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Abstract

The angular dependence of sputtering yields of light-ion sputtering and heavy-ion sputtering has been investigated in detail , and the following empirical formula is proposed:

$$\frac{Y(\theta)}{Y(0)} = t^f \exp [-\Sigma (t - 1)] ,$$

where θ is the angle of incidence measured from the surface normal, and $t = 1/\cos\theta$. The parameters f and Σ are adjustable parameters which are determined by the least-square method so as to fit the present empirical formula to available experimental data.

The best-fit parameters and their average values are listed in tables, where the value of θ_{opt} is listed in place of Σ. Here, θ_{opt} is the angle of incidence at the maximum yield and the relation between θ_{opt} and Σ is simple, i.e.,

$$\Sigma = f \cos \theta_{opt}.$$

The present empirical formula has been compared with available experimental data of various ion-target combinations, and it is found that the agreement is satisfactory in a wide range of the angle of incidence.

1. Introduction

Current needs for sputtering yield at normal incidence and at oblique incidence have accelerated the experimental measurements of sputtering yields, particularly by light ions. The extensive uses of sputtering data for the design of the fusion reactors required the comparison of experimental data with empirical formula and the reliable empirical formulae at normal and oblique incidences.

The empirical formulae for the sputtering yields at normal incidence have been proposed by Bohdansky et al.[1], Matsunami et al.[2], and Yamamura et al.[3] The compilations of the experimental data for available combinations of ions and target atoms have been published[4,5].

The angular dependence of sputtering yields has been investigated by many authors[6-25] and it was found that its dependence on the angle of incidence was roughly given by $\cos^{-1}\theta$ for not-too-oblique incidence,[8] where θ is measured from the surface normal. On the other hand, the theoretical investigation on the angular dependence of sputtering yields was done by Sigmund[26], who showed that the normalized yield $Y(\theta)/Y(0)$ had the $\cos^{-f}\theta$-dependence at not-too-oblique incidence, where $1 < f < 2$.

At energies around 1 keV, the angular dependence of sputtering yields has been investigated systematically by Oechsner[19]. For not-too-large angles of incidence, he found that the normalized yield obeyed a simple relation $\Delta Y(\theta)/\Delta Y(\theta_{opt}) = 1.2\ \hat{\theta}^2$, where $\hat{\theta} = \theta/\theta_{opt}$, $\Delta Y(\theta) = Y(\theta) - Y(0)$, and θ_{opt} is the angle of incidence at the maximum yield.

The rapid variation of sputtering yields with the angle of incidence has been reported by Bay et al.[20] for light-ion sputtering in low keV region. They found that the lighter the projectile, the maximum of the normalized yield was higher and also it increased with increasing the energy and increasing the surface binding energy. For the grazing angle of incidence, the surface channeling plays an important role and makes the drop-off of the sputtering yield at the glancing angles.

It is desired to have some analytical formula describing the angular dependence of the sputtering yields in a wide range of the angle of incidence. In this paper, a simple formula for the angular dependence of the normalized sputtering yield $Y(\theta)/Y(0)$ is proposed, taking into account the effect of the surface channeling at large angles, and the comparison of the present empirical formula with the existing experimental data will be made in detail.

2. An empirical formula for angular dependence of sputtering yields

Light-ion sputtering is mainly due to collision cascades created by ions backscattered from the interior of the solid, while the heavy-ion sputtering is due to collision cascades generated by incoming ions directly[27]. This difference is very important for low-energy sputtering, especially for the angular dependence of low-energy sputtering.

In the case of light-ion sputtering, the angular dependence of the threshold energy does not have a clear minimum. On the contrary, in the case of heavy-ion sputtering, the angular dependence of the threshold energy has a minimum near 60°. The threshold energy of heavy-ion sputtering is a decreasing function of the angle of incidence because of the anisotropic velocity distribution of recoil atoms near the surface, and for grazing angles of incidence it increases rapidly with increasing angle of incidence because of surface channeling. (see APPENDIX A). In other words, even if the ion energy is less than the threshold energy at normal incidence, the finite number of target atoms will be sputtered in oblique incidence in the case of heavy-ion sputtering. It must be noted that the normalized sputtering yield $Y(\theta)/Y(0)$ can not be well defined in such a low energy region.

2.1 Angular dependence of light-ion sputtering

Light-ion sputtering is directly connected with the particle reflection coefficient because it is due to collision cascades generated by backscattered ions. Recently, Yamamura et al. have derived the following formula[28]

$$Y(E) = 0.042 \frac{F_D(E^*) R_N(E)}{U_s} [1 - (\frac{E_{th}}{E})^{\frac{1}{2}}]^{2.8} \qquad (1)$$

for light-ion sputtering at normal incidence, where $F_D(E^*)$ is the deposited energy near the solid surface by a backscattered ion, E^* is the average energy of the reflected ion, and $R_N(E)$ is the particle reflection coefficient of the ion with the incident energy E。 The surface binding energy U_s is taken to be equal to the sublimation energy。 E_{th} is the threshold energy of the sputtering at normal incidence.

For not-too-oblique incidence, the normalized yield is given by

$$\frac{Y(\theta)}{Y(0)} = \frac{F_D(E^*(\theta))}{F_D(E^*)} \frac{R_N(E,\theta)}{R_N(E)} \qquad (2)$$

where the threshold effect of the light ion sputtering is neglected because of its weak angular dependence and Y(0) is the sputtering yield at normal incidence which is described by Y(E) in eq.(1)。 Similarly $R_N(E)$ means $R_N(E,\theta=0)$。

The angular dependence of the reflection coefficient is roughly estimated in terms of the range distribution. For very small angles of incidence, the ratio $R_N(E,\theta)/R_N(E)$ is given by

$$\frac{R_N(E,\theta)}{R_N(E)} = \frac{\int_{\infty}^{0} dx\ F(E,\theta,x)}{\int_{-\infty}^{0} dx\ F(E,0,x)} = (\cos\theta)^{-f_R}, \qquad (3)$$

where

$$f_R = 1 + \frac{\langle Y^2 \rangle_R}{\langle \Delta X^2 \rangle_R}, \qquad (4)$$

and $F(E,\theta,x)$ is the range distribution and the subscript R of the moments means those of the range distribution. The exponent f_R is nearly equal to 2 for large mass ratio[29].

Since $E^*(\theta)$ does not depend so largely on the angle of incidence, the angular dependence of $Y(\theta)/Y(0)$ is mainly determined by those of the particle reflection coefficient, and we can write

$$\frac{Y(\theta)}{Y(0)} = (\cos\theta)^{-f_R} \quad . \tag{5}$$

As the angle of incidence increases, the effect of surface channeling becomes important. In order to sputter target atoms at the outermost layer, the projectile must penetrate the first layer of the solid surface, and this penetration probability is roughly estimated by

$$\exp(-N\sigma R_0/\cos\theta),$$

where σ is the hard-sphere collision cross section between a projectile and a target atom, $R_0 = N^{-\frac{1}{3}}$ is the average lattice constant of the random target, and N is the number density of the target atom.

From above discussions we know that the angular dependence of the normalized yield will have the form

$$\frac{Y(\theta)}{Y(0)} = t^f \exp[-\Sigma(t-1)] \quad , \tag{6}$$

where $t = 1/\cos\theta$ and the parameters f and Σ are adjustable parameters. The angle of incidence at the maximum yield is simply given by

$$\theta_{opt} = \cos^{-1}\left(\frac{\Sigma}{f}\right) \quad . \tag{7}$$

Using the least-square method, the best-fit parameters to the present empirical formula are obtained from experimental data[19,20,21,24] and computer results (ACAT)[30]. The best-fit values of f and θ_{opt} are listed in Table 2. It is very interesting that the best fit f's are nearly equal to 2 which is a theoretical value of Eq. (4).

The best-fit values of f depend slightly on the sublimation energy and so the ratio of the best-fit f to $\sqrt{U_s}$ is plotted as a function of mass ratio M_2/M_1 in Fig. 1, where M_1 and M_2 are the atomic masses of a projectile and a target atom, respectively. The solid line in Fig. 1 corresponds to the average value of f which satisfies the following relation:

$$\frac{f}{\sqrt{U_s}} = 0.94 - 1.33 \times 10^{-3}(M_2/M_1)\ . \tag{8}$$

In Fig. 2 the best-fit values of θ_{opt} are plotted as a function of

$$\eta = \frac{a}{R_0}\left(\frac{1}{2\varepsilon q}\right)^{\frac{1}{2}}\ , \tag{9}$$

where $q = (U_s/\gamma E)^{\frac{1}{2}}$ corresponds to the cosine of the scattering angle of a recoil atom which gains the energy U_s in a single collision. The LSS reduced energy ε is defined by $\varepsilon = E/E_L$, where

$$E_L = \frac{M_1 + M_2}{M_2}\ \frac{Z_1 Z_2 e^2}{a}\ , \tag{10}$$

$$a = 0.4685\left(\frac{1}{Z_1^{2/3} + Z_2^{2/3}}\right)^{\frac{1}{2}}. \tag{11}$$

Z_1 and Z_2 are the atomic numbers of a projectile and a target atom, respectively and $\gamma = 4M_1M_2/(M_1+M_2)^2$, M_1 and M_2 being their masses.

The solid line in Fig. 2 is a theoretical curve of θ_{opt}[31]

$$\theta_{opt} = 90° - 57.3\,\eta \tag{12}$$

which is derived from the direct knock-out model. The Agreement between the best-fit values and the theoretical results is very good, and so we can calculate θ_{opt} from the theoretical formula.

2.2 Angular dependence of heavy-ion sputtering

In the case of heavy-ion sputtering, one cannot neglect the threshold effect which is a decreasing function of the angle of incidence for the not-too-oblique incidence. This means that the normalized yield has the following angular dependence:

$$\frac{Y(\theta)}{Y(0)} = (\cos\theta)^{-f_s}\left[\frac{1 - (E_{th}/E)^{\frac{1}{2}}\cos\theta}{1 - (E_{th}/E)^{\frac{1}{2}}}\right] \tag{13}$$

where the exponent f_s is given in the form by Sigmund[26] as follows:

$$f_S = 1 + \frac{<Y^2>_D}{<\Delta X^2>_D} \left[\frac{<X>_D^{\,2}}{<\Delta X^2>_D} - 1 \right] \qquad (14)$$

for not-too-large angles of incidence, where the subscript D of the moment means those of the damage distribution.

The neccessary condition for the genuine collision cascade near the solid surface is that the projectile must penetrate a few layer of the surface. This means that an empirical formula for heavy-ion sputtering can be expressed by the product of the similar expression to that for light-ion sputtering and the threshold term of Eq. (13). At present, the threshold energy is not well established. For simplicity, let us employ an empirical formula with the same functional form as that of light-ion sputtering, eq.(6), i.e.,

$$\frac{Y(\theta)}{Y(0)} = t^{f} \exp[- \Sigma(t - 1)] \ , \qquad (15)$$

where the exponent f will include the threshold effect of Eq. (13), and so it will depend on the ion energy in the low-energy region. This tendency is much different from light-ion sputtering.

The best-fit parameters to the present formula, Eq. (15), are obtained for about 25 ion-target combinations (Table 1), using the least-square method and are listed in Table 3. In the energy region where the threshold effect can be neglected, the best-fit values of f are consistent with Sigmund f_S, as shown in Fig. 3.

In Fig. 4 the ratios of the best-fit f's to Sigmund f_S are plotted as a function of $\zeta = 1 - (E_{th}/E)^{\frac{1}{2}}$, where E_{th} is calculated from the following relation: [3]

$$E_{th} = 1.5 \frac{U_s}{\gamma} [1 + 1.38 (M_1/M_2)^{h}]^2 \qquad (16)$$

with $h = 0.834$ for $M_2 > M_1$ and $h = 0.18$ for $M_2 < M_1$. This empirical relation for the threshold energy corresponds to the second Matsunami formula for sputtering yields at normal incidence[3]. The solid line in Fig. 4 is

$$\frac{f}{f_S} = 1 + 2.5 \frac{1 - \zeta}{\zeta} . \quad (17)$$

Equation (17) shows that f is infinite at $E = E_{th}$, which corresponds to the fact that the normalized sputtering yield $Y(\theta)/Y(0)$ is not well defined in the energy region of $E < E_{th}$.

In Fig.5 the best-fit values of $90° - \theta_{opt}$ are plotted against

$$\psi = (\frac{a}{R_0})^{3/2} \left| \frac{Z_1 Z_2}{(Z_1{}^{2/3} + Z_2{}^{2/3})^{\frac{1}{2}}} \frac{1}{E} \right|^{\frac{1}{2}} . \quad (18)$$

The parameter ψ is directly connected with the critical angle

$$\psi_c = (U_R(0)/E)^{\frac{1}{2}} \quad (19)$$

of surface channeling, where $U_R(0)$ is the average potential at the amorphous solid surface which is defined in APPENDIX A. The solid line in Fig. 5 means the average value of the best-fit θ_{opt}'s which has the form

$$\theta_{opt} = 90° - 286.0 \ \psi^{0.45} . \quad (20)$$

3. Compilation of Experimental Data on Angular Dependence of Sputtering Yields

The angular dependence of sputtering yields of various combinations has been compiled and stored in a computer. The compiled data are summarized in Table 1. When determining the best-fit values of the adjustable parameters f and Σ, we excluded the experimental data which do not have explicit maximum values or which do not have the data at normal incidence.

Table 4 shows the physical constants necessary for calculating the angular dependece of the sputtering yield by means of the present empirical formula. For extensive use of the present empirical formula, the parameters f and η are calculated from Eq. (8) and Eq. (9) for typical projectiles H, D, T and He, which are listed in Tables 5, 6

7 and 8, where the calculated parameters η correspond to 1 keV ion.

For calculations of the angular dependence of heavy-ion sputtering, Sigmund f of m = 1/3[26] and ψ for 1 eV ion are also calculated and listed in Tables 9 through 18, where as the typical projectiles C, Ne, Al, Ar, Fe, Ni, Cu, Kr, Xe and Hg ions are selected.

The plots of the angular dependence of sputtering yields for various combinations of the incident ions and the target atoms are shown in Figs. 6 through 58, where Figs. 6 through 24 correspond to light-ion sputtering and Figs. 25 through 58 to heavy-ion sputtering. The solid lines in these figures are best fit curves to the present empirical formula, and the solid lines with cross marks show the results calculated by putting the average values of the best-fit parameters into each empirical formula.

In order to know the absolute yield $Y(\theta)$, one must calculate the sputtering yield at normal incidence. The authors recommend to use the third Matsunami formula for the sputtering yield at normal incidence, which has the form[32]

$$Y(E) = P \frac{s_n(\varepsilon)}{1 + 0.35 U_s s_e(\varepsilon)} \left[1 - (E_{th}/E)^{\frac{1}{2}} \right]^{2.8}, \tag{21}$$

where

$$P = 0.042 \frac{E_L}{R_L} \frac{N}{U_s} \alpha(M_2/M_1) Q(Z_2), \qquad (22)$$

$$R_L = \frac{1}{\pi a^2 N \gamma}, \qquad (22)$$

$$s_e(\varepsilon) = k \varepsilon^{\frac{1}{2}}, \tag{23}$$

and $s_n(\varepsilon)$ is the LSS elastic stopping cross section in the reduced unit and the following analytical expression is useful for the present purpose:[2]

$$s_n(\varepsilon) = \frac{3.441\sqrt{\varepsilon}\log(\varepsilon + 2.718)}{1 + 6.355\sqrt{\varepsilon} + \varepsilon(-1.708 + 6.882\sqrt{\varepsilon})} . \tag{24}$$

The inelastic coefficient k of $s_e(\varepsilon)$ is given as[33]

$$k = 0.0793\ Z_1^{1/6} \frac{(Z_1 Z_2)^{\frac{1}{2}}\ (M_1 + M_2)^{3/2}}{(Z_1^{2/3} + Z_2^{2/3})^{3/4} M_1 (M_1 M_2)^{\frac{1}{2}}}\ , \qquad (25)$$

and the threshold energy E_{th} for the third Matsunami formula has the following empirical relation:

$$E_{th} = U_s\ [1.9 + 3.8(M_1/M_2) + 0.314(M_2/M_1)^{1.24}]. \qquad (26)$$

The parameter $\alpha(M_2/M_1)$ is represented as

$$\alpha(M_2/M_1) = 0.08 + 0.164\ (M_2/M_1)^{0.45} + 0.0145\ (M_2/M_1)^{1.29} \qquad (27)$$

and $Q(Z_2)$ is listed in Table 4 for each element. For extensive uses of the third Matsunami formula, the parameters E_L, P, E_{th}, α and k are listed in Tables 19 through 32 for various ion-target combinations, where as the projectile H, D, T, He, C, Ne, Al, Ar, Fe, Ni, Cu, Kr, Xe and Hg are selected.

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References

1) J. Bohdansky, J. Roth, and H.L. Bay, J. Appl. Phys. 51, 2861 (1980)

2) N. Matsunami, Y. Yamamura, Y. Itikawa, N. Itoh, Y. Kazumata, S. Miyagawa, K. Morita, and R. Shimizu, Radiat. Eff. Lett. 50, 39 (1980).

3) Y. Yamamura, N. Matsunami, and N. Itoh, Radiat. Eff. Lett. 68, 83 (1982).

4) N. Matsunami, Y. Yamamura, Y. Itikawa, N. Itoh, Y. Kazumata, S. Miyagawa, K. Morita, and R. Shimizu, Report IPPJ-AM-14,Institute of Plasma Physics, Nagaya University (1980).

5) J. Roth, J. Bohdansky, and W. Ottenberger, IPP 9/26, Max-Plank-Institut fur Plasmaphysik (1979).

6) G.K. Wehner, J. Appl. Phys. 30, 1762 (1959).

7) P.K. Rol, J.M. Fluit, and J. Kistemaker, Physica 26, 1000 (1960).

8) V.A. Malchanov and V.G. Tel'kovskii, Soviet Phys. - Doklady 6, 137 (1961).

9) D. Almen and G. Bruce, Nucl. Instr. Methods 11, 257 (1961).

10) I.I. Dushkov, V.A. Malchanov, V.G. Tel'chanov, V.M. Chicherov, Soviet Phys. - Technical Phys. 6, 735 (1962).

11) C.E. Ramer, M.A. Narasimham, H.K. Reynolds, and J.C. Allred, J. Appl. Phys. 35, 1673 (1964).

12) E.S. Mashkova and V.A. Malchanov, Soviet Phys. - Technical Phys. 9, 1601 (1965).

13) K.B. Cheney and E.T. Pitkin, J. Appl. Phys. 36, 3542 (1965).

14) G. Dupp and A. Scharmann, Zeit. Phys. 194, 448 (1966).

15) L.N. Evdokimov and V.A. Malchanov, Can. J. Phys. 46, 779 (1968).

16) H. Ismail and A. Septier, Proc. 3rd Int. Symp. on Discharges and Electrical Insulation in Vacuum, (1968) p 95.

17) G. Holmen and Q. Almen, Ark. Fys. 40, 429 (1970).

18) A.J. Summers, N.J. Freeman, and N.R. Daly,
J. Appl. Phys. 42, 4774 (1971).

19) H. Oechsner, Z. Phys. 261, 37 (1973).

20) H.L. Bay and J. Bohdansky, Appl. Phys. 19, 421 (1979).

21) H.L. Bay, J. Bohdansky, W.O. Hofer, and J. Roth,
Appl. Phys. 21, 327 (1980)

22) W. Kruger, A. Scharmann, H. Afrid, and G. Brauer,
Proc. of Symposium on Sputtering, Perchtoldsdorf/Wien,
Austria (1980), p. 28.

23) D.A. Thompson and S.S. Johar, Radiat. Eff. 55, 91 (1981).

24) J. Bohdansky, G.L. Chen, W. Eckstein, J. Roth, and B.M.U. Scherzer,
J. Nucl. Mater. 111&112, 717 (1982).

25) J. Bohdansky, Nucl. Fusion (to be published).

26) P. Sigmund, Phys. Rev. 184, 383 (1969).

27) M.W. Weissmann and P. Sigmund, Radiat. Eff. 19, 7 (1973).

28) Y. Yamamura, N. Matsunami, and N. Itoh,
Radiat. Eff. 71, 65 (1983).

29) K.B. Winterbon, P. Sigmund, and J.B. Sanders,
Mat.-Fys. Medd. Dan. Vid. Selsk. 37, 14 (1970)

30) W. Takeuchi and Y. Yamamura, Radiat. Eff. 71, 53 (1983).

31) Y. Yamamura, Radiat. Eff. (to be published).

32) N. Matsunami, Y. Yamamura, Y. Itikawa, N. Itoh, Y. Kazumata,
S. Miyagawa, K. Morita, and R. Shimizu,
ATOMIC DATA AND NUCLEAR DATA TABLES (to be published).

33) J. Lindhard, M. Scharff, and H.E. Schiott,
Mat.-Fys. Medd. Dan. Vid. Selsk. 33, No.14 (1963).

34) R. Behrisch, G. Maderlechner, B.M.U. Scherzer, and M.T. Robinson,
Appl. Phys. 18, 391 (1981).

35) Y. Yamamura, Radiat. Eff. 55, 49 (1980).

APPENDIX A: ANGULAR DEPENDENCE OF THRESHOLD ENERGY OF LIGHT-ION SPUTTERING AND HEAVY-ION SPUTTERING

The sputtering mechanism for oblique incidence is separated into three parts: 1) The mechanism due to the direct knock-out collisions with incident ions at the outermost layer of the solid surface (mechanism Ia of Fig. A1). 2) The mechanism due to collision cascades created by incoming ions near the solid surface (mechansim Ib of Fig. A1) 3) The mechanism due to collision cascades generated by ions backscatted from the interior of the solids (mechanism II of Fig. A1).

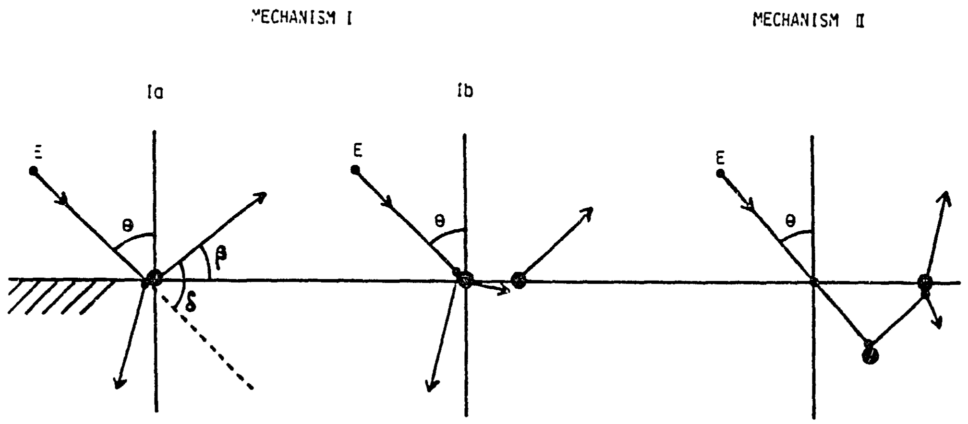


Fig. A1 Schematic representation of sputtering mechanism at oblique incidence

For light-ion sputtering the mechanisms Ia and II play an important role.

The threshold energy of mechanism II is given as[34]

$$E_{th} = \frac{U_s}{\gamma} \frac{1}{(1 - \gamma)} \qquad (A1)$$

for normal incidence. For not-too-large angles of incidence, the factor $(1 - \gamma)$ of Eq. (A1) must be modified. If only a single collision process is taken into consideration, the threshold energy will be a slightly decreasing function of the angle of incidence. For oblique incidence, however, the multiple scattering becomes important and this effect weaken the angular dependence of the factor $(1 - \gamma)$. Roughly speaking, the threshold energy of mechanism II is

$$E_{th} = \frac{U_s}{\gamma} \frac{1}{1 - \gamma\cos^2(\theta/2)} \qquad \text{(A2)}$$

for not-too-oblique incidence, where the difference of the scattering angles between in the L system and in the CM system is neglected because of large mass ratio.

For oblique incidence, an incoming ion must penetrate the first layer for mechanism II . The average potential at the surface of the amorphous solids is roughly estimated by

$$U_R(y) = \frac{1}{R_0{}^3} \int_{-R_0/2}^{+R_0/2} dz \int_0^\infty 2\pi r dr\ V(\sqrt{(y - z)^2 + r^2}\ ), \qquad \text{(A3)}$$

where y is the distance from the surface and V(r) is the interatomic potential. If one employ the Moliere potential as the interatomic potential we have

$$U_R(y) = 4\pi \frac{A}{A + 1} E_L(\frac{a}{R_0})^3 \sum_{i=1}^{3} \frac{\alpha_i}{\beta_i{}^2} \sinh(\frac{\beta_i R_0}{2a}) \exp(-\frac{\beta_i}{a}y) ,$$

where $A = M_2/M_1$, (A4)

$\alpha_i = (0.35,\ 0.55,\ 0.10)$

$\beta_i = (0.3\ ,\ 1.2\ ,\ 6.0\ )$.

The critical angle for penetration through the first layer is given as

$$\psi_c = \cos^{-1}[\frac{U_R(0)}{E}]^{\frac{1}{2}} , \qquad \text{(A5)}$$

where ψ_c is measured from the surface normal. The critical angle ψ_c for the incident energy of the order of the threshold energy is about 50° for H - Ni. For $\theta < \psi_c$, E_{th} of the mechanism II is given by eq.(2).

For grazing angles of incidence ($\theta > 70°$), the direct knock-out process become important and the criterion of the sputtering due to this process is given by [31]

$$\cos\theta + 2q < 1 \tag{A7}$$

$$p_2 > p_1 > R_0 \cos\theta \tag{A8}$$

where $q = (U_s/\gamma E)^{\frac{1}{2}}$ and the impact parameters p_1 and p_2 are the lower and the upper limits of the impact parameters available for the sputtering due to the direct knock-out process.

From the inequality of Eq. (A7) we obtain

$$E_{th}(\theta) = \frac{U_s}{\gamma} \frac{1}{\sin^4(\theta/2)} \quad . \tag{A9}$$

The criterion of Eq. (A8) is not important as compared with surface channeling for oblique incidence. Namely, in order to knock off an atom at the outermost layer, an ion must arrive at the surface. This leads to the following expression for the threshold energy:

$$E_{th}(\theta) = \frac{U_R(R_0/2)}{\cos^2\theta} \tag{A10}$$

where $U_R(R_0/2)$ is the average potential at the distance $R_0/2$, at which there exists an atom with a finite probability in the case of the random target. From Eq. (A4), $U_R(R_0/2) \simeq U_R(0)/2$.

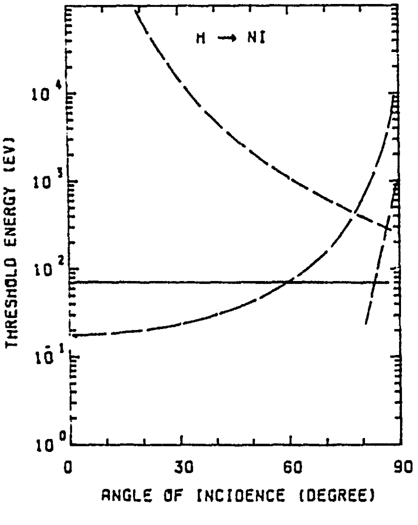


Fig. A2
The angular dependence of the threshold energies for H + Ni.

——— mechanism II
– – – – direct knock-out process
—- —— surface channeling

In Fig. A2 the threshold energies corresponding to each mechanism are plotted against the angle of incidence. Figure A2 tells us that the threshold energies corresponding to the direct knock-out process can be neglected. Finally we get

$$E_{th}^{L}(\theta) = \begin{cases} \dfrac{U_s}{\gamma} \dfrac{1}{1 - \gamma\cos^2(\theta/2)} & \text{for not-too-oblique incidence} \\ \dfrac{26.85 \dfrac{A}{1 + A} E_L (\dfrac{a}{R_0})^2}{\cos^2\theta} & \text{for grazing angles of incidence} \end{cases} \qquad (A11)$$

When the incident energy is very low, sputtered atoms will be ejected before they lose the memory of the direction of the incident ion beam. This means that the velocity distribution of recoil atoms generated by incoming heavy-ions is anisotropic. Taking into account the anisotropic effect of the recoil flux, Yamamura showed that the angular dependence of the heavy-ion sputtering was proportional to $\cos^2 \theta$ [35].

For grazing angles of incidence, the surface channeling will play an important role. In the case of heavy-ion sputtering, the threshold energy due to surface channeling is given by

$$E_{th}(\theta) = \frac{U_R(y_{min})}{\cos^2\theta} , \qquad (A12)$$

where y_{min} is the minimum distance above which the projectile will be reflected without producing any recoil atom available for sputtering. For the amorphous solid surface the minimum distance y_{min} may be of the order of

$$y_{min} = \frac{R_0}{2} + p_{min} , \qquad (A13)$$

where p_{min} is the collision diameter for the Moliere potential and depends on the incident energy. Since the incident energy of present interest is very low, p_{min} is roughly given by

$$p_{min} = sa$$

where s is the solution of the following transcendental equation:

$$\varepsilon = \exp(-0.3s)/s \ .$$

Let us consider a typical example, i.e., $Ar^+ - Cu$. In this case, s is nearly equal to 15. In Fig. A3 the angular dependence of threshold energy for $Ar^+ - Cu$ is plotted as a function of the angle of incidence. Finally, we have

$$E_{th}^{H}(\theta) = \begin{cases} E_{th}(0) \cos^2\theta & \text{for not-too-oblique incidence} \\ \dfrac{0.3 \frac{A}{A+1} E_L (\frac{a}{R_0})^3}{\cos^2\theta} & \text{for grazing angles of incidence} \end{cases} \qquad (A14)$$

where $E_{th}(0)$ is the threshold energy at normal incidence, and y_{min} is set to equal to $R_0/2 + 15a$.

Fig. A3

The angular dependence of the threshold energies for Ar + Cu.

——— mechanism I

— — — surface channeling

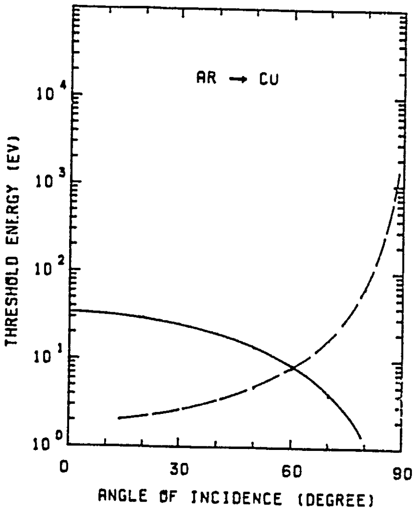


Table 1 Ion-target combinations in the present data compilation

References	Ion	Target C	Al	Ti	Fe	Ni	Cu	Zr	Nb	Mo	Pd	Ag	Ta	W	Pt	Au
Wehner (1959)	Hg				o	o				o		o	o	o	o	
Rol et al. (1960)	Ar						o									
Marchanov et al. (1961)	Ar						o									
Almen et al. (1961)	Kr						o									
Dushikov et al. (1962)	He						o									
	N						o									
	Ne						o									
	Ar						o									
Ramer et al. (1964)	Ar						o						o			
Marchanov et al. (1965)	Ar						o			o				o		
Cheney et al. (1965)	Ar						o									
	Xe						o			o				o		
Dupp et al. (1966)	Ar						o									
Evdokimov et al. (1968)	Ne									o						
	Ar						o			o						
	Kr						o									
Ismail et al. (1968)	Hg						o									
Holmen et al. (1970)	Hg	o			o											
Summers et al. (1971)	D						o									
	He						o									
	Nb						o									
Oechsner (1973)	He						o									
	Ne						o									
	Ar		o	o		o	o	o			o	o	o	o		o
	Kr						o									
	Xe						o									
Bay et al. (1979)	H					o				o						
	D					o				o						
	He									o						
Bay et al. (1980)	H					o										
Kruger et al. (1980)	Ar			o					o			o				
Thompson et al. (1980)	P											o				
	Sb											o				o
	Bi											o				
Bohdansky et al. (1982)	H			o		o	o			o			o			
	D									o						
	He			o						o			o			
Bohdansky (1983)	H					o										

Table 2 Best-fit parameters of the present empirical formula for light-ion sputtering

Energy	Ion	Target	Best-fit values		Ref.
			f	θ_{opt}	
450 eV	H	Ni	1.62	74.4°	25
1 keV	H	Ni	2.34	78.3°	20
4 keV	H	Ni	2.27	82.3°	20
450 eV	H	Ni	2.19	78.7°	20
1 keV	H	Ni	2.32	82.9°	30
4 keV	H	Ni	2.62	84.2°	30
1 keV	D	Ni	1.88	80.4°	25
100 eV	He	Ni	3.20	56.3°	30
500 eV	He	Ni	3.30	66.1°	30
1 keV	He	Ni	2.50	72.1°	30
4 keV	He	Ni	2.09	79.0°	30
4 keV	He	Ni	1.52	80.5°	20
50 keV	H	Cu	1.88	82.1°	24
1.05 keV	He	Cu	1.55	66.5°	19
2 keV	H	Mo	2.40	81.8°	20
8 keV	H	Mo	2.80	82.0°	20
2 keV	D	Mo	1.98	82.0°	20
4 keV	He	Mo	2.23	77.3°	20
1 keV	H	Au	1.14	78.0°	20
4 keV	H	Au	1.53	79.5°	20
1 keV	D	Au	1.22	79.2°	20

Table 3 Best-fit parameters of the present empirical formula for heavy-ion sputtering

Energy	Ion	Target	Best-fit values		Ref.
			f	θ_{opt}	
30 eV	Ar	Cu	35.4	44.2°	30
50 eV	Ar	Cu	9.33	46.1°	30
100 eV	Ar	Cu	5.25	43.6°	30
500 eV	Ar	Cu	3.35	49.6°	30
1 keV	Ar	Cu	3.07	55.7°	30
5 keV	Ar	Cu	2.66	65.7°	30
20 keV	Ar	Cu	2.19	75.0°	30
50 eV	Hg	Ni	37.1	47.5°	30
100 eV	Hg	Ni	15.0	52.5°	30
500 eV	Hg	Ni	5.01	61.2°	30
1 keV	Hg	Ni	4.02	63.3°	30
5 keV	Hg	Ni	3.56	64.7°	30
50 eV	Ni	Ni	22.8	44.2	30
100 eV	Ni	Ni	11.8	45.5°	30
500 eV	Ni	Ni	3.75	50.5°	30
1 keV	Ni	Ni	3.05	56.2°	30
5 keV	Ni	Ni	3.13	64.2°	30
10 keV	Ni	Ni	3.37	66.4°	30
200 eV	Hg	Ni	12.8	48.2	6
800 eV	Hg	Ni	8.57	51.0°	6
400 eV	Hg	Fe	15.5	57.6°	6
800 eV	Hg	Fe	9.53	60.7°	6
200 ev	Hg	Mo	26.0	53.0°	6
800 eV	Hg	Mo	26.9	50.9°	6
400 eV	Hg	Ta	15.0	62.0°	6
200 eV	Hg	W	5.87	58.3°	6
400 eV	Hg	W	10.6	52.8°	6
800 eV	Hg	W	7.64	56.1°	6

Table 3 (continued)

Energy	Ion	Target	Best-fit values		Ref.
			f	θ_{opt}	
1.05 keV	Ar	Al	2.10	70.2°	19
1.05 keV	Ar	Ti	2.04	68.8°	19
1.05 keV	Ar	Ni	1.72	69.5°	19
1.05 keV	Ne	Cu	1.03	70.6°	19
1.05 keV	Ar	Cu	1.29	69.8°	19
1.05 keV	Kr	Cu	2.19	66.9°	19
550 eV	Xe	Cu	9.40	53.8°	19
1.05 keV	Xe	Cu	4.56	61.5°	19
1.55 keV	Xe	Cu	3.89	64.0°	19
2.05 keV	Xe	Cu	2.44	69.0°	19
1.05 keV	Ar	Zr	1.73	67.7°	19
1.05 keV	Ar	Pd	1.85	63.1°	19
1.05 keV	Ar	Ag	1.50	63.7°	19
1.05 keV	Ar	Ta	1.75	67.5°	19
1.05 keV	Ar	Au	1.50	59.8°	19
37 keV	Ar	Cu	1.16	71.9°	13
30 keV	Xe	Cu	1.94	75.0°	13
9.5 keV	Xe	Cu	2.53	69.5°	13
30 keV	Xe	Mo	2.58	76.7°	13
30 keV	Xe	W	1.33	78.5°	13
9.5 keV	Xe	W	1.07	76.0°	13

Table 4 Some physical constants for calculations of sputtering yields.

Table 5 through 8

The parameters for the angular dependence of light-ion sputtering.

The correspondence between Tables and projectiles are as follows:

H : Table 5
D : Table 6
T : Table 7
He : Table 8

Let us show briefly how to use these tables and suppose the angular dependence of 4 keV $H^+ \longrightarrow Ni$ is desired.

The appropriate table is Table 5. From Table 5 we have

$$f = (\mathit{4.44})^{\frac{1}{2}}\times(0.94 - 0.00133\times\mathit{58.24}) = 1.82 \quad ,$$

where figures in italics corresponds to values in Table 5.

The quantity η is inversely proportional to $E^{1/4}$ and so we get

$$\eta = (\frac{1}{4})^{1/4} \times \mathit{0.1535} = 0.1085 \quad .$$

From Eq. (12) θ_{opt} can be calculated as follows:

$$\theta_{opt} = 90° - 57.3\times0.1085 = 83.8°.$$

Since $\Sigma = f\cos\theta_{opt}$, we have

$$\Sigma = 1.82 \cos 83.8° = 0.197.$$

Finally, we have the following angular dependence for 4 keV $H^+ \longrightarrow Ni$:

$$\frac{Y(\theta)}{Y(0)} = x^{1.82}\exp[- 0.197 (x - 1)] ,$$

where $x = 1/\cos\theta$

Tables 9 through 18

The parameters for the angular dependence of heavy-ion sputtering.

The correspondence between Tables and projectiles are as follows:

C : Table 9
Ne : Table 10
Al : Table 11
Ar : Table 12
Fe : Table 13
Ni : Table 14
Cu : Table 15
Kr : Table 16
Xe : Table 17
Hg : Table 18

Let us show briefly how to use these table for calculations of the angular dependence of heavy-ion sputtering. Then, suppose the angular dependence of 1 keV $Ar^+ \longrightarrow Cu$ is desired. The appropriate table is Table 15. Fist of all, we must calculate the quantity ζ

$$\zeta = 1 - (E_{th}/E)^{\frac{1}{2}} = 1 - (\mathit{20.72}/1000)^{\frac{1}{2}} = 0.8561.$$

Since $f_s = \mathit{1.71}$, the parameter f is calculated from Eq. (17),

$$f = \mathit{1.71} \times (1 + 2.5 \times 0.1439/0.8561) = 2.43$$

The quantity ψ is inversely proportional to $\sqrt{E}$, which is known from Eq. (18). Then, we have

$$\psi = \mathit{0.1305}/\sqrt{1000} = 0.004127 \ .$$

From Eq. (20) we get

$$\theta_{opt} = 90° -286 \times 0.004127^{0.45} = 65.8°$$

The relation $\Sigma = f \cos \theta_{opt}$ yields

$$\Sigma = 2.43 \cos 65.8° = 0.9961.$$

In the above calculations, figures in italics are the values in Table 15. Finally, we get the following angular dependence for 1 keV $Ar^+ \longrightarrow Cu$;

$$\frac{Y(\theta)}{Y(0)} = x^{2.43} \exp[- 0.9961(x - 1)] .$$

where $x = 1/\cos \theta$.

Table 19 through 32

The parameters for the third Matsunami formula, where the correspondences between Tables and projectiles are as follows:

H : Table 19   D : Table 20   T : Table 21
He : Table 22   C : Table 23   Ne : Table 24
Al : Table 25   Ar : Table 26   Fe : Table 27
Ni : Table 28   Cu : Table 29   Kr : Table 30
Xe : Table 31   Hg : Table 32.

Let us show how to use these tables for calculations of sputtering yields at normal incidence by the third Matsunami formula. Suppose the sputtering yield of 1 keV H^+ — Ni is desired. The appropriate table is Table 19. The reduced energy ε for 1 keV $Ar^+ \longrightarrow$ Ni is calculated like this

$$\varepsilon = 1000/(\mathit{2.799} \times 1000) = 0.3572.$$

Direct insertion of this value into Eqs. (23) and (24) yields

$$s_e(\varepsilon) = \mathit{4.35} \times \sqrt{0.3572} = 2.60$$

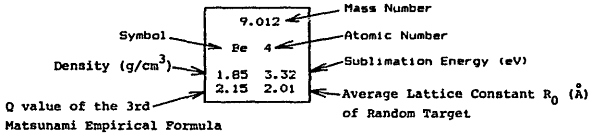
$$s_n(\varepsilon) = 0.408 \quad .$$

Since $P = \mathit{0.4814}$ and $E_{th} = \mathit{100.6}$, we have

$$Y = \mathit{0.4814} \times 0.408/(1 + 0.35 \times \mathit{4.44} \times 2.60\,) \times [\,1 - (\mathit{100.6})^{\frac{1}{2}}\,]^{2.8} = 1.33 \times 10^{-2} \text{(atoms/ion)},$$

where $U_s = \mathit{4.44}$ eV is in Table 4, and in the above calculations figures in italics corresponds to those in the present tables.

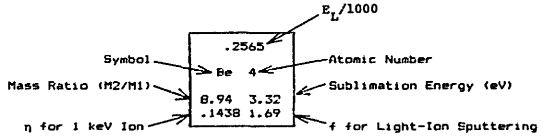
TABLE **4** PHYSICAL CONSTANTS FOR THE THIRD MATSUNAMI FORMULA AND THE PRESENT EMPIRICAL FORMULA



1.008 H 1 .089 0 1 2.66																	4.003 He 2 .179 0 1 3.34
6.941 Li 3 .53 1.63 1 2.8	9.012 Be 4 1.85 3.32 2.15 2.01											10.81 B 5 2.34 5.77 1 1.98	12.01 C 6 2.26 7.37 2.96 2.07	14.01 N 7 1.03 4.92 1 2.83	16 O 8 1.43 2.6 1 2.65	19 F 9 1.97 .84 1 2.53	20.18 Ne 10 1.56 .02 1 2.78
23 Na 11 .97 1.11 1 3.41	24.3 Mg 12 1.74 1.51 1 2.86											26.98 Al 13 2.7 3.39 1.1 2.56	28.08 Si 14 2.33 4.63 .75 2.72	30.97 P 15 1.82 3.43 1 3.05	32.06 S 16 2.07 2.85 1 2.96	35.45 Cl 17 2.09 1.4 1 3.05	39.94 Ar 18 1.78 .08 1 3.35
39.09 K 19 .86 .93 1 4.23	40.08 Ca 20 1.54 1.84 1 3.52	44.95 Sc 21 2.99 3.9 1 2.93	47.9 Ti 22 4.51 4.85 .59 2.61	50.94 V 23 6.1 5.31 .88 2.41	52 Cr 24 7.19 4.1 1.27 2.29	54.93 Mn 25 7.43 2.92 1.21 2.31	55.85 Fe 26 7.86 4.28 1.12 2.28	58.93 Co 27 8.9 4.39 1.13 2.23	58.71 Ni 28 8.9 4.44 1.11 2.22	63.55 Cu 29 8.96 3.49 1.33 2.28	65.38 Zn 30 7.14 1.35 1 2.48	69.72 Ga 31 5.91 2.81 1 2.7	72.59 Ge 32 5.32 3.85 .84 2.83	74.92 As 33 5.72 2.96 1 2.8	78.96 Se 34 4.79 2.25 1 3.02	79.91 Br 35 4.1 1.22 1 3.19	83.8 Kr 36 3.07 .12 1 3.57
85.47 Rb 37 1.53 .85 1 4.53	87.62 Sr 38 2.6 1.72 1 3.83	88.91 Y 39 4.46 4.37 1 3.22	91.22 Zr 40 6.49 6.25 .67 2.86	92.91 Nb 41 8.4 7.57 .93 2.64	95.94 Mo 42 10.2 6.82 .91 2.5	98.91 Tc 43 11.5 6.85 1 2.43	101 Ru 44 12.2 6.74 1.42 2.4	102.9 Rh 45 12.4 5.75 1.22 2.4	106.4 Pd 46 12 3.89 1.05 2.46	107.8 Ag 47 10.5 2.95 1.13 2.58	112.4 Cd 48 8.65 1.16 1 2.79	114.8 In 49 7.31 2.52 1 2.97	118.6 Sn 50 7.3 3.14 .21 3	121.7 Sb 51 6.62 2.75 1 3.13	127.6 Te 52 6.24 2.23 1 3.24	126.9 I 53 4.94 1.11 1 3.5	131.3 Xe 54 3.77 .16 1 3.87
132.9 Cs 55 1.9 .8 1 4.89	137.3 Ba 56 3.5 1.9 1 4.03	138.9 La 57 6.17 4.47 1 3.35	178.4 Hf 72 13.1 6.44 .69 2.83	180.9 Ta 73 16.6 8.1 .71 2.63	183.8 W 74 19.3 8.9 1 2.51	186.2 Re 75 21 8.03 1.16 2.46	190.2 Os 76 22.6 8.17 1.3 2.41	192.2 Ir 77 22.5 6.94 1.25 2.42	195 Pt 78 21.4 5.84 1.03 2.48	196.9 Au 79 19.3 3.81 .98 2.57	200.5 Hg 80 13.6 .67 1 2.91	204.3 Tl 81 11.85 1.88 1 3.06	207.1 Pb 82 11.4 2.03 1 3.12	208.9 Bi 83 9.8 2.18 1 3.29	210 Po 84 9.4 1.5 1 3.34	210 At 85 0 0 1 0	222 Rn 86 4.4 .2 1 4.38
223 Fr 87 0 0 1 0	226 Ra 88 5 1.66 1 4.23	227 Ac 89 10.1 4.25 1 3.35		140.1 Ce 58 6.77 4.32 1 3.26	140.9 Pr 59 6.77 3.7 1 3.26	144.2 Nd 60 7 3.4 1 3.25	145 Pm 61 0 0 1 0	150.3 Sm 62 7.54 2.14 1 3.22	151.9 Eu 63 7.9 1.86 1 3.18	157.2 Gd 64 8.23 4.14 1 3.17	158.9 Tb 65 8.54 4.05 1 3.14	162.5 Dy 66 8.78 3.04 1 3.14	164.9 Ho 67 9.05 3.14 1 3.12	167.2 Er 68 9.37 3.29 1 3.1	168.9 Tm 69 9.31 2.42 1 3.12	173 Yb 70 6.97 1.6 1 3.46	174.9 Lu 71 9.84 4.43 1 3.1
				232 Th 90 11.7 6.2 .92 3.21	231 Pa 91 15.4 0 1 2.93	238 U 92 19.07 5.55 .72 2.75											

TABLE 5 PARAMETERS FOR ANGULAR DEPENDENCE OF LIGHT-ION SPUTTERING YIELD

PROJECTILE ....H
Z - NUMBER........ 1
MASS-NUMBER....... 1.008



.0869 H 1 1 0 0 0																	.1238 He 2 3.971 0 0 0
.1853 Li 3 6.886 1.63 .1178 1.19	.2565 Be 4 8.94 3.32 .1438 1.69											.3328 B 5 10.72 5.77 .1321 2.22	.4146 C 6 11.91 7.37 .124 2.51	.4978 N 7 13.9 4.92 .1022 2.04	.5845 O 8 15.87 2.6 .1301 1.48	.6723 F 9 18.85 .84 .1807 .84	.7665 Ne 10 20.02 .02 .4286 .13
.8606 Na 11 22.82 1.11 .1282 .96	.9597 Mg 12 24.11 1.51 .1441 1.12											1.0592 Al 13 26.77 3.39 .1319 1.67	1.1632 Si 14 27.86 4.63 .1167 1.94	1.2669 P 15 30.72 3.43 .1122 1.67	1.3752 S 16 31.81 2.85 .1229 1.52	1.4826 Cl 17 35.17 1.4 .1419 1.06	1.5911 Ar 18 39.62 .08 .2618 .25
1.7071 K 19 38.78 .93 .1151 .86	1.8231 Ca 20 39.76 1.84 .118 1.2	1.9367 Sc 21 44.59 3.9 .1161 1.74	2.0542 Ti 22 47.52 4.85 .1235 1.93	2.1734 V 23 50.54 5.31 .1308 2.01	2.2958 Cr 24 51.59 4.1 .1483 1.76	2.4183 Mn 25 54.49 2.92 .1601 1.48	2.5439 Fe 26 55.41 4.28 .1489 1.79	2.6693 Co 27 58.46 4.39 .1512 1.81	2.7988 Ni 28 58.24 4.44 .1535 1.82	2.9258 Cu 29 63.05 3.49 .1576 1.6	3.0564 Zn 30 64.86 1.35 .1846 .99	3.1868 Ga 31 69.17 2.81 .1405 1.42	3.3195 Ge 32 72.01 3.85 .124 1.66	3.4539 As 33 74.33 2.96 .1342 1.45	3.5886 Se 34 78.33 2.25 .1329 1.25	3.7263 Br 35 79.28 1.22 .1477 .92	3.8636 Kr 36 83.13 .12 .2352 .29
4.0034 Rb 37 84.79 .85 .1141 .76	4.1441 Sr 38 86.92 1.72 .1135 1.08	4.2865 Y 39 88.2 4.37 .1075 1.72	4.4294 Zr 40 90.5 6.25 .111 2.05	4.5738 Nb 41 92.17 7.57 .115 2.25	4.7186 Mo 42 95.18 6.82 .1247 2.12	4.8646 Tc 43 98.13 6.85 .1282 2.12	5.0121 Ru 44 100.2 6.74 .1307 2.09	5.1608 Rh 45 102.1 5.75 .1364 1.93	5.3097 Pd 46 105.6 3.89 .1467 1.58	5.4607 Ag 47 106.9 2.95 .1505 1.37	5.6113 Cd 48 111.5 1.16 .1752 .85	5.7638 In 49 113.9 2.52 .1358 1.25	5.9168 Sn 50 117.7 3.14 .1271 1.39	6.0711 Sb 51 120.7 2.75 .126 1.29	6.2252 Te 52 126.6 2.23 .1276 1.15	6.3829 I 53 125.9 1.11 .1417 .81	6.5396 Xe 54 130.3 .16 .2076 .31
6.6983 Cs 55 131.8 .8 .1102 .68	6.8569 Ba 56 136.2 1.9 .1075 1.05	7.0174 La 57 137.8 4.47 .1048 1.6	9.5229 Hf 72 177 6.44 .1152 1.79	9.6965 Ta 73 179.5 8.1 .1172 2	9.8707 W 74 182.3 8.9 .1201 2.08	10.046 Re 75 184.7 8.03 .1259 1.97	10.221 Os 76 188.7 8.17 .1278 1.97	10.398 Ir 77 190.7 6.94 .1328 1.81	10.575 Pt 78 193.5 5.84 .1354 1.65	10.754 Au 79 195.3 3.81 .1457 1.33	10.932 Hg 80 198.9 .67 .1987 .55	11.111 Tl 81 202.7 1.88 .1459 .92	11.292 Pb 82 205.5 2.03 .1405 .95	11.473 Bi 83 207.2 2.18 .1311 .98	11.655 Po 84 208.3 1.5 .1422 .81	11.838 At 85 208.3 0 0 0	12.019 Rn 86 220.2 .2 .1784 .29
12.203 Fr 87 221.2 0 0 0	12.387 Ra 88 224.2 1.66 .1092 .83	12.573 Ac 89 225.2 4.25 .1093 1.32		7.1789 Ce 58 139 4.32 .109 1.57	7.3416 Pr 59 139.8 3.7 .1138 1.45	7.5041 Nd 60 143.1 3.4 .1166 1.38	7.6685 Pm 61 143.8 0 0 0	7.8321 Sm 62 149.1 2.14 .1323 1.08	7.9979 Eu 63 150.7 1.86 .1391 1.01	8.1632 Gd 64 156 4.14 .1139 1.49	8.3306 Tb 65 157.6 4.05 .1159 1.47	8.4983 Dy 66 161.2 3.04 .1245 1.27	8.6671 Ho 67 163.6 3.14 .1245 1.28	8.8368 Er 68 165.9 3.29 .124 1.3	9.0075 Tm 69 167.6 2.42 .1334 1.12	9.1782 Yb 70 171.6 1.6 .1332 .9	9.3504 Lu 71 173.5 4.43 .1155 1.49
				12.758 Th 90 230.2 6.2 .1036 1.58	12.945 Pa 91 229.2 0 0 0	13.131 U 92 236.1 5.55 .1245 1.47											

TABLE **6** PARAMETERS FOR ANGULAR DEPENDENCE OF LIGHT-ION SPUTTERING YIELD

PROJECTILE ....D
Z - NUMBER........ 1
MASS-NUMBER....... 2.014

	.2822	E_L/1000
Symbol	Be 4	Atomic Number
Mass Ratio (M2/M1)	4.475 3.32	Sublimation Energy (eV)
η for 1 keV Ion	.1709 1.7	f for Light-Ion Sputtering

.1303 H 1 .5 0 0 0																	.1486 He 2 1.988 0 0 0
.2088 Li 3 3.446 1.63 .1401 1.19	.2822 Be 4 4.475 3.32 .1709 1.7											.3612 B 5 5.367 5.77 .1571 2.24	.4467 C 6 5.963 7.37 .1474 2.53	.5312 N 7 6.956 4.92 .1215 2.06	.6191 O 8 7.944 2.6 .1546 1.5	.7061 F 9 9.434 .84 .2149 .85	.8029 Ne 10 10.02 .02 .5095 .13
.8967 Na 11 11.42 1.11 .1525 .97	.9979 Mg 12 12.07 1.51 .1713 1.14											1.0972 Al 13 13.4 3.39 .1568 1.7	1.2034 Si 14 13.94 4.63 .1388 1.98	1.3068 P 15 15.38 3.43 .1334 1.7	1.417 S 16 15.92 2.85 1461 1.55	1.5235 Cl 17 17.6 1.4 .1687 1.08	1.6302 Ar 18 19.83 .08 .3112 .26
1.75 K 19 19.41 .93 .1368 .88	1.8677 Ca 20 19.9 1.84 .1403 1.24	1.9791 Sc 21 22.32 3.9 .1381 1.8	2.0965 Ti 22 23.78 4.85 .1468 2	2.2155 V 23 25.29 5.31 .1555 2.09	2.3394 Cr 24 25.82 4.1 .1763 1.83	2.4618 Mn 25 27.27 2.92 .1904 1.54	2.5889 Fe 26 27.73 4.28 .177 1.87	2.7141 Co 27 29.26 4.39 .1798 1.89	2.8459 Ni 28 29.15 4.44 .1825 1.9	2.9714 Cu 29 31.55 3.49 .1873 1.68	3.1028 Zn 30 32.46 1.35 .2194 1.04	3.2321 Ga 31 34.62 2.81 .167 1.5	3.3649 Ge 32 36.04 3.85 .1474 1.75	3.4996 As 33 37.2 2.96 .1596 1.53	3.6337 Se 34 39.21 2.25 .158 1.33	3.7726 Br 35 39.68 1.22 .1756 .98	3.9095 Kr 36 41.61 .12 .2796 .31
4.05 Rb 37 42.44 .85 .1357 .81	4.1912 Sr 38 43.51 1.72 .135 1.16	4.3344 Y 39 44.15 4.37 .1278 1.84	4.4777 Zr 40 45.29 6.25 .1319 2.2	4.6228 Nb 41 46.13 7.57 .1368 2.42	4.7676 Mo 42 47.64 6.82 .1483 2.29	4.9136 Tc 43 49.11 6.85 .1525 2.29	5.0615 Ru 44 50.15 6.74 .1554 2.27	5.2107 Rh 45 51.09 5.75 .1622 2.09	5.3595 Pd 46 52.83 3.89 .1744 1.72	5.5112 Ag 47 53.53 2.95 .1789 1.49	5.661 Cd 48 55.81 1.16 .2083 .93	5.8139 In 49 57 2.52 .1614 1.37	5.9666 Sn 50 58.89 3.14 .1511 1.53	6.1208 Sb 51 60.43 2.75 .1498 1.43	6.2739 Te 52 63.36 2.23 .1517 1.28	6.4331 I 53 63.01 1.11 .1685 .9	6.5893 Xe 54 65.19 .16 .2468 .34
6.7486 Cs 55 65.99 .8 .131 .76	6.9067 Ba 56 68.17 1.9 .1278 1.17	7.0678 La 57 68.97 4.47 .1246 1.79	9.5763 Hf 72 88.58 6.44 .137 2.09	9.7501 Ta 73 89.82 8.1 .1394 2.34	9.9245 W 74 91.26 8.9 .1427 2.44	10.1 Re 75 92.45 8.03 .1496 2.32	10.275 Os 76 94.44 8.17 .152 2.33	10.452 Ir 77 95.43 6.94 .1579 2.14	10.63 Pt 78 96.82 5.84 .161 1.96	10.808 Au 79 97.77 3.81 .1732 1.58	10.987 Hg 80 99.55 .67 .2362 .66	11.166 Tl 81 101.4 1.88 .1735 1.1	11.346 Pb 82 102.8 2.03 .167 1..4	11.528 Bi 83 103.7 2.18 .1559 1.18	11.71 Po 84 104.3 1.5 .1691 .98	11.894 At 85 104.3 0 0 0	12.073 Rn 8 110.2 .2 .2121 .35
12.257 Fr 87 110.7 0 0 0	12.442 Ra 88 112.2 1.66 .1299 1.02	12.628 Ac 89 112.7 4.25 .13 1.63		7.2301 Ce 58 69.56 4.32 .1296 1.76	7.3936 Pr 59 69.96 3.7 .1333 1.63	7.5561 Nd 60 71.6 3.4 .1386 1.56	7.7213 Pm 61 72 0 0 0	7.8842 Sm 62 74.63 2.14 .1572 1.23	8.0505 Eu 63 75.42 1.86 .1654 1.15	8.2151 Gd 64 78.05 4.14 .1354 1.7	8.3831 Tb 65 78.9 4.05 .1378 1.68	8.5506 Dy 66 80.69 3.04 .148 1.45	8.7197 Ho 67 81.88 3.14 .148 1.47	8.8897 Er 68 83.02 3.29 .1474 1.5	9.0608 Tm 69 83.86 2.42 .1586 1.29	9.2313 Yb 70 85.9 1.6 .1584 1.04	9.4039 Lu 71 86.84 4.43 .1373 1.74
				12.813 Th 90 115.2 o.2 .1232 1.96	13.001 Pa 91 114.7 0 0 0	13.187 U 92 118.2 5.55 .148 1.84											

TABLE **7** PARAMETERS FOR ANGULAR DEPENDENCE OF LIGHT-ION SPUTTERING YIELD

PROJECTILE ....T
Z - NUMBER........ 1
·MASS-NUMBER....... 3.016

	.3079	$E_L/1000$
Symbol	Be 4	Atomic Number
Mass Ratio (M2/M1)	2.988 3.32	Sublimation Energy (eV)
η for 1 keV Ion	.1891 1.71	f for Light-Ion Sputtering

.1735 H 1 .334 0 0 0																	.1734 He 2 1.327 0 0 0
.2321 Li 3 2.301 1.63 .155 1.2	.3079 Be 4 2.988 3.32 .1891 1.71											.3894 B 5 3.584 5.77 .1738 2.25	.4786 C 6 3.982 7.37 .1631 2.54	.5644 N 7 4.645 4.92 .1344 2.07	.6535 O 8 5.305 2.6 .1711 1.5	.7398 F 9 6.3 .84 .2377 .85	.8392 Ne 10 6.691 .02 .5636 .13
.9326 Na 11 7.626 1.11 .1687 .98	1.0359 Mg 12 8.057 1.51 .1895 1.14											1.1351 Al 13 8.946 3.39 .1734 1.71	1.2435 Si 14 9.31 4.63 .1535 2	1.3465 P 15 10.27 3.43 .1476 1.72	1.4587 S 16 10.63 2.85 .1616 1.56	1.5643 Cl 17 11.75 1.4 .1866 1.09	1.6692 Ar 18 13.24 .08 .3443 .26
1.7926 K 19 12.96 .93 .1513 .89	1.9122 Ca 20 13.29 1.84 .1552 1.25	2.0213 Sc 21 14.9 3.9 .1527 1.87	2.1386 Ti 22 15.88 4.85 .1624 2.02	2.2574 V 23 16.89 5.31 .172 2.11	2.3828 Cr 24 17.24 4.1 .195 1.86	2.5051 Mn 25 18.21 2.92 .2106 1.56	2.6338 Fe 26 18.52 4.28 .1958 1.89	2.7588 Co 27 19.54 4.39 .1989 1.92	2.8929 Ni 28 19.47 4.44 .2019 1.93	3.0168 Cu 29 21.07 3.49 .2073 1.7	3.1489 Zn 30 21.68 1.35 .2428 1.06	3.2773 Ga 31 23.12 2.81 .1848 1.52	3.4101 Ge 32 24.07 3.85 .1631 1.78	3.5452 As 33 24.84 2.96 .1765 1.56	3.6787 Se 34 26.18 2.25 .1748 1.36	3.8188 Br 35 26.5 1.22 .1942 1	3.9551 Kr 36 27.79 .12 .3093 .31
4.0964 Rb 37 28.34 .85 .1501 .83	4.238 Sr 38 29.05 1.72 .1493 1.18	4.3822 Y 39 29.48 4.37 .1414 1.88	4.5258 Zr 40 30.25 6.25 .1459 2.25	4.6716 Nb 41 30.81 7.57 .1513 2.47	4.8164 Mo 42 31.81 6.82 .164 2.34	4.9624 Tc 43 32.8 6.85 .1687 2.35	5.1108 Ru 44 33.49 6.74 .1719 2.32	5.2605 Rh 45 34.12 5.75 .1795 2.15	5.409 Pd 46 35.28 3.89 .1929 1.76	5.5615 Ag 47 35.74 2.95 .1979 1.53	5.7106 Cd 48 37.27 1.16 .2304 .96	5.8638 In 49 38.06 2.52 .1786 1.41	6.0161 Sn 50 39.32 3.14 .1672 1.57	6.1704 Sb 51 40.35 2.75 .1657 1.47	6.3224 Te 52 42.31 2.23 .1678 1.32	6.4831 I 53 42.08 1.11 .1864 .93	6.6388 Xe 54 43.53 .16 .273 .35
6.7987 Cs 55 44.06 .8 .145 .79	6.9564 Ba 56 45.52 1.9 .1414 1.21	7.1181 La 57 46.05 4.47 .1378 1.86	9.6295 Hf 72 59.15 6.44 .1515 2.19	9.8035 Ta 73 59.98 8.1 .1542 2.45	9.978 W 74 60.94 8.9 .1579 2.56	10.154 Re 75 61.74 8.03 .1655 2.43	10.329 Os 76 63.06 8.17 .1681 2.45	10.506 Ir 77 63.73 6.94 .1747 2.25	10.684 Pt 78 64.66 5.84 .1781 2.06	10.863 Au 79 65.29 3.81 .1916 1.67	11.041 Hg 80 66.48 .67 .2613 .7	11.22 Tl 81 67.74 1.88 .1919 1.17	11.401 Pb 82 68.67 2.03 .1848 1.21	11.582 Bi 83 69.26 2.18 .1725 1.25	11.766 Po 84 69.63 1.5 .1871 1.04	11.951 At 85 69.63 0 0 0	12.127 Rn 86 73.61 .2 .2347 .38
12.312 Fr 87 73.94 0 0 0	12.497 Ra 88 74.93 1.66 .1436 1.08	12.683 Ac 89 75.27 4.25 .1438 1.73															
				7.2811 Ce 58 46.45 4.32 .1434 1.83	7.4454 Pr 59 46.72 3.7 .1497 1.69	7.6079 Nd 60 47.81 3.4 .1534 1.62	7.7739 Pm 61 48.08 0 0 0	7.936 Sm 62 49.83 2.14 .174 1.28	8.1029 Eu 63 50.36 1.86 .1829 1.19	8.2668 Gd 64 52.12 4.14 .1498 1.77	8.4353 Tb 65 52.69 4.05 .1524 1.75	8.6026 Dy 66 53.88 3.04 .1637 1.51	8.772 Ho 67 54.68 3.14 .1637 1.54	8.9423 Er 68 55.44 3.29 .1631 1.57	9.1139 Tm 69 56 2.42 .1754 1.35	9.2841 Yb 70 57.36 1.6 .1752 1.09	9.4572 Lu 71 57.99 4.43 .1519 1.82
				12.868 Th 90 76.92 6.2 .1363 2.09	13.057 Pa 91 76.59 0 0 0	13.242 U 92 78.91 5.55 .1638 1.97											

TABLE **8** PARAMETERS FOR ANGULAR DEPENDENCE OF LIGHT-ION SPUTTERING YIELD

PROJECTILE ....He
Z - NUMBER........ 2
MASS-NUMBER....... 4.0026

	.7197	$E_L/1000$
Symbol	Be 4	Atomic Number
Mass Ratio (M2/M1)	2.252 3.32	Sublimation Energy (eV)
η for 1 keV Ion	.2761 1.71	f for Light-Ion Sputtering

.4915 H 1 .252 0 0 0																	.4381 He 2. 1 0 0 0
.5568 Li 3 1.734 1.63 .2252 1.2	.7197 Be 4 2.252 3.32 .2761 1.71											.8946 B 5 2.701 5.77 .2548 2.25	1.0874 C 6 3.001 7.37 .2397 2.54	1.2673 N 7 3.5 4.92 .1981 2.07	1.4533 O 8 3.997 2.6 .2526 1.51	1.629 F 9 4.747 .84 .3515 .86	1.8386 Ne 10 5.042 .02 .8346 .13
2.0293 Na 11 5.746 1.11 .25 .98	2.2453 Mg 12 6.071 1.51 .2813 1.15											2.4482 Al 13 6.741 3.39 .2576 1.71	2.6743 Si 14 7.015 4.63 .2282 2	2.8838 P 15 7.737 3.43 .2196 1.72	3.117 S 16 8.01 2.85 .2406 1.57	3.3303 Cl 17 8.857 1.4 .2781 1.1	3.5402 Ar 18 9.98 .08 .5,32 .26
3.7997 K 19 9.766 .93 .2257 .89	4.0468 Ca 20 10.01 1.84 .2315 1.26	4.2642 Sc 21 11.23 3 9 .228 1.83	4.5023 Ti 22 11.97 4.85 .2426 2.04	4.7436 V 23 12.73 5.31 .2571 2.13	5.0016 Cr 24 12.99 4.1 .2915 1.87	5.2499 Mn 25 13.72 2.92 .3149 1.58	5.5144 Fe 26 13.95 4.28 .2929 1.91	5.7677 Co 27 14.72 4.39 .2976 1.93	6.0448 Ni 28 14.67 4.44 .3023 1.94	6.2929 Cu 29 15.88 3.49 .3103 1.72	6.5623 Zn 30 16.33 1.35 .3636 1.07	6.8206 Ga 31 17.42 2.81 .2768 1.54	7.0899 Ge 32 18.14 3.85 .2444 1.8	7.3647 As 33 18.72 2.96 .2646 1.57	7.6338 Se 34 19.73 2.25 .2621 1.37	7.9201 Br 35 19.96 1.22 .2912 1.01	8.1951 Kr 36 20.94 .12 .4638 .32
8.4827 Rb 37 21.35 .85 .2251 .84	8.7704 Sr 38 21.89 1.72 .224 1.19	9.0642 Y 39 22.21 4.37 .2122 1.9	9.3556 Zr 40 22.79 6.25 .219 2.27	9.652 Nb 41 23.21 7.57 .2271 2.5	9.9448 Mo 42 23.97 6.82 .2463 2.37	10.24 Tc 43 24.71 6.85 .2533 2.37	10.541 Ru 44 25.23 6.74 .2582 2.35	10.845 Rh 45 25.71 5.75 .2695 2.17	11.145 Pd 46 26.58 3.89 .2898 1.78	11.455 Ag 47 26.93 2.95 .2974 1.55	11.755 Cd 48 28.08 1.16 .3462 .97	12.065 In 49 28.68 2.52 .2684 1.43	12.372 Sn 50 29.63 3.14 .2512 1.6	12.684 Sb 51 30.41 2.75 .249 1.49	12.988 Te 52 31.88 2.23 .2522 1.34	13.316 I 53 31.7 1.11 .2802 .95	13.63 Xe 54 32.8 .16 .4105 .36
13.954 Cs 55 33.2 .8 .218 .8	14.271 Ba 56 34.3 1.9 .2:27 1.23	14.599 La 57 34.7 4.47 .2073 1.89	19.672 Hf 72 44.57 6.44 .2282 2.24	20.023 Ta 73 45.2 8.1 .2322 2.5	20.375 W 74 45.92 8.9 .2378 2.62	20.73 Re 75 46.52 8.03 .2493 2.49	21.082 Os 76 47.52 8.17 .2532 2.51	21.441 Ir 77 48.02 6.94 .2632 2.31	21.799 Pt 78 48.72 5.84 .2684 2.12	22.161 Au 79 49.19 3.81 .2887 1.71	22.52 Hg 80 50.09 .67 .3937 .71	22.88 Tl 81 51.04 1.88 .2891 1.2	23.244 Pb 82 51.74 2.03 .2784 1.24	23.612 Bi 83 52.19 2.18 .2599 1.29	23.982 Po 84 52.47 1.5 .2819 1.07	24.356 At 85 52.47 0 0 0	24.707 Rn 86 55.46 .2 .3537 .39
25.081 Fr 87 55.71 0 0 0	25.453 Ra 88 56.46 1.66 .2165 1.11	25.83 Ac 89 56.71 4.25 .2167 1.78		14.93 Ce 58 35 4.32 .2157 1.86	15.263 Pr 59 35.2 3.7 .2252 1.72	15.591 Nd 60 36.03 3.4 .2308 1.64	15.928 Pm 61 36.23 0 0 0	16.253 Sm 62 37.55 2.14 .2618 1.3	16.591 Eu 63 37.95 1.86 .2753 1.21	16.92 Gd 64 39.27 4.14 .2254 1.81	17.261 Tb 65 39.7 4.05 .2294 1.79	17.599 Dy 66 40.6 3.04 .2464 1.54	17.941 Ho 67 41.2 3.14 .2464 1.57	18.285 Er 68 41.77 3.29 .2455 1.6	18.632 Tm 69 42.2 2.42 .2641 1.37	18.975 Yb 70 43.22 1.6 .2638 1.12	19.325 Lu 71 43.7 4.43 .2288 1.86
				26.201 Th 90 57.96 6.2 .2055 2.15	26.585 Pa 91 57.71 0 0 0	26.954 U 92 59.46 5.55 .2469 2.03											

TABLE **9** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE C
Z - NUMBER........ 6
MASS-NUMBER....... 12.01

	30.59	Threshold Energy (eV)
Symbol	Be 4	Atomic Number
Mass Ratio (M2/M1)	.75 3.32	Sublimation Energy (eV)
for 1 eV	.0947 1.85	Sigmund f

0 H 1 .084 0 .0421 1.7																	0 He 2 .333 0 .0372 1.82
16.76 Li 3 .578 1.63 .054 1.85	30.59 Be 4 .75 3.32 .0947 1.85											50.26 B 5 .9 5.77 .1013 1.83	62.62 C 6 1 7.37 .0978 1.81	36.38 N 7 1.167 4.92 .0627 1.79	17.33 O 8 1.332 2.6 .0705 1.76	5.003 F 9 1.582 .84 .0768 1.71	.115 Ne 10 1.68 .02 .0675 1.69
6.002 Na 11 1.915 1.11 .0502 1.64	7.984 Mg 12 2.023 1.51 .0658 1.63											17.29 Al 13 2.246 3.39 .0783 1.59	23.34 Si 14 2.338 4.63 .0719 1.58	16.9 P 15 2.579 3.43 .0609 1.54	13.95 S 16 2.669 2.85 .0639 1.53	6.755 Cl 17 2.952 1.4 .0613 1.48	.383 Ar 18 3.326 .08 .0534 1.43
4.457 K 19 3.255 .93 .0378 1.44	8.811 Ca 20 3.337 1.84 .0498 1.43	18.71 Sc 21 3.743 3.9 .0658 1.36	23.38 Ti 22 3.988 4.85 .0783 1.34	25.77 V 23 4.241 5.31 .0884 1.31	19.95 Cr 24 4.33 4.1 .0955 1.31	14.34 Mn 25 4.574 2.92 .0944 1.29	21.08 Fe 26 4.65 4.28 .0963 1.28	21.85 Co 27 4.907 4.39 .0996 1.25	22.08 Ni 28 4.888 4.44 .1003 1.25	17.68 Cu 29 5.291 3.49 .0964 1.21	6.891 Zn 30 5.444 1.35 .085 1.19	14.61 Ga 31 5.805 2.81 .0748 1.14	20.27 Ge 32 6.044 3.85 .0697 1.12	15.75 As 33 6.238 2.96 .0709 1.11	12.19 Se 34 6.575 2.25 .0632 1.08	6.641 Br 35 6.654 1.22 .0582 1.07	.665 kr 36 6.978 .12 .0492 1.05
4.749 Rb 37 7.117 .85 .0344 1.04	9.706 Sr 38 7.296 1.72 .0442 1.03	24.81 Y 39 7.403 4.37 .0573 1.02	35.87 Zr 40 7.595 6.25 .0685 1.01	43.79 Nb 41 7.736 7.57 .0772 1	40.02 Mo 42 7.988 6.82 .0837 .98	40.76 Tc 43 8.236 6.85 .0873 .96	40.5 Ru 44 8.41 6.74 .0889 .95	34.86 Rh 45 8.568 5.75 .0888 .93	23.97 Pd 46 8.859 3.89 .0855 .91	18.3 Ag 47 8.976 2.95 .0796 .9	7.347 Cd 48 9.359 1.16 .0707 .88	16.14 In 49 9.559 2.52 .0613 .86	20.46 Sn 50 9.875 3.14 .0633 .84	18.17 Sb 51 10.13 2.75 .0594 .82	15.12 Te 52 10.62 2.23 .0564 .78	7.503 I 53 10.57 1.11 .0502 .79	1.102 Xe 54 10.93 .16 .0431 .76
5.55 Cs 55 11.07 .8 .0303 .75	13.43 Ba 56 11.43 1.9 .0405 .73	31.82 La 57 11.57 4.47 .0534 .72	53.61 Hf 72 14.85 6.44 .0679 .48	68.06 Ta 73 15.06 8.1 .0758 .46	75.58 W 74 15.3 8.9 .0812 .44	68.79 Re 75 15.5 8.03 .0836 .43	71 Os 76 15.84 8.17 .0861 .4	60.74 Ir 77 16 6.94 .0855 .39	51.62 Pt 78 16.24 5.84 .0824 .38	33.9 Au 79 16.39 3.81 .078 .36	6.037 Hg 80 16.69 .67 .0647 .34	17.16 Tl 81 17.01 1.88 .06 .32	18.71 Pb 82 17.24 2.03 .0582 .3	20.21 Bi 83 17.39 2.18 .0537 .29	13.96 Po 84 17.49 1.5 .0525 .28	0 At 85 17.49 0 0 .28	1.936 Rn 86 18.48 .2 .0349 .21
0 Fr 87 18.57 0 0 .21	16.28 Ra 88 18.82 1.66 .0367 .19	41.81 Ac 89 18.9 4.25 .052 .18		30.91 Ce 58 11.67 4.32 .0556 .71	26.56 Pr 59 11.73 3.7 .0555 .7	24.74 Nd 60 12.01 3.4 .0557 .68	0 Pm 61 12.07 0 0 .68	15.97 Sm 62 12.51 2.14 .0564 .65	13.97 Eu 63 12.65 1.86 .0575 .64	31.77 Gd 64 13.09 4.14 .0577 .6	31.29 Tb 65 13.23 4.05 .0585 .59	23.82 Dy 66 13.53 3.04 .0584 .57	24.83 Ho 67 13.73 3.14 .0589 .56	26.25 Er 68 13.92 3.29 .0594 .54	19.44 Tm 69 14.06 2.42 .0588 .53	13.05 Yb 70 14.4 1.6 .0503 .51	36.4 Lu 71 14.56 4.43 .0593 .5
				61.97 Th 90 19.32 6.2 .0554 .15	0 Pa 91 19.23 0 .0635 .16	56.51 U 92 19.82 5.55 .0698 .11											

TABLE **10** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE ....Ne
Z - NUMBER........ 10
MASS-NUMBER....... 20.18

Threshold Energy (eV): 39.3
Symbol: Be
Atomic Number: 4
Mass Ratio (M2/M1): .447
Sublimation Energy (eV): 3.32
for 1 eV: .0994
Sigmund f: 1.84

0 H 1 .05 0 .0414 1.7																	0 He 2 .198 0 .0377 1.8
22.92 Li 3 .344 1.63 .0558 1.82	39.3 Be 4 .447 3.32 .0994 1.84											61.66 B 5 .536 5.77 .1076 1.85	74.75 C 6 .595 7.37 .105 1.85	46.68 N 7 .694 4.92 .0679 1.85	23.51 O 8 .793 2.6 .0769 1.84	7.234 F 9 .942 .84 .0943 1.82	.17 Ne 10 1 .02 .0745 1.81
8.37 Na 11 1.14 1.11 .0557 1.79	10.88 Mg 12 1.204 1.51 .0735 1.78											22.54 Al 13 1.337 3.39 .0878 1.76	29.92 Si 14 1.391 4.63 .0809 1.75	20.8 P 15 1.535 3.43 .0688 1.72	16.93 S 16 1.589 2.85 .0725 1.71	7.879 Cl 17 1.757 1.4 .0697 1.68	.427 Ar 18 1.979 .08 .061 1.63
5.004 K 19 1.937 .93 .0432 1.64	9.8 Ca 20 1.986 1.84 .0572 1.63	19.94 Sc 21 2.227 3.9 .0756 1.59	24.35 Ti 22 2.374 4.85 .0903 1.57	26.27 V 23 2.524 5.31 .1021 1.55	20.2 Cr 24 2.577 4.1 .1106 1.54	14.24 Mn 25 2.722 2.92 .1095 1.52	20.82 Fe 26 2.768 4.28 .1119 1.51	21.21 Co 27 2.92 4.39 .116 1.48	21.46 Ni 28 2.909 4.44 .117 1.48	16.75 Cu 29 3.149 3.49 .1126 1.45	6.47 Zn 30 3.24 1.35 .0995 1.44	13.45 Ga 31 3.455 2.81 .0877 1.41	18.44 Ge 32 3.597 3.85 .0818 1.38	14.2 As 33 3.713 2.96 .0833 1.37	10.83 Se 34 3.913 2.25 .0744 1.35	5.877 Br 35 3.96 1.22 .0686 1.34	.581 Kr 36 4.153 .12 .058 1.32
4.125 Rb 37 4.235 .85 .0406 1.32	8.375 Sr 38 4.342 1.72 .0523 1.3	21.32 Y 39 4.406 4.37 .0679 1.3	30.62 Zr 40 4.52 6.25 .0812 1.29	37.21 Nb 41 4.604 7.57 .0916 1.28	33.72 Mo 42 4.754 6.82 .0994 1.27	34.09 Tc 43 4.901 6.85 .1038 1.25	33.69 Ru 44 5.005 6.74 .1058 1.24	28.87 Rh 45 5.099 5.75 .1058 1.23	19.69 Pd 46 5.273 3.89 .102 1.21	14.98 Ag 47 5.342 2.95 .095 1.2	5.958 Cd 48 5.57 1.16 .0845 1.18	13.02 In 49 5.689 2.52 .0769 1.15	16.39 Sn 50 5.877 3.14 .0758 1.13	14.47 Sb 51 6.031 2.75 .0711 1.12	11.92 Te 52 6.323 2.23 .0675 1.1	5.922 I 53 6.288 1.11 .0601 1.1	.864 Xe 54 6.506 .16 .0517 1.09
4.339 Cs 55 6.586 .8 .0364 1.08	10.43 Ba 56 6.804 1.9 .0486 1.06	24.65 La 57 6.883 4.47 .0642 1.06	39.64 Hf 72 8.84 6.44 .0823 .91	50.2 Ta 73 8.964 8.1 .0919 .91	55.6 W 74 9.108 8.9 .0985 .9	50.5 Re 75 9.227 8.03 .1015 .89	51.94 Os 76 9.425 8.17 .1046 .87	44.36 Ir 77 9.524 6.94 .1039 .86	37.61 Pt 78 9.663 5.84 .1001 .85	24.66 Au 79 9.757 3.81 .0949 .85	4.379 Hg 80 9.94 .67 .0787 .83	12.41 Tl 81 10.12 1.88 .073 .82	13.5 Pb 82 10.26 2.03 .0708 .81	14.57 Bi 83 10.35 2.18 .0654 .8	10.05 Po 84 10.41 1.5 .0639 .8	0 At 85 10.41 0 0 .8	1.383 Rn 86 11 .2 .0425 .76
0 Fr 87 11.05 0 0 .75	11.6 Ra 88 11.2 1.66 .0448 .74	29.77 Ac 89 11.25 4.25 .0635 .74		23.9 Ce 58 6.943 4.32 .0668 1.05	20.51 Pr 59 6.982 3.7 .0668 1.05	19.03 Nd 60 7.146 3.4 .0671 1.04	0 Pm 61 7.185 0 0 1.04	12.18 Sm 62 7.448 2.14 .068 1.02	10.63 Eu 63 7.527 1.86 .0693 1.01	24.02 Gd 64 7.79 4.14 .0696 .99	23.61 Tb 65 7.874 4.05 .0706 .99	17.9 Dy 66 8.053 3.04 .0706 .97	18.62 Ho 67 8.171 3.14 .0712 .96	19.63 Er 68 8.285 3.29 .0719 .96	14.51 Tm 69 8.37 2.42 .0712 .75	9.703 Yb 70 8.573 1.6 .0609 .93	27.01 Lu 71 8.667 4.43 .0718 .93
				43.98 Th 90 11.5 6.2 .0676 .72	0 Pa 91 11.45 0 .0775 .72	39.96 U 92 11.79 5.55 .0852 .7											

TABLE **11** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

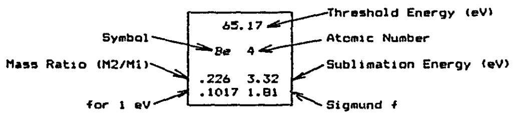
PROJECTILE ....Al
Z - NUMBER........ 13
MASS-NUMBER....... 26.98

47.68 ← Threshold Energy (eV)
Symbol → Be 4 ← Atomic Number
Mass Ratio (M2/M1) → .334 3.32 ← Sublimation Energy (eV)
for 1 eV → .1008 1.82 ← Sigmund f

0 H 1 .037 0 .0408 1.7																	0 He 2 .148 0 .0376 1.76
28.63 Li 3 .257 1.63 .0562 1.81	47.68 Be 4 .334 3.32 .1008 1.82											73.11 B 5 .401 5.77 .1098 1.83	87.41 C 6 .445 7.37 .1077 1.84	53.44 N 7 .519 4.92 .0699 1.85	26.41 O 8 .593 2.6 .0796 1.85	7.925 F 9 .704 .84 .0875 1.85	.185 Ne 10 .748 .02 .0776 1.85
9.815 Na 11 .852 1.11 .0581 1.83	13.15 Mg 12 .901 1.51 .0769 1.83											28.8 Al 13 1 3.39 .092 1.81	37.87 Si 14 1.041 4.63 .0851 1.8	25.71 P 15 1.148 3.43 .0724 1.79	20.75 S 16 1.188 2.85 .0764 1.78	9.425 Cl 17 1.314 1.4 .0737 1.76	.496 Ar 18 1.48 .08 .0645 1.73
5.849 K 19 1.449 .93 .0458 1.74	11.39 Ca 20 1.486 1.84 .0607 1.73	22.56 Sc 21 1.666 3.9 .0804 1.69	27.15 Ti 22 1.775 4.85 .0961 1.67	28.89 V 23 1.888 5.31 .1088 1.65	22.11 Cr 24 1.927 4.1 .118 1.64	15.4 Mn 25 2.036 2.92 .1169 1.62	22.44 Fe 26 2.07 4.28 .1197 1.62	22.59 Co 27 2.104 4.39 .1242 1.6	22.87 Ni 28 2.176 4.44 .1254 1.6	17.56 Cu 29 2.355 3.49 .1208 1.57	6.743 Zn 30 2.423 1.35 .1068 1.56	13.84 Ga 31 2.584 2.81 .0942 1.54	18.82 Ge 32 2.691 3.85 .088 1.52	14.39 As 33 2.777 2.96 .0896 1.51	10.87 Se 34 2.927 2.25 .0802 1.48	5.885 Br 35 2.962 1.22 .074 1.48	.576 Kr 36 3.106 .12 .0626 1.46
4.078 Rb 37 3.168 .85 .0439 1.45	8.243 Sr 38 3.248 1.72 .0565 1.44	20.93 Y 39 3.295 4.37 .0734 1.43	29.92 Zr 40 3.381 6.25 .0878 1.42	36.24 Nb 41 3.444 7.57 .0991 1.41	32.66 Mo 42 3.556 6.82 .1076 1.38	32.83 Tc 43 3.666 6.85 .1124 1.37	32.34 Ru 44 3.744 6.74 .1146 1.36	27.62 Rh 45 3.814 5.75 .1147 1.36	18.73 Pd 46 3.944 3.89 .1106 1.34	14.22 Ag 47 3.996 2.95 .1031 1.34	5.617 Cd 48 4.166 1.16 .0917 1.32	12.24 In 49 4.255 2.52 .0836 1.31	15.32 Sn 50 4.396 3.14 .0824 1.3	13.47 Sb 51 4.511 2.75 .0773 1.29	11.02 Te 52 4.729 2.23 .0735 1.27	5.478 I 53 4.703 1.11 .0655 1.27	.795 Xe 54 4.867 .16 .0563 1.26
3.985 Cs 55 4.926 .8 .0397 1.25	9.534 Ba 56 5.089 1.9 .053 1.23	22.49 La 57 5.148 4.47 .07 1.23	34.98 Hf 72 6.612 6.44 .0902 1.08	44.22 Ta 73 6.705 8.1 .1007 1.07	48.88 W 74 6.812 8.9 .108 1.06	44.32 Re 75 6.901 8.03 .1113 1.06	45.47 Os 76 7.05 8.17 .1148 1.05	38.79 Ir 77 7.124 6.94 .114 1.04	32.83 Pt 78 7.228 5.84 .1099 1.03	21.5 Au 79 7.298 3.81 .1042 1.03	3.81 Hg 80 7.431 .67 .0864 1.02	10.78 Tl 81 7.572 1.88 .0802 1.01	11.7 Pb 82 7.676 2.03 .0778 1	12.62 Bi 83 7.743 2.18 .0719 .99	8.701 Po 84 7.784 1.5 .0702 .99	0 At 85 7.784 0 0 .99	1.19 Rn 86 8.228 .2 .0468 .96
0 Fr 87 8.265 0 0 .96	9.956 Ra 88 8.377 1.66 .0492 .95	25.54 Ac 89 8.414 4.25 .0699 .95															
				21.78 Ce 58 5.193 4.32 .0729 1.22	18.68 Pr 59 5.222 3.7 .0729 1.22	17.27 Nd 60 5.345 3.4 .0733 1.2	0 Pm 61 5.374 0 0 1.2	10.99 Sm 62 5.571 2.14 .0743 1.18	9.583 Eu 63 5.63 1.86 .0757 1.15	21.55 Gd 64 5.827 4.14 .0761 1.14	21.15 Tb 65 5.89 4.05 .0772 1.13	15.99 Dy 66 6.023 3.04 .0772 1.12	16.59 Ho 67 6.112 3.14 .078 1.11	17.47 Er 68 6.197 3.29 .0787 1.11	12.89 Tm 69 6.26 2.42 .078 1.1	8.594 Yb 70 6.412 1.6 .0668 1.09	23.89 Lu 71 6.483 4.43 .0787 1.09
				37.65 Th 90 8.599 6.2 .0745 .93	0 Pa 91 8.562 0 .0854 .93	34.13 U 92 8.821 5.55 .0938 .92											

TABLE **12** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE ....Ar
Z - NUMBER........ 18
MASS-NUMBER....... 39.94



0 H 1 .025 0 .0399 1.7																	0 He 2 .1 0 .0373 1.7
40.5 Li 3 .174 1.63 .0562 1.78	65.17 Be 4 .226 3.32 .1017 1.81											97.33 B 5 .271 5.77 .1115 1.81	114.5 C 6 .301 7.37 .11 1.82	68.23 N 7 .351 4.92 .0718 1.82	32.95 O 8 .401 2.6 .0821 1.83	9.58 F 9 .476 .84 .0906 1.85	.22 Ne 10 .505 .02 .0806 1.85
11.44 Na 11 .576 1.11 .0606 1.85	15.16 Mg 12 .608 1.51 .0805 1.85											32.52 Al 13 .676 3.39 .0966 1.85	43.71 Si 14 .703 4.63 .0895 1 85	31.25 P 15 .775 3.43 .0764 1.84	25.67 S 16 .903 2.85 .0808 1.84	12.24 Cl 17 .888 1.4 .0781 1.83	.68 Ar 18 1 .08 .0685 1.81
7.938 K 19 .979 .93 .0487 1.81	15.58 Ca 20 1.004 1.84 .0647 1.81	29.73 Sc 21 1.125 3.9 .0858 1.79	35.05 Ti 22 1.199 4.85 .1028 1.78	36.56 V 23 1.275 5.31 .1166 1.77	27.79 Cr 24 1.302 4.1 .1266 1.76	19.02 Mn 25 1.375 2.92 .1257 1.75	27.57 Fe 26 1.398 4.28 .1288 1.74	27.29 Co 27 1.475 4.39 .1338 1.73	27.66 Ni 28 1.47 4.44 .1353 1.73	20.72 Cu 29 1.591 3.49 .1305 1.71	7.885 Zn 30 1.637 1.35 .1155 1.7	15.86 Ga 31 1.746 2.81 .102 1.68	21.31 Ge 32 1.817 3.85 .0954 1.66	16.15 As 33 1.876 2.96 .0972 1.65	12.01 Se 34 1.977 2.25 .087 1.63	6.479 Br 35 2.001 1.22 .0804 1.63	.626 Kr 36 2.098 .12 .0681 1.61
4.404 Rb 37 2.14 .85 .0478 1.61	8.838 Sr 38 2.194 1.72 .0616 1.6	22.35 Y 39 2.226 4.37 .08 1.59	31.72 Zr 40 2.284 6.25 .0958 1.59	38.22 Nb 41 2.326 7.57 .1083 1.58	34.14 Mo 42 2.402 6.82 .1177 1.57	34.04 Tc 43 2.476 6.85 .123 1.56	33.34 Ru 44 2.529 6.74 .1255 1.55	28.33 Rh 45 2.576 5.75 .1257 1.54	19.04 Pd 46 2.664 3.89 .1213 1.53	14.41 Ag 47 2.699 2.95 .1131 1.52	5.63 Cd 48 2.814 1.16 .1007 1.5	12.2 In 49 2.874 2.52 .0918 1.49	15.14 Sn 50 2.969 3.14 .0906 1.48	13.23 Sb 51 3.047 2.75 .0851 1.47	10.69 Te 52 3.195 2.23 .0809 1.45	5.325 I 53 3.177 1.11 .0721 1.45	.766 Xe 54 3.287 .16 .0621 1.43
3.831 Cs 55 3.327 .8 .0437 1.43	9.095 Ba 56 3.438 1.9 .0585 1.41	21.4 La 57 3.478 4.47 .0773 1.41	31.49 Hf 72 4.467 6.44 .1003 1.29	39.7 Ta 73 4.529 8.1 .112 1.29	43.74 W 74 4.602 8.9 .1201 1.28	39.56 Re 75 4.662 8.03 .1239 1.28	40.41 Os 76 4.762 8.17 .1278 1.27	34.4 Ir 77 4.812 6.94 .127 1.26	29.04 Pt 78 4.882 5.84 .1224 1.25	18.98 Au 79 4.93 3.81 .1161 1.25	3.352 Hg 80 5.02 .67 .0964 1.24	9.445 Tl 81 5.115 1.88 .0894 1.23	10.23 Pb 82 5.185 2.03 .0868 1.22	11.01 Bi 83 5.23 2.18 .0802 1.22	7.587 Po 84 5.258 1.5 .0784 1.21	0 At 85 5.258 0 0 1.21	1.027 Rn 86 5.558 .2 .0522 1.18
0 Fr 87 5.583 0 0 1.18	8.565 Ra 88 5.658 1.66 .055 1.15	21.96 Ac 89 5.684 4.25 .0781 1.15		20.68 Ce 58 3.508 4.32 .0805 1.4	17.71 Pr 59 3.528 3.7 .0806 1.4	16.29 Nd 60 3.61 3.4 .081 1.38	0 Pm 61 3.63 0 0 1.37	10.27 Sm 62 3.763 2.14 .0823 1.36	8.932 Eu 63 3.803 1.86 .0839 1.36	19.93 Gd 64 3.936 4.14 .0843 1.34	19.52 Tb 65 3.978 4.05 .0856 1.34	14.68 Dy 66 4.069 3.04 .0856 1.33	15.19 Ho 67 4.129 3.14 .0865 1.33	15.94 Er 68 4.186 3.29 .0874 1.32	11.74 Tm 69 4.229 2.42 .0865 1.32	7.788 Yb 70 4.331 1.6 .0741 1.31	21.6 Lu 71 4.379 4.43 .0874 1.3
				32.24 Th 90 5.809 6.2 .0833 1.14	0 Pa 91 5.784 0 .0955 1.14	29.09 U 92 5.959 5.55 .105 1.13											

TABLE **13** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE ....Fe
Z - NUMBER........ 26
MASS-NUMBER....... 55.85

88.51 — Threshold Energy (eV)
Be — Symbol
4 — Atomic Number
.161 — Mass Ratio (M2/M1)
3.32 — Sublimation Energy (eV)
.1016 — for 1 eV
1.77 — Sigmund f

0 H 1 .018 0 .0385 1.7																	υ He 2 .072 0 .0365 1.7
56.27 Li 3 .124 1.63 .0557 1.76	88.51 Be 4 .161 3.32 .1016 1.77											129.8 B 5 .194 5.77 .1121 1.8	150.9 C 6 .215 7.37 .1113 1.8	88.3 N 7 .251 4.92 .0731 1.81	41.93 O 8 .286 2.6 .0839 1.82	11.91 F 9 .34 .84 .093 1.82	.272 Ne 10 .361 .02 .0831 1.82
13.82 Na 11 .412 1.11 .0628 1.83	18.16 Mg 12 .435 1.51 .0835 1.84											38.32 Al 13 .483 3.39 .1006 1.85	51.18 Si 14 .503 4.63 .0935 1.85	36.01 P 15 .555 3.43 .08 1.85	29.41 S 16 .574 2.85 .0849 1.85	13.79 Cl 17 .635 1.4 .0822 1.85	.75 Ar 18 .715 .08 .0723 1.85
8.795 K 19 .7 .93 .0515 1.85	17.24 Ca 20 .718 1.84 .0686 1.85	35.1 Sc 21 .805 3.9 .0912 1.84	42.81 Ti 22 .858 4.85 .1094 1.83	46.09 V 23 .912 5.31 .1243 1.82	35.41 Cr 24 .931 4.1 .1352 1.82	24.9 Mn 25 .984 2.92 .1344 1.81	36.37 Fe 26 1 4.28 .138 1.81	35.46 Co 27 1.055 4.39 .1435 1.8	35.98 Ni 28 1.051 4.44 .1453 1.8	26.36 Cu 29 1.138 3.49 .1404 1.79	9.953 Zn 30 1.171 1.35 .1244 1.79	19.67 Ga 31 1.248 2.81 .11 1.77	26.13 Ge 32 1.3 3.85 .103 1.76	19.63 As 33 1.341 2.96 .1051 1.75	14.38 Se 34 1.414 2.25 .0943 1.74	7.737 Br 35 1.431 1.22 .0872 1.74	.738 Kr 36 1.5 .12 .0739 1.77
5.164 Rb 37 1.53 .85 .0519 1.72	10.29 Sr 38 1.569 1 72 .067 1.71	25.93 Y 39 1.592 4.37 .0871 1.71	36.55 Zr 40 1.633 6.25 .1044 1.7	43.83 Nb 41 1.664 7.57 .1181 1.69	38.82 Mo 42 1.718 6.82 .1285 1.68	38.4 Tc 43 1.771 6.85 .1345 1.67	37.4 Ru 44 1.808 6.74 .1373 1.66	31.63 Rh 45 1.842 5.75 .1377 1.65	21.08 Pd 46 1.905 3.89 .133 1.64	15.9 Ag 47 1.93 2.95 .1241 1.64	6.146 Cd 48 2.013 1.16 .1106 1.63	13.25 In 49 2.056 2.52 .1009 1.62	16.31 Sn 50 2.124 3.14 .0996 1.61	14.16 Sb 51 2.179 2.75 .0936 1.6	11.32 Te 52 2.285 2.23 .089 1.58	5.642 I 53 2.272 1.11 .0794 1.59	.805 Xe 54 2.351 .16 .0684 1.57
4.014 Cs 55 2.38 .8 .0483 1.57	9.457 Ba 56 2.458 1.9 .0646 1.56	22.19 La 57 2.487 4.47 .0853 1.55	30.89 Hf 72 3.194 6.44 .1117 1.45	38.82 Ta 73 3.239 8.1 .1248 1.44	42.63 W 74 3.291 8.9 .134 1.43	38.45 Re 75 3.334 8.03 .1382 1.43	39.11 Os 76 3.406 8.17 .1426 1.42	33.22 Ir 77 3.441 6.94 .1418 1.41	27.96 Pt 78 3.491 5.84 .1368 1.41	18.24 Au 79 3.526 3.81 .1297 1.4	3.209 Hg 80 3.59 .67 .1077 1.38	9.01 Tl 81 3.658 1.88 .1 1.37	9.735 Pb 82 3.708 2.03 .0972 1.37	10.46 Bi 83 3.74 2.18 .0898 1.36	7.198 Po 84 3.76 1.5 .0878 1.36	0 At 85 3.76 0 0 1.36	.964 Rn 86 3.975 .2 .0585 1.34
0 Fr 87 3.993 0 0 1.34	8.013 Ra 88 4.047 1.66 .0617 1.33	20.52 Ac 89 4.064 4.25 .0876 1.33		21.4 Ce 58 2.509 4.32 .089 1.55	18.31 Pr 59 2.523 3.7 .0891 1.55	16.74 Nd 60 2.582 3.4 .0897 1.54	0 Pm 61 2.596 0 0 1.54	10.46 Sm 62 2.691 2.14 .0912 1.52	9.074 Eu 63 2.72 1.86 .093 1.52	20.09 Gd 64 2.815 4.14 .0935 1.5	19.63 Tb 65 2.845 4.05 .095 1.49	14.69 Dy 66 2.91 3.04 .0951 1.48	15.15 Ho 67 2.953 3.14 .0961 1.48	15.85 Er 68 2.994 3.29 .0971 1.47	11.65 Tm 69 3.024 2.42 .0963 1.47	7.688 Yb 70 3.098 1.6 .0825 1.46	21.27 Lu 71 3.132 4.43 .0974 1.45
				30.01 Th 90 4.154 6.2 .0934 1.32	0 Pa 91 4.136 0 .1072 1.32	26.95 U 92 4.261 5.55 .1179 1.31											

TABLE 14 PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE ....Ni
Z - NUMBER........ 28
MASS-NUMBER....... 58.71

	92.88	Threshold Energy (eV)
Symbol	Be 4	Atomic Number
Mass Ratio (M2/M1)	.154 3.32	Sublimation Energy (eV)
for 1 eV	.1014 1.77	Sigmund f

0 H 1 .017 0 .0383 1.7																	0 He 2 .068 0 .0364 1.7
59.23 Li 3 .118 1.63 .0355 1.76	92.88 Be 4 .154 3.32 .1014 1.77											135.9 B 5 .184 5.77 .1121 1.8	157.7 C 6 .205 7.37 .1114 1.8	92.07 N 7 .239 4.92 .0732 1.81	43.62 O 8 .273 2.6 .0841 1.81	12.35 F 9 .324 .84 .0934 1.82	.281 Ne 10 .344 .02 .0835 1.82
14.27 Na 11 .392 1.11 .0631 1.83	18.74 Mg 12 .414 1.51 .084 1.83											39.45 Al 13 .46 3.39 .1013 1.85	52.64 Si 14 .478 4.63 .0942 1.85	36.95 P 15 .528 3.43 .0806 1.85	30.15 S 16 .546 2.85 .0856 1.85	14.1 Cl 17 .604 1.4 .083 1.85	.765 Ar 18 .68 .08 .073 1.85
8.974 K 19 .666 .93 .052 1.85	17.57 Ca 20 .683 1.84 .0693 1.85	35.68 Sc 21 .766 3.9 .0921 1.84	43.46 Ti 22 .816 4.85 .1105 1.84	46.72 V 23 .868 5.31 .1257 1.83	35.87 Cr 24 .886 4.1 .1367 1.83	25.19 Mn 25 .936 2.92 .136 1.82	36.77 Fe 26 .951 4.28 .1396 1.82	37.17 Co 27 1.004 4.39 .1453 1.81	37.72 Ni 28 1 4.44 .1472 1.81	27.54 Cu 29 1.082 3.49 .1422 1.8	10.39 Zn 30 1.114 1.35 .1261 1.79	20.47 Ga 31 1.188 2.81 .1115 1.78	27.15 Ge 32 1.236 3.85 .1045 1.77	20.37 As 33 1.276 2.96 .1066 1.77	14.89 Se 34 1.345 2.25 .0956 1.75	8.007 Br 35 1.361 1.22 .0884 1.75	.762 kr 36 1.427 .12 .075 1.74
5.329 Rb 37 1.456 .85 .0527 1.74	10.61 Sr 38 1.492 1.72 .068 1.73	26.72 Y 39 1.514 4.37 .0885 1.72	37.62 Zr 40 1.554 6.25 .1061 1.72	45.08 Nb 41 1.583 7.57 .12 1.71	39.87 Mo 42 1.634 6.82 .1306 1.7	39.39 Tc 43 1.685 6.85 .1366 1.69	38.34 Ru 44 1.72 6.74 .1396 1.68	32.4 Rn 45 1.753 5.75 .14 1.68	21.56 Pd 46 1.812 3.89 .1352 1.66	16.25 Ag 47 1.836 2.95 .1262 1.65	6.273 Cd 48 1.914 1.16 .1125 1.64	13.51 In 49 1.955 2.5. .1026 1.64	16.61 Sn 50 2.02 3.14 .1013 1.63	14.41 Sb 51 2.073 2.75 .0952 1.62	11.49 Te 52 2.173 2.23 .0906 1.6	5.731 I 53 2.161 1.11 .0809 1.6	.817 Xe 54 2.236 .16 .0697 1.59
4.071 Cs 55 2.264 .8 .0491 1.59	9.579 Da 56 2.339 1.9 .0658 1.58	22.46 La 57 2.366 4.47 .0869 1.57	30.99 Hf 72 3.039 6.44 .114 1.47	38.93 Ta 73 3.081 8.1 .1274 1.46	42.73 W 74 3.131 8.9 .1367 1.45	38.53 Re 75 3.172 8.03 .141 1.45	39.16 Os 76 3.24 8.17 .1455 1.44	33.25 Ir 77 3.274 6.94 .1448 1.44	27.97 Pt 78 3.321 5.84 .1396 1.43	18.24 Au 79 3.354 3.81 .1325 1.42	3.207 Hg 80 3.415 .67 .11 1.42	9 Tl 81 3.48 1.88 .1021 1.41	9.719 Pb 82 3.528 2.03 .0992 1.4	10.44 Bi 83 3.558 2.18 .0917 1.38	7.184 Po 84 3.577 1.5 .0897 1.38	0 At 85 3.577 0 0 1.38	.96 Rn 86 3.781 .2 .0598 1.36
0 Fr 87 3.798 0 0 1.36	7.978 Ra 88 3.849 1.66 .0631 1.35	20.43 Ac 89 3.866 4.25 .0895 1.35		21.66 Ce 58 2.386 4.32 .0907 1.57	18.53 Pr 59 2.4 3.7 .0908 1.57	16.93 Nd 60 2.456 3.4 .0914 1.56	0 Pm 61 2.47 0 0 1.56	10.56 Sm 62 2.56 2.14 .0929 1.54	9.156 Eu 63 2.587 1.86 .0948 1.54	20.25 Gd 64 2.678 4.14 .0954 1.52	19.77 Tb 65 2.707 4.05 .0968 1.52	14.79 Dy 66 2.768 3.04 .0969 1.51	15.24 Ho 67 2.809 3.14 .098 1.5	15.94 Er 68 2.848 3.29 .099 1.49	11.71 Tm 69 2.877 2.42 .0982 1.49	7.722 Yb 70 2.947 1.6 .0842 1.48	21.36 Lu 71 2.979 4.43 .0993 1.47
				29.86 Th 90 3.952 6.2 .0955 1.34	0 Pa 91 3.935 0 .1096 1.34	26.79 U 92 4.054 5.55 .1206 1.33											

TABLE **15** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE ....Cu
Z - NUMBER........ 29
MASS-NUMBER....... 63.55

100.4 — Threshold Energy (eV)
Be — Symbol
4 — Atomic Number
.142 — Mass Ratio (M2/M1)
3.32 — Sublimation Energy (eV)
.1013 — for 1 eV
1.76 — Sigmund f

0 H 1 .016 0 .0381 1.7																	0 He 2 .063 0 .0363 1.7
64.3 Li 3 .109 1.63 .0554 1.72	100.4 Be 4 .142 3.32 .1013 1.76											146.3 B 5 .17 5.77 .1121 1.78	169.4 C 6 .189 7.37 .1115 1.8	98.55 N 7 .22 4.92 .0733 1.8	46.52 O 8 .252 2.6 .0842 1.81	13.1 F 9 .299 .84 .0935 1.62	.298 Ne 10 .318 .02 .0837 1.82
15.06 Na 11 .362 1.11 .0632 1.82	19.73 Mg 12 .382 1.51 .0842 1.83											41.4 Al 13 .425 3.39 .1015 1.84	55.16 Si 14 .442 4.63 .0945 1.84	38.58 P 15 .487 3.43 .0809 1.85	31.45 S 16 .504 2.85 .0859 1.85	14.65 Cl 17 .558 1.4 .0833 1.85	.791 Ar 18 .628 .08 .0733 1.85
9.289 K 19 .615 .93 .0522 1.85	18.17 Ca 20 .631 1.84 .0696 1.85	36.73 Sc 21 .707 3.9 .0925 1.85	44.62 Ti 22 .754 4.85 .1111 1.85	47.85 V 23 .802 5.31 .1263 1.84	36.7 Cr 24 .818 4.1 .1374 1.84	25.72 Mn 25 .864 2.92 .1367 1.83	37.52 Fe 26 .879 4.28 .1404 1.83	37.95 Co 27 .927 4.39 .1461 1.82	38.42 Ni 28 .924 4.44 .148 1.82	29.65 Cu 29 1 3.49 .1431 1.81	11.16 Zn 30 1.029 1.35 .1268 1.81	21.91 Ga 31 1.097 2.81 .1122 1.8	28.98 Ge 32 1.142 3.85 .1051 1.79	21.69 As 33 1.179 2.96 .1073 1.78	15.81 Se 34 1.242 2.25 .0962 1.77	8.491 Br 35 1.257 1.22 .089 1.77	.806 Kr 36 1.319 .12 .0755 1.76
5.626 Rb 37 1.345 .85 .053 1.75	11.19 Sr 38 1.379 1.72 .0685 1.75	28.14 Y 39 1.399 4.37 .0891 1.74	39.55 Zr 40 1.435 6.25 .1068 1.74	47.33 Nb 41 1.462 7.57 .1208 1.73	41.78 Mo 42 1.51 6.82 .1315 1.72	41.19 Tc 43 1.556 6.85 .1377 1.72	40.03 Ru 44 1.589 6.74 .1406 1.71	33.79 Rh 45 1.619 5.75 .141 1.7	22.44 Pd 46 1.674 3.89 .1362 1.69	16.9 Ag 47 1.696 2.95 .1272 1.69	6.506 Cd 48 1.769 1.16 .1133 1.67	13.99 In 49 1.806 2.52 .1034 1.66	17.17 Sn 30 1.866 3.14 .1021 1.65	14.87 Sb 51 1.915 2.75 .096 1.64	11.83 Te 52 2.008 2.23 .0914 1.63	5.899 I 53 1.997 1.11 .0815 1.63	.839 Xe 54 2.066 .16 .0702 1.62
4.178 Cs 55 2.091 .8 .0495 1.62	9.812 Ba 56 2.161 1.9 .0663 1.6	23 La 57 2.186 4.47 .0877 1.6	31.27 Hf 72 2.807 6.44 .1151 1.5	39.25 Ta 73 2.847 8.1 .1286 1.49	43.04 W 74 2.892 8.9 .138 1.49	38.78 Re 75 2.93 8.03 .1424 1.48	39.37 Os 76 2.993 8.17 .1469 1.47	33.41 Ir 77 3.024 6.94 .1461 1.47	28.08 Pt 78 3.068 5.84 .141 1.46	18.31 Au 79 3.098 3.81 .1337 1.46	3.215 Hg 80 3.155 .67 .1111 1.45	9.014 Tl 81 3.215 1.88 .1031 1.44	9.727 Pb 82 3.259 2.03 .1002 1.44	10.44 Bi 83 3.287 2.18 .0926 1.43	7.184 Po 84 3.304 1.5 .0906 1.43	0 At 85 3.304 0 0 1.43	.957 Rn 86 3.493 .2 .0604 1.41
0 Fr 87 3.509 0 0 1.4	7.949 Ra 88 3.556 1.66 .0637 1.38	20.35 Ac 89 3.572 4.25 .0904 1.38		22.16 Ce 58 2.205 4.32 .0915 1.6	18.95 Pr 59 2.217 3.7 .0916 1.6	17.29 Nd 60 2.269 3.4 .0922 1.59	0 Pm 61 2.282 0 0 1.59	10.76 Sm 62 2.365 2.14 .0937 1.57	9.323 Eu 63 2.39 1.86 .0956 1.57	20.58 Gd 64 2.474 4.14 .0962 1.56	20.08 Tb 65 2.5 4.05 .0977 1.55	15 Dy 66 2.557 3.04 .0978 1.54	15.45 Ho 67 2.595 3.14 .0989 1.54	16.14 Er 68 2.631 3.29 .1 1.53	11.85 Tm 69 2.658 2.42 .0991 1.53	7.804 Yb 70 2.722 1.6 .0849 1.52	21.57 Lu 71 2.752 4.43 .1003 1.51
				29.71 Th 90 3.651 6.2 .0965 1.37	0 Pa 91 3.635 0 .1107 1.37	26.63 U 92 3.745 5.55 .1218 1.36											

TABLE **16** PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD
PROJECTILE ....Kr
Z - NUMBER........ 36
MASS-NUMBER....... 83.8

133.1	Threshold Energy (eV)
Be 4	Symbol, Atomic Number
.108 3.32	Mass Ratio (M2/M1), Sublimation Energy (eV)
.1006 1.72	for 1 eV, Sigmund f

0 H 1 .012 0 .0373 1.7																	0 He 2 .048 0 .0357 1.7
86.45 Li 3 .083 1.63 .0548 1.7	133.1 Be 4 .108 3.32 .1006 1.72											191.8 B 5 .129 5.77 .1117 1.76	220.5 C 6 .143 7.37 .1114 1.76	126.8 N 7 .167 4.92 .0734 1.78	59.21 O 8 .191 2.6 .0846 1.8	16.42 F 9 .227 .84 0942 1.81	.371 Ne 10 .241 .02 .0844 1.91
18.52 Na 11 .274 1.11 .0639 1.81	24.12 Mg 12 .29 1.51 .0853 1.82											50.02 Al 13 .322 3.39 .1031 1.82	66.34 Si 14 .335 4.63 .096 1.82	45.87 P 15 .37 3.43 .0824 1.82	37.23 S 16 .383 2.85 .0876 1.83	17.13 Cl 17 .423 1.4 .085 1.83	.911 Ar 18 .477 .08 .0749 1.85
10.73 K 19 .466 .93 .0535 1.85	20.92 Ca 20 .478 1.84 .0713 1.85	41.64 Sc 21 .536 3.9 .0949 1.85	50.15 Ti 22 .572 4.85 .1141 1.85	53.33 V 23 .608 5.31 .1299 1.85	40.79 Cr 24 .621 4.1 .1415 1.85	28.36 Mn 25 .655 2.92 .1408 1.85	41.28 Fe 26 .666 4.28 .1448 1.65	41.44 Co 27 .703 4.39 .1508 1.85	41.98 Ni 28 .701 4.44 .1529 1.85	32.04 Cu 29 .758 3.49 .1479 1.85	12.27 Zn 30 .78 1.35 .1312 1.84	25.03 Ga 31 .832 2.81 .1162 1.83	33.89 Ge 32 .866 3.85 .1089 1.83	25.83 As 33 .894 2.96 .1113 1.83	19.37 Se 34 .942 2.25 .0999 1.82	10.48 Br 35 .954 1.22 .0925 1.82	1.02 Kr 36 1 .12 .0785 1.81
7.087 Rb 37 1.02 .85 .0552 1.81	14.01 Sr 38 1.046 1.72 .0713 1.8	35.12 Y 39 1.061 4.37 .0928 1.8	49.07 Zr 40 1.089 6.25 .1113 1.8	58.47 Nb 41 1.109 7.57 .126 1.79	51.23 Mo 42 1.145 6.82 .1372 1.79	50.16 Tc 43 1.18 6.85 .1437 1.78	48.51 Ru 44 1.205 6.74 .1469 1.78	40.77 Rh 45 1.228 5.75 .1474 1.78	26.87 Pd 46 1.27 3.89 .1424 1.77	20.18 Ag 47 1.286 2.95 .133 1.76	7.693 Cd 48 1.341 1.16 .1186 1.75	16.46 In 49 1.37 2.52 .1083 1.75	20.06 Sn 50 1.415 3.14 .107 1.74	17.27 Sb 51 1.452 2.75 .1006 1.74	13.59 Te 52 1.523 2.23 .0958 1.72	6.787 I 53 1.514 1.11 .0855 1.72	.958 Xe 54 1.567 .16 .0737 1.71
4.758 Cs 55 1.586 .8 .052 1.71	11.09 Ba 56 1.638 1.9 .0697 1.7	25.93 La 57 1.658 4.47 .0921 1.7	33.42 Hf 72 2.129 6.44 .1215 1.61	41.84 Ta 73 2.159 8.1 .1358 1.6	45.73 W 74 2.193 8.9 .1459 1.6	41.09 Re 75 2.222 8.03 .1505 1.59	41.54 Os 76 2.27 8.17 .1554 1.59	35.18 Ir 77 2.294 6.94 .1546 1.58	29.48 Pt 78 2.327 5.84 .1492 1.58	19.18 Au 79 2.35 3.81 .1416 1.57	3.357 Hg 80 2.393 .67 .1176 1.57	9.376 Tl 81 2.438 1.88 .1092 1.56	10.09 Pb 82 2.471 2.03 .1062 1.56	10.82 Bi 83 2.493 2.18 .0981 1.55	7.434 Po 84 2.506 1.5 .096 1.55	0 At 85 2.506 0 0 1.55	.98 Rn 86 2.649 .2 .064 1.53
0 Fr 87 2.661 0 0 1.53	8.109 Ra 88 2.697 1.66 .0676 1.52	20.75 Ac 89 2.709 4.25 .096 1.52															
				24.94 Ce 58 1.672 4.32 .0962 1.69	21.3 Pr 59 1.681 3.7 .0963 1.69	19.34 Nd 60 1.721 3.4 .097 1.68	0 Pm 61 1.73 0 0 1.68	11.92 Sm 62 1.794 2.14 .0987 1.66	10.31 Eu 63 1.813 1.86 .1007 1.66	22.59 Gd 64 1.876 4.14 .1014 1.65	21.99 Tb 65 1.896 4.05 .103 1.65	16.35 Dy 66 1.939 3.04 .1031 1.64	16.79 Ho 67 1.968 3.14 .1043 1.63	17.49 Er 68 1.995 3.29 .1055 1.63	12.82 Tm 69 2.016 2.42 .1046 1.63	8.396 Yb 70 2.064 1.6 .0897 1.62	23.15 Lu 71 2.087 4.43 .1059 1.62
				30.16 Th 90 2.768 6.2 .1024 1.51	0 Pa 91 2.757 0 .1175 1.51	26.9 U 92 2.84 5.55 .1293 1.49											

TABLE 17 PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

PROJECTILE ....Xe

Z - NUMBER........ 54

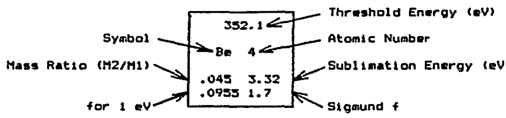
MASS-NUMBER....... 131.3

Threshold Energy (eV)	216.8
Symbol	Be
Atomic Number	4
Mass Ratio (M2/M1)	.069
Sublimation Energy (eV)	3.32
for 1 eV	.0984
Sigmund f	1.7

0 H 1 .008 0 .0355 1.7																	0 He 2 .03 0 .0344 1.7
143.2 Li 3 .053 1.63 .0532 1.7	216.8 Be 4 .069 3.32 .0984 1.7											308 B 5 .082 5.77 .1099 1.7	351 C 6 .091 7.37 .1102 1.7	198.9 N 7 .107 4.92 .073 1.72	91.58 O 8 .122 2.6 .0845 1.76	24.9 F 9 .145 .84 .0944 1.76	.559 Ne 10 .154 .02 .0849 1.77
27.38 Na 11 .175 1.11 .0645 1.78	35.38 Mg 12 .185 1.51 .0864 1.8											72.25 Al 13 .205 3.39 .1047 1.8	95.24 Si 14 .214 4.63 .0978 1.8	64.82 P 15 .236 3.43 .0841 1.81	52.31 S 16 .244 2.85 .0897 1.81	23.66 Cl 17 .27 1.4 .0873 1.81	1.232 Ar 18 .304 .08 .0771 1.82
14.56 K 19 .298 .93 .0551 1.82	28.25 Ca 20 .305 1.84 .0737 1.82	55.03 Sc 21 .342 3.9 .0983 1.82	65.44 Ti 22 .365 4.85 .1184 1.82	68.73 V 23 .388 5.31 .135 1.83	52.35 Cr 24 .396 4.1 .1473 1.83	35.99 Mn 25 .418 2.92 .1469 1.83	52.2 Fe 26 .425 4.28 .1513 1.84	51.81 Co 27 .449 4.39 .1579 1.85	52.52 Ni 28 .447 4.44 .1603 1.85	39.41 Cu 29 .484 3.49 .1553 1.85	15 Zn 30 .498 1.35 .138 1.85	30.16 Ga 31 .531 2.81 .1224 1.85	40.48 Ge 32 .553 3.85 .1149 1.85	30.63 As 33 .571 2.96 .1176 1.85	22.71 Se 34 .601 2.25 .1056 1.85	12.25 Br 35 .609 1.22 .0979 1.85	1.179 Kr 36 .638 .12 .0832 1.85
8.281 Rb 37 .651 .85 .0585 1.85	16.58 Sr 38 .667 1.72 .0757 1.85	41.88 Y 39 .677 4.37 .0988 1.85	59.28 Zr 40 .695 6.25 .1186 1.85	71.29 Nb 41 .708 7.57 .1344 1.85	63.45 Mo 42 .731 6.82 .1465 1.85	63.03 Tc 43 .753 6.85 .1536 1.85	61.57 Ru 44 .769 6.74 .1571 1.84	52.2 Rh 45 .784 5.75 .1578 1.84	34.93 Pd 46 .81 3.89 .1527 1.84	26.38 Ag 47 .821 2.95 .1427 1.84	10.24 Cd 48 .856 1.16 .1274 1.83	22.12 In 49 .874 2.52 .1164 1.83	27.32 Sn 50 .903 3.14 .1151 1.82	23.77 Sb 51 .927 2.75 .1084 1.82	19.06 Te 52 .972 2.23 .1032 1.81	9.501 I 53 .966 1.11 .0923 1.82	1.359 Xe 54 1 .16 .0796 1.81
6.719 Cs 55 1.012 .8 .0562 1.81	15.47 Ba 56 1.046 1.9 .0754 1.8	36.02 La 57 1.058 4.47 .0997 1.8	42.32 Hf 72 1.359 6.44 .1329 1.75	52.71 Ta 73 1.378 8.1 .1486 1.75	57.28 W 74 1.4 8.9 .1597 1.74	51.23 Re 75 1.418 8.03 .1649 1.74	51.39 Os 76 1.449 8.17 .1703 1.74	43.36 Ir 77 1.464 6.94 .1696 1.73	36.15 Pt 78 1.485 5.84 .1637 1.73	23.44 Au 79 1.5 3.81 .1555 1.73	4.076 Hg 80 1.527 .67 .1292 1.72	11.31 Tl 81 1.556 1.88 .12 1.72	12.11 Pb 82 1.577 2.03 .1167 1.71	12.94 Bi 83 1.591 2.18 .108 1.71	8.877 Po 84 1.599 1.5 .1057 1.71	0 At 85 1.599 0 0 1.71	1.148 Rn 86 1.691 .2 .0706 1.69
0 Fr 87 1.698 0 0 1.69	9.439 Ra 88 1.721 1.66 .0746 1.68	24.11 Ac 89 1.729 4.25 .1059 1.68		34.53 Ce 58 1.067 4.32 .1042 1.8	29.42 Pr 59 1.073 3.7 .1044 1.8	26.48 Nd 60 1.098 3.4 .1052 1.79	0 Pm 61 1.104 0 0 1.79	16.08 Sm 62 1.145 2.14 .1072 1.79	13.85 Eu 63 1.157 1.86 .1095 1.79	29.96 Gd 64 1.197 4.14 .1103 1.78	29.05 Tb 65 1.21 4.05 .1121 1.78	21.42 Dy 66 1.238 3.04 .1124 1.77	21.87 Ho 67 1.256 3.14 .1137 1.77	22.68 Er 68 1.273 3.29 .115 1.77	16.55 Tm 69 1.286 2.42 .1142 1.76	10.75 Yb 70 1.318 1.6 .0979 1.76	29.53 Lu 71 1.332 4.43 .1157 1.76
				34.79 Th 90 1.767 6.2 .1131 1.67	0 Pa 91 1.759 0 .1298 1 68	30.76 U 92 1.813 5.55 .143 1.66											

TABLE 18 PARAMETERS FOR ANGULAR DEPENDENCE OF HEAVY-ION SPUTTERING YIELD

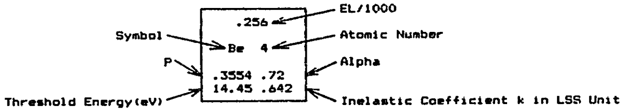
PROJECTILE ....Hg
Z - NUMBER........ 80
MASS-NUMBER....... 200.5



0 H 1 .005 0 .0338 1.7																	0 He 2 .02 0 .033 1.7
235.3 Li 3 .035 1.63 .0513 1.7	352.1 Be 4 .045 3.32 .0955 1.7											495.6 B 5 .054 5.77 .1071 1.7	561.2 C 6 .06 7.37 .1079 1.7	314.9 N 7 .07 4.92 .0717 1.7	143.6 O 8 .08 2.6 .0833 1.7	38.51 F 9 .095 .84 .0934 1.7	.86 Ne 10 .101 .02 .0843 1.7
41.61 Na 11 .115 1.11 .0642 1.76	53.48 Mg 12 .121 1.51 .0863 1.76											108 Al 13 .135 3.39 .1048 1.76	141.7 Si 14 .14 4.63 .0981 1.76	95.37 P 15 .154 3.43 .0846 1.77	76.64 S 16 .16 2.85 .0904 1.77	34.23 Cl 17 .177 1.4 .0882 1.78	1.753 Ar 18 .199 .08 .078 1.8
20.78 K 19 .195 .93 .0559 1.8	40.19 Ca 20 .2 1.84 .0749 1.8	76.99 Sc 21 .224 3.9 .1001 1.81	90.67 Ti 22 .239 4.85 .1208 1.81	94.3 V 23 .254 5.31 .1379 1.81	71.59 Cr 24 .259 4.1 .1508 1.81	48.78 Mn 25 .274 2.92 .1506 1.81	70.56 Fe 26 .279 4.28 .1553 1.81	69.39 Co 27 .294 4.39 .1623 1.82	70.39 Ni 28 .293 4.44 .1651 1.82	52.09 Cu 29 .317 3.49 .1602 1.82	19.73 Zn 30 .326 1.35 .1425 1.82	39.21 Ga 31 .348 2.81 .1266 1.82	52.22 Ge 32 .362 3.85 .119 1.82	39.29 As 33 .374 1.96 .1219 1.83	28.83 Se 34 .394 2.25 .1096 1.83	15.51 Br 35 .399 1.22 .1017 1.83	1.48 Kr 36 .418 .12 .0866 1.83
10.35 Rb 37 .426 .85 .061 1.84	20.63 Sr 38 .437 1.72 .079 1.84	51.95 Y 39 .443 4.37 .1031 1.84	73.16 Zr 40 .455 6.25 .1239 1.85	87.66 Nb 41 .463 7.57 .1406 1.85	77.52 Mo 42 .479 6.82 .1534 1.85	76.53 Tc 43 .493 6.85 .161 1.85	74.43 Ru 44 .504 6.74 .1649 1.85	62.86 Rh 45 .513 5.75 .1657 1.85	41.77 Pd 46 .531 3.89 .1605 1.85	31.46 Ag 47 .538 2.95 .1502 1.85	12.11 Cd 48 .561 1.16 .1342 1.85	26.04 In 49 573 2.52 .1227 1.85	31.94 Sn 50 .592 3.14 .1214 1.85	27.64 Sb 51 .607 2.75 .1144 1.85	21.94 Te 52 .636 2.23 .1091 1.85	10.95 I 53 .633 1.11 .0976 1.85	1.555 Xe 54 .655 .16 .0843 1.85
7.734 Cs 55 .663 .8 .0595 1.85	18.13 Ba 56 .685 1.9 .0799 1.85	42.45 La 57 .693 4.47 .1058 1.85	56.27 Hf 72 .89 6.14 .1425 1.83	70.51 Ta 73 .902 8.1 .1594 1.83	77.16 W 74 .917 8.9 .1714 1.82	69.39 Re 75 .929 8.03 .1771 1.82	70.24 Os 76 .949 8.17 .183 1.82	59.52 Ir 77 .959 6.94 .1823 1.82	49.92 Pt 78 .973 5.84 .1761 1.81	32.5 Au 79 .982 3.81 .1673 1.81	5.693 Hg 80 1 .67 .1392 1.81	15.69 Tl 81 1.019 1.88 .1293 1.81	16.72 Pb 82 1.033 2.03 .1259 1.8	17.81 Bi 83 1.042 2.18 .1165 1.8	12.2 Po 84 1.047 1.5 .1141 1.8	0 At 85 1.047 0 0 1.8	1.547 Rn 86 1.107 .2 .0762 1.79
0 Fr 87 1.112 0 0 1.79	12.64 Ra 88 1.127 1.66 .0806 1.79	32.23 Ac 89 1.132 4.25 .1175 1.79		40.88 Ce 58 .699 4.32 .1106 1.85	34.94 Pr 59 .703 3.7 .111 1.85	31.82 Nd 60 .719 3.4 .1119 1.85	0 Pm 61 .723 0 0 1.85	19.73 Sm 62 .75 2.14 .1142 1.85	17.08 Eu 63 .758 1.86 .1167 1.85	37.58 Gd 64 .784 4.14 .1176 1.84	36.63 Tb 65 .793 4.05 .1196 1.84	27.3 Dy 66 .81 3.04 12 1.84	28.07 Ho 67 .822 3.14 .1215 1.84	29.28 Er 68 .834 3.29 .123 1.83	21.47 Tm 69 .842 2.42 .1221 1.83	14.1 Yb 70 .863 1.6 .1049 1.83	38.92 Lu 71 .872 4.43 .124 1.83
				46.16 Th 90 1.157 6.2 .1224 1.79	0 Pa 91 1.152 0 .1406 1.79	40.45 U 92 1.187 5.55 .1549 1.78											

TABLE **19** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....H
Z - NUMBER........ 1
MASS-NUMBER....... 1.008



.087 H 1 0 .26 0 .132																	.124 He 2 0 .45 0 .303
.185 Li 3 .2886 .61 6.386 .495	.256 Be 4 .3554 .72 14.45 .642											.333 B 5 .108 .81 27.66 .774	.415 C 6 .2807 .88 37.68 .868	.498 N 7 .1547 .98 27.93 1.01	.584 O 8 .3161 1.09 16.3 1.16	.672 F 9 1.042 1.25 6.058 1.37	.767 Ne 10 46.93 1.32 .152 1.46
.861 Na 11 .8946 1.47 9.483 1.67	.96 Mg 12 .6~72 1.55 13.58 1.77											1.059 Al 13 .3594 1.7 33.68 1.96	1.163 Si 14 .1888 1.76 47.84 2.05	1.267 P 15 .3556 1.93 39.07 2.26	1.375 S 16 .4477 1.99 33.62 2.35	1.483 Cl 17 .9502 2.19 18.32 2.6	1.591 Ar 18 17.33 2.46 1.187 2.92
1.707 K 19 1.548 2.41 13.48 2.87	1.823 Ca 20 .8117 2.47 27.4 2.95	1.937 Sc 21 .3975 2.77 65.72 3.31	2.054 Ti 22 .1954 2.96 87.62 3.53	2.173 V 23 .2755 3.15 102.7 3.75	2.296 Cr 24 .5311 3.22 81.11 3.84	2.418 Mn 25 .7336 3.41 61.41 4.06	2.544 Fe 26 .4767 3.47 91.71 4.13	2.669 Co 27 .4834 3.67 99.93 4.36	2.799 Ni 28 .4814 3.66 100.6 4.35	2.926 Cu 29 .757 3.98 86.55 4.71	3.056 Zn 30 1.51 4.1 34.58 4.85	3.187 Ga 31 .747 4.4 77.49 5.17	3.319 Ge 32 .4702 4.6 111.2 5.39	3.454 As 33 .7464 4.76 88.69 5.57	3.589 Se 34 1.008 5.04 71.65 5.87	3.726 Br 35 1.9 5.11 39.39 5.94	3.864 Kr 36 *19.82 5.39 4.096 6.24
4.003 Rb 37 2.858 5.5 29.69 6.36	4.144 Sr 38 1.444 5.66 61.85 6.53	4.286 Y 39 .5796 5.75 159.8 6.63	4.429 Zr 40 .2773 5.92 235.6 6.81	4.574 Nb 41 .324 6.04 291.6 6.94	4.719 Mo 42 .3594 6.27 272.8 7.17	4.865 Tc 43 .4014 6.49 284.1 7.39	5.012 Ru 44 .5904 6.64 286.5 7.55	5.161 Rh 45 .6056 6.78 249.9 7.7	5.31 Pd 46 .7861 7.05 175.9 7.96	5.461 Ag 47 1.134 7.15 135.5 8.07	5.611 Cd 48 2.607 7.51 55.97 8.42	5.764 In 49 1.222 7.69 124.7 8.6	5.917 Sn 50 .2099 7.98 161.5 8.89	6.071 Sb 51 1.162 8.23 145.9 9.12	6.225 Te 52 1.463 8.69 125.2 9.57	6.383 I 53 2.976 8.63 61.91 9.52	6.54 Xe 54 21.03 8.98 9.295 9.85
6.698 Cs 55 4.269 9.11 47.15 9.98	6.857 Ba 56 1.83 9.46 116.5 10.3	7.017 La 57 .7892 9.59 277.8 10.4	9.523 Hf 72 .465 12.9 541.3 13.5	9.697 Ta 73 .3851 13.1 692.5 13.7	9.871 W 74 .4999 13.4 775.7 13.9	10.05 Re 75 .6503 13.6 710.9 14.1	10.22 Os 76 .7259 13.9 742.2 14.4	10.4 Ir 77 .8308 14.1 638.5 14.5	10.58 Pt 78 .8232 14.3 546.8 14.7	10.75 Au 79 1.213 14.5 361 14.9	10.93 Hg 80 7.129 14.8 64.89 15.2	11.11 Tl 81 2.572 15.2 186.3 15.4	11.29 Pb 82 2.409 15.4 204.5 15.7	11.47 Bi 83 2.266 15.6 221.9 15.8	11.65 Po 84 3.324 15.7 153.7 15.9	11.84 At 85 0 15.7 0 15.9	12.02 Rn 86 25.63 16.8 21.93 16.8
12.2 Fr 87 0 16.9 0 16.9	12.39 Ra 88 3.149 17.1 186 17.1	12.57 Ac 89 1.241 17.2 478.8 17.2		7.179 Ce 58 .8276 9.69 271.3 10.5	7.342 Pr 59 .9787 9.75 233.9 10.6	7.504 Nd 60 1.082 10 221 10.8	7.668 Pm 61 0 10.1 0 10.9	7.832 Sm 62 1.772 10.5 146.2 11.3	7.998 Eu 63 2.065 10.7 128.7 11.4	8.163 Gd 64 .9437 11.1 293.6 11.8	8.331 Tb 65 .977 11.2 296 12	8.498 Dy 66 1.321 11.5 228.3 12.2	8.667 Ho 67 1.296 11.7 240 12.4	8.837 Er 68 1.253 11.9 255.7 12.6	9.007 Tm 69 1.723 12.1 190.4 12.7	9.178 Yb 70 2.645 12.4 129.6 13	9.35 Lu 71 .9666 12.6 363.6 13.2
				12.76 Th 90 .7921 17.7 717.2 17.6	12.95 Pa 91 0 17.6 0 17.5	13.13 U 92 .7069 18.2 662.4 18											

TABLE 20 PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....D
Z - NUMBER........ 1
MASS-NUMBER....... 2.014

.282	
Symbol → Be	4 ← Atomic Number
P → .43	.48 ← Alpha
Threshold Energy(eV) → 11.98	.262 ← Inelastic Coefficient k in LSS Unit

.282 ← EL/1000

.13 H 1 0 .21 0 .086																	.149 He 2 . 0 .33 0 .141
.209 Li 3 .3532 .42 5.907 .209	.282 Be 4 .43 .48 11.98 .262											.361 B 5 .1291 .53 21.26 .31	.447 C 6 .3328 .56 27.74 .343	.531 N 7 .1809 .61 19.34 .395	.619 O 8 .3647 .67 10.74 .447	.706 F 9 1.18 .74 3.754 .523	.803 Ne 10 52.76 .78 .092 .556
.897 Na 11 .99 .85 5.526 .628	.998 Mg 12 .7666 .88 7.783 .664											1.097 Al 13 .3901 .96 18.75 .733	1.203 Si 14 .2039 .98 26.34 .764	1.307 P 15 .3794 1.06 20.98 .839	1.417 S 16 .4755 1.09 17.91 .87	1.524 Cl 17 .996 1.18 9.535 .958	1.63 Ar 18 17.9 1.31 .603 1.07
1.75 K 19 1.604 1.28 6.878 1.06	1.868 Ca 20 .8382 1.31 13.91 1.08	1.979 Sc 21 .4047 1.44 32.65 1.21	2.096 Ti 22 .1973 1.53 43.06 1.29	2.215 V 23 .2762 1.61 [illegible].96 1.37	2.339 Cr 24 .5312 1.64 39.35 1.4	2.462 Mn 25 .729 1.73 29.55 1.47	2.589 Fe 26 .4728 1.75 44.02 1.5	2.714 Co 27 .4764 1.84 47.61 1.58	2.846 Ni 28 .4747 1.84 47.98 1.58	2.971 Cu 29 .7397 1.98 40.84 1.71	3.103 Zn 30 1.471 2.03 16.26 1.76	3.232 Ga 31 .7225 2.16 36.16 1.87	3.365 Ge 32 .4528 2.25 51.68 1.95	3.5 As 33 .7164 2.32 41.07 2.01	3.634 Se 34 .9626 2.44 33.01 2.12	3.773 Br 35 1.812 2.47 18.13 2.14	3.909 Kr 36 18.8 2.59 1.876 2.25
4.05 Rb 37 2.706 2.64 13.57 2.29	4.191 Sr 38 1.363 2.71 28.22 2.35	4.334 Y 39 .5467 2.75 72.84 2.39	4.478 Zr 40 .2609 2.82 107.1 2.45	4.623 Nb 41 .3043 2.87 132.4 2.5	4.768 Mo 42 .3365 2.97 123.5 2 58	4.914 Tc 43 .3748 3.06 128.3 2.66	5.062 Ru 44 .5501 3.13 129.2 2.71	5.211 Rh 45 .5633 3.19 112.5 2.77	5.359 Pd 46 .729 3.3 79.03 2.86	5.511 Ag 47 1.051 3.35 60.81 2.9	5.661 Cd 48 2.406 3.5 25.06 3.02	5.814 In 49 1.125 3.58 55.75 3.09	5.967 Sn 50 .1928 3.7 72.07 3.19	6.121 Sb 51 1.065 3.8 64.99 3.27	6.274 Te 52 1.336 4 55.61 3.43	6.433 I 53 2.718 3.98 27.51 3.41	6.589 Xe 54 19.16 4.13 4.123 3.53
6.749 Cs 55 3.885 4.18 20.9 3.57	6.907 Ba 56 1.661 4.33 51.53 3.69	7.068 La 57 .7157 4.39 122.9 3.74	9.576 Hf 72 .4142 5.78 236.7 4.81	9.75 Ta 73 .3427 5.87 302.7 4.88	9.924 W 74 .4444 5.98 338.8 4.95	10.1 Re 75 .5776 6.06 310.4 5.02	10.28 Os 76 .6439 6.21 323.8 5.13	10.45 Ir 77 .7365 6.29 278.5 5.18	10.63 Pt 78 .7291 6.39 238.4 5.26	10.81 Au 79 1.074 6.46 157.[illegible] 5.31	10.99 Hg 80 6.302 6.59 28.26 5.41	11.17 Tl 81 2.271 6.74 81.08 5.51	11.35 Pb 82 2.126 6.84 88.97 5.59	11.53 Bi 83 1.998 6.91 96.53 5.64	11.71 Po 84 2.93 6.95 66.84 5.67	11.89 At 85 0 6.95 0 5.67	12.07 Rn 86 22.53 7.41 9.519 5.99
12.26 Fr 87 0 7.44 0 6.02	12.44 Ra 88 2.765 7.56 80.71 6.1	12.63 Ac 89 1.089 7.6 207.7 6.13		7.23 Ce 58 .7501 4.43 119.9 3.77	7.394 Pr 59 .8866 4.45 103.4 3.79	7.556 Nd 60 .9784 4.57 97.56 3.88	7.721 Pm 61 0 4.6 0 3.9	7.884 Sm 62 1.597 4.78 64.42 4.05	8.05 Eu 63 1.86 4.8[illegible] 56.68 4.09	8.215 Gd 64 .848 5.02 131.3 4.23	8.383 Tb 65 .8772 5.08 130 4.28	8.551 Dy 66 1.184 5.21 100.2 4.38	8.72 Ho 67 1.16 5.29 105.3 4.44	8.89 Er 68 1.121 5.38 112.1 4.5	9.061 Tm 69 1.541 5.44 83.44 4.55	9.231 Yb 70 2.361 5.58 56.74 4.66	9.404 Lu 71 .8621 5.65 159.1 4.71
				12.81 Th 90 .6944 7.79 311 6.26	13 Pa 91 0 7.75 0 6.24	13.19 U 92 .6188 8.02 287 6.43											

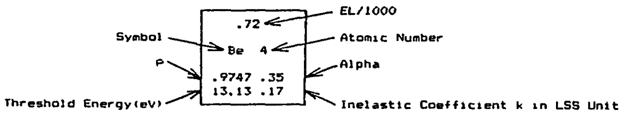
TABLE **21** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....T
Z = NUMBER........ 1
MASS-NUMBER....... 3.016

.308 ← EL/1000
Symbol → Be 4 ← Atomic Number
P → .4852 .39 ← Alpha
Threshold Energy(eV) → 12.26 .163 ← Inelastic Coefficient k in LSS Unit

.174 H 1 0 .19 0 .072																	.173 He 2 0 .28 0 .097
.232 Li 3 .3974 .35 6.402 .134	.303 Be 4 .4852 .39 12.26 .163											.389 B 5 .1456 .43 20.85 .189	.479 C 6 .3747 .45 26.52 .208	.564 N 7 .203 .49 17.8 .236	.653 O 8 .4076 .52 9.561 .264	.74 F 9 1.309 .58 3.206 .306	.839 Ne 10 58.39 .6 .078 .324
.933 Na 11 1.089 .65 4.509 .363	1.036 Mg 12 .8401 .67 6.271 .383											1.135 Al 13 .4249 .72 14.76 .421	1.243 Si 14 .2216 .74 20.55 .438	1.346 P 15 .4096 .79 16.04 .479	1.459 S 16 .5123 .81 13.59 .496	1.564 Cl 17 1.066 .87 7.096 .544	1.669 Ar 18 18.99 .95 .439 .607
1.793 K 19 1.704 .93 5.027 .597	1.912 Ca 20 .8891 .95 10.12 .613	2.021 Sc 21 .4257 1.04 23.3 .681	2.139 Ti 22 .2066 1.09 30.42 .724	2.257 V 23 .2879 1.14 34.97 .767	2.383 Cr 24 .5528 1.16 27.45 .784	2.505 Mn 25 .7556 1.22 20.46 .826	2.634 Fe 26 .4895 1.23 30.41 .841	2.759 Co 27 .4912 1.29 32.65 .885	2.893 Ni 28 .4896 1.29 32.92 .884	3.017 Cu 29 .7584 1.37 27.74 .953	3.149 Zn 30 1.505 1.41 11.01 .98	3.277 Ga 31 .7358 1.49 24.3 1.04	3.41 Ge 32 .4598 1.54 34.56 1.08	3.545 As 33 .7257 1.59 27.38 1.12	3.679 Se 34 .9714 1.66 21.88 1.18	3.819 Br 35 1.827 1.68 12 1.19	3.955 Kr 36 18.89 1.76 1.237 1.25
4.096 Rb 37 2.716 1.79 8.931 1.27	4.238 Sr 38 1.366 1.83 18.52 1.3	4.382 Y 39 .547 1.86 47.75 1.32	4.526 Zr 40 [illegible] 1.9 [illegible] 1.36	4.672 Nb 41 .3036 1.93 86.46 1.38	4.816 Mo 42 .335 1.99 80.46 1.43	4.962 Tc 43 .3723 2.05 83.37 1.47	5.111 Ru 44 .5457 2.09 83.82 1.5	5.261 Rh 45 .558 2.13 72.9 1.53	5.409 Pd 46 .7206 2.2 51.06 1.58	5.561 Ag 47 1.038 2.23 39.25 1.6	5.711 Cd 48 2.37 2.32 16.13 1.67	5.864 In 49 1.107 2.37 35.82 1.71	6.016 Sn 50 .1892 2.45 46.21 1.76	6.17 Sb 51 1.043 2.51 41.6 1.81	6.322 Te 52 1.305 2.63 35.5 1.89	6.483 I 53 2.657 2.62 17.56 1.88	6.639 Xe 54 18.69 2.71 2.627 1.95
6.799 Cs 55 3.786 2.74 13.31 1.97	6.956 Ba 56 1.616 2.83 32.75 2.04	7.118 La 57 .6956 2.87 78.02 2.06	9.63 Hf 72 .3969 3.72 148.6 2.65	9.804 Ta 73 .3281 3.77 189.8 2.68	9.978 W 74 .4251 3.84 212.4 2.73	10.15 Re 75 .5522 3.89 194.4 2.76	10.33 Os 76 .6149 3.98 202.7 2.82	10.51 Ir 77 .7029 4.03 174.2 2.85	10.68 Pt 78 .6953 4.09 149.1 2.89	10.86 Au 79 1.024 4.13 98.33 2.92	11.04 Hg 80 6.003 4.21 17.65 2.97	11.22 Tl 81 2.161 4.3 50.61 3.03	11.4 Pb 82 2.021 4.36 55.51 3.07	11.58 Bi 83 1.899 4.41 60.21 3.1	11.77 Po 84 2.785 4.43 41.68 3.11	11.95 At 85 0 4.43 0 3.12	12.13 Rn 86 21.35 4.71 5.925 3.29
12.31 Fr 87 0 4.73 0 3.31	12.5 Ra 88 2.618 4.8 50.21 3.35	12.68 Ac 89 1.031 4.82 129.2 3.37		7.281 Ce 58 .7286 2.89 76.12 2.08	7.445 Pr 59 .861 2.91 65.6 2.09	7.608 Nd 60 .9488 2.98 61.84 2.14	7.774 Pm 61 0 3 0 2.15	7.936 Sm 62 1.545 3.11 40.74 2.23	8.103 Eu 63 1.798 3.14 35.83 2.25	8.267 Gd 64 .8182 3.26 82.85 2.33	8.435 Tb 65 .8459 3.29 82.03 2.36	8.603 Dy 66 1.14 3.37 63.13 2.41	8.772 Ho 67 1.117 3.42 66.29 2.45	8.942 Er 68 1.078 3.47 70.54 2.48	9.114 Tm 69 1.481 3.51 52.48 2.5	9.284 Yb 70 2.266 3.6 35.65 2.57	9.457 Lu 71 .827 3.64 99.92 2.59
				12.87 Th 90 .6567 4.94 193.3 3.44	13.06 Pa 91 0 4.92 0 3.43	13.24 U 92 .5845 5.08 178.3 3.53											

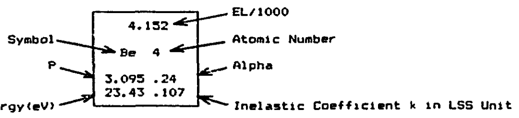
TABLE 22 PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE
PROJECTILE ....He
Z - NUMBER........ 2
MASS-NUMBER....... 4.0026



.492 H 1 0 .18 0 .086																	.438 He 2 . 0 .26 0 .105
.557 Li 3 .7857 .31 7.101 .141	.72 Be 4 .9747 .35 13.13 .17											.895 B 5 .2954 .38 21.73 .196	1.087 C 6 .765 .39 27.19 .216	1.267 N 7 .4164 .42 17.81 .244	1.453 O 8 .8386 .45 9.354 .273	1.629 F 9 2.696 .49 3.045 .314	1.839 Ne 10 120.5 .51 .073 .332
2.029 Na 11 2.244 .55 4.143 .372	2.245 Mg 12 1.733 .57 5.708 .392											2.448 Al 13 .8755 .6 13.19 .43	2.674 Si 14 .4567 .62 18.25 .448	2.884 P 15 .8428 .65 14.01 .489	3.117 S 16 1.054 .67 11.81 .507	3.33 Cl 17 2.188 .71 6.065 .555	3.54 Ar 18 38.82 .77 .368 .618
3.8 K 19 3.491 .76 4.232 .609	4.047 Ca 20 1.821 .78 8.486 .625	4.264 Sc 21 .8682 .84 19.22 .694	4.502 Ti 22 .4205 .88 24.87 .737	4.744 V 23 .5846 .92 28.35 .781	5.002 Cr 24 1.122 .93 22.2 .798	5.25 Mn 25 1.531 .97 16.42 .841	5.514 Fe 26 .992 .99 24.36 .857	5.768 Co 27 .993 1.03 25.99 .902	6.045 Ni 28 .991 1.02 26.21 .901	6.293 Cu 29 1.529 1.09 21.88 .971	6.562 Zn 30 3.032 1.11 8.656 1	6.821 Ga 31 1.478 1.17 18.97 1.06	7.09 Ge 32 .922 1.21 26.88 1.1	7.365 As 33 1.454 1.24 21.22 1.14	7.634 Se 34 1.941 1.3 16.87 1.2	7.92 Br 35 3.65 1.31 9.246 1.21	8.195 Kr 36 37.67 1.37 .948 1.27
8.483 Rb 37 5.412 1.39 6.837 1.3	8.77 Sr 38 2.719 1.42 14.15 1.33	9.064 Y 39 1.089 1.44 36.43 1.35	9.356 Zr 40 .518 1.47 53.34 1.38	9.652 Nb 41 .6032 1.49 65.71 1.41	9.945 Mo 42 .6647 1.54 60.99 1.46	10.24 Tc 43 .7377 1.58 63.04 1.5	10.54 Ru 44 1.081 1.61 63.28 1.53	10.85 Rh 45 1.104 1.64 54.95 1.56	11.14 Pd 46 1.424 1.69 38.4 1.61	11.45 Ag 47 2.05 1.71 29.49 1.64	11.75 Cd 48 4.672 1.77 12.08 1.7	12.06 In 49 2.18 1.81 26.8 1.74	12.37 Sn 50 .3722 1.86 34.49 1.8	12.68 Sb 51 2.05 1.91 31 1.84	12.99 Te 52 2.559 2 26.37 1.93	13.32 I 53 5.212 1.99 13.05 1.92	13.63 Xe 54 36.61 2.05 1.948 1.99
13.95 Cs 55 7.414 2.08 9.862 2.01	14.27 Ba 56 3.16 2.14 24.22 2.08	14.6 La 57 1.36 2.17 57.67 2.1	19.67 Hf 72 .7689 2.77 108.5 2.7	20.02 Ta 73 .6354 2.81 138.5 2.74	20.38 W 74 .8228 2.86 154.9 2.79	20.73 Re 75 1.068 2.9 141.7 2.82	21.08 Os 76 1.189 2.96 147.6 2.88	21.44 Ir 77 1.358 2.99 126.8 2.91	21.8 Pt 78 1.343 3.04 108.4 2.96	22.16 Au 79 1.977 3.07 71.51 2.99	22.52 Hg 80 11.58 3.12 12.83 3.04	22.88 Tl 81 4.168 3.19 36.76 3.1	23.24 Pb 82 3.896 3.23 40.29 3.14	23.61 Bi 83 3.66 3.26 43.69 3.17	23.98 Po 84 5.365 3.28 30.24 3.19	24.36 At 85 0 3.28 0 3.19	24.71 Rn 86 41.05 3.47 4.291 3.37
25.08 Fr 87 0 3.49 0 3.38	25.45 Ra 88 5.031 3.54 36.33 3.43	25.83 Ac 89 1.981 3.56 93.49 3.45															
				14.93 Ce 58 1.424 2.16 56.24 2.12	15.26 Pr 59 1.683 2.2 48.45 2.14	15.59 Nd 60 1.853 2.24 45.62 2.19	15.93 Pm 61 0 2.26 0 2.2	16.25 Sm 62 3.012 2.34 29.99 2.28	16.59 Eu 63 3.504 2.36 26.36 2.3	16.92 Gd 64 1.592 2.44 60.84 2.38	17.26 Tb 65 1.646 2.47 60.21 2.41	17.6 Dy 66 2.217 2.52 46.29 2.46	17.94 Ho 67 2.169 2.56 48.57 2.5	18.28 Er 68 2.092 2.6 51.65 2.53	18.63 Tm 69 2.874 2.62 38.41 2.56	18.97 Yb 70 4.394 2.69 26.06 2.62	19.32 Lu 71 1.603 2.72 73.02 2.65
				26.2 Th 90 1.261 3.64 139.8 3.52	26.58 Pa 91 0 3.62 0 3.51	26.95 U 92 1.122 3.74 128.8 3.61											

TABLE **23** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE C
Z - NUMBER........ 6
MASS-NUMBER....... 12.01



4.94 H 1 0 .14 0 .098																	3.263 He 2 0 .19 0 .086
3.504 Li 3 2.351 .22 13.93 .096	4.152 Be 4 3.095 .24 23.43 .107											4.857 B 5 .9758 .25 36 .118	5.687 C 6 2.589 .26 43 .127	6.326 N 7 1.447 .27 26.17 .137	6.979 O 8 2.972 .28 12.85 .148	7.482 F 9 9.732 .3 3.812 .162	8.291 Ne 10 438.6 .31 .088 .17
8.869 Na 11 8.249 .33 4.644 .184	9.666 Mg 12 6.405 .33 6.19 .193											10.3 Al 13 3.25 .35 13.41 .207	11.13 Si 14 1.701 .35 18.1 .214	11.76 P 15 3.143 .37 13.06 .229	12.6 S 16 3.938 .37 10.76 .237	13.22 Cl 17 8.161 .39 5.18 .254	13.77 Ar 18 144.1 .41 .291 .267
14.79 K 19 13.01 .41 3.391 .275	15.66 Ca 20 6.789 .41 6.69 .282	16.21 Sc 21 3.213 .44 14.05 .307	16.95 Ti 22 1.55 .45 17.45 .323	17.69 V 23 2.144 .47 19.12 .339	18.57 Cr 24 4.115 .47 14.77 .346	19.34 Mn 25 5.586 .48 10.55 .363	20.25 Fe 26 3.616 .49 15.49 .369	21.02 Co 27 3.603 .5 15.97 .386	22.01 Ni 28 3.6 .5 16.14 .387	22.7 Cu 29 5.506 .52 12.83 .412	23.57 Zn 30 10.89 .53 4.986 .423	24.32 Ga 31 5.264 .55 10.51 .447	25.16 Ge 32 3.267 .56 14.54 .463	26.03 As 33 5.131 .57 11.27 .476	26.83 Se 34 6.803 .59 8.69 .498	27.78 Br 35 12.78 .6 4.729 .505	28.61 Kr 36 131 .61 .472 .526
29.54 Rb 37 18.77 .62 3.367 .537	30.45 Sr 38 9.4 .63 6.873 .549	31.41 Y 39 3.757 .64 17.56 .558	32.33 Zr 40 1.781 .65 25.35 .571	33.28 Nb 41 2.069 .65 30.92 .581	34.19 Mo 42 2.269 .67 28.22 .599	35.1 Tc 43 2.506 .68 28.71 .616	36.05 Ru 44 3.66 .69 28.51 .628	37.02 Rh 45 3.73 .7 24.53 .64	37.93 Pd 46 4.783 .71 16.85 .659	38.93 Ag 47 6.875 .72 12.86 .668	39.81 Cd 48 15.56 .74 5.163 .694	40.78 In 49 7.234 .75 11.34 .708	41.72 Sn 50 1.228 .77 14.37 .73	42.68 Sb 51 6.736 .78 12.77 .747	43.56 Te 52 8.338 .81 10.63 .78	44.65 I 53 17.01 .8 5.276 .778	45.59 Xe 54 118.7 .82 .776 .803
46.62 Cs 55 24 .83 3.907 .813	47.57 Ba 56 10.17 .85 9.465 .838	48.61 La 57 4.369 .86 22.43 .848	64.34 Hf 72 2.367 1.03 38.38 1.08	65.43 Ta 73 1.951 1.04 48.78 1.1	66.51 W 74 2.519 1.06 54.25 1.11	67.61 Re 75 3.264 1.07 49.43 1.13	68.68 Os 76 3.618 1.09 51.13 1.15	69.8 Ir 77 4.127 1.1 43.79 1.16	70.91 Pt 78 4.07 1.11 37.27 1.18	72.03 Au 79 5.982 1.12 24.5 1.19	73.13 Hg 80 34.94 1.13 4.371 1.21	74.23 Tl 81 12.53 1.15 12.45 1.23	75.35 Pb 82 11.68 1.16 13.59 1.25	76.49 Bi 83 10.96 1.17 14.7 1.26	77.66 Po 84 16.06 1.18 10.16 1.27	78.85 At 85 0 1.18 0 1.27	79.81 Rn 86 121.6 1.23 1.419 1.34
80.98 Fr 87 0 1.24 0 1.35	82.13 Ra 88 14.86 1.25 11.96 1.36	83.31 Ac 89 5.849 1.25 30.72 1.37		49.66 Ce 58 4.57 .86 21.79 .855	50.73 Pr 59 5.397 .87 18.73 .861	51.74 Nd 60 5.917 .88 17.47 .88	52.82 Pm 61 0 .88 0 .886	53.78 Sm 62 9.55 .91 11.3 .916	54.84 Eu 63 11.09 .92 9.889 .926	55.62 Gd 64 5.009 .94 22.53 .956	56.89 Tb 65 5.168 .95 22.2 .966	57.92 Dy 66 6.933 .96 16.93 .987	58.99 Ho 67 6.768 .97 17.67 1	60.06 Er 68 6.514 .98 18.7 1.02	61.15 Tm 69 8.933 .99 13.85 1.03	62.19 Yb 70 13.6 1.01 9.32 1.05	63.28 Lu 71 4.952 1.02 26.01 1.06
				84.42 Th 90 3.708 1.28 45.66 1.4	85.65 Pa 91 0 1.27 0 1.39	86.74 U 92 3.284 1.3 41.79 1.43											

TABLE **24** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Ne
Z - NUMBER........ 10
MASS-NUMBER....... 20.18

EL/1000 → 10.66
Symbol → Be
Atomic Number → 4
P → 4.858
Alpha → .2
Threshold Energy(eV) → 34.72
Inelastic Coefficient k in LSS Unit → .097

15.35 H 1 0 .13 0 .107																	9.269 He 2 0 .17 0 .086
9.341 Li 3 3.586 .19 21.16 .09	10.66 Be 4 4.858 .2 34.72 .097											12.12 B 5 1.565 .21 52.25 .104	13.93 C 6 4.212 .22 61.58 .11	15.13 N 7 2.395 .23 36.7 .117	16.35 O 8 4.993 .24 17.66 .123	17.08 F 9 16.63 .25 5.091 .132	18.73 Ne 10 755.2 .26 .117 .137
19.66 Na 11 14.38 .27 5.985 .146	21.23 Mg 12 11.23 .28 7.889 .151											22.27 Al 13 5.749 .29 16.73 .16	23.91 Si 14 3.022 .29 22.38 .165	24.94 P 15 5.625 .3 15.79 .174	26.57 S 16 7.074 .3 12.91 .179	27.51 Cl 17 14.75 .32 6.066 .189	28.25 Ar 18 261.9 .33 .331 .203
30.37 K 19 23.66 .33 3.874 .203	32.03 Ca 20 12.38 .33 7.594 .207	32.74 Sc 21 5.883 .35 15.47 .222	33.97 Ti 22 2.845 .36 18.88 .232	35.22 V 23 3.944 .37 20.33 .242	36.87 Cr 24 7.577 .37 15.61 .247	38.16 Mn 25 10.3 .38 10.98 .257	39.85 Fe 26 6.676 .38 16.04 .261	41.15 Co 27 6.657 .39 16.28 .271	43.06 Ni 28 6.659 .39 16.47 .272	44.07 Cu 29 10.19 .4 12.78 .288	45.63 Zn 30 20.16 .41 4.926 .295	46.8 Ga 31 9.746 .42 10.18 .309	48.23 Ge 32 6.05 .43 13.91 .319	49.75 As 33 9.502 .44 10.67 .328	51.05 Se 34 12.59 .45 8.097 .341	52.78 Br 35 23.66 .45 4.389 .346	54.13 Kr 36 242.3 .46 .432 .359
55.78 Rb 37 34.73 .47 3.06 .366	57.38 Sr 38 17.39 .47 6.197 .374	59.1 Y 39 6.949 .48 15.75 .379	60.69 Zr 40 3.294 .48 22.57 .388	62.37 Nb 41 3.825 .49 27.37 .394	63.9 Mo 42 4.191 .49 24.73 .405	65.45 Tc 43 4.626 .5 24.91 .416	67.11 Ru 44 6.752 .51 24.58 .423	68.8 Rh 45 6.879 .51 21.02 .431	70.33 Pd 46 8.812 .52 14.29 .443	72.09 Ag 47 12.66 .53 10.86 .449	73.53 Cd 48 28.6 .54 4.303 .465	75.2 In 49 13.29 .55 9.387 .474	76.75 Sn 50 2.253 .56 11.73 .487	78.38 Sb 51 12.35 .56 10.38 .498	79.78 Te 52 15.24 .58 8.519 .518	81.76 I 53 31.11 .58 4.234 .517	83.31 Xe 54 216.8 .59 .616 .533
85.11 Cs 55 43.82 .59 3.091 .539	86.69 Ba 56 18.53 .61 7.416 .555	88.5 La 57 7.958 .61 17.51 .561	115.4 Hf 72 4.25 .71 27.88 .709	117.3 Ta 73 3.5 .72 35.29 .719	119.1 W 74 4.515 .73 39.08 .729	121 Re 75 5.844 .73 35.49 .739	122.8 Os 76 6.468 .74 36.5 .753	124.7 Ir 77 7.374 .75 31.17 .761	126.6 Pt 78 7.265 .76 26.43 .771	128.5 Au 79 10.67 .76 17.33 .779	130.4 Hg 80 62.24 .77 3.077 .792	132.2 Tl 81 22.29 .78 8.723 .806	134.1 Pb 82 20.77 .79 9.49 .817	136.1 Bi 93 19.47 .79 10.24 .824	138.1 Po 84 28.52 .8 7.068 .829	140.2 At 85 0 .8 0 .829	141.6 Rn 86 215 .83 .973 .872
143.7 Fr 87 0 .83 0 .876	145.6 Ra 88 26.24 .84 8.166 .887	147.7 Ac 89 10.33 .84 20.96 .892		90.36 Ce 58 8.322 .61 16.97 .566	92.25 Pr 59 9.826 .61 14.56 .57	93.95 Nd 60 10.76 .62 13.49 .582	95.85 Pm 61 0 .63 0 .586	97.41 Sm 62 17.33 .64 8.616 .605	99.27 Eu 63 20.12 .64 7.518 .611	100.9 Gd 64 9.064 .66 16.96 .63	102.7 Tb 65 9.347 .66 16.66 .636	104.4 Dy 66 12.52 .67 12.62 .649	106.3 Ho 67 12.21 .68 13.12 .659	108.1 Er 68 11.74 .68 13.83 .667	110 Tm 69 16.1 .69 10.22 .674	111.7 Yb 70 24.46 .7 6.827 .689	113.6 Lu 71 8.904 .7 19 .696
				149.5 Th 90 6.535 .85 30.99 .91	151.7 Pa 91 0 .85 0 .907	153.5 U 92 5.776 .87 28.19 .933											

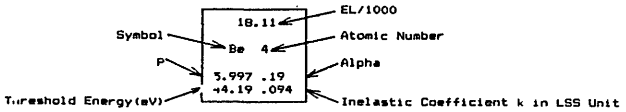
TABLE **25** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NCRMAL INCIDENCE

PROJECTILE ....Ar
Z - NUMBER........ 18
MASS-NUMBER....... 39.94

	36.83	EL/1000
Symbol	Be 4	Atomic Number
P	7.627 .17	Alpha
Threshold Energy(eV)	62.29 .091	Inelastic Coefficient k in LSS Unit

63.05 H 1 0 .12 0 .119																	35.32 He 2 0 .15 0 .089
33.54 Li 3 5.474 .16 38.76 .088	36.83 Be 4 7.627 .17 62.29 .091											40.64 B 5 2.513 .18 92.13 .095	45.79 C 6 6.869 .18 107.4 .1	48.39 N 7 3.987 .19 62.83 .103	51.02 O 8 8.465 .2 29.72 .106	51.68 F 9 28.84 .21 8.351 .109	55.92 Ne 10 1323 .21 .19 .113
57.25 Na 11 25.64 .22 9.509 .115	61.08 Mg 12 20.21 .22 12.41 .12											62.81 Al 13 10.49 .23 25.79 .124	66.81 Si 14 5.552 .23 34.22 .127	68.38 P 15 10.47 .24 23.66 .131	72.28 S 16 13.24 .24 19.2 .134	73.44 Cl 17 27.94 .25 8.816 .139	73.82 Ar 18 502.9 .26 .467 .144
79.49 K 19 45.42 .26 5.499 .146	83.36 Ca 20 23.85 .26 10.71 .148	83.5 Sc 21 11.47 .27 21.18 .155	85.64 Ti 22 5.584 .27 25.4 .16	87.8 V 23 7.79 .28 26.87 .165	91.5 Cr 24 15.01 .28 20.52 .167	93.8 Mn 25 20.51 .29 14.2 .172	97.59 Fe 26 13.32 .29 20.63 .175	99.84 Co 27 13.35 .3 20.6 .18	104.4 Ni 28 13.37 .3 20.87 .181	105.5 Cu 29 20.57 .3 15.8 .188	106.7 Zn 30 40.81 .31 6.032 .192	110.4 Ga 31 19.81 .31 12.21 .199	113 Ge 32 12.33 .32 16.45 .204	115.9 As 33 19.41 .32 12.49 .208	118 Se 34 25.79 .33 9.302 .215	121.7 Br 35 48.52 .33 5.021 .218	124 Kr 36 498 .34 .486 .224
127.3 Rb 37 71.47 .34 3.417 .228	130.5 Sr 38 35.83 .34 6.858 .232	134 Y 39 14.34 .35 17.34 .235	137.1 Zr 40 6.803 .35 24.61 .239	140.5 Nb 41 7.909 .35 29.64 .243	143.3 Mo 42 8.676 .36 26.46 .248	146.1 Tc 43 9.586 .36 26.35 .253	149.4 Ru 44 14 .37 25.79 .258	152.7 Rh 45 14.28 .37 21.9 .261	155.4 Pd 46 18.3 .37 14.7 .268	159 Ag 47 26.31 .38 11.11 .271	161.3 Cd 48 59.46 .38 4.331 .278	164.5 In 49 27.64 .39 9 37 .283	167.2 Sn 50 4.687 .39 11.61 .29	170.2 Sb 51 25.68 .4 10.12 .296	172.3 Te 52 31.7 .41 8.151 .306	176.6 I 53 64.75 .4 4.06 .305	179.2 Xe 54 451.1 .41 .583 313
182.8 Cs 55 91.19 .41 2.91 .317	185.5 Ba 56 38.56 .42 6.887 .324	189.1 La 57 16.56 .42 16.19 .328	239.7 Hf 72 8.799 .48 23.24 .404	243.2 Ta 73 7.245 .48 29.25 .409	246.7 W 74 9.339 .49 32.18 .415	250.2 Re 75 12.08 .49 29.06 .419	253.4 Os 76 13.36 .49 29.62 .427	257.1 Ir 77 15.23 .5 25.19 .431	260.6 Pt 78 14.99 .5 21.23 .436	264.3 Au 79 22.01 .5 13.87 .44	267.7 Hg 80 128.3 .51 2.444 .447	271 Tl 81 45.89 .51 6.875 .454	274.6 Pb 82 42.73 .52 7.438 .46	278.4 Bi 83 40.05 .52 7.999 .463	282.3 Po 84 58.65 .52 5.508 .466	286.5 At 85 0 .52 0 .467	288.2 Rn 86 440.6 .54 .742 .488
292.2 Fr 87 0 .54 0 .49	295.8 Ra 88 53.73 .54 6.177 .496	299.8 Ac 89 21.14 .55 15.83 .498		192.8 Ce 58 17.32 .42 15.63 .331	196.6 Pr 59 20.45 .43 13.38 .333	199.7 Nd 60 22.39 .43 12.28 .339	203.6 Pm 61 0 .43 0 .341	206.1 Sm 62 36.03 .44 7.71 .35	209.7 Eu 63 41.84 .44 6.699 .354	212.4 Gd 64 18.83 .45 14.9 .363	216 Tb 65 19.42 .45 14.57 .367	219.1 Dy 66 25.99 .46 10.94 .373	222.6 Ho 67 25.35 .46 11.7 .378	226.1 Er 68 24.37 .46 11.84 .383	229.8 Tm 69 33.39 .47 8.711 .386	232.8 Yb 70 50.7 .47 5.764 .394	236.5 Lu 71 18.45 .47 15.97 .398
				303 Th 90 13.36 .55 23.2 .508	307.4 Pa 91 0 .55 0 .507	310.3 U 92 11.79 .56 20.89 .519											

TABLE 26 PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE
PROJECTILE ....Al
Z - NUMBER........ 13
MASS-NUMBER....... 26.98



28.35 H 1 0 .12 0 .113																	16.5 He 2 0 .16 0 .087
16.16 Li 3 4.367 .18 27.21 .088	18.11 Be 4 5.997 .19 44.19 .094											20.31 B 5 1.952 .2 65.94 .099	23.13 C 6 5.292 .2 77.28 .105	24.81 N 7 3.038 .21 45.64 .11	26.51 O 8 6.385 .22 21.78 .115	27.32 F 9 21.48 .23 6.202 .12	29.78 Ne 10 979.7 .24 .141 .125
30.91 Na 11 18.79 .25 7.179 .131	33.21 Mg 12 14.74 .25 9.418 .135											34.55 Al 13 7.589 .26 19.78 .141	36.94 Si 14 4.001 .26 26.35 .146	38.22 P 15 7.485 .27 18.42 .152	40.58 S 16 9.435 .27 15 .156	41.68 Cl 17 19.77 .28 6.972 .164	42.43 Ar 18 352.9 .3 .375 .173
45.64 K 19 31.88 .29 4.404 .174	48.02 Ca 20 16.7 .3 8.605 .178	48.68 Sc 21 7.973 .31 17.29 .188	50.27 Ti 22 3.865 .32 20.92 .196	51.88 V 23 5.37 .32 22.34 .203	54.21 Cr 24 10.33 .33 17.11 .207	55.89 Mn 25 14.07 .33 11.94 .214	58.28 Fe 26 9.125 .34 17.4 .218	59.95 Co 27 9.114 .34 17.53 .226	62.72 Ni 28 9.121 .34 17.75 .227	63.87 Cu 29 13.98 .35 13.61 .238	65.99 Zn 30 27.69 .36 5.224 .244	67.42 Ga 31 13.4 .37 10.69 .254	69.29 Ge 32 8.326 .38 14.51 .262	71.33 As 33 13.09 .38 11.08 .268	72.97 Se 34 17.35 .39 8.338 .278	75.36 Br 35 32.62 .39 4.512 .282	77.09 Kr 36 334.2 .4 .44 .292
79.33 Rb 37 47.92 .4 3.11 .297	81.48 Sr 38 24 .41 6.274 .303	83.83 Y 39 9.596 .41 15.91 .307	85.96 Zr 40 4.549 .42 22.69 .314	88.23 Nb 41 5.285 .42 27.44 .319	90.24 Mo 42 5.792 .43 24.65 .327	92.27 Tc 43 6.394 .43 24.71 .335	94.5 Ru 44 9.333 .44 24.29 .341	96.77 Rh 45 9.51 .44 20.71 .347	98.75 Pd 46 12.18 .45 14 .356	101.1 Ag 47 17.5 .45 10.61 .36	103 Cd 48 39.54 .46 4.174 .372	105.2 In 49 18.37 .47 9.072 .379	107.2 Sn 50 3.114 .47 11.32 .389	109.3 Sb 51 17.06 .48 9.928 .398	111 Te 52 21.05 .49 8.081 .413	113.8 I 53 42.98 .49 4.02 .412	115.8 Xe 54 299.4 .5 .581 .424
118.2 Cs 55 60.5 .5 2.911 .429	120.2 Ba 56 25.58 .51 6.943 .44	122.7 La 57 10.98 .52 16.36 .445	158.3 Hf 72 5.84 .59 24.92 .558	160.7 Ta 73 4.809 .6 31.47 .565	163.2 W 74 6.2 .61 34.75 .573	165.7 Re 75 8.023 .61 31.48 .58	168 Os 76 8.874 .62 32.26 .591	170.6 Ir 77 10.12 .62 27.5 .597	173 Pt 78 9.962 .63 23.26 .605	175.6 Au 79 14.63 .63 15.23 .611	178 Hg 80 85.28 .64 2.695 .621	180.4 Tl 81 30.52 .65 7.616 .632	183 Pb 82 28.42 .65 8.267 .64	185.6 Bi 83 26.65 .66 8.908 .645	188.3 Po 84 39.02 .66 6.142 .649	191.1 At 85 0 .66 0 .65	192.8 Rn 86 293.6 .68 .838 .681
195.5 Fr 87 0 .68 0 .685	198 Ra 88 35.82 .69 7.01 .693	200.8 Ac 89 14.09 .69 17.98 .697		125.2 Ce 58 11.49 .52 15.83 .449	127.8 Pr 59 13.56 .52 13.57 .452	130 Nd 60 14.85 .53 12.52 .461	132.6 Pm 61 0 .53 0 .464	134.5 Sm 62 23.89 .54 7.938 .478	137 Eu 63 27.74 .54 6.914 .483	139 Gd 64 12.49 .55 15.5 .497	141.5 Tb 65 12.87 .56 15.2 .503	143.8 Dy 66 17.24 .56 11.47 .512	146.2 Ho 67 16.81 .57 11.89 .519	148.7 Er 68 16.16 .57 12.5 .526	151.2 Tm 69 22.15 .58 9.22 .531	153.4 Yb 70 33.64 .58 6.136 .542	155.9 Lu 71 12.24 .59 17.04 .548
				203.2 Th 90 8.914 .7 26.49 .711	206.1 Pa 91 0 .7 0 .709	208.3 U 92 7.871 .71 24 .728											

TABLE **27** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Fe
Z - NUMBER........ 26
MASS-NUMBE:....... 55.85

77.33 ← EL/1000
Symbol → Be 4 ← Atomic Number
P → 9.856 .16 ← Alpha
Threshold Energy(eV) → 84.54 .094 ← Inelastic Coefficient k in LSS Unit

141 H 1 0 .11 0 .128																	76.94 He 2 0 .14 0 .094
71.46 Li 3 7 .15 52.95 .091	77.33 Be 4 9.856 .16 84.54 .094											84.29 B 5 3.277 .17 124.3 .097	94.16 C 6 9.017 .17 144.4 .101	98.37 N 7 5.278 .18 84 .104	102.6 O 8 11.3 .18 39.5 .106	102.6 F 9 38.88 .19 11.01 .108	110.3 Ne 10 1792 .19 .249 .111
111.6 Na 11 35.02 .2 12.4 .113	118.4 Mg 12 27.73 .2 16.13 .116											120.6 Al 13 14.5 .21 33.29 .118	127.7 Si 14 7.701 .21 44.06 .121	129.5 P 15 14.61 .22 30.24 .124	136.4 S 16 18.54 .22 24.47 .126	137.3 Cl 17 39.41 .22 11.15 .129	136.5 Ar 18 714.8 .23 .584 .133
147 K 19 64.55 .23 6.896 .135	153.7 Ca 20 33.98 .23 13.4 .137	152.4 Sc 21 16.46 .24 26.22 .141	155.3 Ti 22 8.05 .25 31.24 .144	158.2 V 23 11.28 .25 32.85 .148	164.5 Cr 24 21.77 .25 25.03 .15	167.7 Mn 25 29.86 .26 17.21 .154	174.1 Fe 26 19.43 .26 24.97 .156	177.2 Co 27 19.53 .26 24.78 .16	185.2 Ni 28 19.57 .26 25.12 .161	185.8 Cu 29 30.25 .27 18.84 .166	190.9 Zn 30 60.14 .27 7.167 .169	192.7 Ga 31 29.3 .28 14.39 .174	196.5 Ge 32 18.28 .28 19.29 .177	201 As 33 28.[illegible] .29 14.58 .181	203.7 Se 34 38.42 .29 10.79 .186	209.7 Br 35 72.36 .29 5.813 .188	212.7 Kr 36. 744.5 .3 .559 .192
218 Rb 37 107 .3 3.919 .195	222.8 Sr 38 53.71 .3 7.837 .198	228.5 Y 39 21.51 .3 19.78 .201	233.2 Zr 40 10.22 .31 27.95 .204	238.5 Nb 41 11.9 .31 33.58 .207	242.5 Mo 42 13.07 .31 29.83 .211	246.7 Tc 43 14.46 .32 29.58 .215	251.7 Ru 44 21.15 .32 28.85 .218	256.8 Rh 45 21.58 .32 24.43 .221	260.6 Pd 46 27.7 .33 16.31 .225	266.2 Ag 47 39.86 .33 12.31 .228	269.2 Cd 48 90.22 .33 4.764 .233	274.1 In 49 41.98 .34 10.27 .237	277.9 Sn 50 7.127 .34 12.66 .242	282.2 Sb 51 39.09 .34 10.99 .246	284.7 Te 52 48.31 .35 8.778 .253	291.8 I 53 98.69 .35 4.377 .253	295.4 Xe 54 688.3 .35 .625 .259
300.9 Cs 55 139.2 .36 3.112 .262	304.6 Ba 56 58.91 .36 7.324 .268	310.2 La 57 25.31 .36 17.18 .27	385.9 Hf 72 13.53 .41 23.54 .328	391.1 Ta 73 11.14 .41 29.55 .332	396.2 W 74 14.37 .41 32.41 .336	401.6 Re 75 18.59 .41 29.2 .339	406.2 Os 76 20.56 .42 29.64 .345	411.7 Ir 77 23.43 .42 25.15 .348	416.9 Pt 78 23.08 .42 21.14 .352	422.6 Au 79 33.89 .43 13.78 .355	427.5 Hg 80 197.5 .43 2.42 .36	432.3 Tl 81 70.67 .43 6.783 .366	437.5 Pb 82 65.8 .44 7.319 .37	443.3 Bi 83 61.69 .44 7.856 .373	449.4 Po 84 90.34 .44 5.405 .375	455.9 At 85 0 .44 0 .375	457.3 Rn 86 678.5 .45 .72 .391
463.4 Fr 87 0 .45 0 .393	468.7 Ra 88 82.77 .45 5.972 .397	474.9 Ac 89 32.57 .46 15.29 .399		316 Ce 58 26.48 .36 16.56 .272	322.1 Pr 59 31.29 .37 14.16 .274	326.6 Nd 60 34.28 .37 12.94 .279	332.7 Pm 61 0 .37 0 .28	336 Sm 62 55.21 .38 8.066 .287	341.6 Eu 63 64.13 .38 6.995 .29	345.1 Gd 64 28.88 .38 15.46 .297	350.6 Tb 65 29.79 .39 15.09 .3	355.1 Dy 66 39.9 .39 11.28 .305	360.4 Ho 67 38.92 .39 11.62 .308	365.6 Er 68 37.42 .39 12.14 .312	371.3 Tm 69 51.3 .4 8.918 .314	375.6 Yb 70 77.92 .4 5.874 .32	381.2 Lu 71 28.36 .4 16.24 .323
				479.4 Th 90 20.58 .46 22.31 .406	486.4 Pa 91 0 .46 0 .405	490.2 U 92 18.16 .47 19.98 .415											

TABLE **28** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Ni
Z - NUMBER........ 28
MASS-NUMBER....... 58.71

163 H 1 0 .11 0 .13																	88.66 He 2 0 .14 0 .095
82.1 Li 3 7.357 .15 55.5 .092	88.64 Be 4 10.37 .16 88.54 .095											96.45 B 5 3.454 .16 130.1 .098	107.6 C 6 9.514 .17 151 .102	112.2 N 7 5.576 .17 87.81 .104	116.9 O 8 11.95 .18 41.26 .107	116.6 F 9 41.18 .19 11.49 .108	125.3 Ne 10 1899 .19 .26 .111
126.6 Na 11 37.17 .2 12.92 .113	134.2 Mg 12 29.45 .2 16.8 .116											136.5 Al 13 15.42 .21 34.65 .118	144.4 Si 14 8.194 .21 45.83 .121	146.2 P 15 15.57 .21 31.43 .124	153.8 S 16 19.76 .22 25.43 .126	154.6 Cl 17 42.04 .22 11.57 .129	153.5 Ar 18 763.5 .23 .606 .133
165.4 K 19 68.95 .23 7.15 .134	172.8 Ca 20 36.31 .23 13.89 .137	171 Sc 21 17.61 .24 27.14 .141	174.1 Ti 22 8.617 .24 32.31 .144	177.3 V 23 12.08 .25 33.94 .147	184.2 Cr 24 23.33 .25 25.85 .15	187.7 Mn 25 32.02 .25 17.77 .153	194.7 Fe 26 20.84 .25 25.77 .155	198 Co 27 20.97 .26 25.55 .159	207 Ni 28 21 .26 25.9 .16	207.4 Cu 29 32.5 .27 19.4 .165	212.9 Zn 30 64.63 .27 7.378 .167	214.7 Ga 31 31.5 .27 14.8 .172	218.9 Ge 32 19.67 .28 19.82 .176	223.8 As 33 31.03 .28 14.97 .179	226.5 Se 34 41.36 .29 11.07 .183	233.2 Br 35 77.92 .29 5.964 .185	236.4 Kr 36 802.1 .29 .572 .19
242.2 Rb 37 115.3 .29 4.015 .193	247.4 Sr 38 57.89 .3 8.026 .196	253.7 Y 39 23.19 .3 20.25 .198	258.8 Zr 40 11.02 .3 28.61 .201	264.6 Nb 41 12.83 .3 34.35 .204	268.9 Mo 42 14.1 .31 30.5 .208	273.4 Tc 43 15.61 .31 30.22 .212	278.9 Ru 44 22.83 .31 29.46 .215	284.5 Rh 45 23.3 .32 24.94 .218	288.5 Pd 46 29.92 .32 16.64 .222	294.7 Ag 47 43.05 .32 12.55 .224	297.8 Cd 48 97.48 .33 4.854 .23	303.1 In 49 45.37 .33 10.46 .233	307.2 Sn 50 7.703 .33 12.88 .238	311.9 Sb 51 42.26 .34 11.18 .242	314.4 Te 52 52.25 .34 8.918 .249	322.3 I 53 106.7 .34 4.447 .249	326.1 Xe 54 744.6 .35 .634 .255
332.1 Cs 55 150.6 .35 3.158 .257	336.1 Ba 56 63.74 .35 7.427 .263	342.1 La 57 27.39 .36 17.42 .265	424.2 Hf 72 14.66 .4 23.71 .321	429.9 Ta 73 12.08 .4 29.76 .325	435.4 W 74 15.57 .4 32.62 .329	441.2 Re 75 20.15 .4 29.38 .333	446.1 Os 76 22.29 .41 29.81 .338	452.2 Ir 77 25.41 .41 25.29 .341	457.8 Pt 78 25.02 .41 21.24 .345	464 Au 79 36.75 .42 13.85 .348	469.2 Hg 80 214.2 .42 2.43 .353	474.4 Tl 81 76.64 .42 6.807 .358	480.1 Pb 82 71.36 .43 7.342 .362	486.4 Bi 83 66.9 .43 7.88 .365	493 Po 84 97.99 .43 5.42 .367	500.2 At 85 0 .43 0 .367	501.4 Rn 86 736 .44 .72 .382
508.1 Fr 87 0 .44 0 .384	513.9 Ra 88 89.78 .44 5.976 .388	520.6 Ac 89 35.33 .44 15.3 .39															
				348.5 Ce 58 28.66 .36 16.79 .268	355.2 Pr 59 33.87 .36 14.36 .269	360 Nd 60 37.1 .36 13.11 .274	366.7 Pm 61 0 .36 0 .275	370.2 Sm 62 59.79 .37 8.162 .282	376.3 Eu 63 69.45 .37 7.076 .285	379.9 Gd 64 31.28 .37 15.02 .291	386 Tb 65 32.27 .38 15.25 .294	390.9 Dy 66 43.22 .38 11.39 .299	396.5 Ho 67 42.16 .38 11.73 .302	402.3 Er 68 40.55 .39 12.25 .306	408.4 Tm 69 55.59 .39 8.997 .308	413.1 Yb 70 84.44 .39 5.922 .314	419.1 Lu 71 30.74 .39 16.37 .317
				525.4 Th 90 22.33 .45 22.31 .397	533.[illegible] Pa 91 0 .45 0 .396	537.1 U 92 19.7 .46 19.97 .405											

EL/1000 — 88.64
Atomic Number — 4
Symbol — Be
Alpha — .16
P — 10.37
Threshold Energy(eV) — 88.54
Inelastic Coefficient k in LSS Unit — .095

TABLE **29** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Cu
Z - NUMBER........ 29
MASS-NUMBER.. .... 63.55

99.28 Be 4 10.58 .16 95.31 .094	
99.28	EL/1000
Be	Symbol
4	Atomic Number
10.58	P
.16	Alpha
95.31	Threshold Energy(eV)
.094	Inelastic Coefficient k in LSS Unit

184.5 H 1 0 .11 0 .131																	99.9 He 2 0 .13 0 .095
92.18 Li 3 7.495 .15 59.82 .092	99.28 Be 4 10.58 .16 95.31 .094											107.8 B 5 3.528 .16 139.9 .097	120.1 C [illegible] 9.727 .17 162.3 .101	125 N 7 5.708 .17 94.26 .103	130 O 8 12.25 .18 44.25 .105	129.3 F 9 42.29 .18 12.3 .106	138.8 Ne 10 1952 .19 .278 .109
139.9 Na 11 38.26 .19 13.81 .111	148.2 Mg 12 30.34 .2 17.94 .114											150.4 Al 13 15.9 .2 36.94 .116	159 Si 14 8.457 .2 48.84 .118	160.8 P 15 16.09 .21 33.45 .12	169 S 16 20.43 .21 27.05 .122	169.5 Cl 17 43.53 .22 12.29 .125	167.9 Ar 18 791.9 .22 .642 .128
181 K 19 71.5 .22 7.581 .13	189 Ca 20 37.67 .22 14.72 .132	186.6 Sc 21 18.3 .23 28.7 .136	189.7 Ti 22 8.963 .24 34.12 .138	192.9 V 23 12.58 .24 35.8 .141	200.3 Cr 24 24.3 .24 27.26 .144	203.9 Mn 25 33.38 .25 18.71 .147	211.5 Fe 26 21.73 .25 27.13 .149	214.8 Co 27 21.87 .25 26.87 .152	224.5 Ni 28 21.91 .25 27.24 .153	224.6 Cu 29 33.95 .26 20.36 .157	230.4 Zn 30 67.53 .26 7.739 .16	232.1 Ga 31 32.95 .27 15.49 .164	236.4 Ge 32 20.58 .27 20.73 .167	241.5 As 33 32.48 .27 15.65 .17	244.2 Se 34 43.33 .28 11.55 .174	251.4 Br 35 81.64 .28 6.222 .176	254.5 Kr 36 840.9 .28 .596 .18
260.6 Rb 37 120.9 .29 4.181 .183	266.2 Sr 38 60.73 .29 8.352 .185	272.8 Y 39 24.34 .29 21.06 .187	278.1 Zr 40 11.57 .29 29.73 .19	284.2 Nb 41 13.47 .29 35.68 .193	288.7 Mo 42 14.81 .3 31.65 .196	293.4 Tc 43 16.4 .3 31.33 .2	299.1 Ru 44 23.99 .3 30.53 .203	305 Rh 45 24.49 .31 25.82 .205	309.1 Pd 46 31.46 .31 17.21 .209	315.6 Ag 47 45.28 .31 12.97 .211	318.7 Cd 48 102.6 .32 5.011 .216	324.2 In 49 47.74 .32 10.79 .219	328.4 Sn 50 8.109 .32 13.27 .224	333.3 Sb 51 44.5 .33 11.51 .227	335.7 Te 52 55.03 .33 9.167 .234	344.1 I 53 112.4 .33 4.572 .234	348 Xe 54 784.5 .34 .651 .239
354.3 Cs 55 158.7 .34 3.241 .241	358.3 Ba 56 67.18 .34 7.614 .246	364.7 La 57 28.87 .34 17.84 .249	450.2 Hf 72 15.48 .38 24.06 .299	456.1 Ta 73 12.75 .39 30.17 .303	461.8 W 74 16.44 .39 33.05 .306	467.9 Re 75 21.28 .39 29.75 .309	473 Os 76 23.54 .39 30.16 .314	479.3 Ir 77 26.84 .4 25.57 .317	485.2 Pt 78 26.43 .4 21.47 .321	491.6 Au 79 38.82 .4 13.99 .323	497 Hg 80 226.2 .4 2.453 .328	502.3 Tl 81 80.96 .41 6.866 .332	508.3 Pb 82 75.39 .41 7.401 .336	514.8 Bi 83 70.69 .41 7.94 .339	521.8 Po 84 103.5 .41 5.46 .34	529.4 At 85 0 .41 0 .341	530.3 Rn 86 777.7 .42 .724 .354
537.3 Fr 87 0 .42 0 .356	543.3 Ra 88 94.87 .43 6 .36	550.4 Ac 89 37.33 .43 15.36 .362		371.4 Ce 58 30.22 .35 17.2 .251	378.5 Pr 59 35.71 .35 14.7 .252	383.5 Nd 60 39.13 .35 13.41 .256	390.5 Pm 61 0 .35 0 .258	394 Sm 62 63.06 .36 8.338 .264	400.4 Eu 63 73.26 .36 7.225 .266	404.1 Gd 64 33 .36 15.93 .272	410.5 Tb 65 34.05 .36 15.54 .274	415.5 Dy 66 45.61 .37 11.6 .279	421.4 Ho 67 44.5 .37 11.94 .282	427.4 Er 68 42.8 .37 12.47 .285	433.8 Tm 69 58.68 .37 9.148 .287	438.6 Yb 70 89.14 .38 6.016 .292	444.9 Lu 71 32.45 .38 16.62 .295
				555.3 Th 90 23.59 .43 22.37 .368	563.4 Pa 91 0 .43 0 .367	567.4 U 92 20.82 .44 20 .376											

TABLE **30** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Kr
Z - NUMBER........ 36
MASS-NUMBER....... 83.8

167 ← EL/1000
Be ← Symbol
4 ← Atomic Number
12.11 ← P
.15 ← Alpha
123.6 ← Threshold Energy(eV)
.095 ← Inelastic Coefficient k in LSS Unit

321.2 H 1 0 .11 0 .136																	171.6 He 2 0 .13 0 .098
156.4 Li 3 8.534 .14 77.89 .093	167 Be 4 12.11 .15 123.6 .095											180.1 B 5 4.057 .15 181 .098	199.6 C 6 11.22 .16 209.5 .102	206.4 N 7 6.618 .16 121.2 .103	213.2 O 8 14.26 .17 56.73 .104	210.3 F 9 49.55 .17 15.69 .104	224.8 Ne 10 2294 .18 .354 .107
225 Na 11 45.19 .18 17.51 .108	237.3 Mg 12 35.94 .18 22.7 .11											239.4 Al 13 18.93 .19 46.56 .111	252.3 Si 14 10.09 .19 61.46 .114	253.5 P 15 19.28 .19 41.92 .115	265.8 S 16 24.54 .2 33.84 .117	264.8 Cl 17 52.54 .2 15.3 .118	260.1 Ar 18 961.4 .21 .794 .12
280.6 K 19 86.78 .21 9.391 .122	292.4 Ca 20 45.8 .21 18.21 .124	286.4 Sc 21 22.38 .21 35.28 .126	289.9 Ti 22 11 .22 41.78 .128	293.4 V 23 15.48 .22 43.67 .13	304.1 Cr 24 29.95 .22 33.2 .131	308.2 Mn 25 41.27 .23 22.71 .134	319.1 Fe 26 26.9 .23 32.88 .135	322.8 Co 27 27.16 .23 32.44 .138	337.4 Ni 28 27.22 .23 32.9 .139	335.6 Cu 29 42.33 .24 24.45 .142	343.4 Zn 30 84.35 .24 9.273 .144	344.3 Ga 31 41.29 .24 18.47 .146	349.5 Ge 32 25.85 .25 24.64 .149	356.1 As 33 40.87 .25 18.55 .151	358.7 Se 34 54.67 .25 13.63 .154	368.8 Br 35 103.1 .25 7.334 .155	372 Kr 36 1064 .26 .7 .158
380.4 Rb 37 153.2 .26 4.899 .16	387.7 Sr 38 77.06 .26 9.763 .162	396.8 Y 39 30.91 .26 24.58 .164	403.7 Zr 40 14.72 .27 34.62 .166	412 Nb 41 17.15 .27 41.48 .168	417.4 Mo 42 18.89 .27 36.68 .171	423.2 Tc 43 20.94 .27 36.2 .173	430.6 Ru 44 30.67 .28 35.19 .175	438.5 Rh 45 31.34 .28 29.71 .177	443.4 Pd 46 40.32 .28 19.73 .18	452.2 Ag 47 58.07 .28 14.86 .182	455.3 Cd 48 131.8 .29 5.714 .185	462.3 In 49 61.4 .29 12.28 .188	467.1 Sn 50 10.44 .29 15.04 .191	473.2 Sb 51 57.37 .29 13.01 .194	475.1 Te 52 71.08 .3 10.31 .198	487 I 53 145.2 .3 5.143 .198	491.3 Xe 54 1015 .3 .729 .202
499.8 Cs 55 205.4 .3 3.627 .204	504.3 Ba 56 87.04 .31 8.486 .208	512.8 La 57 37.42 .31 19.86 .209	621.9 Hf 72 20.25 .34 25.93 .247	629.6 Ta 73 16.68 .34 32.47 .25	636.8 W 74 21.52 .34 35.49 .253	644.6 Re 75 27.87 .35 31.89 .255	650.7 Os 76 30.84 .35 32.23 .259	658.9 Ir 77 35.17 .35 27.29 .261	666.4 Pt 78 34.65 .35 22.86 .263	674.8 Au 79 50.9 .35 14.87 .265	681.4 Hg 80 296.8 .36 2.602 .269	688 Tl 81 106.3 .36 7.263 .272	695.5 Pb 82 98.97 .36 7.814 .275	704.1 Bi 83 92.82 .36 8.372 .277	713.3 Po 84 136 .36 5.753 .278	723.6 At 85 0 .36 0 .279	722.6 Rn 86 1022 .37 .757 .289
731.9 Fr 87 0 .37 0 .29	739.5 Ra 88 124.8 .38 6.254 .293	748.8 Ac 89 49.1 .38 16 .294		521.9 Ce 58 39.19 .31 19.12 .211	531.5 Pr 59 46.32 .31 16.34 .212	537.6 Nd 60 50.8 .31 14.86 .215	547.3 Pm 61 0 .31 0 .216	550.8 Sm 62 82.01 .32 9.192 .221	559.3 Eu 63 95.31 .32 7.954 .223	563.2 Gd 64 42.98 .32 17.46 .227	571.6 Tb 65 44.36 .32 17.01 .229	577.7 Dy 66 59.47 .33 12.66 .232	585.3 Ho 67 58.05 .33 13 .234	593 Er 68 55.86 .33 13.56 .237	601.5 Tm 69 76.62 .33 9.934 .239	607.2 Yb 70 116.5 .34 6.512 .242	615.5 Lu 71 42.42 .34 17.96 .244
				754.6 Th 90 31.04 .38 23.23 .299	765.7 Pa 91 0 .38 0 .299	769.9 U 92 27.4 .38 20.68 .305											

TABLE **31** PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Xe
Z - NUMBER........ 54
MASS-NUMBER....... 131.3

423.8 ← EL/1000
Symbol → Be 4 ← Atomic Number
P → 15.53 .14 ← Alpha
Threshold Energy(eV) → 190.1 .1 ← Inelastic Coefficient k in LSS Unit

851.8 H 1 0 .1 0 .147																	447.1 He 2 0 .12 0 .105
401.2 Li 3 10.88 .13 120.3 .099	423.8 Be 4 15.53 .14 190.1 .1											452.6 B 5 5.231 .14 277.3 .102	498.4 C 6 14.54 .14 320.2 .106	510.5 N 7 8.625 .15 184.6 .107	522.8 O 8 18.7 .15 86.04 .107	509.8 F 9 65.44 .16 23.66 .106	542.1 Ne 10 3042 .16 .533 .108
537.2 Na 11 60.35 .16 26.21 .108	563.6 Mg 12 48.19 .17 33.9 .11											563.5 Al 13 25.54 .17 69.2 .11	591.3 Si 14 13.66 .17 91.16 .112	588.8 P 15 26.27 .17 61.85 .113	614.7 S 16 33.55 .18 49.84 .114	606.8 Cl 17 72.31 .18 22.4 .114	589.2 Ar 18 1334 .19 1.154 .114
636 K 19 120.4 .18 13.67 .117	660.6 Ca 20 63.71 .19 26.46 .118	639.6 Sc 21 31.39 .19 50.84 .119	642.8 Ti 22 15.51 .19 59.92 .12	646 V 23 21.94 .2 62.32 .121	667.7 Cr 24 42.55 .2 47.3 .122	672.3 Mn 25 58.9 .2 32.2 .123	694.5 Fe 26 38.47 .2 46.57 .125	698.1 Co 27 39.03 .2 45.73 .126	729.3 Ni 28 39.13 .2 46.39 .127	718.9 Cu 29 61.25 .21 34.22 .128	733 Zn 30 122.4 .21 12.94 .13	729.2 Ga 31 60.25 .21 25.62 .131	736.4 Ge 32 37.85 .22 34.02 .132	747.4 As 33 60.03 .22 25.53 .134	748.1 Se 34 80.67 .22 18.65 .135	767.6 Br 35 152.4 .22 10.02 .136	769.8 Kr 36 1580 .23 .952 .138
784.9 Rb 37 227.8 .23 6.644 .139	797.2 Sr 38 114.9 .23 13.2 .141	814.2 Y 39 46.15 .23 33.19 .142	825.6 Zr 40 22.03 .23 46.59 .143	840.3 Nb 41 25.73 .23 55.7 .145	847.9 Mo 42 28.41 .23 49.05 .146	856.1 Tc 43 31.59 .24 48.22 .148	868.8 Ru 44 46.36 .24 46.75 .149	882.4 Rh 45 47.46 .24 39.38 .15	888.4 Pd 46 61.23 .24 26.03 .152	904.3 Ag 47 88.31 .24 19.57 .153	905.8 Cd 48 201.1 .25 7.481 .155	917.3 In 49 93.88 .25 16.03 .157	923 Sn 50 16.01 .25 19.55 .159	931.9 Sb 51 88.15 .25 16.83 .16	930.3 Te 52 109.6 .26 13.25 .163	953.8 I 53 224 .26 6.616 .164	958.3 Xe 54 1569 .26 .933 .166
973.1 Cs 55 318 .26 4.632 .167	978 Ba 56 135.1 .26 10.78 .169	992.8 La 57 58.16 .26 25.19 .17	1166 Hf 72 32.1 .29 31.51 .195	1178 Ta 73 26.48 .29 39.35 .197	1190 W 74 34.2 .29 42.88 .198	1202 Re 75 44.32 .29 38.43 .2	1211 Os 76 49.11 .29 38.69 .202	1224 Ir 77 56.05 .29 32.69 .204	1236 Pt 78 55.27 .3 27.32 .205	1250 Au 79 81.26 .3 17.74 .207	1260 Hg 80 474.4 .3 3.092 .209	1269 Tl 81 170 .3 8.599 .211	1281 Pb 82 158.5 .3 9.226 .213	1295 Bi 83 148.7 .3 9.868 .214	1311 Po 84 218 .3 6.774 .215	1330 At 85 0 .3 0 .216	1320 Rn 86 1644 .31 .881 .221
1336 Fr 87 0 .31 0 .222	1348 Ra 88 200.8 .31 7.255 .224	1364 Ac 89 79.08 .31 18.54 .225		1009 Ce 58 60.96 .26 24.22 .171	1027 Pr 59 72.11 .26 20.67 .172	1035 Nd 60 79.23 .27 18.74 .174	1053 Pm 61 0 .27 0 .175	1055 Sm 62 128.3 .27 11.51 .178	1070 Eu 63 149.3 .27 9.942 .179	1073 Gd 64 67.48 .27 21.7 .182	1087 Tb 65 69.71 .28 21.1 .183	1096 Dy 66 93.62 .28 15.64 .185	1108 Ho 67 91.48 .28 16.02 .187	1121 Er 68 88.12 .28 16.66 .188	1135 Tm 69 121 .28 12.19 .189	1143 Yb 70 184.2 .28 7.956 .192	1157 Lu 71 67.15 .28 21.9 .193
				1371 Th 90 50.04 .32 26.8 .228	1392 Pa 91 0 .32 0 .228	1395 U 92 44.24 .32 23.73 .232											

TABLE 32 PARAMETERS OF THE THIRD MATSUNAMI EMPIRICAL FORMUALA AT NORMAL INCIDENCE

PROJECTILE ....Hg
Z - NUMBER........ 80
MASS-NUMBER....... 200.5

1050 ← EL/1000
Symbol → Be 4 ← Atomic Number
P → 19.63 .13 ← Alpha
Threshold Energy(eV) → 287 .106 ← Inelastic Coefficient k in LSS Unit

2175 H 1 0 .1 0 .159																	1128 He 2 0 .11 0 .112
1002 Li 3 13.71 .12 182 .105	1050 Be 4 19.63 .13 287 .106											1114 B 5 6.635 .13 417.7 .108	1221 C 6 18.5 .13 481.6 .112	1243 N 7 11.01 .14 276.9 .112	1265 O 8 23.96 .14 128.8 .112	1223 F 9 84.24 .14 35.29 .11	1295 Ne 10 3927 .15 .793 .113
1275 Na 11 78.26 .15 38.89 .112	1332 Mg 12 62.67 .15 50.23 .114											1323 Al 13 33.36 .15 102.2 .113	1384 Si 14 17.89 .16 134.5 .115	1369 P 15 34.55 .16 90.94 .114	1425 S 16 44.23 .16 73.18 .116	1396 Cl 17 95.8 .16 32.77 .115	1344 Ar 18 1778 .17 1.68 .114
1451 K 19 160.5 .17 19.91 .117	1503 Ca 20 85.09 .17 38.51 .119	1443 Sc 21 42.19 .17 73.6 .117	1442 Ti 22 20.92 .17 86.47 .118	1441 V 23 29.73 .18 89.64 .118	1486 Cr 24 57.76 .18 67.97 .119	1489 Mn 25 80.26 .18 46.13 .12	1535 Fe 26 52.51 .18 66.64 .121	1535 Co 27 53.46 .18 65.23 .121	1602 Ni 28 53.63 .18 66.19 .123	1568 Cu 29 84.4 .19 48.59 .123	1594 Zn 30 169.1 .19 18.34 .124	1575 Ga 31 83.6 .19 36.15 .124	1584 Ge 32 52.69 .19 47.87 .125	1602 As 33 83.79 .19 35.84 .126	1595 Se 34 113 .2 26.08 .127	1634 Br 35 213.8 .2 14 .128	1630 Kr 36 2225 .2 1.324 .128
1658 Rb 37 321.5 .2 9.232 .129	1679 Sr 38 162.5 .2 18.31 .13	1712 Y 39 65.37 .2 45.96 .131	1730 Zr 40 31.27 .2 64.39 .132	1757 Nb 41 36.59 .21 76.85 .133	1767 Mo 42 40.51 .21 67.48 .134	1778 Tc 43 45.16 .21 66.16 .135	1799 Ru 44 66.4 .21 64.04 .136	1823 Rh 45 68.1 .21 53.84 .137	1828 Pd 46 88.1 .21 35.48 .138	1858 Ag 47 127.3 .21 26.64 .139	1852 Cd 48 290.7 .22 10.14 .14	1871 In 49 136 .22 21.68 .141	1875 Sn 50 23.26 .22 26.36 .142	1868 Sb 51 128.3 .22 22.64 .143	1874 Te 52 160.2 .22 17.72 .144	1922 I 53 327.3 .22 8.858 .145	1923 Xe 54 2299 .23 1.245 .146
1950 Cs 55 466.5 .23 6.171 .147	1952 Ba 56 198.8 23 14.31 .148	1979 La 57 85.66 .23 33.39 .149	2252 Hf 72 48.34 .25 40.49 .165	2272 Ta 73 39.92 .25 50.46 .166	2289 W 74 51.62 .25 54.87 .167	2309 Re 75 66.98 .25 49.1 .168	2320 Os 76 74.34 .25 49.28 .17	2343 Ir 77 84.93 .25 41.58 .171	2361 Pt 78 83.86 .26 34.67 .172	2384 Au 79 123.4 .26 22.48 .173	2398 Hg 80 721.4 .26 3.909 .174	2410 Tl 81 258.9 .26 10.84 .176	2428 Pb 82 241.6 .26 11.61 .177	2453 Bi 83 226.9 .26 12.4 .178	2481 Po 84 332.8 .26 8.505 .178	2515 At 85 0 .26 0 .179	2483 Rn 86 2519 .27 1.097 .182
2511 Fr 87 0 .27 0 .183	2529 Ra 88 308.3 .27 9.008 .184	2557 Ac 89 121.4 .27 23 .185		2008 Ce 58 89.87 .23 32.07 .15	2041 Pr 59 106.4 .23 27.36 .151	2053 Nd 60 117.1 .23 24.73 .152	2086 Pm 61 0 .23 0 .153	2082 Sm 62 190.4 .24 15.11 .154	2108 Eu 63 221.7 .24 13.04 .155	2105 Gd 64 100.5 .24 28.34 .156	2131 Tb 65 103.9 .24 27.52 .157	2142 Dy 66 139.8 .24 20.34 .159	2162 Ho 67 136.8 .24 20.8 .16	2183 Er 68 132 .24 21.59 .161	2208 Tm 69 181.4 .24 15.78 .162	2216 Yb 70 276.7 .25 10.27 .163	2239 Lu 71 101 .25 28.22 .164
				2565 Th 90 76.97 .27 33.14 .187	2604 Pa 91 0 .27 0 .187	2601 U 92 68.18 .27 29.23 .189											

Captions of Figures

Fig. 1 Best-fit values of f for light-ion sputtering, where the ratio of f to $\sqrt{U_s}$ is plotted as a function of the mass ratio M_2/M_1, the solid line is calculated from eq.(8).

Fig. 2 Best-fit values of θ_{opt} for light-ion sputtering, where the best-fit θ_{opt}'s are plotted against η and the solid line is the theoretical curve calculated from Eq. (12).

Fig. 3 The best-fit values of f for relatively high-energy heavy ion sputtering, where the solid line corresponds to Sigmund f_s of $m = 1/3$.

Fig. 4 The ratios of the best-fit f's to Sigmund f_s as a function of $\eta = 1 - (E_{th}/E)^{\frac{1}{2}}$, where the solid line corresponds to Eq. (17).

Fig. 5 The best-fit values of $90° - \theta_{opt}$ as a function of ψ, where the solid line corresponds to

$$\theta_{opt} = 90° - 286\,\psi^{0.45}\ .$$

Figs. 6 through 58

The normalized sputtering yield $Y(\theta)/Y(0)$ as a function of the angle of incidence, where the solid lines in these figures are best-fit curves to the present empirical formula, and the solid lines with x marks show the results calculated by putting the average values of f and Σ into the present empirical formula. The average parameters of f and Σ are easily calculated using the parameters listed in Table 5 through 18.

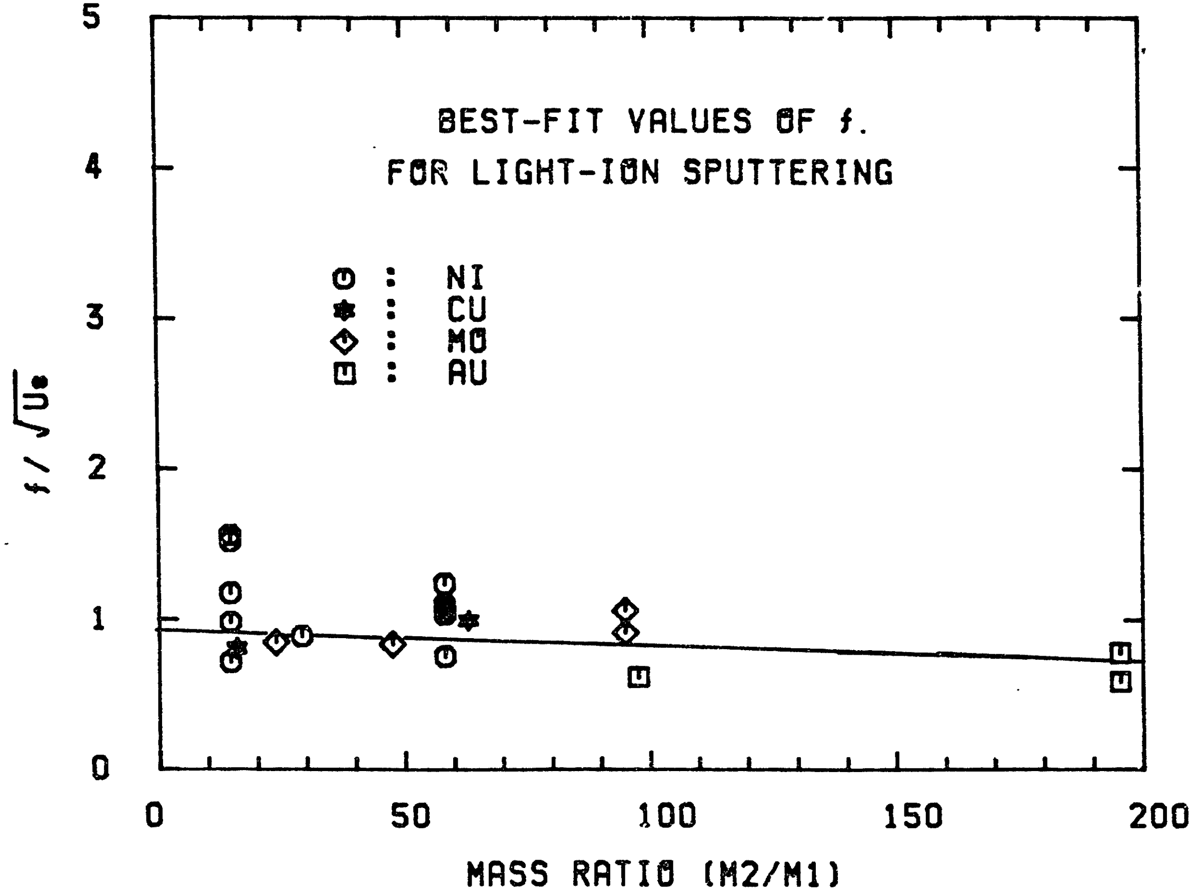

BEST-FIT VALUES OF ƒ.
FOR LIGHT-ION SPUTTERING
⊖ : NI
✱ : CU
◇ : MO
⊟ : AU
ƒ / √U₀
0
1
2
3
4
5
0
50
100
150
200
MASS RATIO (M2/M1)

Fig. 1

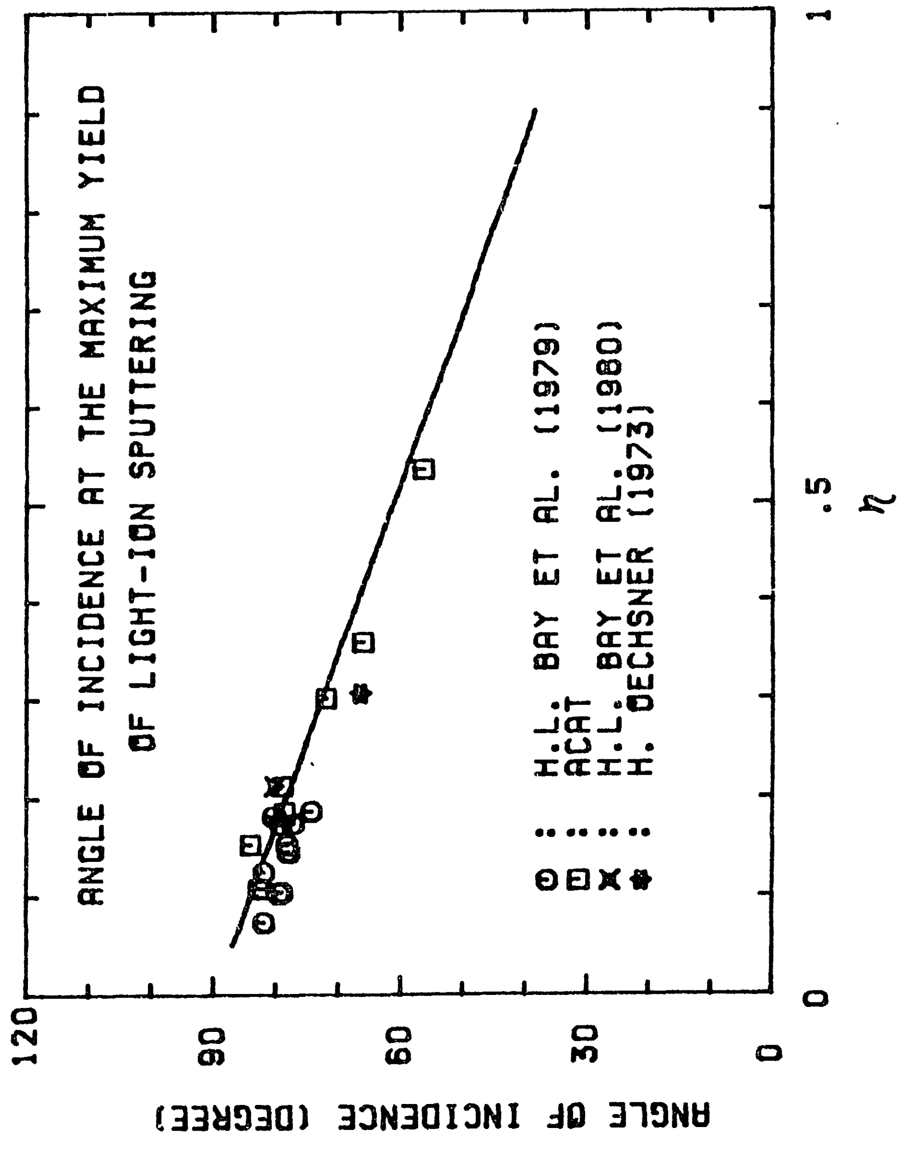

ANGLE OF INCIDENCE AT THE MAXIMUM YIELD
OF LIGHT-ION SPUTTERING
⊙ : H.L. BAY ET AL. (1979)
⊡ : ACAT
✕ : H.L. BAY ET AL. (1980)
✱ : H. OECHSNER (1973)
ANGLE OF INCIDENCE (DEGREE)
120
90
60
30
0
0
.5
1
η

Fig. 2

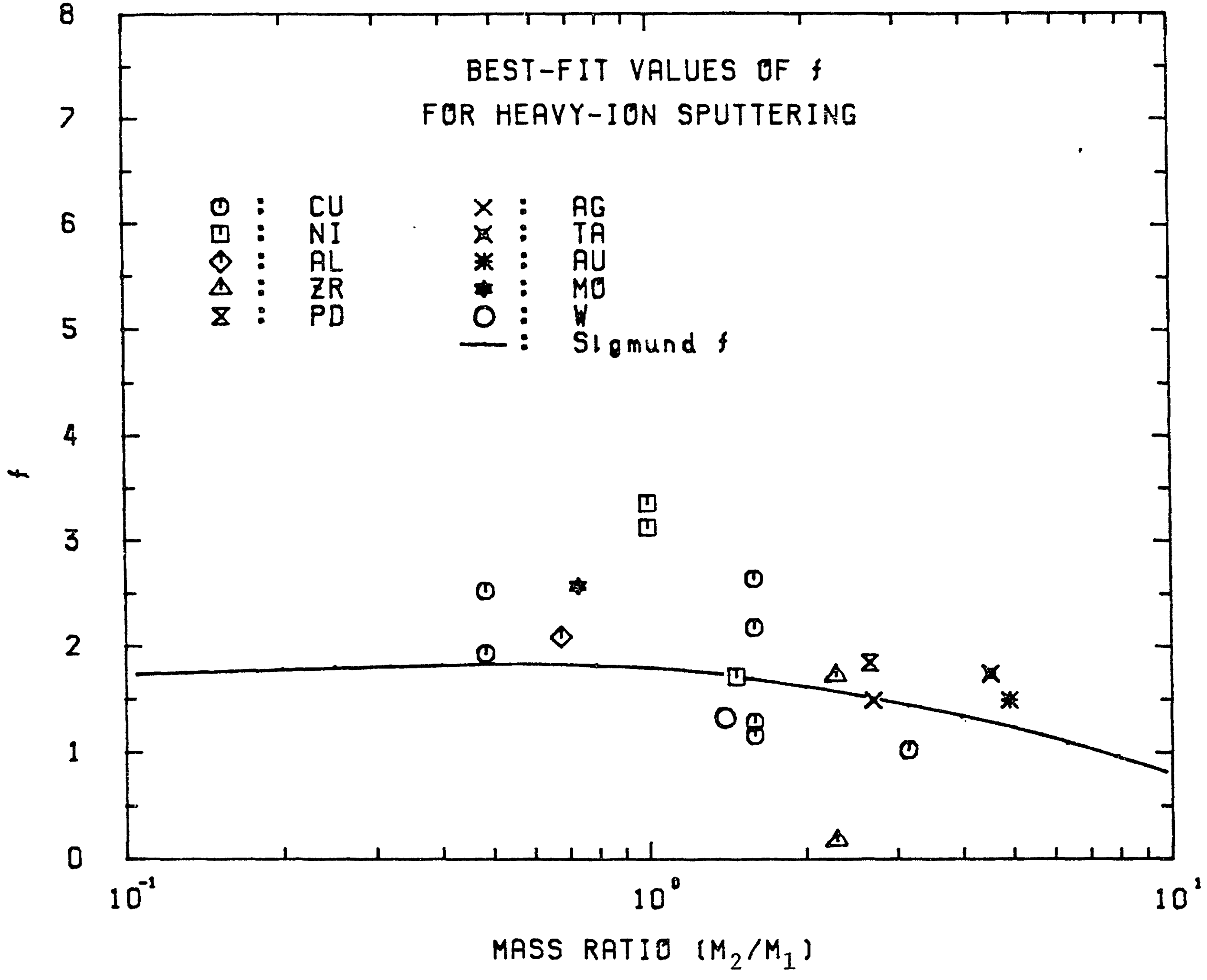

BEST-FIT VALUES OF f
FOR HEAVY-ION SPUTTERING
CU
NI
AL
ZR
PD
AG
TA
AU
MO
W
Sigmund f
f
0
1
2
3
4
5
6
7
8
10^{-1}
10^{0}
10^{1}
MASS RATIO (M_2/M_1)

Fig. 3

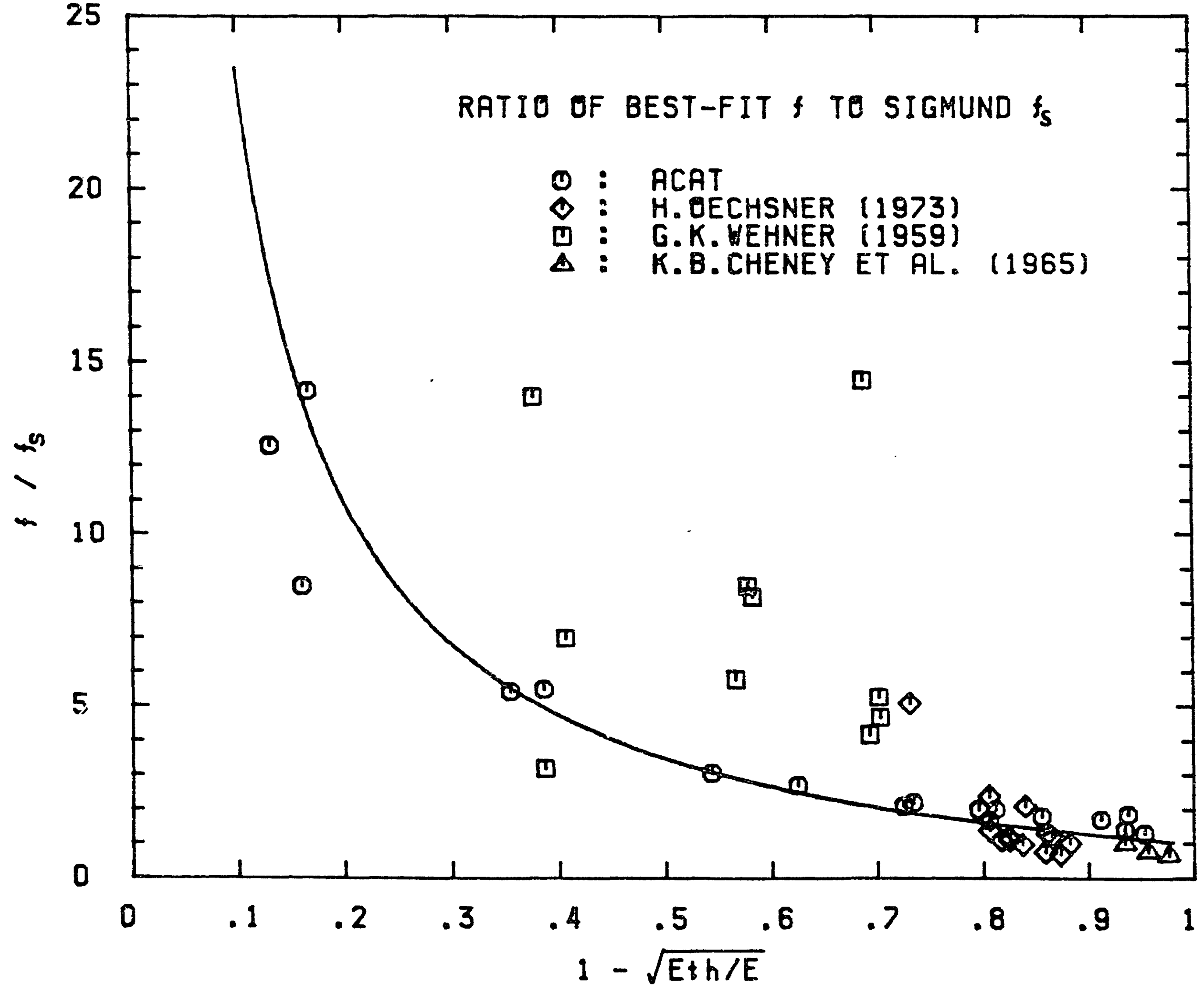

RATIO OF BEST-FIT f TO SIGMUND f_s
○ : ACAT
◇ : H.OECHSNER (1973)
□ : G.K.WEHNER (1959)
△ : K.B.CHENEY ET AL. (1965)
f / f_s
25
20
15
10
5
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
1 - $\sqrt{Eth/E}$

Fig. 4

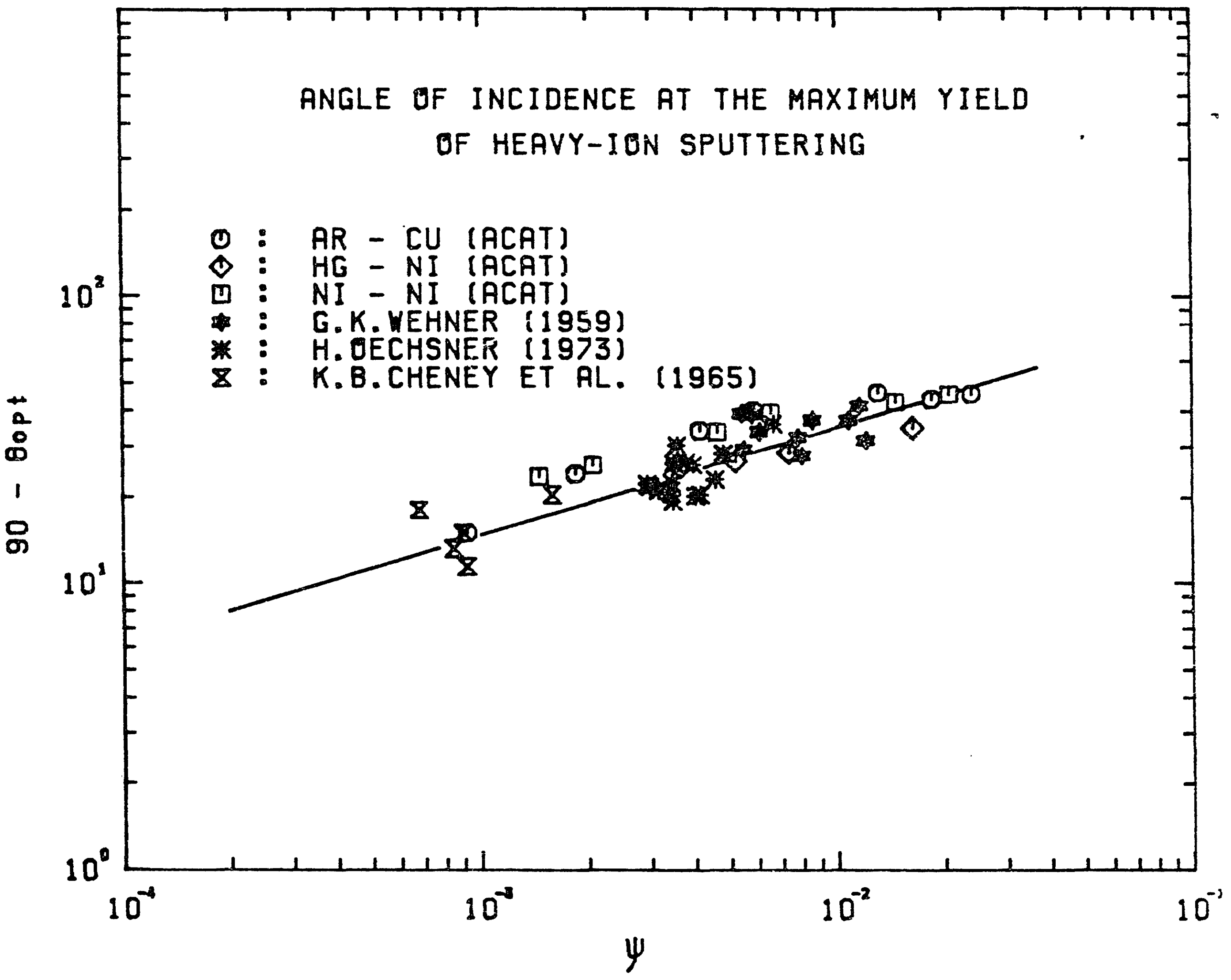

ANGLE ØF INCIDENCE AT THE MAXIMUM YIELD
ØF HEAVY-IØN SPUTTERING
⊖ : AR - CU (ACAT)
◇ : HG - NI (ACAT)
⊟ : NI - NI (ACAT)
✱ : G.K.WEHNER (1959)
✳ : H.ØECHSNER (1973)
⧗ : K.B.CHENEY ET AL. (1965)
10^2
10^1
10^0
90 - θopt
10^{-4}
10^{-3}
10^{-2}
10^{-1}
ψ

Fig. 5

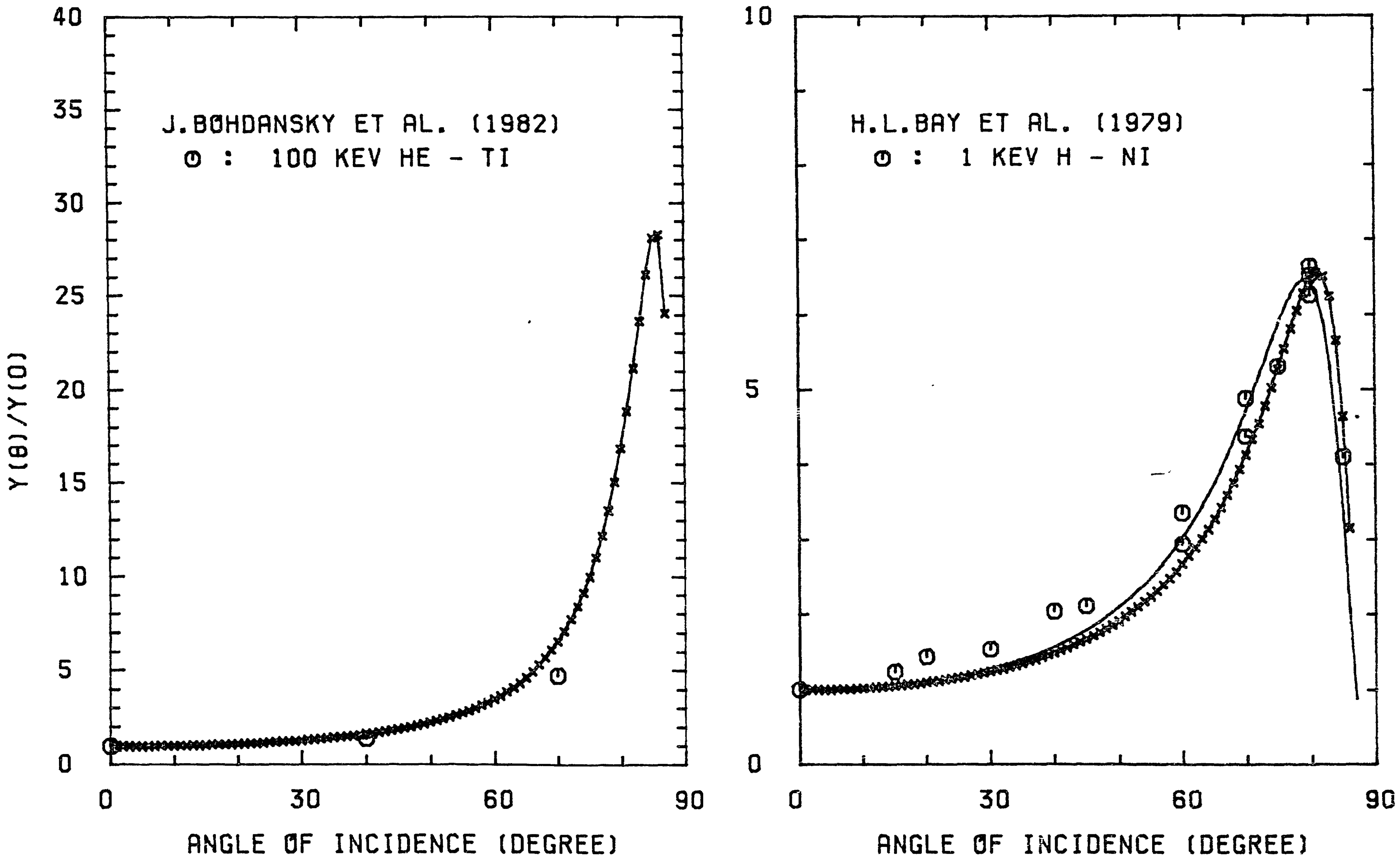

J.BØHDANSKY ET AL. (1982)
⊙ : 100 KEV HE - TI
H.L.BAY ET AL. (1979)
⊙ : 1 KEV H - NI
Y(θ)/Y(0)
0
5
10
15
20
25
30
35
40
0
5
10
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 6

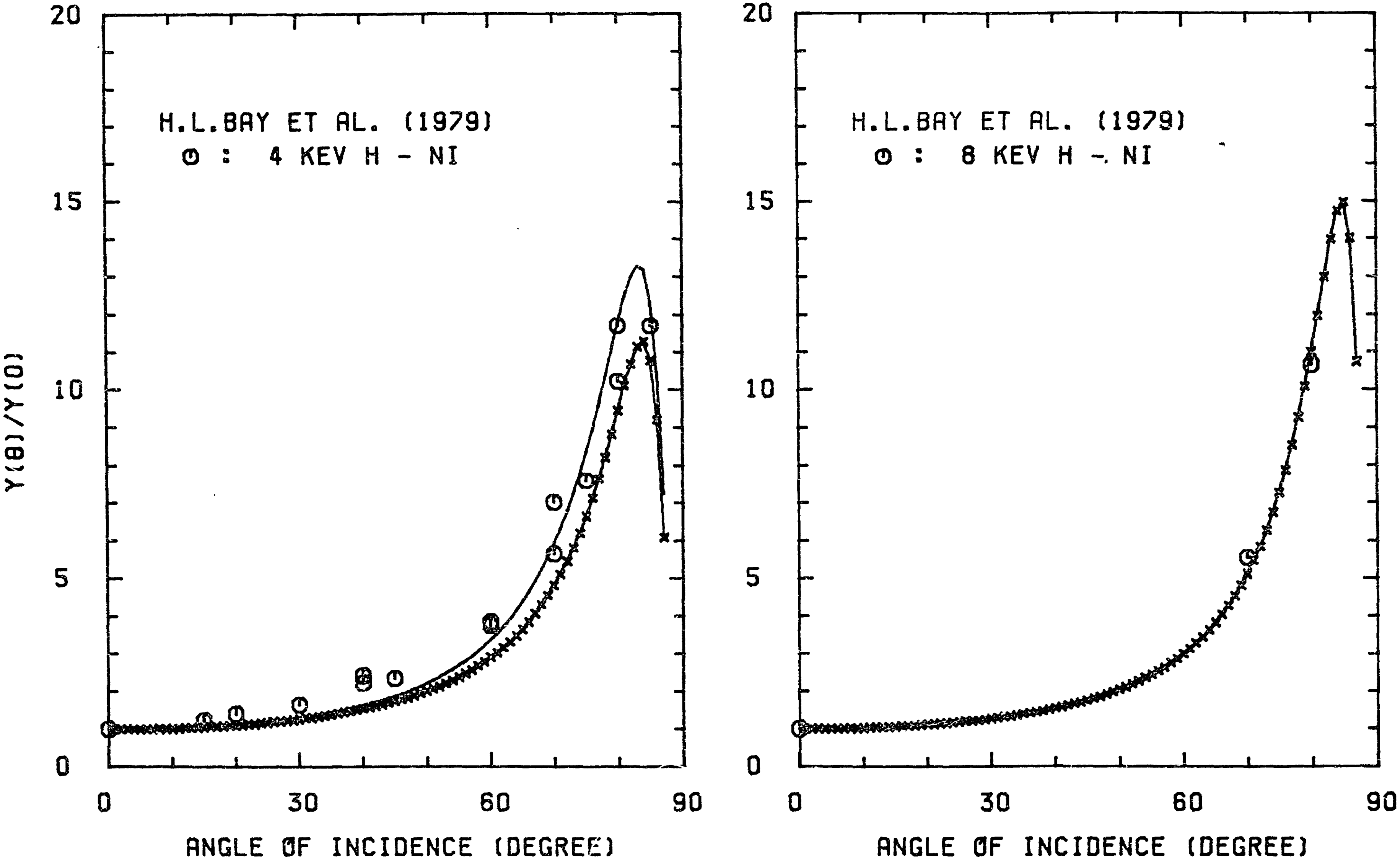

H.L.BAY ET AL. (1979)
Θ : 4 KEV H - NI
H.L.BAY ET AL. (1979)
Θ : 8 KEV H -. NI
Y(θ)/Y(0)
0
5
10
15
20
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 7

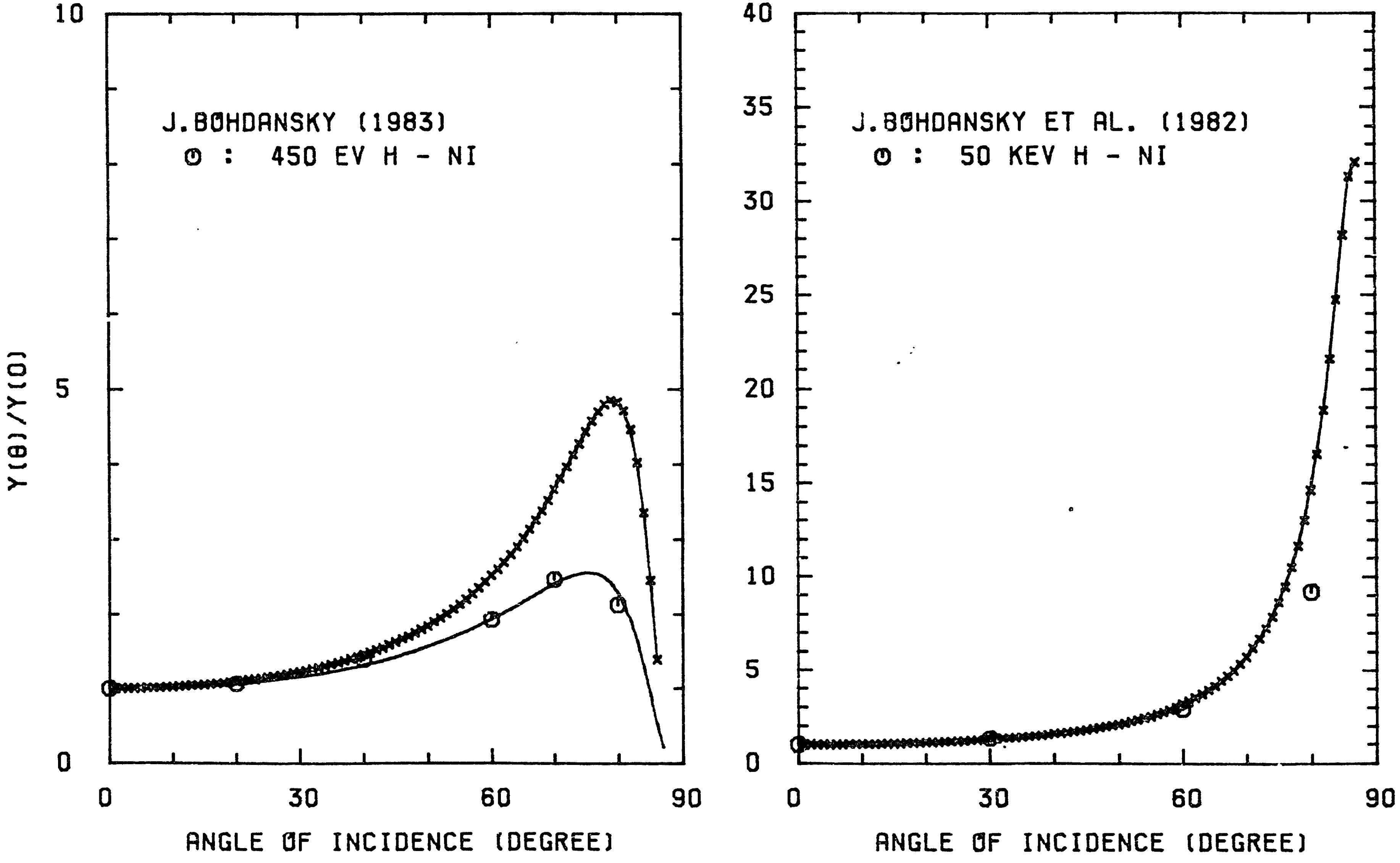

J.BØHDANSKY (1983)
Θ : 450 EV H - NI
J.BØHDANSKY ET AL. (1982)
Θ : 50 KEV H - NI
Y(θ)/Y(0)
0
5
10
0
5
10
15
20
25
30
35
40
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 8

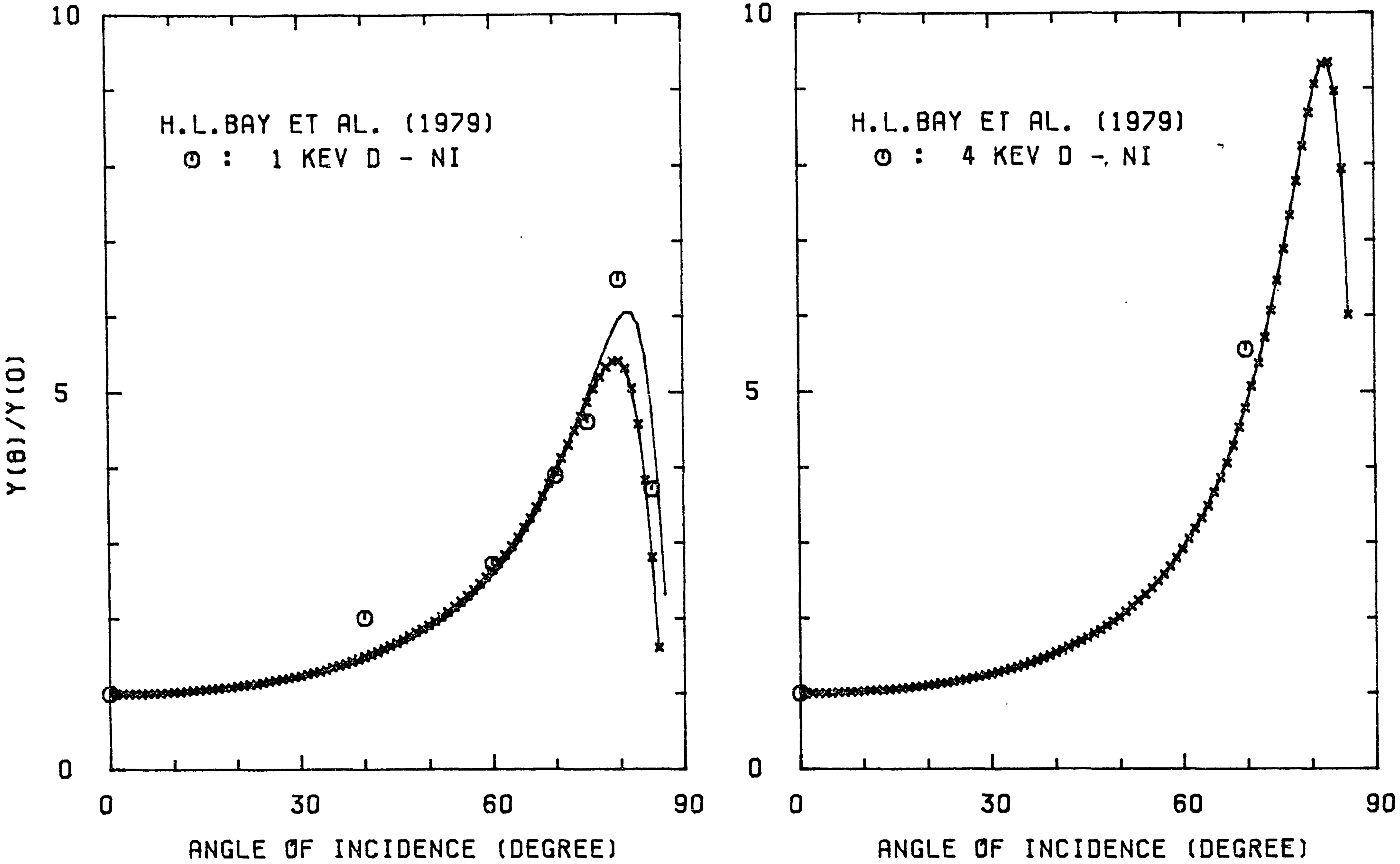

H.L.BAY ET AL. (1979)
Θ : 1 KEV D - NI
H.L.BAY ET AL. (1979)
Θ : 4 KEV D -, NI
Y(θ)/Y(0)
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 9

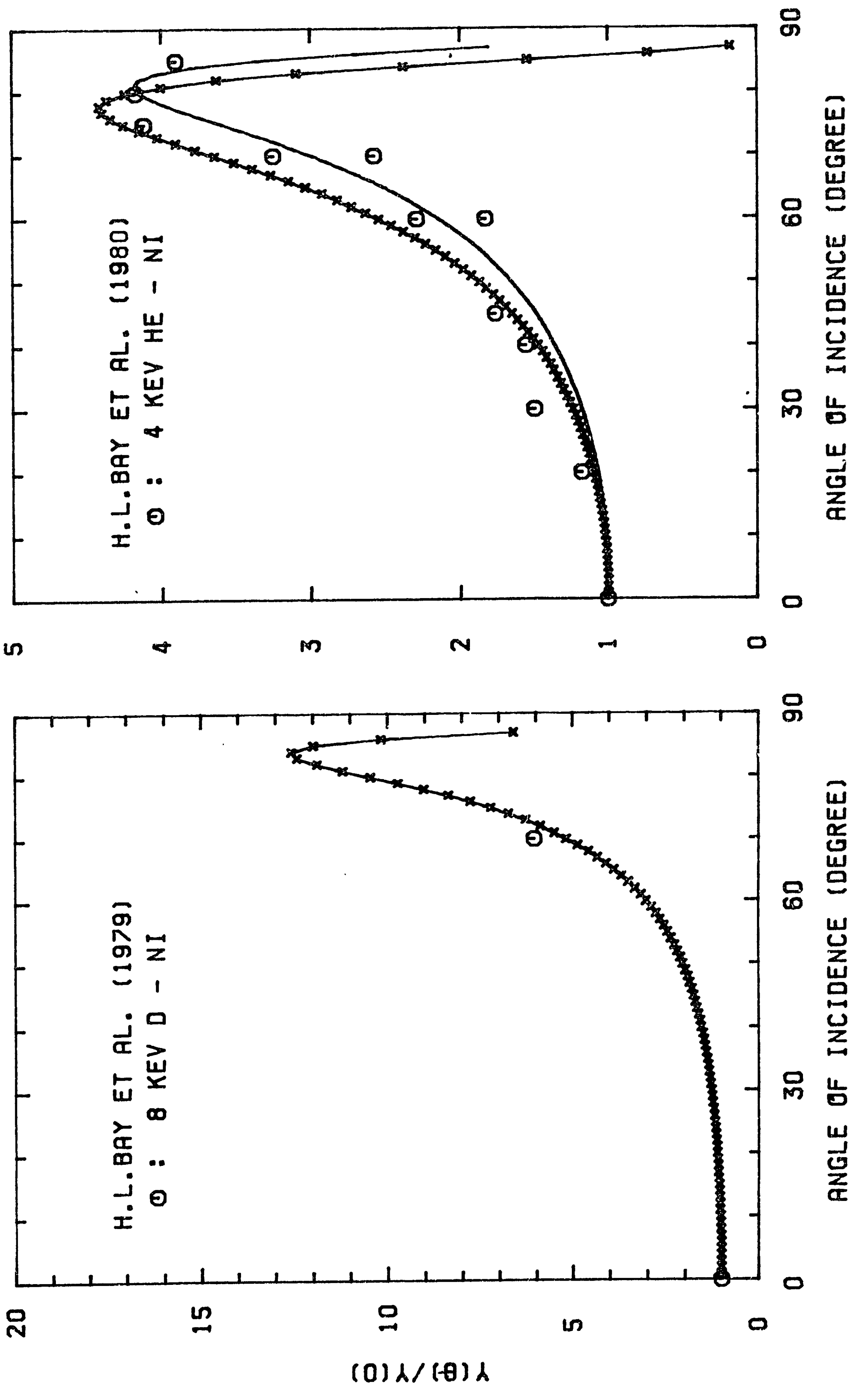

H.L.BAY ET AL. (1979)
Θ : 8 KEV D - NI
H.L.BAY ET AL. (1980)
Θ : 4 KEV HE - NI
Y(Θ)/Y(0)
ANGLE OF INCIDENCE (DEGREE)
0
30
60
90
0
5
10
15
20
0
1
2
3
4
5

Fig. 10

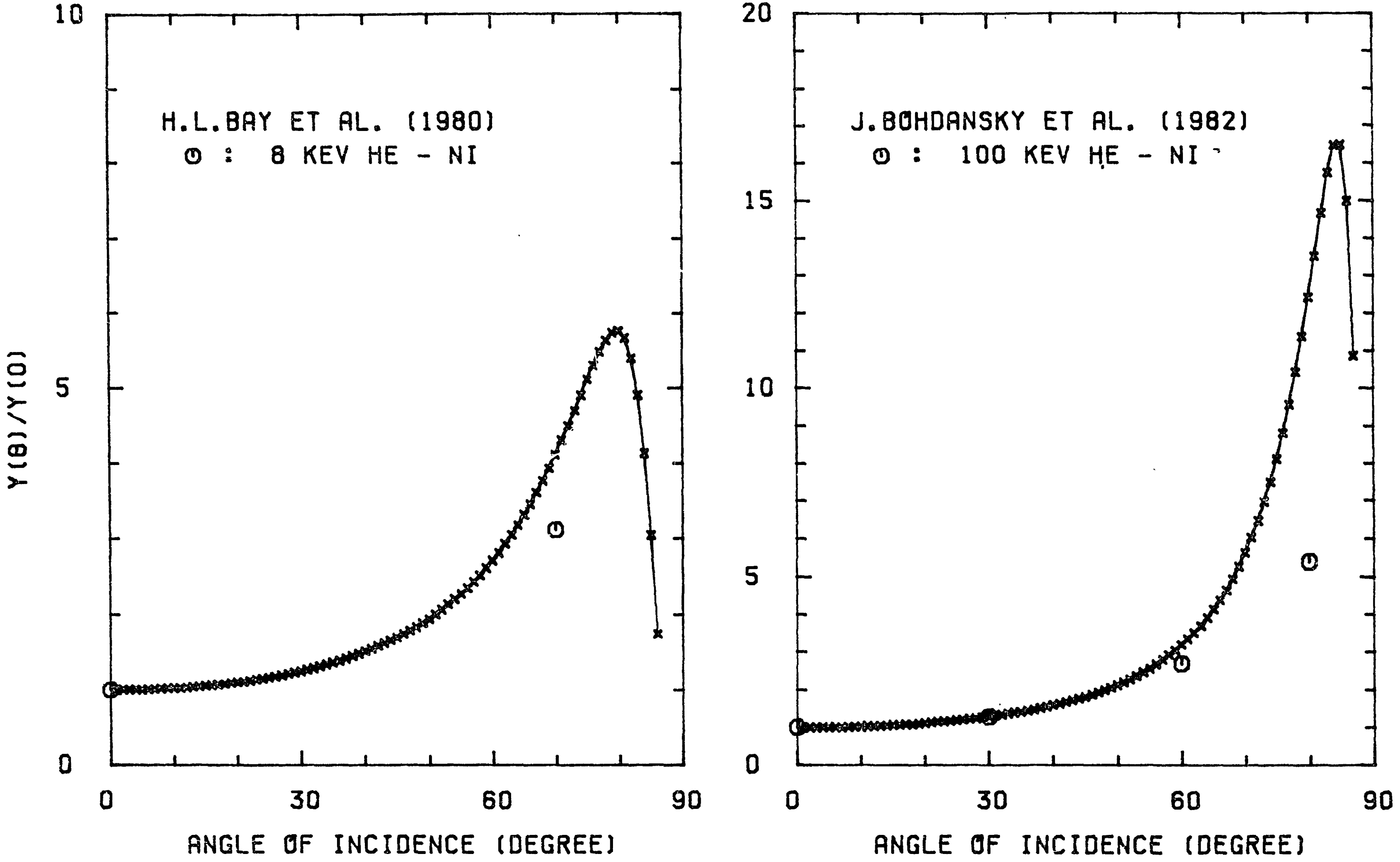

H.L.BAY ET AL. (1980)
ʘ : 8 KEV HE - NI
J.BØHDANSKY ET AL. (1982)
ʘ : 100 KEV HE - NI
Y(θ)/Y(0)
10
5
0
20
15
10
5
0
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 11

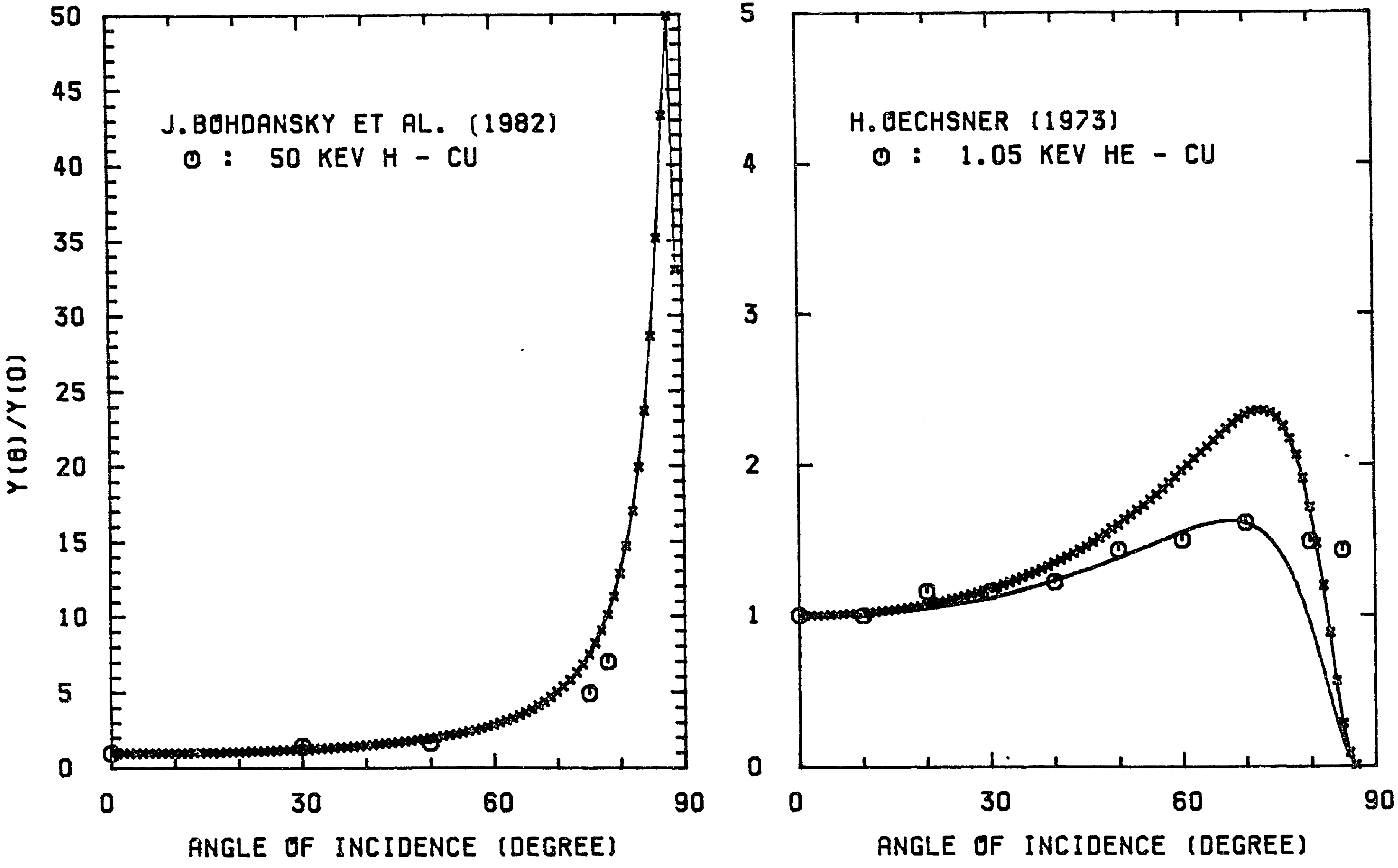
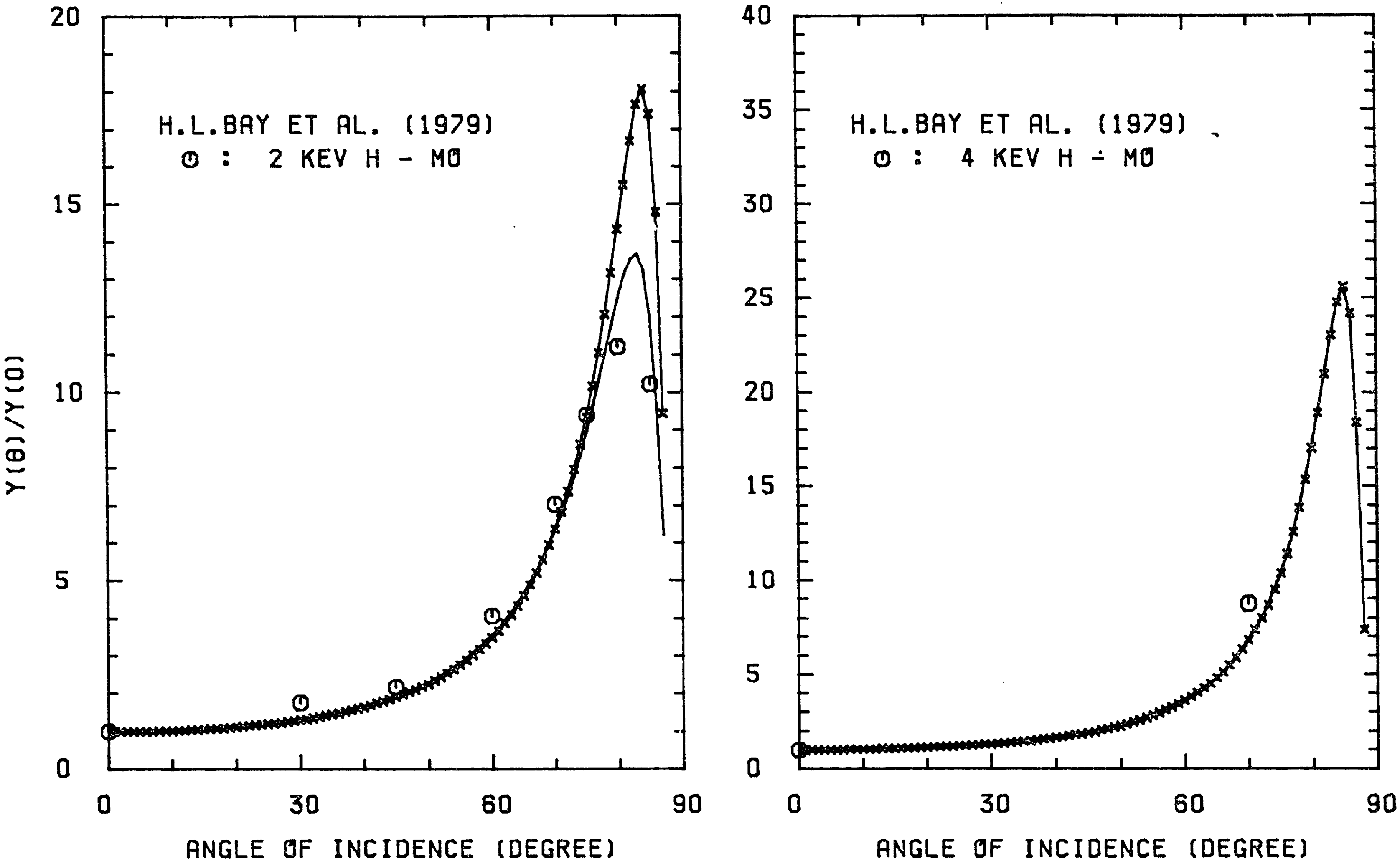

J.BOHDANSKY ET AL. (1982)
Θ : 50 KEV H - CU
H.OECHSNER (1973)
Θ : 1.05 KEV HE - CU
Y(Θ)/Y(0)
0
5
10
15
20
25
30
35
40
45
50
1
2
3
4
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 12



H.L.BAY ET AL. (1979)
⊙ : 2 KEV H - MO
Y(θ)/Y(0)
0
5
10
15
20
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
H.L.BAY ET AL. (1979)
⊙ : 4 KEV H - MO
0
5
10
15
20
25
30
35
40
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 13

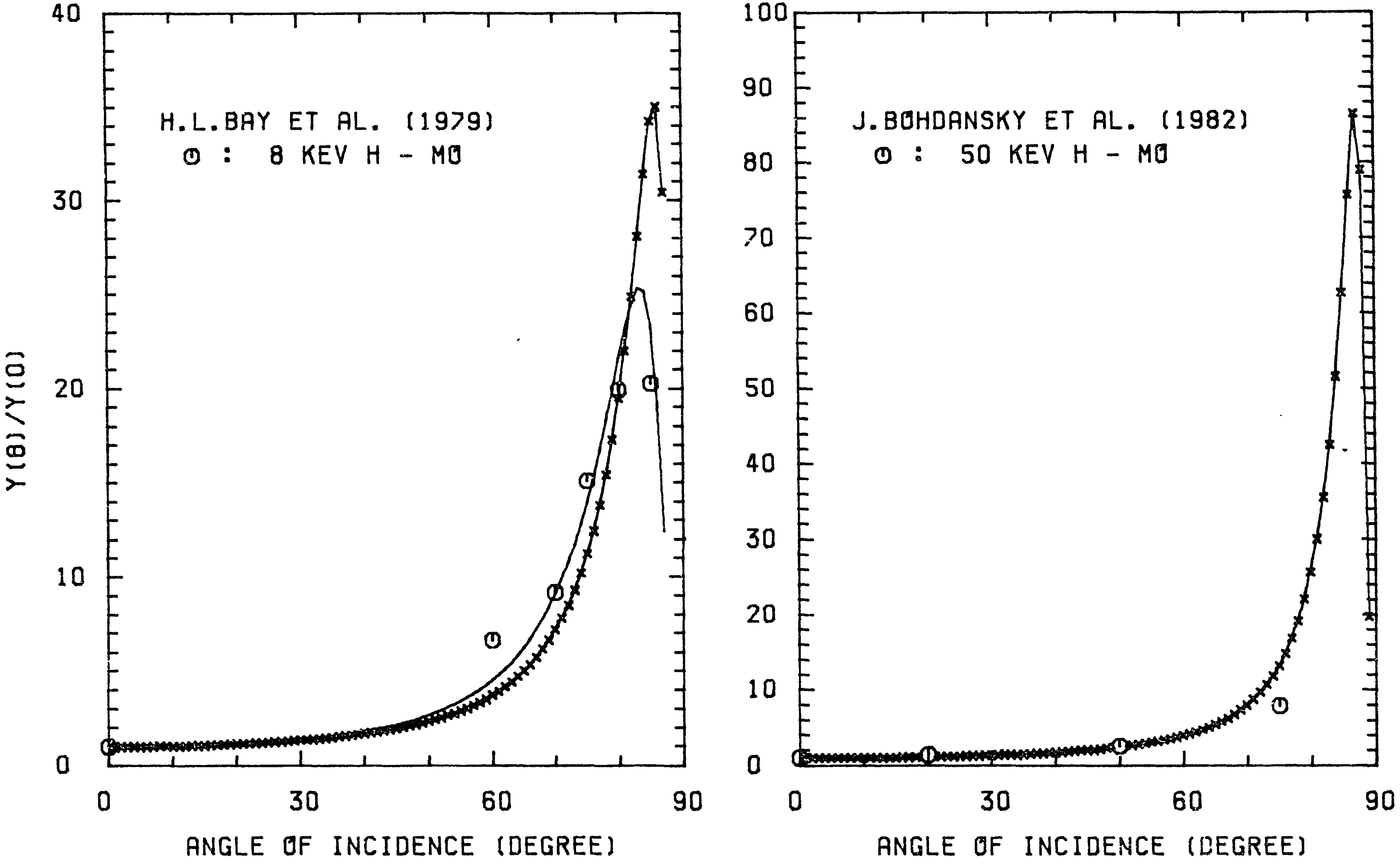

H.L.BAY ET AL. (1979)
⊙ : 8 KEV H - MO
Y(θ)/Y(0)
0
10
20
30
40
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
J.BOHDANSKY ET AL. (1982)
⊙ : 50 KEV H - MO
0
10
20
30
40
50
60
70
80
90
100
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 14

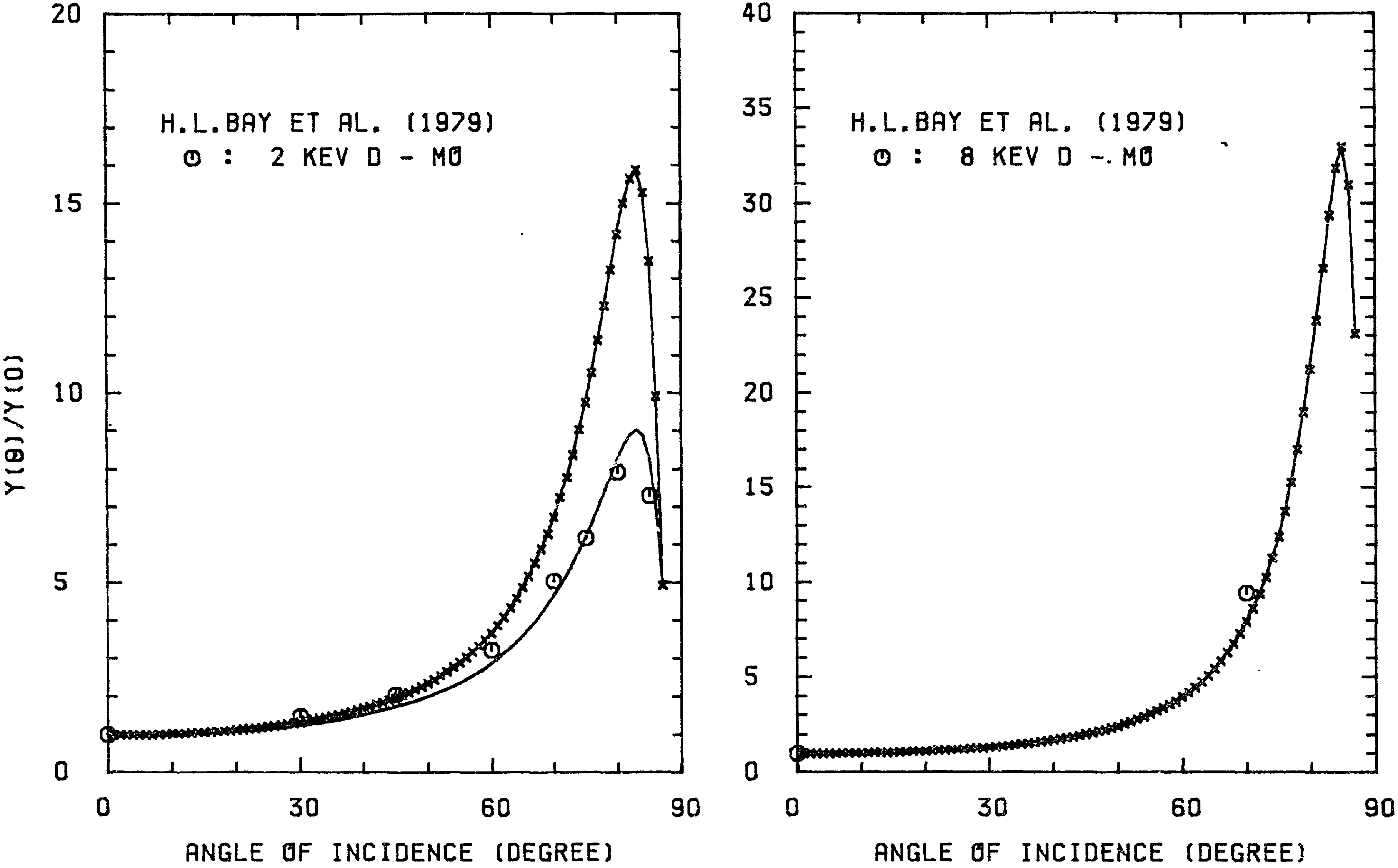

H.L.BAY ET AL. (1979)
Θ : 2 KEV D - MO
Y(θ)/Y(0)
0
5
10
15
20
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
H.L.BAY ET AL. (1979)
Θ : 8 KEV D -. MO
0
5
10
15
20
25
30
35
40
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 15

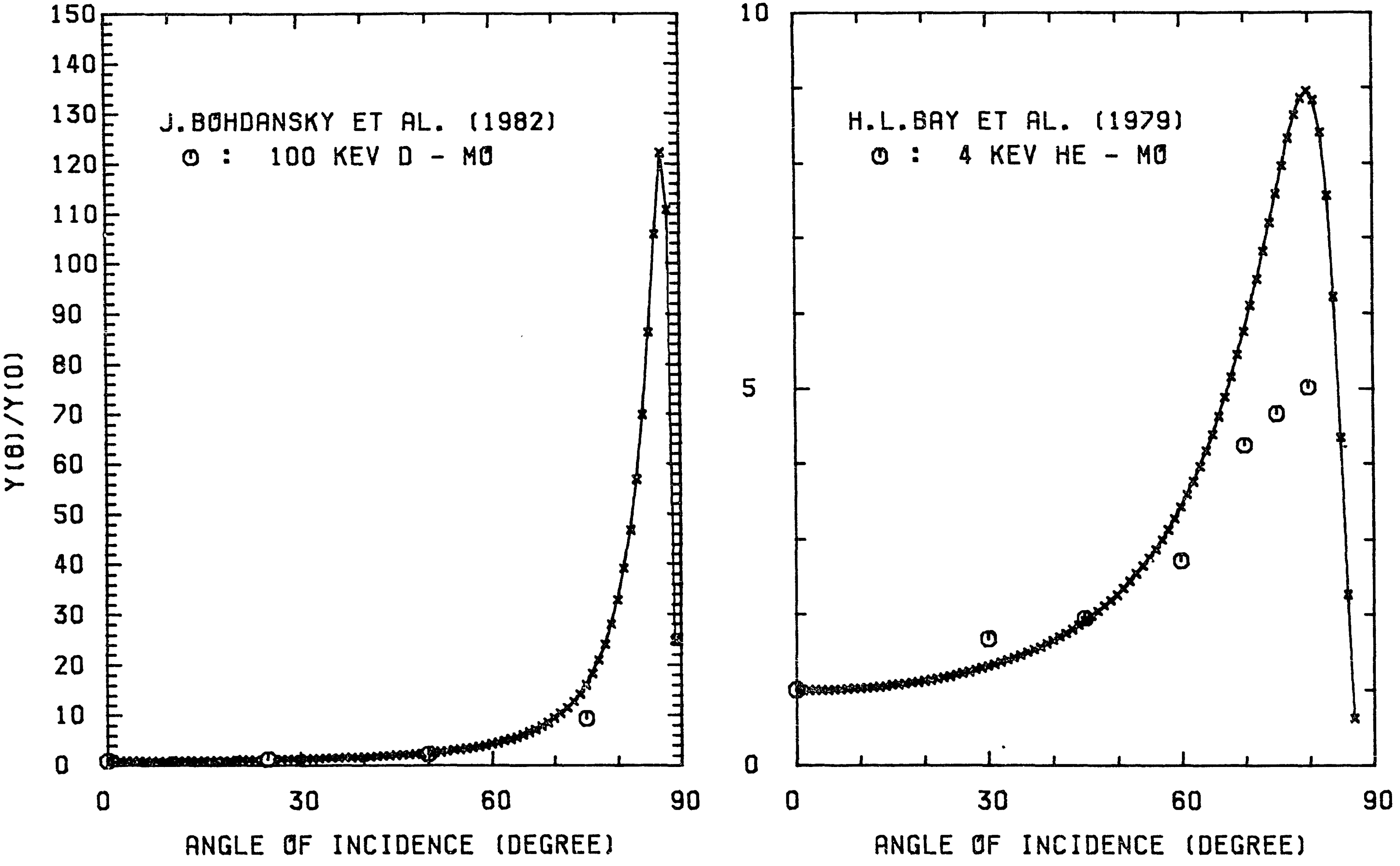

Y(θ)/Y(0)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
J.BOHDANSKY ET AL. (1982)
Θ : 100 KEV D - MO
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
10
5
0
H.L.BAY ET AL. (1979)
Θ : 4 KEV HE - MO
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 16

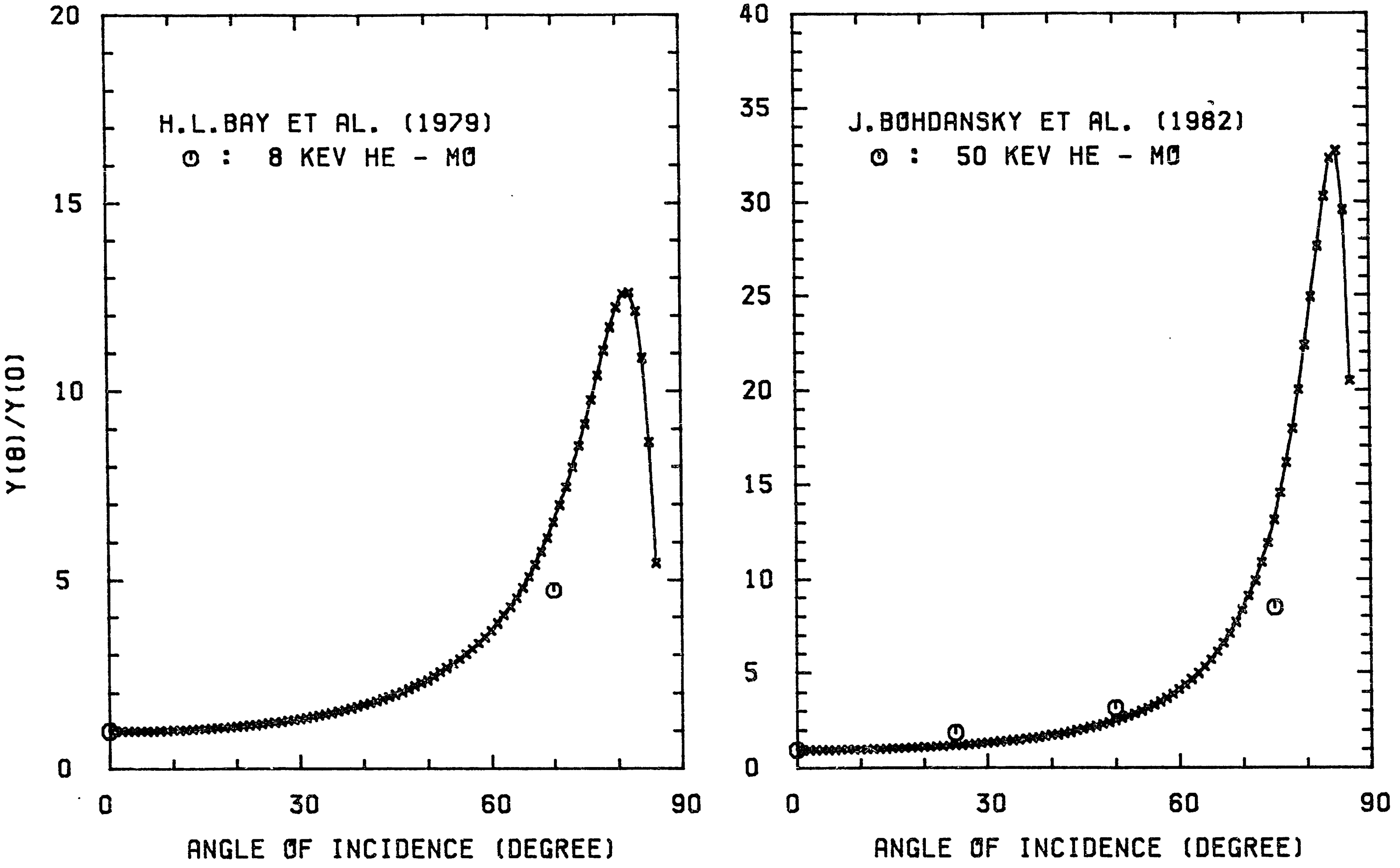

Y(θ)/Y(0)
20
15
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
H.L.BAY ET AL. (1979)
Θ : 8 KEV HE - MO
40
35
30
25
20
15
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
J.BOHDANSKY ET AL. (1982)
Θ : 50 KEV HE - MO

Fig. 17

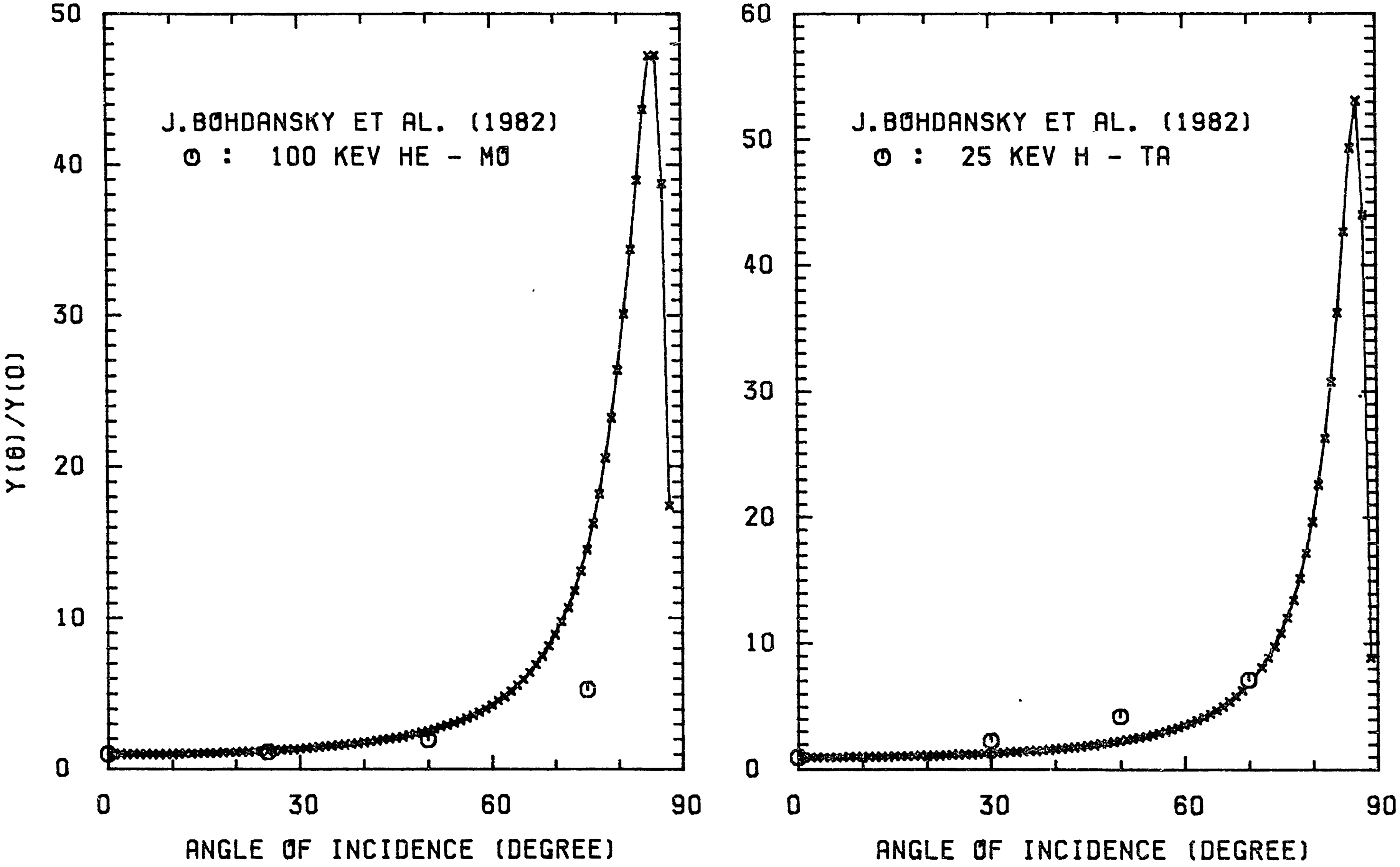

J.BOHDANSKY ET AL. (1982)
Θ : 100 KEV HE - MO
Y(θ)/Y(0)
0
10
20
30
40
50
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
J.BOHDANSKY ET AL. (1982)
Θ : 25 KEV H - TA
0
10
20
30
40
50
60
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 18

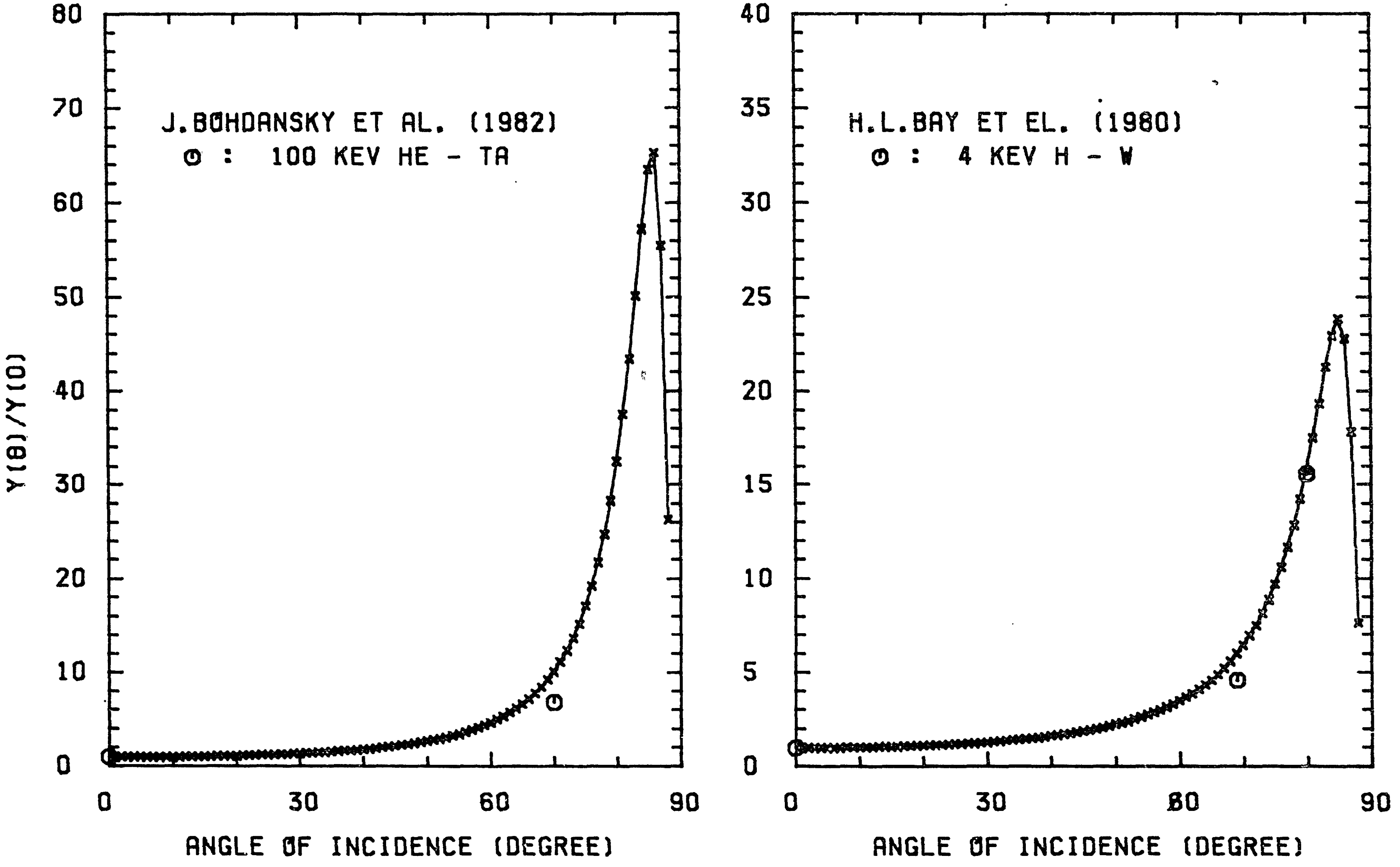
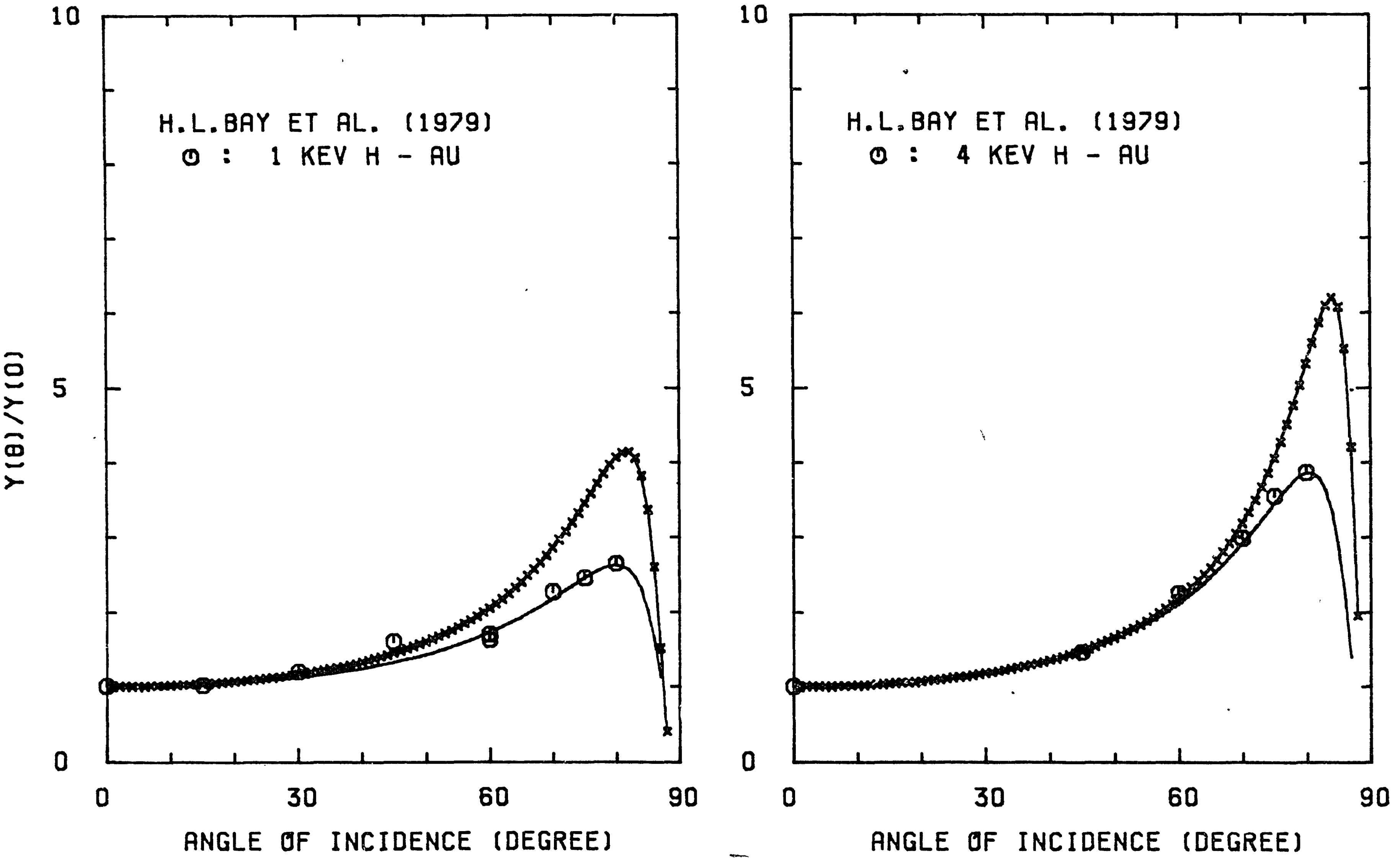

J.BØHDANSKY ET AL. (1982)
Θ : 100 KEV HE - TA
H.L.BAY ET EL. (1980)
Θ : 4 KEV H - W
Y(θ)/Y(0)
0
10
20
30
40
50
60
70
80
5
15
25
35
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 19



H.L.BAY ET AL. (1979)
Θ : 1 KEV H - AU
H.L.BAY ET AL. (1979)
Θ : 4 KEV H - AU
Y(θ)/Y(0)
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 20

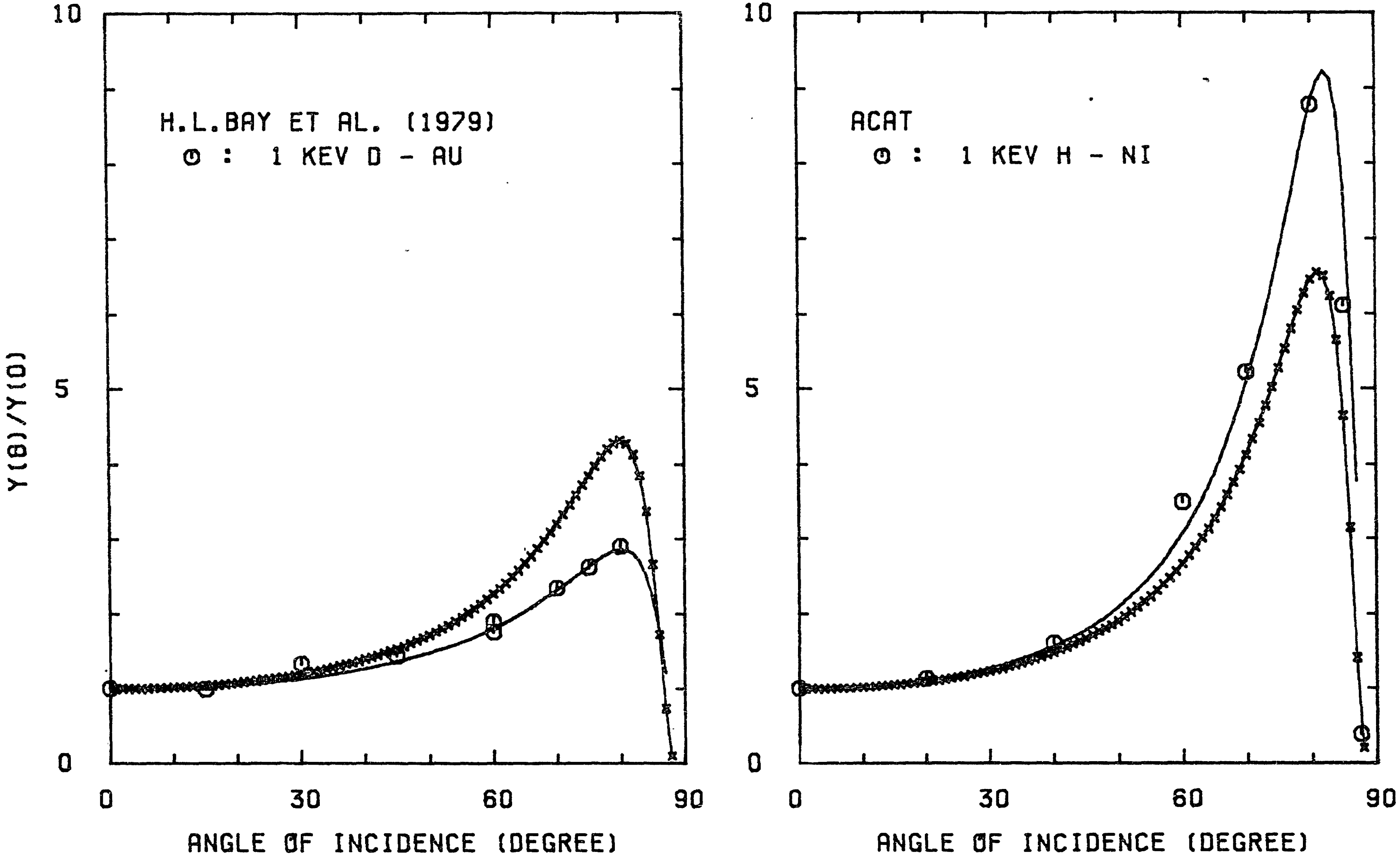

10
5
0
Y(B)/Y(0)
H.L.BAY ET AL. (1979)
⊙ : 1 KEV D - AU
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
10
5
0
ACAT
⊙ : 1 KEV H - NI
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 21

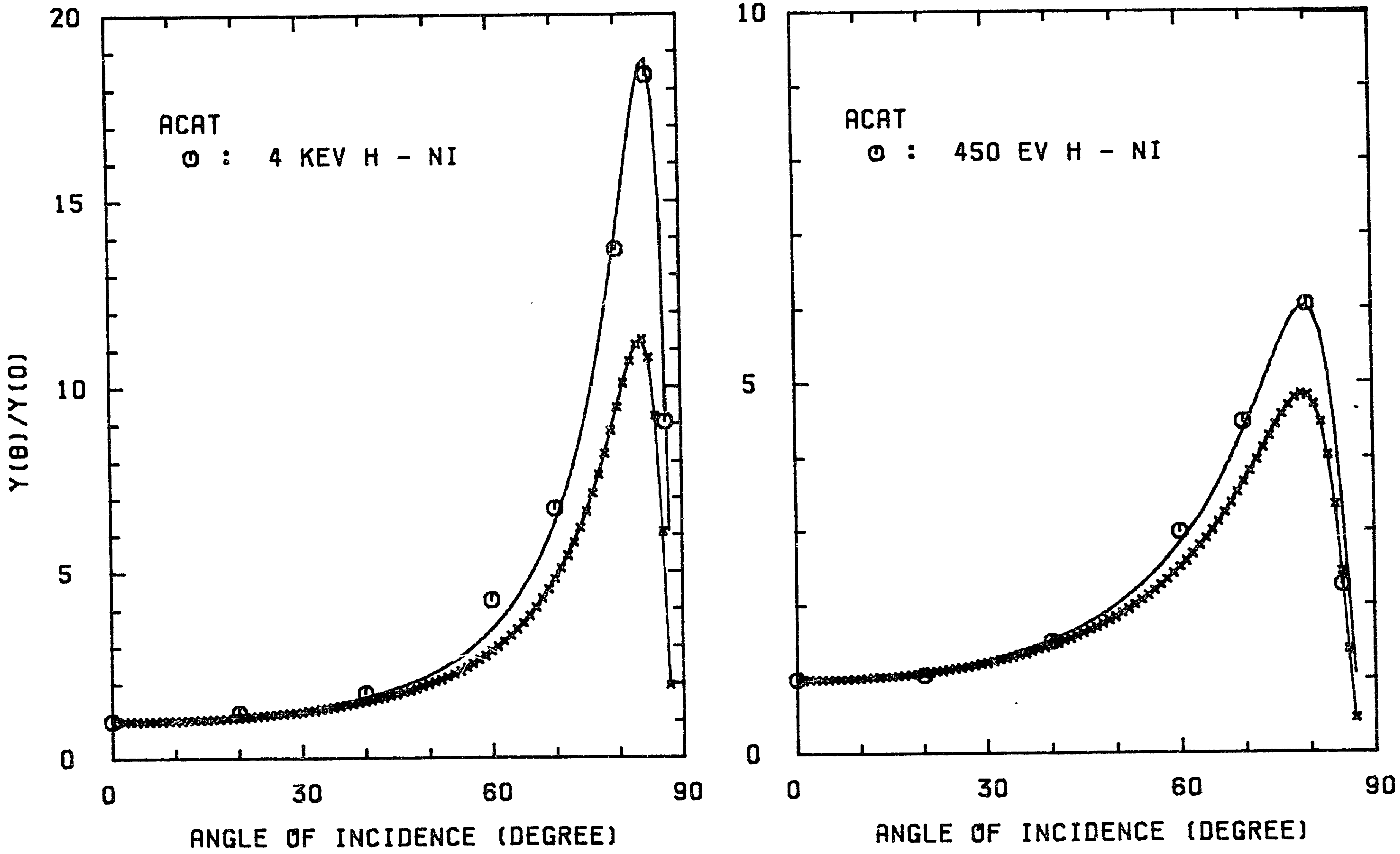

Y(θ)/Y(0)
20
15
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ACAT
Θ : 4 KEV H - NI
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ACAT
Θ : 450 EV H - NI

Fig. 22

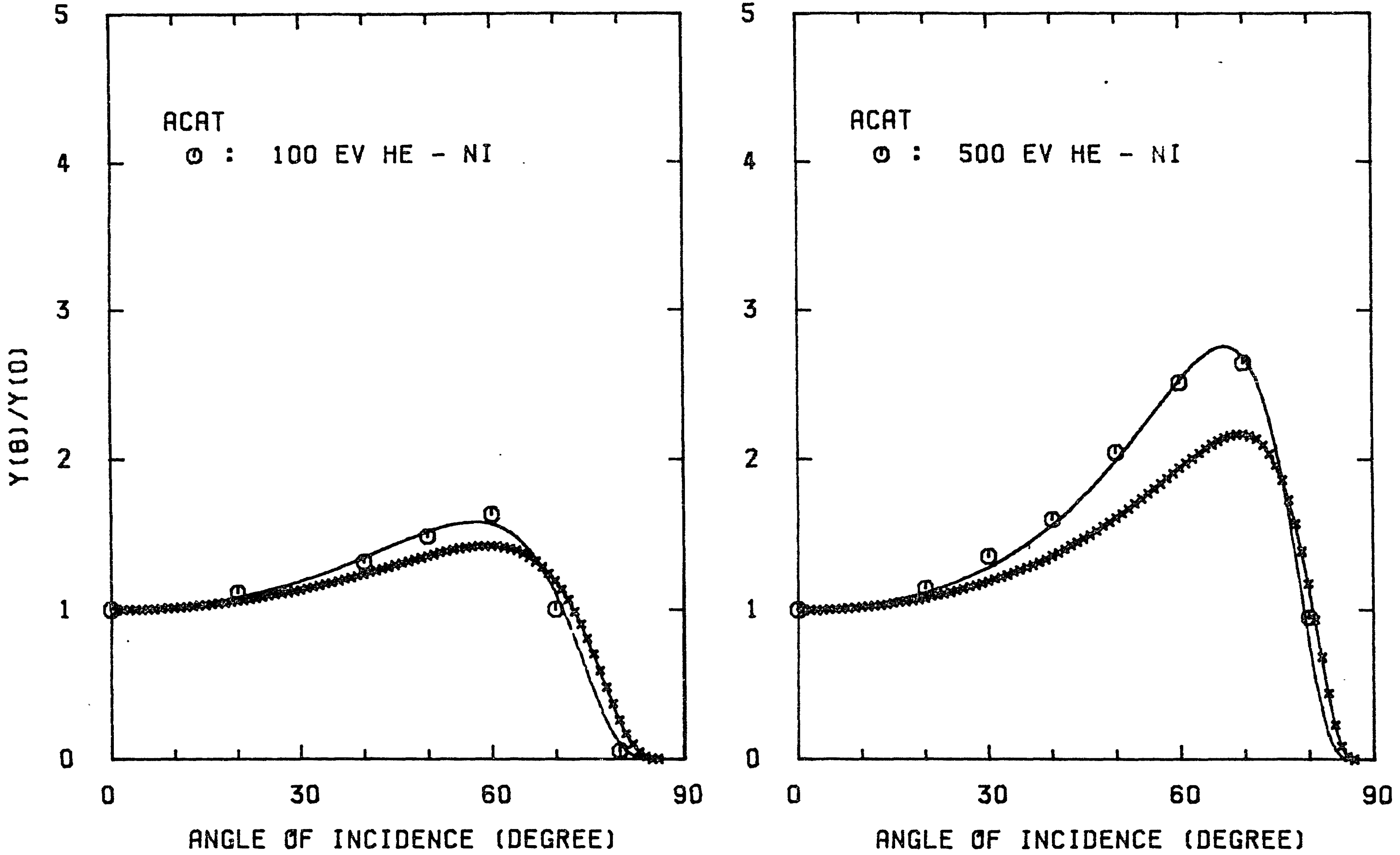

ACAT
Θ : 100 EV HE - NI
ACAT
Θ : 500 EV HE - NI
Y(Θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 23

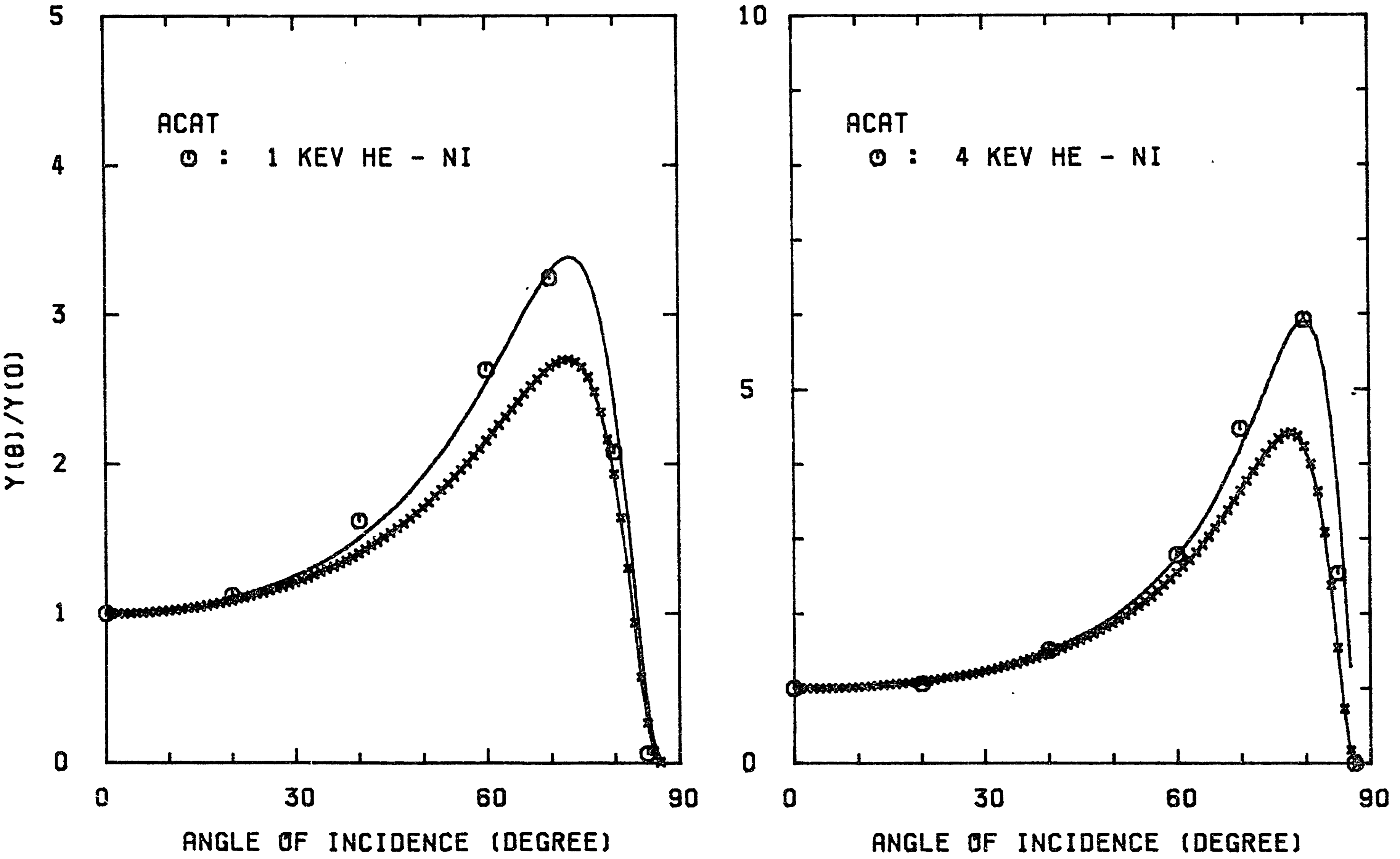

5
4
3
2
1
0
Y(θ)/Y(0)
ACAT
Θ : 1 KEV HE - NI
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
10
5
0
ACAT
Θ : 4 KEV HE - NI
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 24

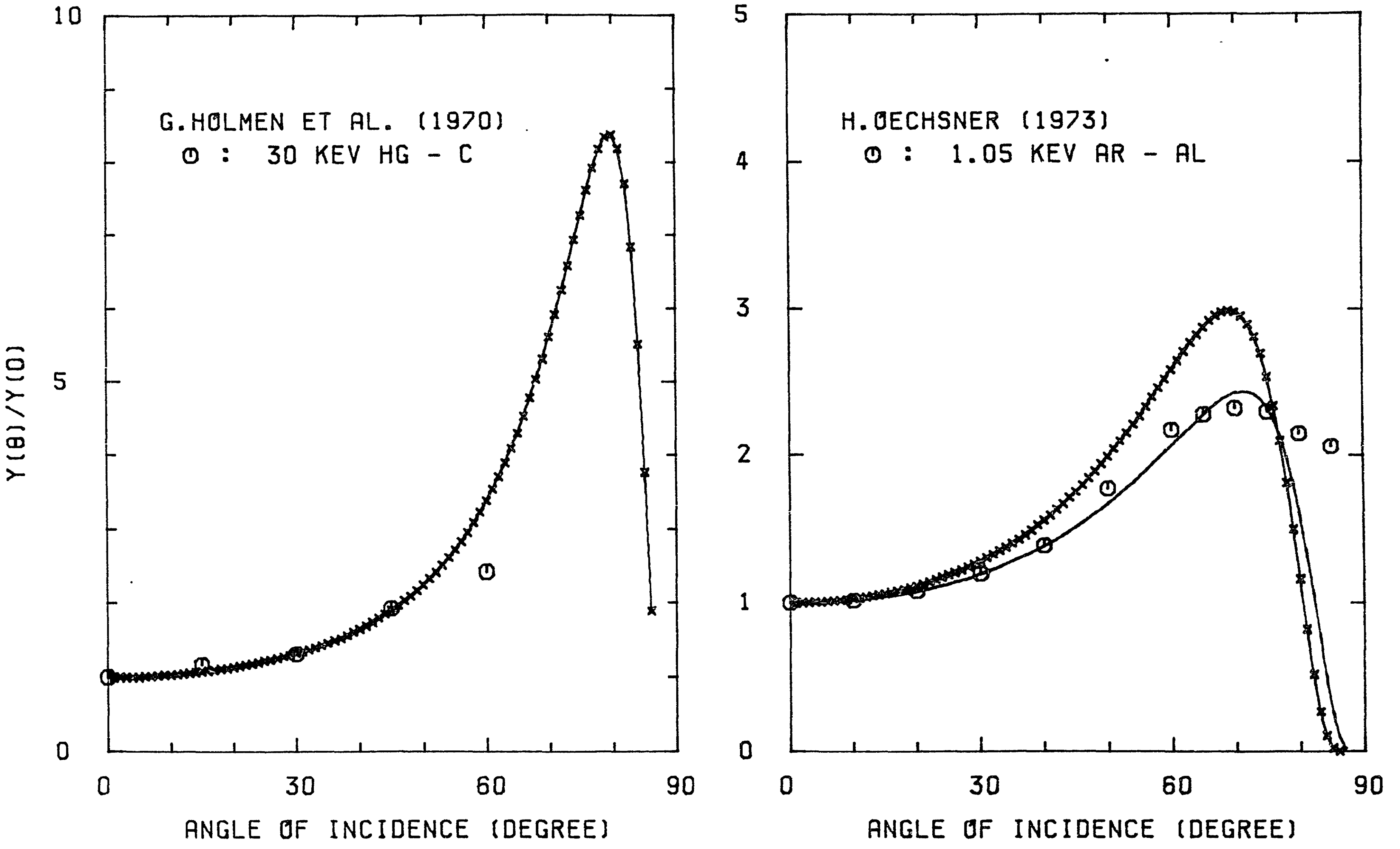

G.HØLMEN ET AL. (1970)
ʘ : 30 KEV HG - C
H.ØECHSNER (1973)
ʘ : 1.05 KEV AR - AL
Y(θ)/Y(0)
10
5
0
4
3
2
1
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 25

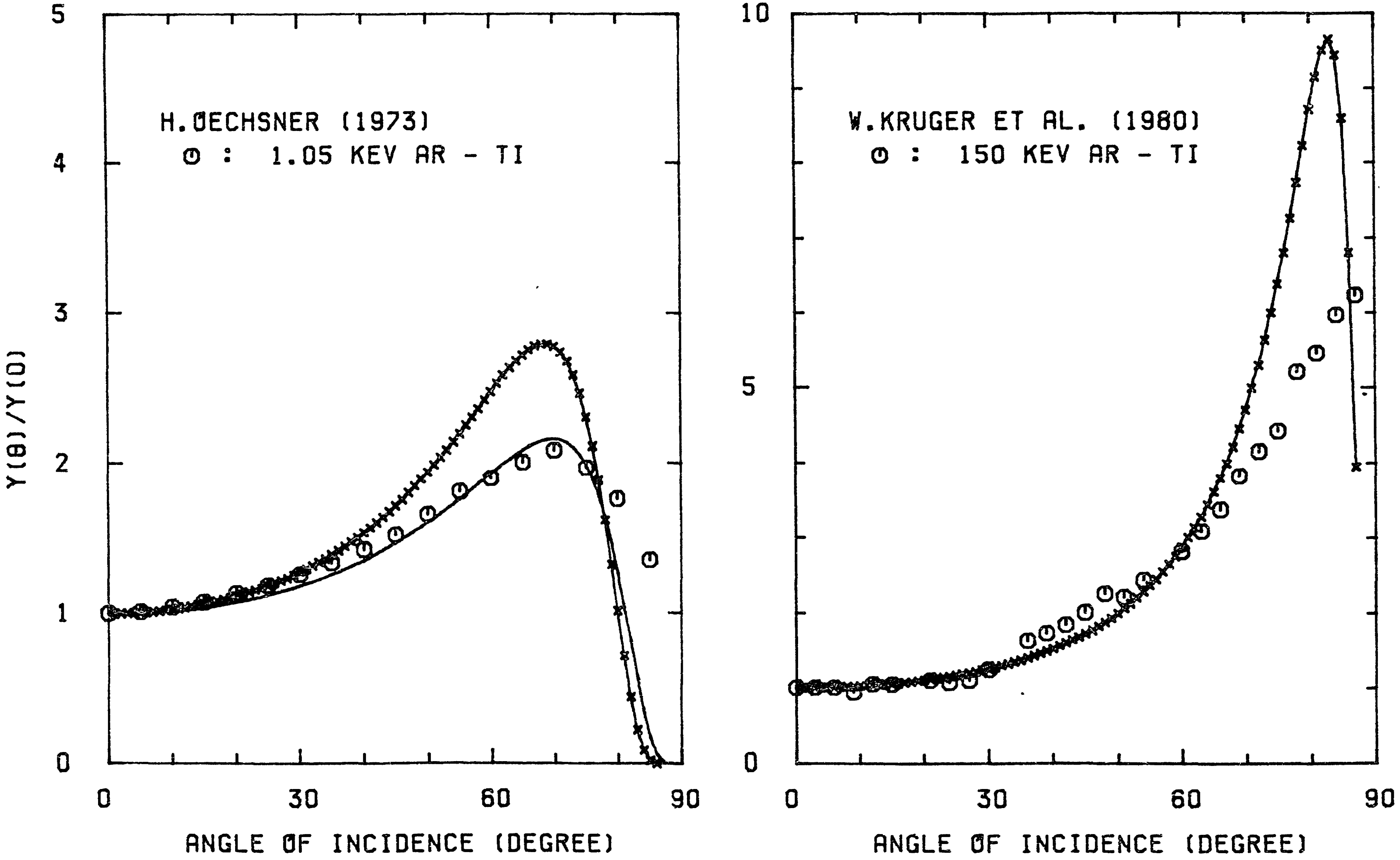

H.ØECHSNER (1973)
⊙ : 1.05 KEV AR - TI
W.KRUGER ET AL. (1980)
⊙ : 150 KEV AR - TI
Y(θ)/Y(0)
0
1
2
3
4
5
10
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 26

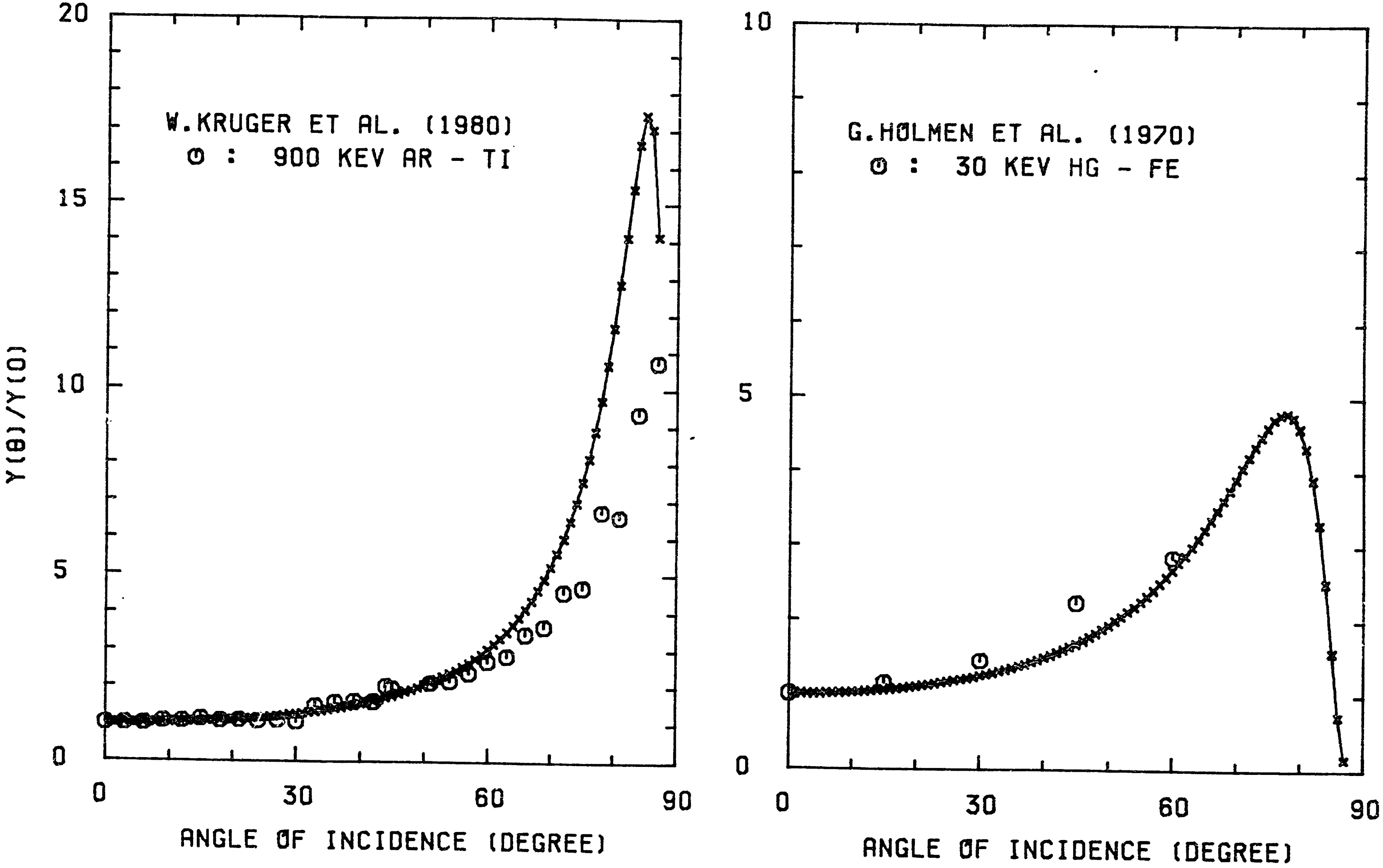

Y(θ)/Y(0)
20
15
10
5
0
W.KRUGER ET AL. (1980)
Θ : 900 KEV AR - TI
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
10
5
0
G.HØLMEN ET AL. (1970)
Θ : 30 KEV HG - FE
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 27

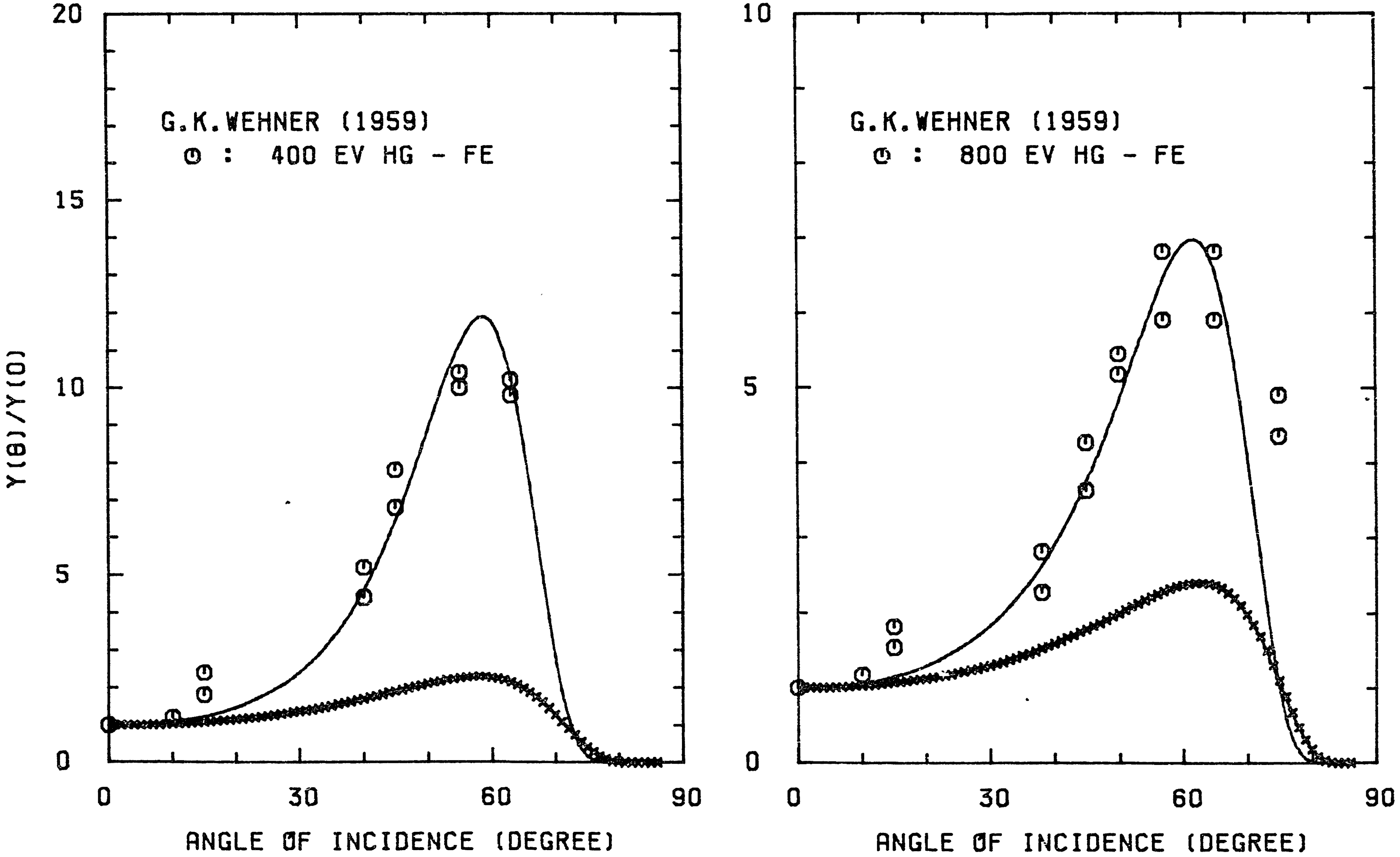

G.K.WEHNER (1959)
⊝ : 400 EV HG - FE
Y(θ)/Y(0)
0
5
10
15
20
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
G.K.WEHNER (1959)
⊝ : 800 EV HG - FE
0
5
10
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 28

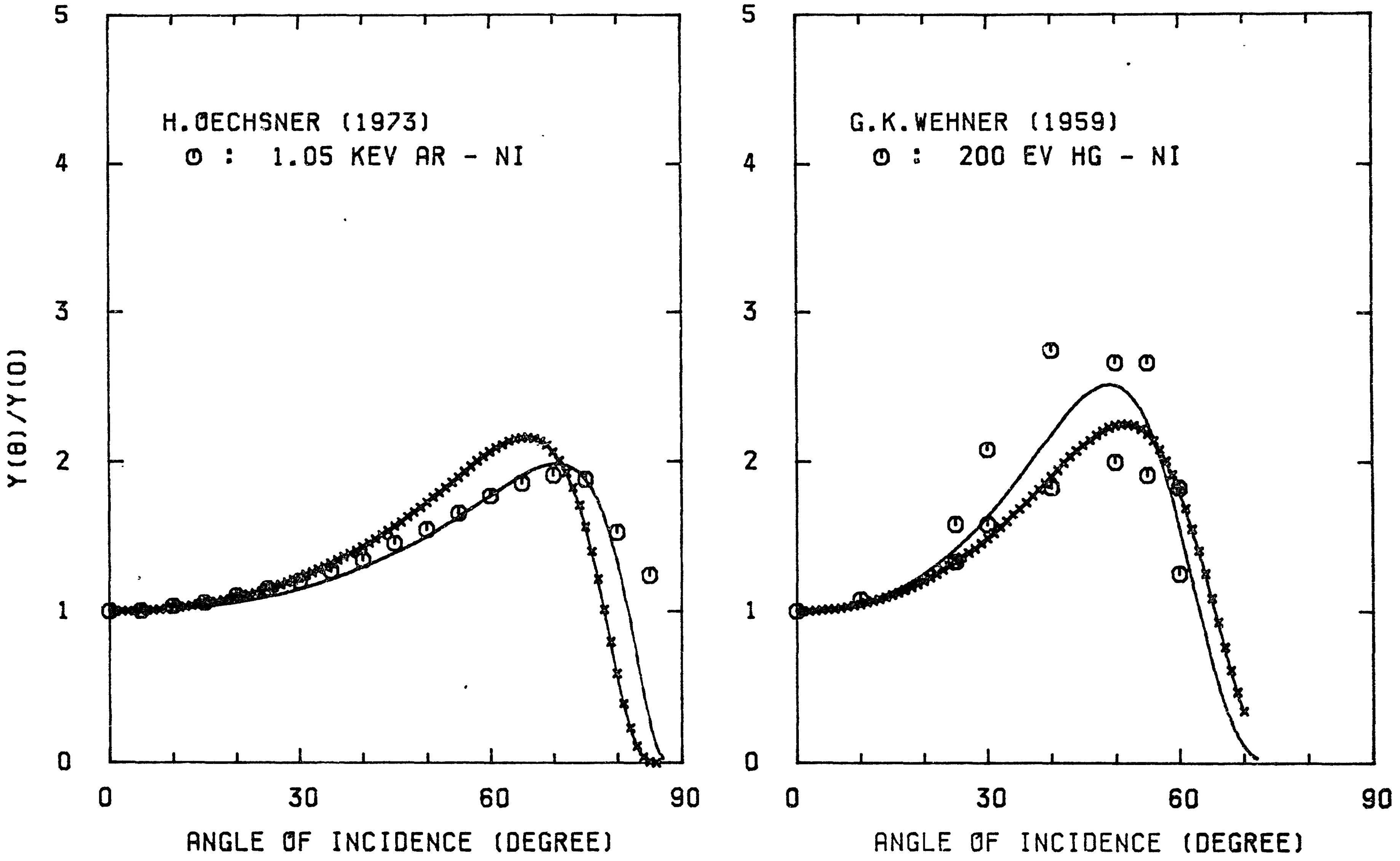

Y(θ)/Y(0)
H.OECHSNER (1973)
Θ : 1.05 KEV AR - NI
G.K.WEHNER (1959)
Θ : 200 EV HG - NI
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 29

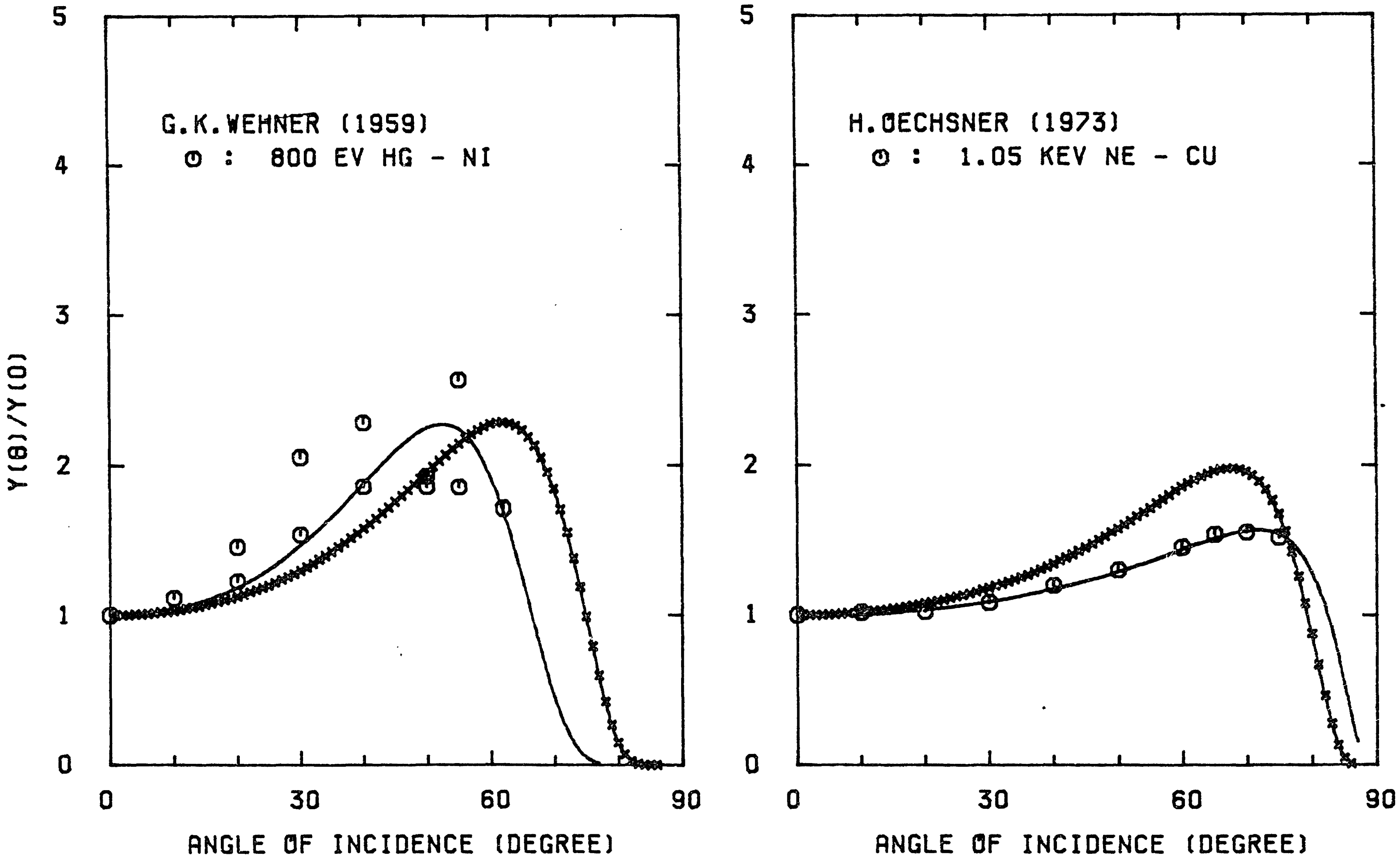

G.K.WEHNER (1959)
⊙ : 800 EV HG - NI
H.OECHSNER (1973)
⊙ : 1.05 KEV NE - CU
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 30

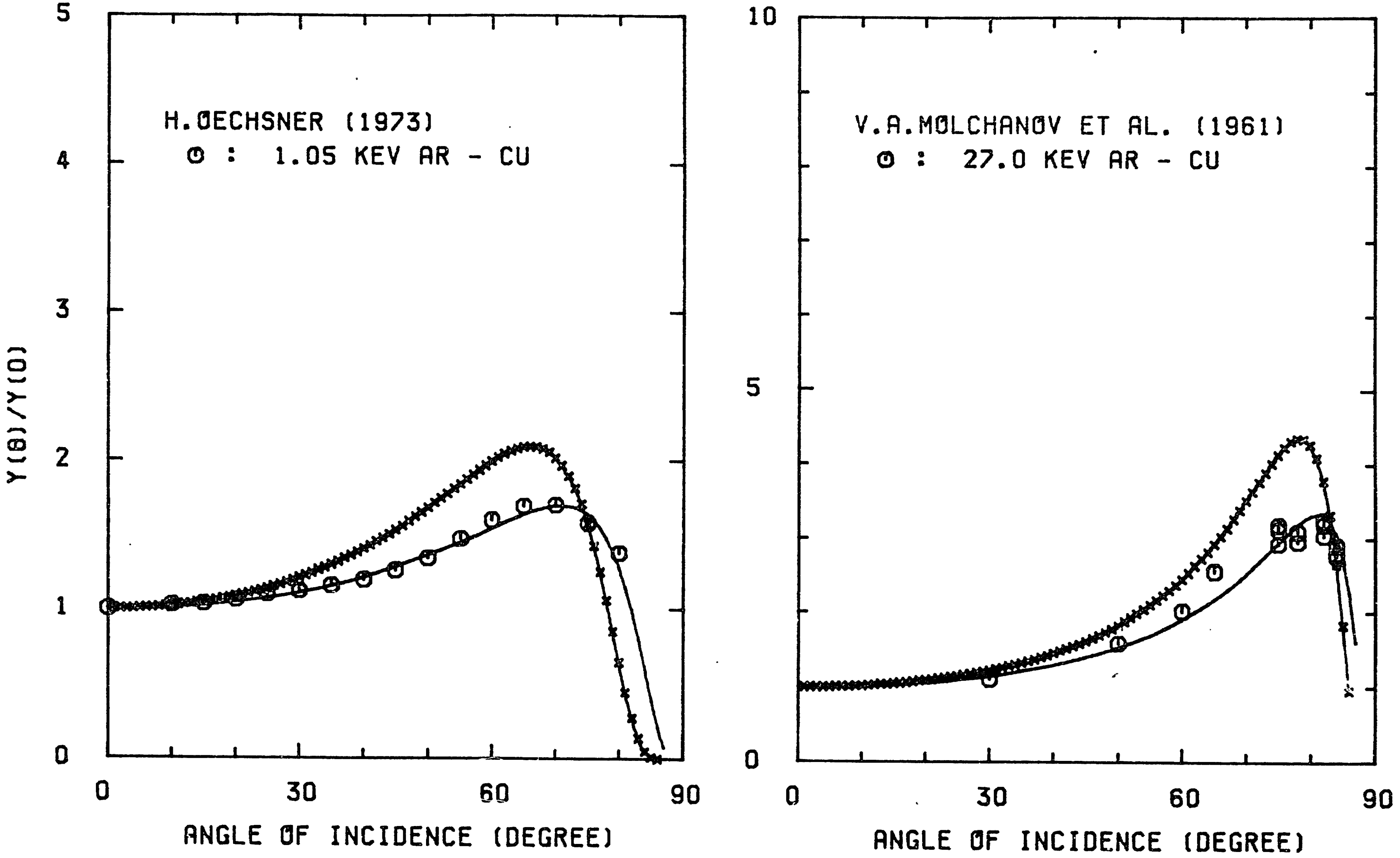

H.ØECHSNER (1973)
⊙ : 1.05 KEV AR - CU
V.A.MØLCHANØV ET AL. (1961)
⊙ : 27.0 KEV AR - CU
Y(θ)/Y(0)
0
1
2
3
4
5
10
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 31

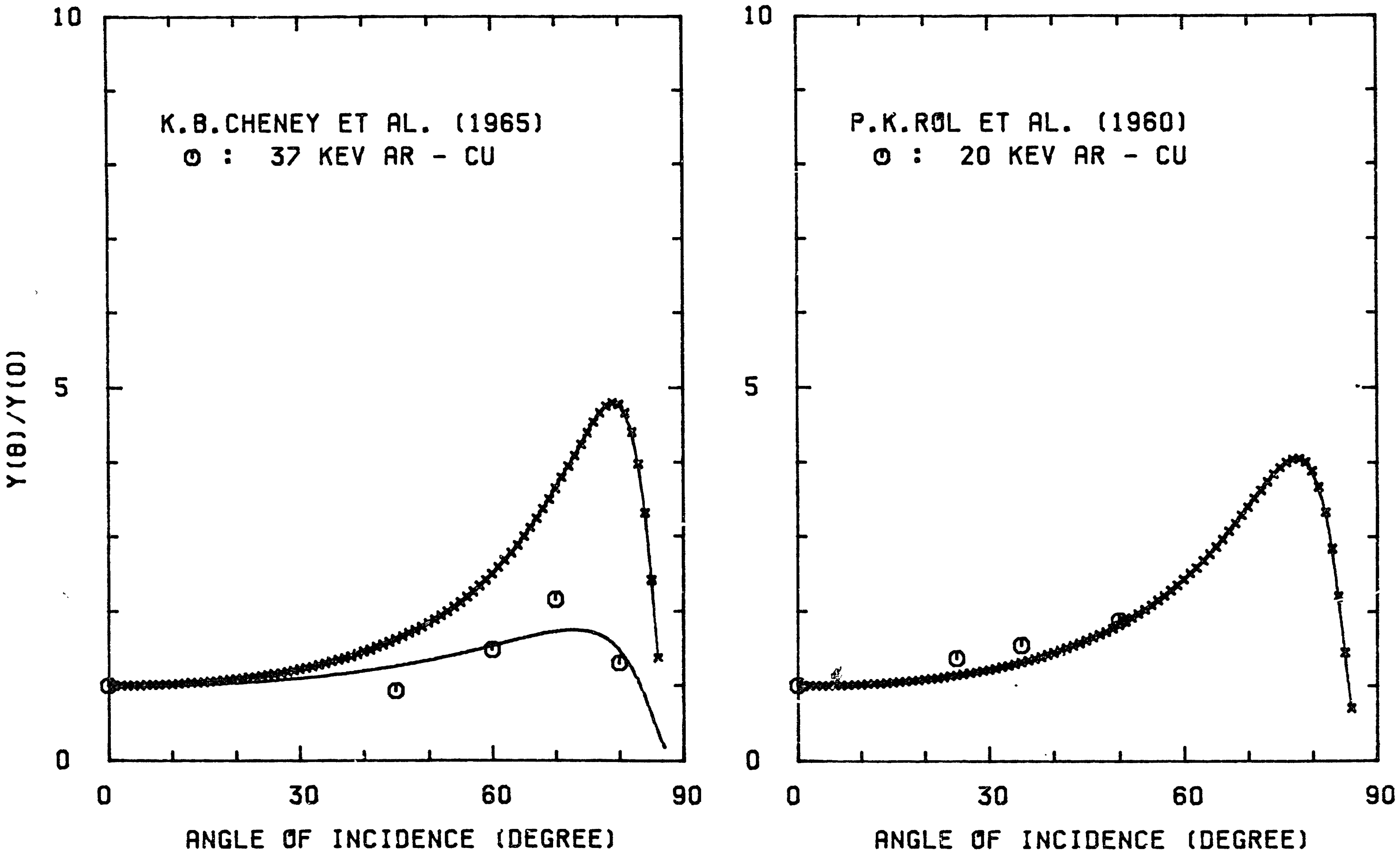

K.B.CHENEY ET AL. (1965)
Θ : 37 KEV AR - CU
P.K.RØL ET AL. (1960)
Θ : 20 KEV AR - CU
Y(θ)/Y(0)
10
5
0
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 32

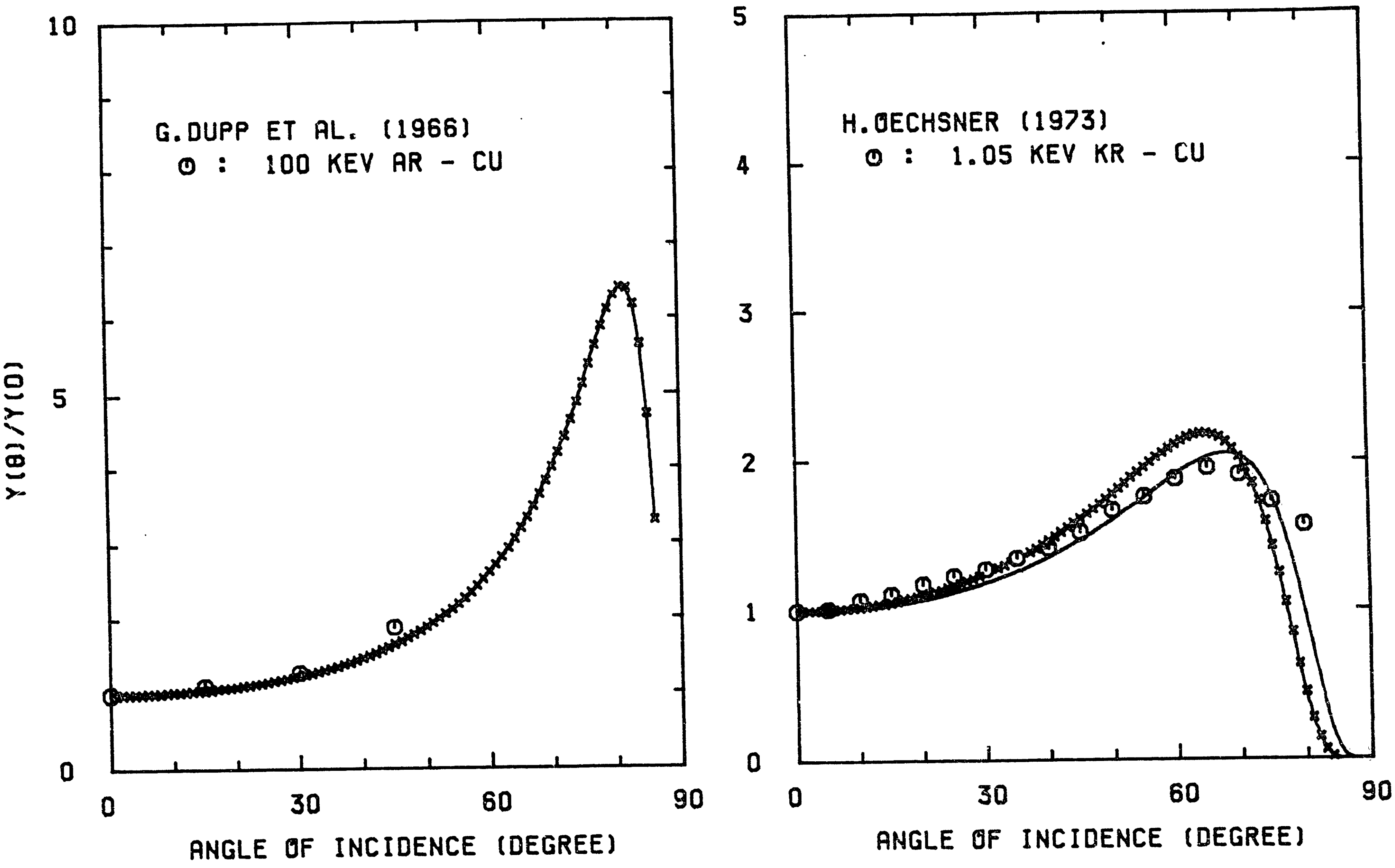

G.DUPP ET AL. (1966)
ʘ : 100 KEV AR - CU
H.OECHSNER (1973)
ʘ : 1.05 KEV KR - CU
Y(θ)/Y(0)
0
5
10
1
2
3
4
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 33

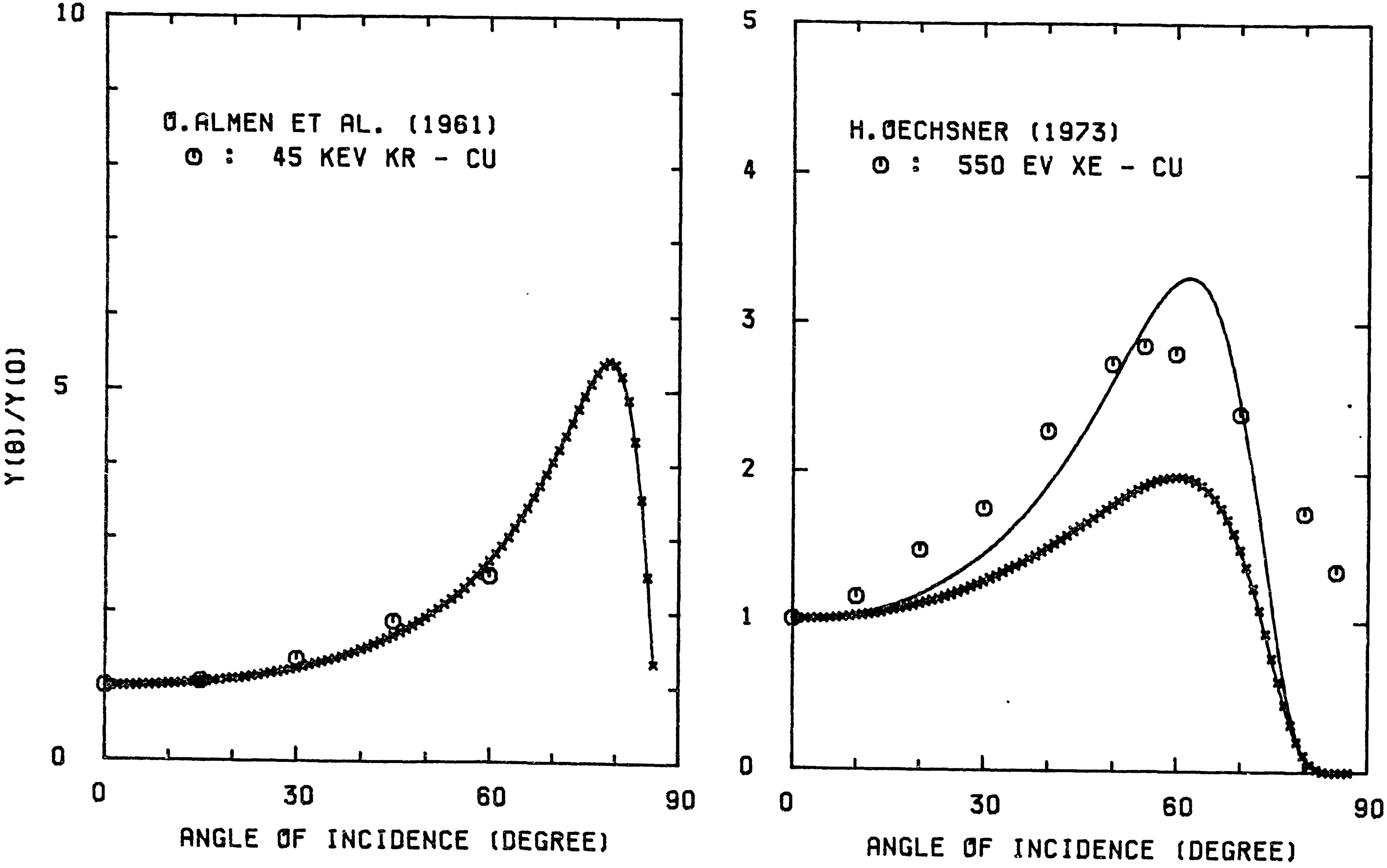

Y(θ)/Y(0)
10
5
0
O.ALMEN ET AL. (1961)
Θ : 45 KEV KR - CU
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
5
4
3
2
1
0
H.OECHSNER (1973)
Θ : 550 EV XE - CU
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 34

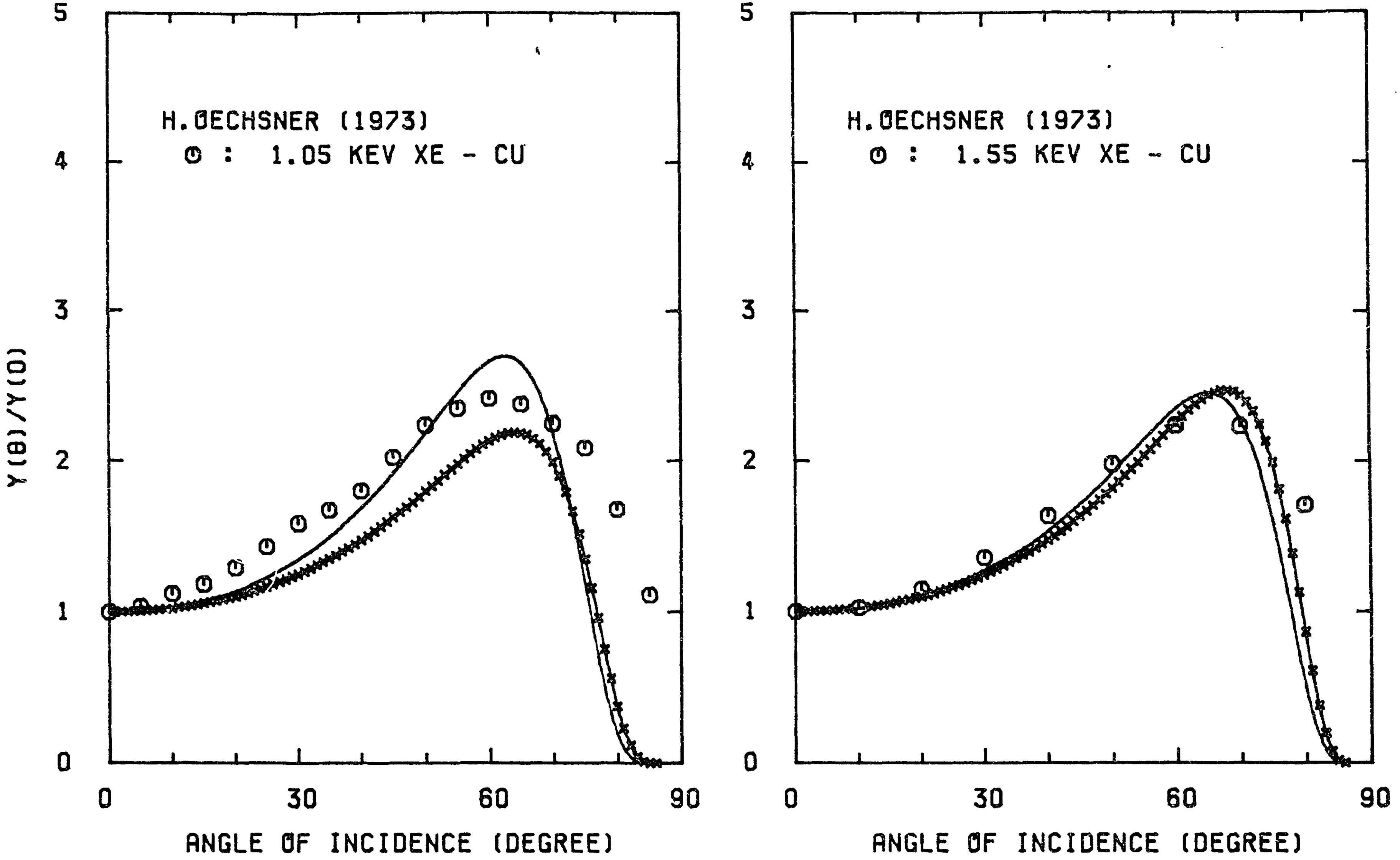

H.OECHSNER (1973)
Θ : 1.05 KEV XE - CU
H.OECHSNER (1973)
Θ : 1.55 KEV XE - CU
Y(Θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 35

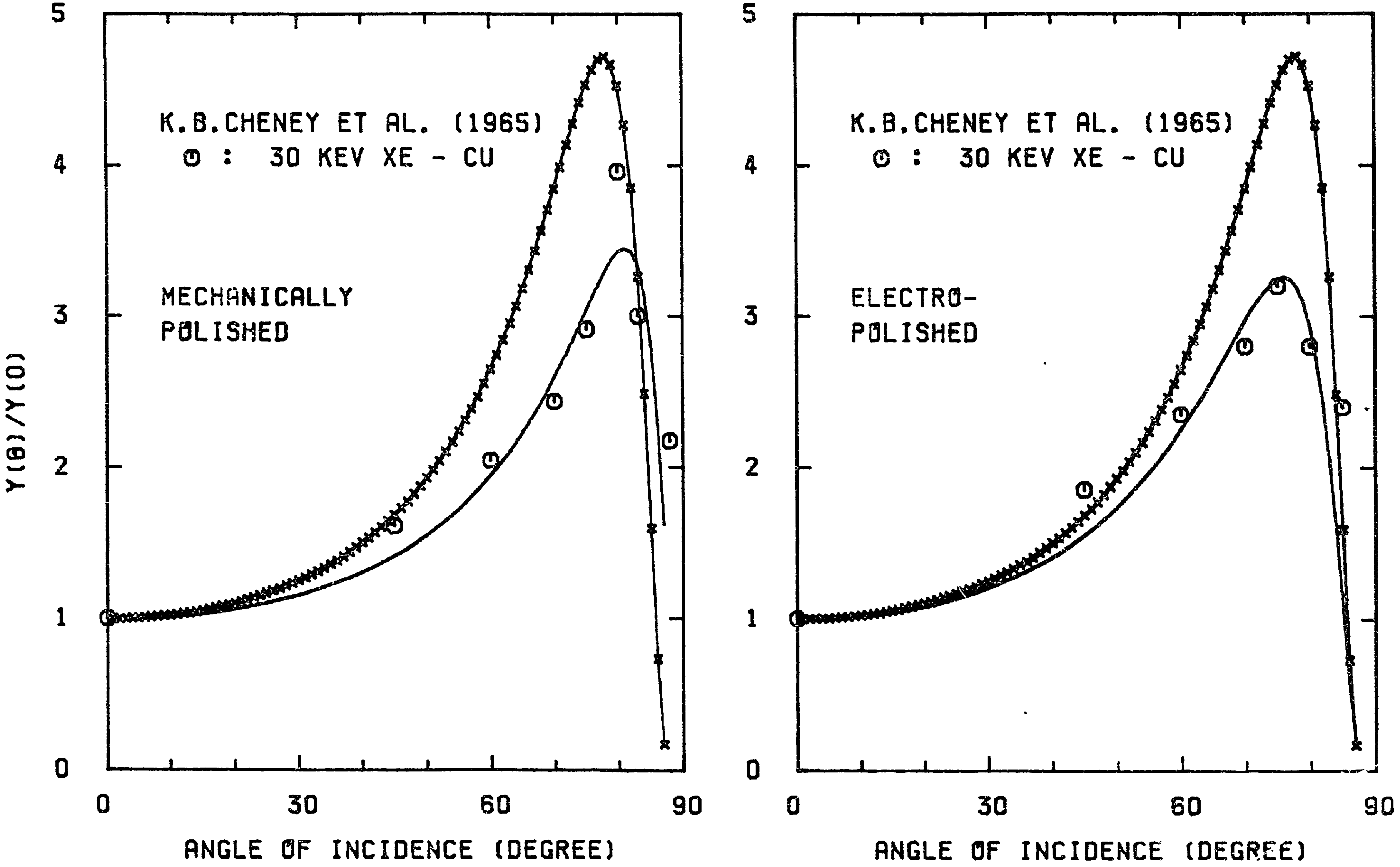

K.B.CHENEY ET AL. (1965)
Θ : 30 KEV XE - CU
MECHANICALLY
POLISHED
ELECTRO-
POLISHED
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 36

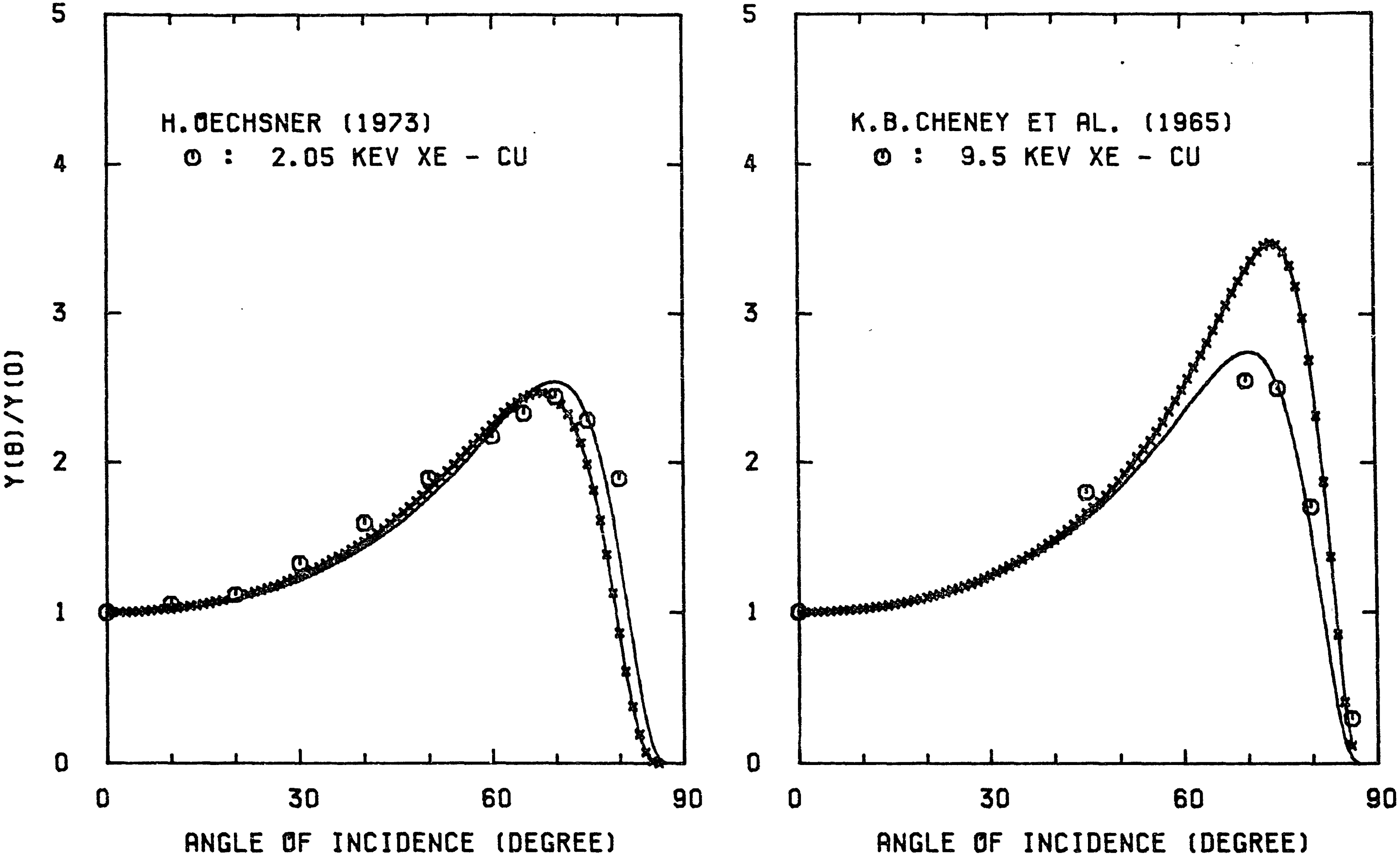

H.OECHSNER (1973)
⊙ : 2.05 KEV XE - CU
K.B.CHENEY ET AL. (1965)
⊙ : 9.5 KEV XE - CU
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 37

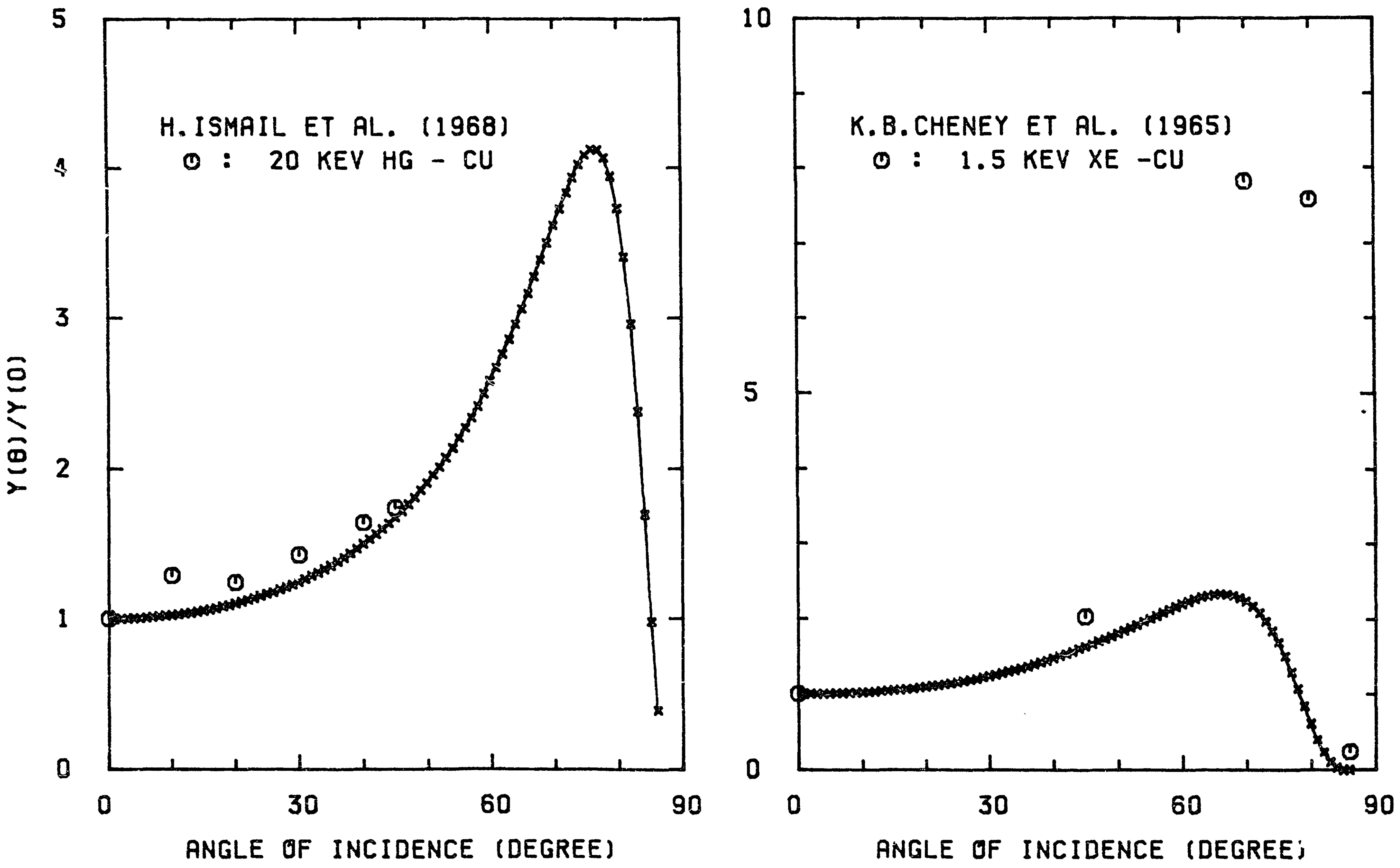

H.ISMAIL ET AL. (1968)
ʘ : 20 KEV HG - CU
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
K.B.CHENEY ET AL. (1965)
ʘ : 1.5 KEV XE -CU
0
5
10
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 38

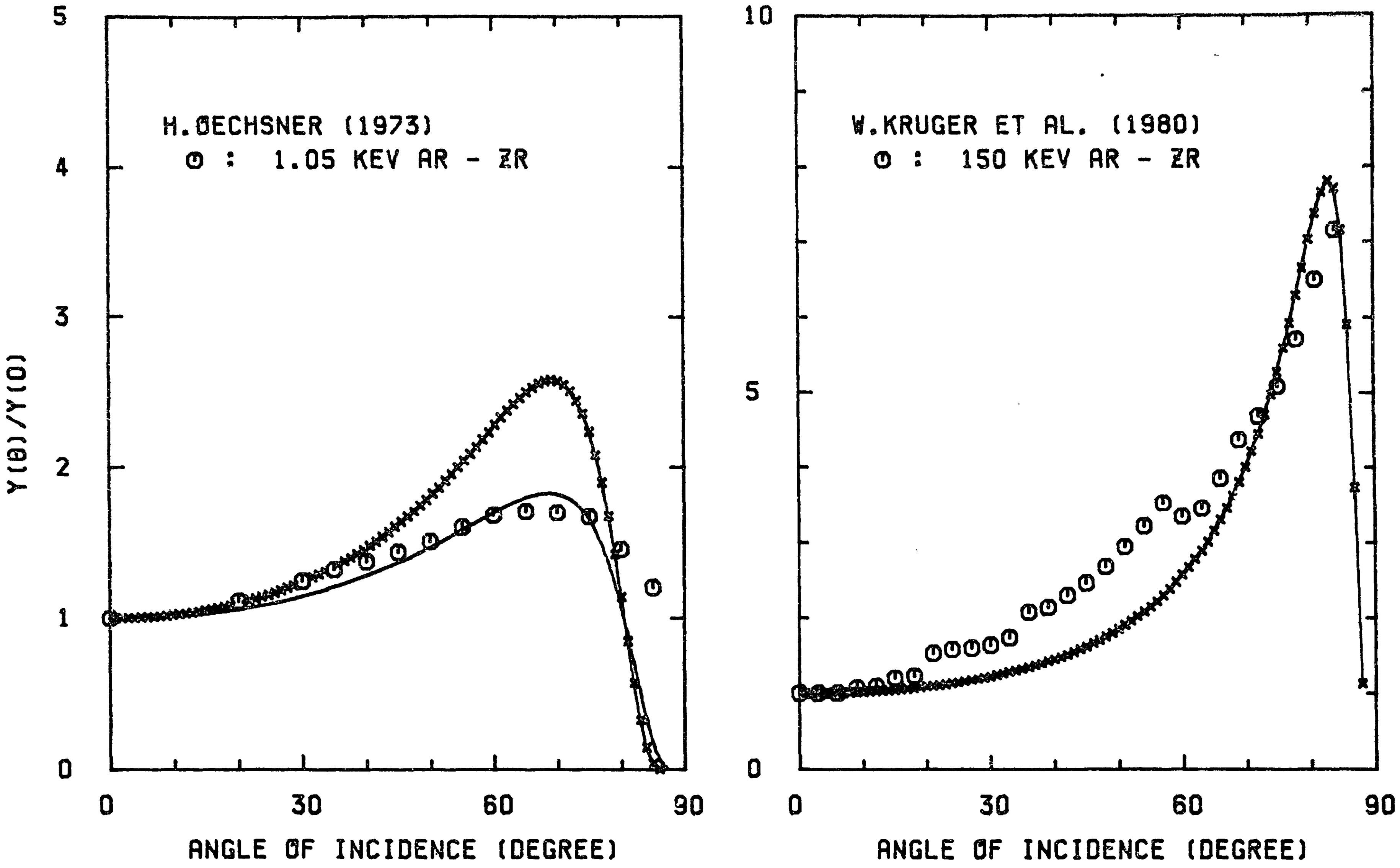

H.ŒCHSNER (1973)
ʘ : 1.05 KEV AR - ZR
W.KRUGER ET AL. (1980)
ʘ : 150 KEV AR - ZR
Y(θ)/Y(0)
0
1
2
3
4
5
10
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 39

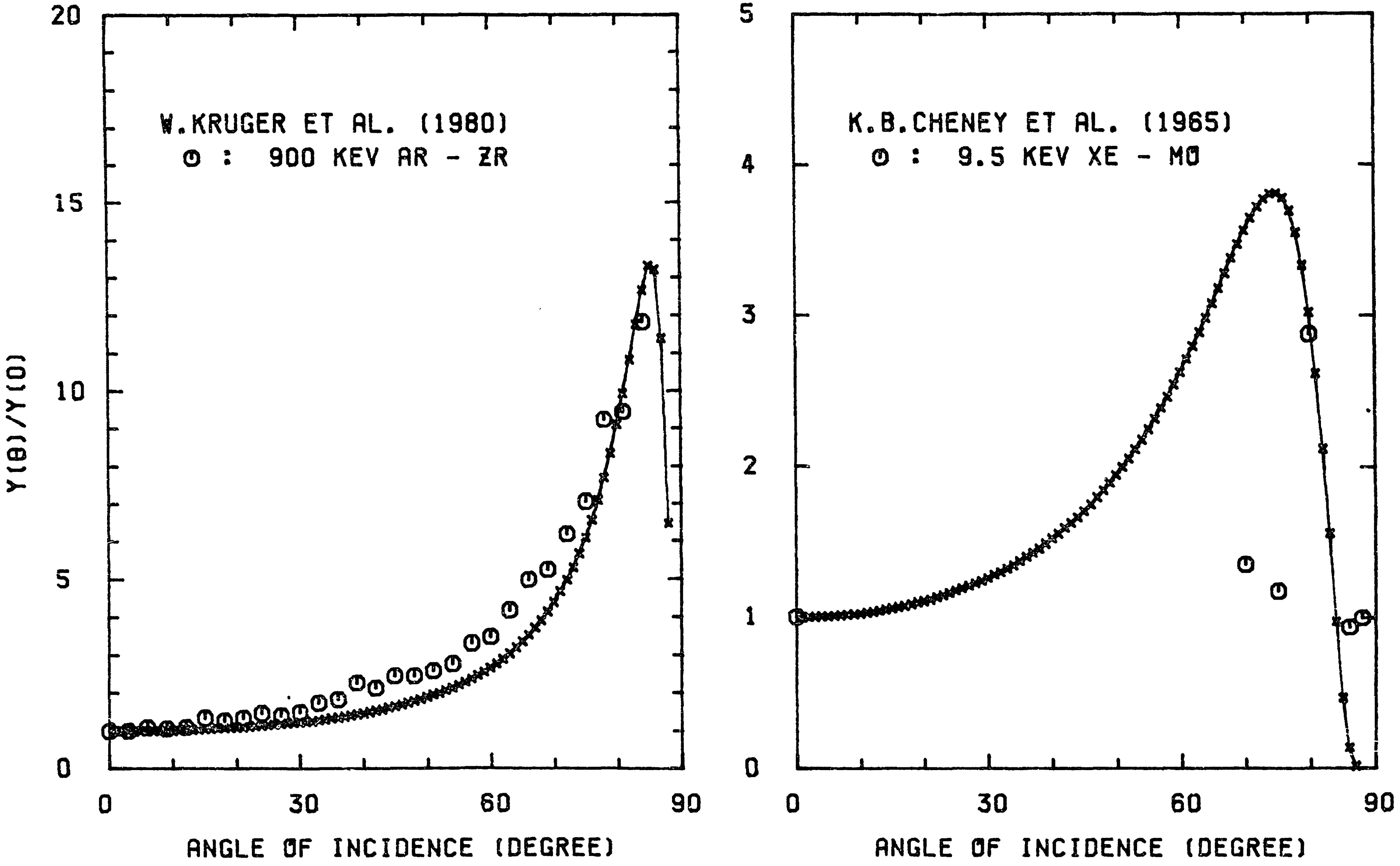

Y(θ)/Y(0)
0
5
10
15
20
W.KRUGER ET AL. (1980)
⊙ : 900 KEV AR - ZR
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
0
1
2
3
4
5
K.B.CHENEY ET AL. (1965)
⊙ : 9.5 KEV XE - MO
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 40

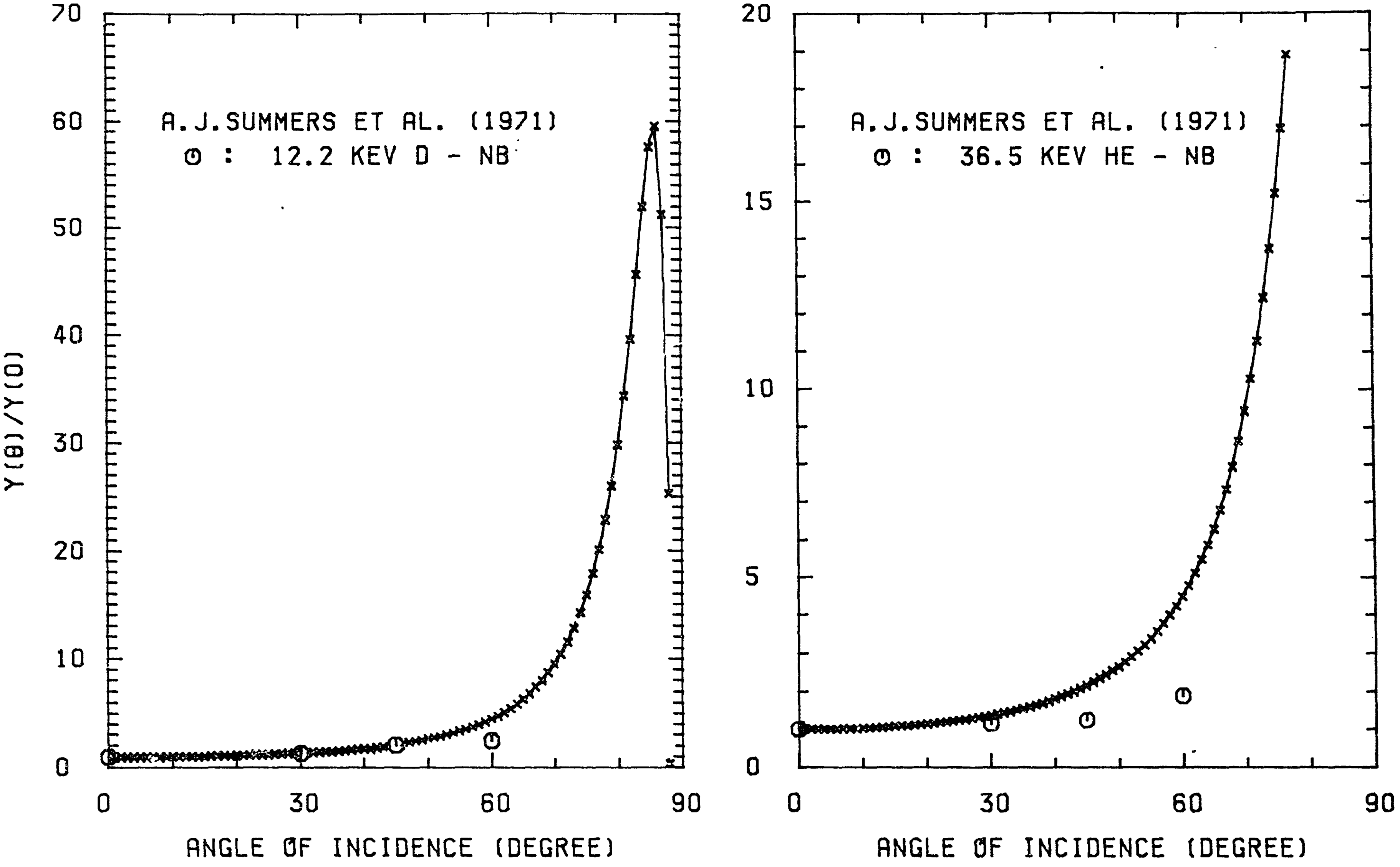

70
60
50
40
30
20
10
0
Y(θ)/Y(0)
A.J.SUMMERS ET AL. (1971)
⊙ : 12.2 KEV D - NB
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
20
15
10
5
0
A.J.SUMMERS ET AL. (1971)
⊙ : 36.5 KEV HE - NB
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 41

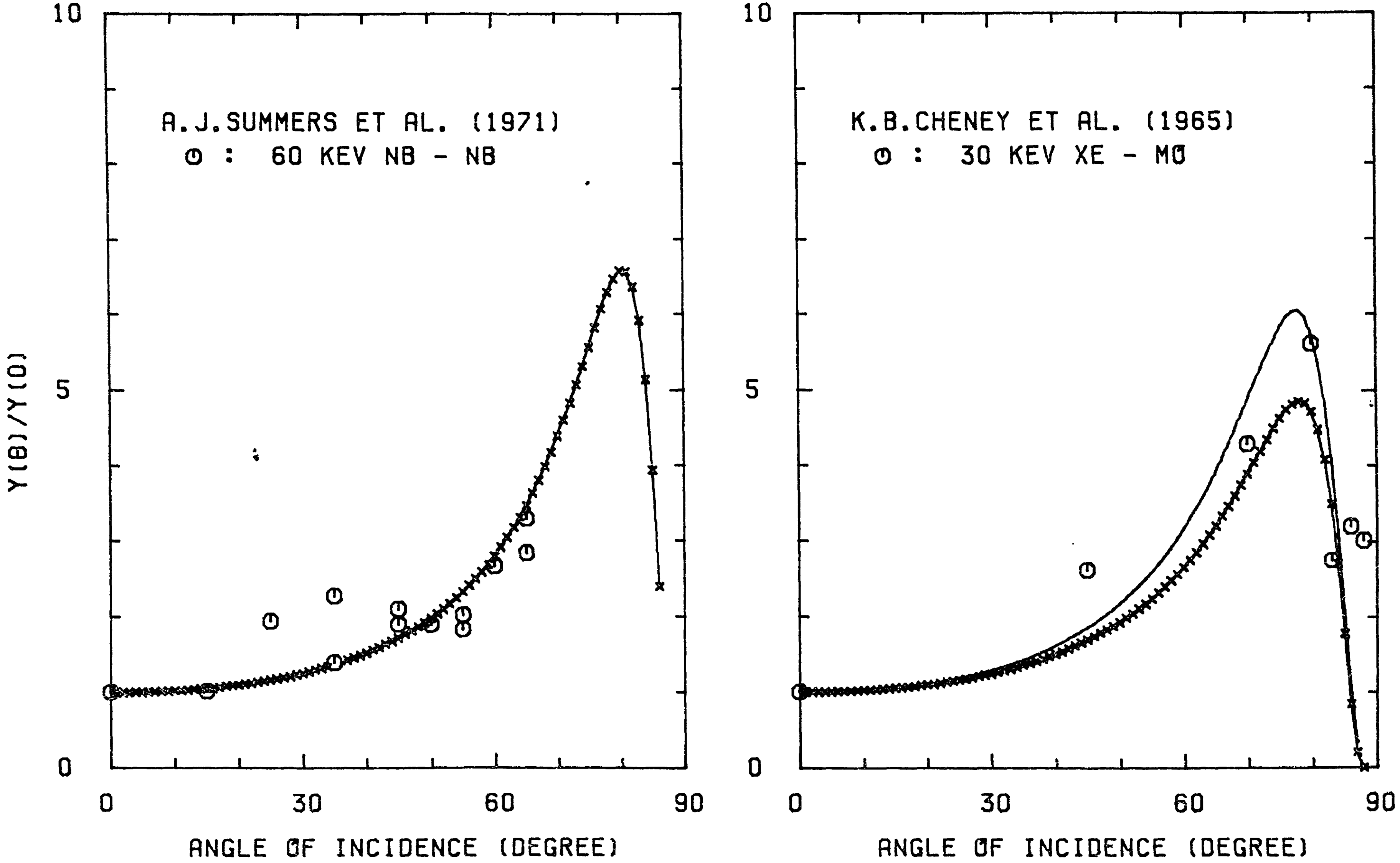

A.J.SUMMERS ET AL. (1971)
Θ : 60 KEV NB - NB
K.B.CHENEY ET AL. (1965)
Θ : 30 KEV XE - MO
Y(θ)/Y(0)
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 42

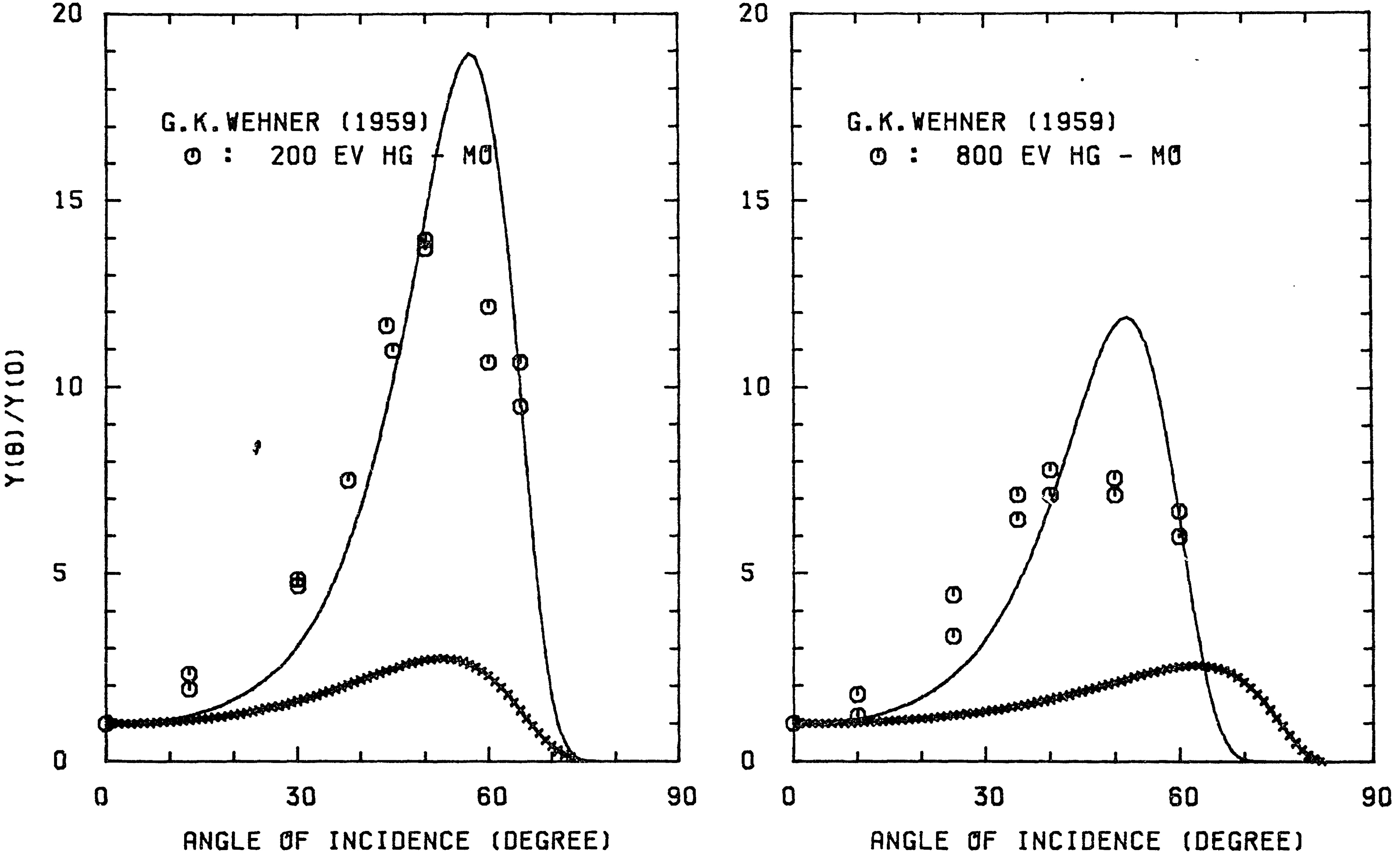

G.K.WEHNER (1959)
ʘ : 200 EV HG - MO
G.K.WEHNER (1959)
ʘ : 800 EV HG - MO
Y(θ)/Y(0)
0
5
10
15
20
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 43

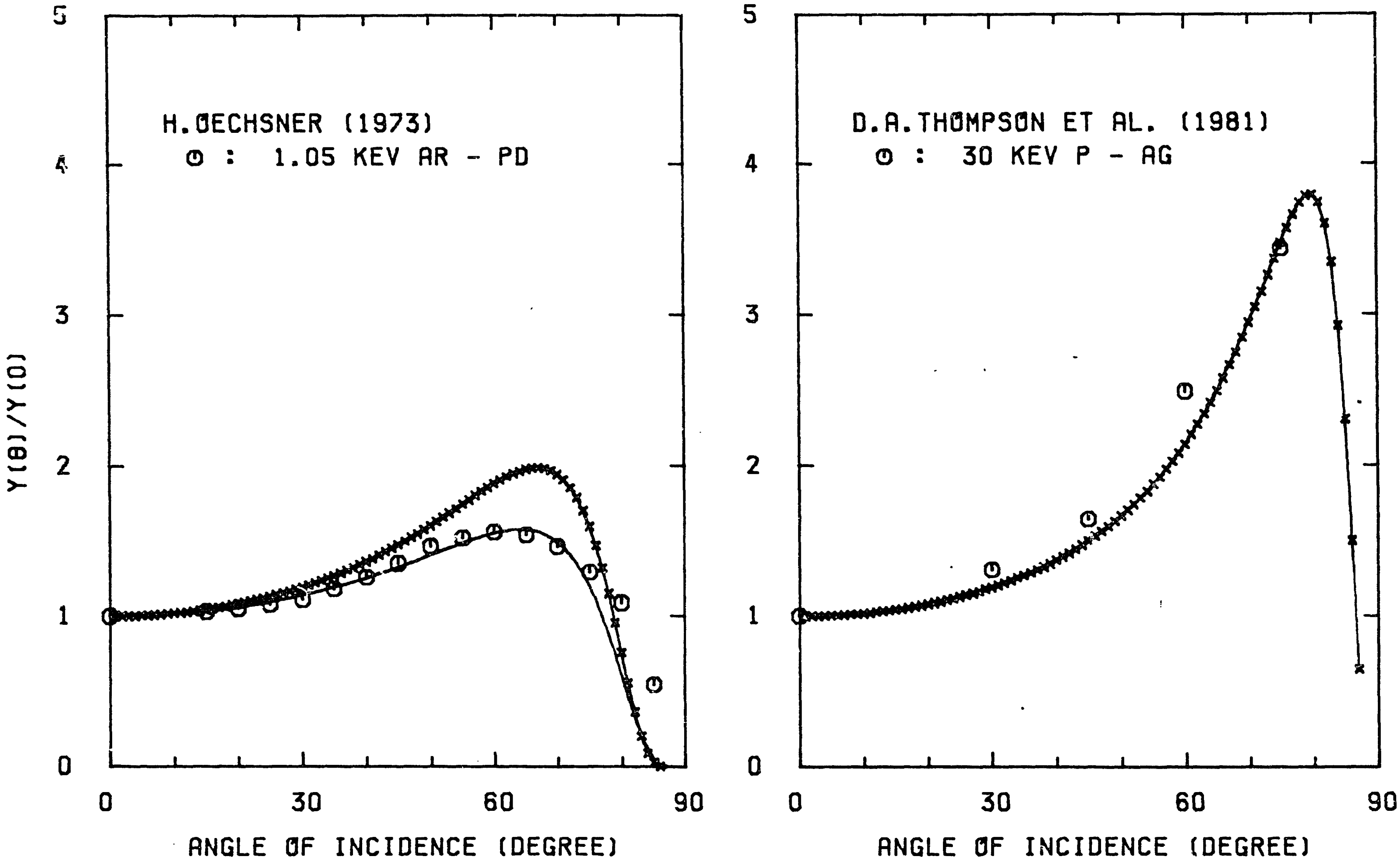

H.OECHSNER (1973)
Θ : 1.05 KEV AR - PD
D.A.THOMPSON ET AL. (1981)
Θ : 30 KEV P - AG
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 44

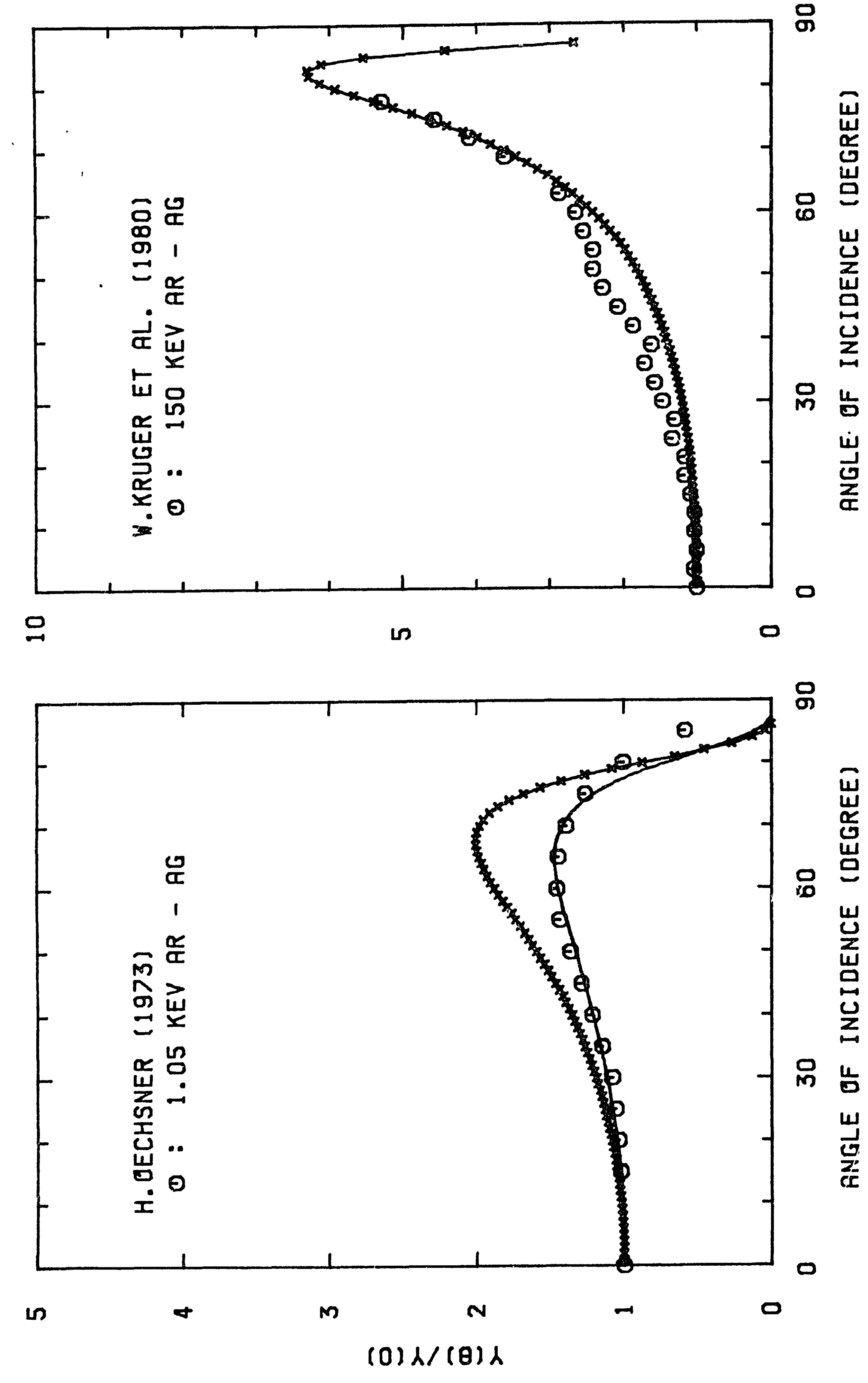

H.OECHSNER (1973)
Θ : 1.05 KEV AR - AG
W.KRUGER ET AL. (1980)
Θ : 150 KEV AR - AG
Y(θ)/Y(0)
0
1
2
3
4
5
0
5
10
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 45

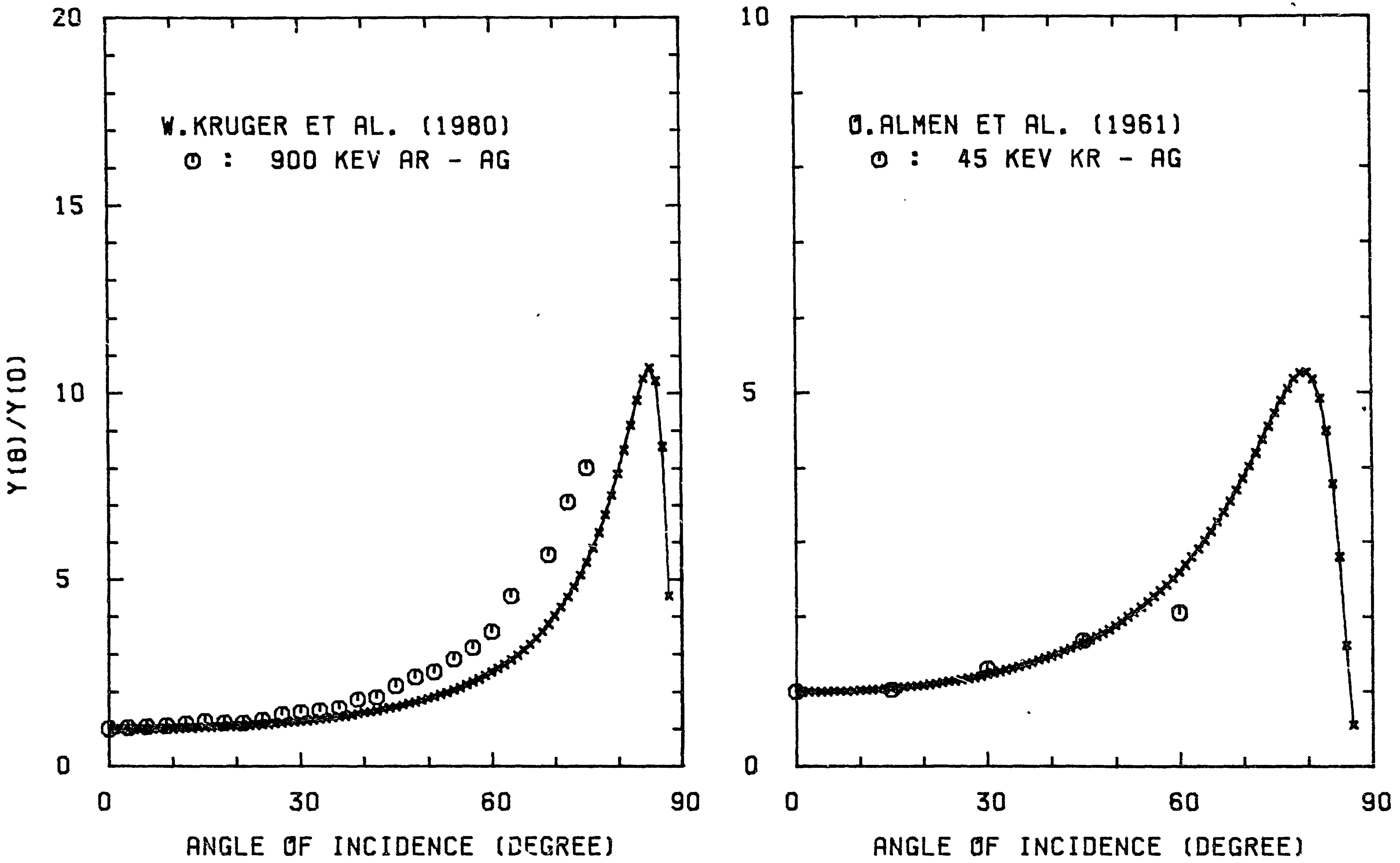

W.KRUGER ET AL. (1980)
⊖ : 900 KEV AR - AG
Ø.ALMEN ET AL. (1961)
⊖ : 45 KEV KR - AG
Y(θ)/Y(0)
20
15
10
5
0
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
10
5
0
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 46

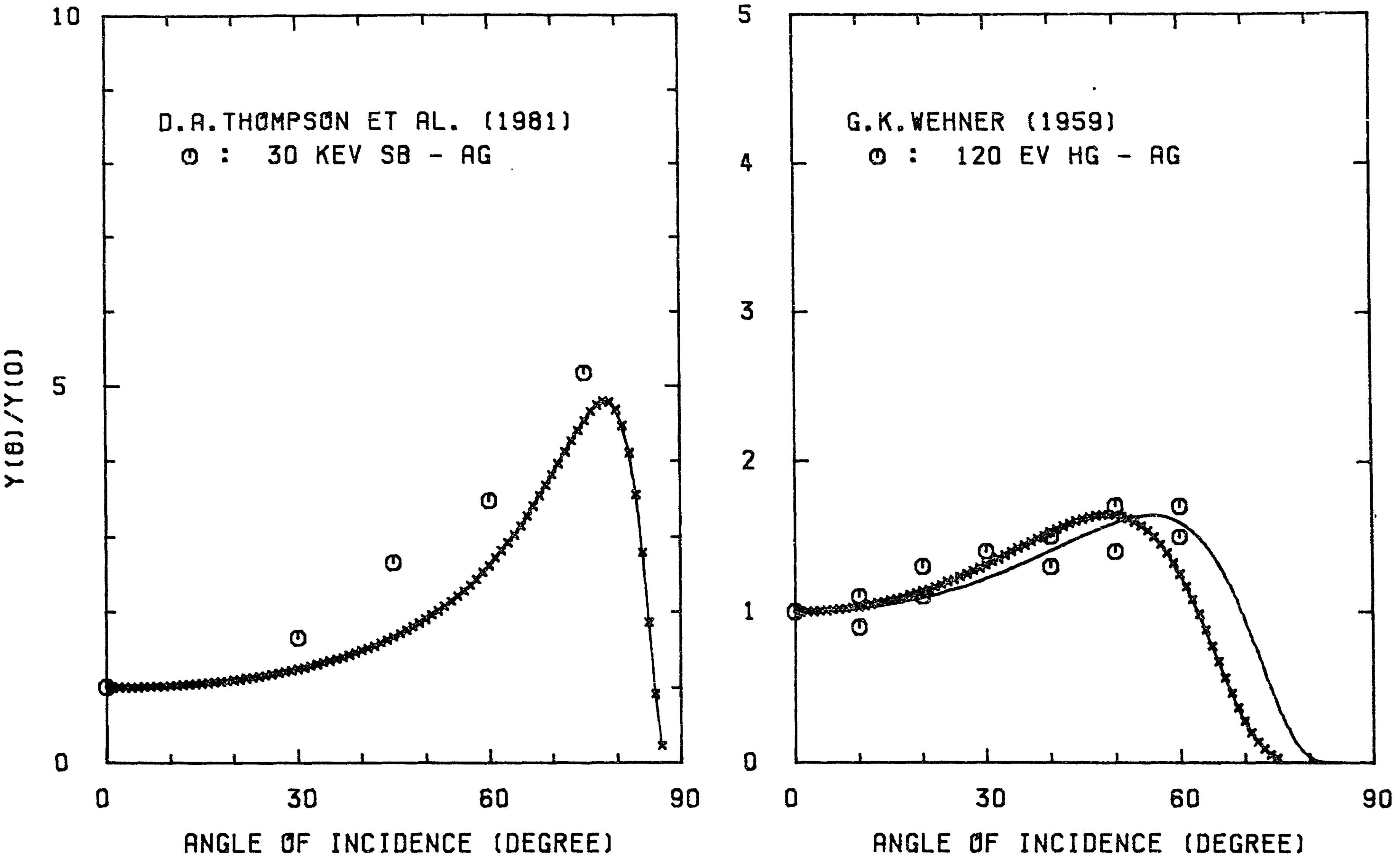

D.A.THOMPSON ET AL. (1981)
⊖ : 30 KEV SB - AG
G.K.WEHNER (1959)
⊖ : 120 EV HG - AG
Y(θ)/Y(0)
10
5
0
5
4
3
2
1
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 47

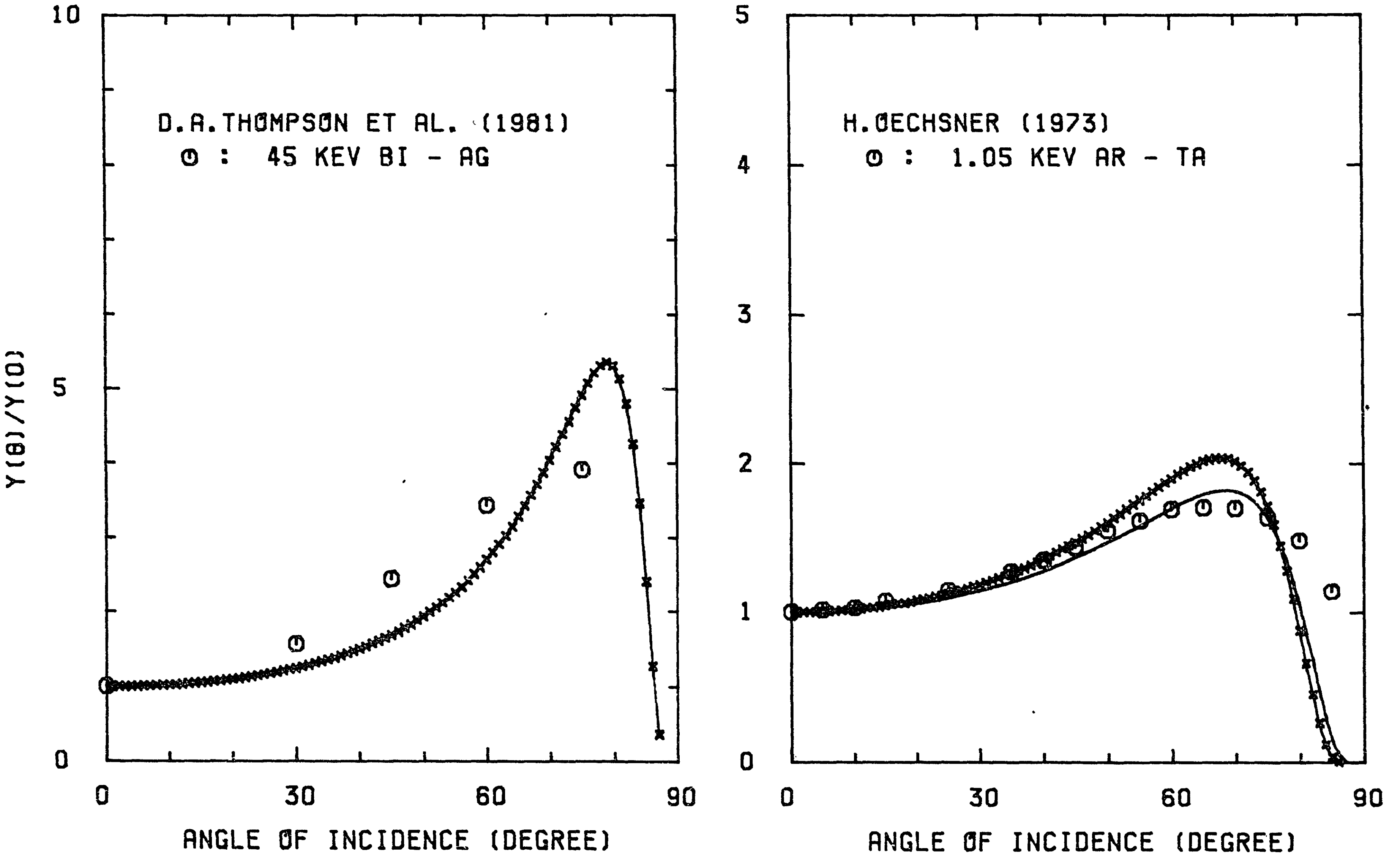

D.A.THOMPSON ET AL. (1981)
Θ : 45 KEV BI - AG
H.OECHSNER (1973)
Θ : 1.05 KEV AR - TA
Y(θ)/Y(0)
10
5
0
4
3
2
1
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 48

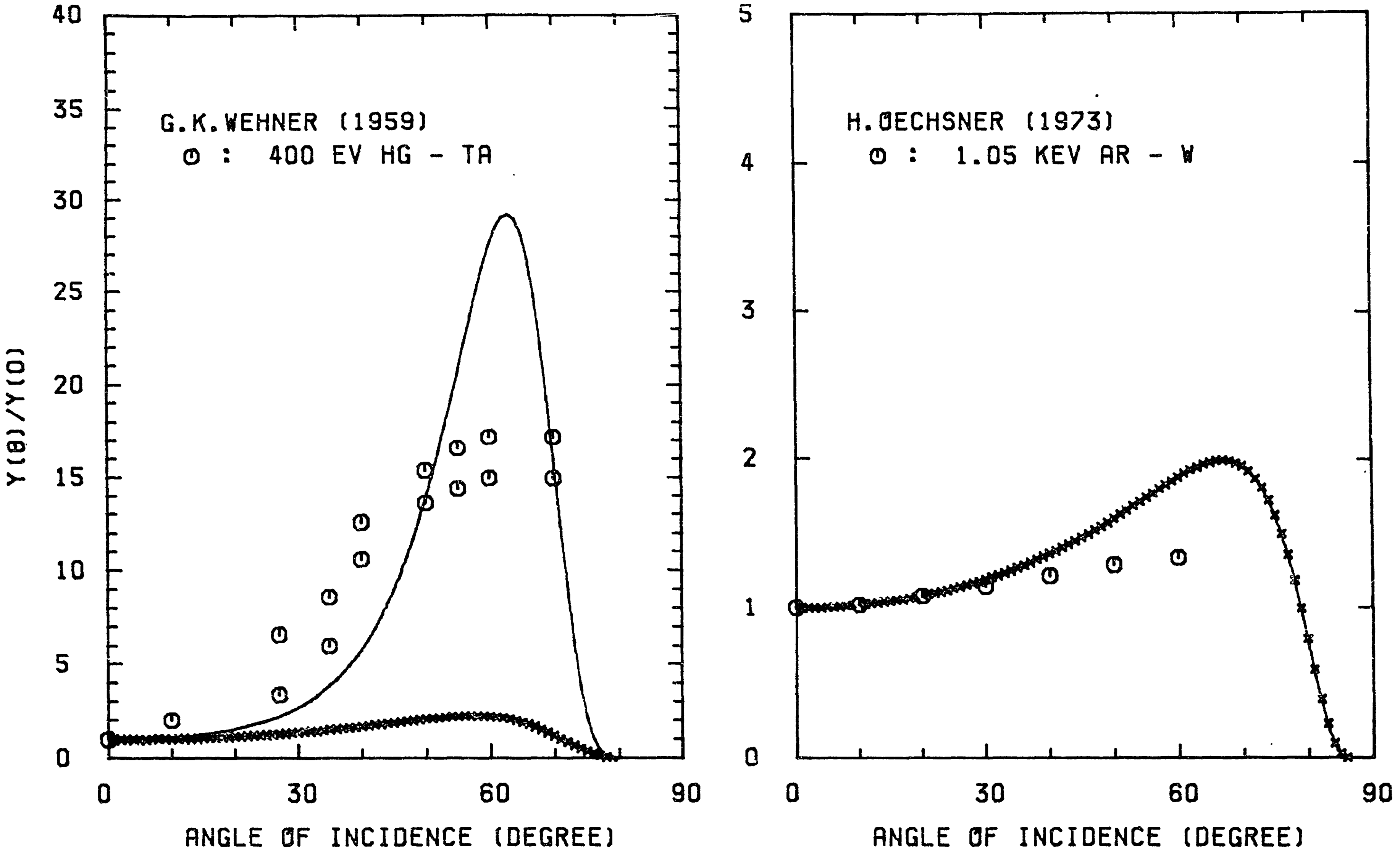

G.K.WEHNER (1959)
⊙ : 400 EV HG - TA
Y(θ)/Y(0)
0
5
10
15
20
25
30
35
40
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
H.OECHSNER (1973)
⊙ : 1.05 KEV AR - W
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 49

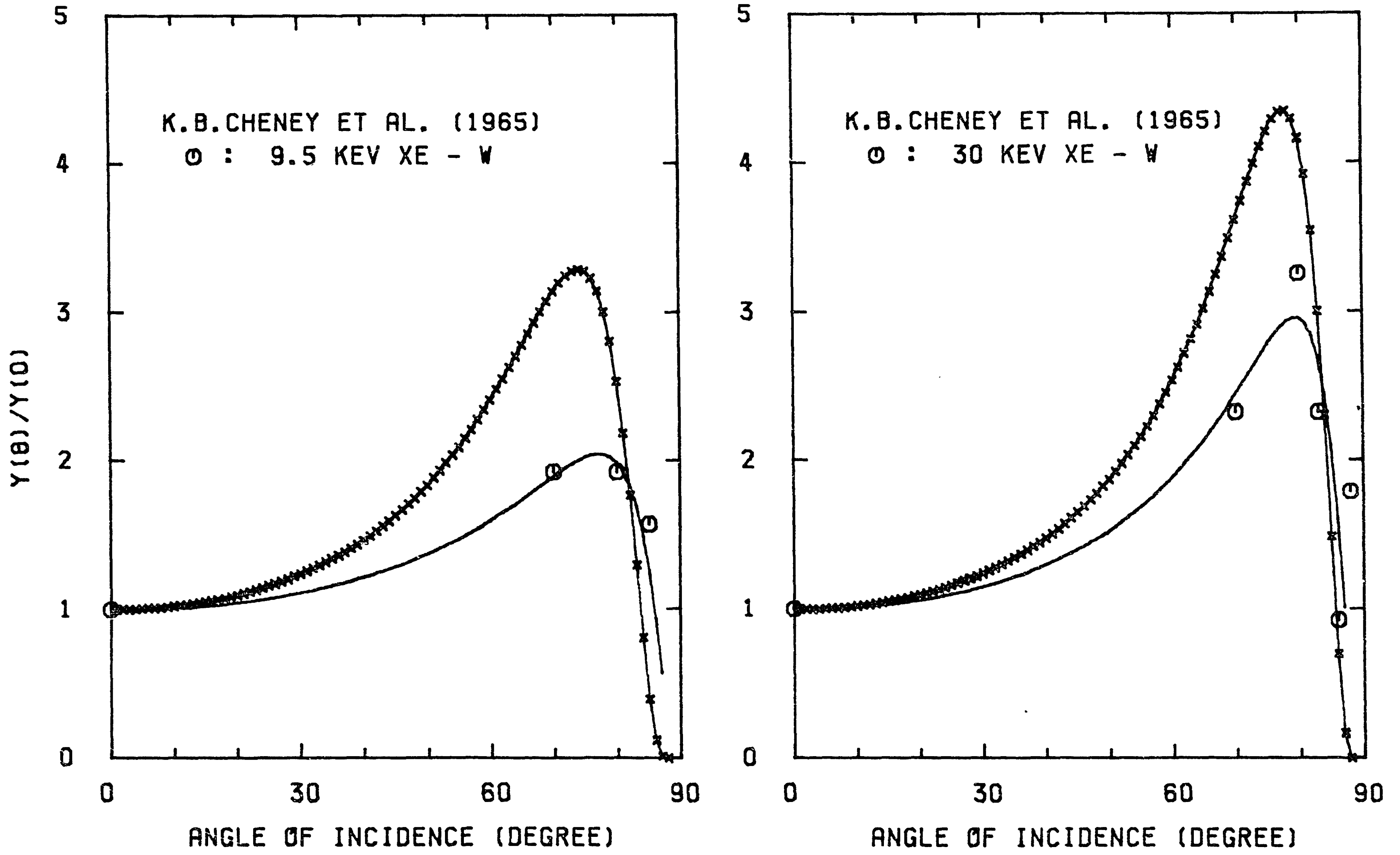

K.B.CHENEY ET AL. (1965)
⊖ : 9.5 KEV XE - W
K.B.CHENEY ET AL. (1965)
⊖ : 30 KEV XE - W
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ANGLE OF INCIDENCE (DEGREE)

Fig. 50

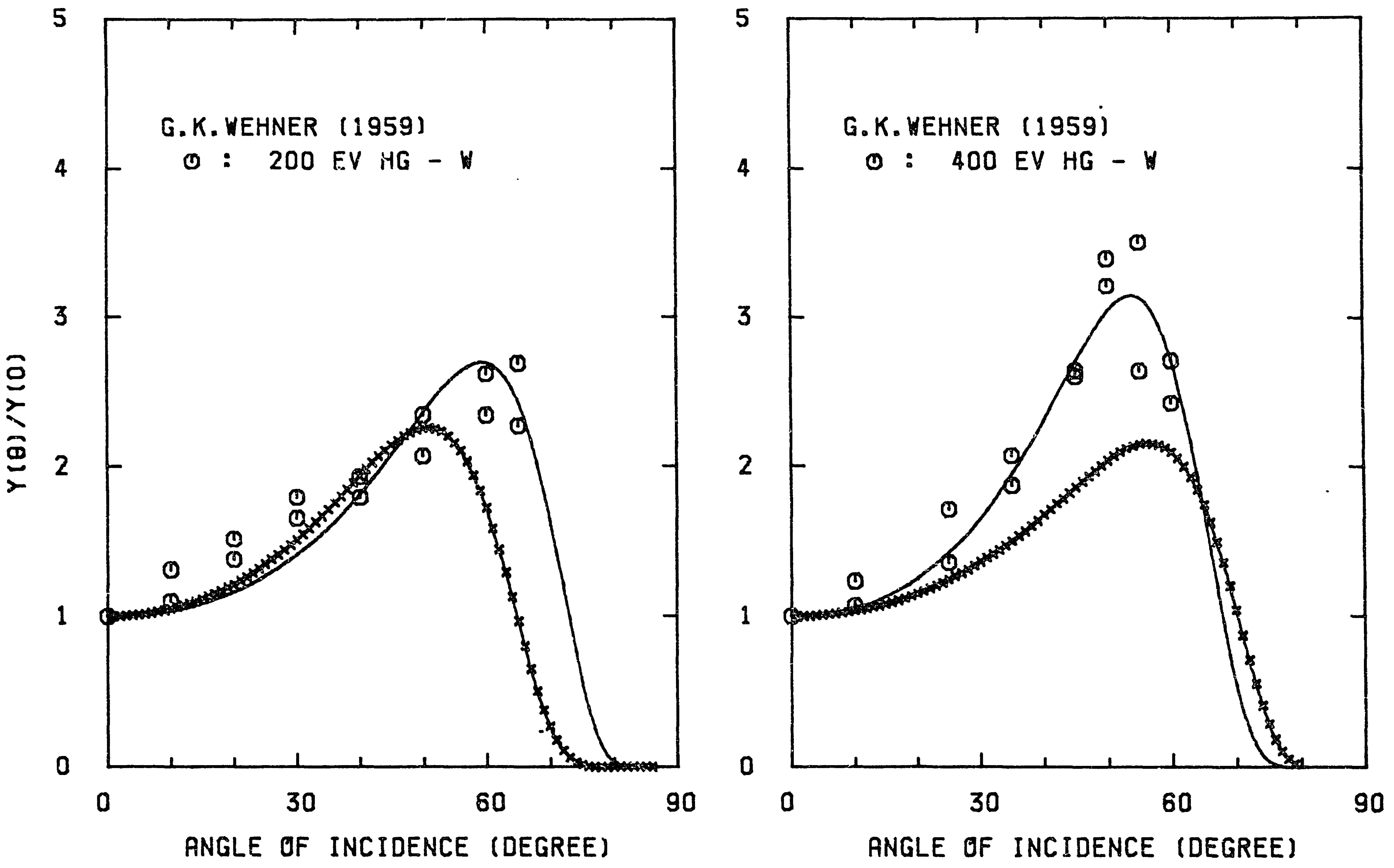

G.K.WEHNER (1959)
ʘ : 200 EV HG - W
G.K.WEHNER (1959)
ʘ : 400 EV HG - W
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 51

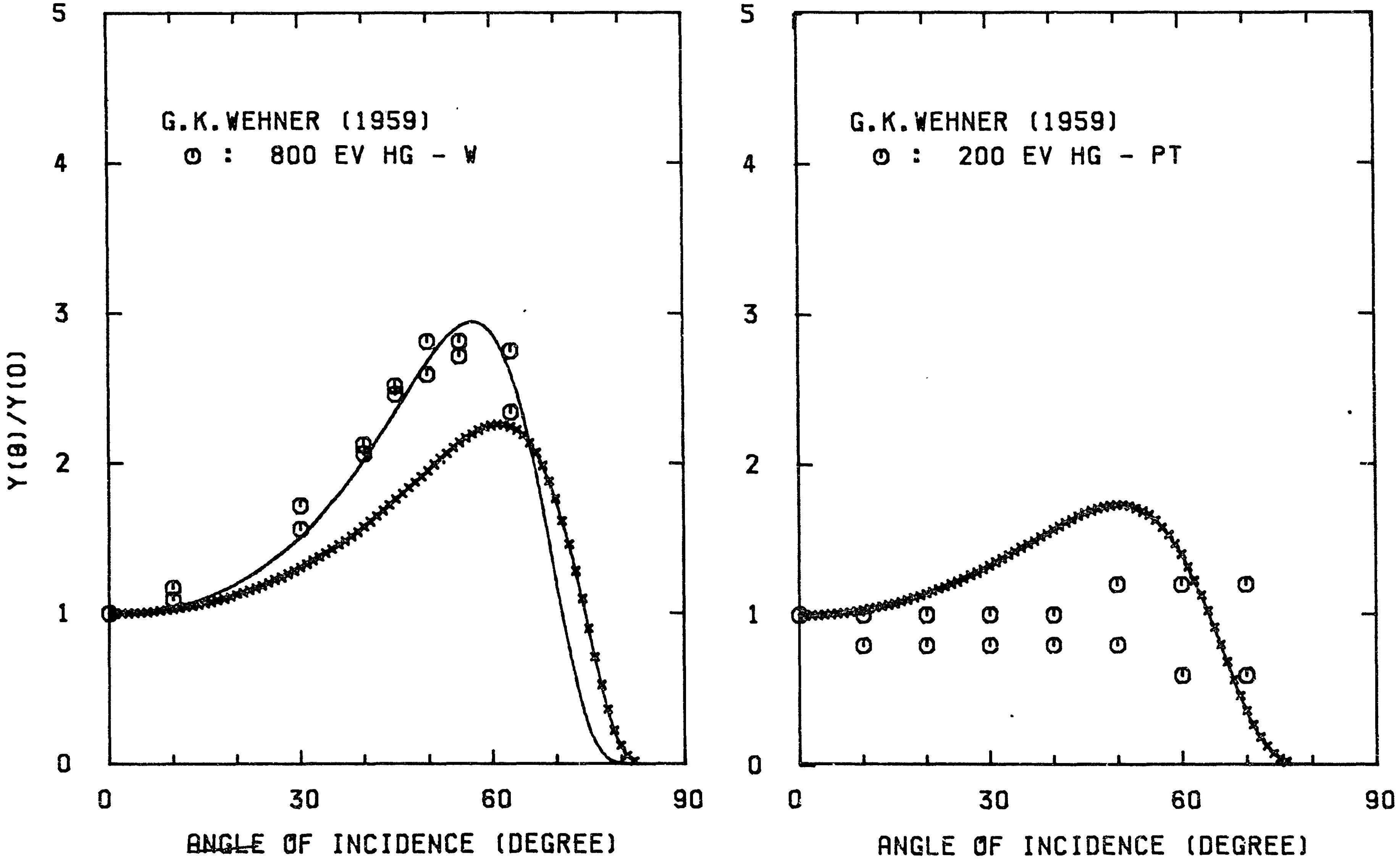

G.K.WEHNER (1959)
ʘ : 800 EV HG - W
G.K.WEHNER (1959)
ʘ : 200 EV HG - PT
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 52

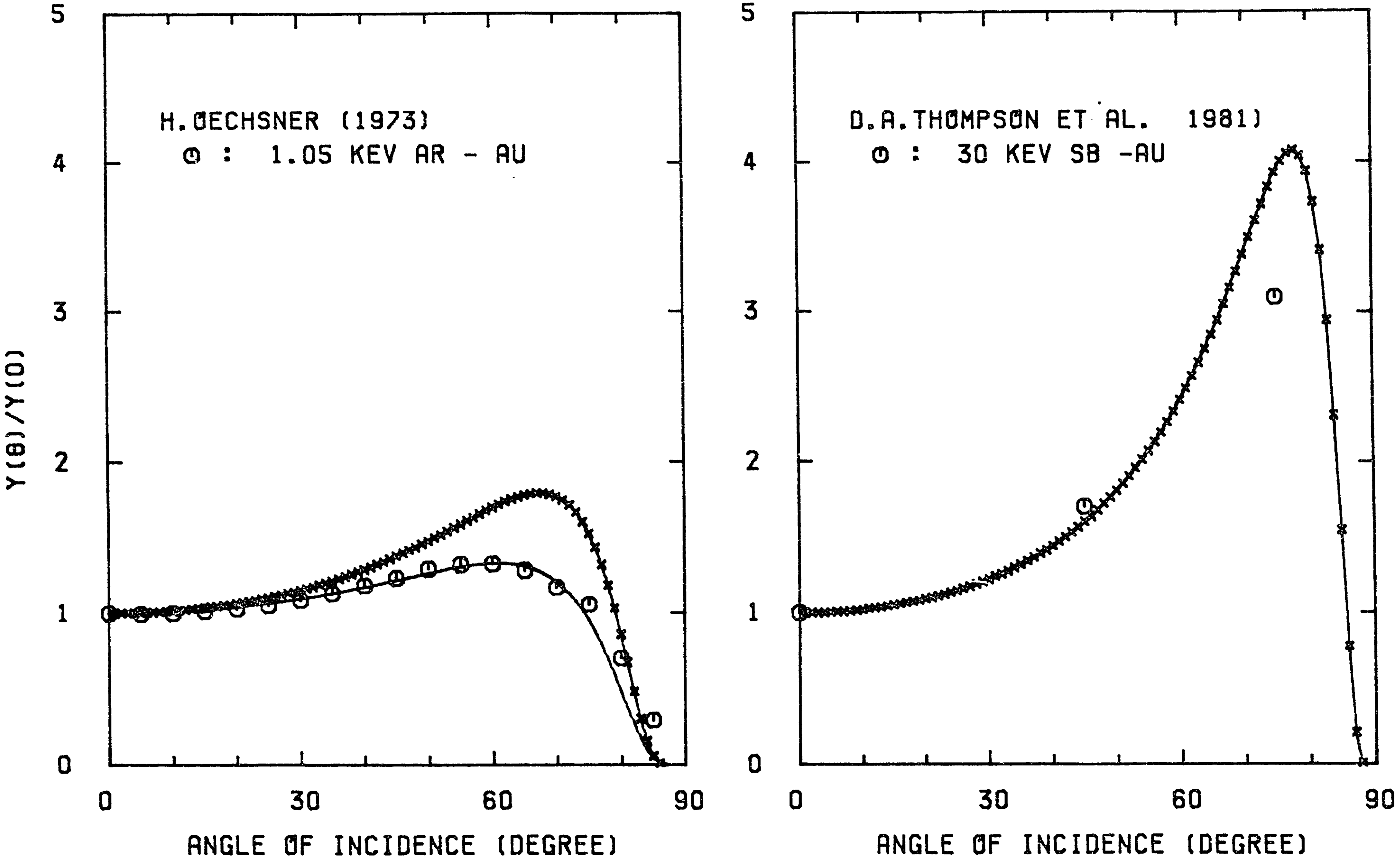

H.OECHSNER (1973)
⊖ : 1.05 KEV AR - AU
D.A.THOMPSON ET AL. 1981)
⊖ : 30 KEV SB -AU
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 53

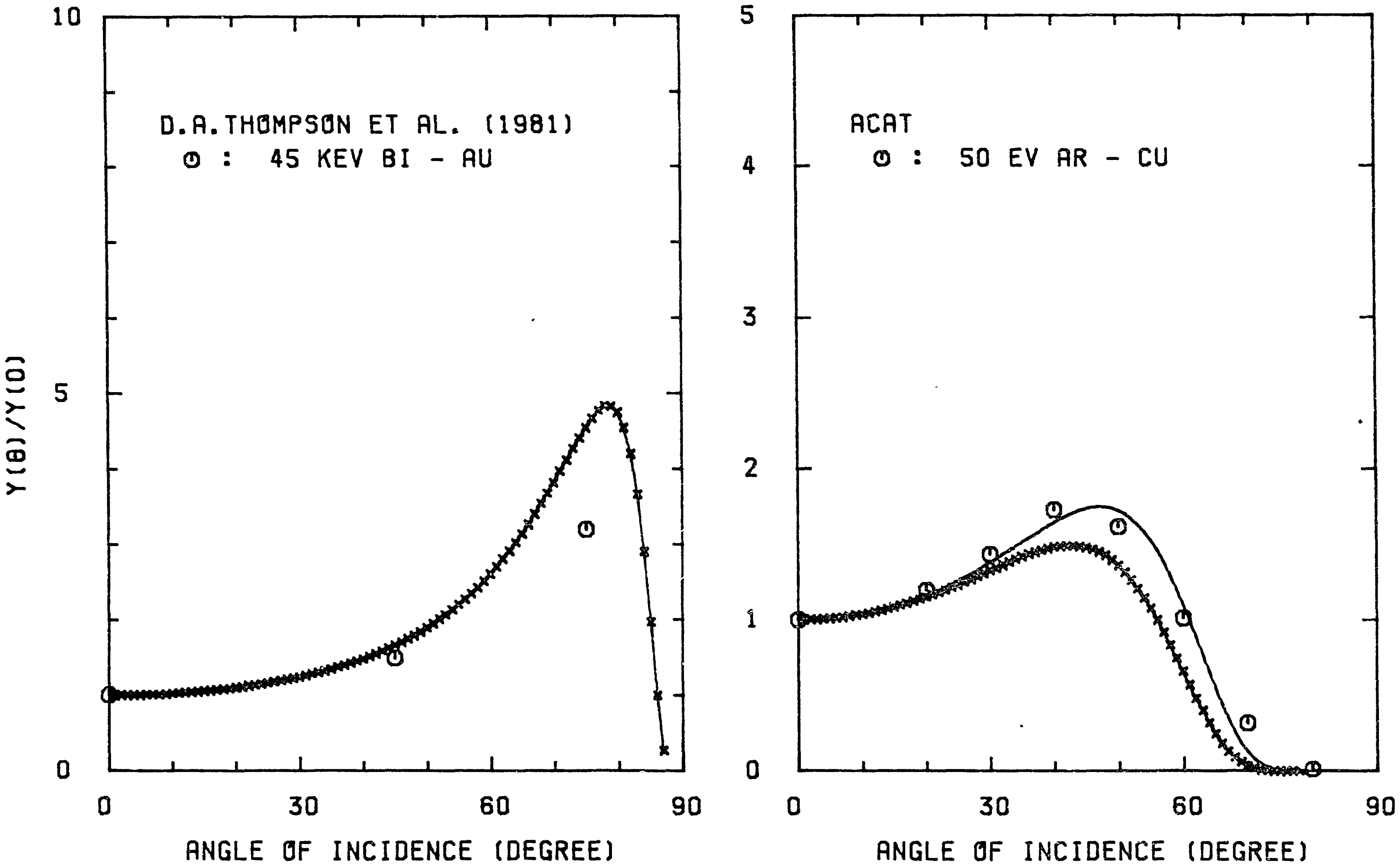

D.A.THOMPSON ET AL. (1981)
Θ : 45 KEV BI - AU
Y(θ)/Y(0)
10
5
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)
ACAT
Θ : 50 EV AR - CU
5
4
3
2
1
0
0
30
60
90
ANGLE OF INCIDENCE (DEGREE)

Fig. 54

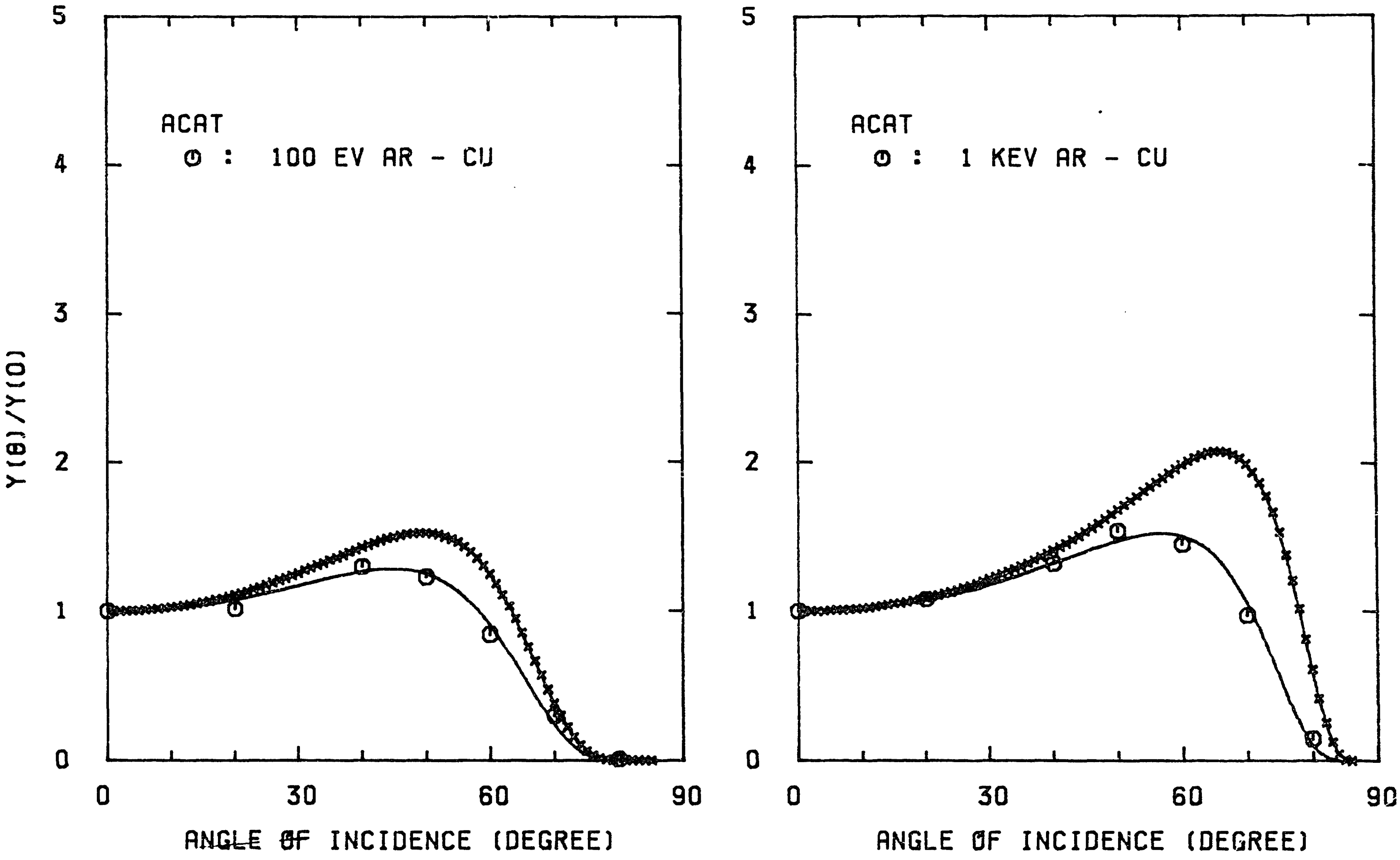

5
4
3
2
1
0
Y(θ)/Y(O)
ACAT
ʘ : 100 EV AR - CU
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
5
4
3
2
1
0
ACAT
ʘ : 1 KEV AR - CU
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 55

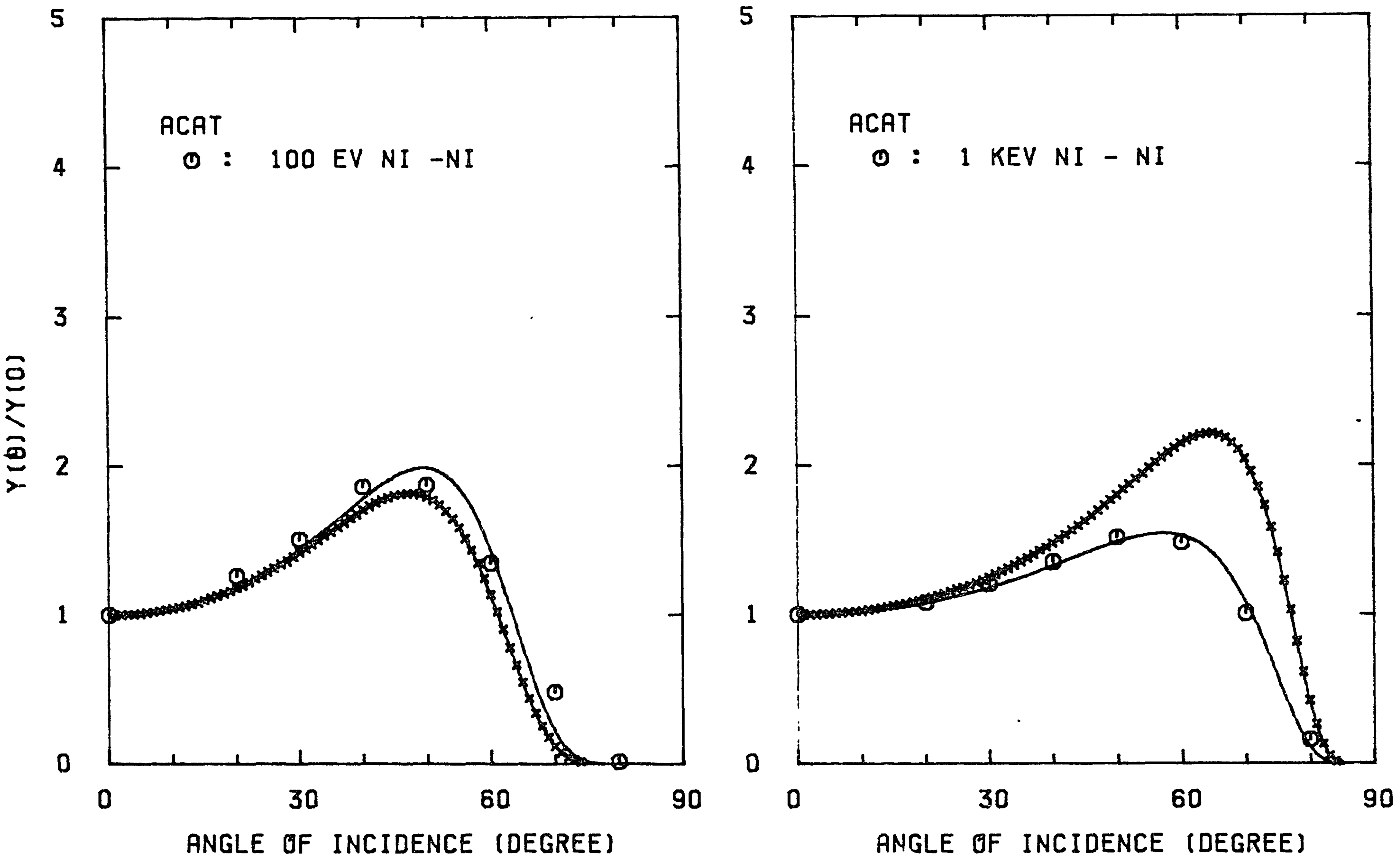

ACAT
ʘ : 100 EV NI -NI
ACAT
ʘ : 1 KEV NI - NI
Y(θ)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 56

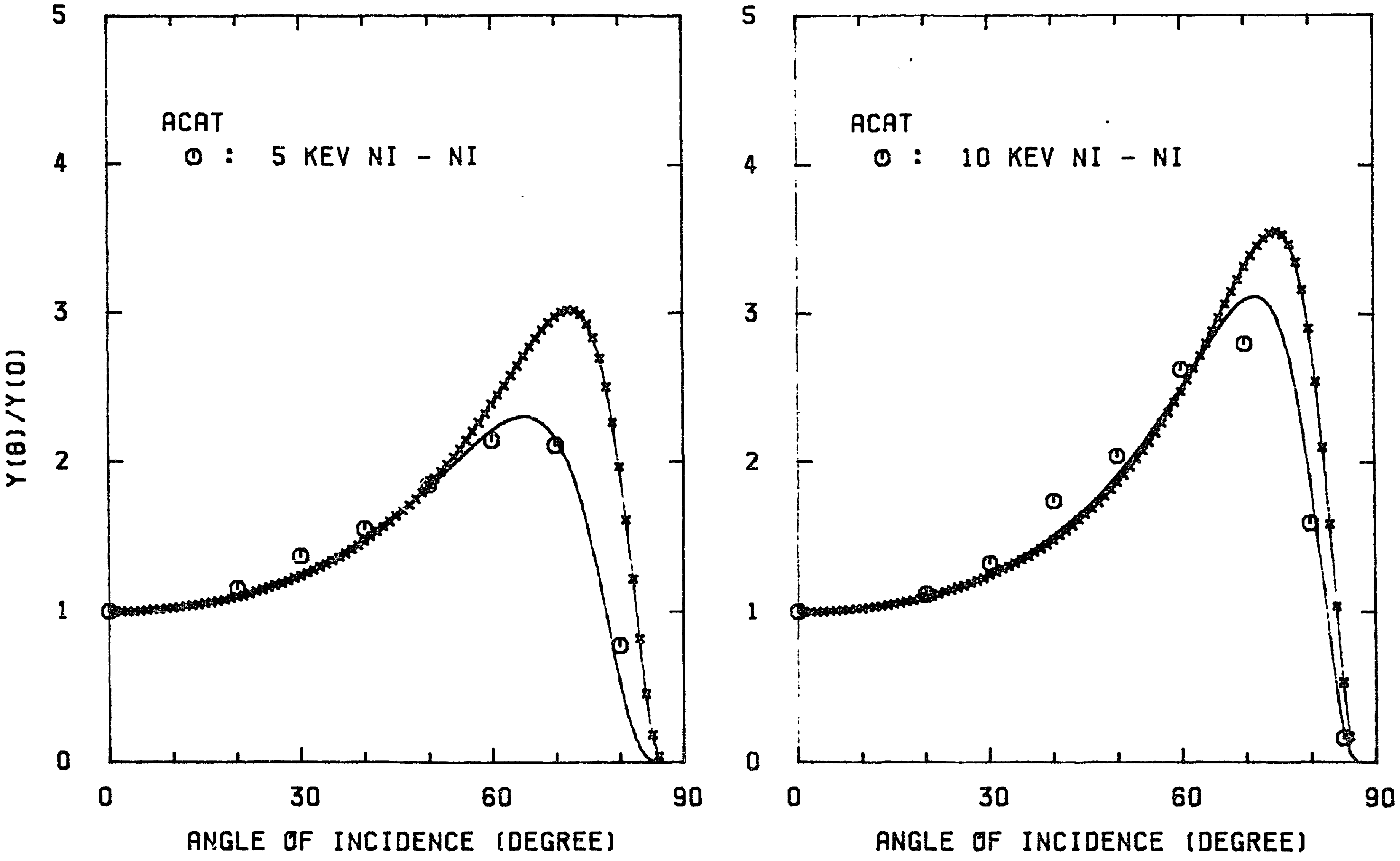

5
4
3
2
1
0
Y(θ)/Y(0)
ACAT
ⵙ : 5 KEV NI - NI
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
5
4
3
2
1
0
ACAT
ⵙ : 10 KEV NI - NI
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)

Fig. 57

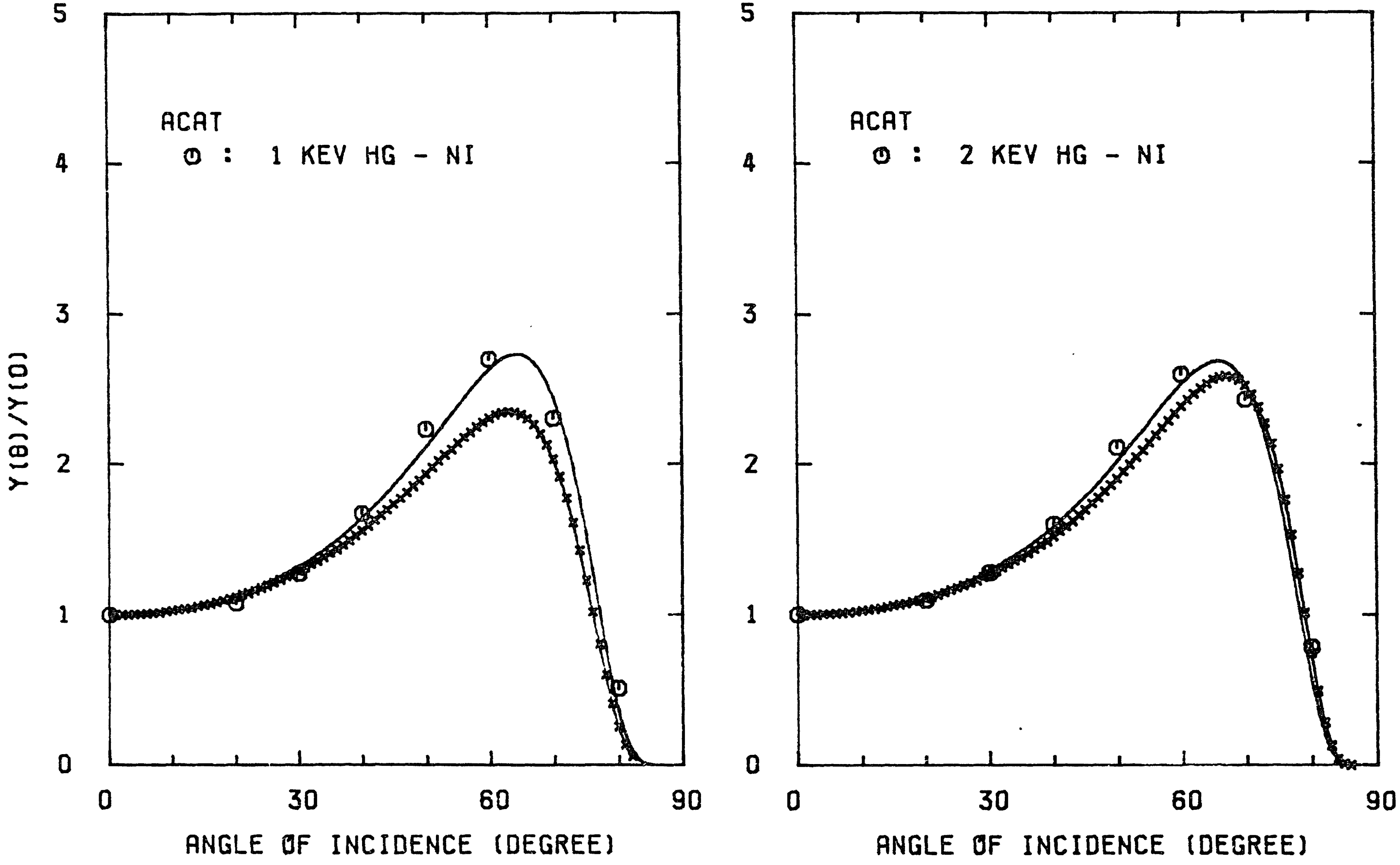

ACAT
Φ : 1 KEV HG - NI
ACAT
Φ : 2 KEV HG - NI
Y(B)/Y(0)
0
1
2
3
4
5
0
30
60
90
ANGLE ØF INCIDENCE (DEGREE)
ANGLE ØF INCIDENCE (DEGREE)

Fig. 58

LIST OF IPPJ-AM REPORTS

IPPJ-AM-1*	"Cross Sections for Charge Transfer of Hydrogen Beams in Gases and Vapors in the Energy Range 10 eV–10 keV" H. Tawara (1977) [Published in Atomic Data and Nuclear Data Tables 22, 491 (1978)]
IPPJ-AM-2*	"Ionization and Excitation of Ions by Electron Impact –Review of Empirical Formulae–" T. Kato (1977)
IPPJ-AM-3	"Grotrian Diagrams of Highly Ionized Iron FeVIII-FeXXVI" K. Mori, M. Otsuka and T. Kato (1977) [Published in Atomic Data and Nuclear Data Tables 23, 196 (1979)]
IPPJ-AM-4	"Atomic Processes in Hot Plasmas and X-Ray Emission" T. Kato (1978)
IPPJ-AM-5*	"Charge Transfer between a Proton and a Heavy Metal Atom" S.Hiraide, Y. Kigoshi and M. Matsuzawa (1978)
IPPJ-AM-6*	"Free-Free Transition in a Plasma –Review of Cross Sections and Spectra–" T. Kato and H. Narumi (1978)
IPPJ-AM-7*	"Bibliography on Electron Collisions with Atomic Positive Ions: 1940 Through 1977" K. Takayanagi and T. Iwai (1978)
IPPJ-AM-8	"Semi-Empirical Cross Sections and Rate Coefficients for Excitation and Ionization by Electron Collision and Photoionization of Helium" T. Fujimoto (1978)
IPPJ-AM-9	"Charge Changing Cross Sections for Heavy-Particle Collisions in the Energy Range from 0.1 eV to 10 MeV I. Incidence of He, Li, Be, B and Their Ions" Kazuhiko Okuno (1978)
IPPJ-AM-10	"Charge Changing Cross Sections for Heavy-Particle Collisions in the Energy Range from 0.1 eV to 10 MeV II. Incidence of C, N, O and Their Ions" Kazuhiko Okuno (1978)
IPPJ-AM-11	"Charge Changing Cross Sections for Heavy-Particle Collisions in the Energy Range from 0.1 eV to 10 Mev III. Incidence of F, Ne, Na and Their Ions" Kazuhiko Okuno (1978)
IPPJ-AM-12*	"Electron Impact Excitation of Positive Ions Calculated in the Coulomb-Born Approximation –A Data List and Comparative Survey–" S. Nakazaki and T. Hashino (1979)
IPPJ-AM-13	"Atomic Processes in Fusion Plasmas – Proceedings of the Nagoya Seminar on Atomic Processes in Fusion Plasmas Sept. 5-7, 1979" Ed. by Y. Itikawa and T. Kato (1979)
IPPJ-AM-14	"Energy Dependence of Sputtering Yields of Monatomic Solids" N. Matsunami, Y. Yamamura, Y. Itikawa, N. Itoh, Y. Kazumata, S. Miyagawa, K. Morita and R. Shimizu (1980)

IPPJ-AM-15	"Cross Sections for Charge Transfer Collisions Involving Hydrogen Atoms" Y. Kaneko, T. Arikawa, Y. Itikawa, T. Iwai, T. Kato, M. Matsuzawa, Y. Nakai, K. Okuno, H. Ryufuku, H. Tawara and T. Watanabe (1980)
IPPJ-AM-16	"Two-Centre Coulomb Phaseshifts and Radial Functions" H. Nakamura and H. Takagi (1980)
IPPJ-AM-17	"Empirical Formulas for Ionization Cross Section of Atomic Ions for Electron Collisions –Critical Review with Compilation of Experimental Data–" Y. Itikawa and T. Kato (1981)
IPPJ-AM-18	"Data on the Backscattering Coefficients of Light Ions from Solids" T. Tabata, R. Ito, Y. Itikawa, N. Itoh and K. Morita (1981)
IPPJ-AM-19	"Recommended Values of Transport Cross Sections for Elastic Collision and Total Collision Cross Section for Electrons in Atomic and Molecular Gases" M. Hayashi (1981)
IPPJ-AM-20	"Electron Capture and Loss Cross Sections for Collisions between Heavy Ions and Hydrogen Molecules" Y. Kaneko, Y. Itikawa, T. Iwai, T. Kato, Y. Nakai, K. Okuno and H. Tawara (1981)
IPPJ-AM-21	"Surface Data for Fusion Devices – Proceedings of the U.S–Japan Workshop on Surface Data Review Dec. 14-18, 1981" Ed. by N. Itoh and E.W. Thomas (1982)
IPPJ-AM-22	"Desorption and Related Phenomena Relevant to Fusion Devices" Ed. by A. Koma (1982)
IPPJ-AM-23	"Dielectronic Recombination of Hydrogenic Ions" T. Fujimoto, T. Kato and Y. Nakamura (1982)
IPPJ-AM-24	"Bibliography on Electron Collisions with Atomic Positive Ions: 1978 Through 1982 (Supplement to IPPJ-AM-7)" Y. Itikawa (1982)
IPPJ-AM-25	"Bibliography on Ionization and Charge Transfer Processes in Ion-Ion Collision" H. Tawara (1983)
IPPJ-AM-26	"Angular Dependence of Sputtering Yields of Monatomic Solids" Y. Yamamura, Y. Itikawa and N. Itoh (1983)

Available upon request to Research Information Center, Institute of Plasma Physics, Nagoya University, Nagoya 464, Japan, except for the reports noted with*.