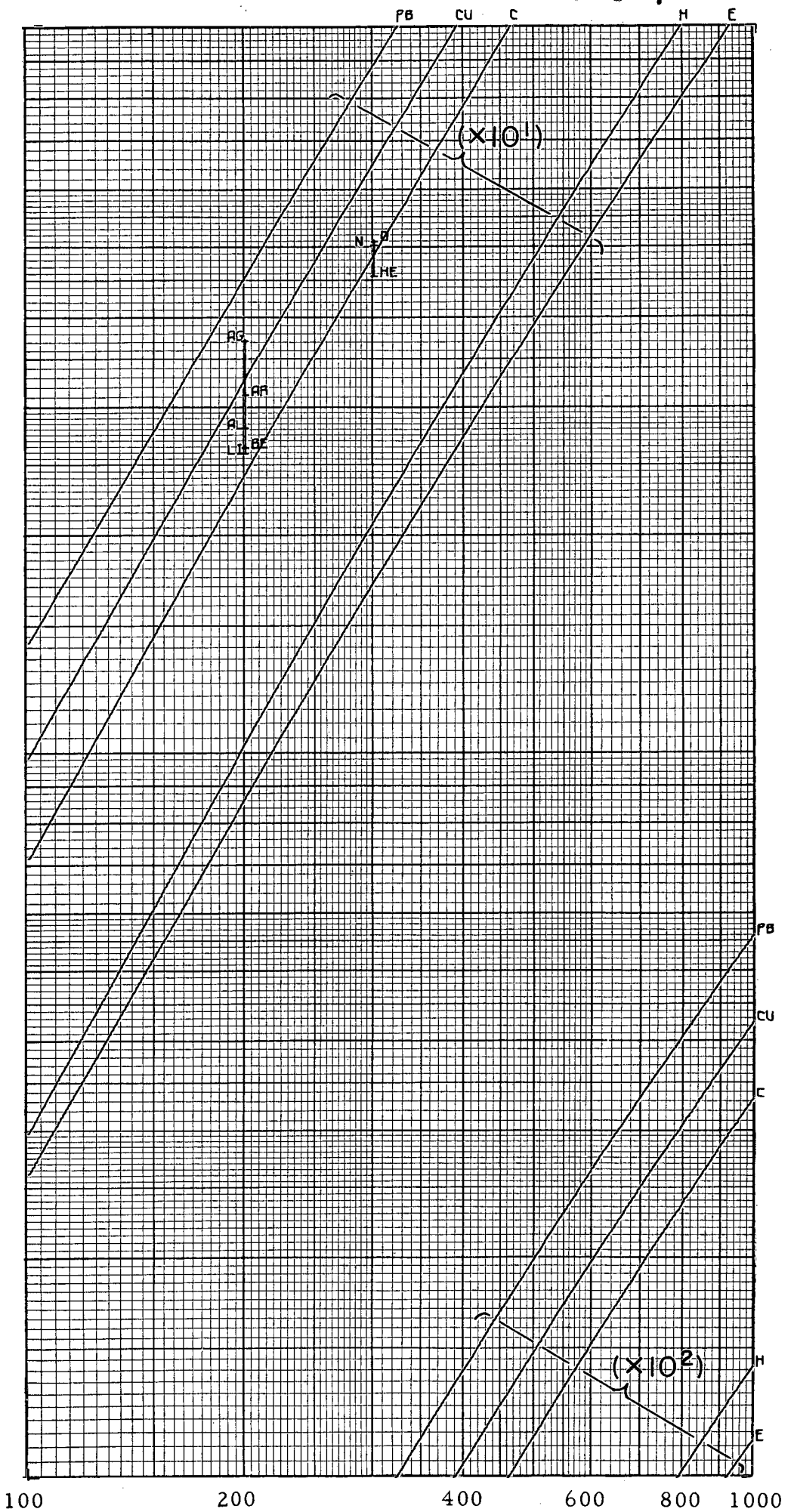

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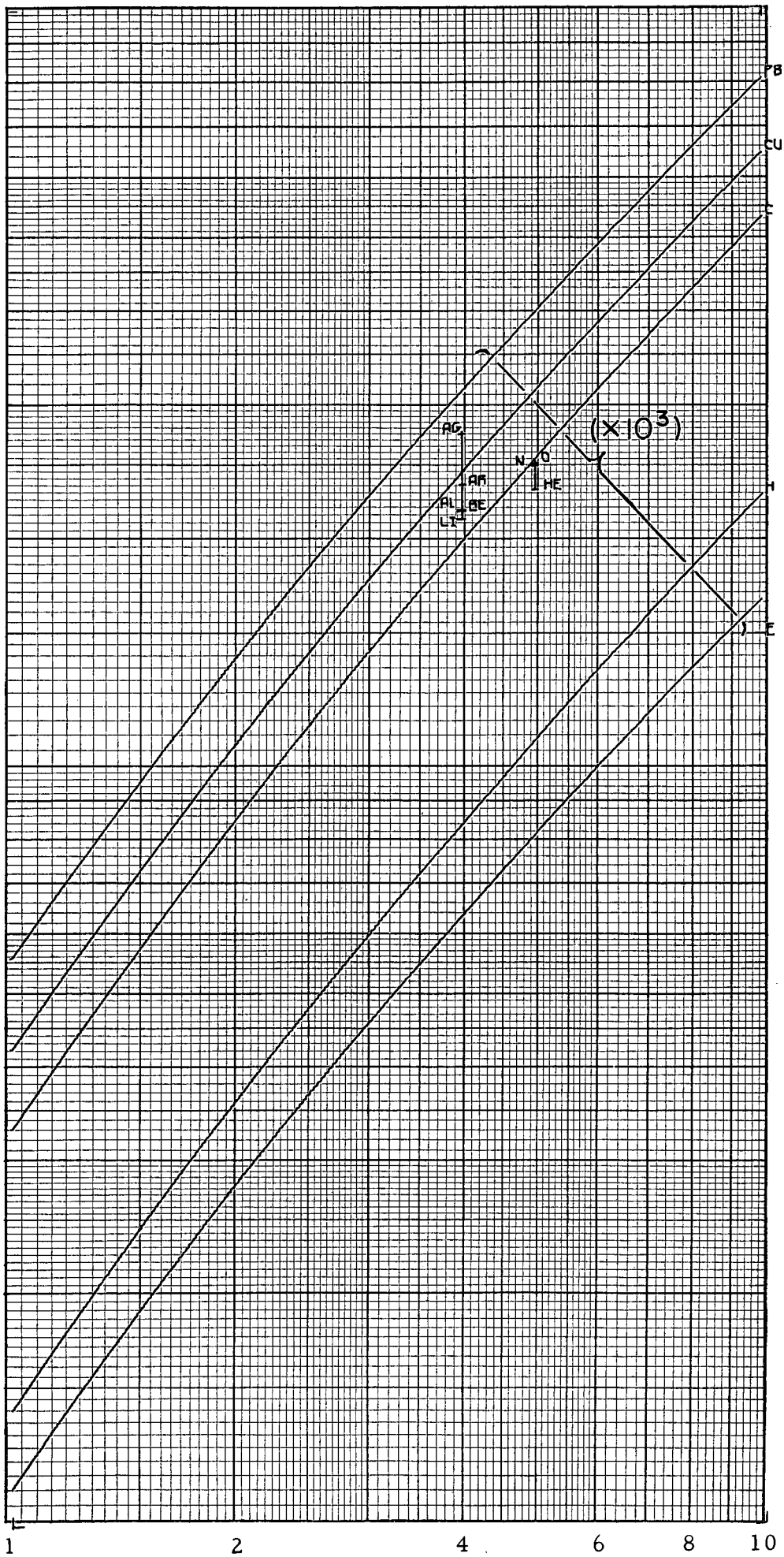

SIGMA+HYPERONS

(1 TO 10 GEV)

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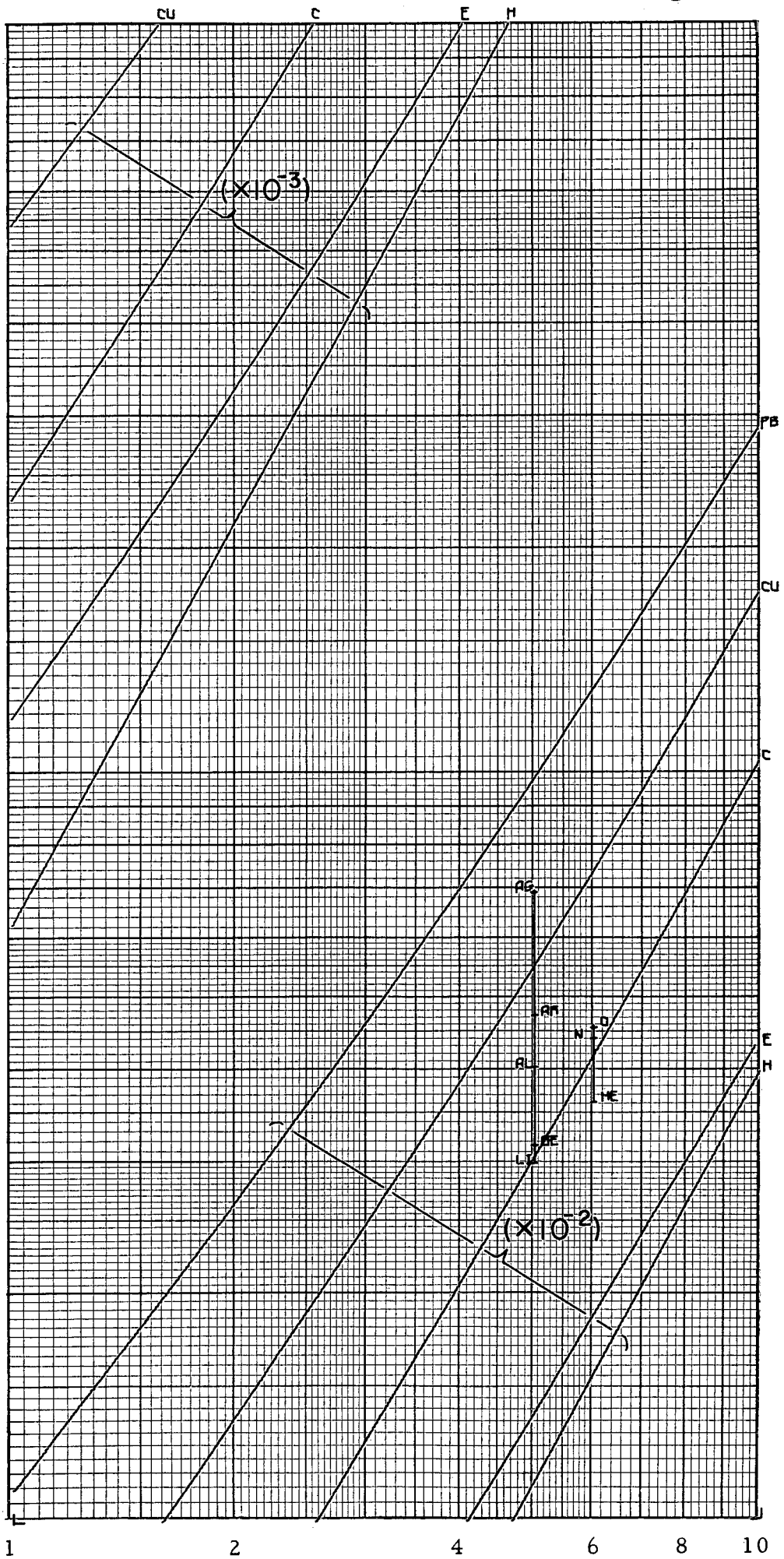
= 2327.6 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



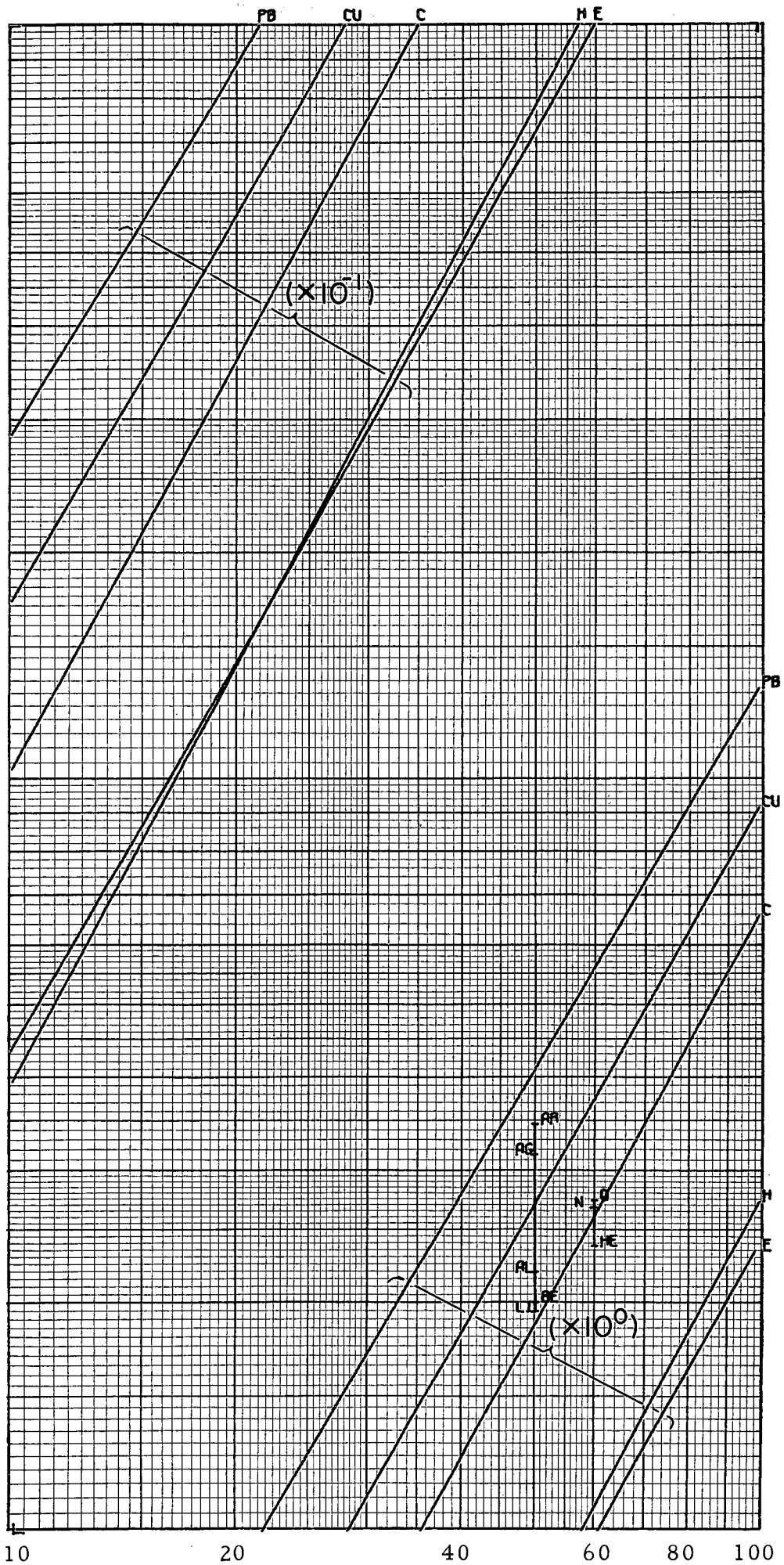
XI- HYPERONS

(1 TO 10 MEV)

M = 1920.0 MEV

= 2565.26 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



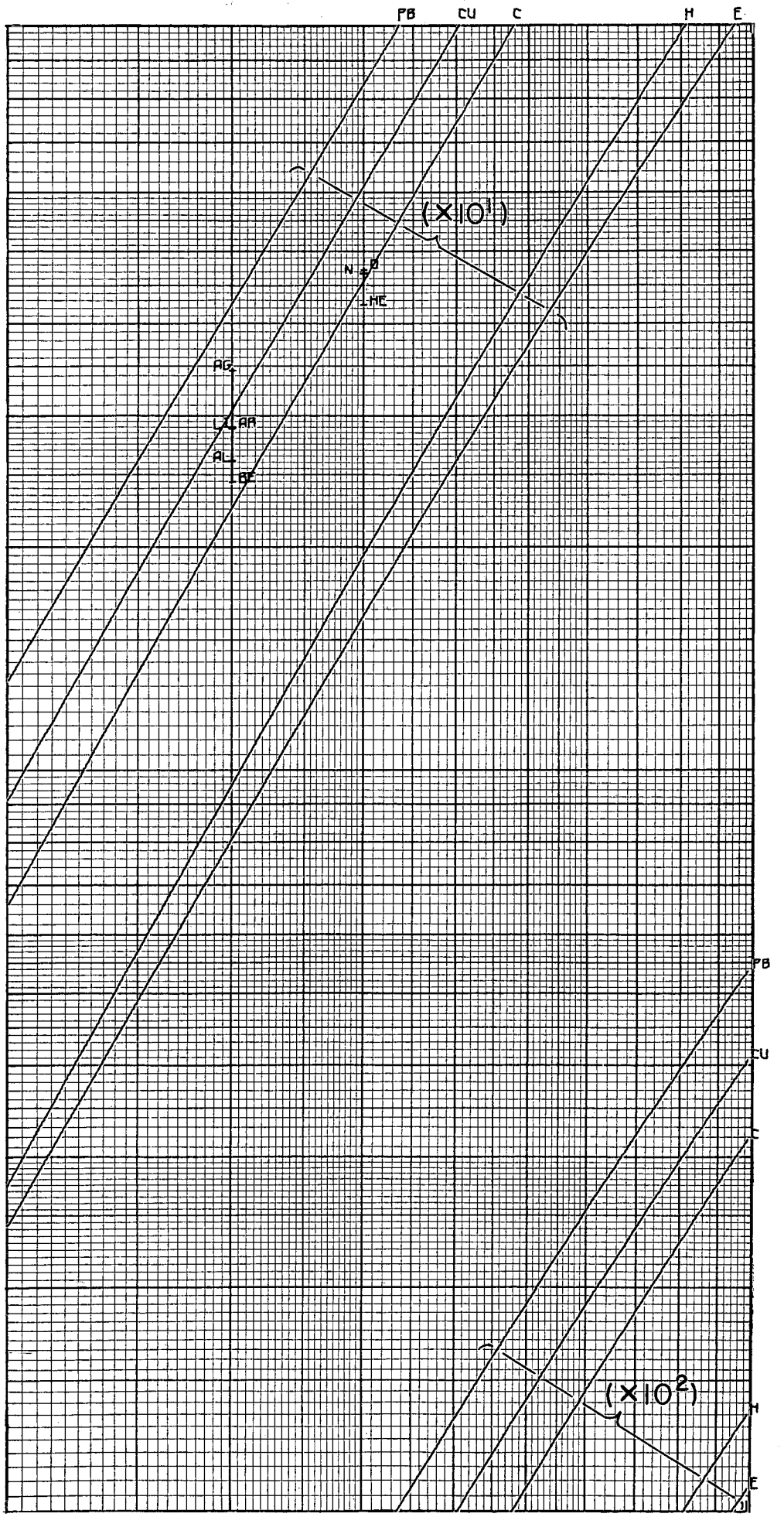
XI- HYPERONS

(10 TO 100 MEV)

M = 1320.0 MEV

= 2585.20 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



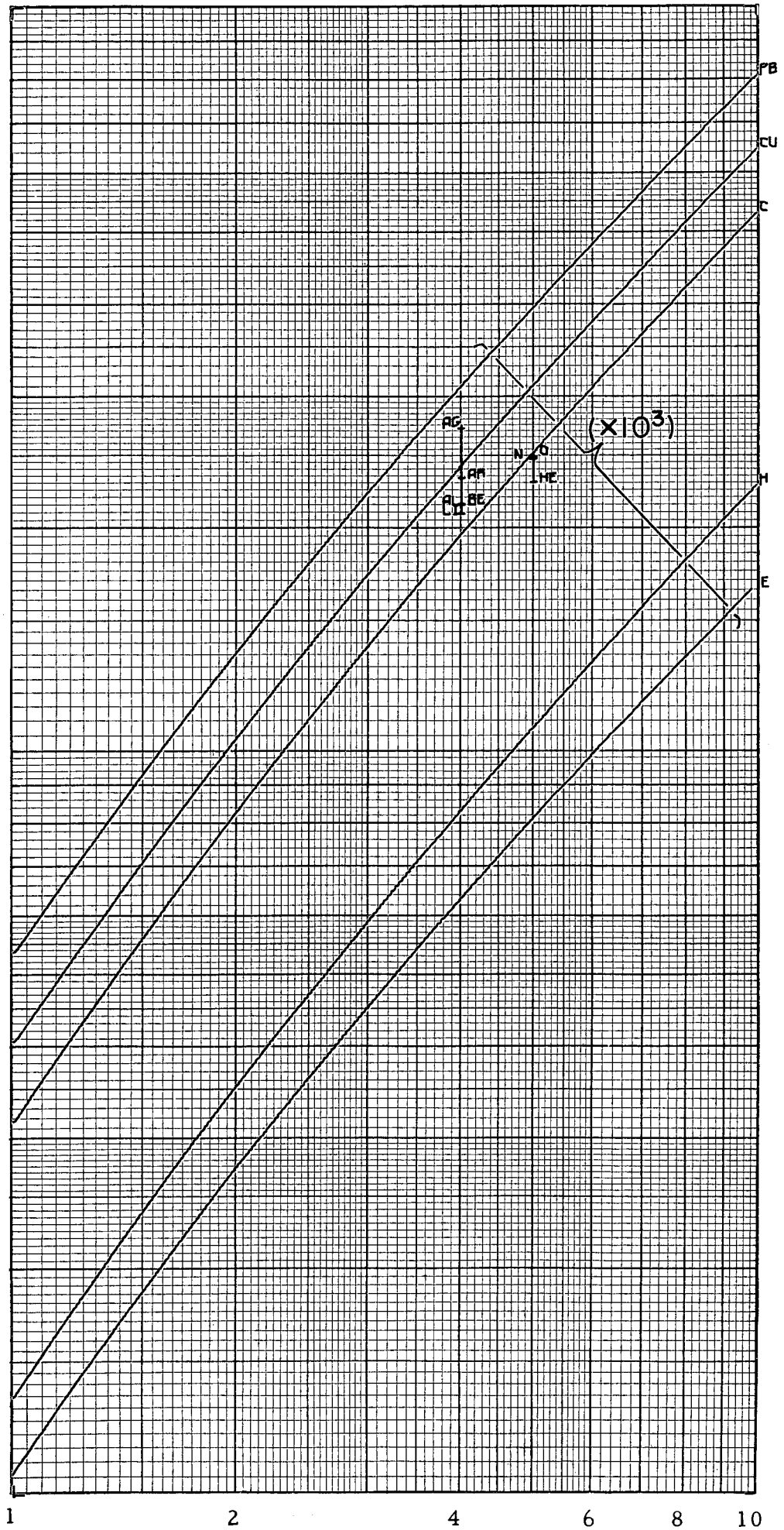
XI- HYPERONS

(100 TO 1000 MEV)

M = 1320.0 MEV

= 2585.28 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



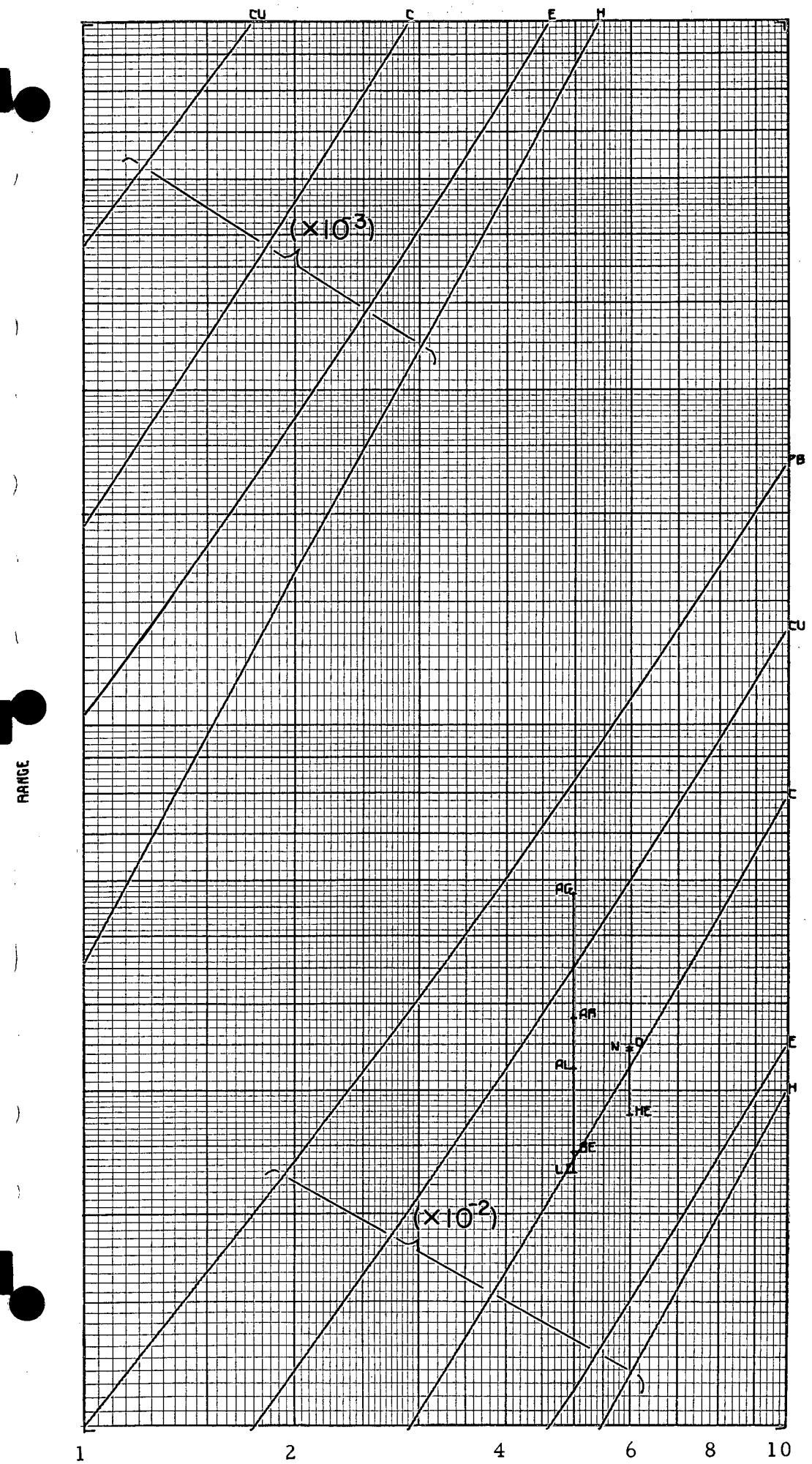
XI- HYPERONS

(1 TO 10 GEV)

M = 1320.8 MEV

= 2585.28 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILLFORD G-5 EMULSION IN CM.



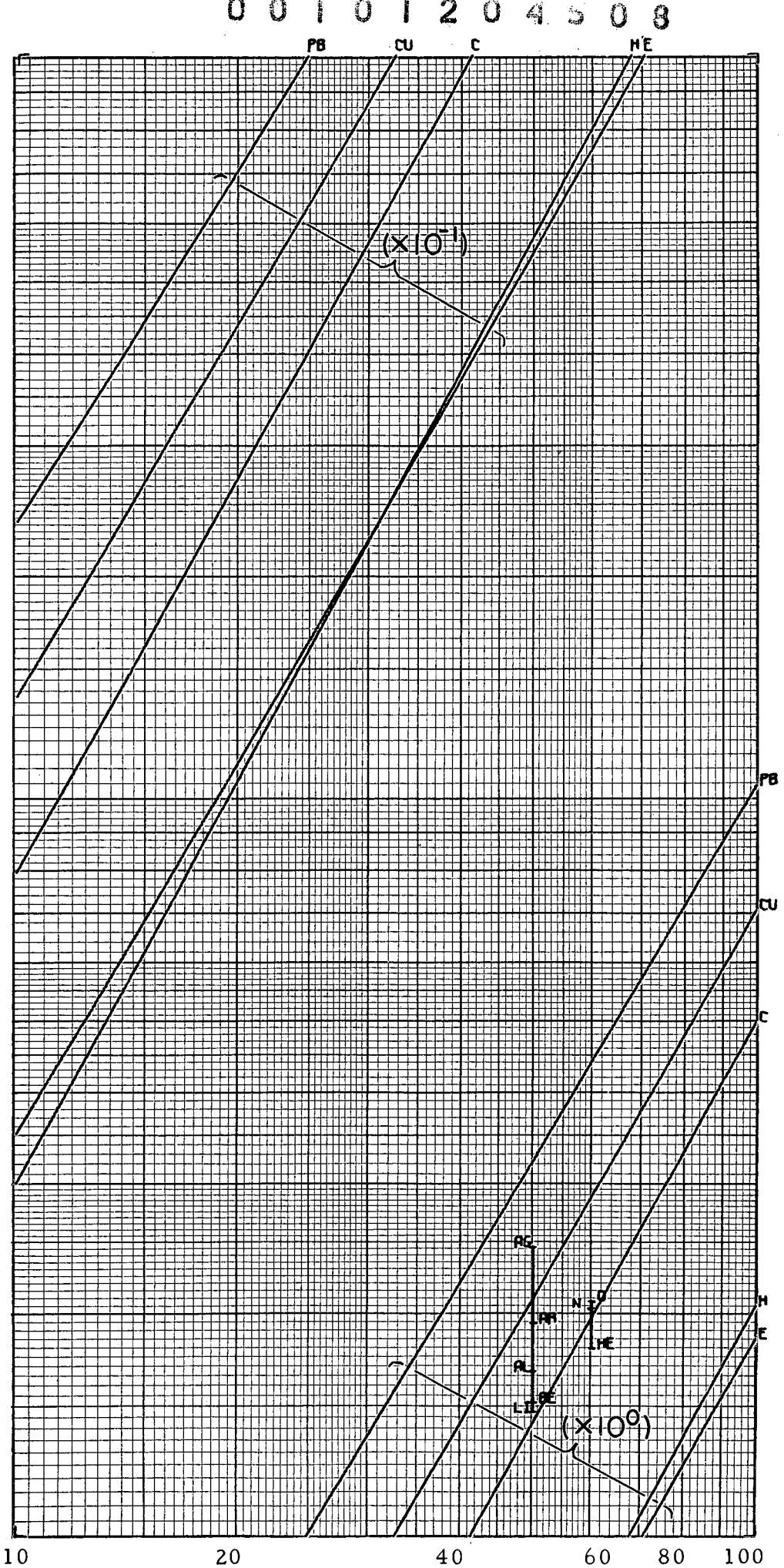
DEUTERONS

(1 TO 10 MEV)

M = 1875.49 MEV

= 9670.45 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



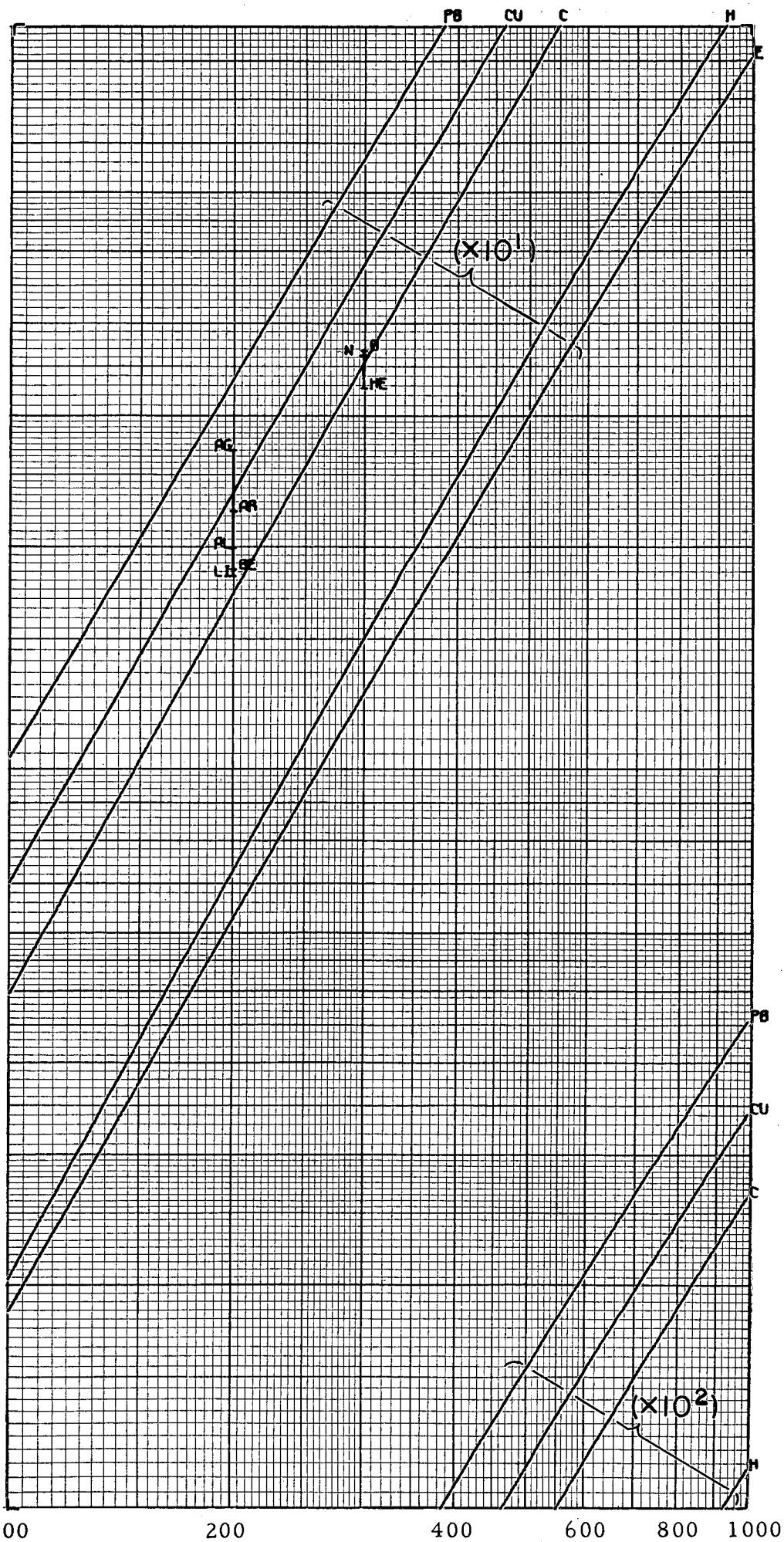
DEUTERONS

(10 TO 100 MEV)

M = 1875.49 MEV

= 9670.45 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



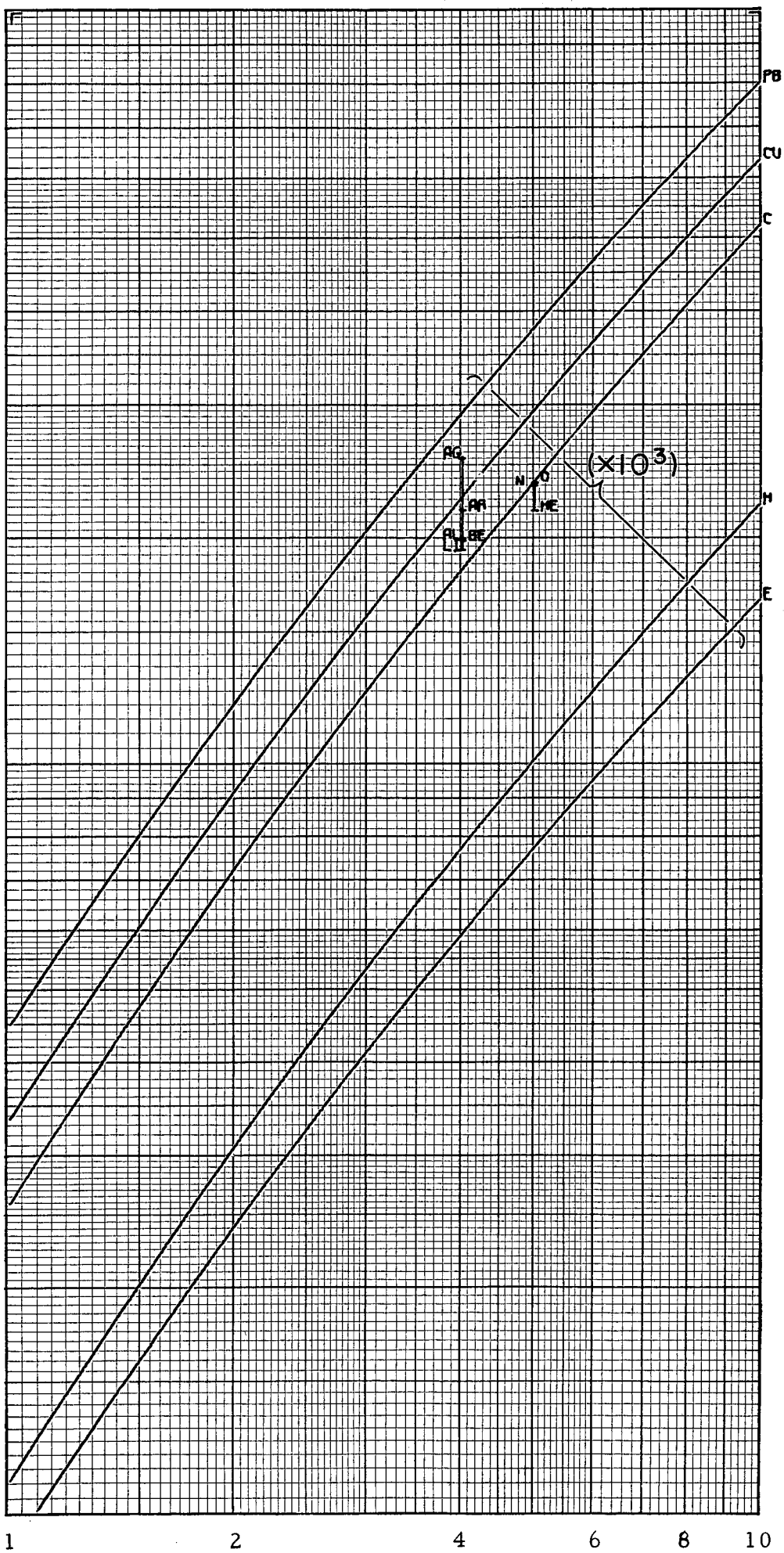
DEUTERONS

(100 TO 1000 MEV)

M = 1875.49 MEV

= 3670.45 m

RANGE OF H.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



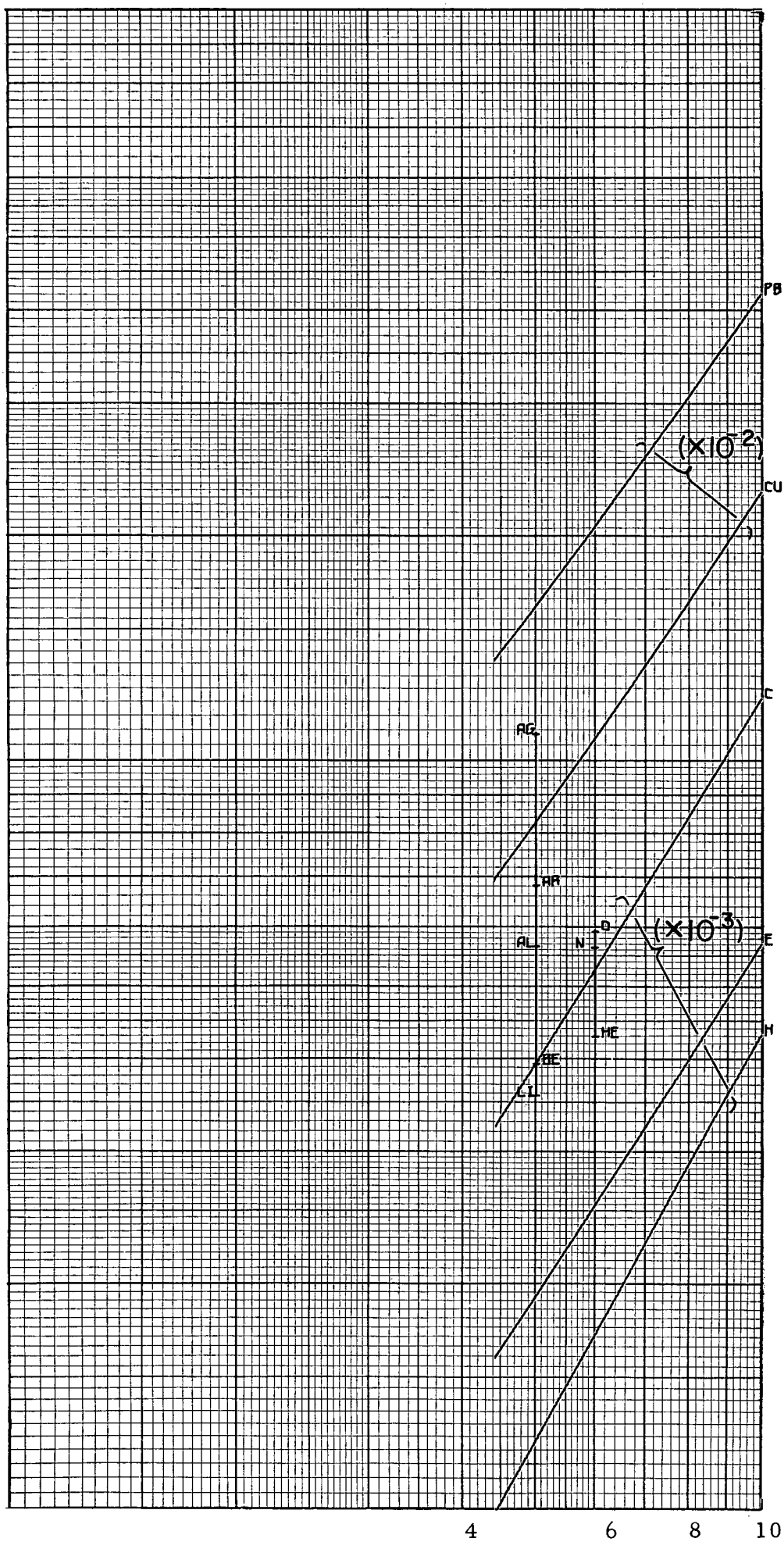
DEUTERONS

(1 TO 10 GEV)

M = 1875.49 MEV

= 3670.45 m

RANGE OF M.C.CV. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



ALPHA PARTICLES

(4.5 TO 10 MEV)

M = 3727.23 MEV

= 7294.47 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.

0 0 1 0 1 2 0 4 5 1 2

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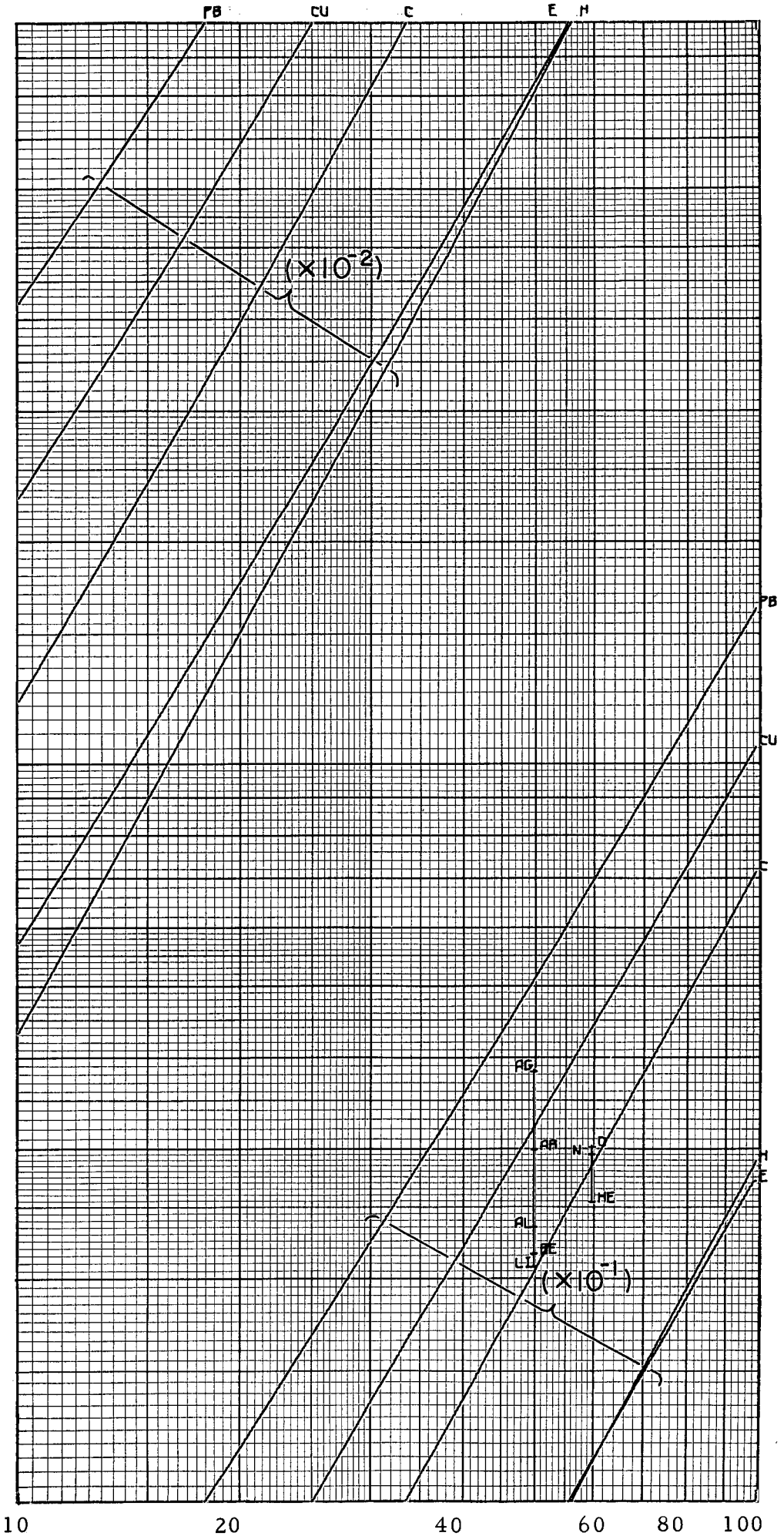
(GRAPHS)



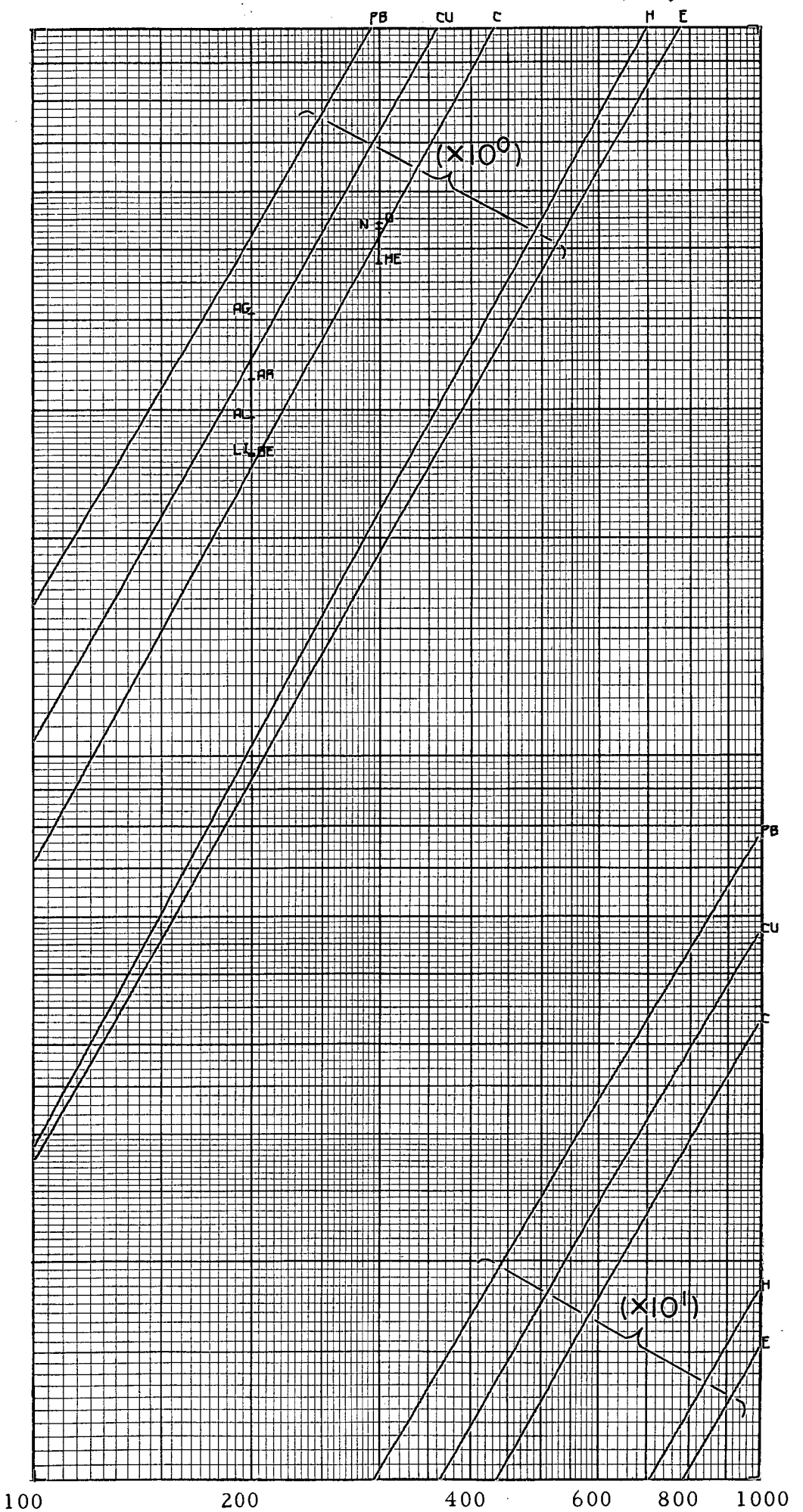
ALPHA PARTICLES

(10 TO 100 MEV)

M = 5727.25 MEV

= 7294.47 m

RANGE OF M.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



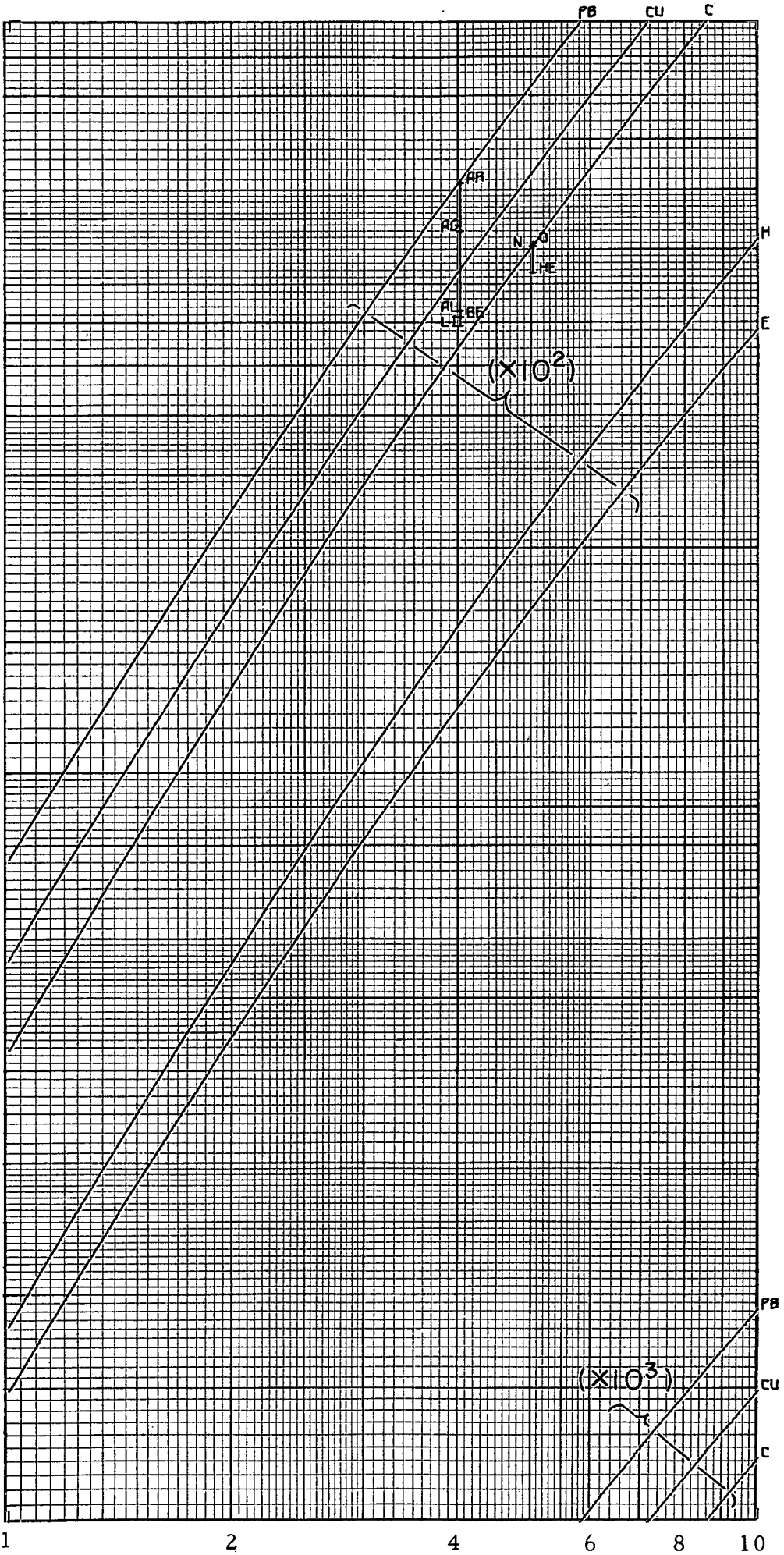
ALPHA PARTICLES

(100 TO 1000 MEV)

M = 9727.23 MEV

= 7294.47 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.



RANGE

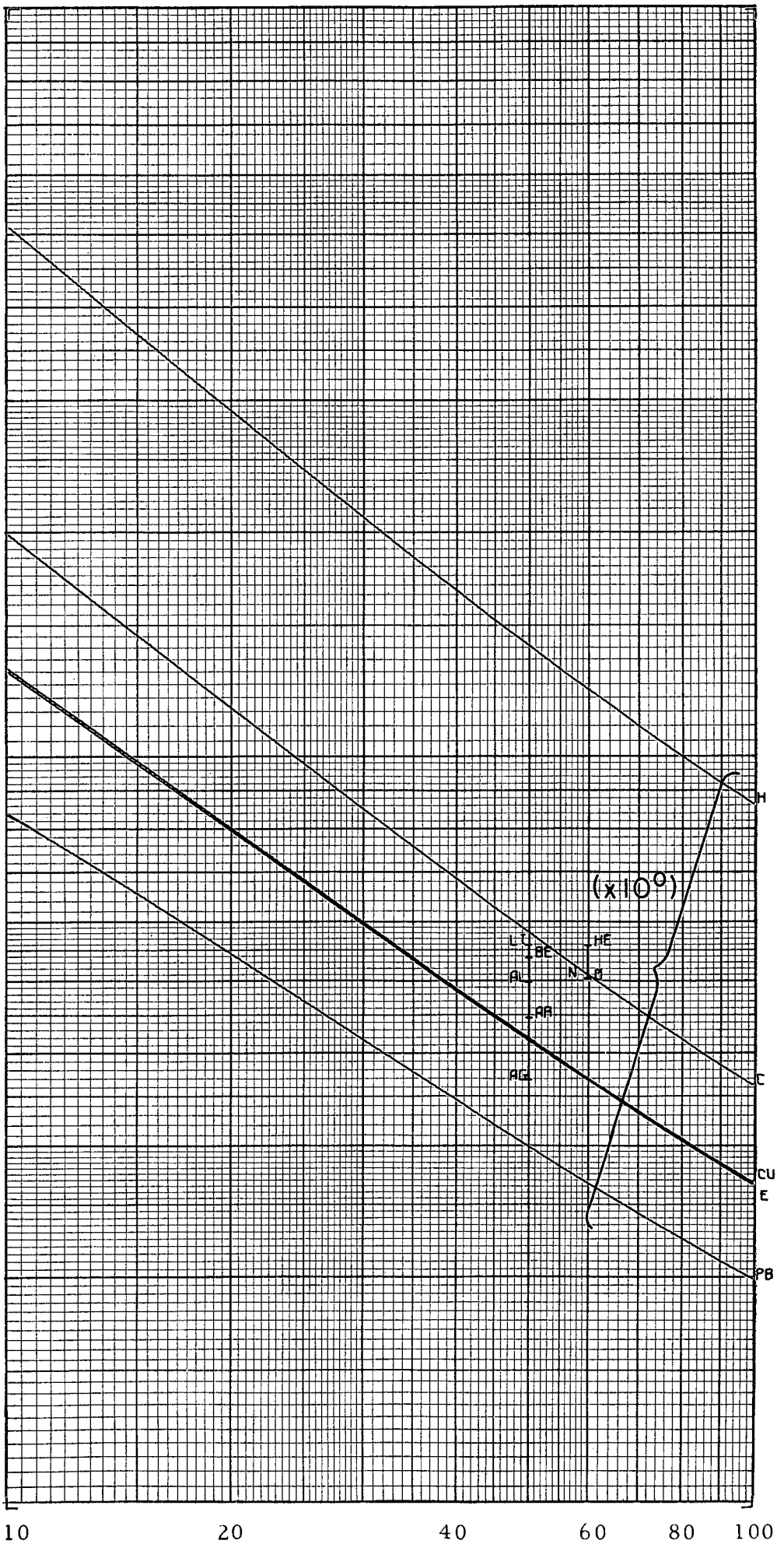
ALPHA PARTICLES

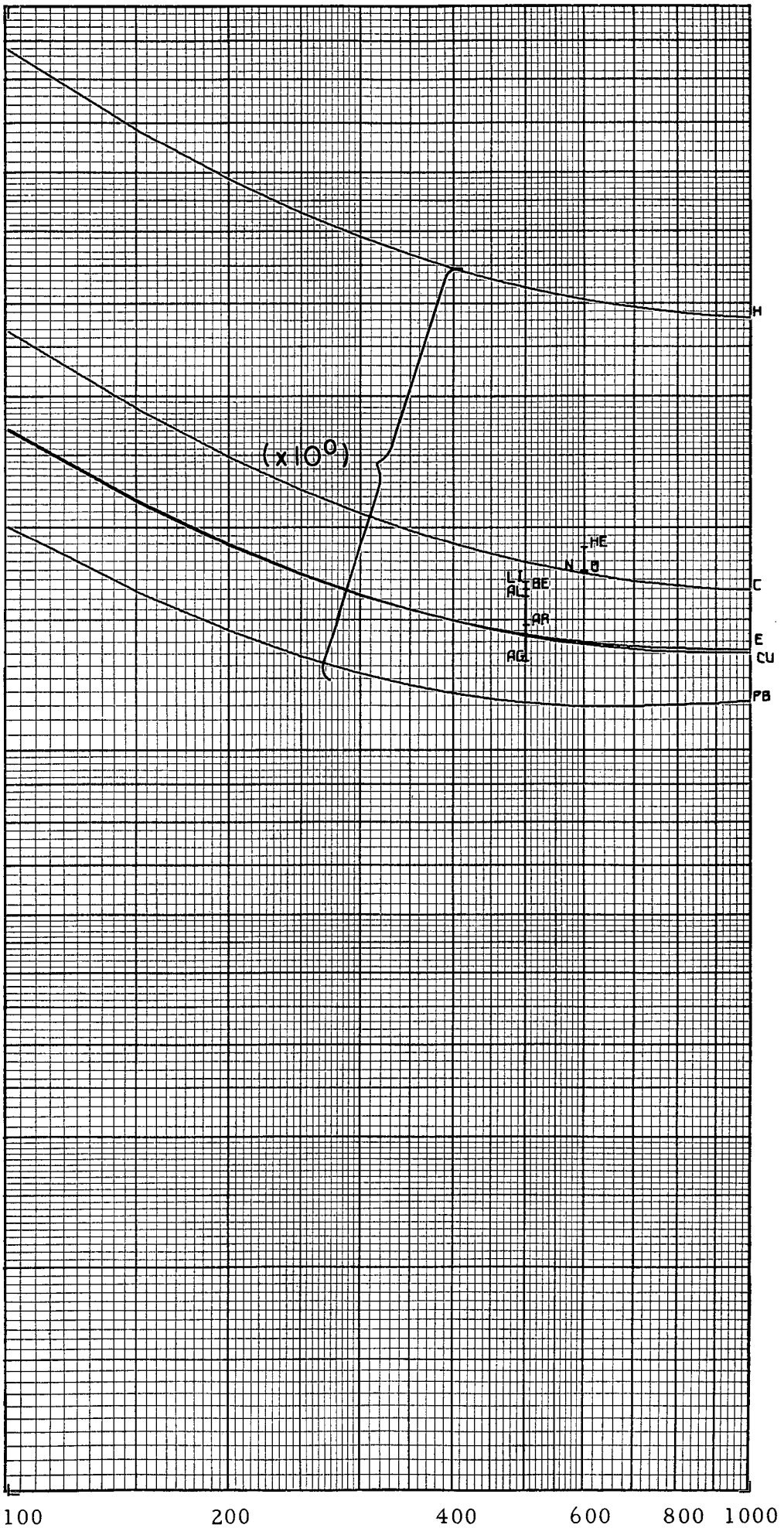
(1 TO 10 GEV)

M = 3727.23 MEV

= 7294.47 m

RANGE OF H.C.CU. AND PB IN G/CM2 AND OF ILFORD G-5 EMULSION IN CM.


ELECTRONS
(10 TO 100 KEV)
M = .511 MEV
= 1 m
DE/DX OF H, C, CU,
AND PB IN MEV CM2/G
AND OF ILFORD G-5
EMULSION IN MEV/CM.
(x10⁰)
H
C
CU
E
PB
LI
BE
HE
AL
N
O
AR
AG
DE/DX
10
20
40
60
80
100



ELECTRONS

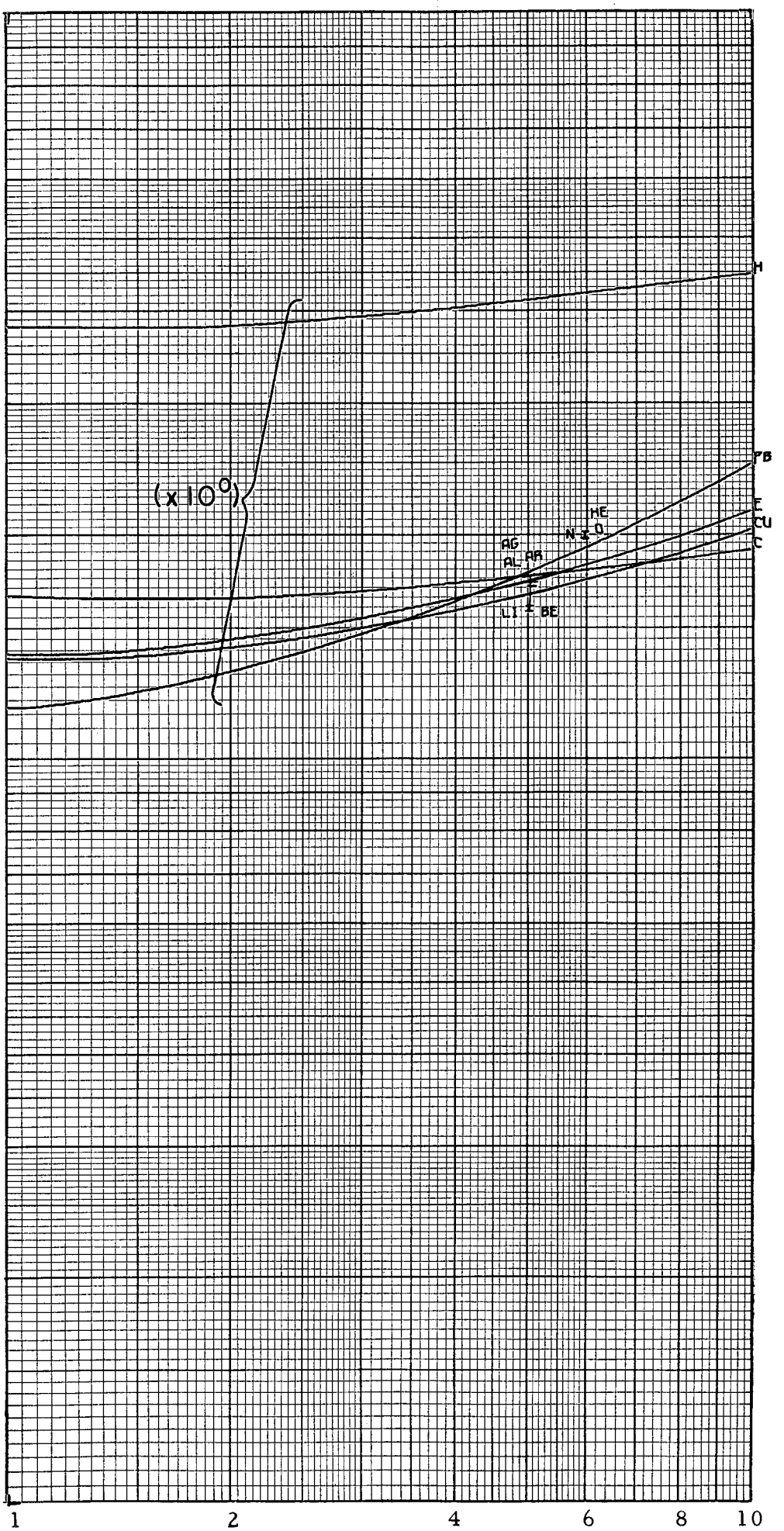
(100 TO 1000 KEV)

M = .511 MEV

= 1 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.

DE/DX



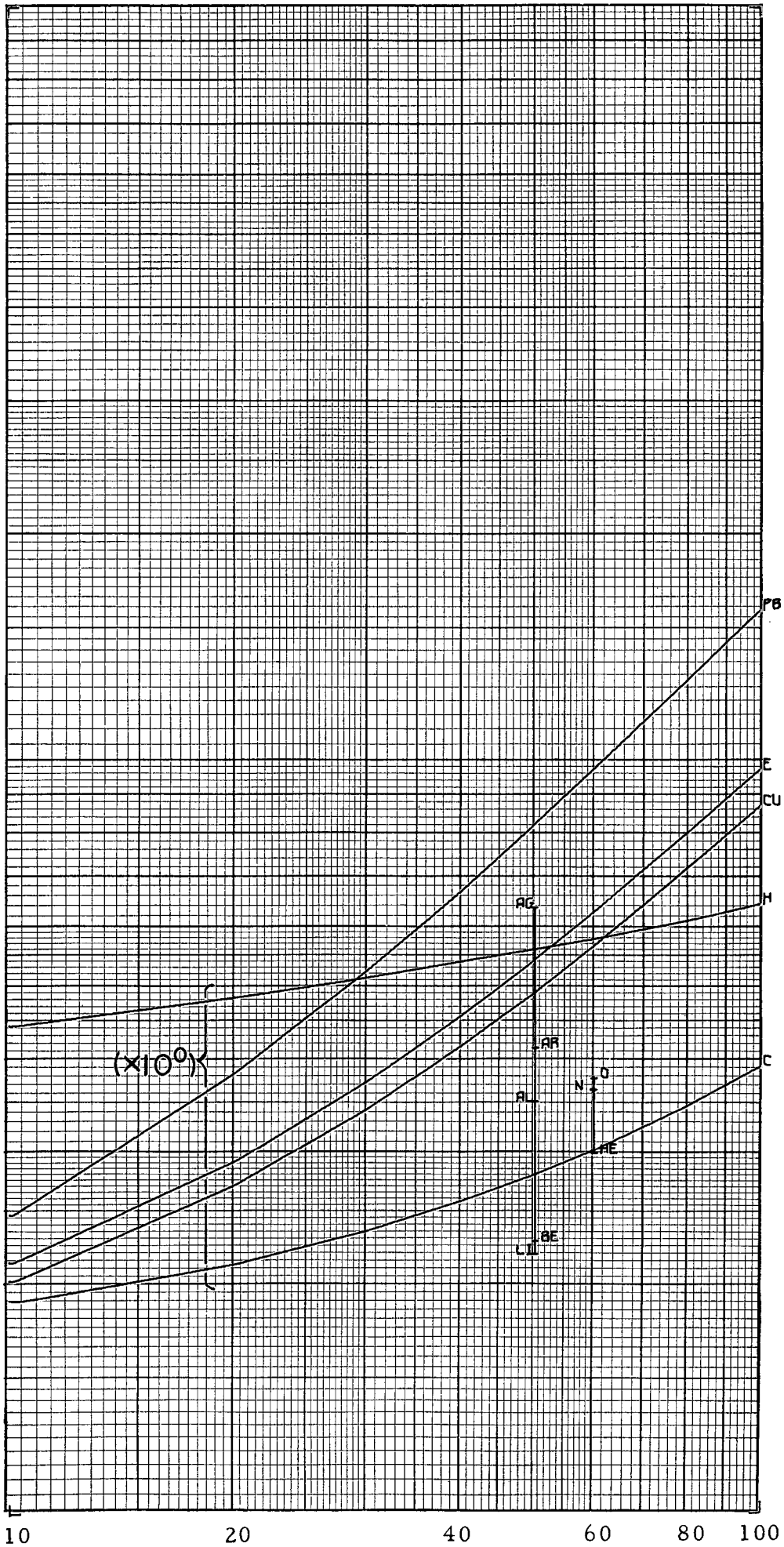
ELECTRONS

(1 TO 10 MEV)

M = .511 MEV

= 1 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



ELECTRONS

(10 TO 100 MEV)

M = .511 MEV

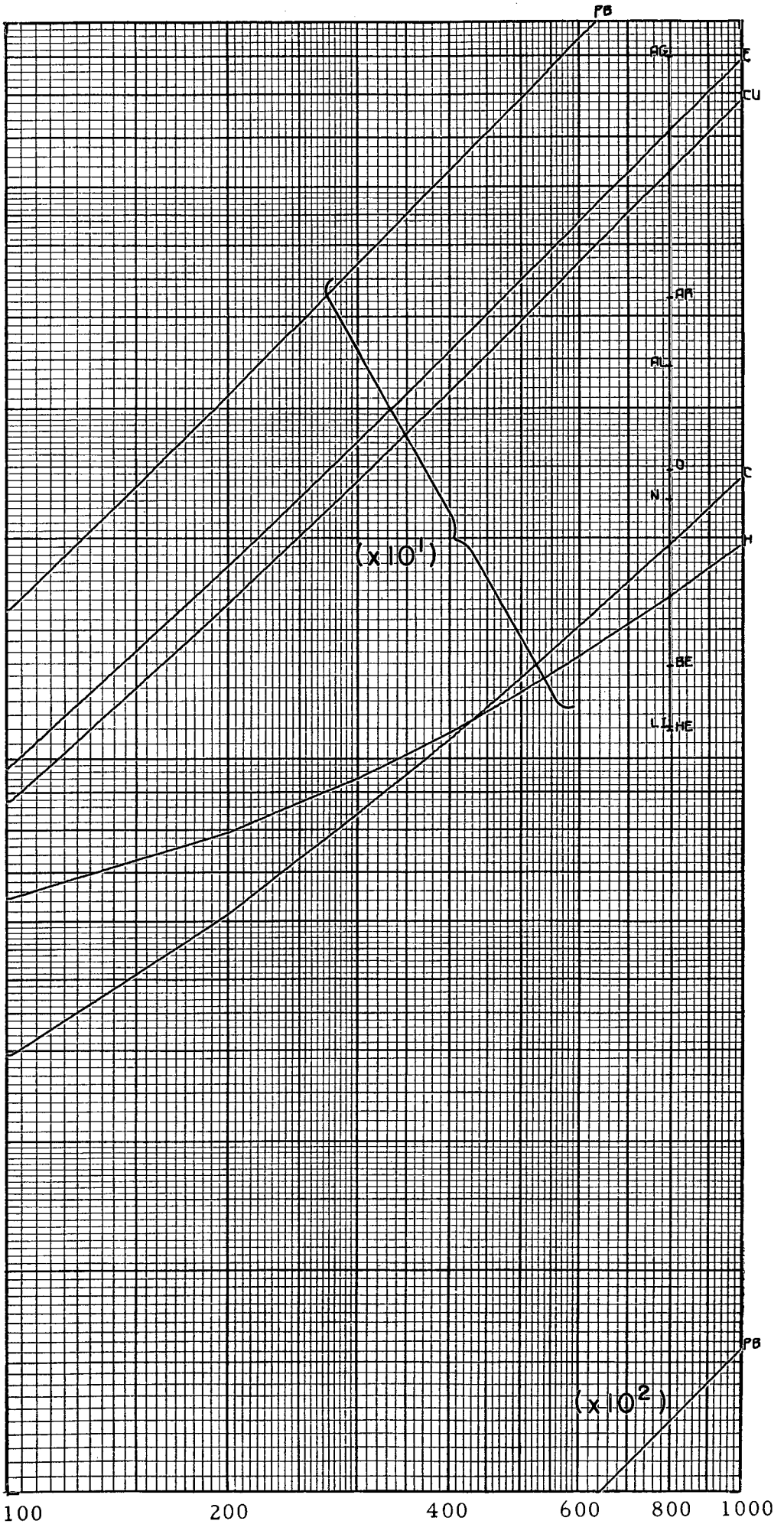
= 1 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.

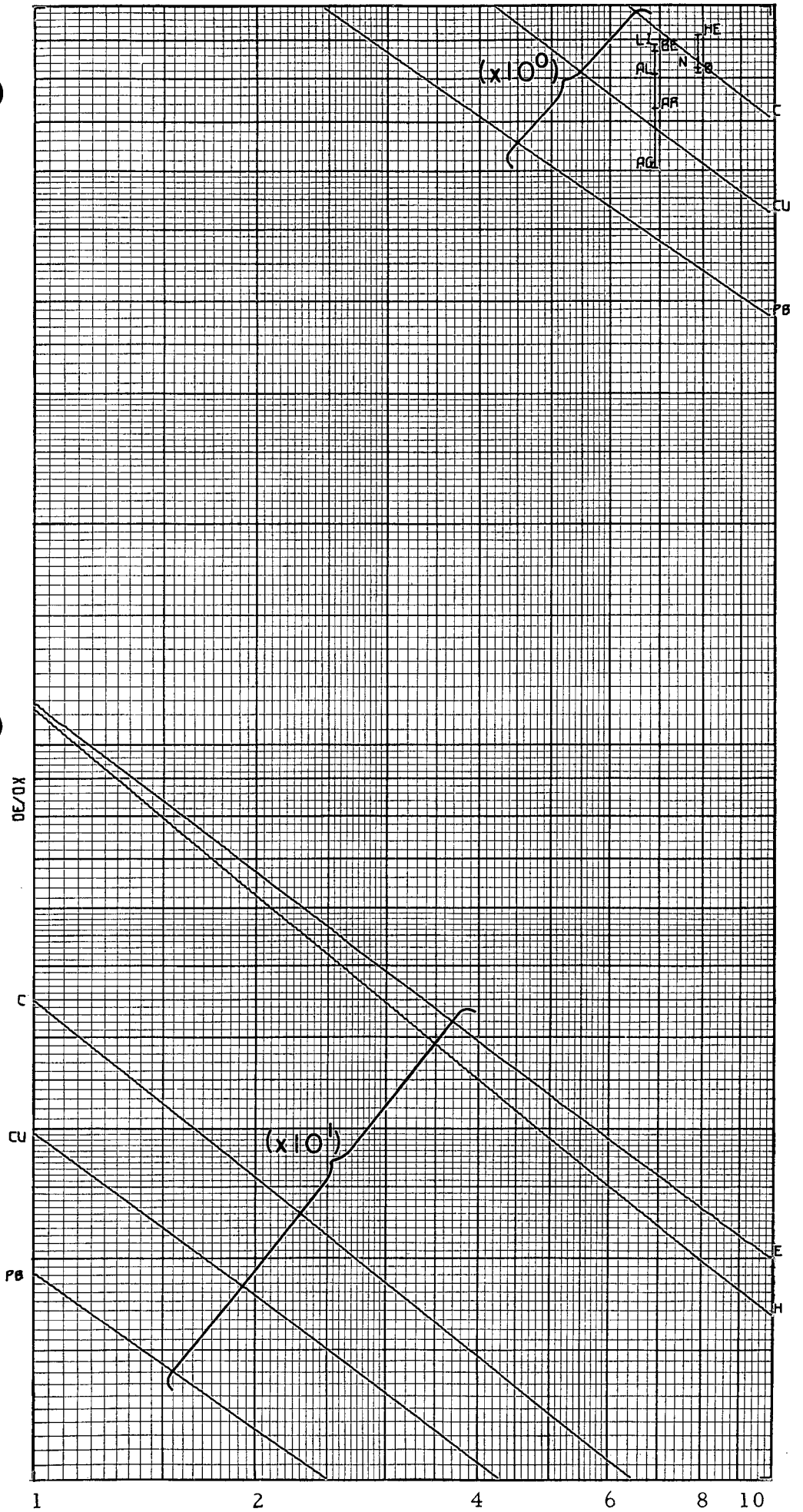


ELECTRONS

(100 TO 1000 MEV)

M = .511 MEV

= 1 m



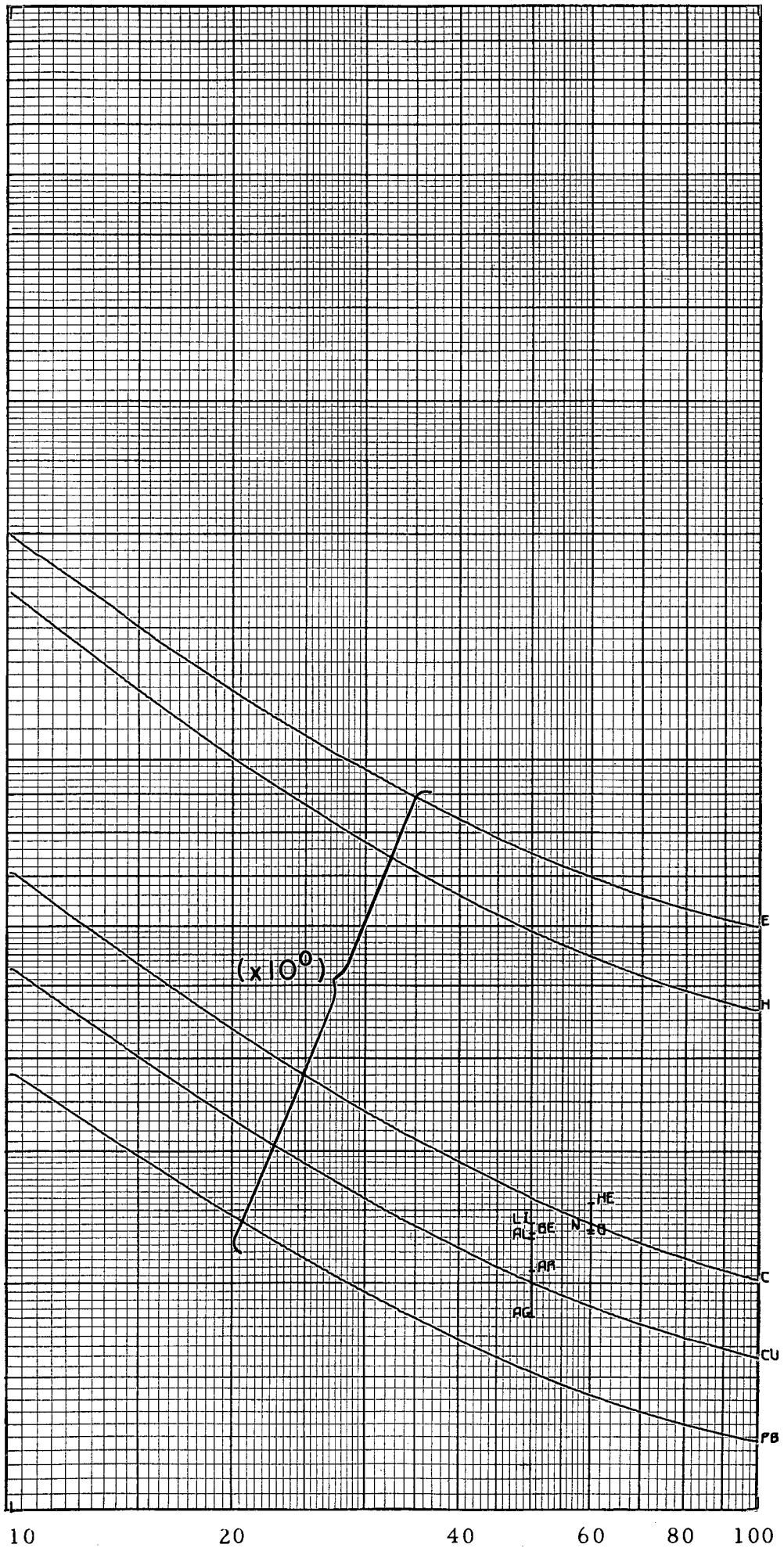
MUONS ±

(1 TO 10 MEV)

M = 105.659 MEV

= 206.86 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



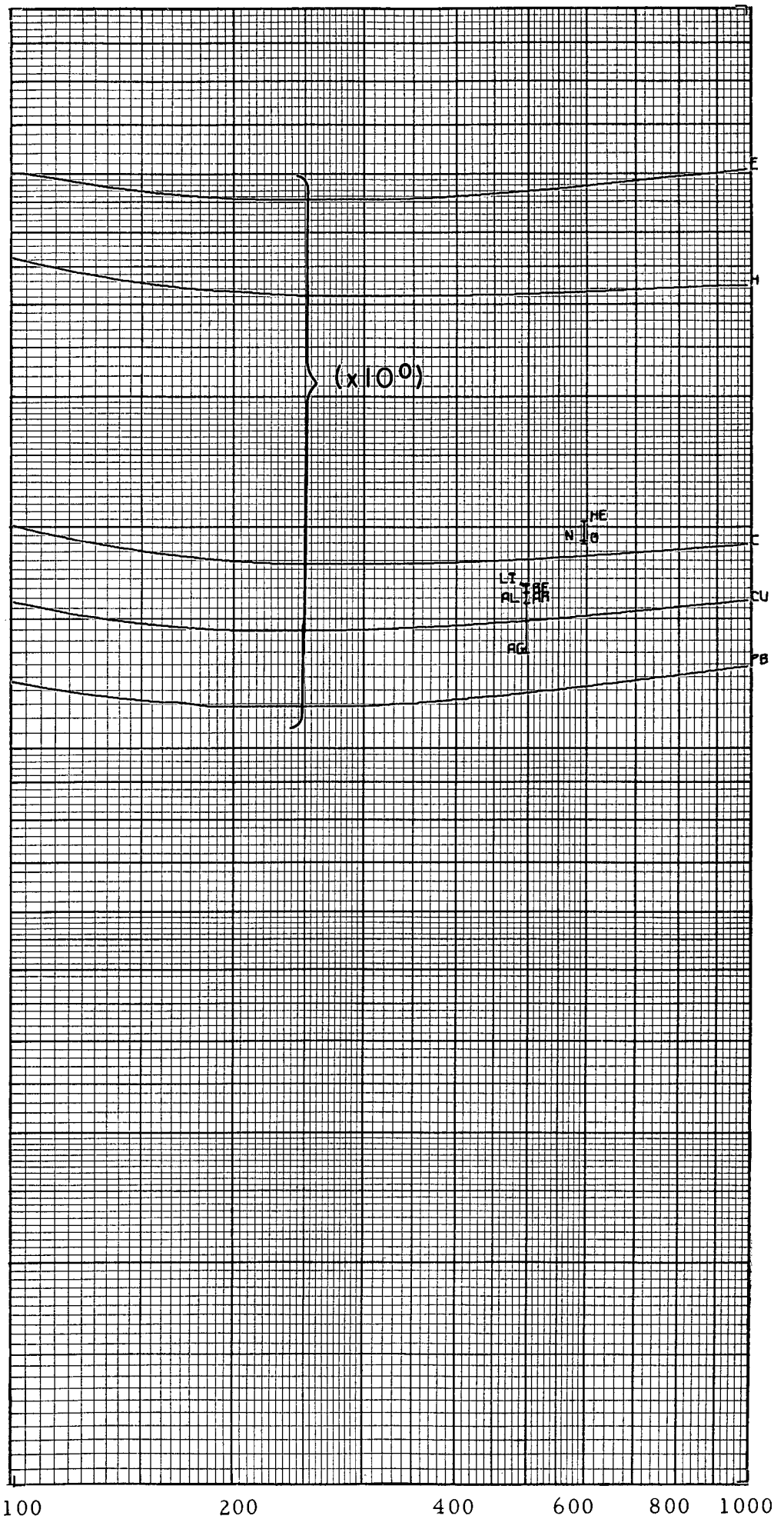
MUONS ±

(10 TO 100 MEV)

M = 105.659 MEV

= 206.86 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



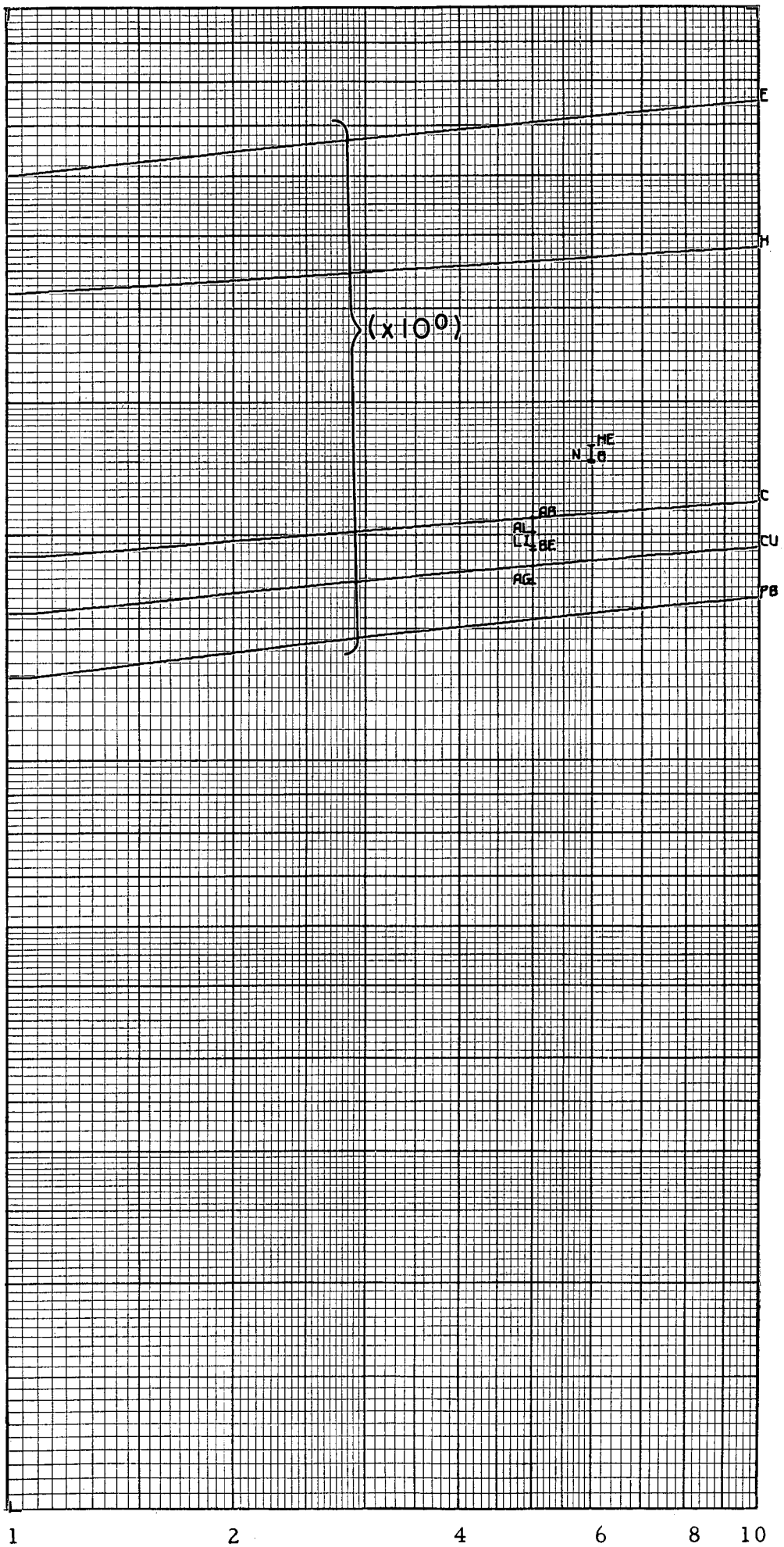
MUONS ±

(100 TO 1000 MEV)

M = 105.659 MEV

= 206.86 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



MUONS ±

(1 TO 10 GEV)

M = 105.659 MEV

= 206.86 m

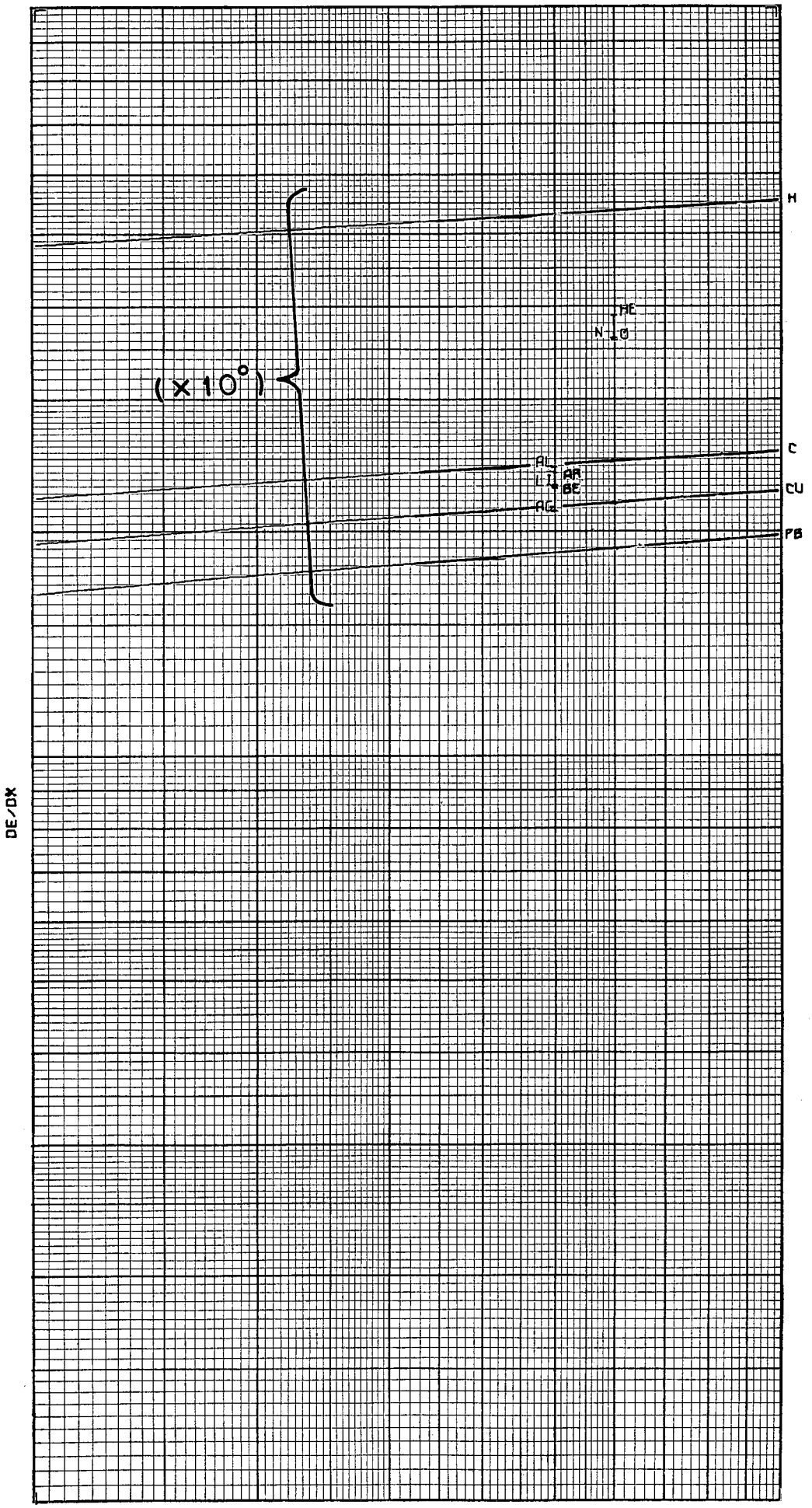
DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.

DE/DX



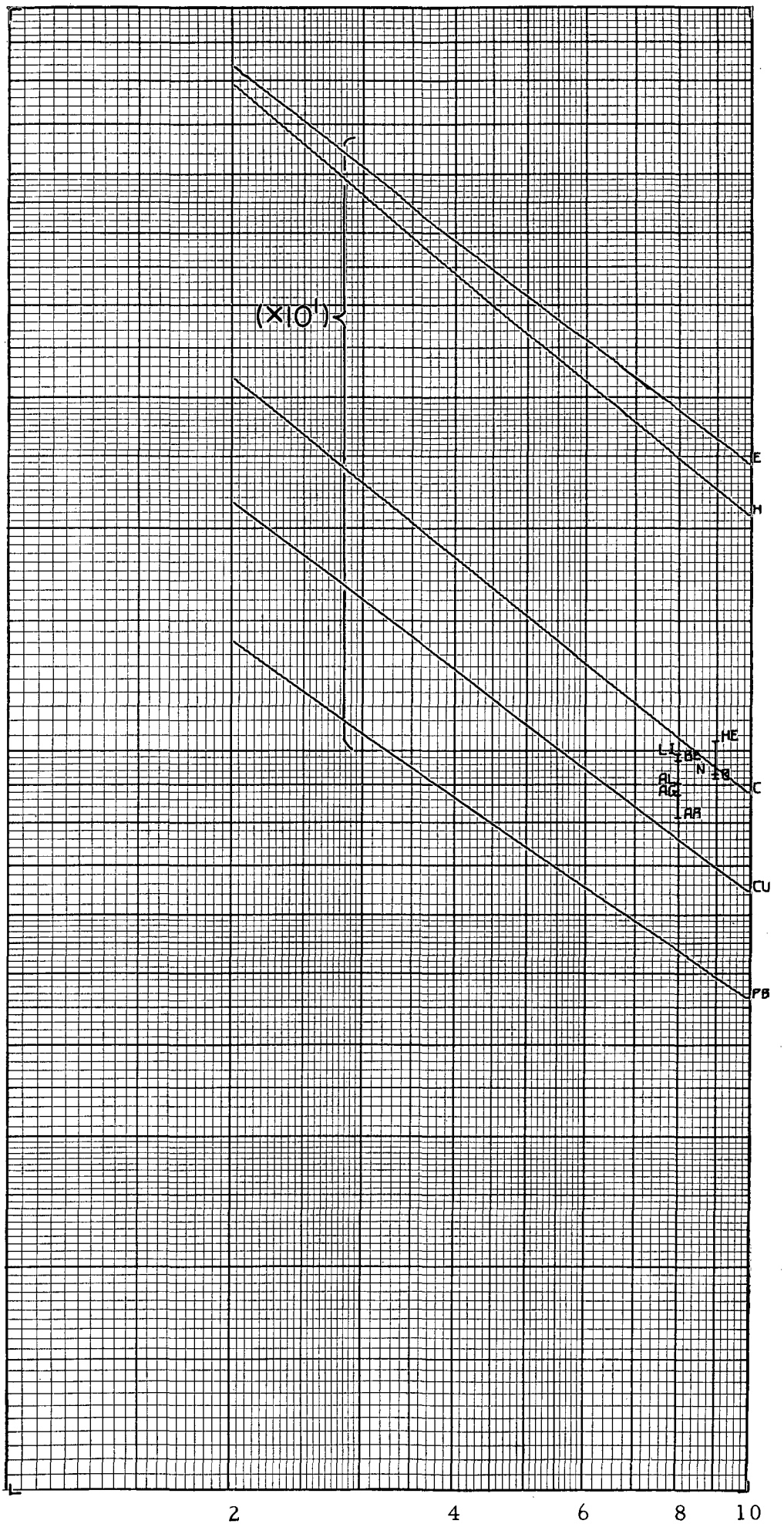
MUONS ±

(10 TO 100 GEV)

M = 105.659 MEV

= 206.86 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



PI±MESONS

(2 TO 10 MEV)

M = 139.58 MEV

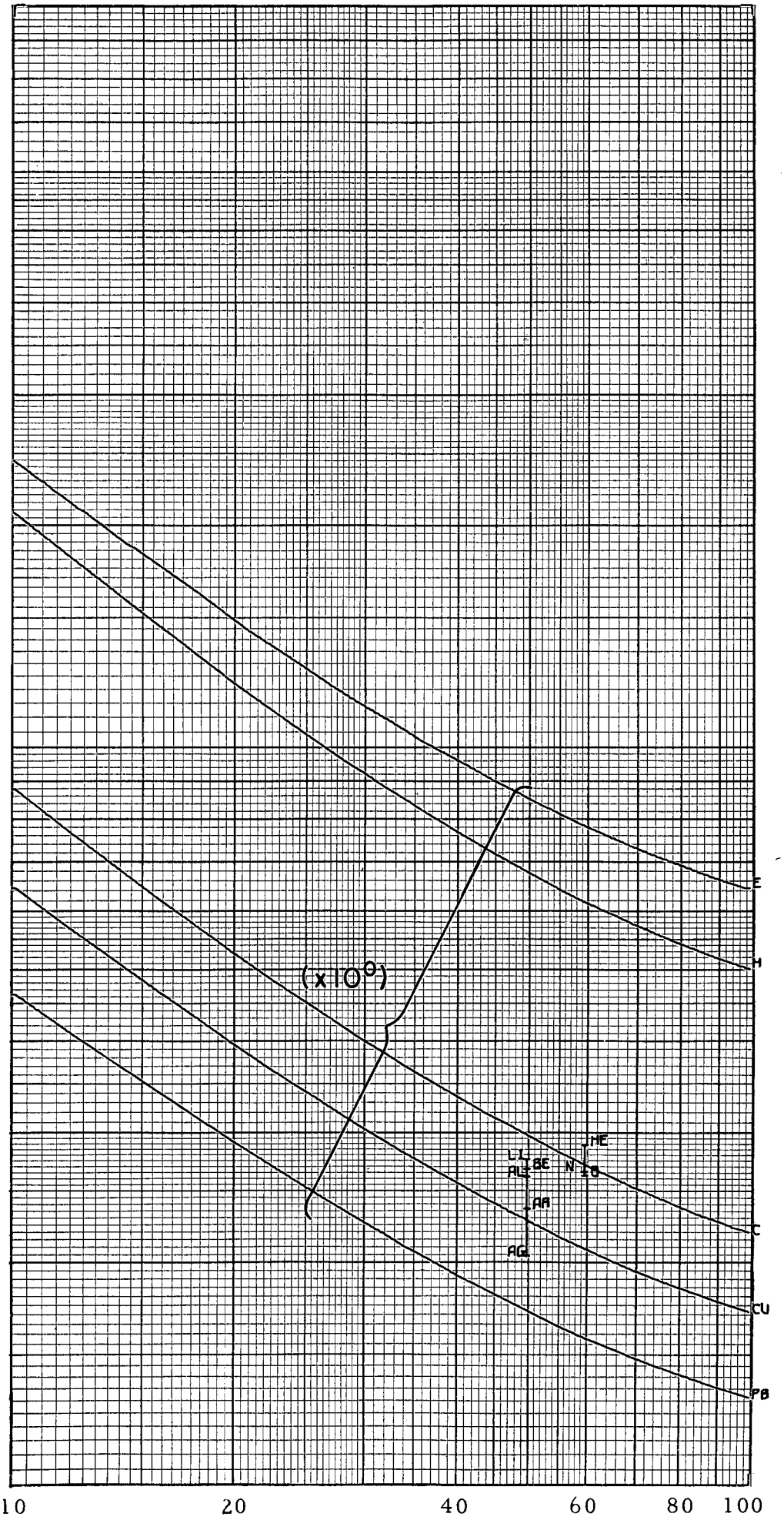
= 273.27 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



PI± MESONS

(10 TO 100 MEV)

M = 139.58 MEV

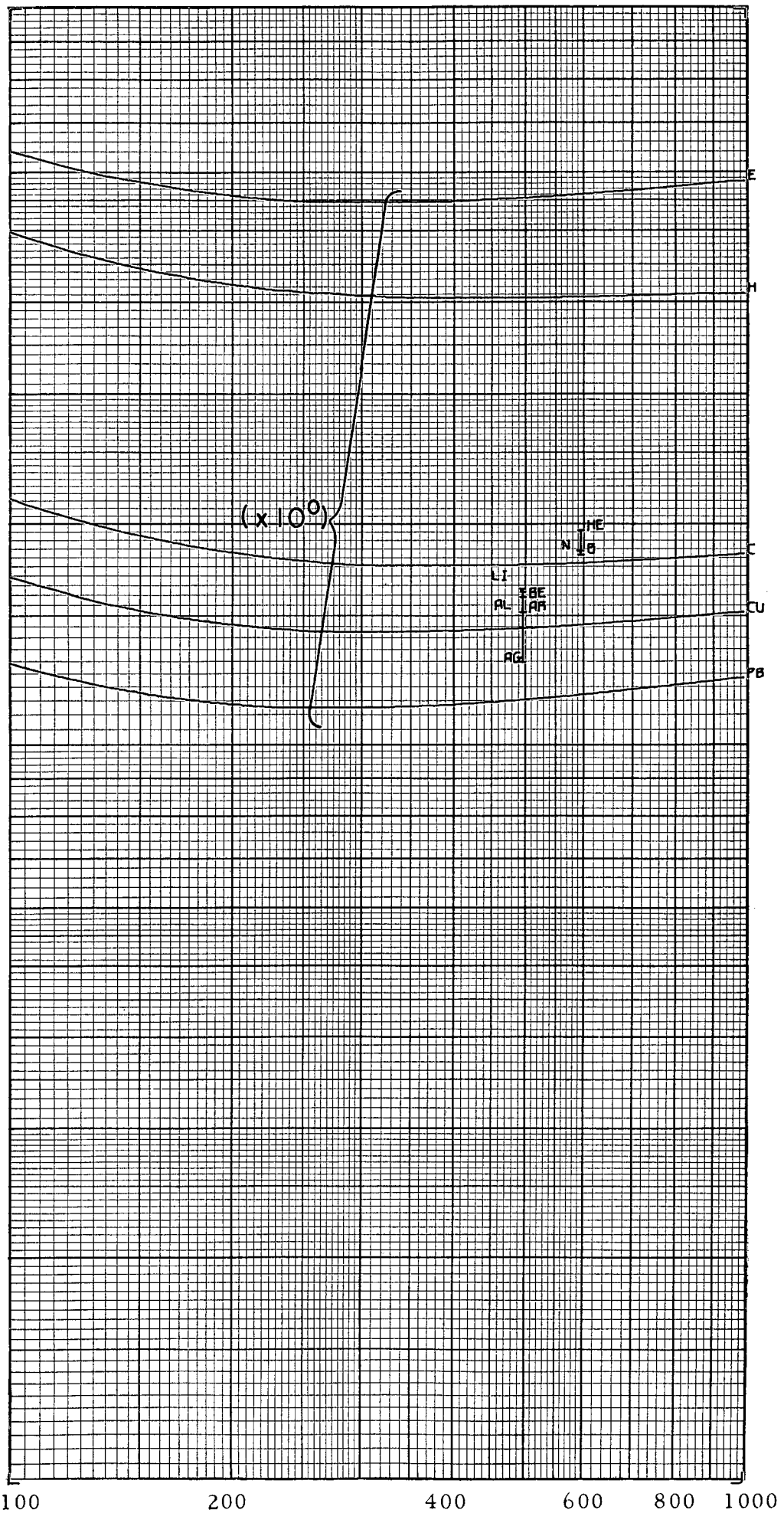
= 273.27 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



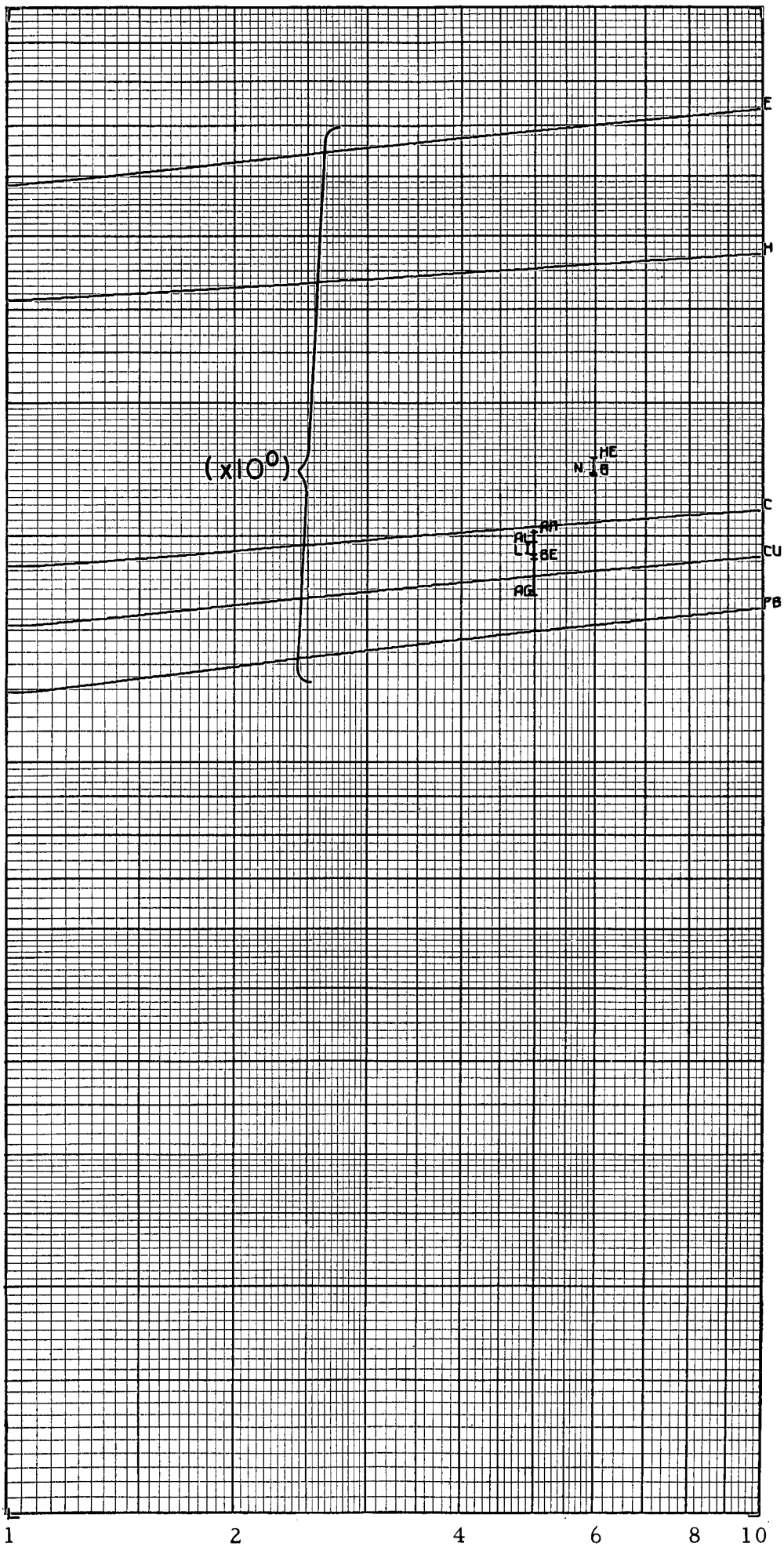
PI± MESØNS

(100 TO 1000 MEV)

M = 139.58 MEV

= 273.27 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



PI± MESONS

(1 TO 10 GEV)

M = 139.58 MEV

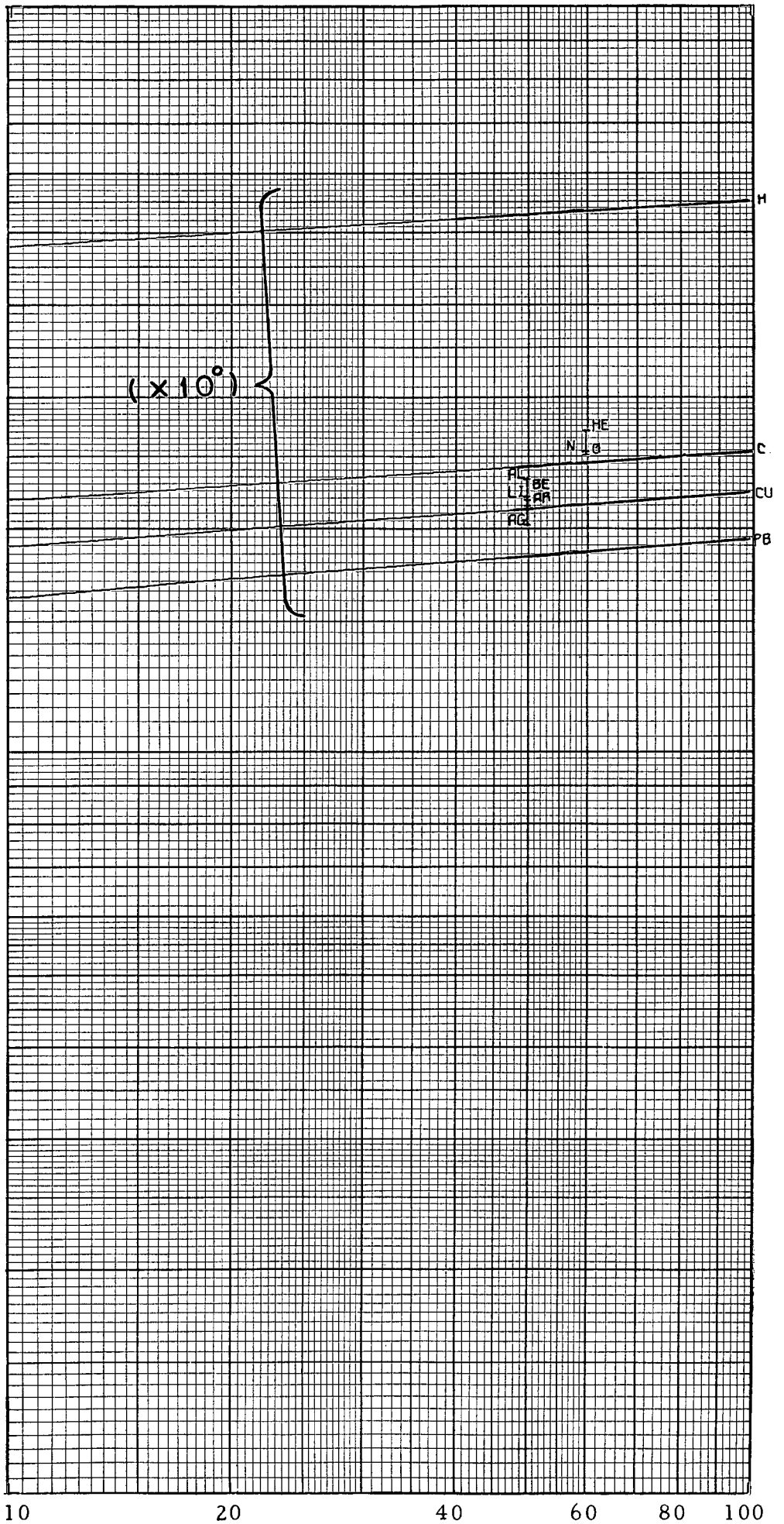
= 273.27 M

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



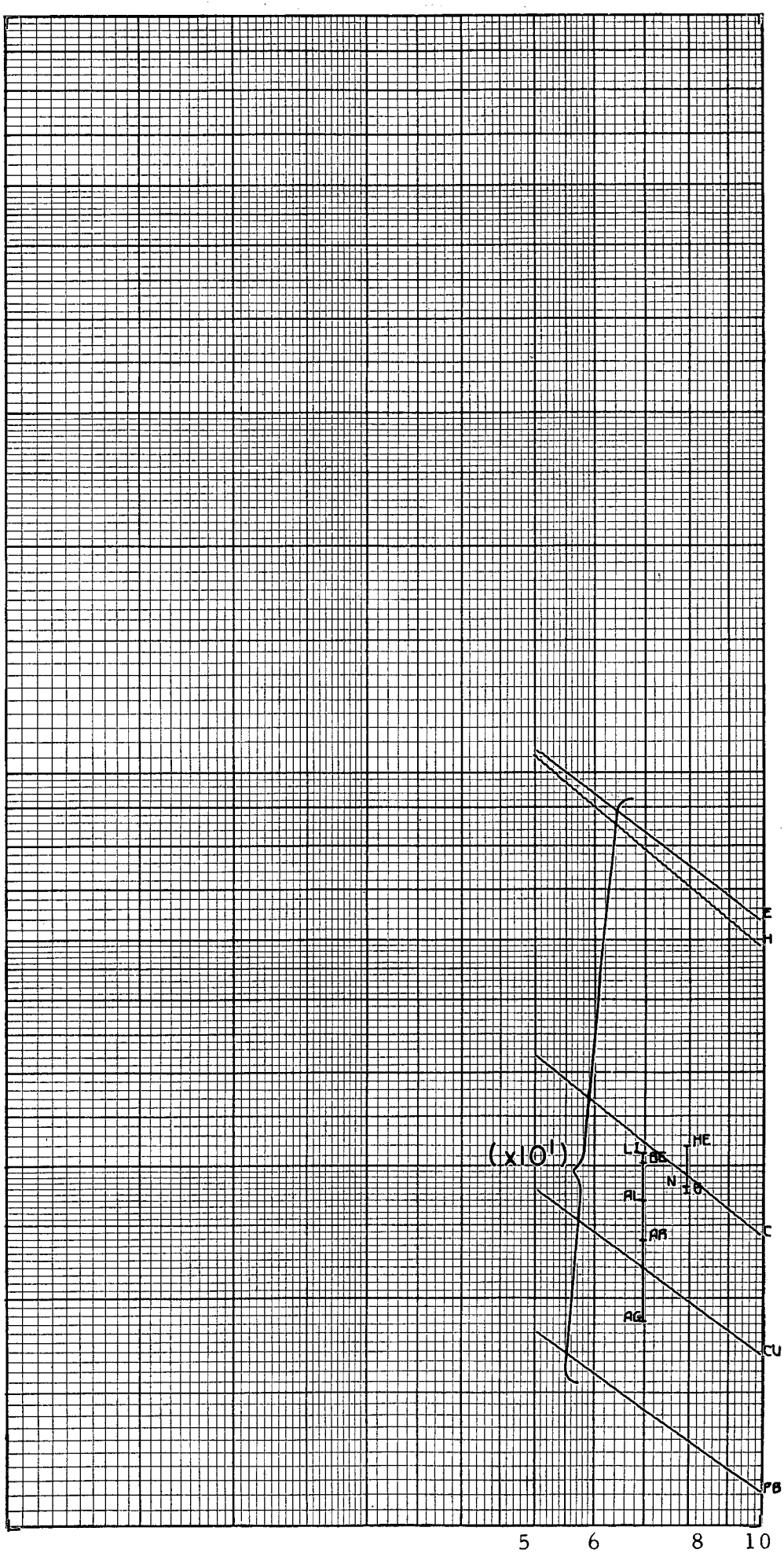
PI± MESONS

(10 TO 100 GEV)

M = 139.58 MEV

= 273.27 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



K± MESONS

(5 TO 10 MEV)

M = 493.78 MEV

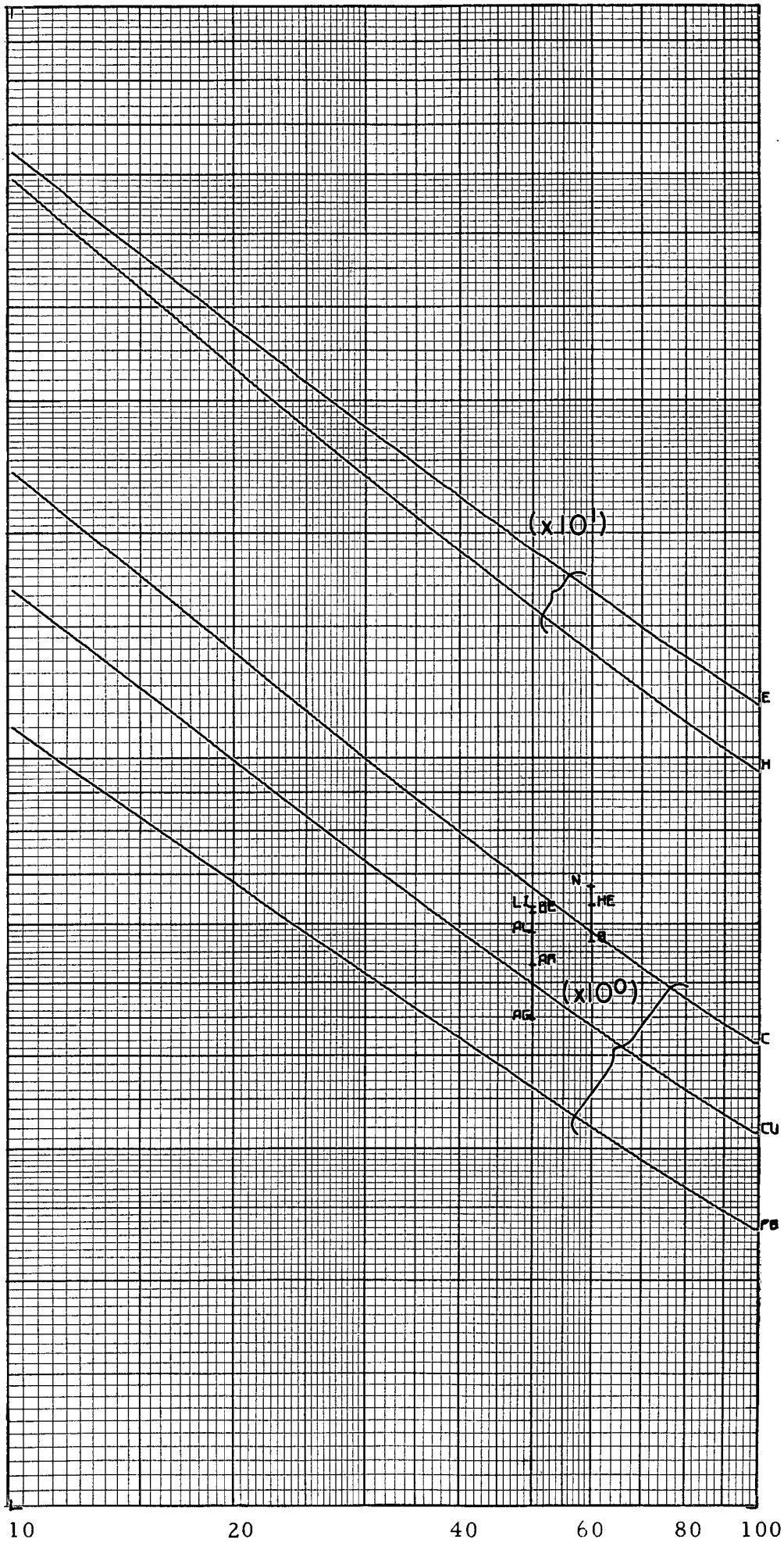
= 966.71 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



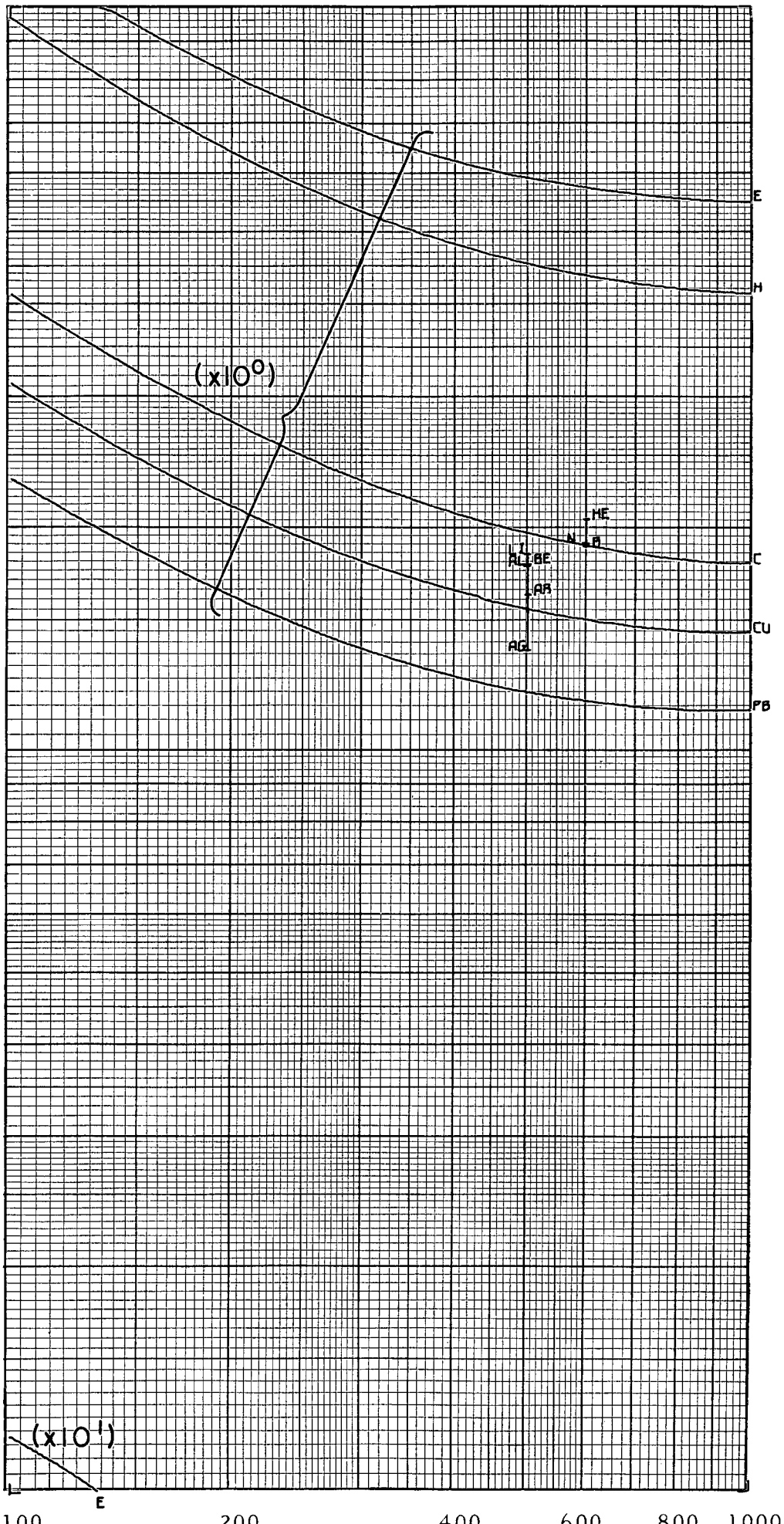
K± MESONS

(10 TO 100 MEV)

M = 493.78 MEV

= 966.71 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



K± MESONS

(100 TO 1000 MEV)

M = 493.78 MEV

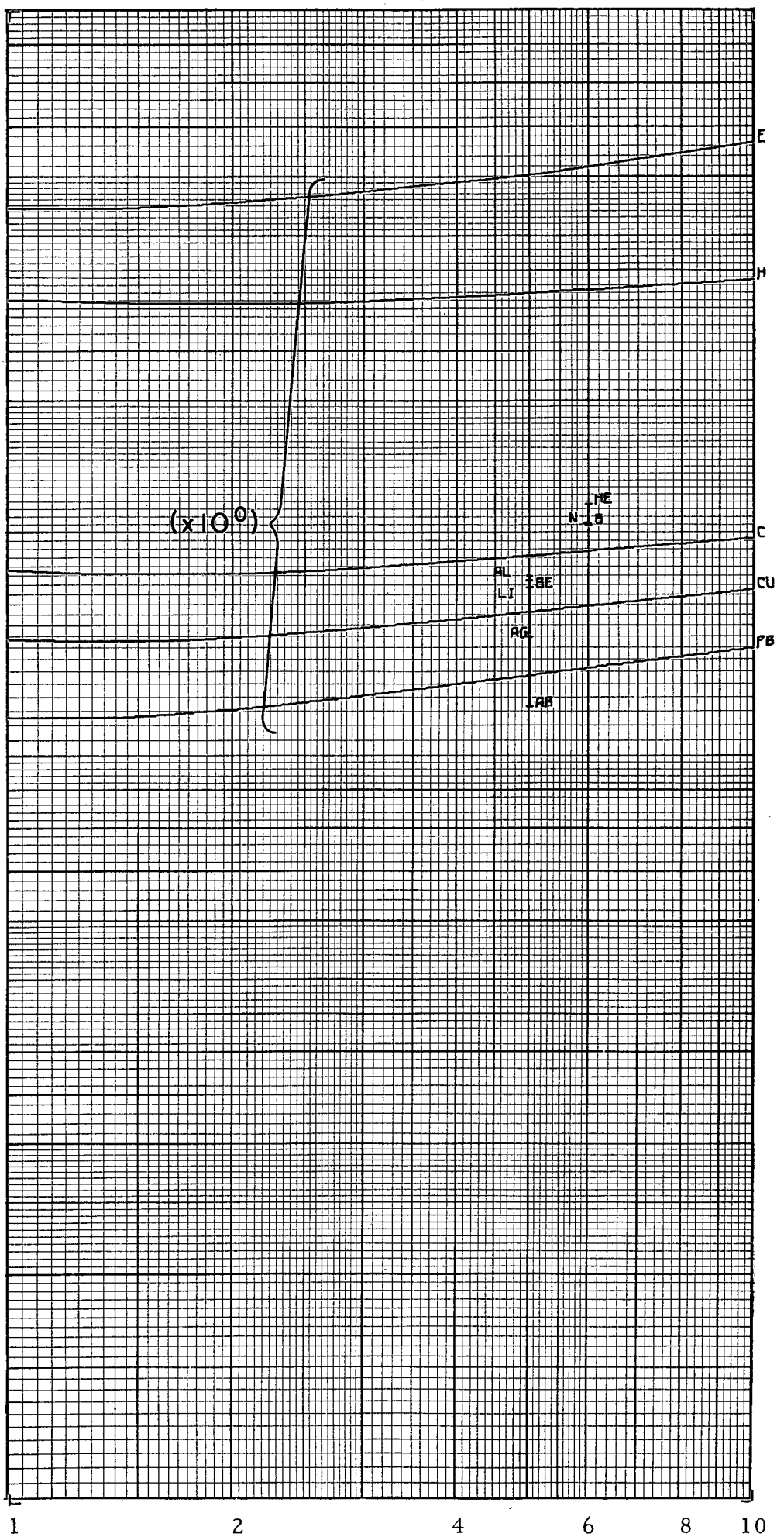
= 966.71 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



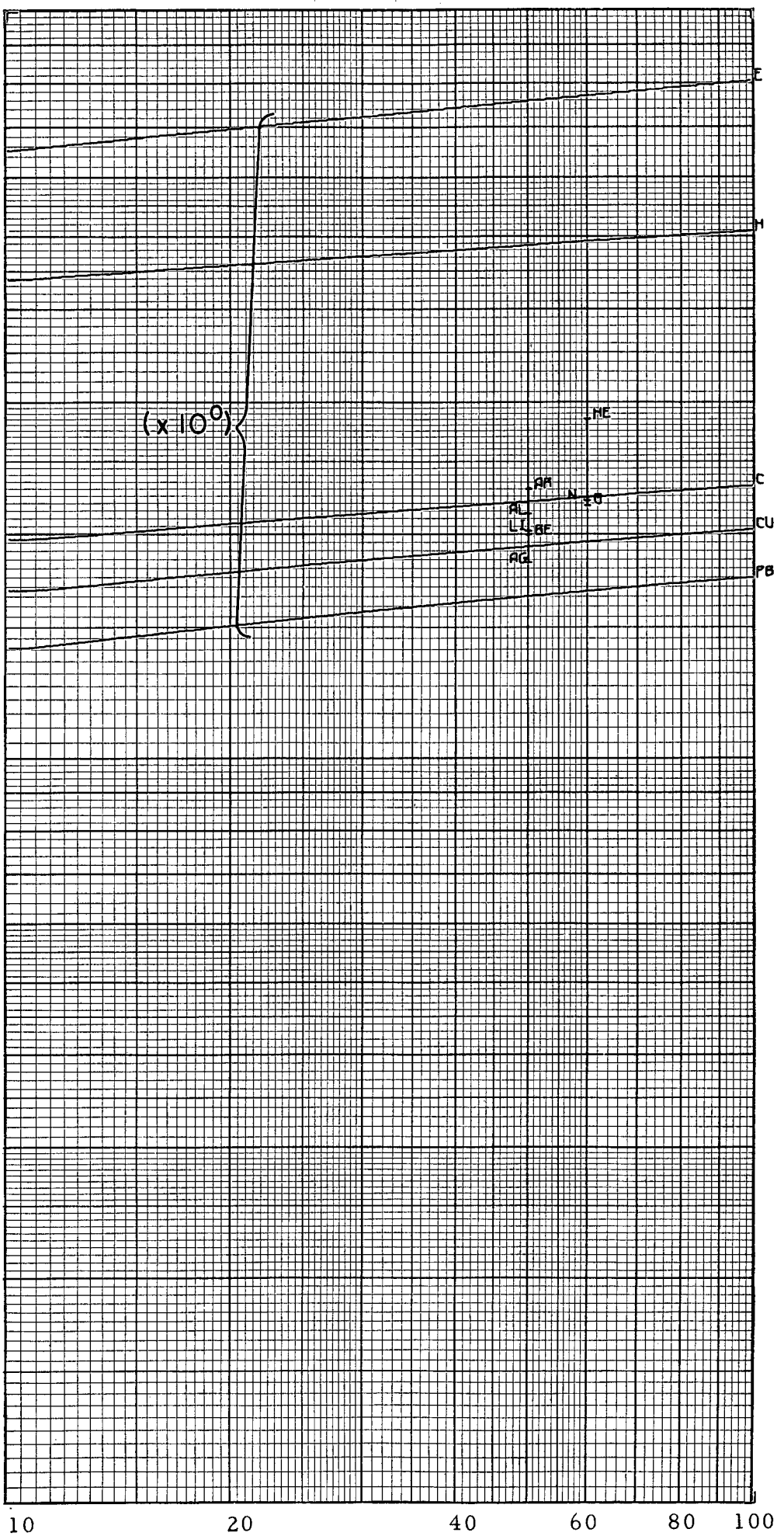
K± MESONS

(1 TO 10 GEV)

M = 493.78 MEV

= 966.71 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



K± MESONS

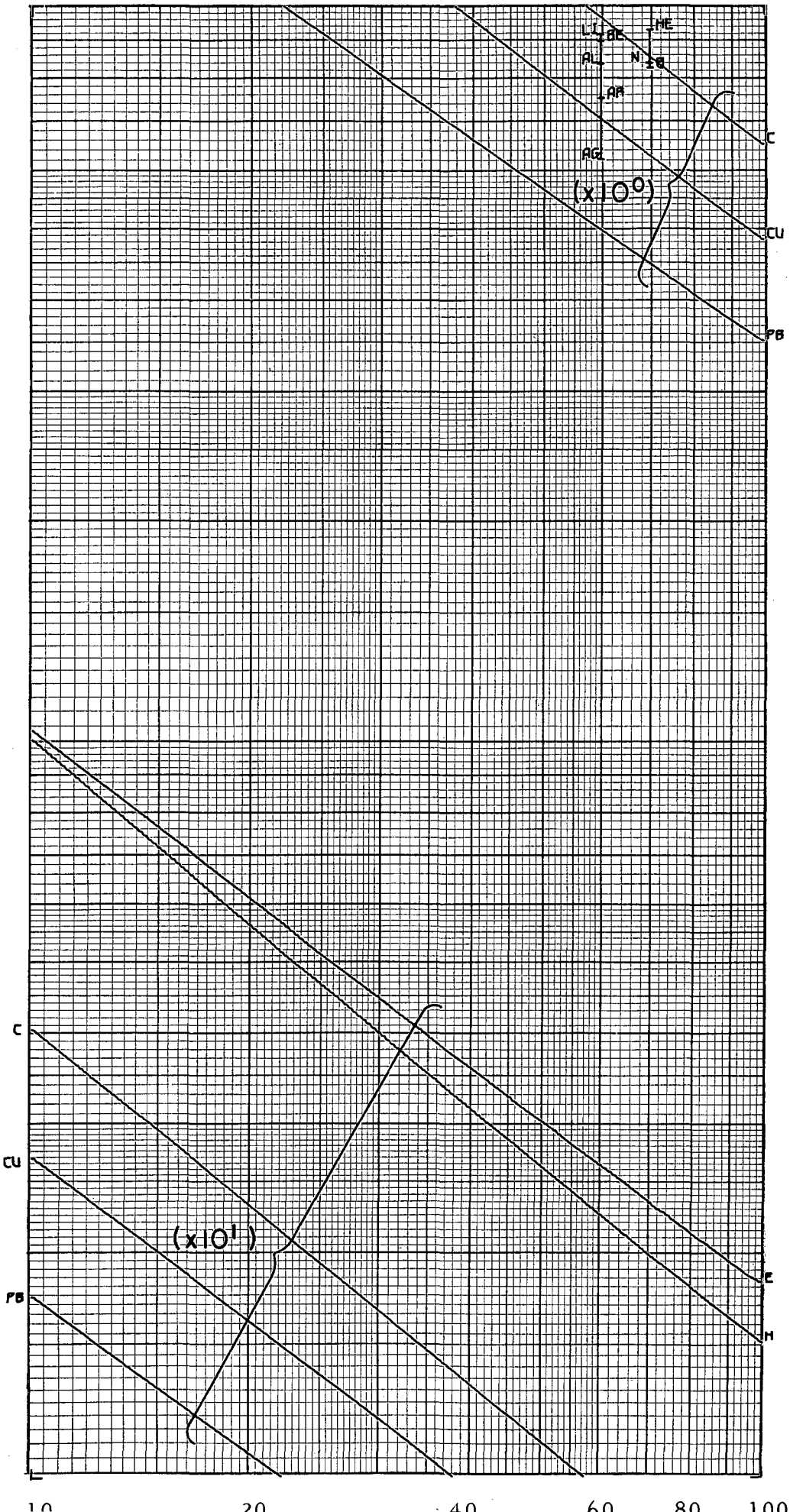
(10 TO 100 GEV)

M = 493.78 MEV

= 966.71 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.

DE/DX



PROTONS

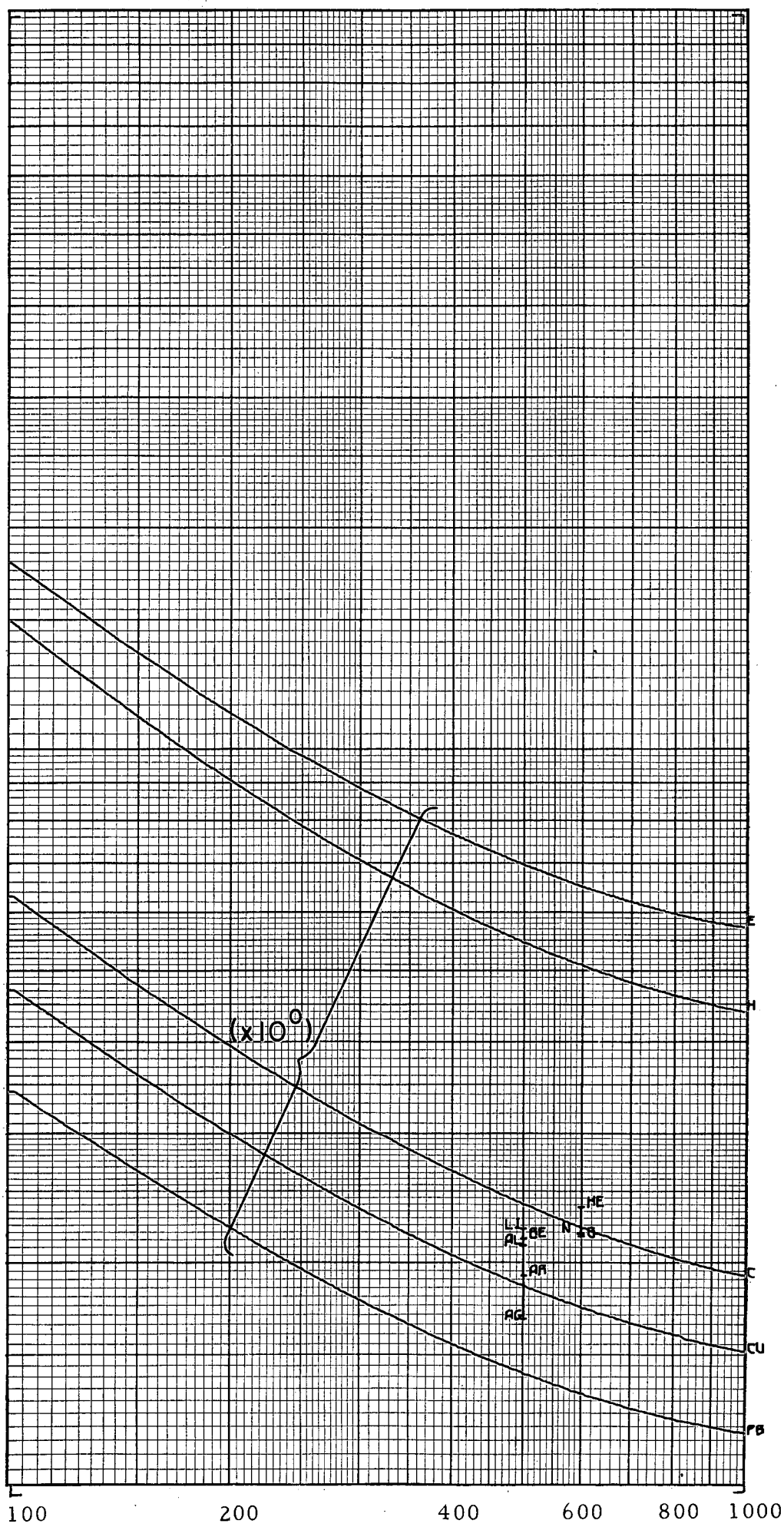
(10 TO 100 MEV)

M = 938.256 MEV

= 1836.1 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.

DE/DX



PROTONS

(100 TO 1000 MEV)

M = 938.256 MEV

= 1836.1 M

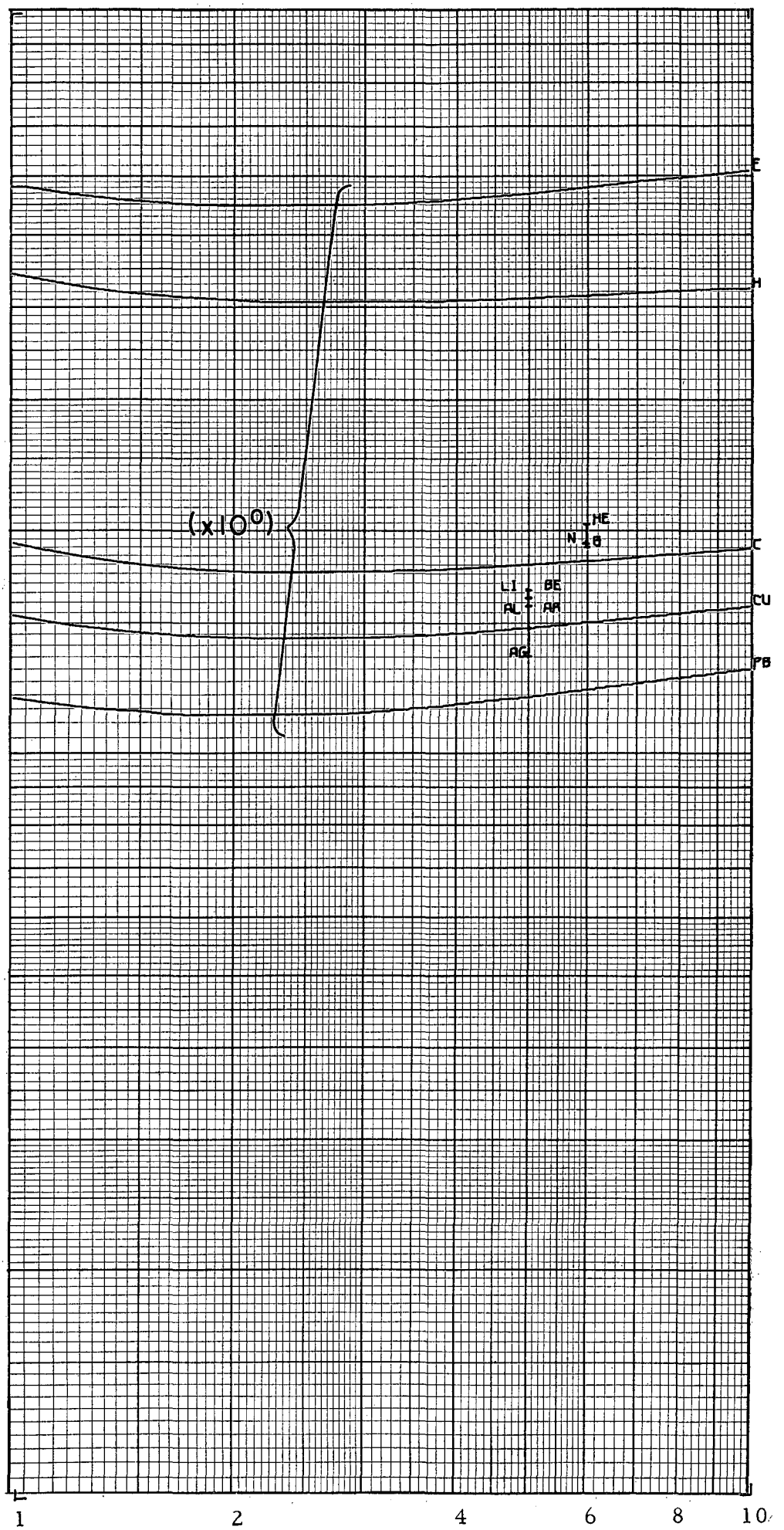
DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.

DE/DX



PROTONS

(1 TO 10 GEV)

M = 938.256 MEV

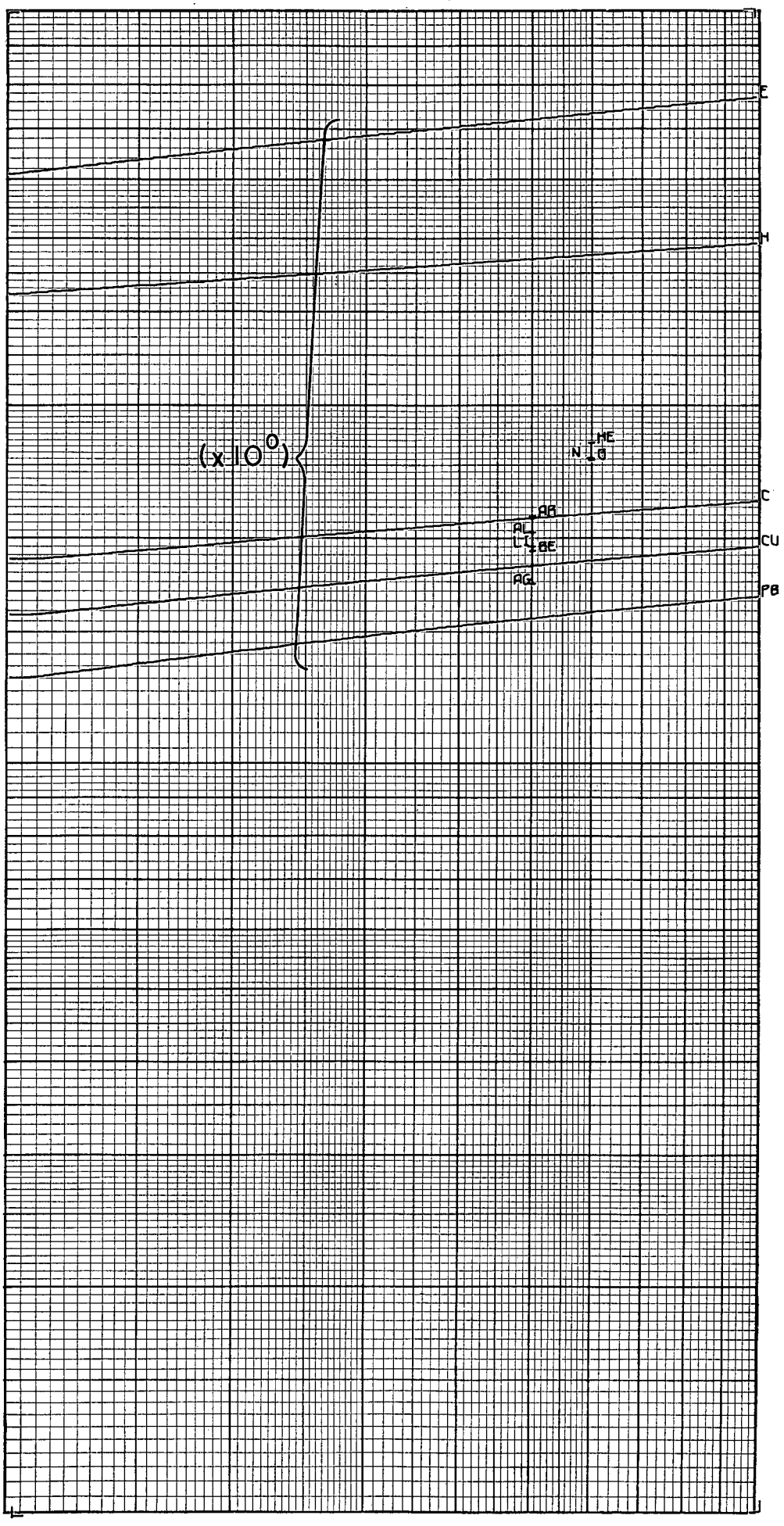
= 1836.1 M

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



PROTONS

(10 TO 100 GEV)

M = 938.256 MEV

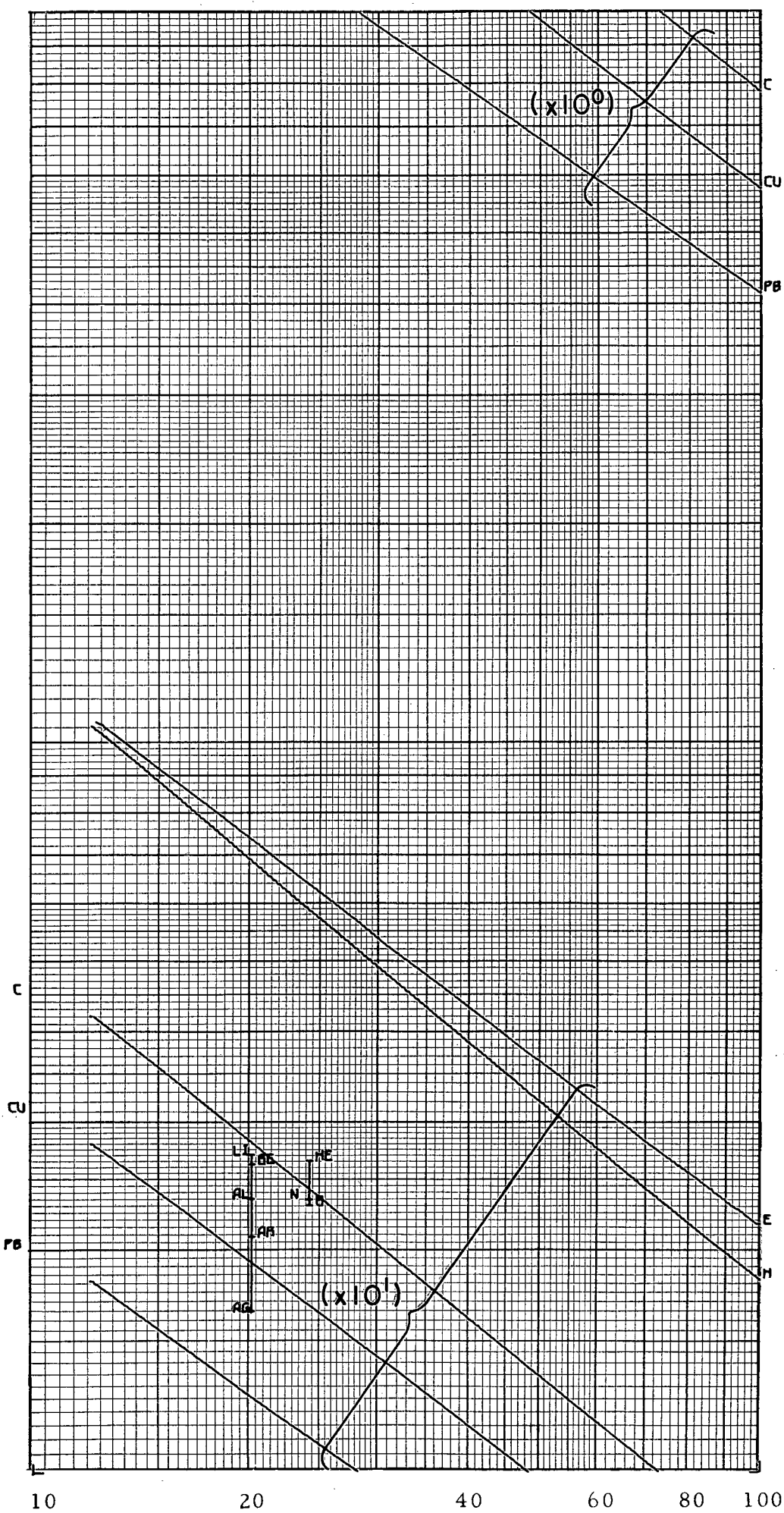
= 1836.1 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



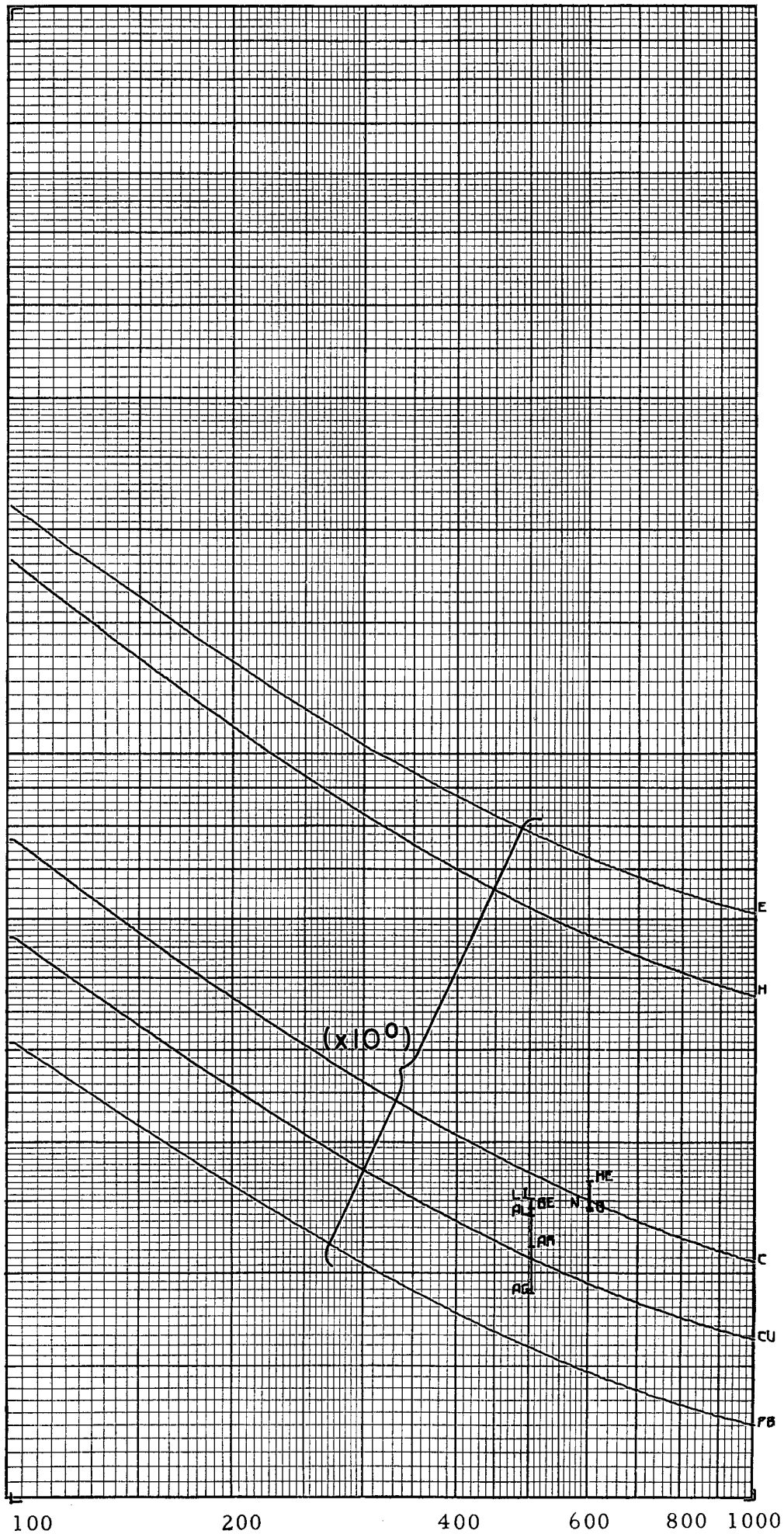
SIGMA+ HYPERONS

(12 TO 100 MEV)

M = 1189.39 MEV

= 2327.6 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



SIGMA+ HYPERONS

(100 TO 1000 MEV)

M = 1189.39 MEV

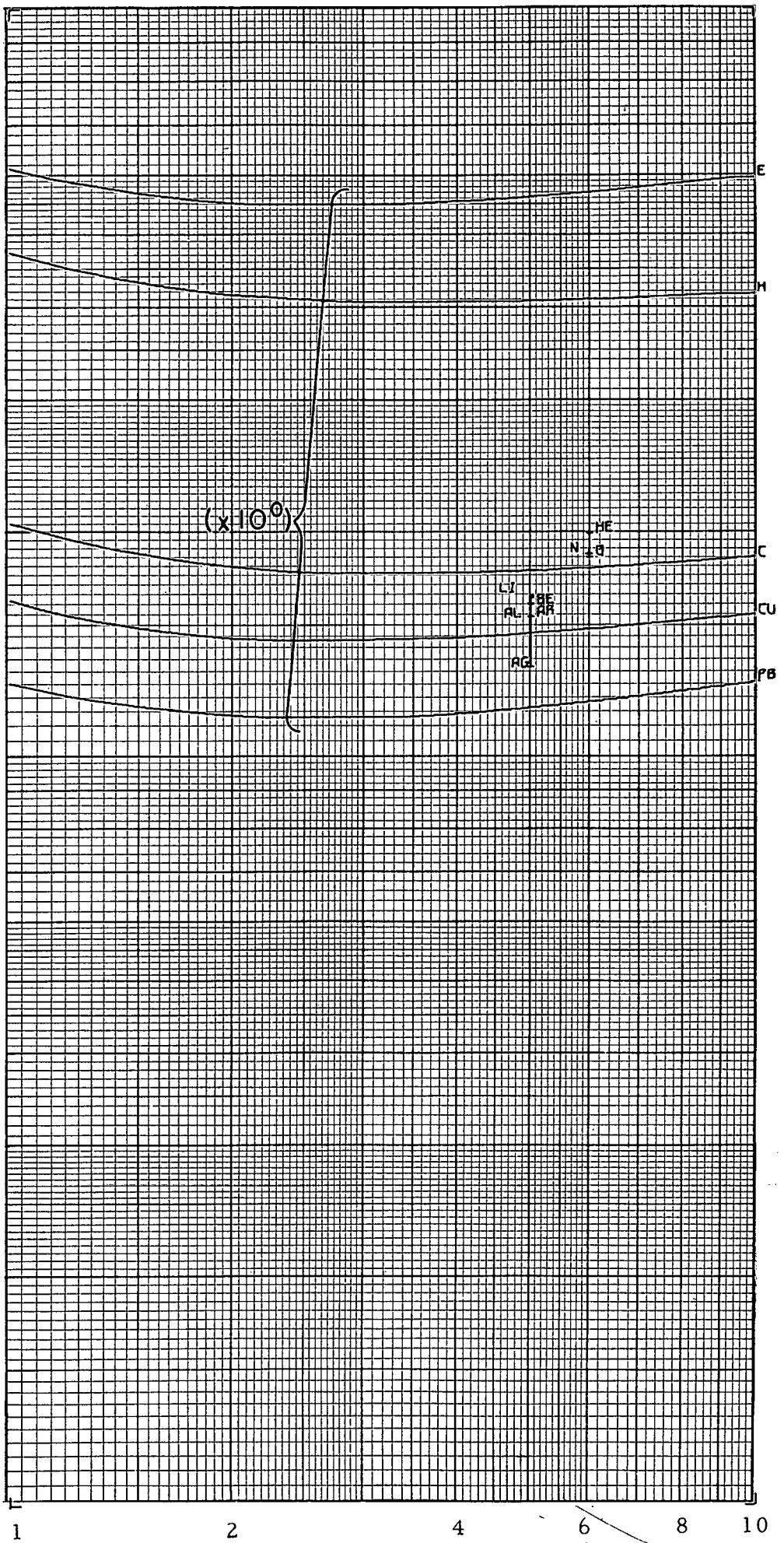
= 2327.6 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



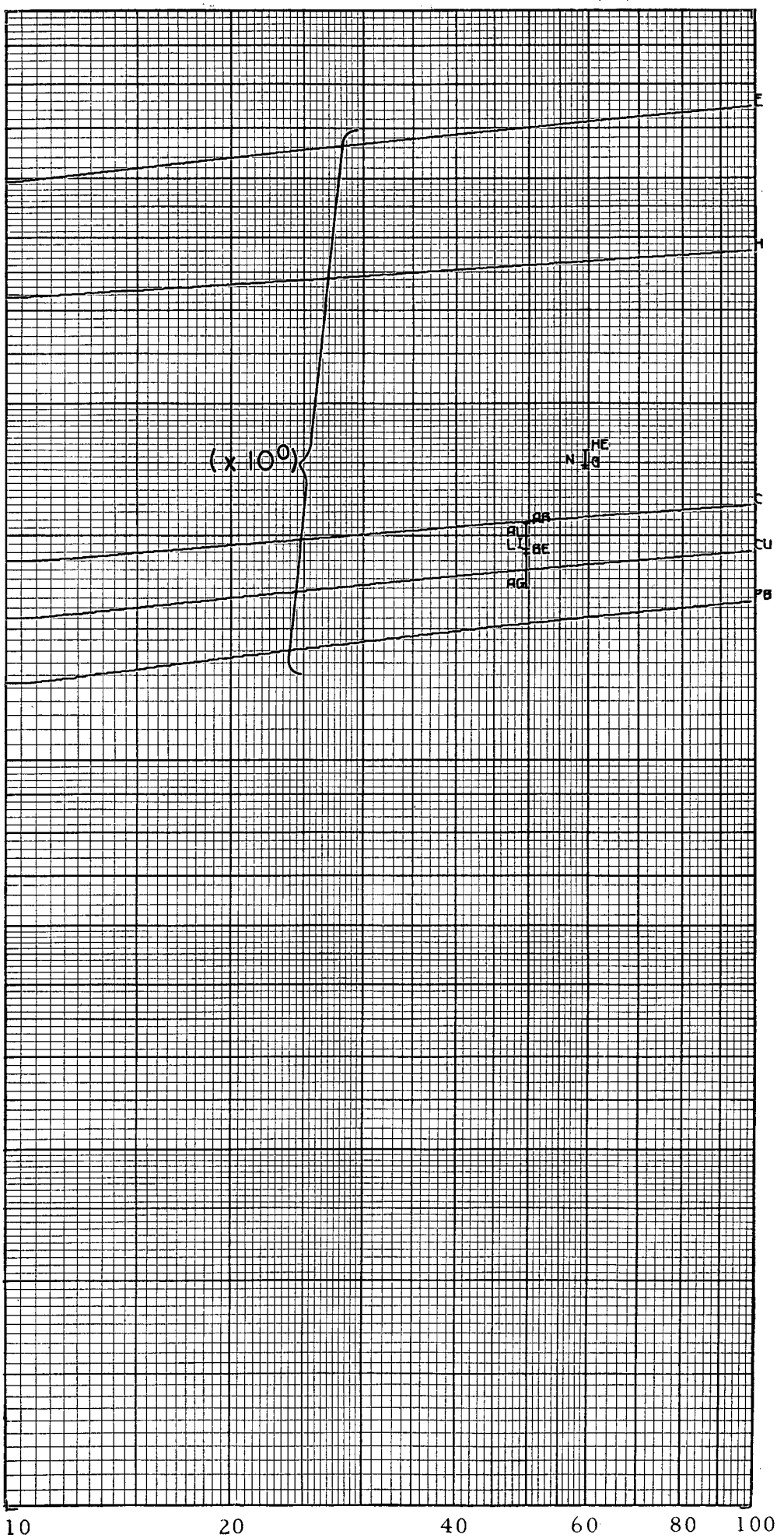
SIGMA+ HYPERONS

(1 TO 10 GEV)

M = 1189.39 MEV

= 2327.6 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



SIGMA+ HYPERONS

(10 TO 100 GEV)

M = 1189.39 MEV

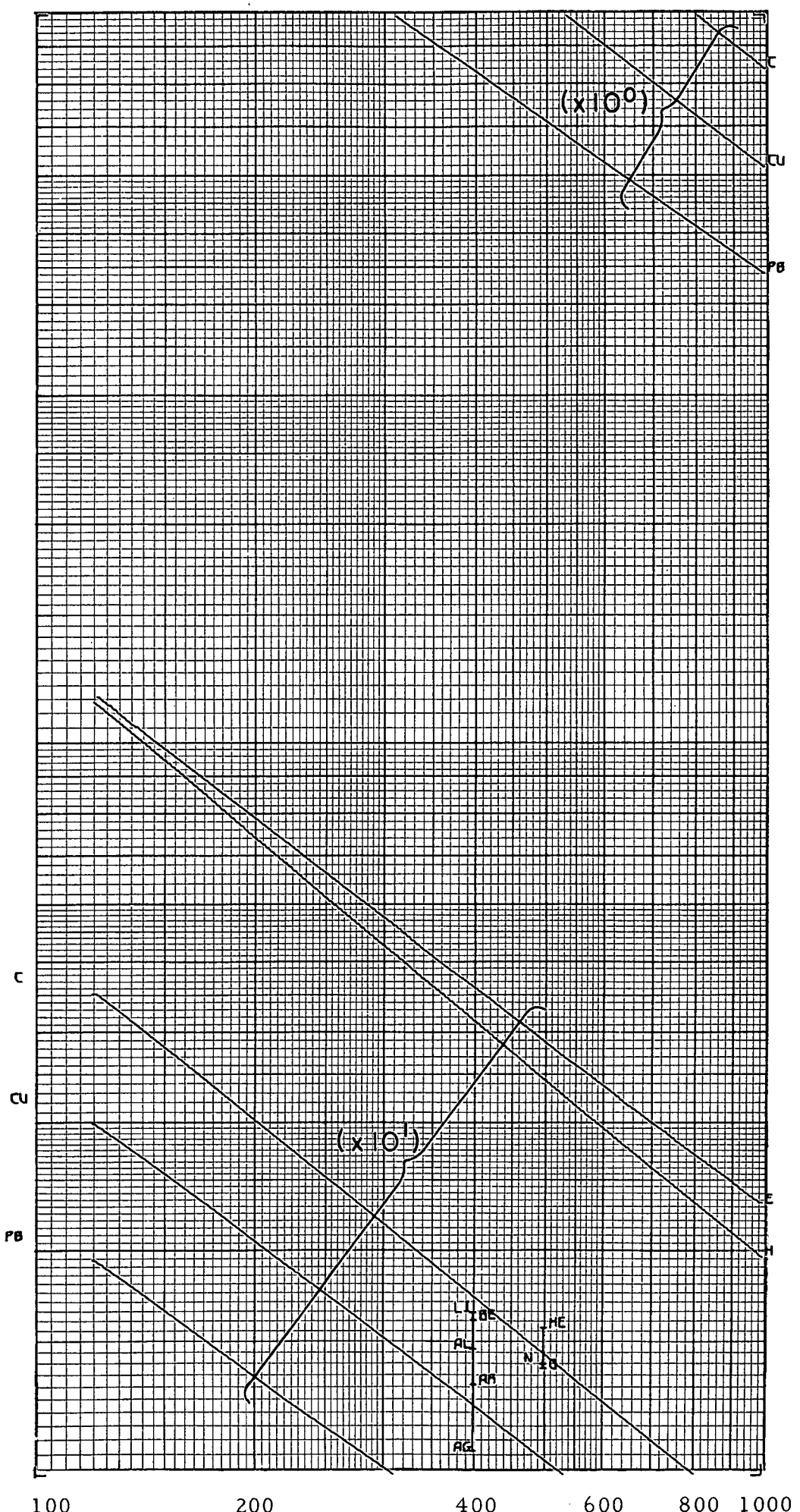
= 2327.6 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



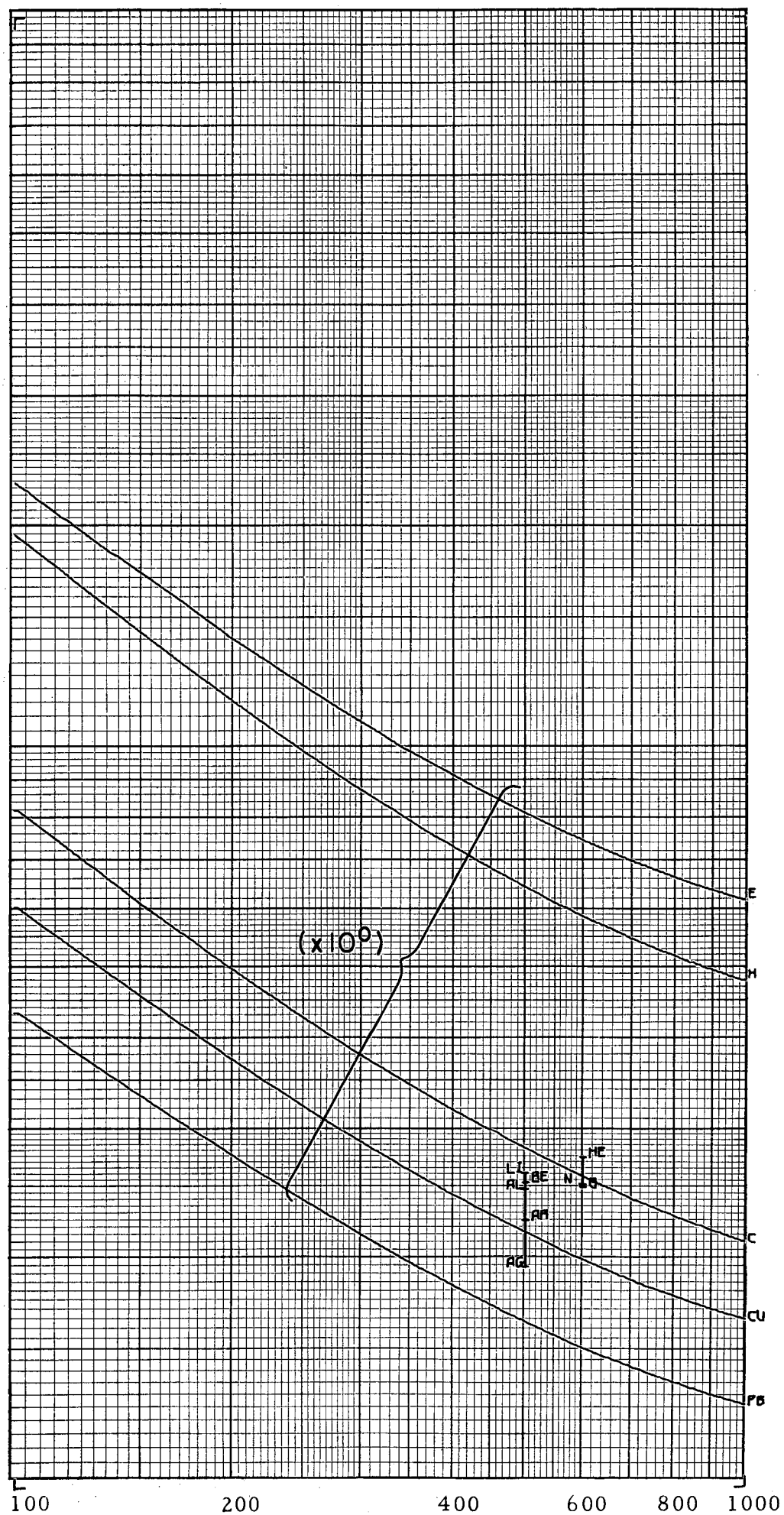
XI- HYPERONS

(12 TO 100 MEV)

M = 1320.0 MEV

= 2585.28 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-S EMULSION IN MEV/CM.



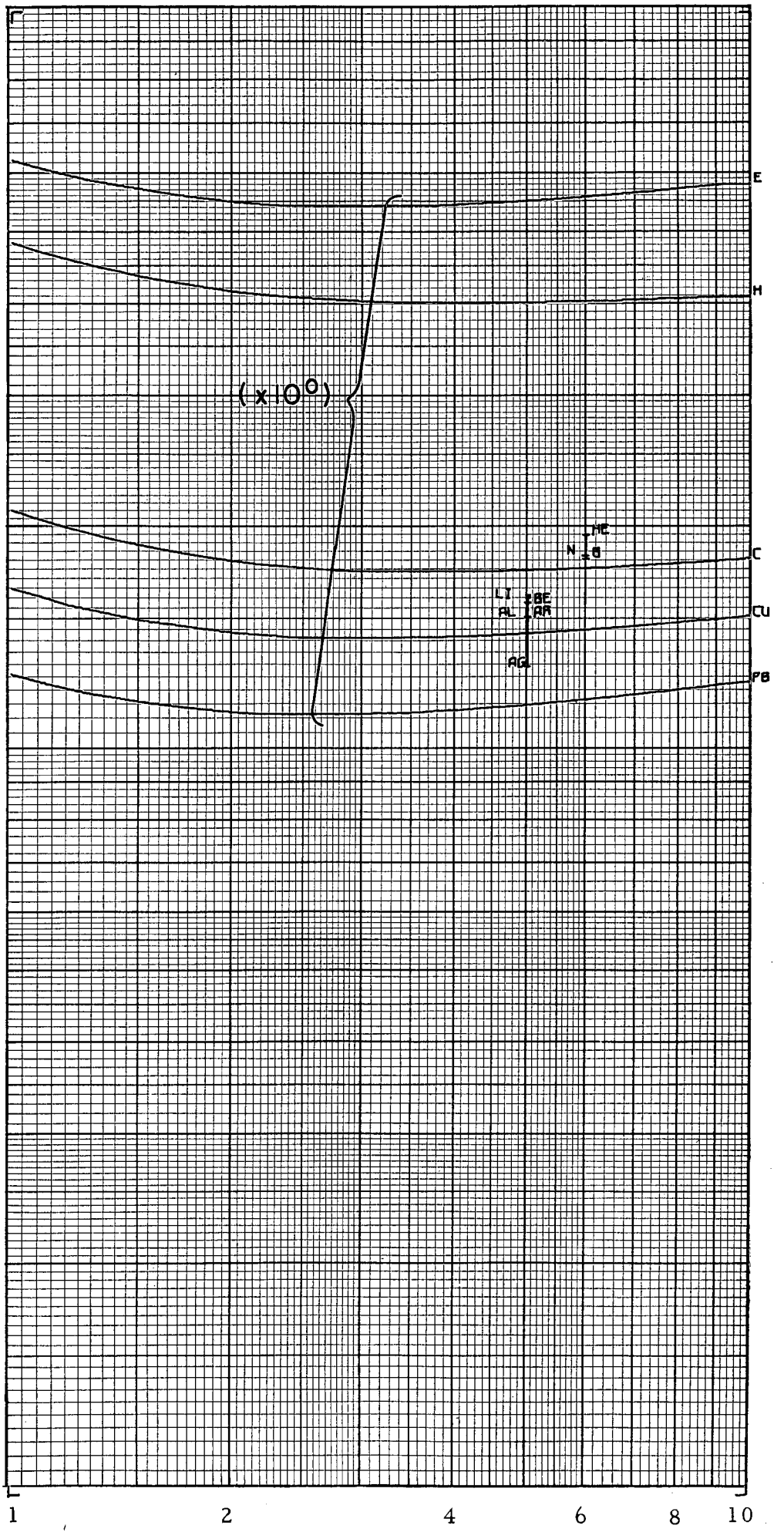
XI- HYPERONS

(100 TO 1000 MEV)

M = 1320.0 MEV

= 2505.28 M

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



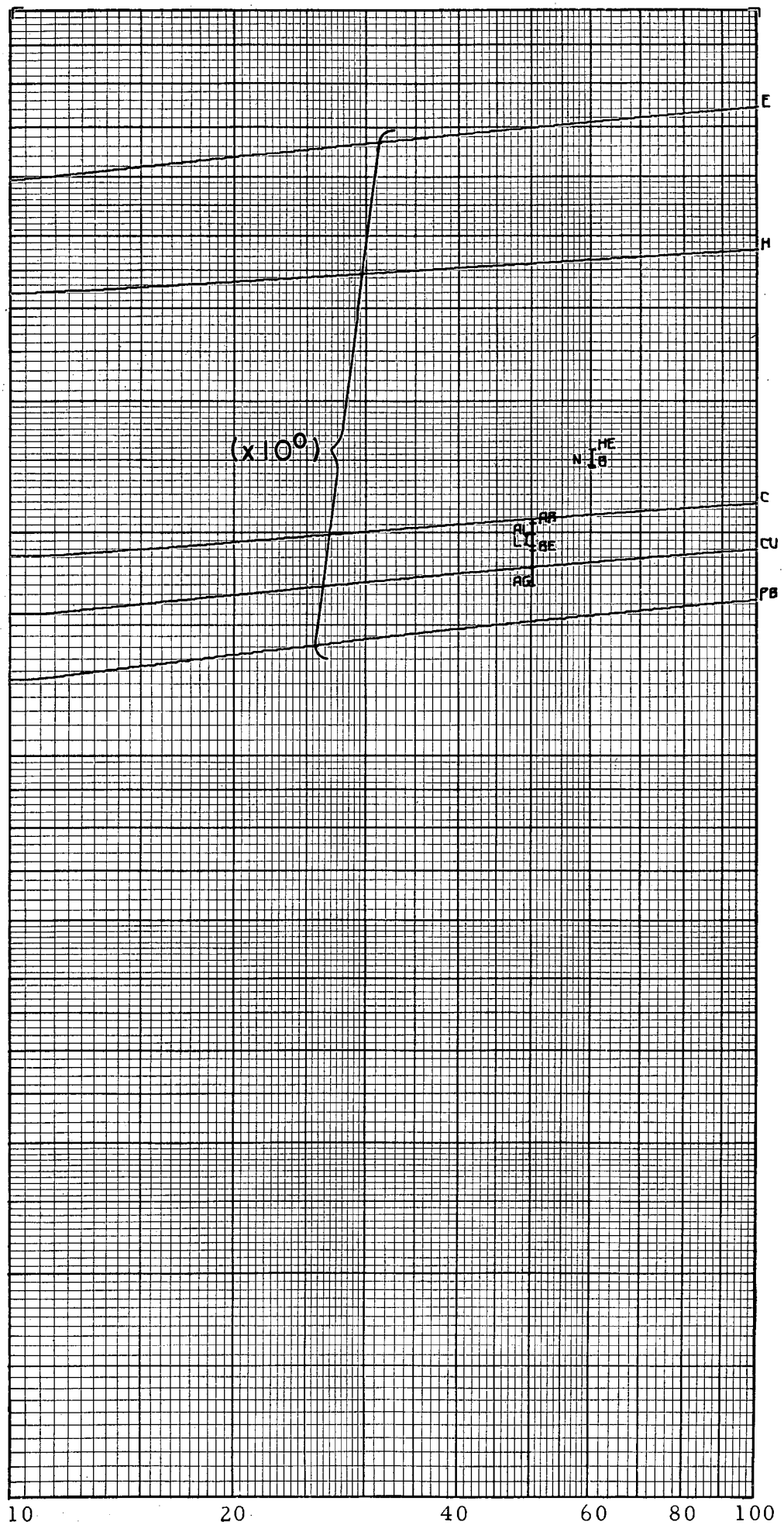
XI- HYPERONS

(1 TO 10 GEV)

M = 1320.0 MEV

= 2585.20 M

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



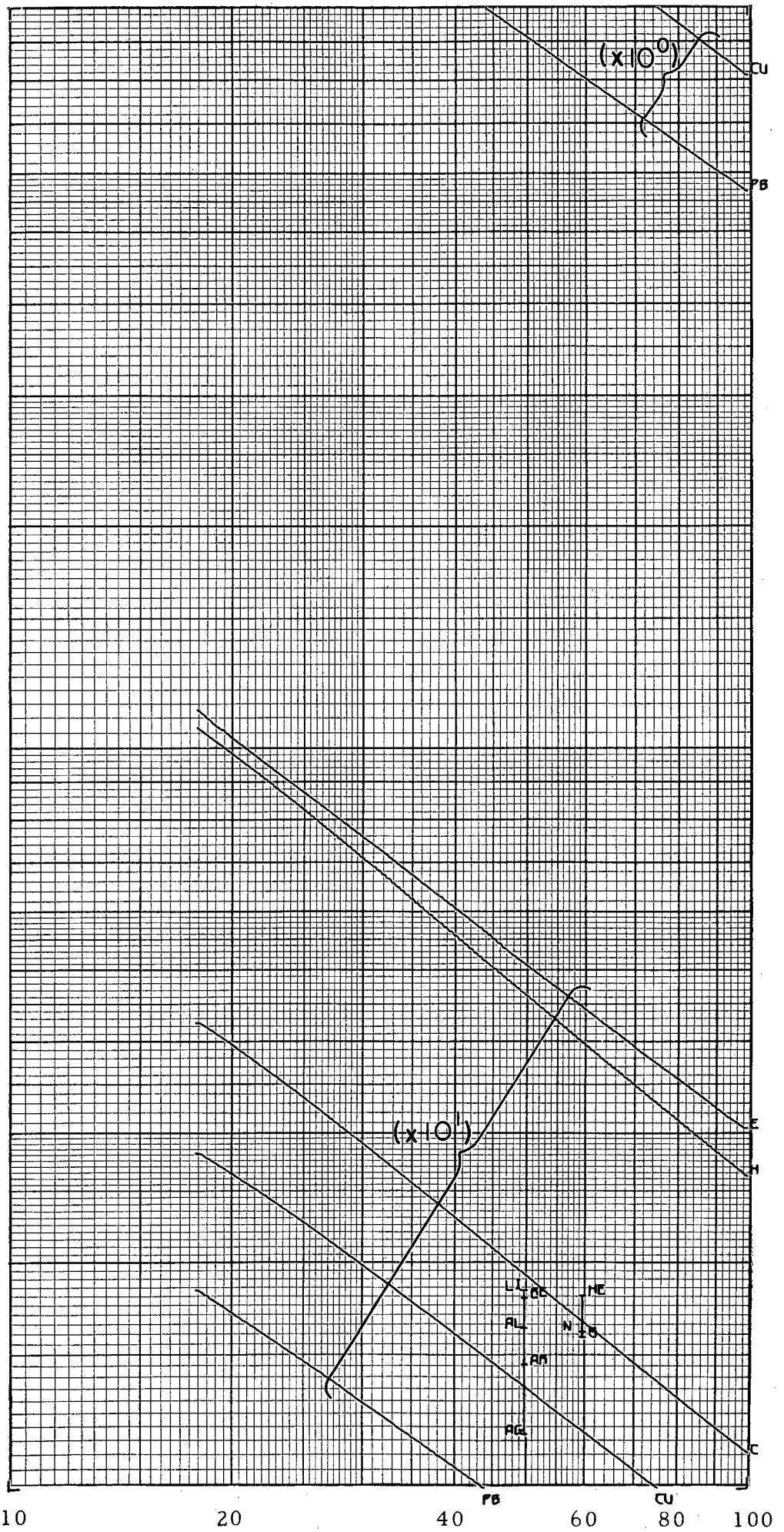
XI- HYPERONS

(10 TO 100 GEV)

M = 1320.0 MEV

= 2585.20 M

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



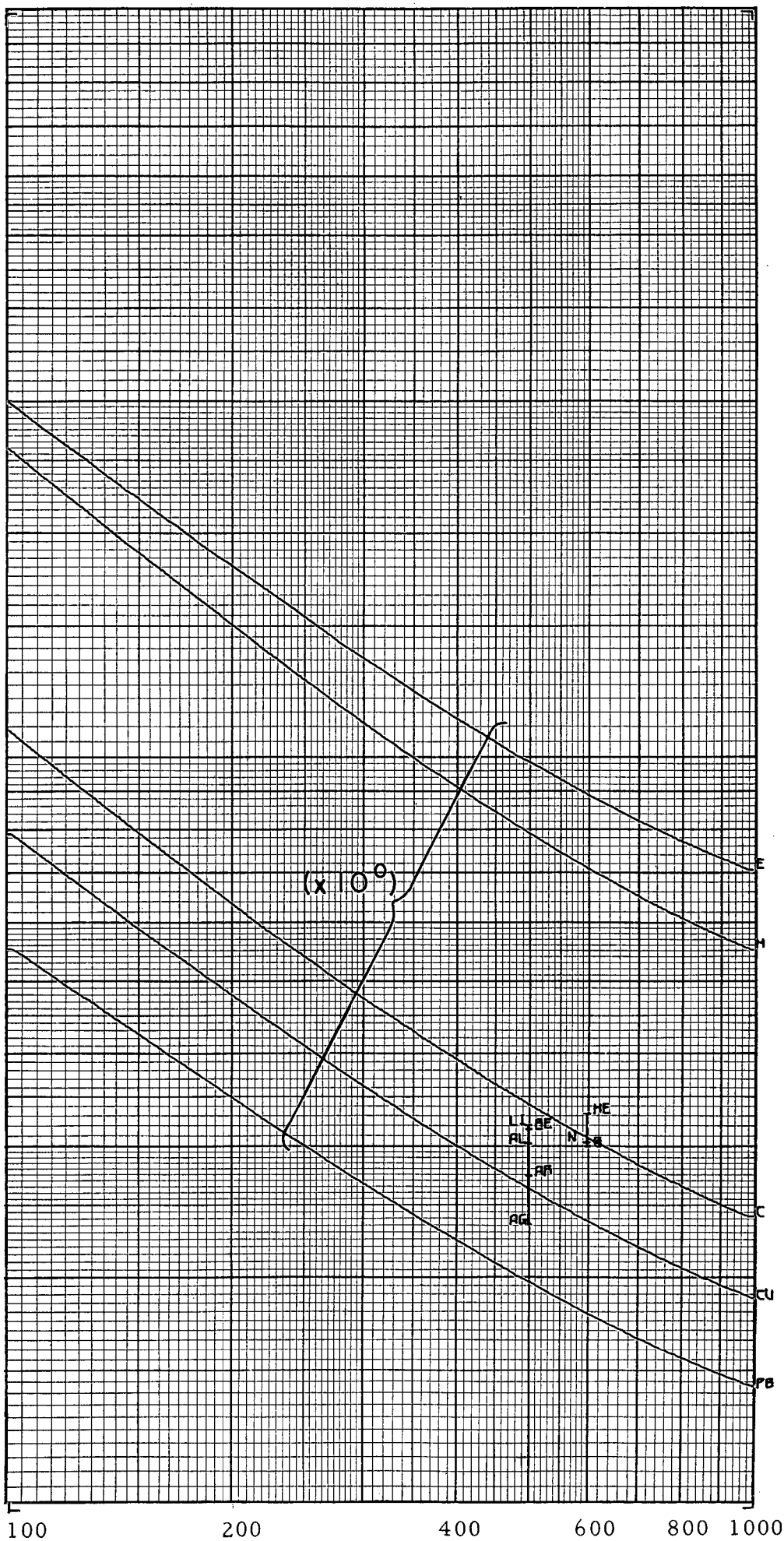
DEUTERONS

(10 TO 100 MEV)

M = 1875.49 MEV

= 3670.45 m

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



DEUTERONS

(100 TO 1000 MEV)

M = 1875.49 MEV

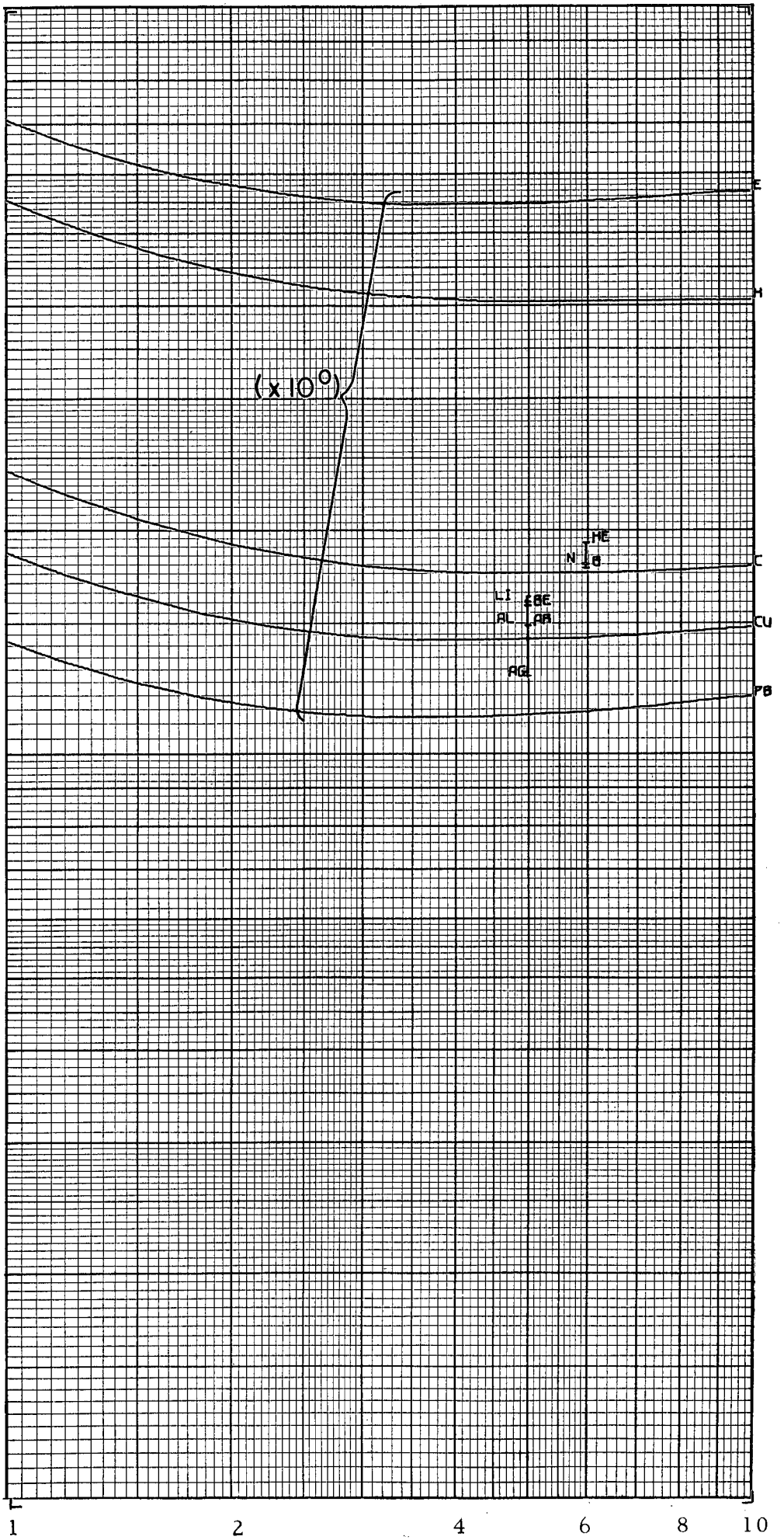
= 3670.45 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



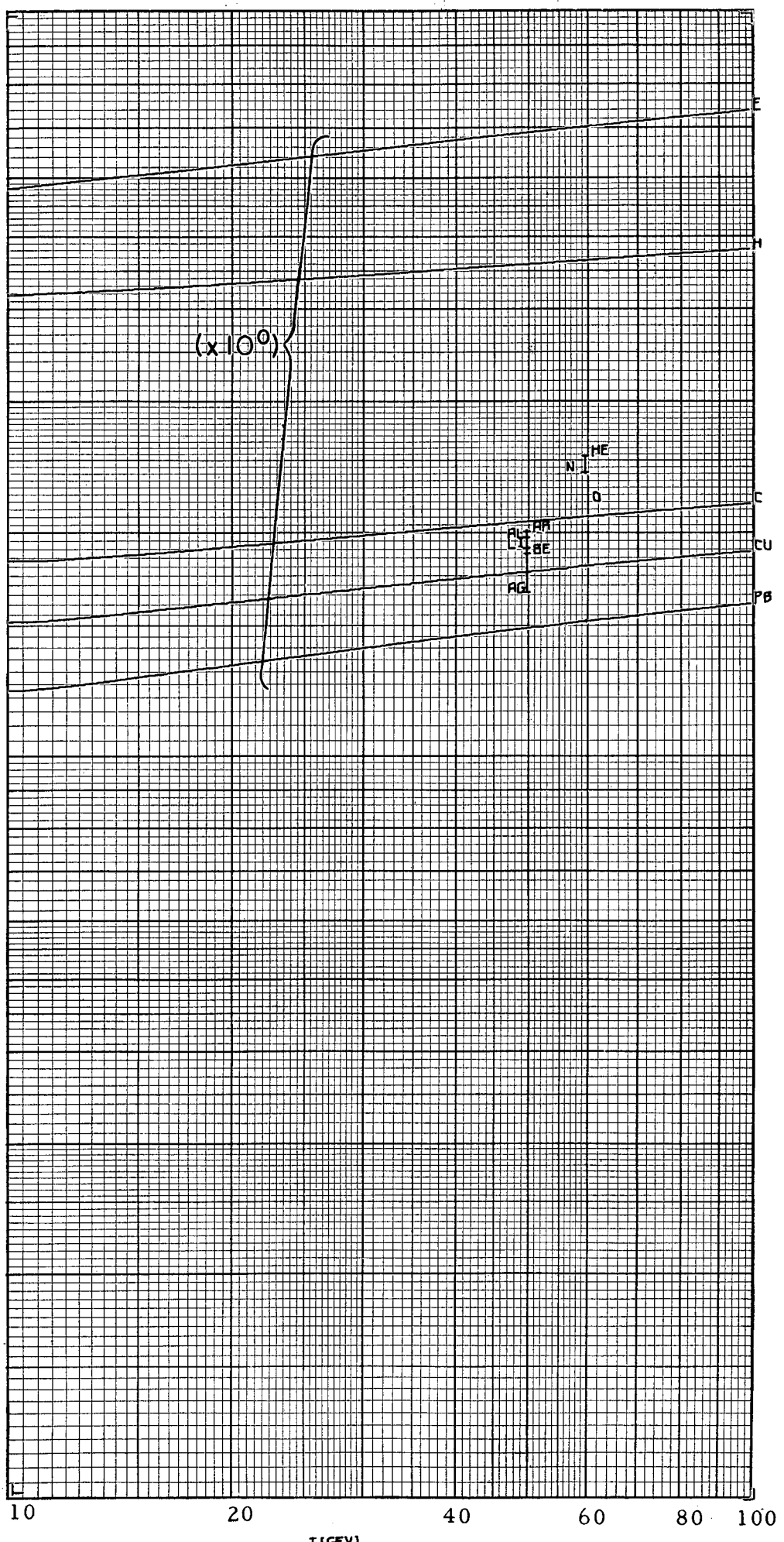
DEUTERONS

(1 TO 10 GEV)

M = 1875.49 MEV

= 3670.45 M

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



DEUTERONS

(10 TO 100 GEV)

M = 1875.49 MEV

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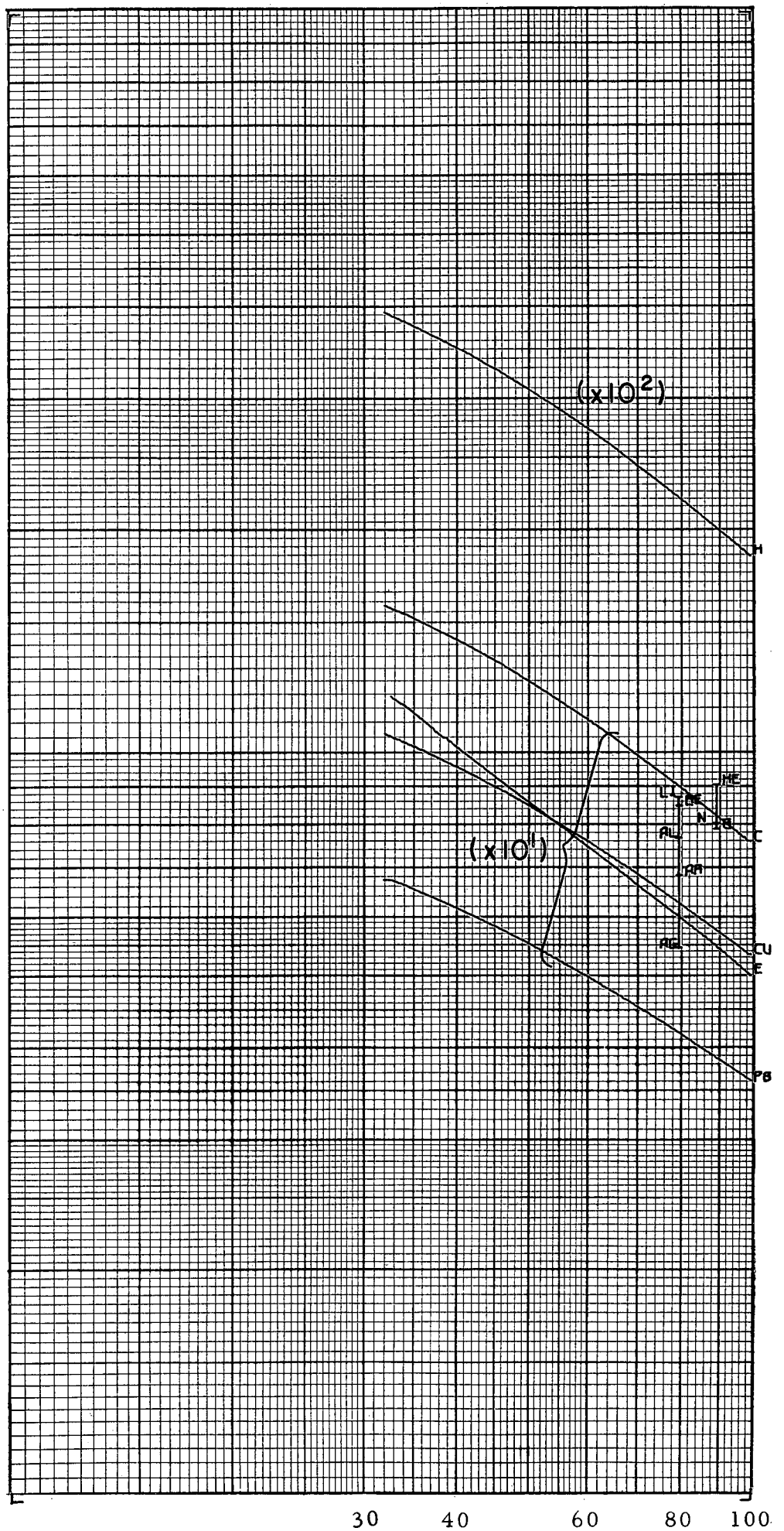
DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.



ALPHA PARTICLES

(3.2 TO 100 MEV)

M = 3727.23 MEV

= 7294.47 M

DE/DX OF H, C, CU, AND PB IN MEV CM2/G AND OF ILFORD G-5 EMULSION IN MEV/CM.

0 0 1 0 1 2 0 4 5 5 3

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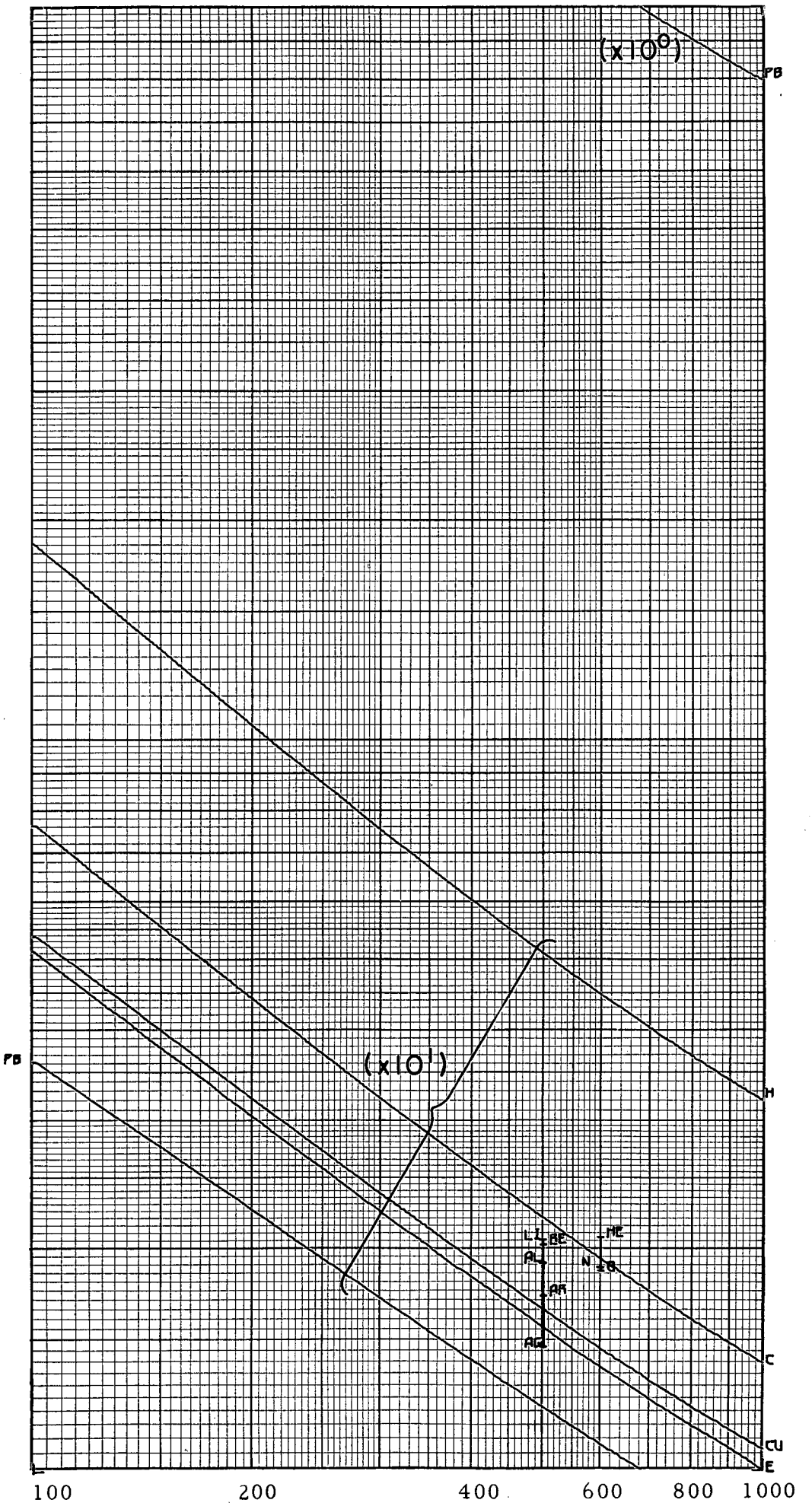
SUPPLEMENTAL DATA
(GRAPHS and TABLES)



ALPHA PARTICLES

(100 TO 1000 MEV)

M = 3727.23 MEV

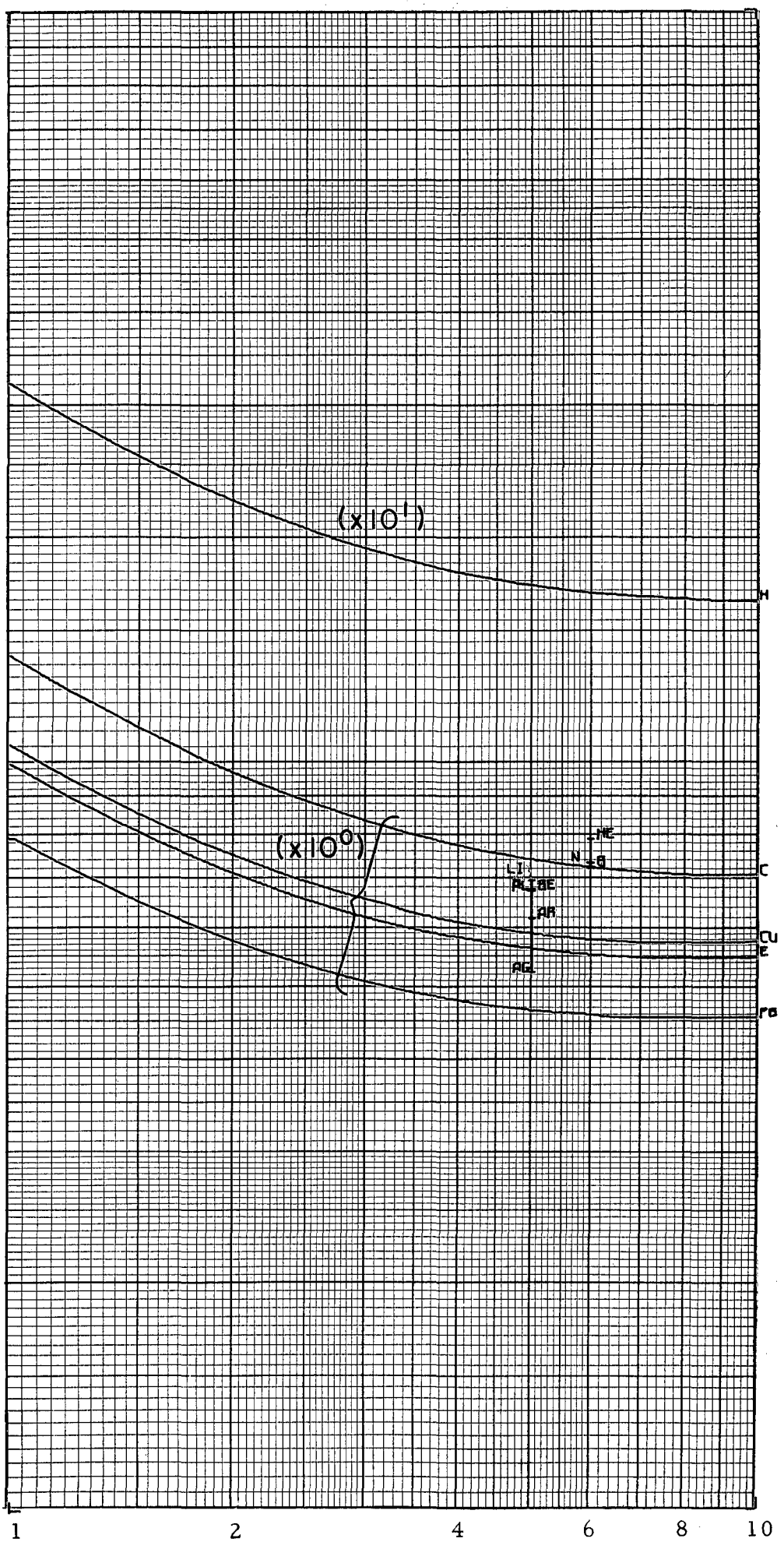
= 7294.47 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



ALPHA PARTICLES

(1 TO 10 GEV)

M = 3727.23 MEV

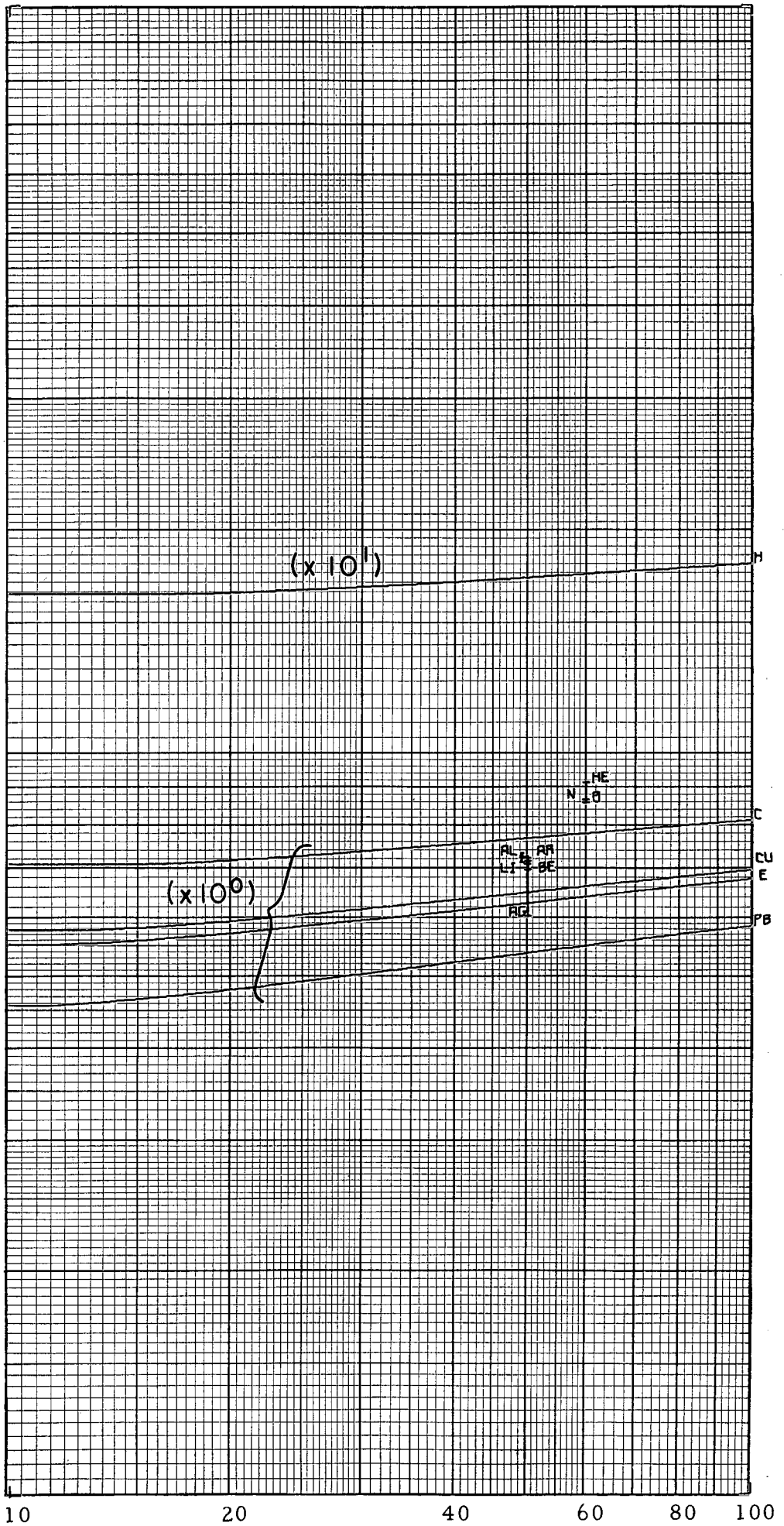
= 7294.47 m

DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.



ALPHA PARTICLES

(10 TO 100 GEV)

M = 3727.23 MEV

= 7294.47 m

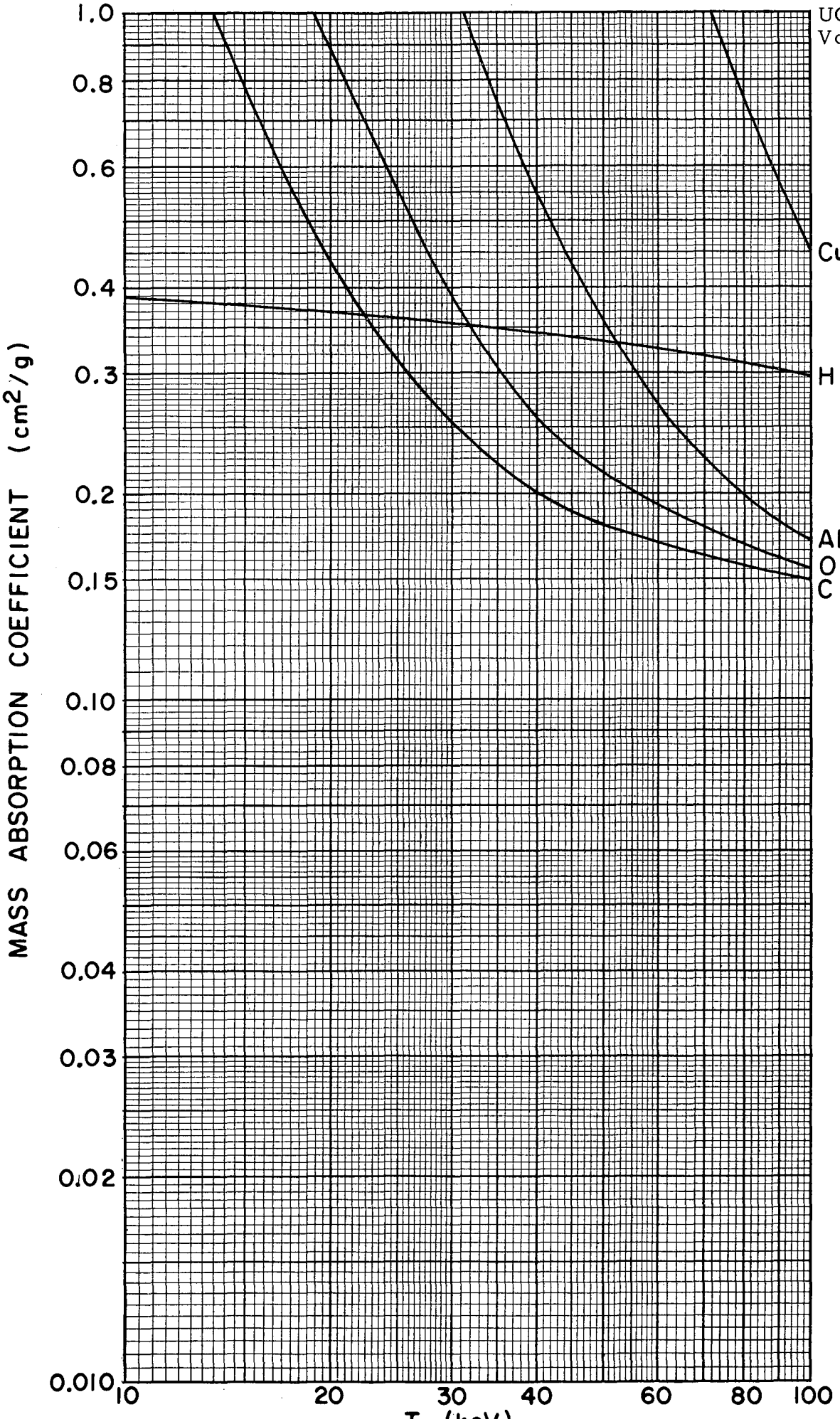
DE/DX OF H, C, CU,

AND PB IN MEV CM2/G

AND OF ILFORD G-5

EMULSION IN MEV/CM.

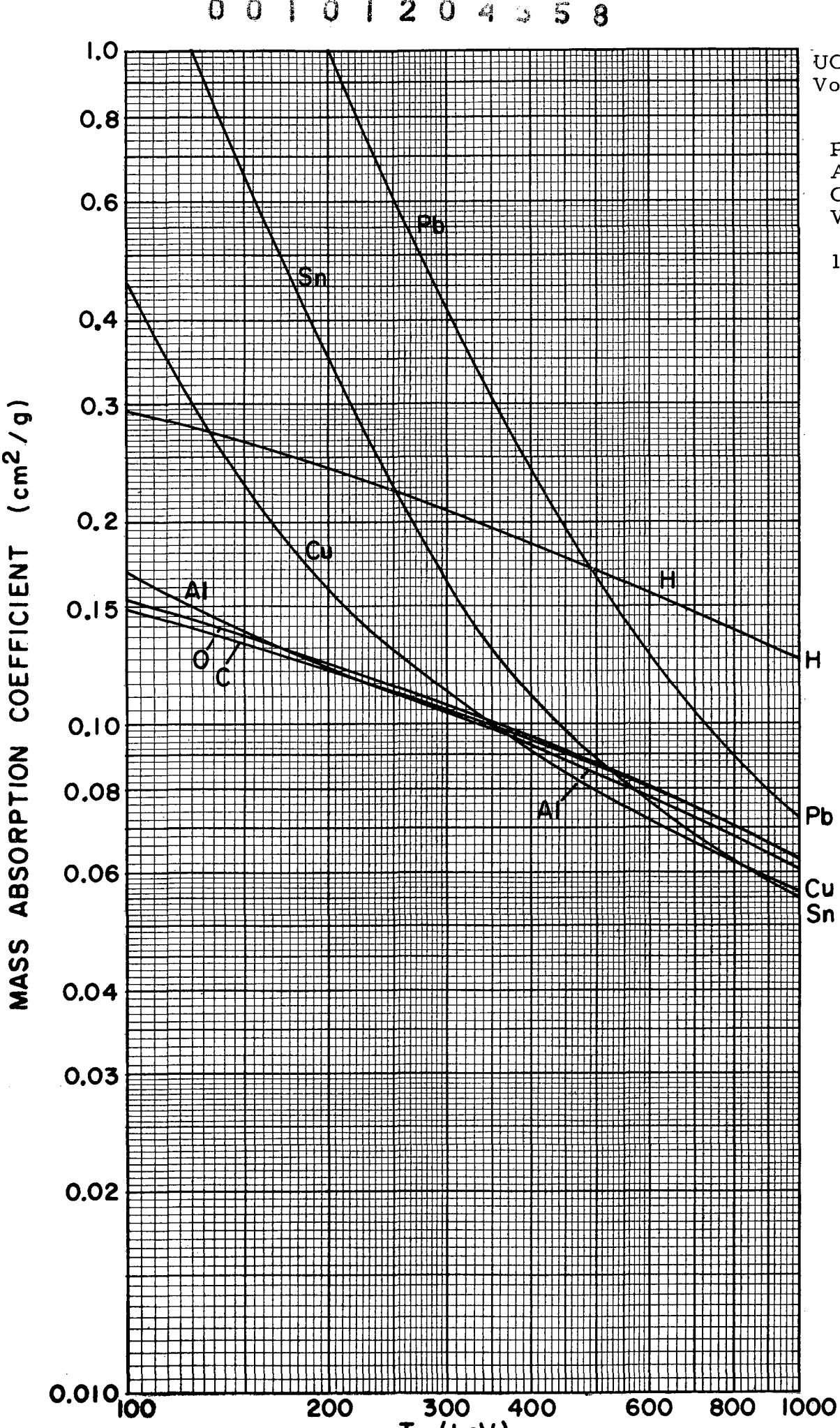
PHOTON MASS-ABSORPTION COEFFICIENT VS ENERGY



10 - 100 keV

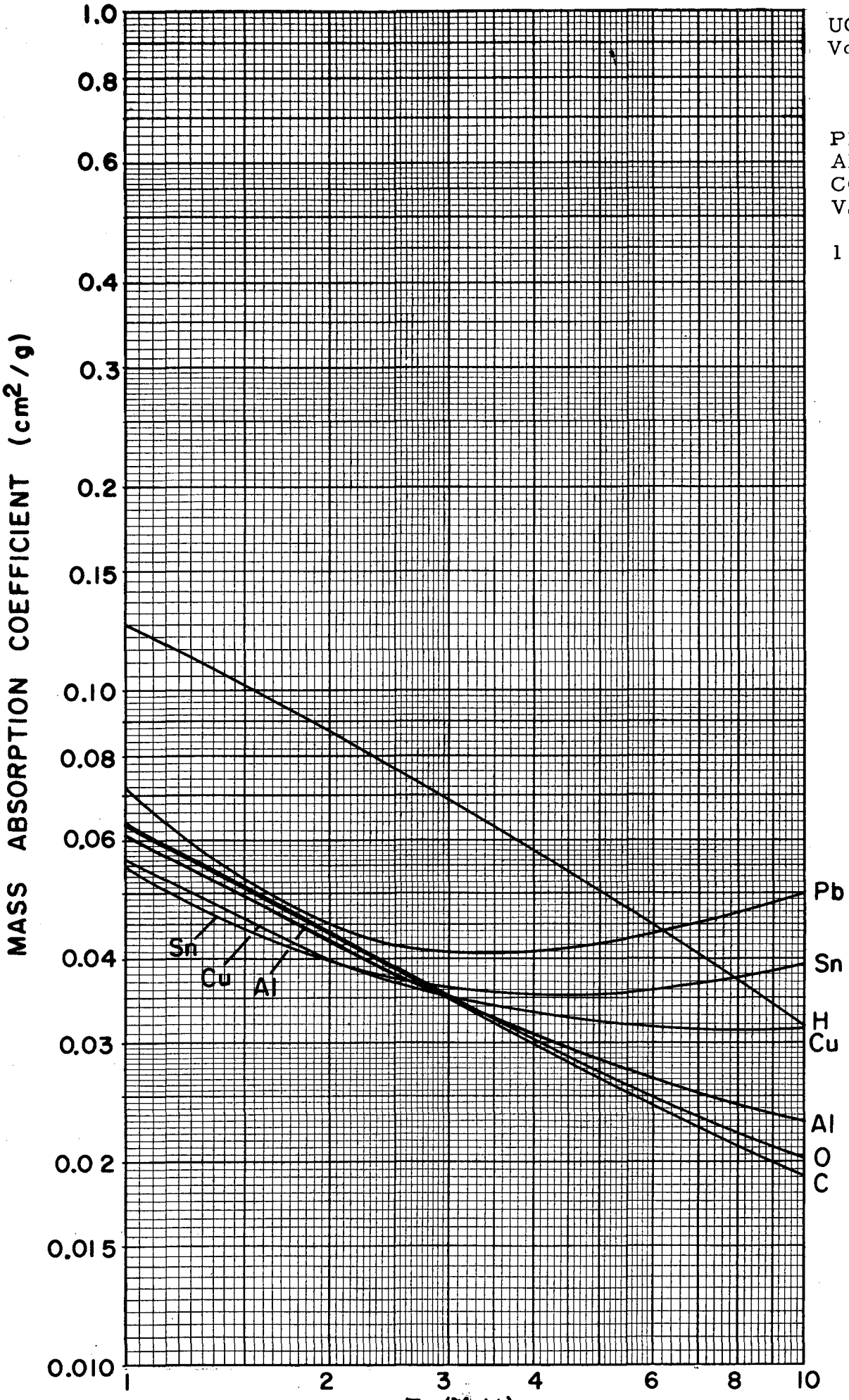
PHOTON MASS-ABSORPTION COEFFICIENT VS ENERGY

100 - 1000 keV



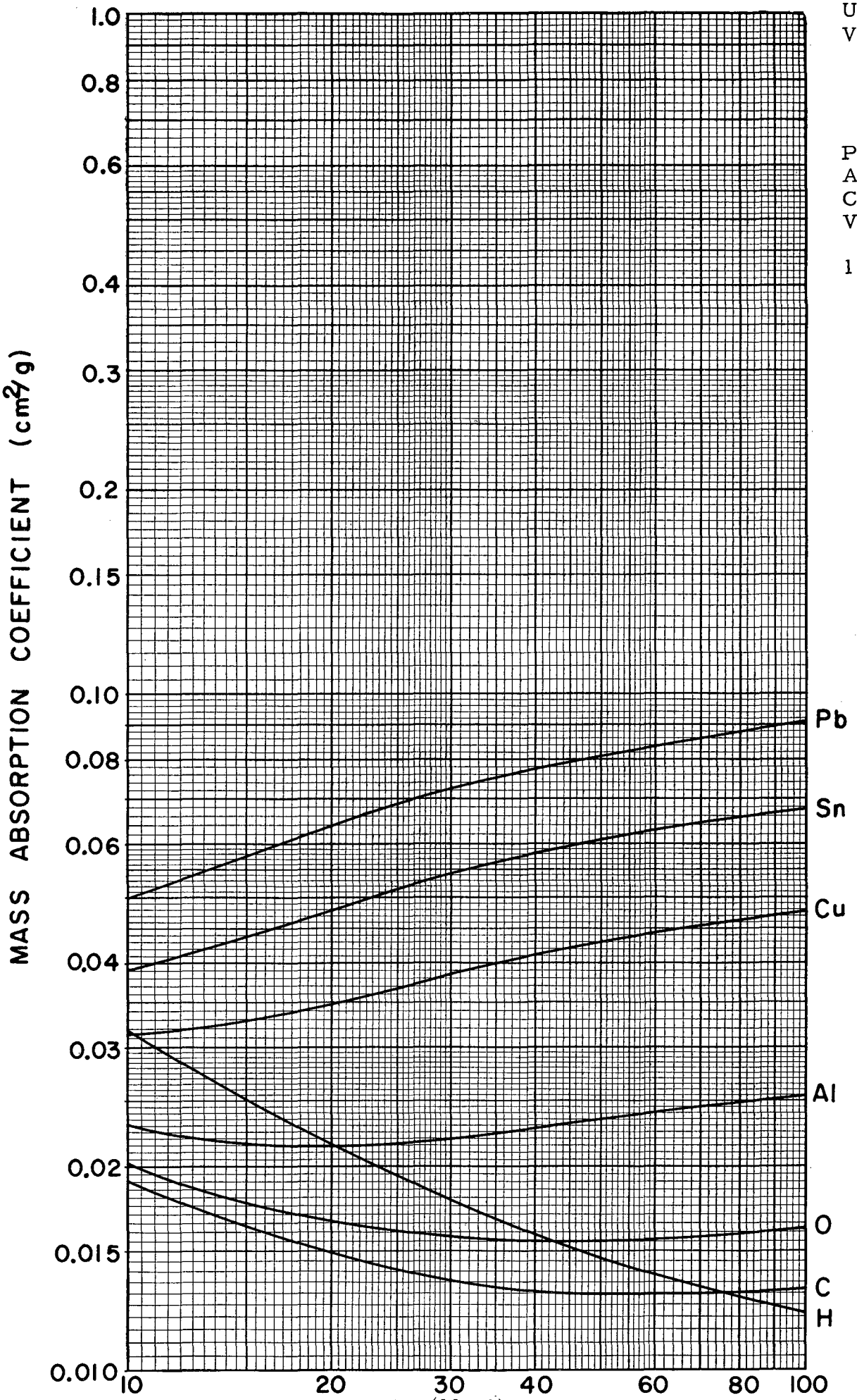
PHOTON MASS-ABSORPTION COEFFICIENT VS ENERGY

1 - 10 MeV



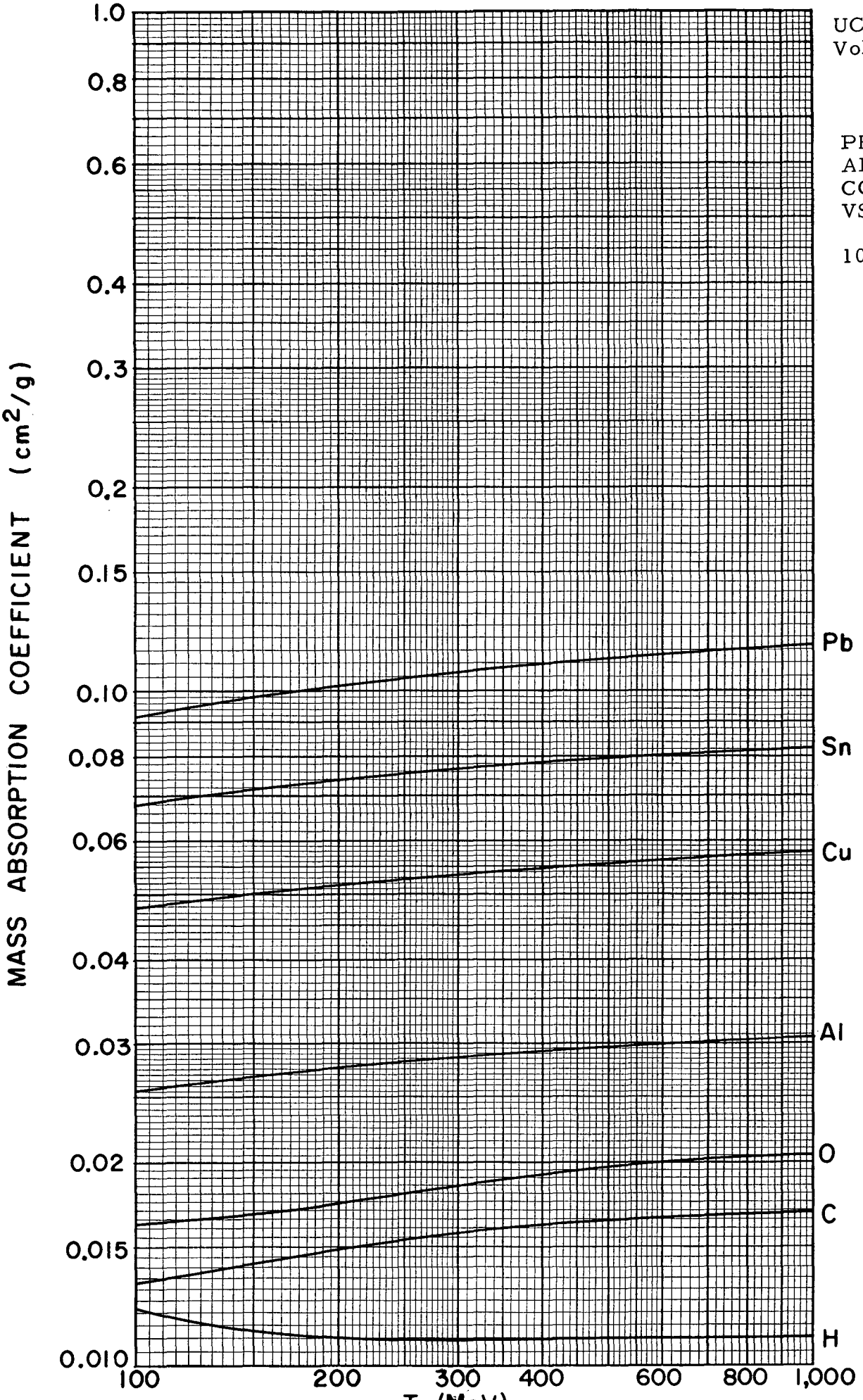
PHOTON MASS-ABSORPTION COEFFICIENT VS ENERGY

10 - 100 MeV



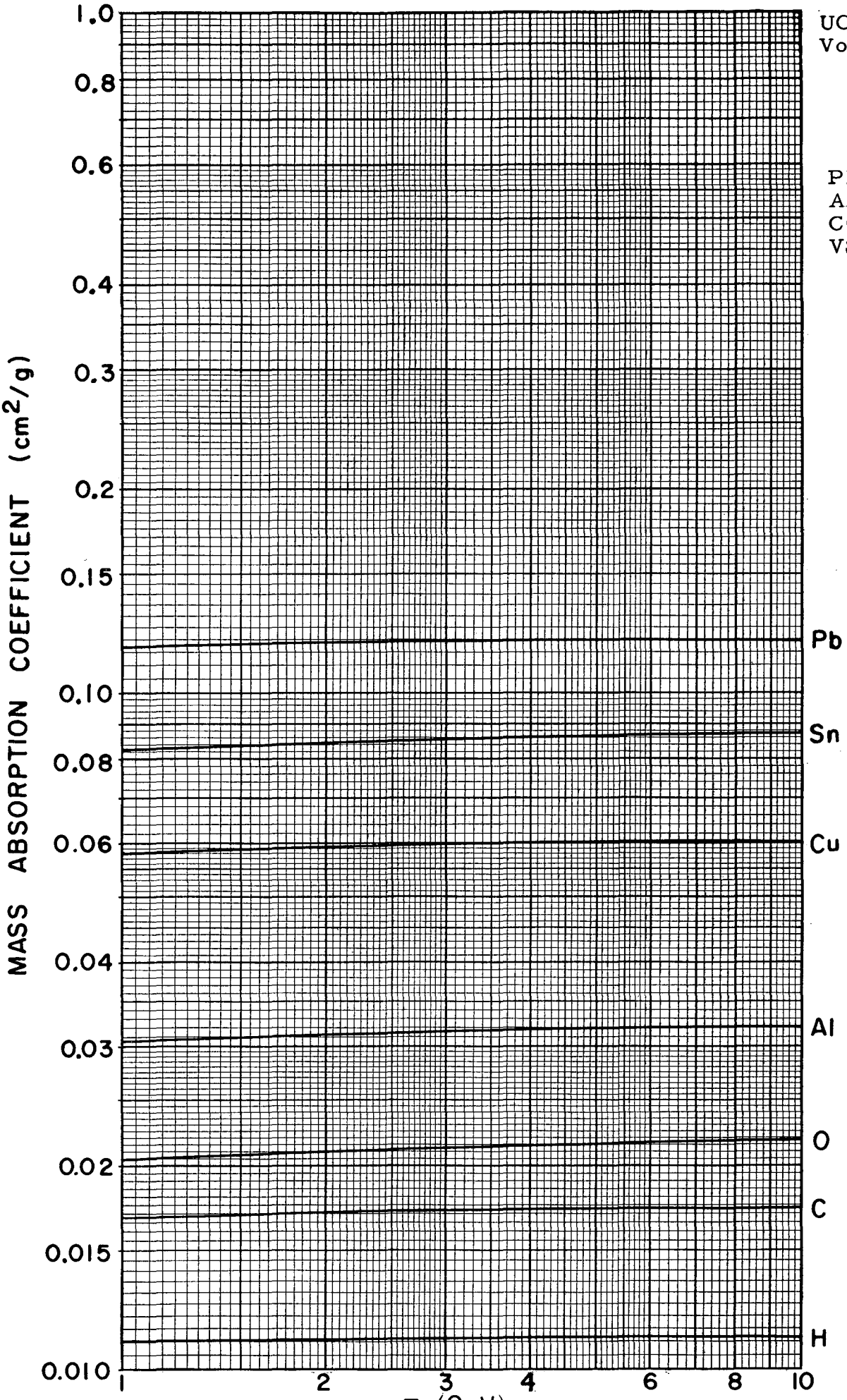
PHOTON MASS-ABSORPTION COEFFICIENT VS ENERGY

100 - 1000 MeV



PHOTON MASS-ABSORPTION COEFFICIENT VS ENERGY

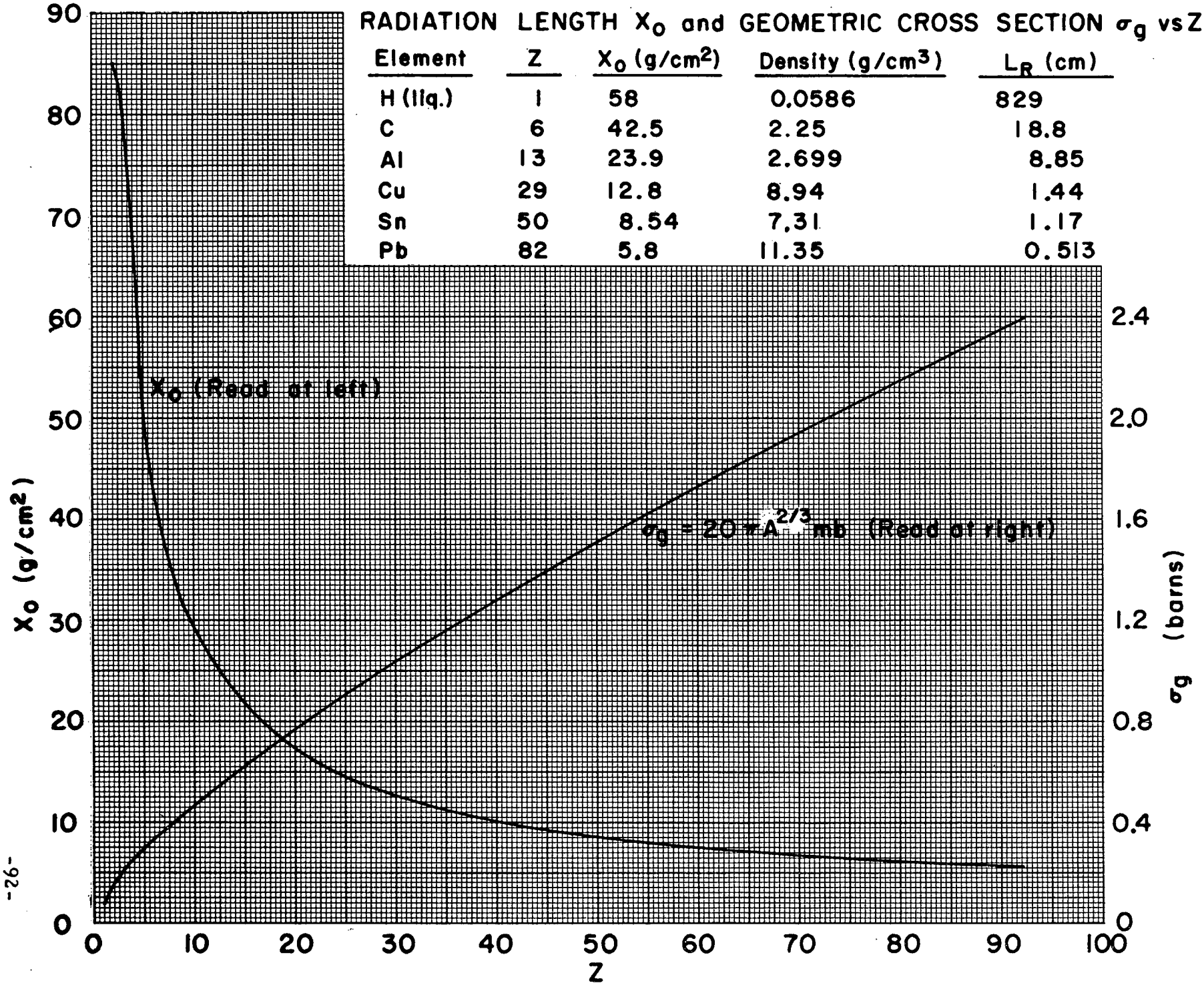
1 - 10 GeV

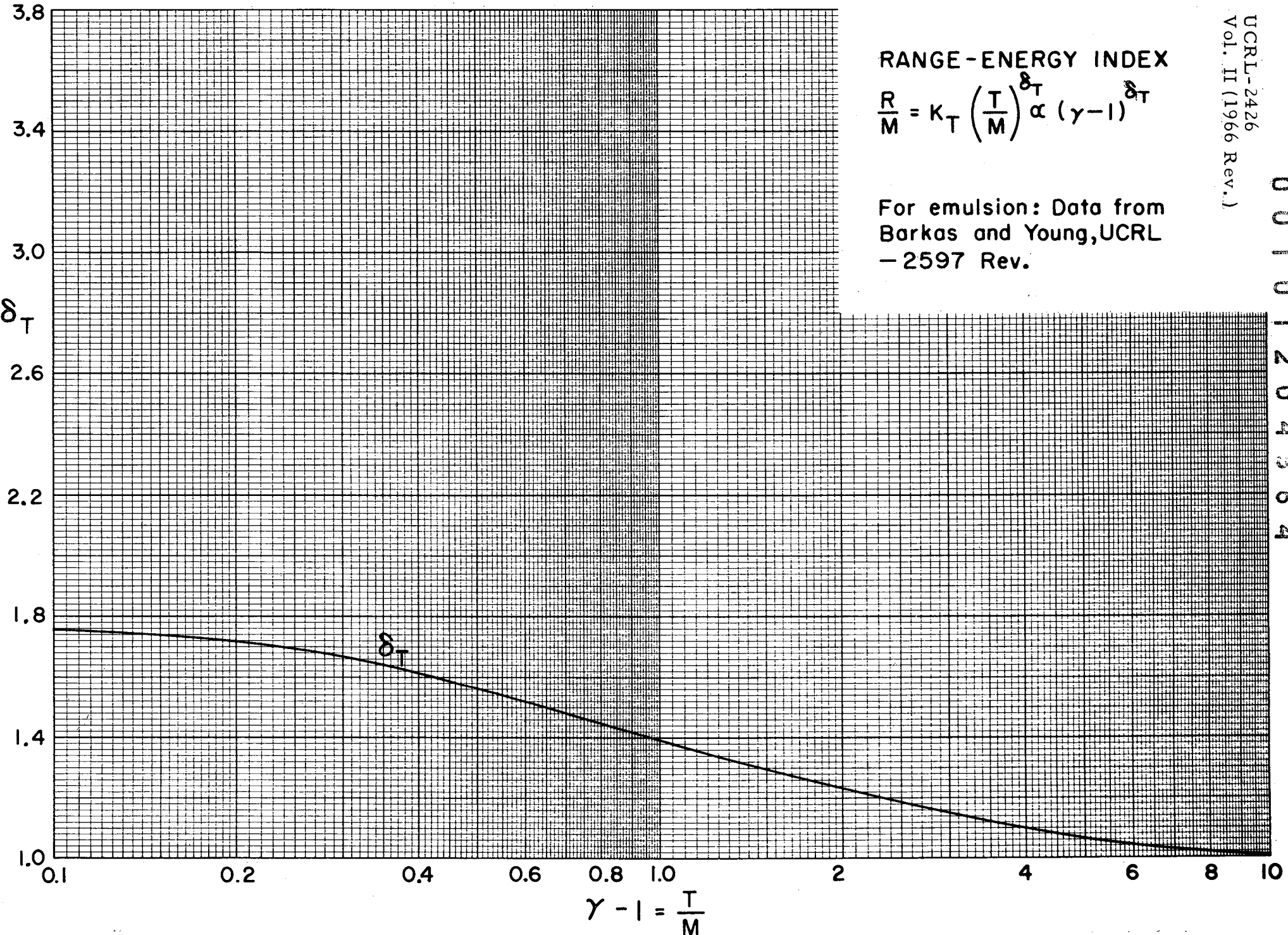


0 0 1 0 1 2 0 4 5 6 3

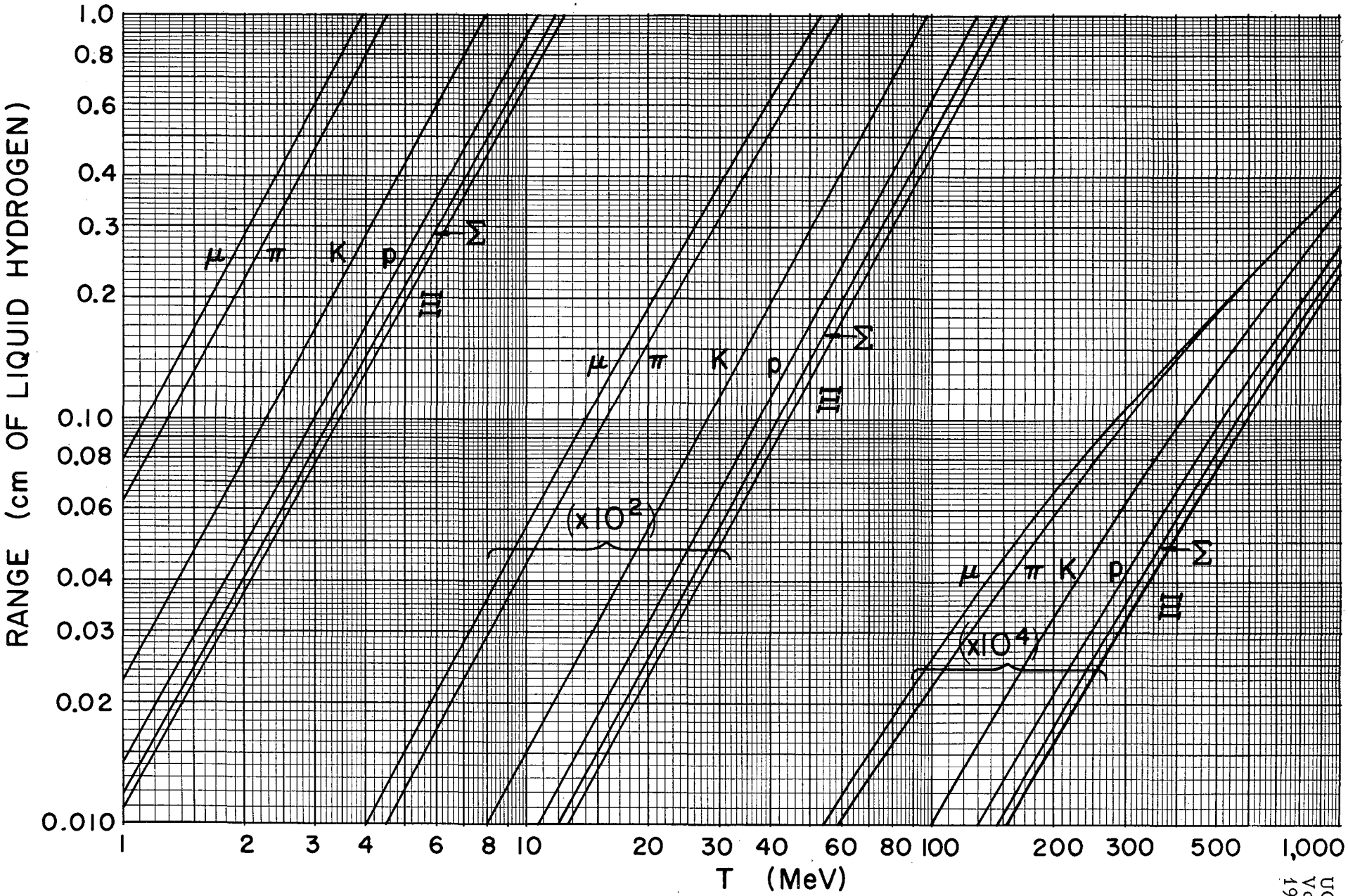
RADIATION LENGTH X_0 and GEOMETRIC CROSS SECTION σ_g vs Z

Element	Z	X_0 (g/cm^2)	Density (g/cm^3)	L_R (cm)
H (liq.)	1	58	0.0586	829
C	6	42.5	2.25	18.8
Al	13	23.9	2.699	8.85
Cu	29	12.8	8.94	1.44
Sn	50	8.54	7.31	1.17
Pb	82	5.8	11.35	0.513





0 0 1 0 1 2 0 4 3 6 4



Ranges in liquid hydrogen bubble chamber, determined by a μ^+ range of 1.103 ± .003 cm from the $\pi^+ \rightarrow \mu^+ \nu$ decay. Liquid hydrogen conditions: T = 27.6 ± .1°K; P = 48 ± 5 psia; $\rho = (5.86 \pm .06)10^{-2}$ g/cm^3. (Data by Clark and Diehl.)

0 0 1 0 1 2 0 4 5 6 5

Normalized emulsion quantities tabulated as functions of the particle velocity.[a]

Proton kinetic energy	Kinetic energy	Velocity	Magnetic curvature	Multiple scattering	Maximum energy of δ-ray	Energy loss rate	Residual Range
T_p (Mev)	$\gamma - 1 = T/M$	$\beta = v/c$	$\beta\gamma = Pc/M = 2.99793\times10^{-4}\ \beta pz/M$	$\beta^2\gamma = \frac{PBc}{M} = \frac{Kz}{aM}\left(\frac{S}{100}\right)^2$	$\epsilon = 1.022(\gamma^2-1)$ (Mev)	$L = I/z^2$ (Mev/cm)	$\lambda = \frac{z^2RM_p}{M}$ (cm)
0.10	0.000106573	0.014599212	0.014600769	0.000213154	0.000217833	1500	0.99×10^{-4}
0.20	0.000213146	0.020644754	0.020649157	0.000426292	0.000435710	1130	1.78
0.30	0.000319749	0.025282539	0.025290623	0.000639409	0.000653654	950	2.76
0.40	0.000426322	0.029191434	0.029203877	0.000852503	0.000871584	820	3.91
0.60	0.000639498	0.035746343	0.035769202	0.001278616	0.001307540	650	6.69
0.80	0.000852674	0.041269727	0.041304916	0.001704641	0.001743592	559	10.06
1.00	0.001065835	0.046133593	0.046182767	0.002130575	0.002179720	490	13.92
1.20	0.001279011	0.050528750	0.050593376	0.002556413	0.002615958	439	18.26
1.40	0.001492187	0.054568581	0.054650001	0.002982169	0.003052294	399	23.06
1.60	0.001705348	0.058326952	0.058426425	0.003407829	0.003488697	367	28.30
1.80	0.001918524	0.061855212	0.061973877	0.003833406	0.003925219	342	33.94
2.00	0.002131701	0.065190718	0.065329686	0.004258886	0.004361823	320	40.0
2.50	0.002664626	0.072856396	0.073050529	0.005322196	0.005453743	271	57.0
3.00	0.003197551	0.079778396	0.080033489	0.006384939	0.006546237	242	76.4
3.50	0.003730476	0.086136214	0.086457543	0.007447124	0.007639296	219	97.9
4.00	0.004263416	0.092046864	0.092439294	0.008508742	0.008732982	200	121.9
4.50	0.004796341	0.097591631	0.098059714	0.009569801	0.009827219	185	148.0
5.00	0.005329266	0.102829739	0.103377752	0.010630302	0.010922030	172	175.9
5.50	0.005862191	0.107805923	0.108437903	0.011690244	0.012017436	161	206.0
6.00	0.006395116	0.112554938	0.113274738	0.012749627	0.013113402	152	237.9
6.50	0.006928042	0.117104441	0.117915742	0.013808452	0.014209963	144	271.5
7.00	0.007460982	0.121476859	0.122383200	0.014866725	0.015307121	136	307.8
7.50	0.007993907	0.125690699	0.126695454	0.015924439	0.016404845	129	345.6
8.00	0.008526832	0.129761413	0.130867869	0.016981594	0.017503142	124	385.3
8.50	0.009059757	0.133702092	0.134913400	0.018038198	0.018602021	119	426.8
9.00	0.009592682	0.137523927	0.138843149	0.019094251	0.019701481	114	470.3
9.50	0.010125622	0.141236581	0.142666690	0.020149752	0.020801544	109	515.4
10.00	0.010658547	0.144848466	0.146392338	0.021204703	0.021902159	105.0	562.5
11.00	0.011724398	0.151798524	0.153578274	0.023312956	0.024105139	97.7	662.0
12.00	0.012790263	0.158423483	0.160449766	0.025419012	0.026310474	91.5	769.1
13.00	0.013856098	0.164762663	0.167045623	0.027522877	0.028518073	86.1	882.0
14.00	0.014921963	0.170847915	0.173397303	0.029624566	0.030728042	81.5	1002.
15.00	0.015987813	0.176705591	0.179530725	0.031724080	0.032940313	77.3	1129.
16.00	0.017053679	0.182357676	0.185467549	0.033821426	0.035154939	73.6	1262.
17.00	0.018119544	0.187822819	0.191226080	0.035916619	0.037371881	70.2	1402.
18.00	0.019185394	0.193116948	0.196821973	0.038009658	0.039591111	67.2	1548.
19.00	0.020251244	0.198253825	0.202268712	0.040100545	0.041812673	64.4	1700.
20.00	0.021317109	0.203245454	0.207578063	0.042189293	0.044036575	61.9	1858.
22.50	0.023981750	0.215155080	0.220314875	0.047401860	0.049606457	56.5	2283.
25.00	0.026646391	0.226353571	0.232385069	0.052601188	0.055190861	52.1	2744.
27.50	0.029311031	0.236942686	0.243887715	0.057787411	0.060789771	48.3	3243.
30.00	0.031975657	0.247001544	0.254899576	0.062960587	0.066403158	45.2	3777.
32.50	0.034640312	0.256593339	0.265481815	0.068120860	0.072031140	42.5	4347.
35.00	0.037304953	0.265769310	0.275683820	0.073268294	0.077673584	40.2	4952.
37.50	0.039969593	0.274571918	0.285546444	0.078403033	0.083330542	38.1	5591.
40.00	0.042634234	0.283036582	0.295103624	0.083525121	0.089002036	36.3	6264.
42.50	0.045298859	0.291193478	0.304384209	0.088634692	0.094687991	34.7	6970.
45.00	0.047963500	0.299068347	0.313412711	0.093731821	0.100388490	33.2	7709.
50.00	0.053292781	0.314058520	0.330795571	0.103889167	0.111833043	30.7	7275.
55.00	0.058622062	0.328154199	0.347391278	0.113997906	0.123335630	28.5	1.097×10^{0}
60.00	0.063951343	0.341470219	0.363307700	0.124058761	0.134896293	26.7	1.278
65.00	0.069280624	0.354098372	0.378630526	0.134072453	0.146514989	25.2	1.471
70.00	0.074609905	0.366113432	0.393429115	0.144039683	0.158191733	23.8	1.675
75.00	0.079939187	0.377577327	0.407760546	0.153961137	0.169926539	22.7	1.891
80.00	0.085268468	0.388542078	0.421672463	0.163837492	0.181715407	21.6	2.117
85.00	0.090597749	0.399051882	0.435205080	0.173669405	0.193570316	20.7	2.353
90.00	0.095927015	0.409144729	0.448392756	0.183457531	0.205479249	19.8	2.600
95.00	0.101256296	0.418853521	0.461265080	0.193202503	0.217446260	19.1	2.860
100.00	0.106585577	0.428207047	0.473847739	0.202904940	0.229471326	18.4	3.124
120.00	0.127902701	0.462534502	0.521693908	0.241301432	0.278152108	16.2	4.286
140.00	0.149219826	0.492777184	0.566309310	0.279064305	0.327761739	14.5	5.594
160.00	0.170536965	0.519765817	0.608405098	0.316228166	0.378300227	13.3	7.034
180.00	0.191854060	0.544086881	0.648472153	0.352825187	0.429767437	12.3	8.596

a. Data compiled by W. Peter Trower for Walter H. Barkas in Nuclear Research Emulsions (Academic Press, New York), to be published. Data used with permission.

1 Proton kinetic energy (Mev)	2 Kinetic energy	3 Velocity	4 Magnetic curvature	5 Multiple scattering	6 Maximum energy of δ-ray (Mev/cm)	7 Energy loss rate (Mev/cm)	8 Proton kinetic energy (cm)
200.00	0.213171184	0.566173688	0.686865598	0.388885230	0.482163556	11.5	10.27
220.00	0.234488308	0.586357750	0.723851785	0.424436100	0.535488524	10.9	12.06
240.00	0.255805433	0.604899675	0.759636290	0.459503748	0.589742310	10.3	13.95
260.00	0.277122572	0.622008853	0.794381544	0.494112350	0.644924983	9.88	15.92
280.00	0.298439667	0.637856610	0.828218319	0.528284527	0.701036356	9.48	17.99
300.00	0.319756791	0.652585194	0.861253738	0.562041432	0.758076645	9.13	20.14
320.00	0.341073915	0.666314252	0.893576659	0.595402859	0.816045783	8.83	22.37
340.00	0.362391040	0.679145530	0.925261781	0.628387399	0.874943741	8.56	24.67
360.00	0.383708149	0.691166311	0.956372455	0.661012419	0.934770495	8.32	27.04
380.00	0.405025274	0.702452168	0.986963049	0.693294324	0.995526120	8.11	29.48
400.00	0.426342398	0.713068940	1.017080456	0.725248478	1.057210565	7.91	31.98
420.00	0.447659507	0.723074406	1.046765536	0.756889366	1.119823813	7.74	34.53
440.00	0.468976632	0.732519530	1.076054066	0.788230605	1.183365941	7.58	37.14
460.00	0.490293756	0.741449527	1.104977593	0.819285117	1.247836918	7.44	39.81
480.00	0.511610880	0.749904662	1.133564040	0.850064956	1.313236728	7.31	42.52
500.00	0.532927990	0.757921003	1.161838308	0.880581655	1.379565299	7.19	45.28
520.00	0.554245129	0.765530884	1.189822644	0.910845973	1.446822807	7.09	48.08
540.00	0.575562239	0.772763528	1.217537031	0.940868206	1.515009075	7.00	50.93
560.00	0.596879363	0.779645301	1.244999483	0.970657989	1.584124193	6.91	53.81
580.00	0.618196487	0.786200166	1.272226334	1.000224546	1.654168174	6.81	56.73
600.00	0.639513612	0.792449914	1.299232408	1.029576614	1.725140974	6.72	59.69
620.00	0.660830721	0.798414417	1.326031178	1.058722407	1.797042534	6.64	62.68
640.00	0.682147846	0.804111831	1.352634981	1.087669790	1.869873002	6.58	65.71
660.00	0.703464970	0.809558816	1.379055083	1.116426185	1.943632320	6.52	60.76
680.00	0.724782094	0.814770661	1.405301839	1.144998699	2.018320441	6.46	71.84
700.00	0.746099219	0.819761448	1.431384817	1.173394084	2.093937427	6.40	74.96
720.00	0.767416328	0.824544132	1.457312748	1.201618671	2.170483172	6.35	78.09
740.00	0.788733453	0.829130724	1.483093858	1.229678676	2.247957826	6.20	81.26
760.00	0.810050592	0.833532281	1.508735597	1.257579803	2.326361358	6.25	84.44
780.00	0.831367716	0.837759115	1.534244984	1.285327718	2.405693650	6.21	87.65
800.00	0.852684826	0.841820732	1.559628487	1.312927574	2.485954732	6.17	90.88
820.00	0.874001935	0.845726021	1.584892198	1.340384558	2.567144632	6.13	94.13
840.00	0.895319045	0.849483214	1.610041708	1.367703393	2.649263382	6.10	97.40
860.00	0.916636184	0.853100002	1.635082319	1.394888729	2.732311100	6.06	100.7
880.00	0.937953293	0.856583588	1.660018980	1.421945006	2.816287518	6.03	104.0
900.00	0.959270418	0.859940633	1.684856236	1.448876336	2.901192844	6.00	107.3
920.00	0.980587542	0.863177449	1.709598497	1.475686848	2.987026960	5.97	110.7
940.00	1.001904666	0.866299890	1.734249786	1.502380386	3.073789924	5.95	114.0
960.00	1.023221791	0.869313456	1.758813918	1.528960586	3.161481768	5.92	117.4
980.00	1.044538885	0.872223333	1.783294514	1.555431083	3.250102282	5.90	120.8
1000.00	1.065856010	0.875034340	1.807694942	1.581795141	3.339651793	5.88	124.2
1200.00	1.279027224	0.898592710	2.047917247	1.840243489	4.286232293	5.71	158.7
1400.00	1.492198437	0.915967628	2.282773077	2.090946227	5.325696170	5.61	194.1
1600.00	1.705369651	0.929176934	2.513767064	2.335734367	6.458043456	5.55	229.9
1800.00	1.918540835	0.939467892	2.741875380	2.575903893	7.683273911	5.51	266.1
2000.00	2.131712049	0.947648920	2.967763513	2.812397867	9.001387835	5.49	302.4
2200.00	2.344883293	0.954264358	3.191902906	3.045919150	10.412385583	5.49	338.8
2400.00	2.558054477	0.959692404	3.414637834	3.277001977	11.916266084	5.49	375.3
2600.00	2.771225661	0.964202844	3.636226505	3.506059915	13.513030052	5.50	411.7
2800.00	2.984396905	0.967992529	3.856866419	3.733417869	15.202677846	5.51	448.0
3000.00	3.197568059	0.971207984	4.076711595	3.959334821	16.985208035	5.53	484.2
3200.00	3.410739303	0.973960131	4.295884192	4.184019923	18.860622644	5.54	520.4
3400.00	3.623910487	0.976334222	4.514482021	4.407643259	20.828919888	5.56	556.4
3600.00	3.837081730	0.978396714	4.732584834	4.630345404	22.890101433	5.58	592.3
3800.00	4.050252974	0.980200015	4.950258017	4.852242947	25.044166088	5.60	628.1
4000.00	4.263424098	0.981785953	5.167555809	5.073433697	27.291112900	5.62	663.7
4200.00	4.476595342	0.983188182	5.384523809	5.294000089	29.630944252	5.64	699.2
4400.00	4.689766467	0.984434105	5.601200104	5.514012396	32.063657761	5.66	734.6
4600.00	4.902937770	0.985546149	5.817617536	5.733530521	34.589256763	5.68	769.9
4800.00	5.116109014	0.986542895	6.033803880	5.952606320	37.207738400	5.70	805.0
5000.00	5.329280019	0.987439789	6.249782920	6.171284318	39.919100285	5.72	840.0
6000.00	6.395136178	0.990815051	7.327212214	7.249912133	54.869175434	5.82	1013.
7000.00	7.460992098	0.992991067	8.401689529	8.342802644	72.141330719	5.91	1184.
8000.00	8.526848197	0.994475760	9.474219561	9.421881557	91.735573769	5.99	1352.
9000.00	9.592704177	0.995533913	10.545396209	10.498299479	113.651899338	6.06	1518.
10000.00	10.658560038	0.996314637	11.615593910	11.572786212	137.890304565	6.13	1682.
20000.00	21.317120075	0.998995602	22.294704676	22.272311926	507.989032745	6.59	3249.
30000.00	31.975680828	0.999540083	32.960514545	32.945355415	1110.296218872	6.86	4735.

9 Percentage straggling	10 Delta-ray density (cm^{-1})	11 Residual proper time (sec)	12 Restricted energy loss rate (Mev cm^2/g)	13 Range-energy index	14 Range-momentum index	15 Proton momentum (Mev/c)
1.13	25	7.13×10^{-10}	1.65	0.591	0.324	644.43
1.12	24	7.90	1.57	0.598	0.330	679.13
1.11	23	8.78	1.49	0.599	0.333	712.70
1.10	22	9.65	1.41	0.605	0.339	745.30
1.09	22	1.05×10^{-9}	1.36	0.609	0.344	777.05
1.08	21	1.15	1.30	0.613	0.349	808.04
1.09	21	1.23	1.26	0.617	0.354	838.37
1.07	20	1.32	1.23	0.621	0.358	868.09
1.06	20	1.40	1.19	0.625	0.363	897.26
1.06	19	1.49	1.16	0.629	0.368	925.98
1.05	19	1.57	1.12	0.632	0.372	954.24
1.05	19	1.65	1.10	0.636	0.376	982.09
1.04	18	1.73	1.08	0.640	0.381	1009.57
1.03	18	1.82	1.06	0.644	0.385	1036.70
1.03	17	1.90	1.04	0.648	0.390	1063.52
1.02	17	1.98	1.02	0.651	0.394	1090.05
1.02	17	2.06	1.01	0.656	0.399	1116.31
1.01	16	2.14	1.00	0.660	0.404	1142.31
1.01	16	2.22	0.99	0.664	0.408	1168.07
1.00	16	2.30	0.98	0.666	0.412	1193.62
1.00	16	2.38	0.97	0.669	0.415	1218.96
0.997	15	2.45	0.96	0.671	0.419	1244.10
0.995	15	2.53	0.95	0.676	0.424	1269.06
0.992	15	2.60	0.93	0.679	0.428	1293.85
0.990	15	2.68	0.91	0.682	0.432	1318.47
0.987	14	2.75	0.902	0.684	0.436	1342.94
0.984	14	2.82	0.897	0.689	0.440	1367.27
0.981	14	2.89	0.892	0.692	0.444	1391.46
0.978	14	2.96	0.887	0.694	0.447	1415.52
0.975	13	3.03	0.881	0.698	0.451	1439.45
0.972	13	3.11	0.876	0.701	0.455	1463.26
0.970	13	3.17	0.871	0.704	0.459	1486.97
0.968	13	3.24	0.866	0.707	0.463	1510.56
0.966	13	3.30	0.860	0.710	0.466	1534.06
0.964	12	3.37	0.855	0.713	0.470	1557.45
0.963	12	3.43	0.850	0.715	0.474	1580.75
0.961	12	3.50	0.845	0.718	0.477	1603.97
0.959	12	3.56	0.840	0.722	0.481	1627.10
0.957	12	3.62	0.834	0.724	0.485	1650.14
0.955	12	3.69	0.829	0.727	0.488	1673.11
0.952	12	3.75	0.824	0.730	0.492	1696.00
0.935	12	4.35	0.799	0.755	0.525	1921.38
0.923	11	4.87	0.784	0.778	0.555	2141.73
0.913	10	5.35	0.775	0.797	0.582	2358.45
0.907	10	5.80	0.769	0.813	0.607	2572.46
0.904	10	6.24	0.766	0.830	0.629	2784.39
0.903	10	6.65	0.765	0.846	0.651	2994.68
0.903	10	7.03	0.764	0.859	0.670	3203.66
0.904	10	7.39	0.763	0.871	0.688	3411.55
0.906	10	7.73	0.762	0.882	0.705	3618.56
0.913	10	8.05	0.761	0.893	0.721	3824.82
0.916	10	8.34	0.760	0.901	0.734	4030.45
0.922	10	8.62	0.763	0.910	0.748	4235.55
0.926	10	8.89	0.766	0.918	0.761	4440.17
0.931	10	9.17	0.769	0.926	0.773	4644.40
0.935	9	9.44	0.772	0.933	0.784	4848.27
0.940	9	9.65	0.774	0.939	0.791	5051.83
0.946	9	9.86	0.775	0.945	0.804	5255.12
0.952	9	1.01×10^{-8}	0.777	0.951	0.813	5458.16
0.957	9	1.03	0.779	0.956	0.822	5660.99
0.963	9	1.05	0.787	0.961	0.830	5863.63
0.990	9	1.14	0.788	0.983	0.866	6874.49
1.02	9	1.22	0.795	1.000	0.894	7882.57
1.05	9	1.28	0.801	1.012	0.919	8888.84
1.08	9	1.35	0.807	1.022	0.934	9893.83
1.11	9	1.40	0.814	1.031	0.949	10897.90
1.38	9	1.76	0.848	1.071	1.024	20917.18
1.62	9	1.95	0.864	1.083	1.051	30923.98

9 Percentage straggling	10 Delta-ray density	11 Residual proper time	12 Restricted energy loss rate	13 Range-energy index	14 Range-momentum index	15 Proton momentum
$\phi = 100\,\sigma/\lambda = \frac{100S}{R}\sqrt{\frac{M}{M_p}}$	$\nu = N/z^2$	$\theta = z^2 t \frac{M}{M_p}$	$i' = I'/z^2$ (agBr) 2-kev cutoff	$\eta = \frac{i\lambda}{T_p}$	$w = \frac{i\lambda}{p_p}$	P_p
	(cm^{-1})	(sec)	(Mev cm^2/g)			(Mev/c)
3.05	0	9.25×10^{-13}	560	1.485	0.743	13.70
2.80	0	9.40	330	1.006	0.503	19.37
2.62	0	9.52	280	0.874	0.437	23.73
2.50	0	9.66	190	0.802	0.401	27.40
2.35	0	9.94	125	0.725	0.362	33.56
2.20	0	1.22×10^{-12}	112	0.703	0.352	38.75
2.11	0	1.44	95	0.682	0.341	43.33
2.07	0	1.80	83	0.668	0.334	47.47
2.04	0	2.07	73	0.657	0.329	51.27
2.00	0	2.39	66	0.649	0.325	54.82
1.97	0	2.66	60	0.645	0.323	58.14
1.94	0	2.97	56	0.640	0.320	61.29
1.86	0	3.79	47.5	0.618	0.309	68.54
1.79	0	4.57	41.0	0.616	0.309	75.12
1.75	0	5.40	36.0	0.613	0.308	81.12
1.71	0	6.28	32.5	0.610	0.305	86.73
1.69	0	7.15	30.0	0.608	0.305	92.00
1.66	1	8.13	27.3	0.605	0.305	96.99
1.65	2	9.02	25.6	0.603	0.303	101.74
1.63	4	1.00×10^{-11}	23.6	0.602	0.302	106.28
1.62	5	1.09	22.5	0.601	0.302	110.63
1.60	7	1.20	20.9	0.598	0.301	114.82
1.59	8	1.31	19.5	0.597	0.301	118.87
1.57	10	1.41	18.8	0.597	0.300	122.78
1.56	13	1.52	18.0	0.596	0.300	126.58
1.55	17	1.62	17.1	0.596	0.299	130.26
1.54	24	1.73	16.4	0.593	0.297	133.85
1.53	30	1.83	15.8	0.591	0.297	137.35
1.52	43	2.02	14.7	0.588	0.296	144.09
1.50	52	2.21	13.6	0.588	0.295	150.54
1.49	61	2.40	13.0	0.584	0.294	156.72
1.48	70	2.60	12.4	0.583	0.294	162.68
1.46	79	2.79	11.7	0.582	0.293	168.44
1.45	82	3.08	10.9	0.581	0.293	174.01
1.44	85	3.36	10.4	0.579	0.292	179.41
1.43	89	3.65	10.1	0.578	0.292	184.66
1.42	92	3.93	9.61	0.576	0.291	189.77
1.42	96	4.21	9.13	0.575	0.291	194.75
1.40	97	4.87	8.61	0.574	0.290	206.70
1.38	98	5.53	7.94	0.573	0.290	218.03
1.37	94	6.17	7.30	0.570	0.289	228.82
1.36	89	6.91	6.65	0.569	0.289	239.15
1.35	86	7.65	6.42	0.569	0.289	249.08
1.34	83	8.39	6.26	0.569	0.290	258.65
1.33	80	9.15	6.10	0.569	0.290	267.90
1.32	77	9.90	5.31	0.569	0.290	276.87
1.31	74	1.07×10^{-10}	5.21	0.569	0.291	285.58
1.30	72	1.14	4.96	0.569	0.291	294.05
1.29	69	1.30	4.47	0.569	0.292	310.36
1.28	65	1.47	4.30	0.569	0.292	325.93
1.27	61	1.64	4.00	0.569	0.293	340.86
1.26	59	1.81	3.70	0.570	0.295	355.24
1.25	57	1.98	3.45	0.570	0.295	369.12
1.24	55	2.16	3.32	0.571	0.297	382.57
1.23	53	2.35	3.19	0.572	0.298	395.62
1.22	51	2.53	3.05	0.572	0.299	408.32
1.22	49	2.72	2.91	0.573	0.299	420.69
1.21	48	2.91	2.78	0.575	0.301	432.76
1.21	47	3.10	2.65	0.575	0.302	444.57
1.19	42	3.91	2.37	0.579	0.307	489.46
1.18	37	4.71	2.09	0.579	0.310	531.32
1.16	32	5.52	1.95	0.585	0.315	570.81
1.14	29	6.34	1.80	0.587	0.319	608.41

Composition, density, and refractive index of various materials.

Material	Chemical formula	State	(g/cm^3)	Source	Refractive index	λ (mμ)	Source
Concrete	—	Solid	~ 2.4	a	—	—	—
Deuterium	D_2	Gas	0.000178	b			
	D_2	Liquid	0.165	b	~ 1.1	530	c
Fluor chemical (FC-75)	$C_8F_{16}O$	Liquid	1.76	e	1.276	589	e
Freon	CF_3Br	Liquid	~ 1.5	c			
Glass, crown	SiO_2(67%)	Solid	2.243	e	1.517	589	f
, lead	SiO_2(20%)PbO(80%)	Solid	3.89	e	1.649	589	f
Helium	He	Liquid	0.125	d	1.03	530	c
Hydrogen	H_2	Liquid	0.0586	c	1.093	530	c
Lucite	$C_5H_8O_2$	Solid	~ 1.18	e	~ 1.50	589	f
Mylar	$C_{12}H_{14}O_4$	Solid	1.124	f	1.51	589	f
Nitrogen	N_2	Liquid	0.81	f	1.2053	589	f
Polyethylene	C_4H_8	Solid	0.92	e			
Polystyrene	C_8H_8	Solid	~ 1.06	e	1.592	589	f
Propane	C_3H_8	Liquid	~ 0.44	c	~ 1.22	530	c
Quartz, fuzed	SiO_2	Solid	~ 2.60	f	1.4585	589	f
Sodium iodide	NaI	Solid	3.67	f	1.7745	589	f
Water	H_2O	Liquid	1.00	f	1.3335	589	f
Xenon	Xe	Liquid	~ 2.18	c	1.18	530	c

a. A. Achermann, The Shielding and Its Handling Devices for the P.S. Machine, CERN Gl-13, 1961.

b. D. B. Chelton and D. B. Mann, Cryogenic Data Book, UCRL-3421, 1956.

c. H. Bradner, Bubble Chambers, Ann. Rev. Nucl. Sci. 10, 109 (1960).

d. E. C. Kerr, J. Chem. Phys. 26, 511 (1957).

e. J. H. Atkinson, Jr., and B. H. Willis, High-Energy Particle Data, UCRL-2426 Vol. II (1957 Rev.).

f. Handbook of Chemistry and Physics, R. C. Weast, Editor (Chemical Rubber Company, Cleveland, Ohio), 1965 edition, 46th.

0010120457 0

Atomic number, atomic weight, mean ionization potential, and density of the elements.

Element	At. #	At. wt.	Mean ionization potential	Density	Element	At. #	At. wt.	Mean ionization potential	Density
H	1	1.00797	18.0	0.0586	He	2	4.0026	40.0	0.126
Li	3	6.939	39.032	0.534	Be	4	9.0122	56.0	1.8
B	5	10.811		2.34	C	6	12.01115	79.0	2.25
N	7	14.0067	92.0	0.808	O	8	15.9994	105.0	1.14
F	9	18.9984		1.11	Ne	10	20.183	130.016	1.2
Na	11	22.9898		0.971	Mg	12	24.312	156.4	1.74
Al	13	26.9815	163	2.699	Si	14	28.086		2.42
P	15	30.9738		1.82	S	16	32.064		2.07
Cl	17	35.453		1.56	Ar	18	39.948	240.0	1.40
R	19	39.102		0.87	Ca	20	40.08	200	1.55
Sc	21	44.956		3.02	Ti	22	47.90	225	4.5
V	23	50.942	254	5.96	Cr	24	51.996		7.1
Mn	25	54.9380		7.20	Fe	26	55.847	273	7.86
Co	27	58.9332	298	8.9	Ni	28	58.71	312	8.90
Cu	29	63.54	322	8.94	Zn	30	65.37	331	7.14
Ga	31	69.72		5.91	Ge	32	72.59		5.36
As	33	74.9216		5.73	Se	34	78.96		4.8
Br	35	79.909		3.12	Kr	36	83.80	493.68	2.6
Rb	37	85.47		1.53	Sr	38	87.62		2.54
Y	39	88.905		5.51	Zn	40	91.22		6.4
Nb	41	92.906	410	8.4	Mo	42	95.94	420	10.2
Tc	43	99			Ru	44	101.07		12.2
Rh	45	102.905	450	12.5	Pd	46	106.4	460	12.16
Ag	47	107.870	485	10.50	Cd	48	112.40	468.0	8.65
In	49	114.82	490	7.28	Sn	50	118.69	500	7.31
Sb	51	121.75		6.691	Te	52	127.60		6.24
I	53	126.9044		4.93	Xe	54	131.30	757.52	3.52
Cs	55	132.905		1.873	Ba	56	137.34		3.5
La	57	138.91		6.155	Ce	58	140.12		3.92
Pr	59	140.907		6.5	Nd	60	144.24		6.95
Pm	61	147			Sm	62	150.35		7.8
Eu	63	151.96		5.24	Gd	64	157.25		
Tb	65	158.924			Dy	66	162.50		8.56
Ho	67	164.930			Er	68	167.26		4.77
Tm	69	168.934			Yb	70	173.04		
Lu	71	174.97			Hf	72	178.49		13.3
Ta	73	180.948	720	16.6	W	74	183.85	740	19.3
Re	75	186.2		20.53	Os	76	190.2		22.48
Ir	77	192.2	760	22.42	Pt	78	195.09	777	21.37
Au	79	196.967	786	19.32	Hg	80	200.59		13.546
Tl	81	204.37		11.85	Pb	82	207.19	818	11.35
Bi	83	208.980	826	9.747	Po	84	210		
At	85	210			Rn	86	222		9.73
Fr	87	223			Ra	88	226		
Ac	89	227			Th	90	232.038		11.3
Pa	91	231			U	92	238.03	908	18.68

FOOTNOTES AND REFERENCES

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1. W. P. Trower, FORTRAN Subroutine RANGE: Calculating the Range-Energy Relation for Charged Particles in Chemical Elements, UCRL-11647 (September 1964).
2. M. J. Berger and S. M. Seltzer, Tables of Energy Losses and Ranges of Electrons and Positrons, NASA SP-3012, 1964.
3. W. H. Barkas, Nuclear Research Emulsions, Vol. I (Academic Press, New York, 1963) p. 362.
4. T. H. Thompson, Effects of Chemical Structure on Stopping Powers of High-Energy Protons (Ph.D. Thesis), UCRL-1910 (August 1952).
5. Arthur H. Rosenfeld, Angela Barbaro-Galtieri, Walter H. Barkas, Pierre L. Bastein, Janos Kirz, and Matts Roos, Data on Particles and Resonant States, UCRL-8030, Part I (March 1965).
6. Unclassified extract from Classified report by Ralph Zirkland, ORNL-503.
7. W. H. Barkas, Nuclear Research Emulsions, Vol II (Academic Press, New York, to be published).

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