# SURFACE FIELD DATA FOR CONE-SPHERE-LIKE OBJECTS

by

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## I INTRODUCTION

In the course of a recent study of the currents excited on the surfaces of various metallic objects by an incident plane wave, the surface fields have been measured for a number of cone-sphere-like shapes. The prime purpose in making these measurements was to provide a basis for the development and checking of formulae for predicting the scattering behavior through approximations applied to the surface fields, and the conclusions reached from analyses of the data are described elsewhere (Senior and Zukowski, 1966) Although it is realized that the results of such 'interpretative' studies are not everybody's 'cup of tea', it is felt that the experimental data itself may be of somewhat wider interest, and could be of particular value to those concerned with the verification of digital computer methods for the direct derivation of the surface field from the appropriate integral equations. A selection of the surface field traces has therefore been assembled and is presented here.

## II THE MEASUREMENTS

These were all made in a new facility designed and constructed by the staff of the Radiation Laboratory. A sketch of the facility has been given by Knott et al (1965), and for our purposes it is sufficient to note that the body to be tested is placed on a pedestal within an anechoic chamber and is illuminated by a transmitting antenna placed approximately 35 feet away. The surface field is sampled using a small probe whose type depends on the field component to be measured, and to minimize the disturbances created by the lead from the probe to the detector, the incident illumination is horizontally polarized and the probe lead maintained vertical. L, S, C and X-band frequencies are employed, and the facility is equipped for both phase and amplitude measurements. A detailed description of measurement techniques and operating procedures can be found in a companion report by Knott (1965).

The shapes covered by this study were all bodies of revolution of the general character of cone-spheres. In the particular case of the cone-sphere (i. e. a cone terminated in a spherical cap with continuity of tangency at the join), the body is specified completely by the half-angle, $\alpha$, of the cone, and the value of ka, where a is the radius of the cap and $k = 2\pi/\lambda$, but for more complex shapes, additional parameterization is required. The models used were made of cold-rolled aluminum stock, machines to a high degree of surface finish. Being metallic with (effectively) infinite conductivity, linear scaling laws can be assumed to hold, and to provide reasonable coverage of the low resonance region, $1 < ka < 10$ (say), it is sufficient to vary the frequency with only a single model of each shape. In practice, however, it was desirable to add extra models to ensure continuity of coverage with the experimental frequencies readily available.

Even for a single model at one frequency and aspect, any attempt at measuring the (vector) surface field at all points of a closely spaced grid extending over the entire surface of the body would be a very time-consuming task, and in consonance with the aim of providing the maximum assistance to the theoretical investigations within the time available, attention was restricted to that component of the induced current which is in the direction of the cone generators and their continuations over the cone termination. For the data given here, the probe displacement was confined to the trajectory in a horizontal plane through the axis of the model. Only the current amplitude was measured, and this is shown as a function of $s/\lambda$, where s is the distance from the foremost point of the body. Since readings are usually taken with the probe stationary, each curve is the result of a sequence of datum points whose separation averages less than $0.1\lambda$.

For a body of revolution at nose-on incidence, a knowledge of the longitudinal component of the current over the above trajectory specifies the component everywhere by virtue of its known azimuthal variation. In particular, the amplitudes at corresponding points on the left and right trajectories should be identical, but the measured data did show some slight discrepancies. These can be attributed to a partial sensitivity of the probe to the normal component of the electric vector as well as to a tangential component of the magnetic field, and the nature of this effect (and its consequences as regards probe design) are discussed by Knott (1965). The amount of asymmetry can be judged from Fig. 15, a case chosen at random from those investigated, in which the values of the amplitude on the negative side (or right hand trajectory as viewed from the transmitter) are compared with the curve based on the readings for the positive side. Since detailed studies of measured data for a sphere showed that errors are drastically reduced if the amplitudes for the two sides are averaged, all of the nose-on ($\phi$=0) data presented here are the averages of readings at corresponding points on the two sides of the body. For oblique incidence, of course, no such averaging is possible, and the measured data is given directly: the solid curves then represent the current amplitudes measured along that side of the object inclined toward the direction of incidence at the indicated angle $\phi$, and the curves shown as broken lines refer to the opposite side (which, for $\phi$ greater than the half cone angle, will be shadowed).

## III. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the dedicated and painstaking work of the experimental staff, directed by Mr. E. F. Knott, and to express our thanks to Miss C. E. Hayes and Messrs. R. E. Cook, D. E. Goings, R. Liang, D. P. Teeter and R. E. Wetter who, at various times, were involved in the lengthy and tedious process of reducing the measured data to the form in which the results are presented here. We are also indebted to the Lincoln Laboratory of the Massachusetts Institute of Technology for the loan of the Golf model.

## IV REFERENCES

Knott, E. F. (1965), "Design and Operation of a Surface Field Measurement Facility," The University of Michigan Radiation Laboratory Technical Report 7030-7-T

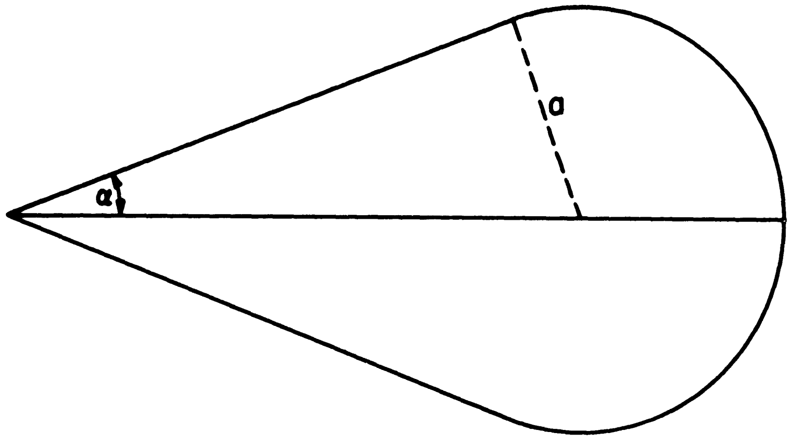
Knott, E. F., V. V. Liepa and T. B. A. Senior (1965), "A Surface Field Measurement Facility," Proc. IEEE, 53, pp. 1105-1107.

Senior, T. B. A. and L. P. Zukowski (1966), "The Interpretation of Some Surface Field Data," The University of Michigan Radiation Laboratory Technical Report 7030-8-T

## MODELS

### 1. Cone-Sphere

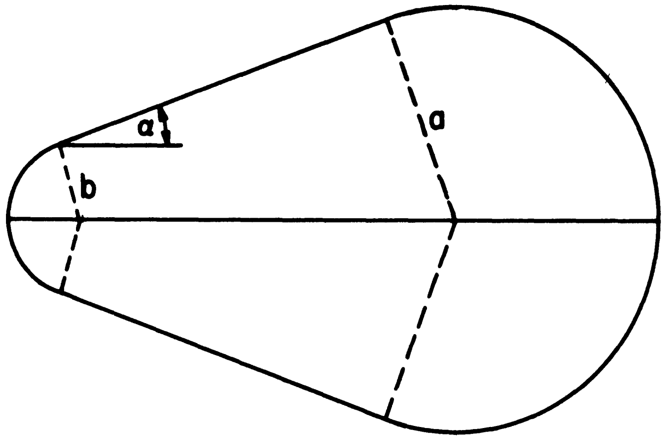
This is formed from a cone of semi-vertex angle $\alpha$ terminated in a spherical cap of radius a, with continuity of tangency at the join.




| Model No. | $\alpha$ (degrees) | a (inches) |
|---|---|---|
| 1 | 7.50 | 1.500 |
| 2 | 15.00 | 1.500 |
| 3 | 7.50 | 3.000 |
| 4 | 15.00 | 3.000 |
| 5 | 7.53 | 2.210 |

### 2. Cone-Sphere with Rounded Tip

The tip of Model No. 5 was removed in favor of one or other of two spherical tips of radius b which could be screwed in place to produce continuity of tangency at the join with the conical surface.



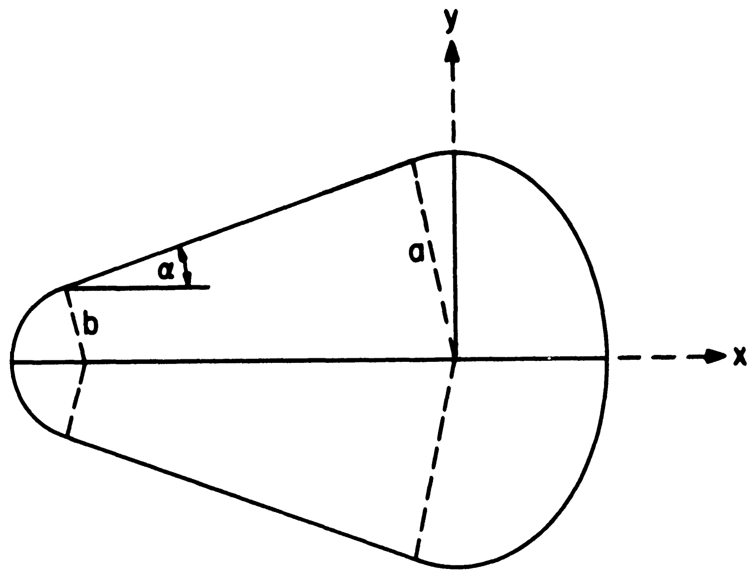

| Model | α (degrees) | a (inches) | b (inches) |
|---|---|---|---|
| A | 7.53 | 2.210 | 0.250 |
| B | 7.53 | 2.210 | 1.000 |

3. Cone-Spheroid with Rounded Tip

The spherical cap of Models A and B above was unscrewed and replaced by an oblate spheroidal cap to give Models C and E respectively. With axes as shown in the diagram, the cap corresponded to the rotation of the ellipse

$$\frac{(x-\delta)^2}{\ell^2} + \frac{y^2}{4\ell^2} = 1$$

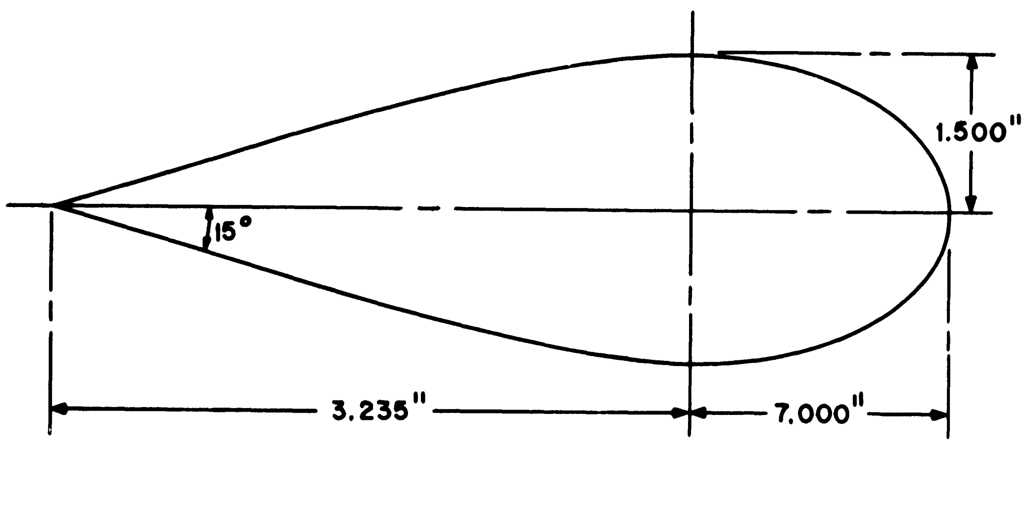
about the x axis, where $\ell$ = 1.098 inches and $\delta$ = 0.072 inches, and produced continuity of tangency at its join with the cone.




| Model | α (degrees) | Cap | b (inches) |
|---|---|---|---|
| C | 7.53 | spheroid | 0.250 |
| E | 7.53 | spheroid | 1.000 |

4. Cone-Quartic-Spheroid (Golf)

This is a three-part surface in which a quartic transition region is inserted between the cone and a prolate spheroical cap. The radius of curvature, as well as the tangent, is continuous at each join.



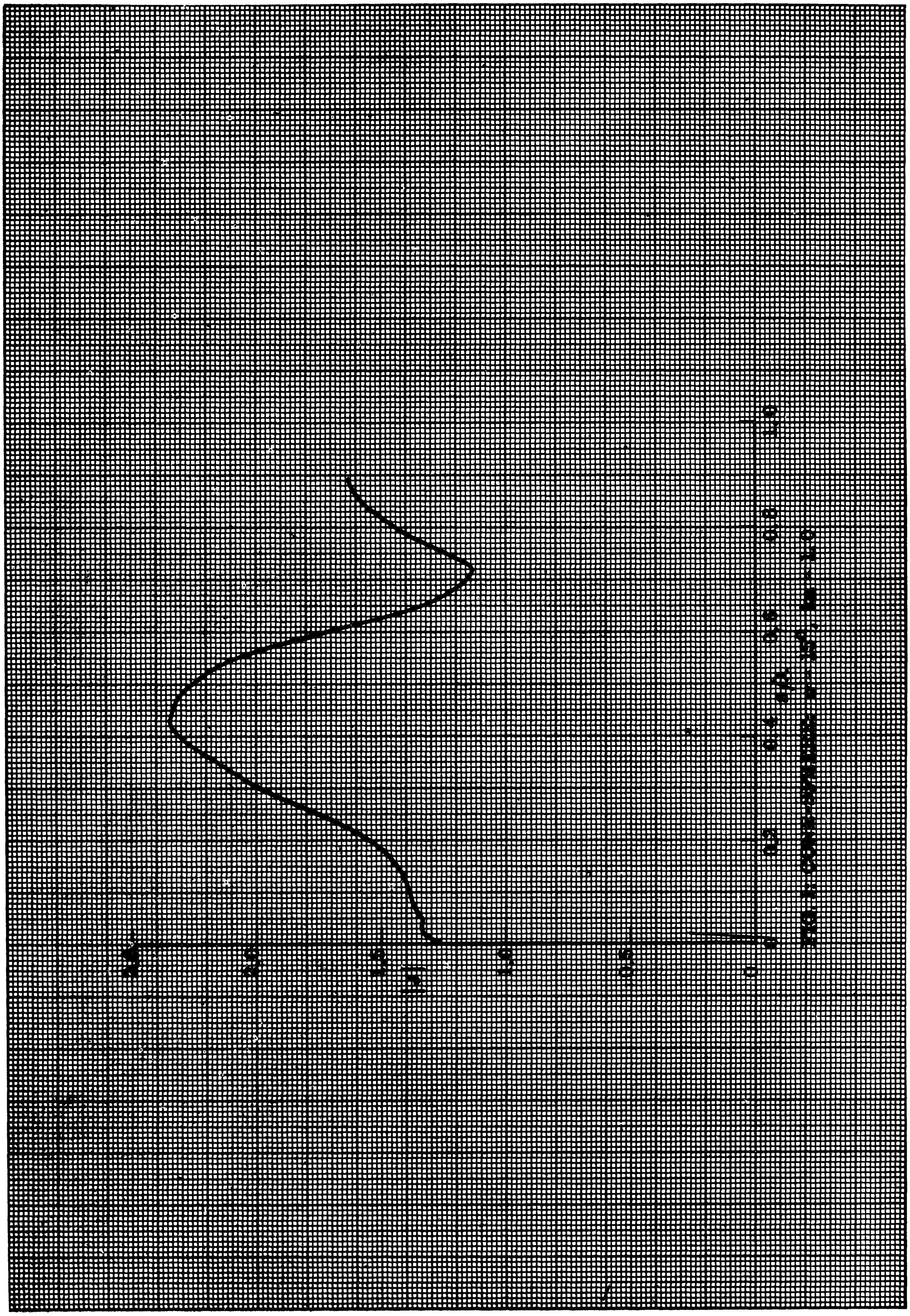
| Fig. No. | Model | $\alpha$ (°) | Freq. (Gc) | ka | $\phi$ (°) |
|---|---|---|---|---|---|
| 1 | 2 | 15 | 1.252 | 1.0 | 0 |
| 2 | 2 | 15 | 1.502 | 1.2 | 0 |
| 3 | 2 | 15 | 1.753 | 1.4 | 0 |
| 4 | 4 | 15 | 1.002 | 1.6 | 0 |
| 5 | 4 | 15 | 1.127 | 1.8 | 0 |
| 6 | 4 | 15 | 1.252 | 2.0 | 0 |
| 7 | 2 | 15 | 2.755 | 2.2 | 0 |
| 8 | 2 | 15 | 3.005 | 2.4 | 0 |
| 9 | 2 | 15 | 3.256 | 2.6 | 0 |
| 10 | 2 | 15 | 3.507 | 2.8 | 0 |
| 11 | 2 | 15 | 3.757 | 3.0 | 0 |
| 12 | 4 | 15 | 3.131 | 5.0 | 0 |
| 13 | 4 | 15 | 3.256 | 5.2 | 0 |
| 14 | 4 | 15 | 6.263 | 10.0 | 0 |
| 15 | 4 | 15 | 3.256 | 5.2 | 0 |
| 16 | 2 | 15 | 5.278 | 4.2 | 0 |
| 17 | 2 | 15 | 5.278 | 4.2 | 7 1/2 |
| 18 | 2 | 15 | 5.278 | 4.2 | 13 |
| 19 | 2 | 15 | 5.278 | 4.2 | 15 |
| 20 | 2 | 15 | 5.278 | 4.2 | 17 |
| 21 | 2 | 15 | 5.278 | 4.2 | 30 |
| 22 | 2 | 15 | 5.278 | 4.2 | 75 |
| 23 | 1 | 7 1/2 | 1.252 | 1.0 | 0 |
| 24 | 1 | 7 1/2 | 1.502 | 1.2 | 0 |
| 25 | 1 | 7 1/2 | 1.753 | 1.4 | 0 |
| 26 | 5 | 7 1/2 | 1.360 | 1.6 | 0 |
| 27 | 5 | 7 1/2 | 1.530 | 1.8 | 0 |
| 28 | 5 | 7 1/2 | 1.700 | 2.0 | 0 |
| 29 | 1 | 7 1/2 | 2.755 | 2.2 | 0 |
| 30 | 1 | 7 1/2 | 3.005 | 2.4 | 0 |

(continued)

| Fig. No. | Model | $\alpha$ (°) | Freq. (Gc) | ka | $\phi$ (°) |
|---|---|---|---|---|---|
| 31 | 1 | 7 1/2 | 3.256 | 2.6 | 0 |
| 32 | 1 | 7 1/2 | 3.507 | 2.8 | 0 |
| 33 | 1 | 7 1/2 | 3.757 | 3.0 | 0 |
| 34 | A | 7 1/2 | 2.550 | 3.0 | 0 |
| 35 | 5 | 7 1/2 | 4.250 | 5.0 | 0 |
| 36 | 5 | 7 1/2 | 4.420 | 5.2 | 0 |
| 37 | A | 7 1/2 | 3.570 | 4.2 | 0 |
| 38 | A | 7 1/2 | 3.570 | 4.2 | 2 1/2 |
| 39 | A | 7 1/2 | 3.570 | 4.2 | 5 |
| 40 | A | 7 1/2 | 3.570 | 4.2 | 7 1/2 |
| 41 | A | 7 1/2 | 3.570 | 4.2 | 32 1/2 |
| 42 | A | 7 1/2 | 3.570 | 4.2 | 57 1/2 |
| 43 | A | 7 1/2 | 3.570 | 4.2 | 82 1/2 |
| 44 | A | 7 1/2 | 5.100 | 6.0 | 0 |
| 45 | B | 7 1/2 | 2.550 | 3.0 | 0 |
| 46 | B | 7 1/2 | 8.500 | 10.0 | 0 |
| 47 | C | 7 1/2 | 1.700 | 2.0 | 0 |
| 48 | C | 7 1/2 | 3.400 | 4.0 | 0 |
| 49 | C | 7 1/2 | 5.100 | 6.0 | 0 |
| 50 | C | 7 1/2 | 8.500 | 10.0 | 0 |
| 51 | E | 7 1/2 | 1.700 | 2.0 | 0 |
| 52 | E | 7 1/2 | 3.400 | 6.0 | 0 |
| 53 | E | 7 1/2 | 5.100 | 6.0 | 0 |
| 54 | E | 7 1/2 | 8.500 | 10.0 | 0 |
| 55 | Golf | 15 | 2.005 | 2.0 | 0 |
| 56 | Golf | 15 | 3.757 | 3.0 | 0 |
| 57 | Golf | 15 | 5.009 | 4.0 | 0 |
| 58 | Golf | 15 | 6.262 | 5.0 | 0 |

## EXPERIMENTAL DATA

In each of the following graphs the measured amplitude of the longitudinal component J of the surface current, normalized relative to the amplitude of the incident field, is plotted as a function of the distance s, in wavelengths, from the tip (or front-most) point of the body.


0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0

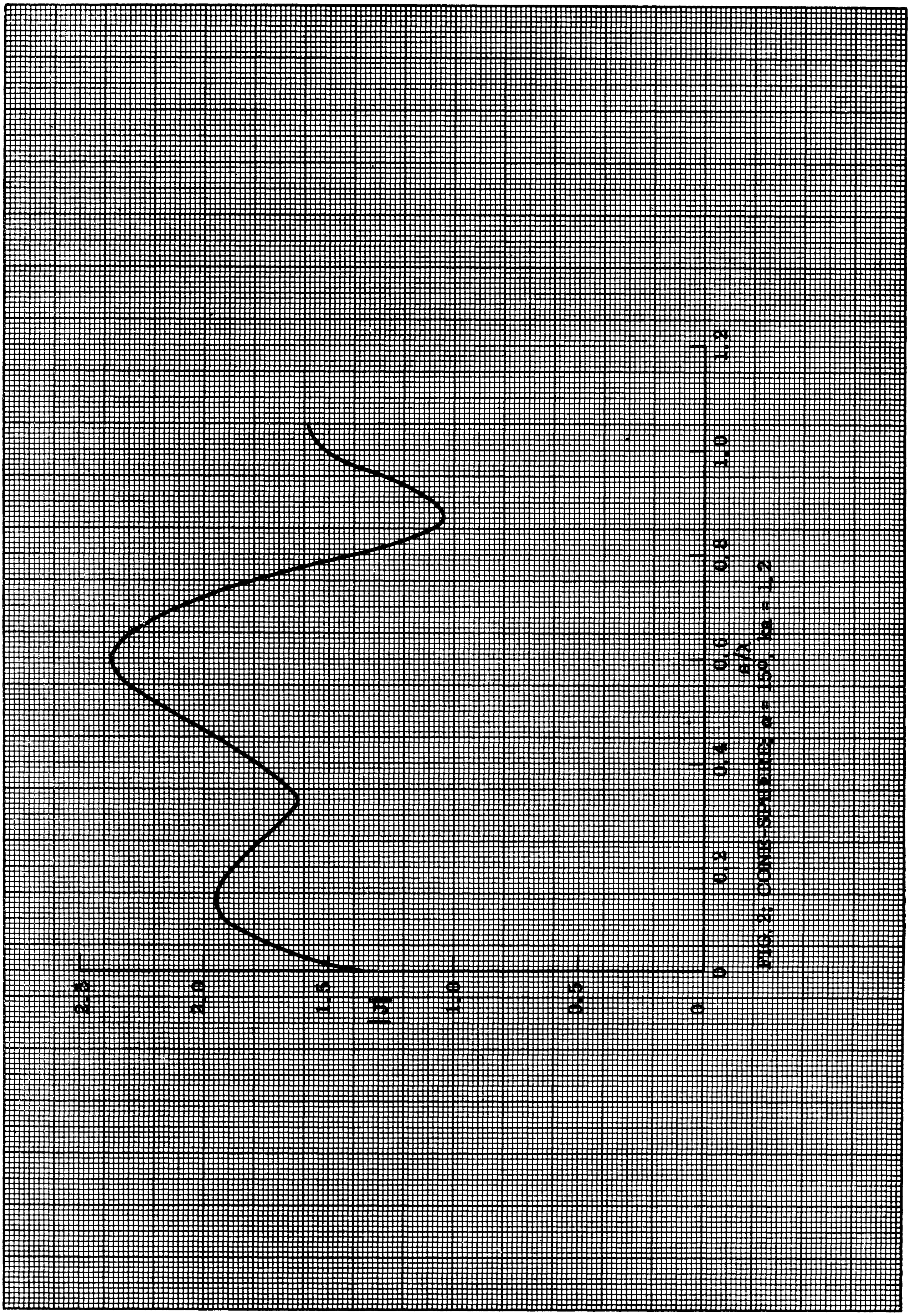



FIG. 2: CONE-SPHERE, α = 15°, ka = 1.2

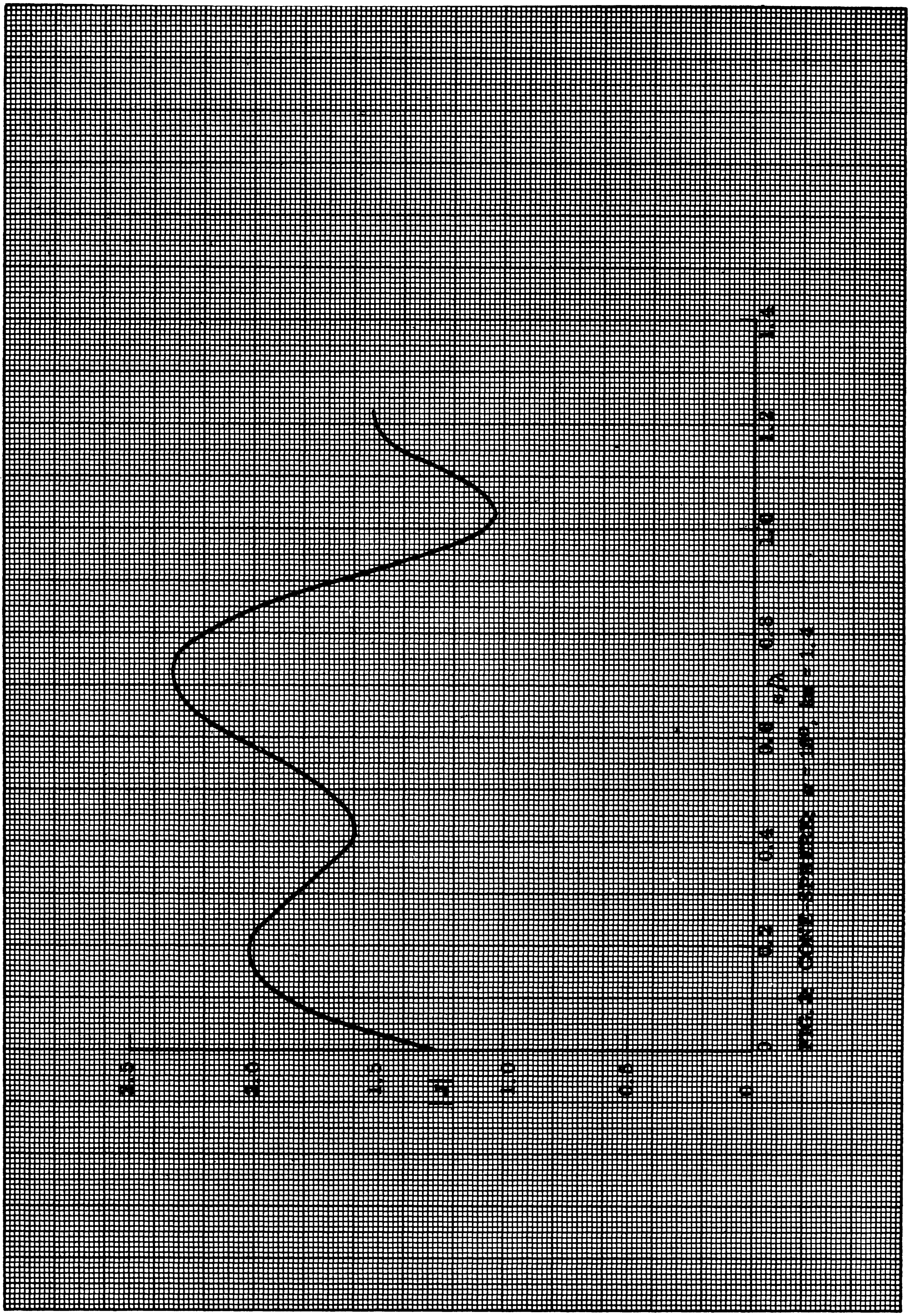



FIG. [illegible]: CONE-SPHERE, α = [illegible], ka = 1.4

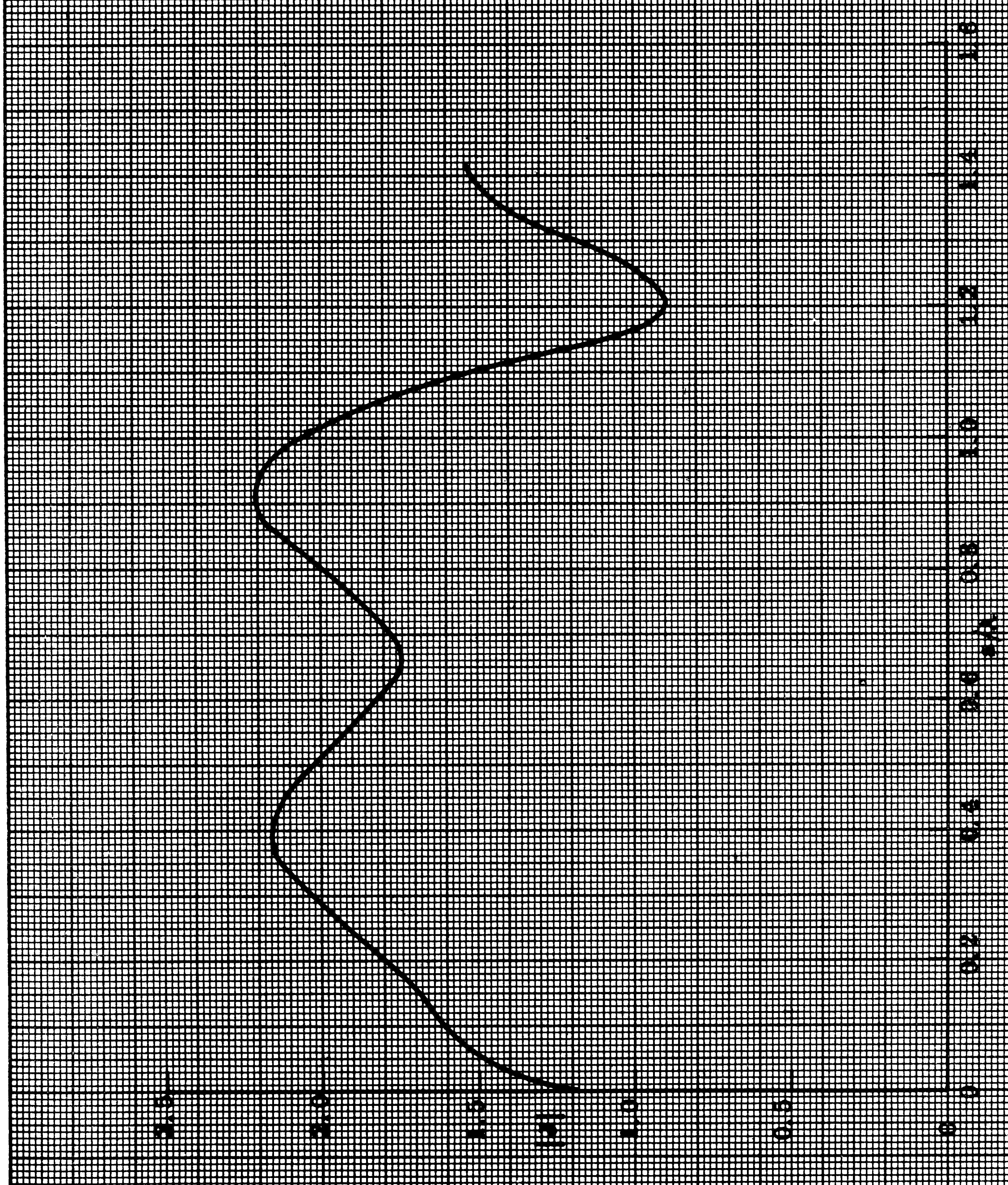



FIG. 4: CONE-SPHERE, α = 15°, ka = 1.6

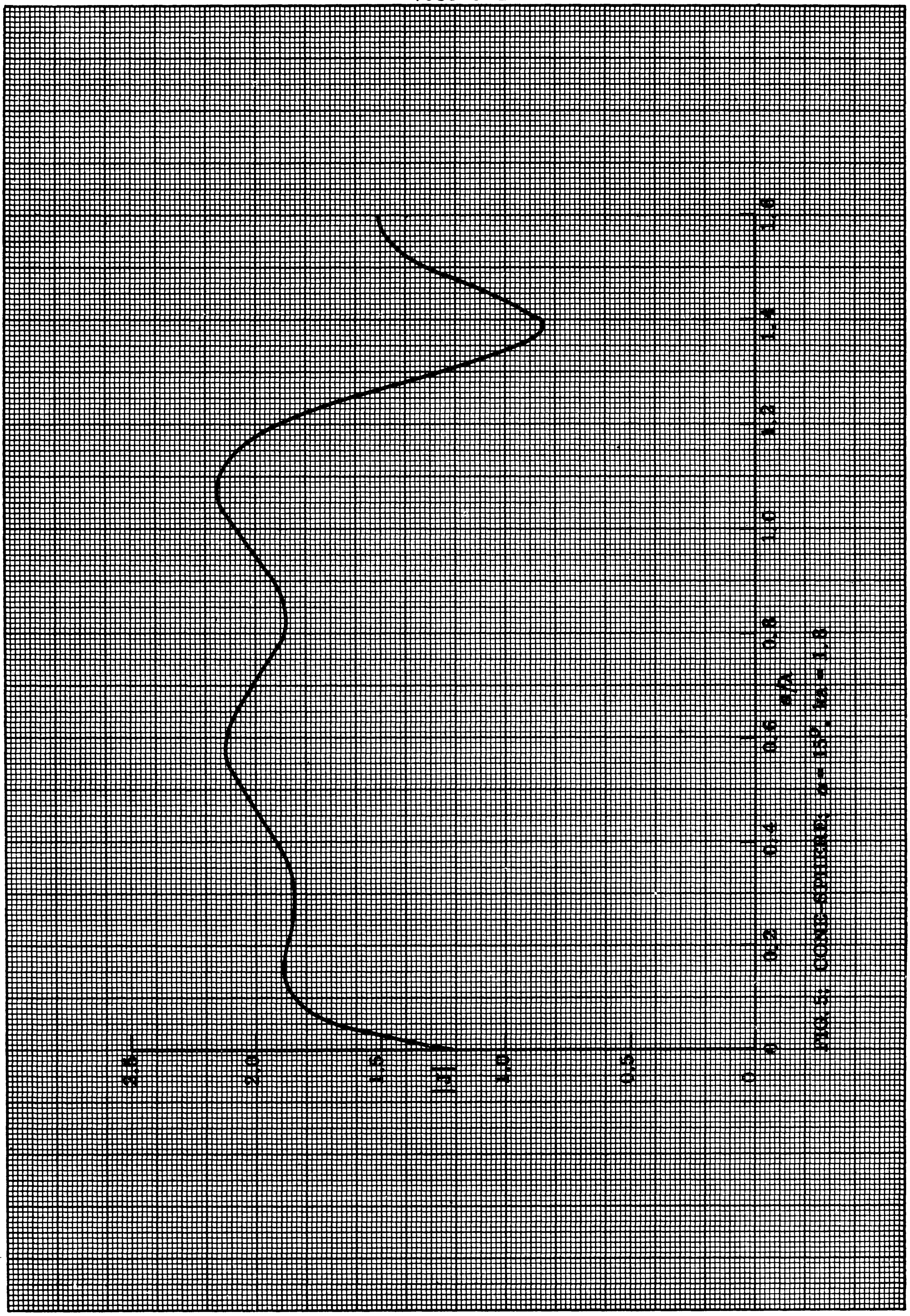



FIG. 5: CONE-SPHERE, α = 15°, ka = 1.8

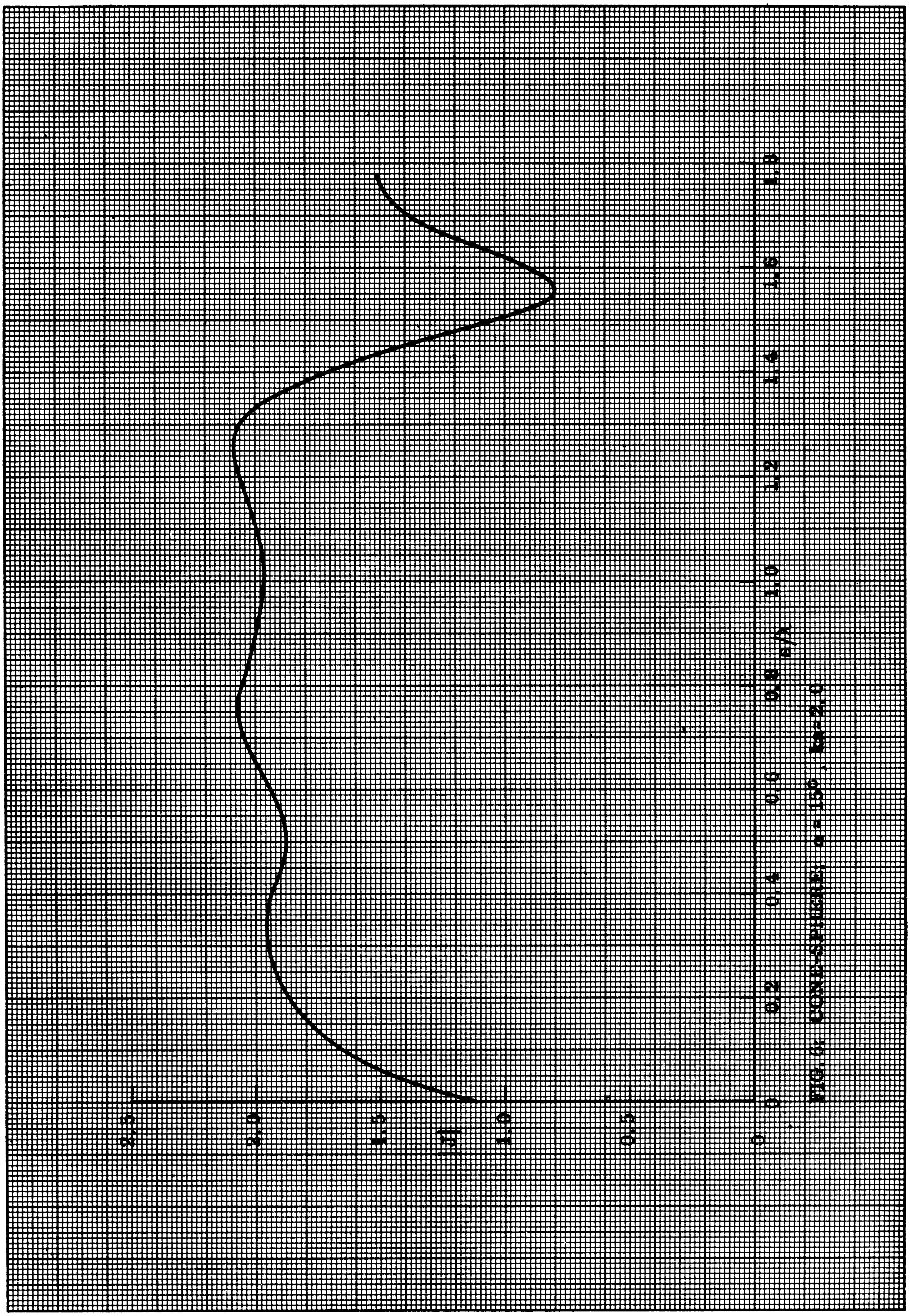



FIG. 6: CONE-SPHERE; α = 15°, ka = 2.0

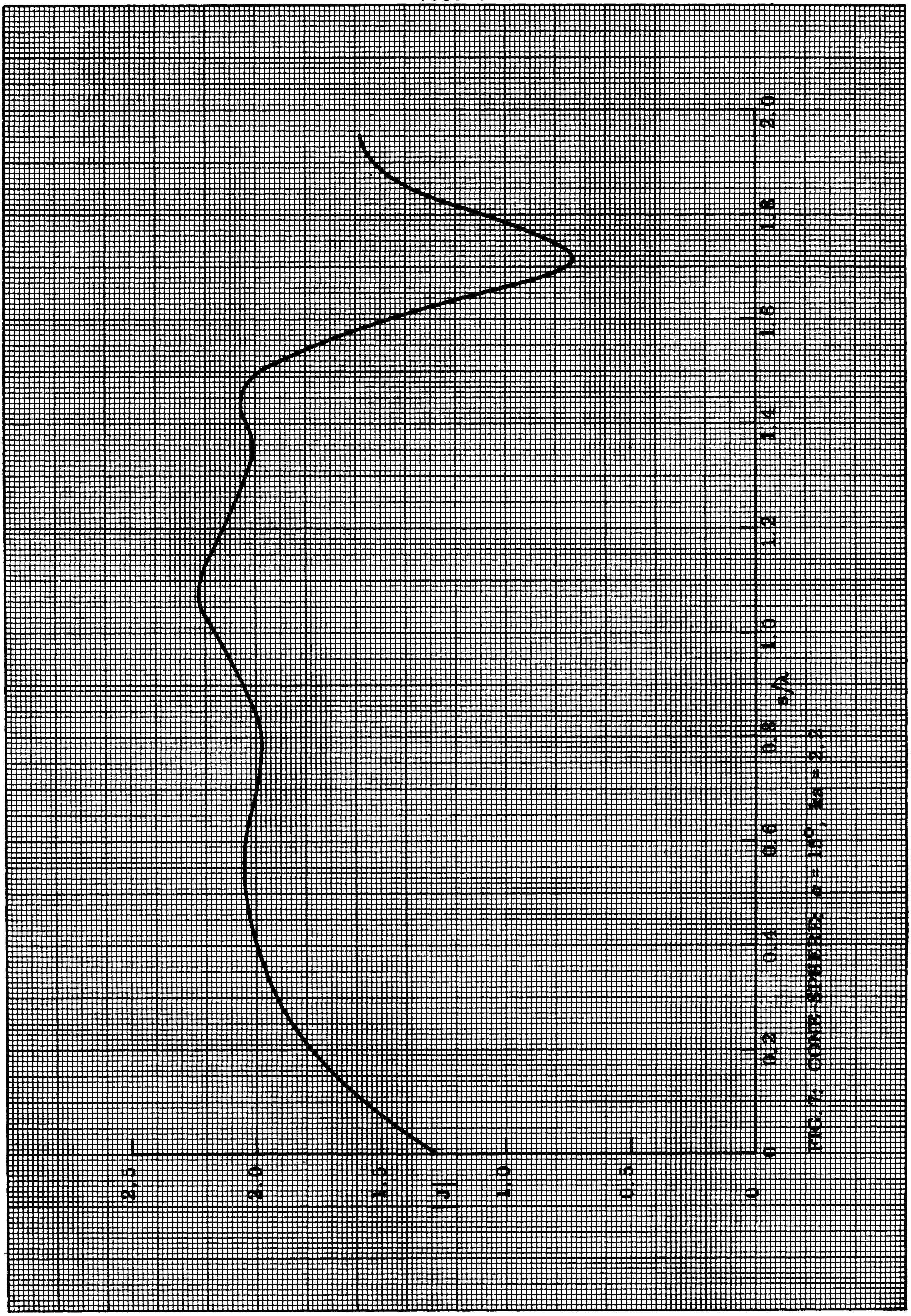
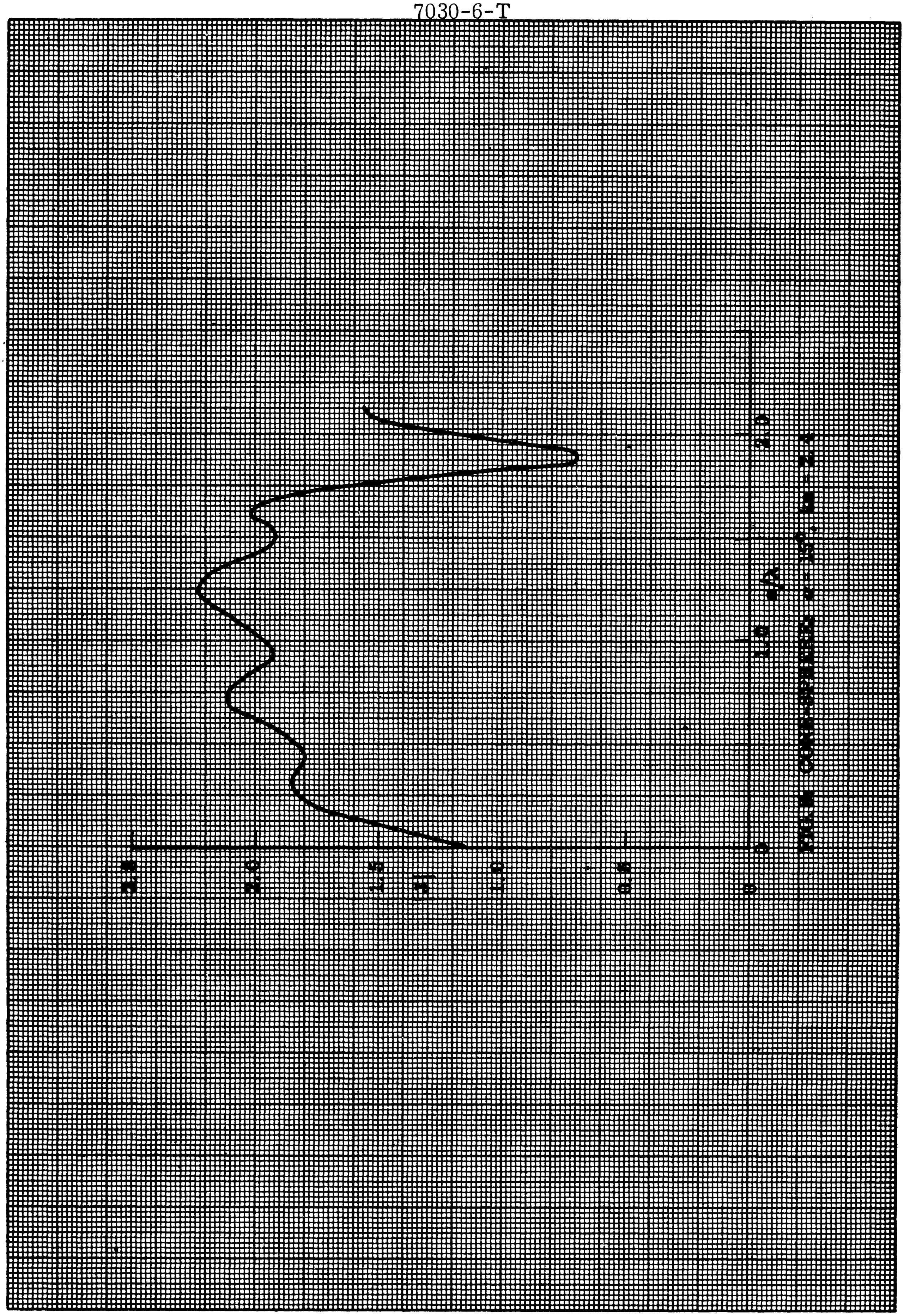



FIG. 7: CONE-SPHERE $\alpha = 15^{o}$, $ka = 2.2$


2.5
2.0
1.5
1.0
0.5
0
1.0
2.0

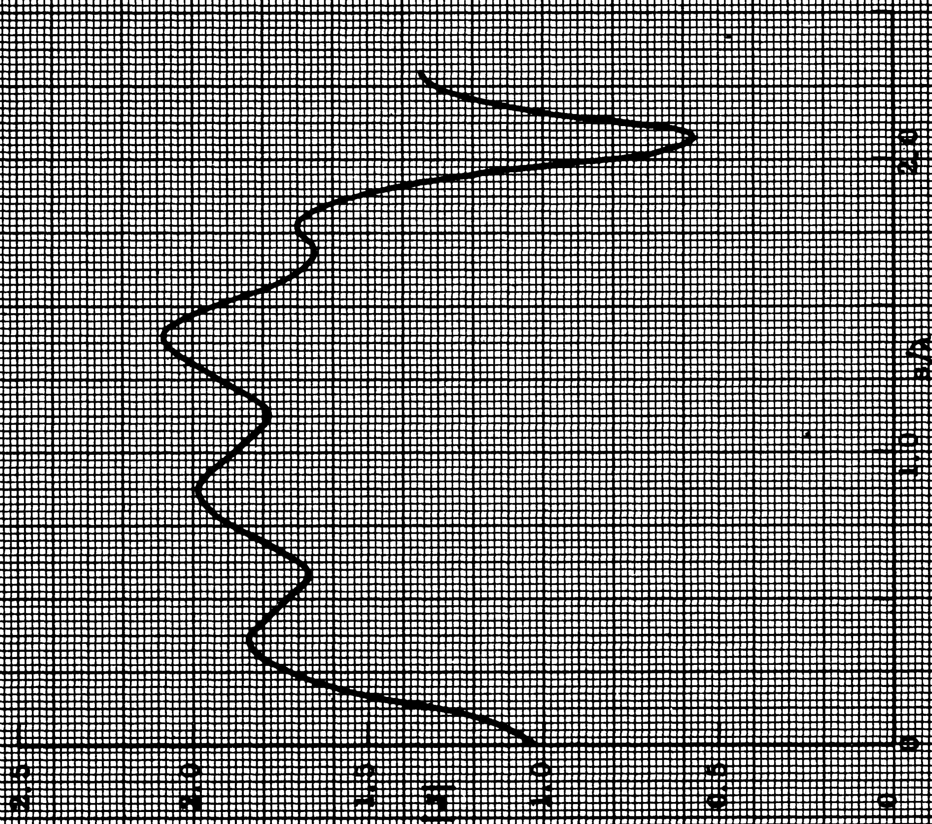



FIG. 9 - CONE-SPHERE, α = 15°, ka = 2.5

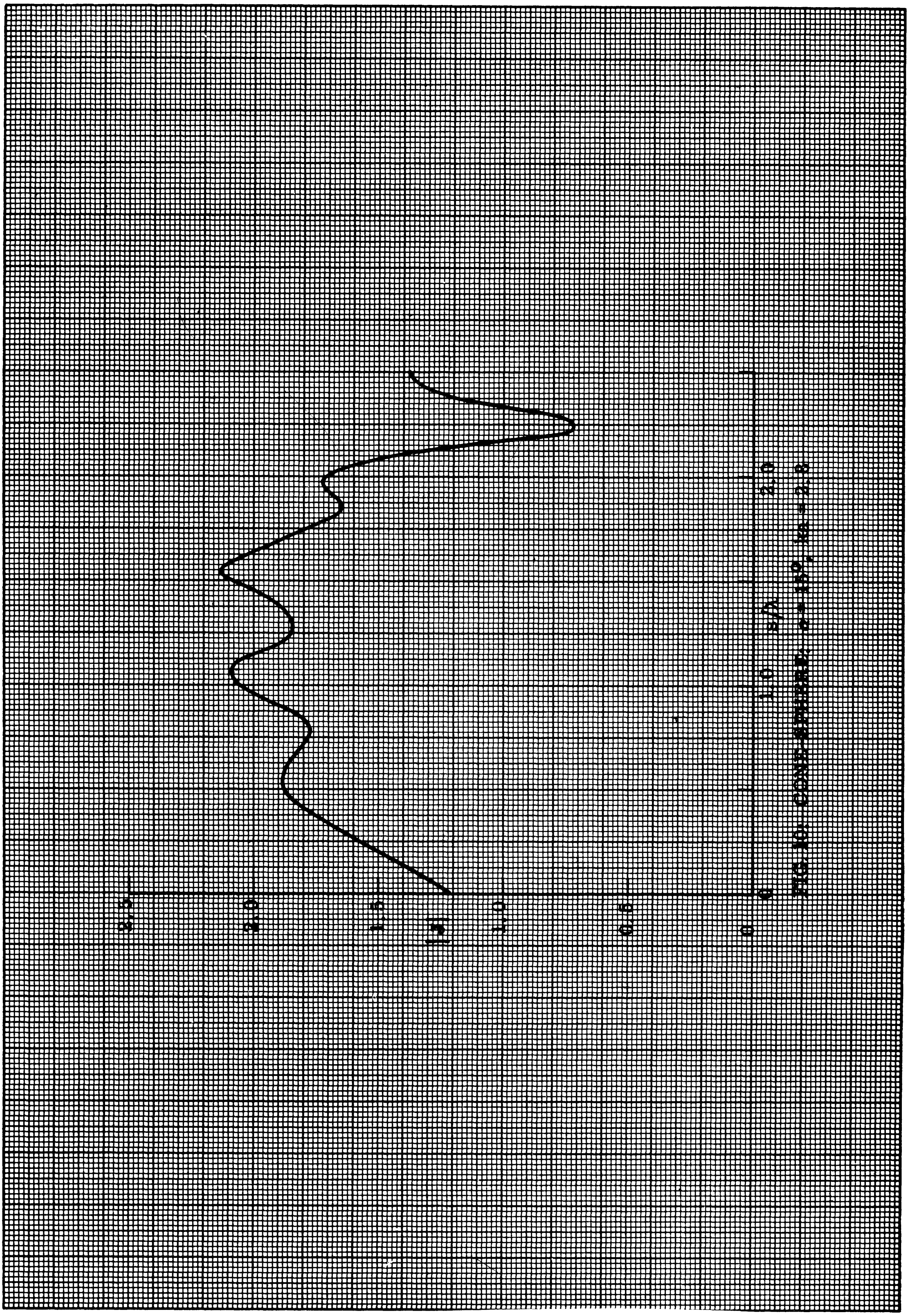



FIG. 10: CONE-SPHERE, $\alpha = 15°$, $ka = 2.8$

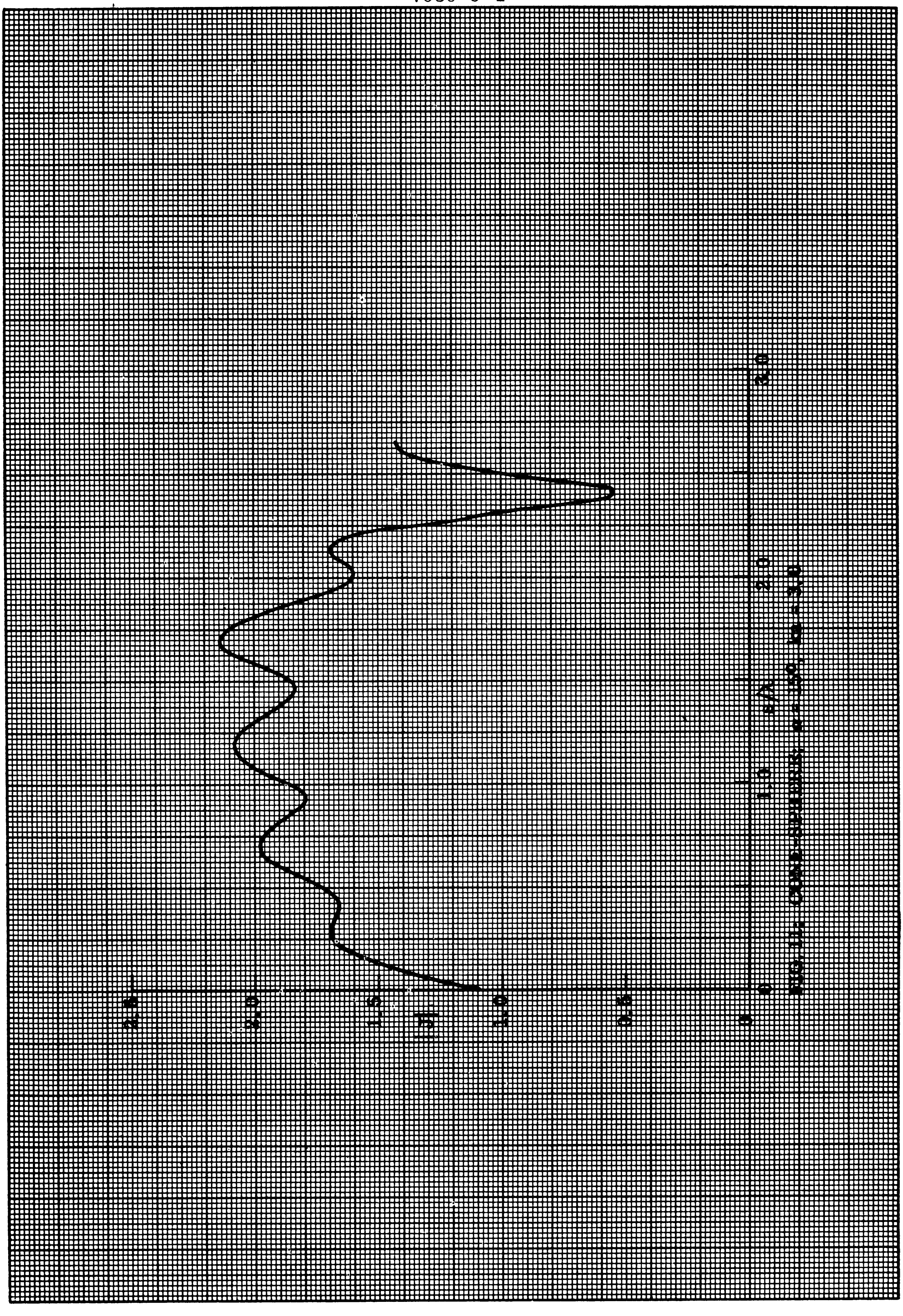



FIG. 11: CONE-SPHERE, α = 15°, ka = 3.0

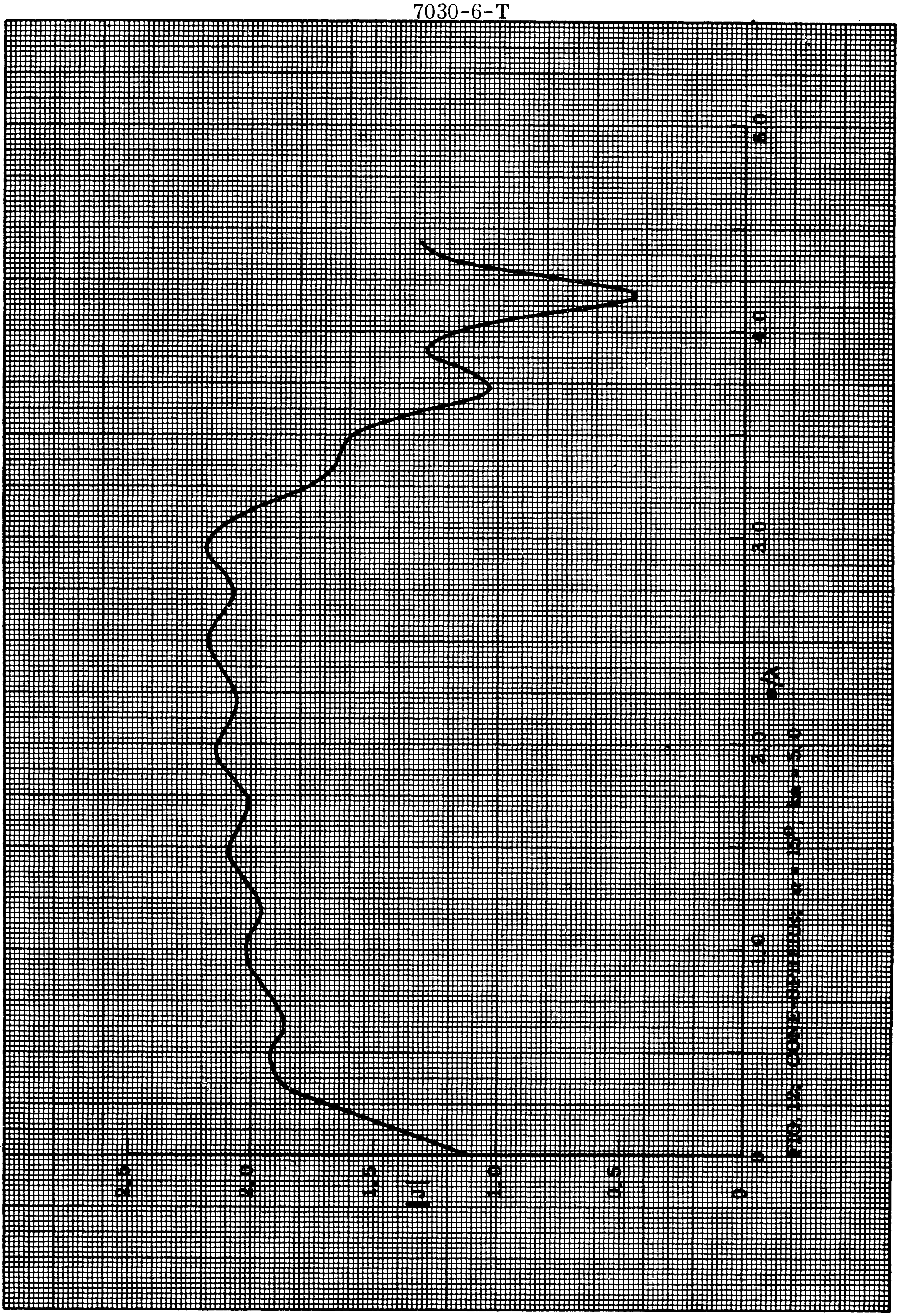



FIG. 12: CONE-SPHERE: α = 15°, ka = 5.0

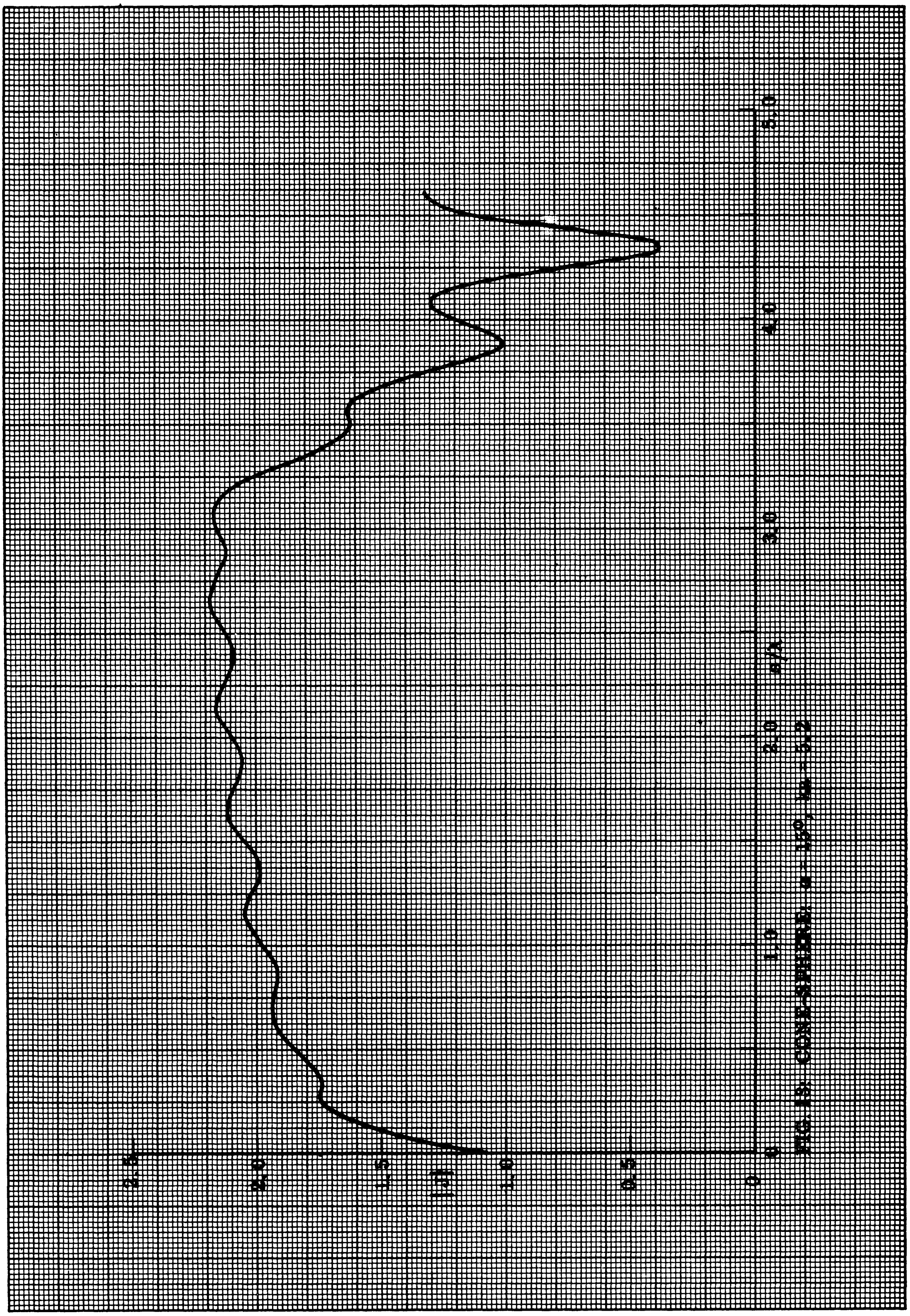



FIG. 13: CONE-SPHERE, α = 15°, ka = 5.2

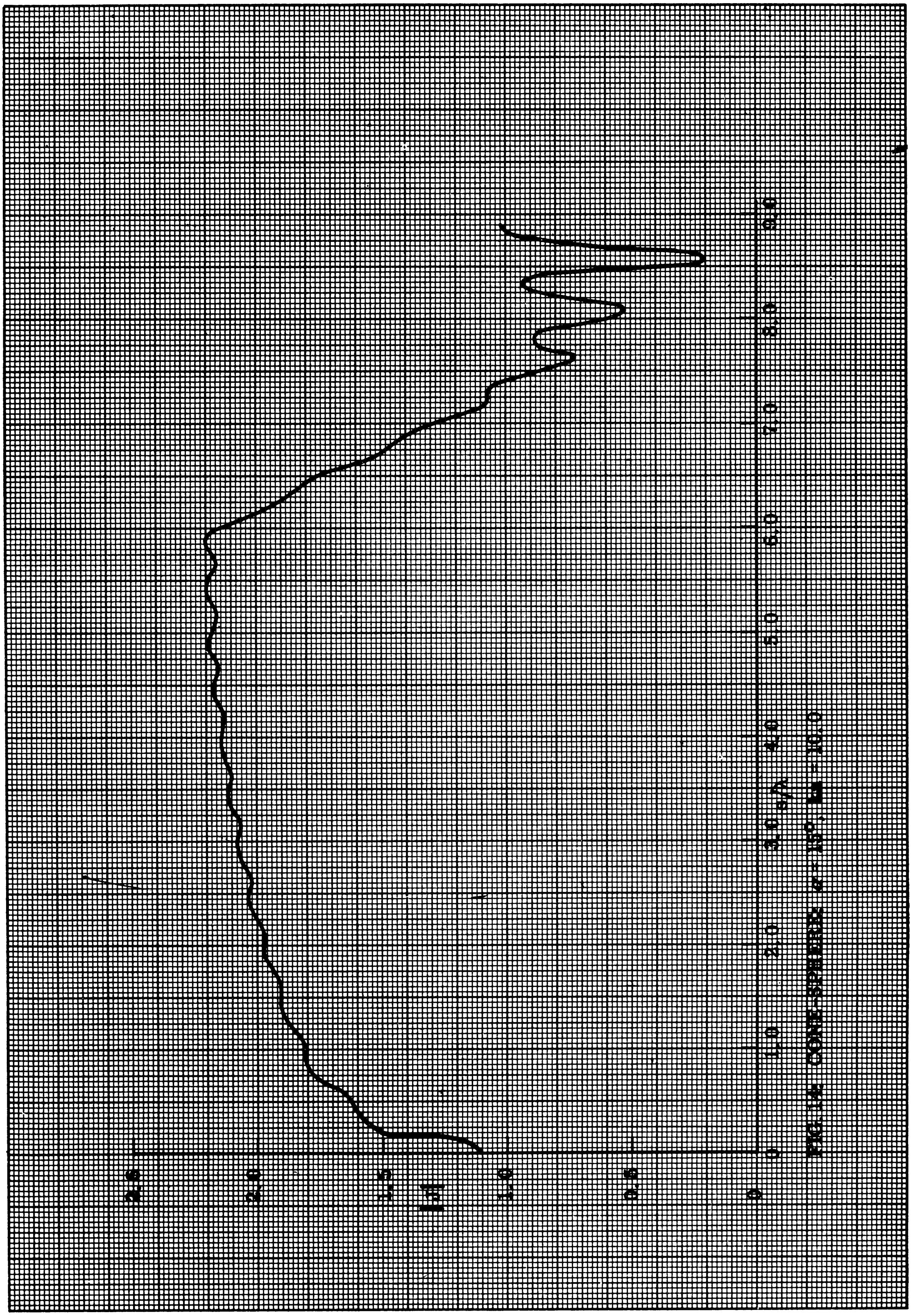



FIG. 14 CONE-SPHERE: α = 15°, ka = 10.0

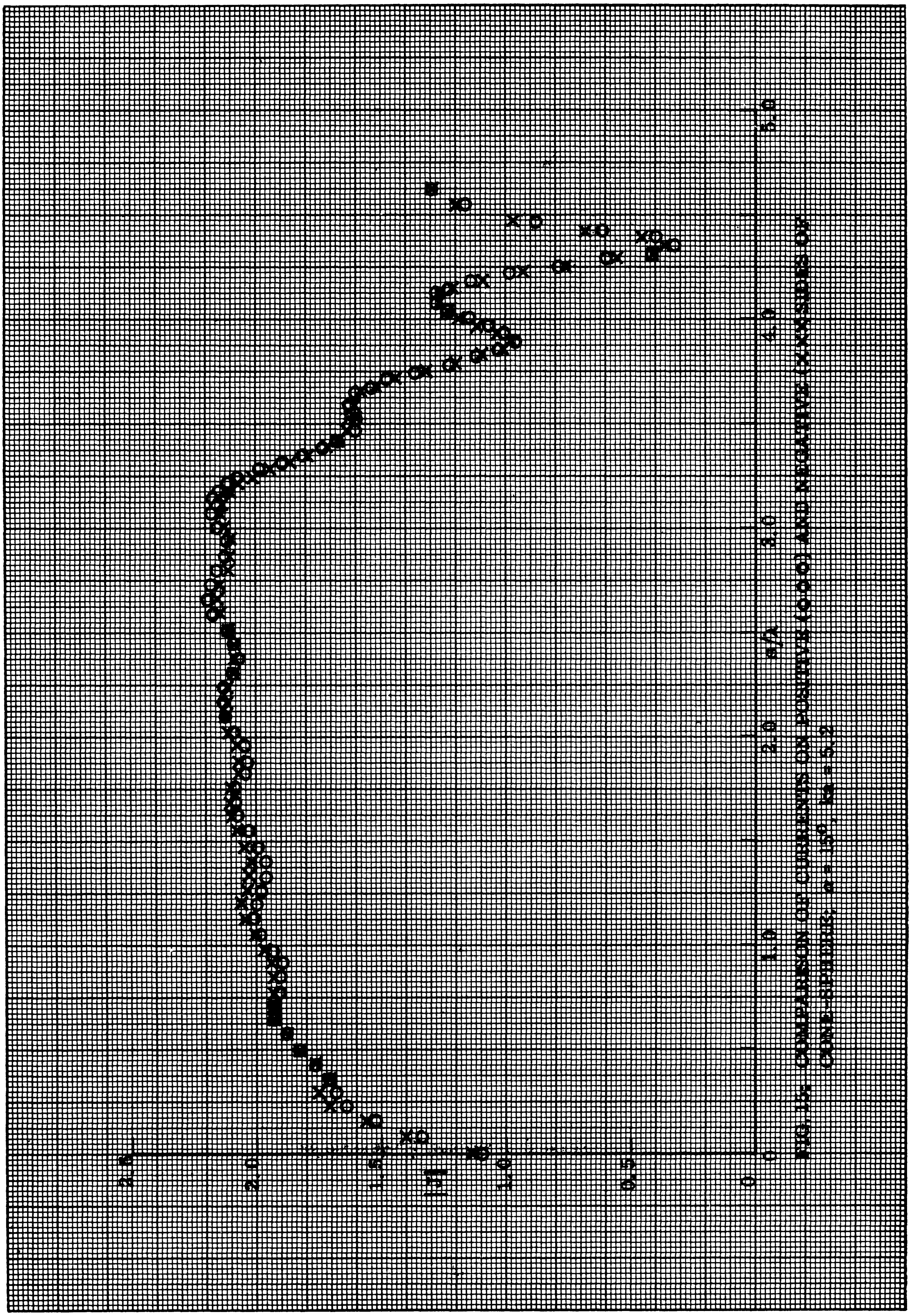



FIG. 15: COMPARISON OF CURRENTS ON POSITIVE (O-O-O) AND NEGATIVE (X-X-X) SIDES OF CONE-SPHERE; $\alpha = 15^{\circ}$, $ka = 5.2$

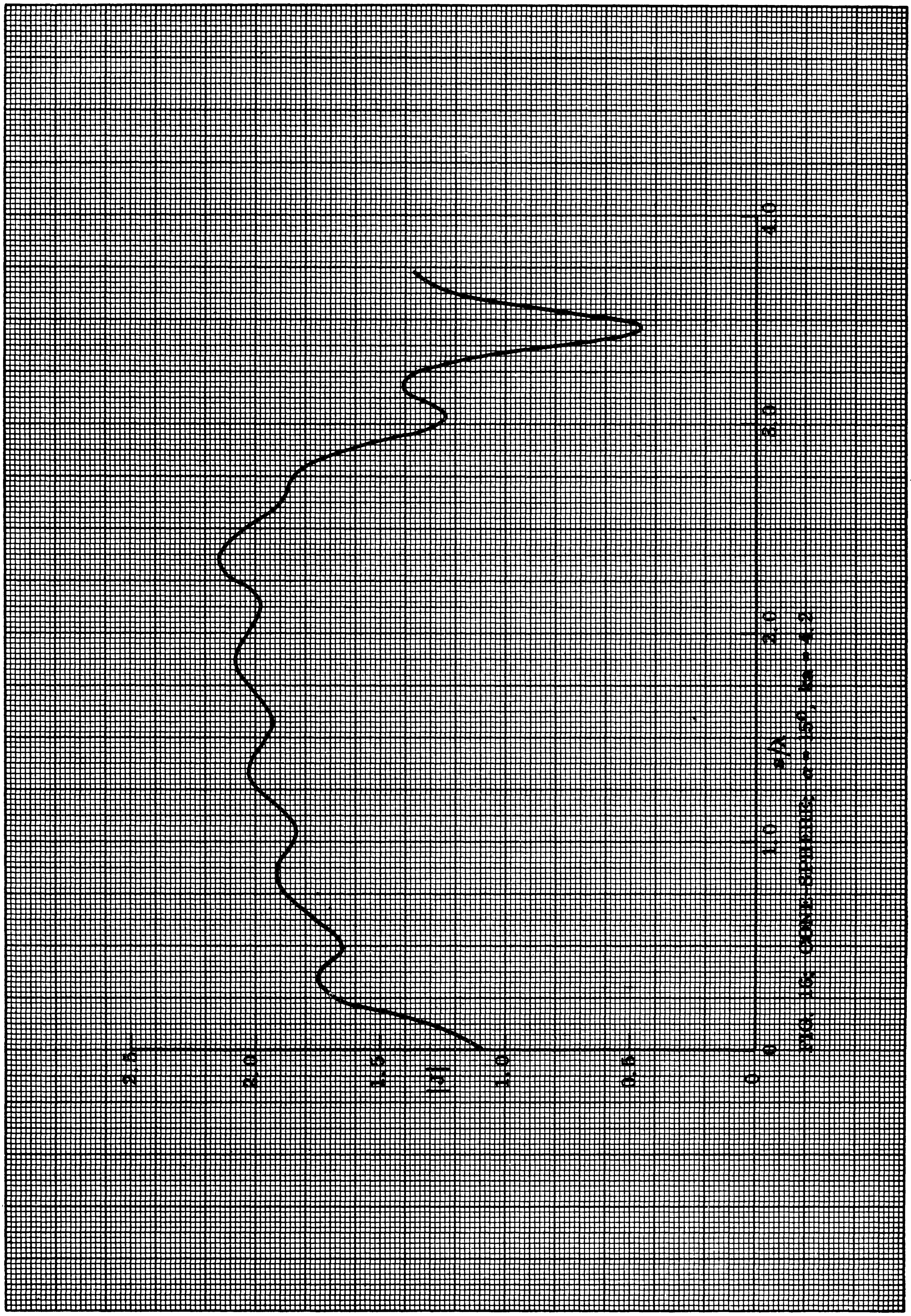



FIG. 16: CONE-SPHERE, α = 15°, ka = 4.2

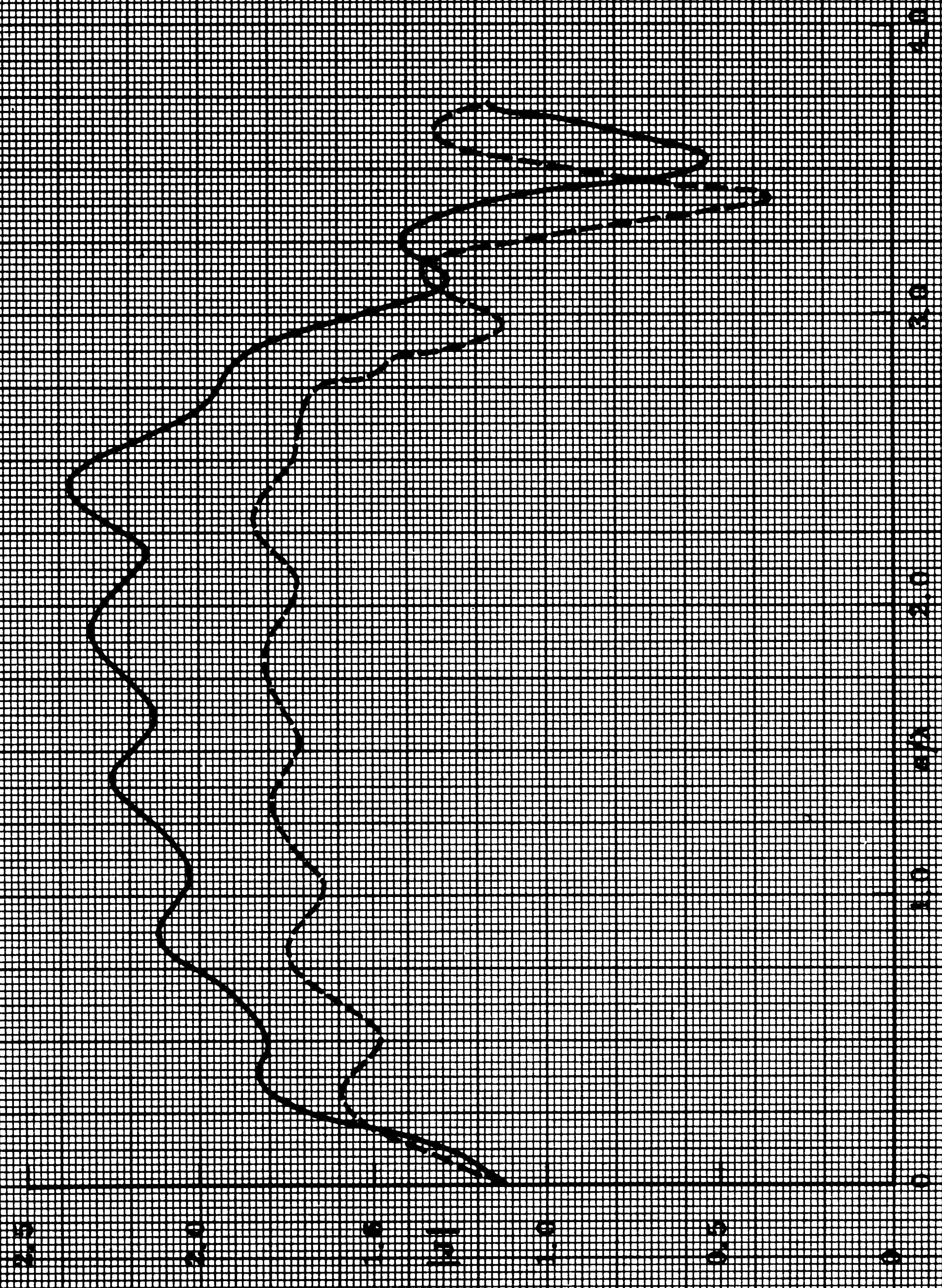



FIG. 17: OBLIQUE INCIDENCE ON CONE-SPHERE, α = 15°, ka = 4.2, β = 7 1/2°

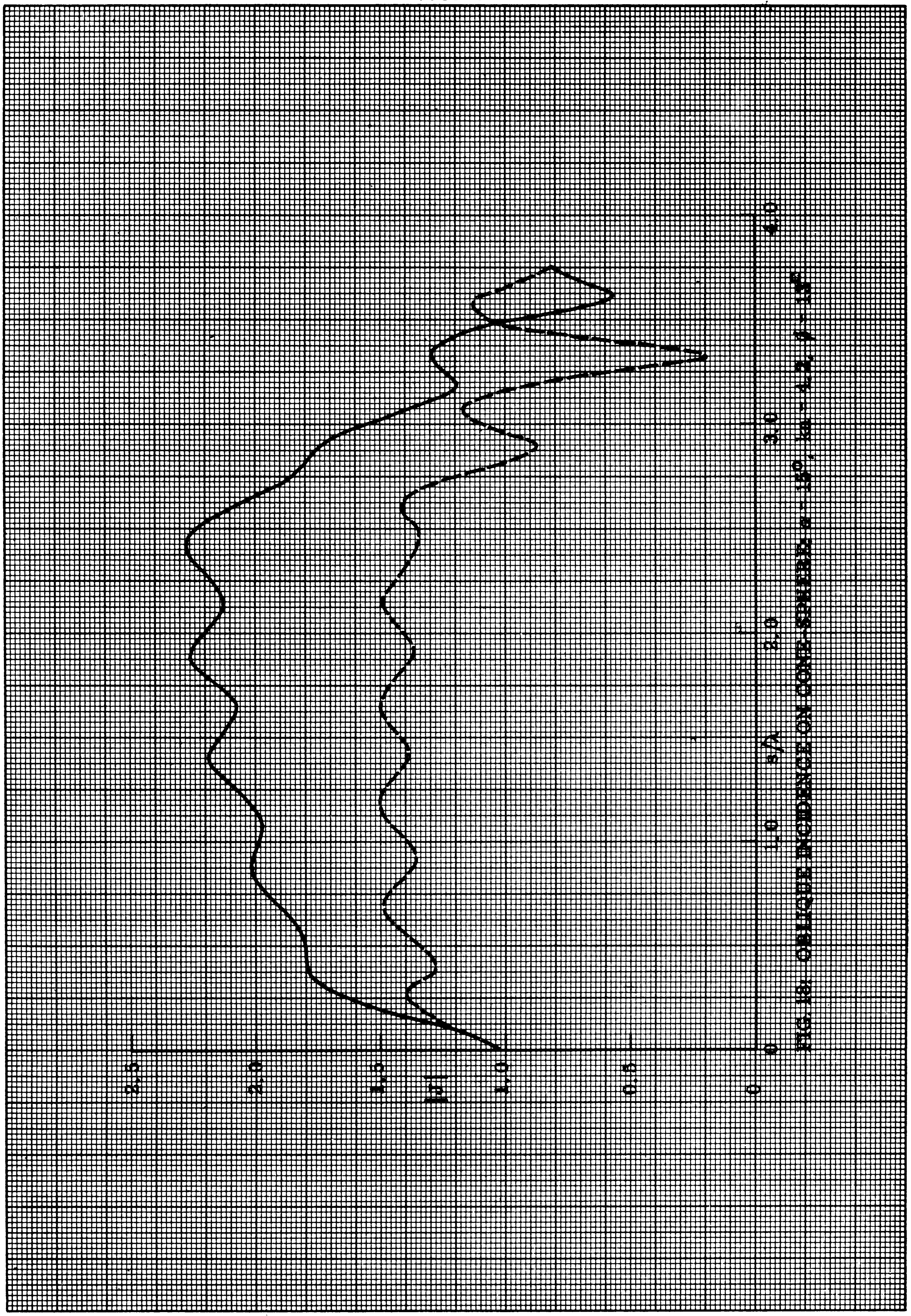
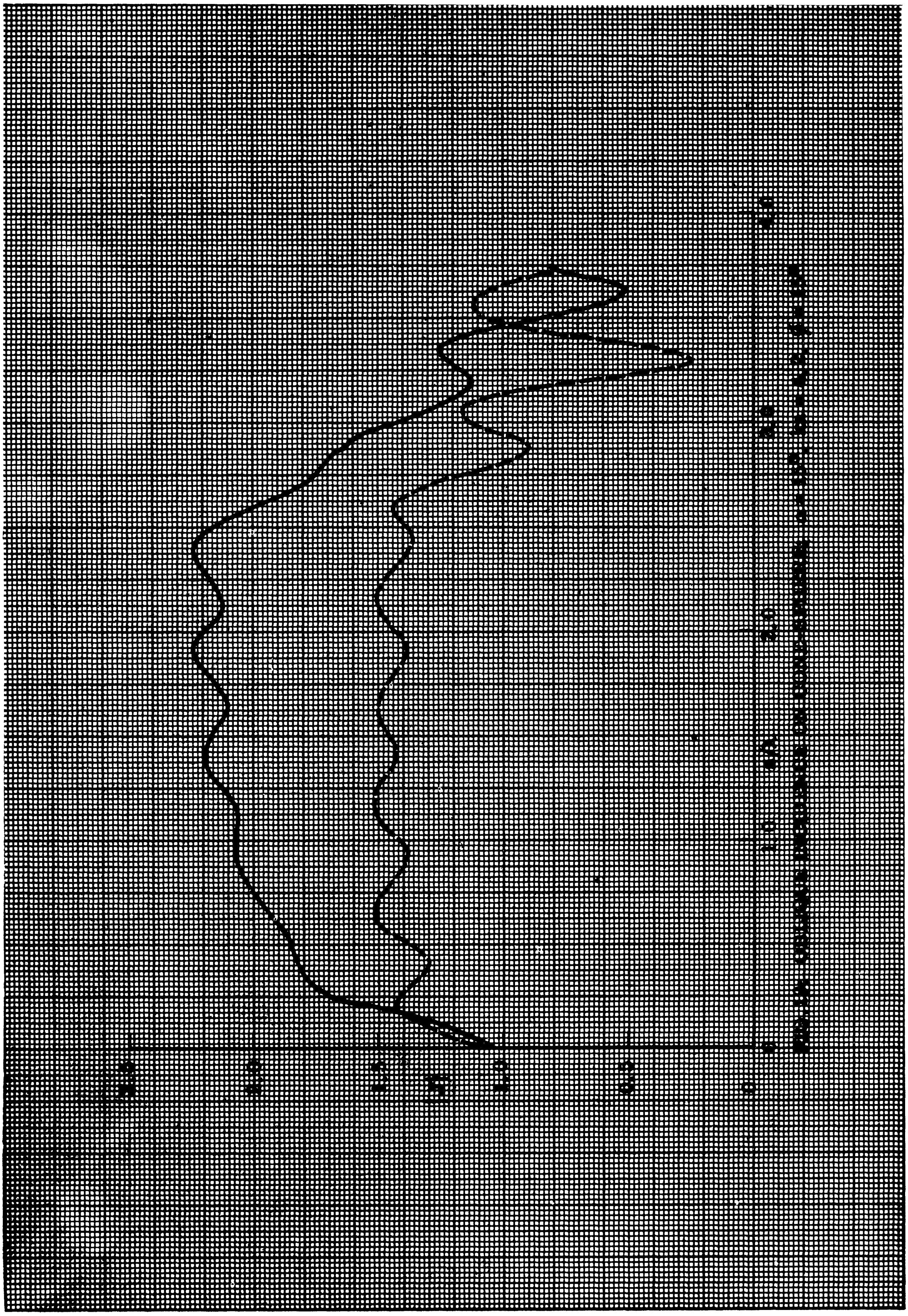



FIG. 18: OBLIQUE INCIDENCE ON CONE-SPHERE, α = 15°, ka = 4.2, θ = 15°



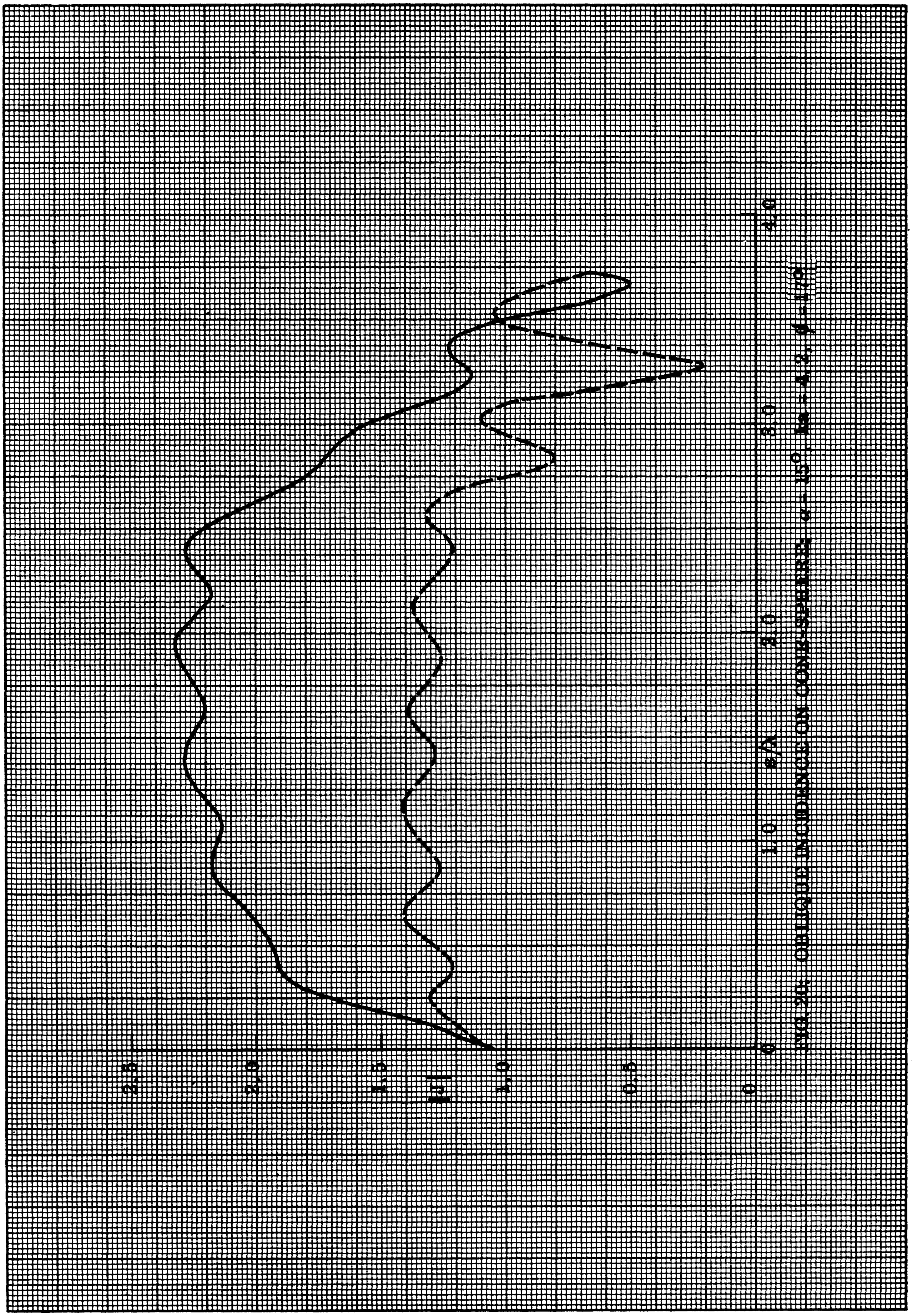



FIG. 20: OBLIQUE INCIDENCE ON CONE-SPHERE: $\alpha = 15^\circ$, $ka = 4.2$, $\beta = 17^\circ$

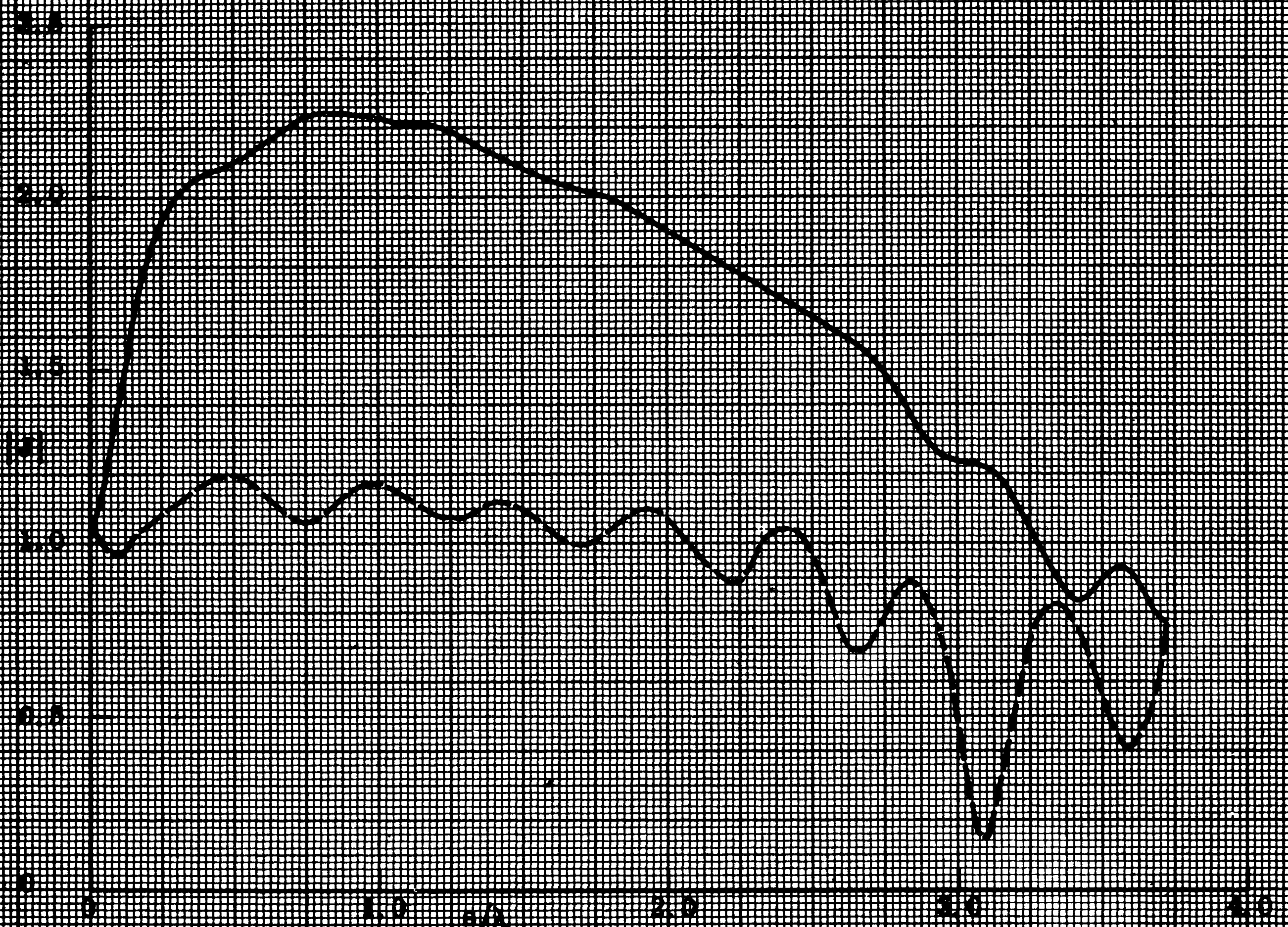



FIG. [illegible]: OBLIQUE INCIDENCE ON CONE-SPHERE, α = 15°, ka = [illegible], ψ = [illegible]°

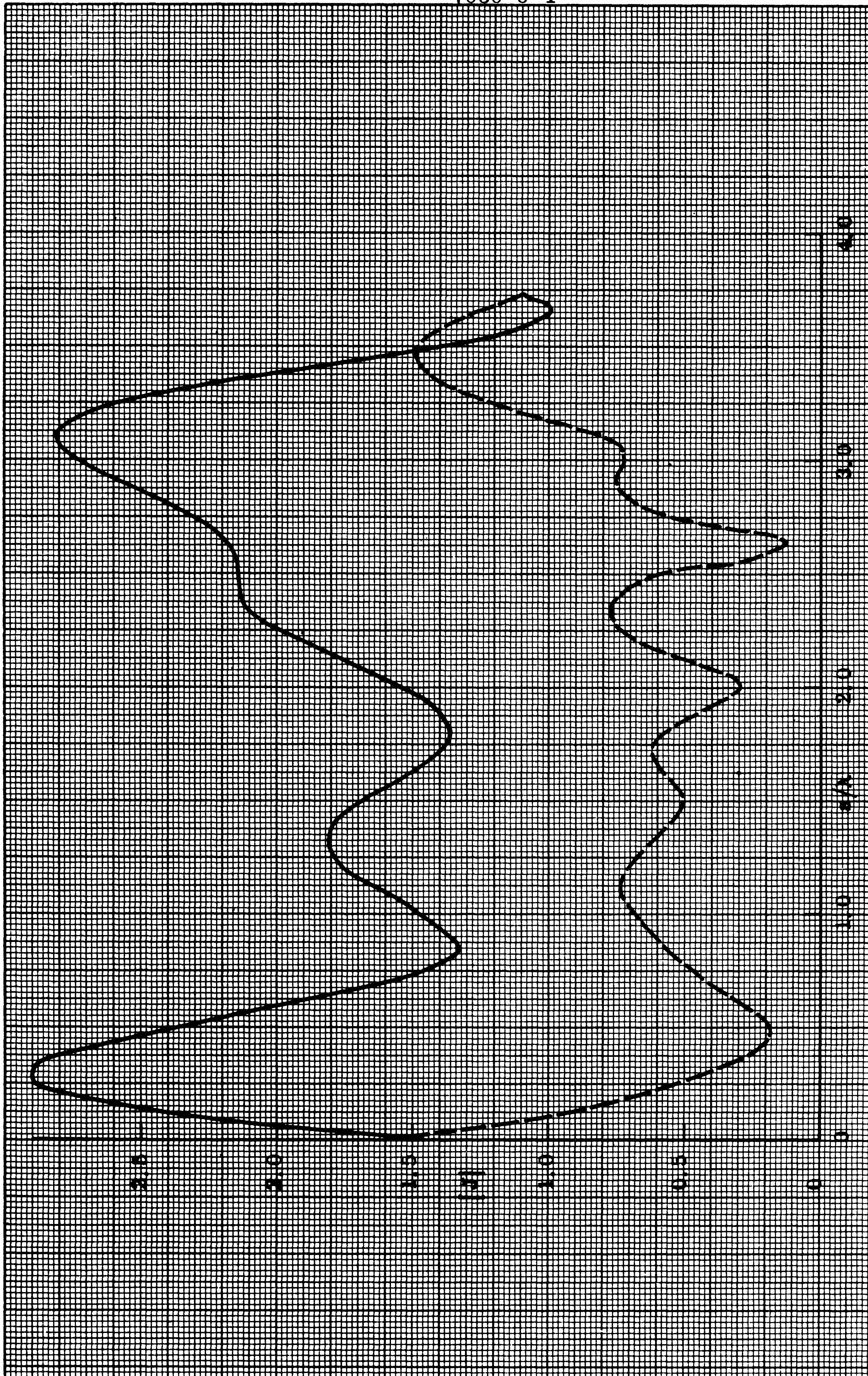



FIG. 22: OBLIQUE INCIDENCE ON CONE-SPHERE; $\alpha = 15^\circ$, $ka = 4.2$, $\theta = 75^\circ$

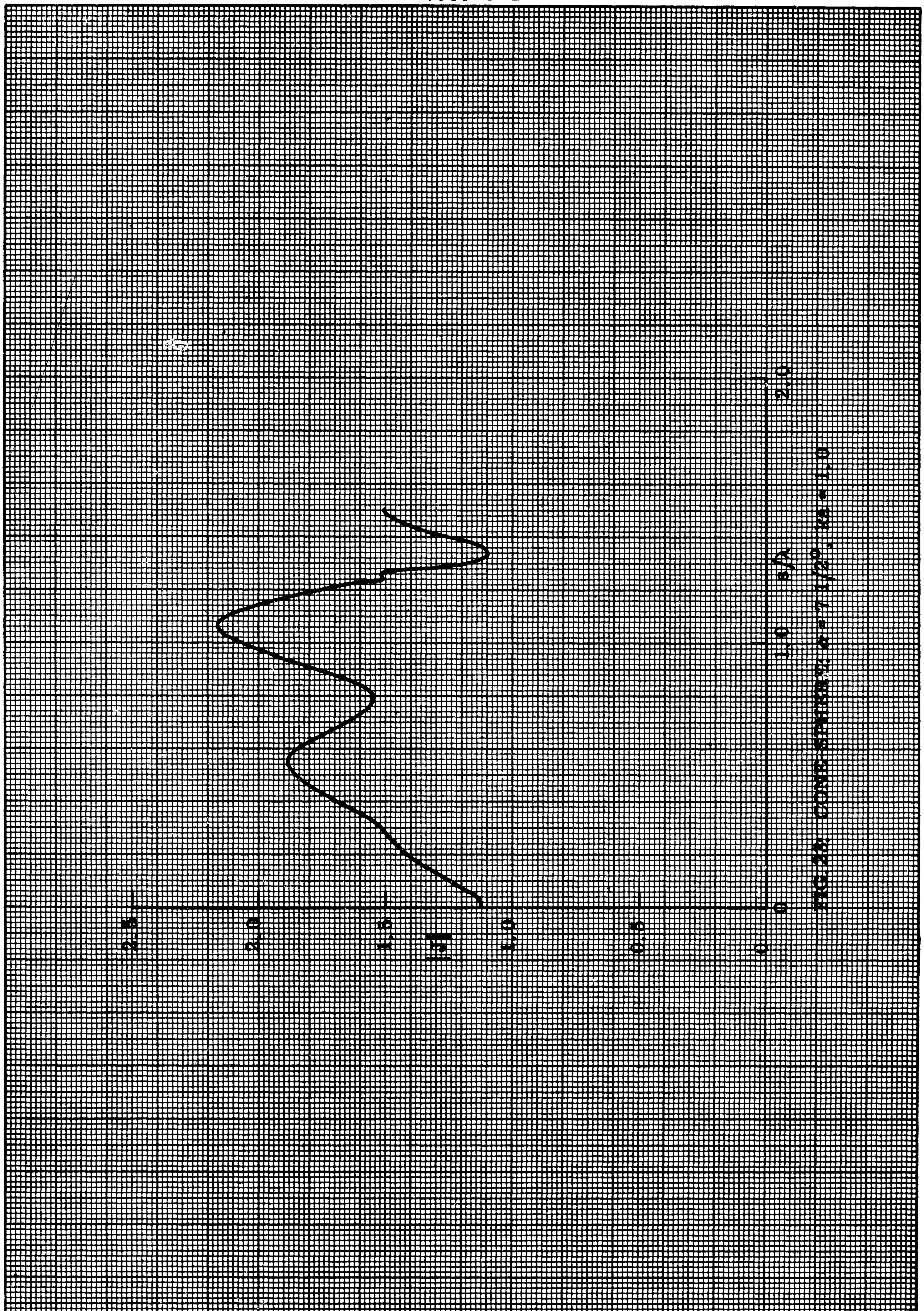



FIG. 28: CONE-SPHERE, α = 7 1/2°, ka = 1.0

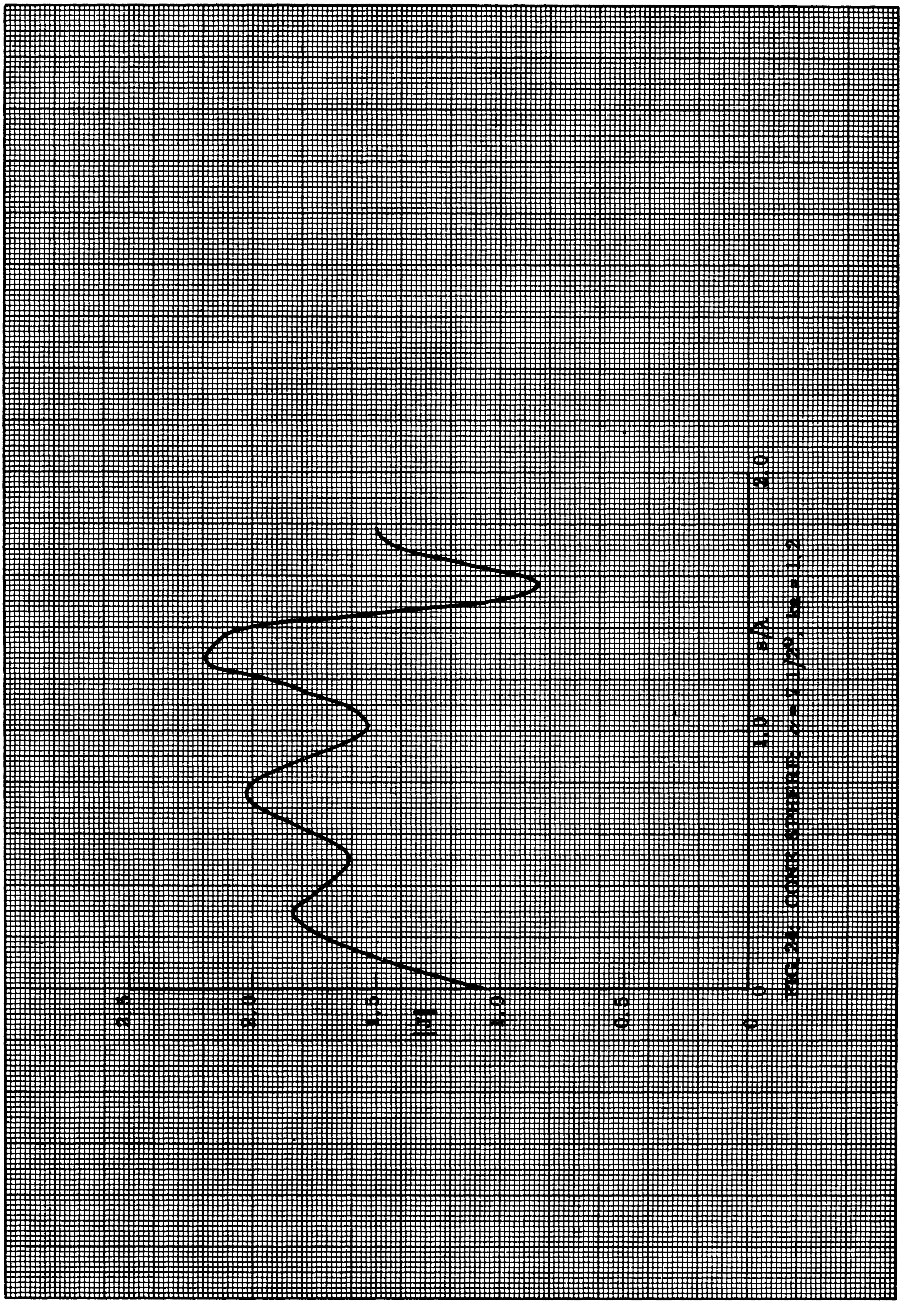



FIG. 24: CONE-SPHERE: $\alpha = 7\frac{1}{2}°$, ka = 1.2

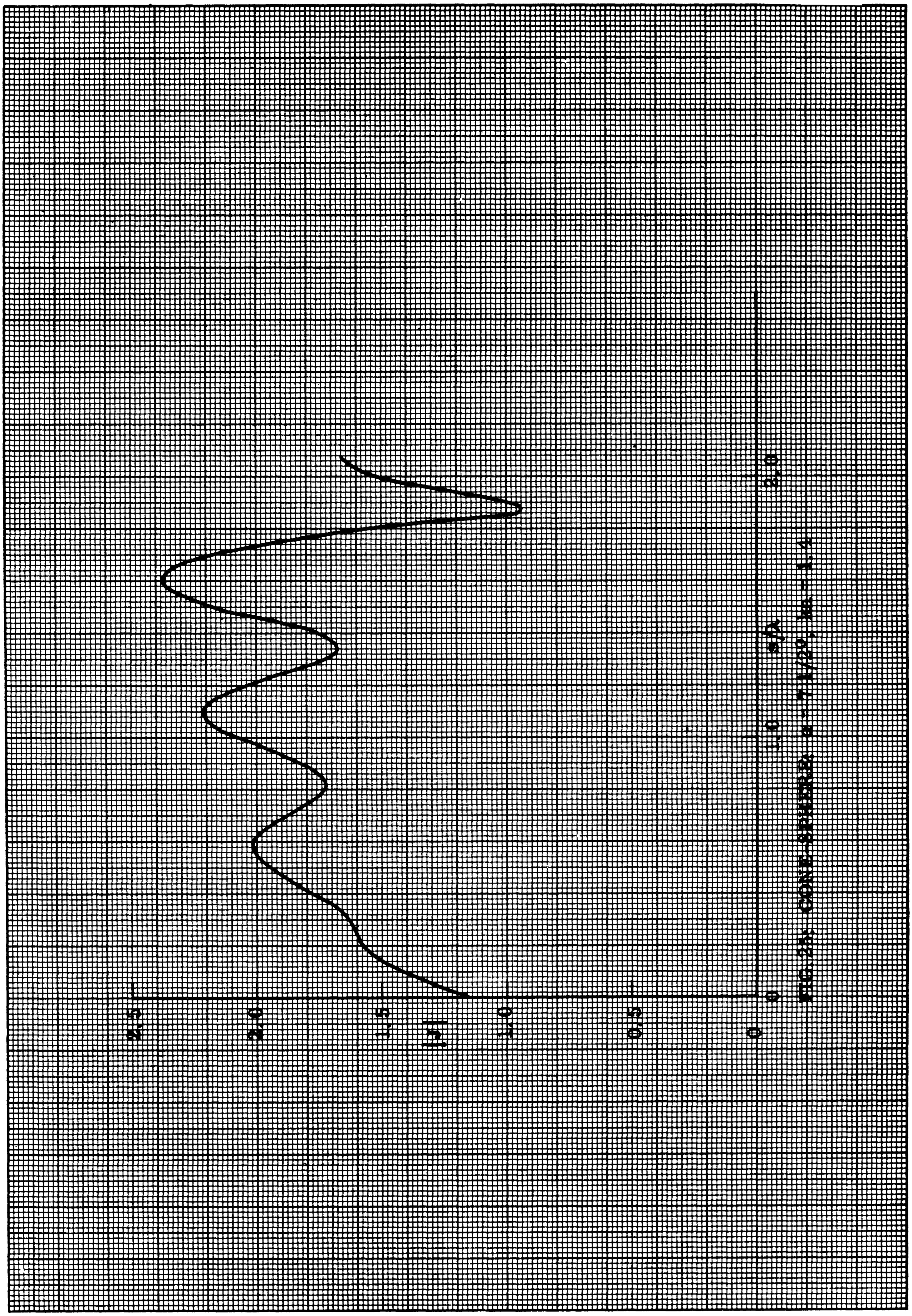



FIG. 23. CONE-SPHERE, α = 7 1/2°, ka = 1.4

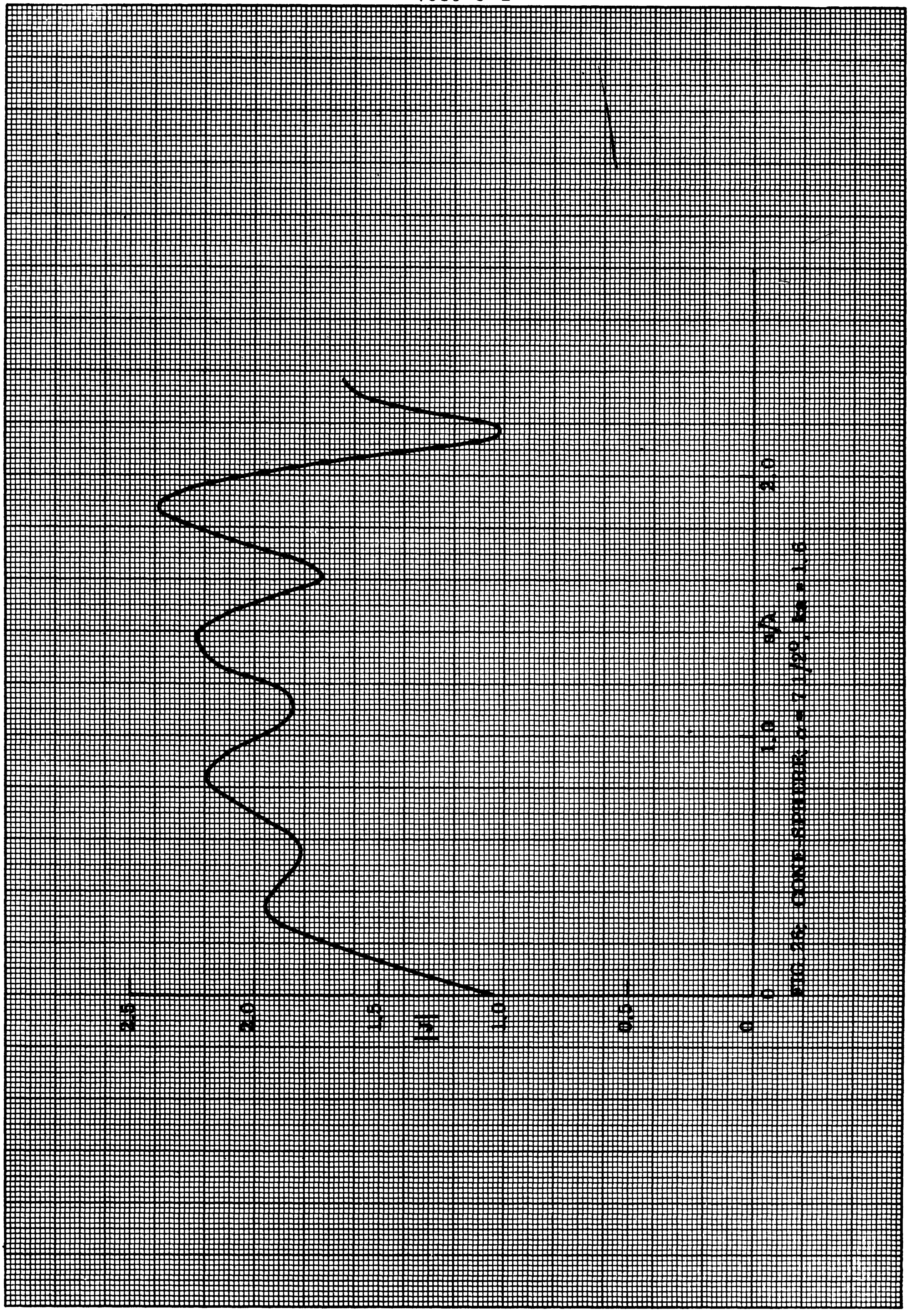



FIG. 26: CONE-SPHERE, α = 7 1/2°, ka = 1.6

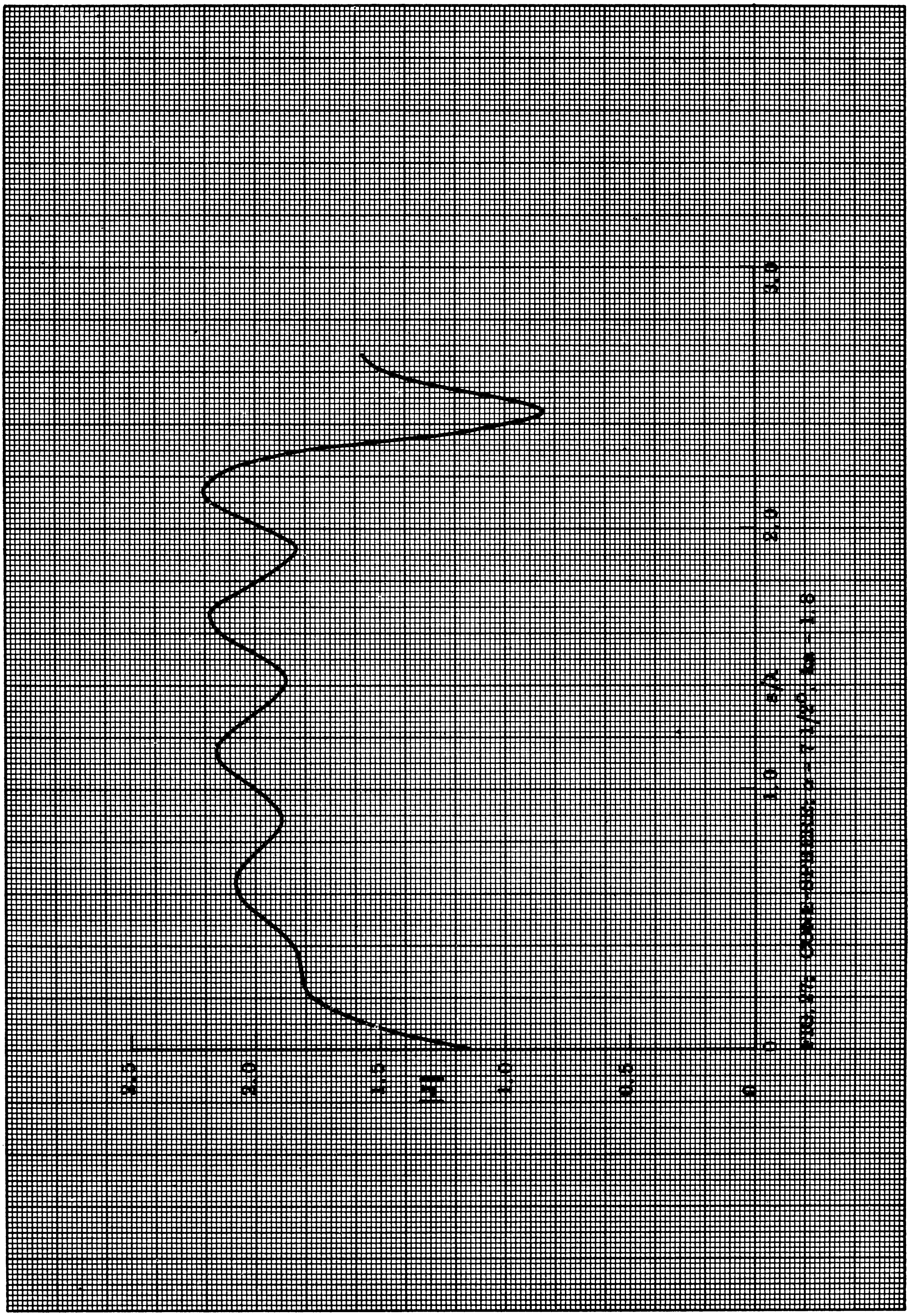



FIG. 27: CONE-SPHERE: α = 7 1/2°, ka = 1.6

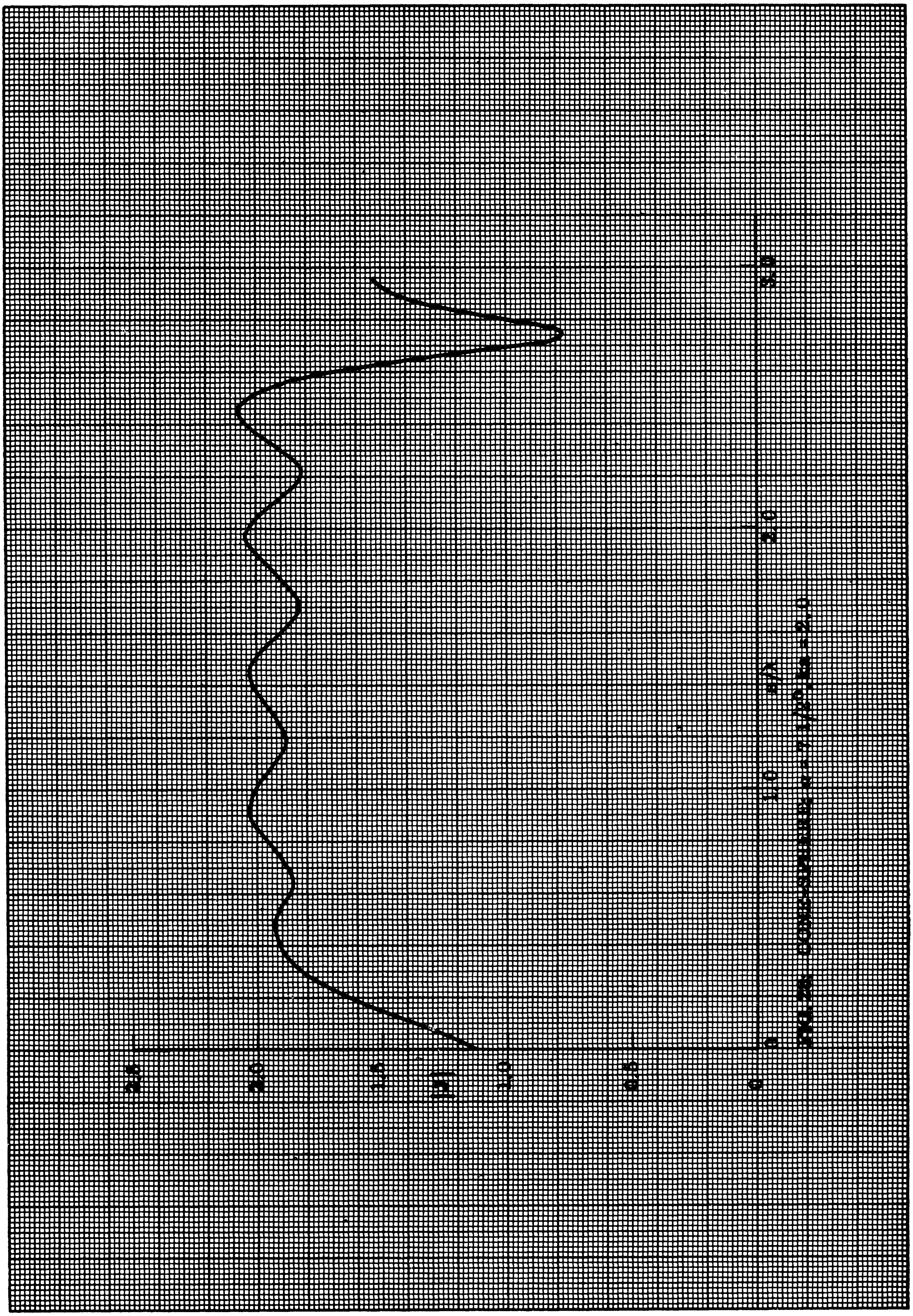



FIG. 28: CONE-SPHERE, α = 7 1/2°, ka = 2.0

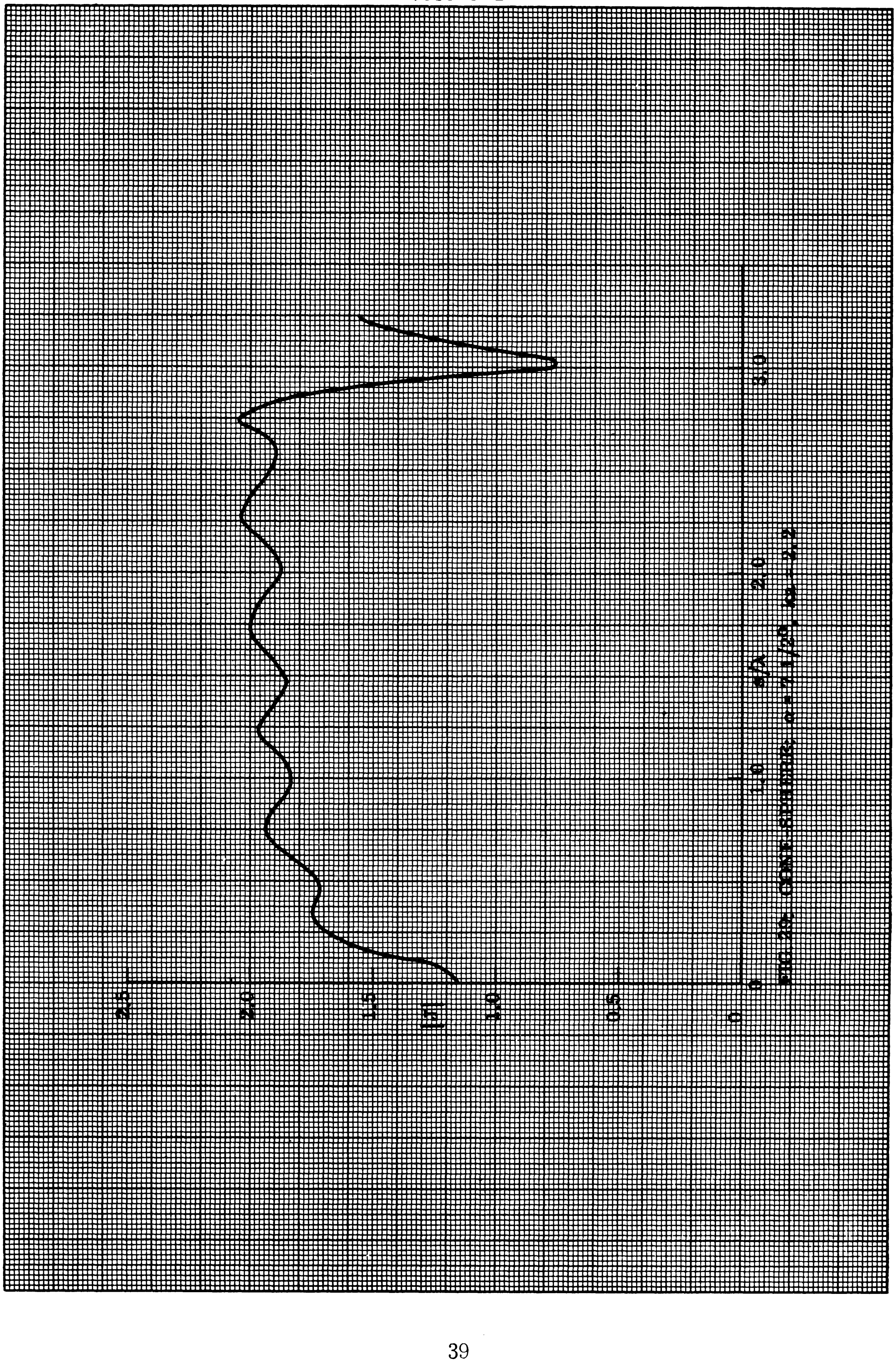



FIG 29: CONE-SPHERE, α = 7 1/2°, ka = 2.2

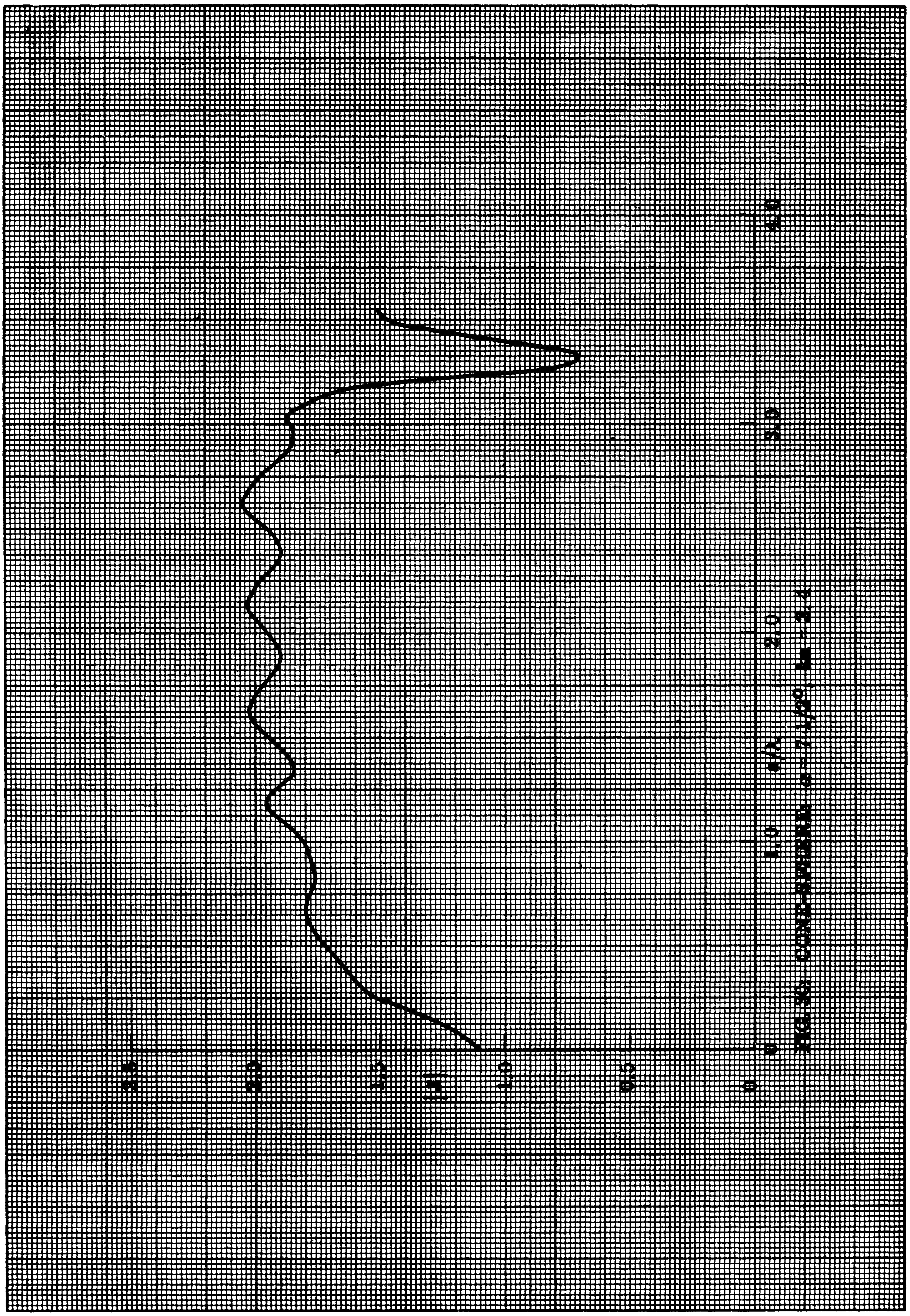
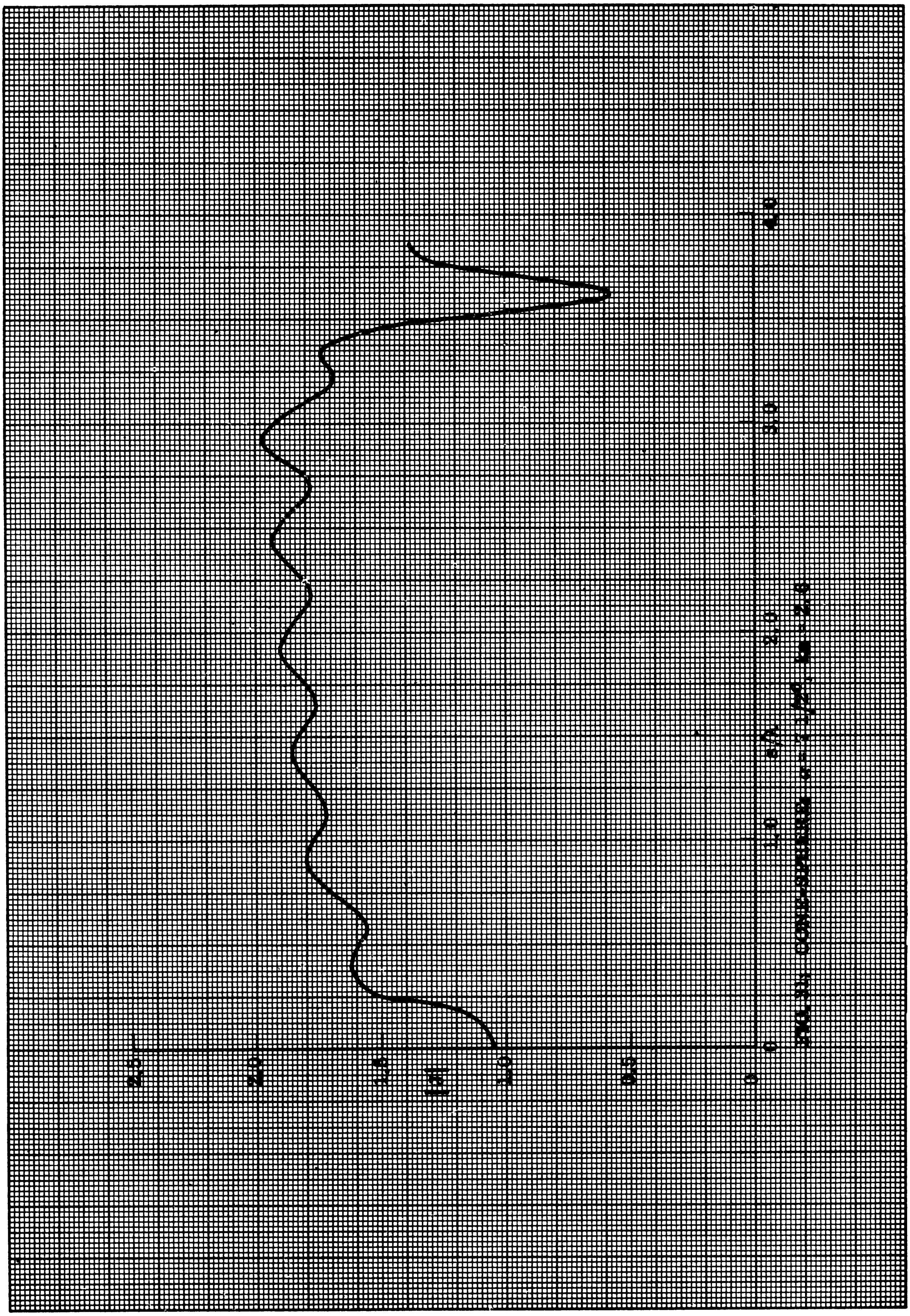



FIG. 30: CONE-SPHERE, $\alpha = 7\frac{1}{2}°$, $ka = 2.4$


2.5
2.0
1.5
|E|
1.0
0.5
0
0
1.0
s/λ
2.0
3.0
4.0

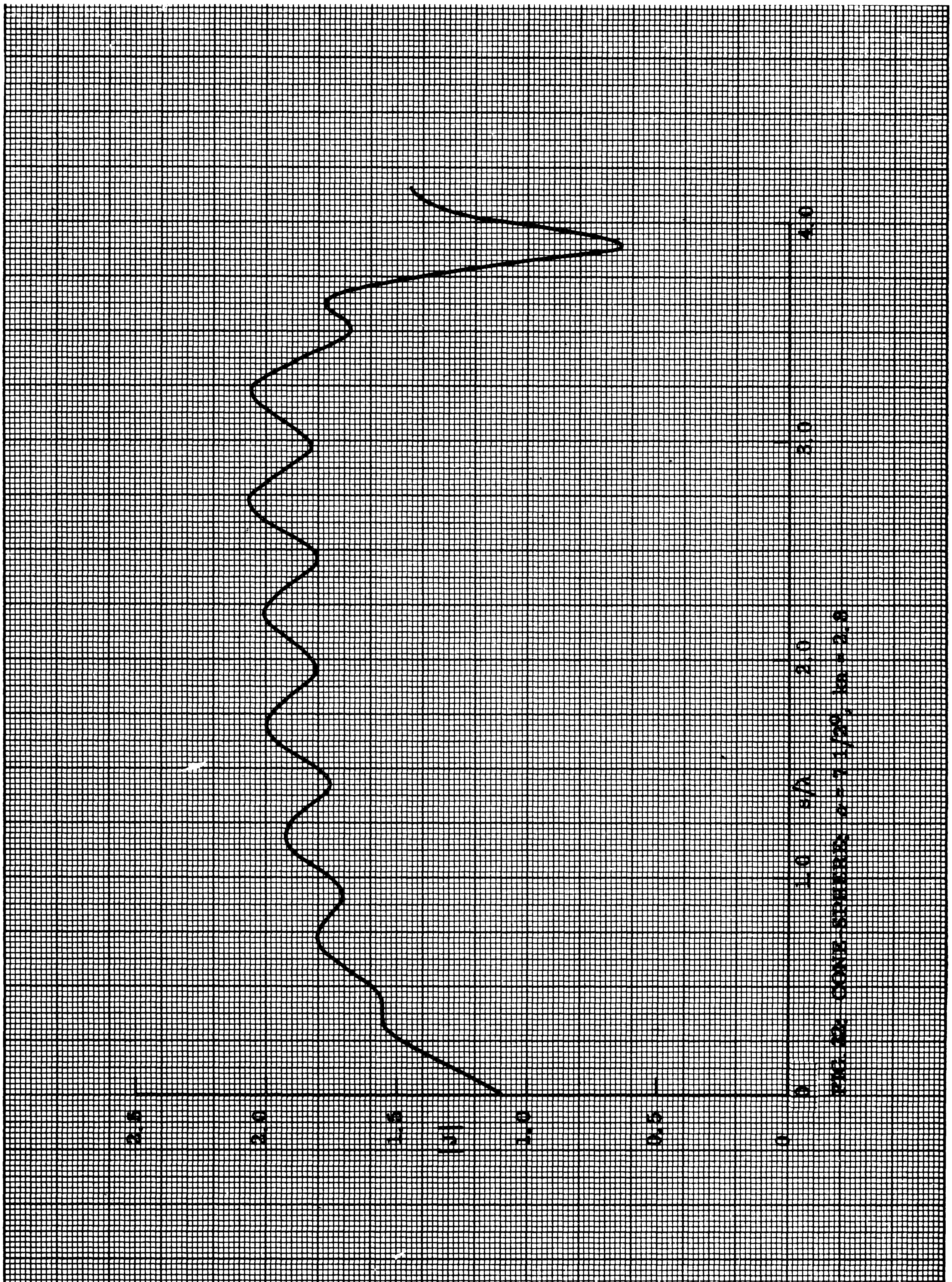



FIG. 22. CONE-SPHERE, $\alpha = 7\,1/2°$, $ka = 2.8$

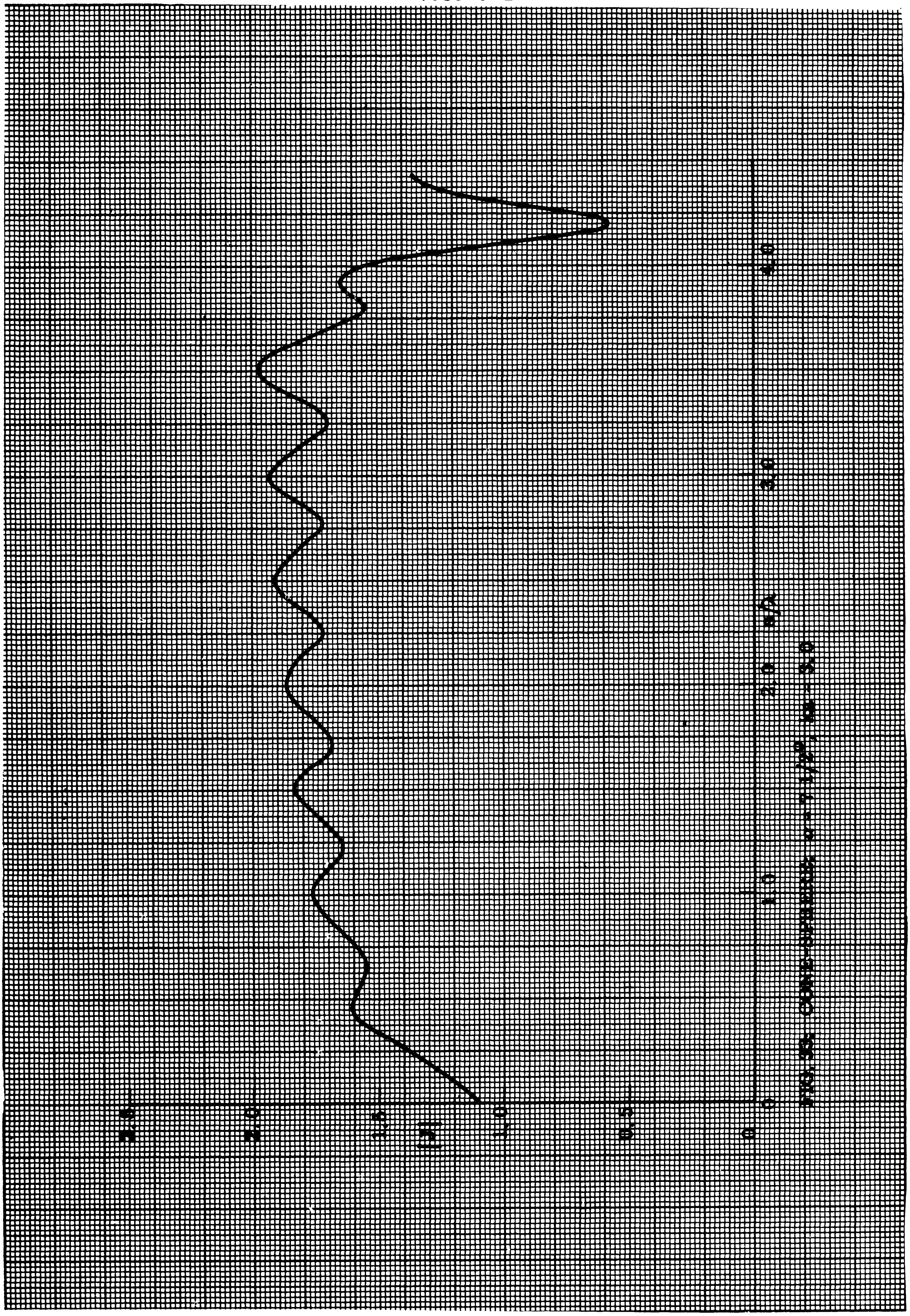



FIG. [illegible]: CONE-SPHERE, α = 7 1/2°, ka = 3.0

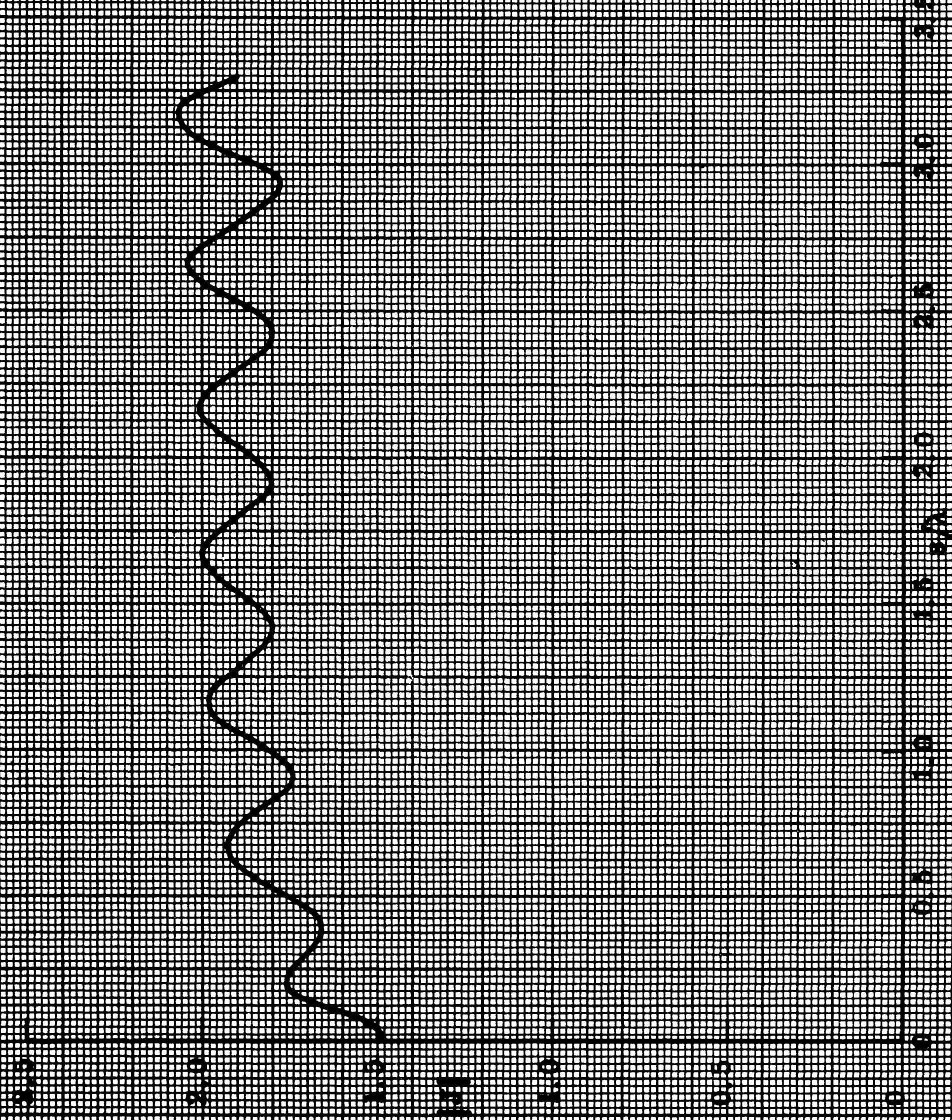
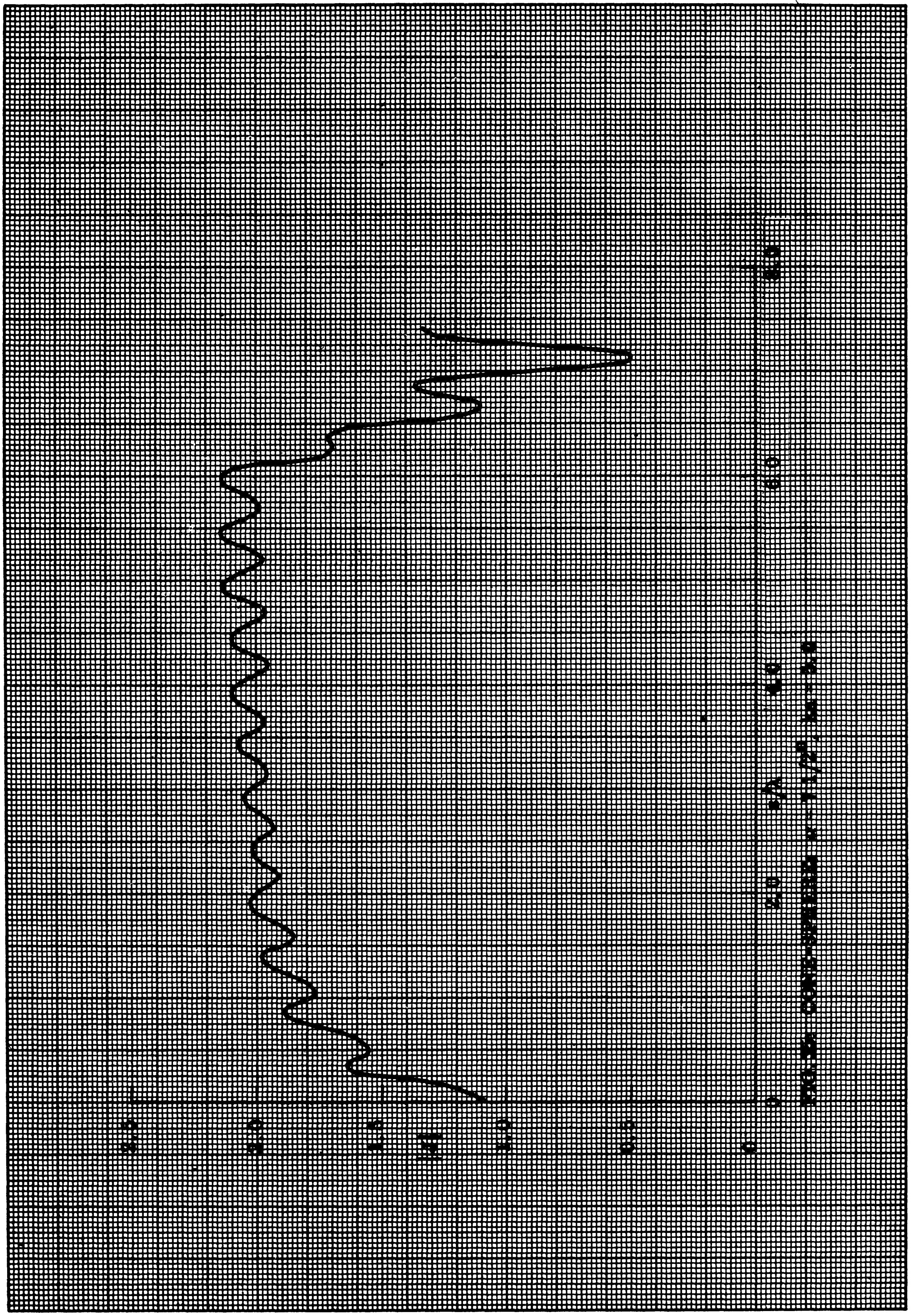
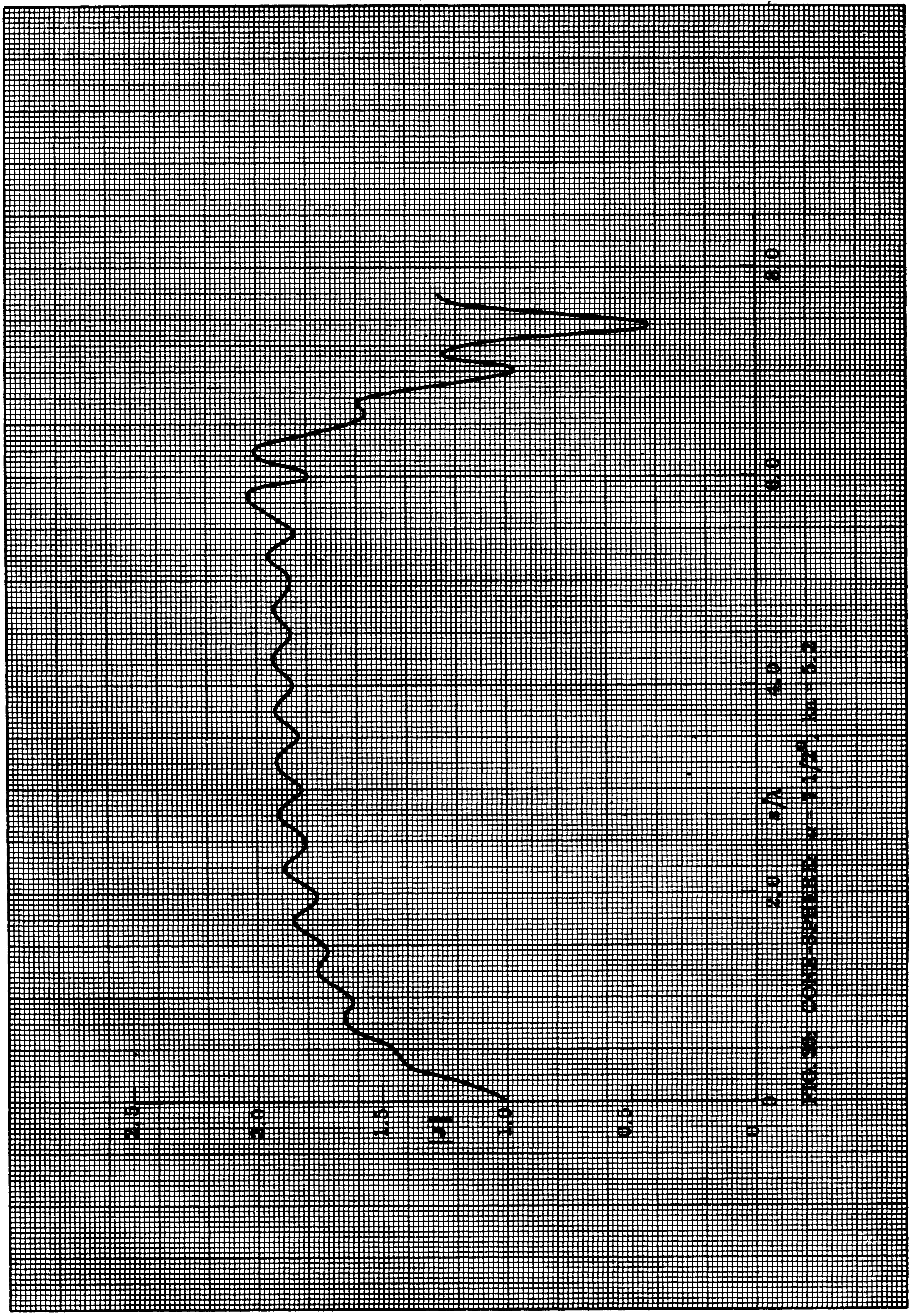



FIG. 34: MODEL A; ka = 3.0. COMPARISON WITH FIG. 33 SHOWS EFFECT OF SLIGHTLY BLUNTED TIP.




2.5
2.0
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1.0
0.5
0
0
2.0
4.0
6.0
8.0

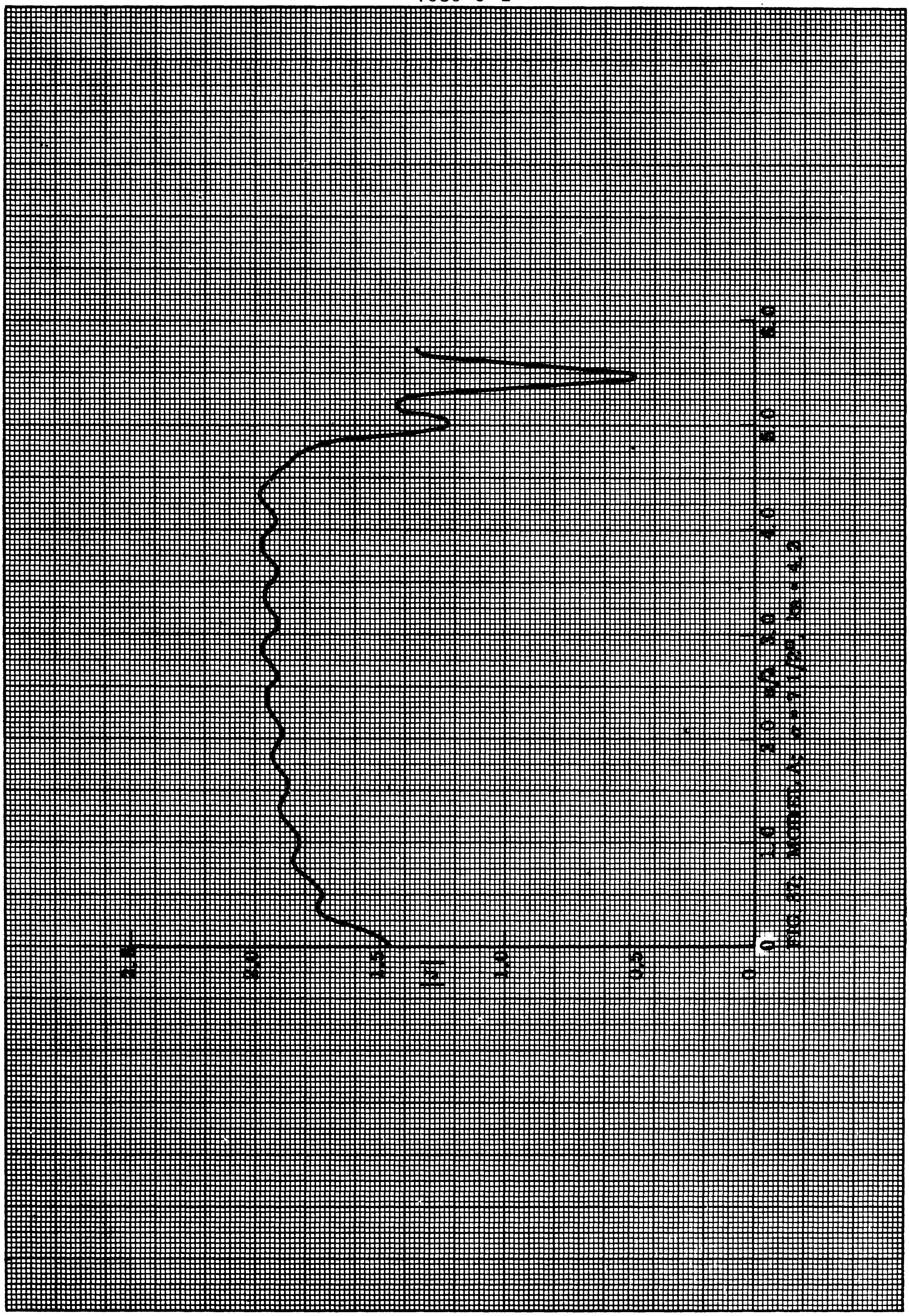


FIG. 27. MODEL A, θ = 7 1/2°, ka = 4.2

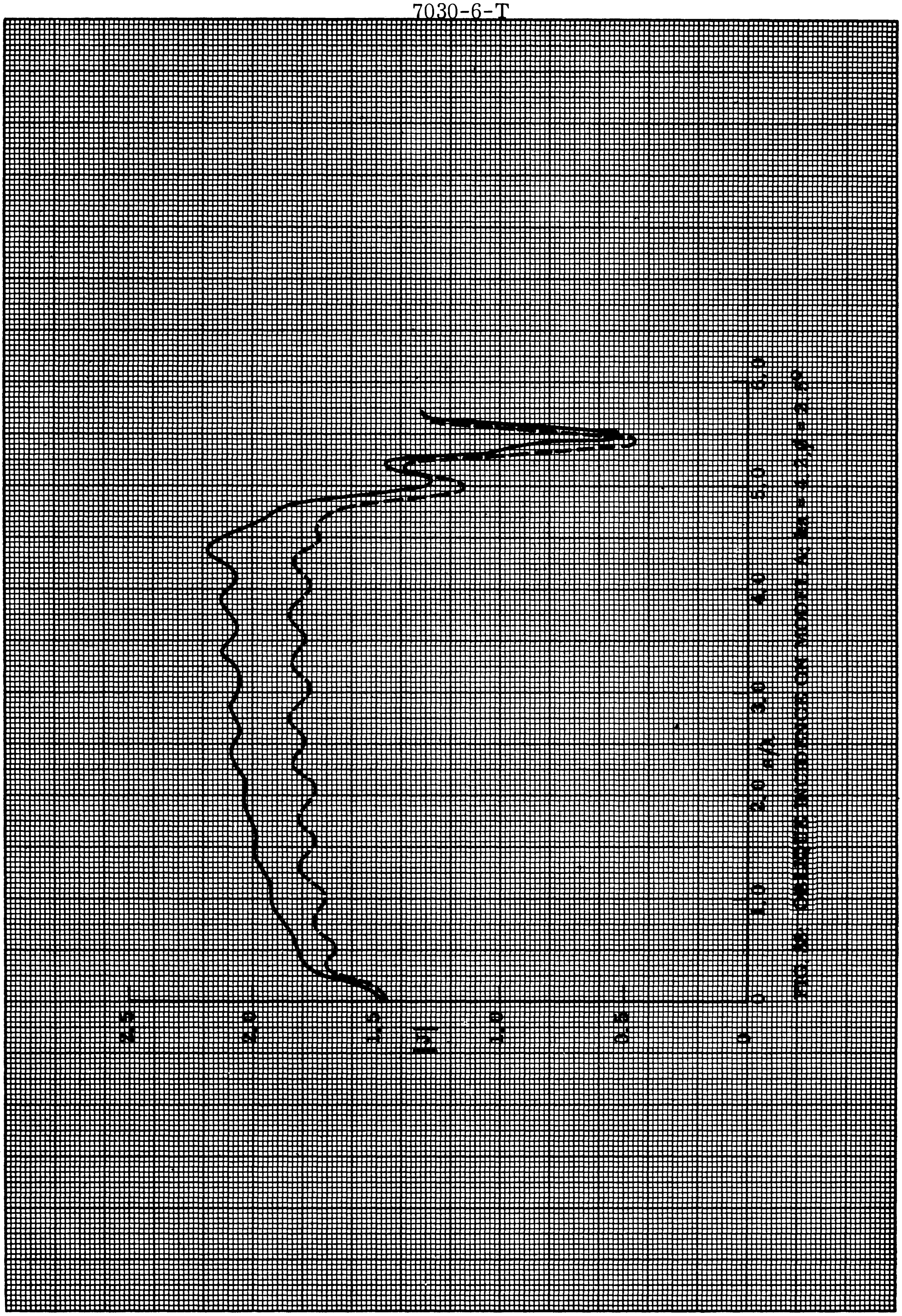



FIG. 30: OBLIQUE INCIDENCE ON MODEL A, ka = 4.2, β = 2.80

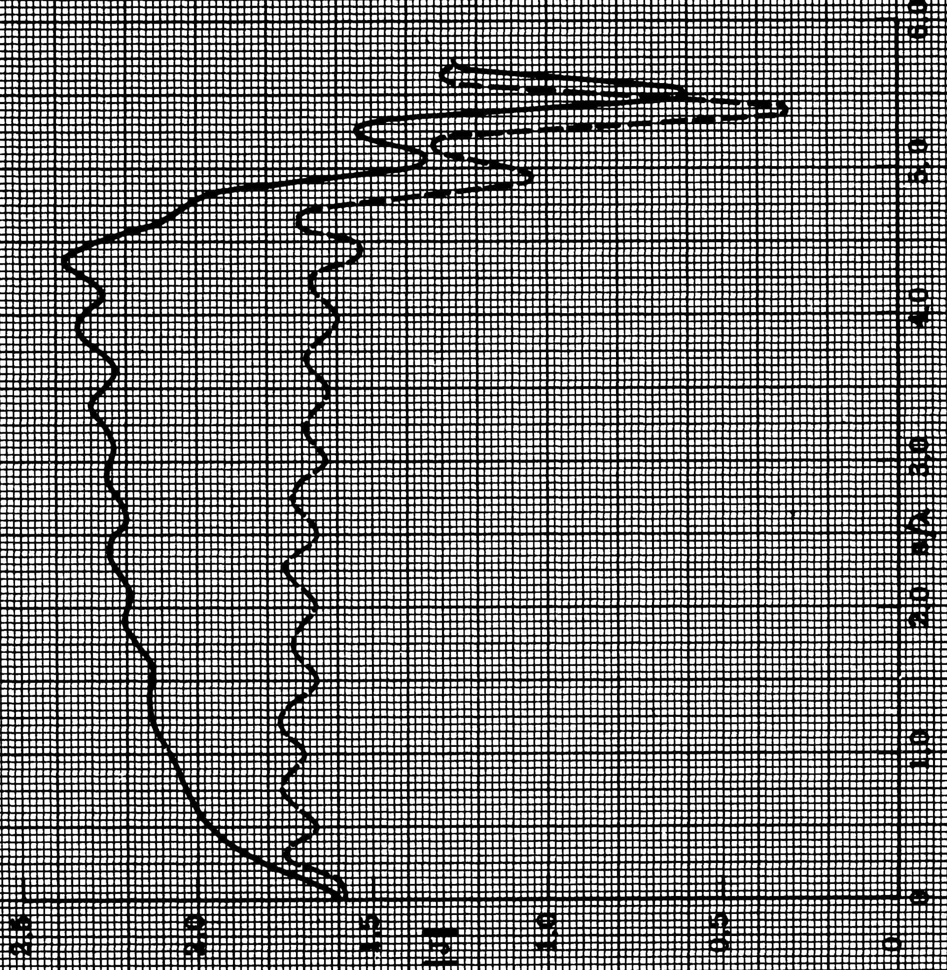



FIG. 39: OBLIQUE INCIDENCE ON MODEL A: $ka = 4.2$, $\beta = 5^\circ$

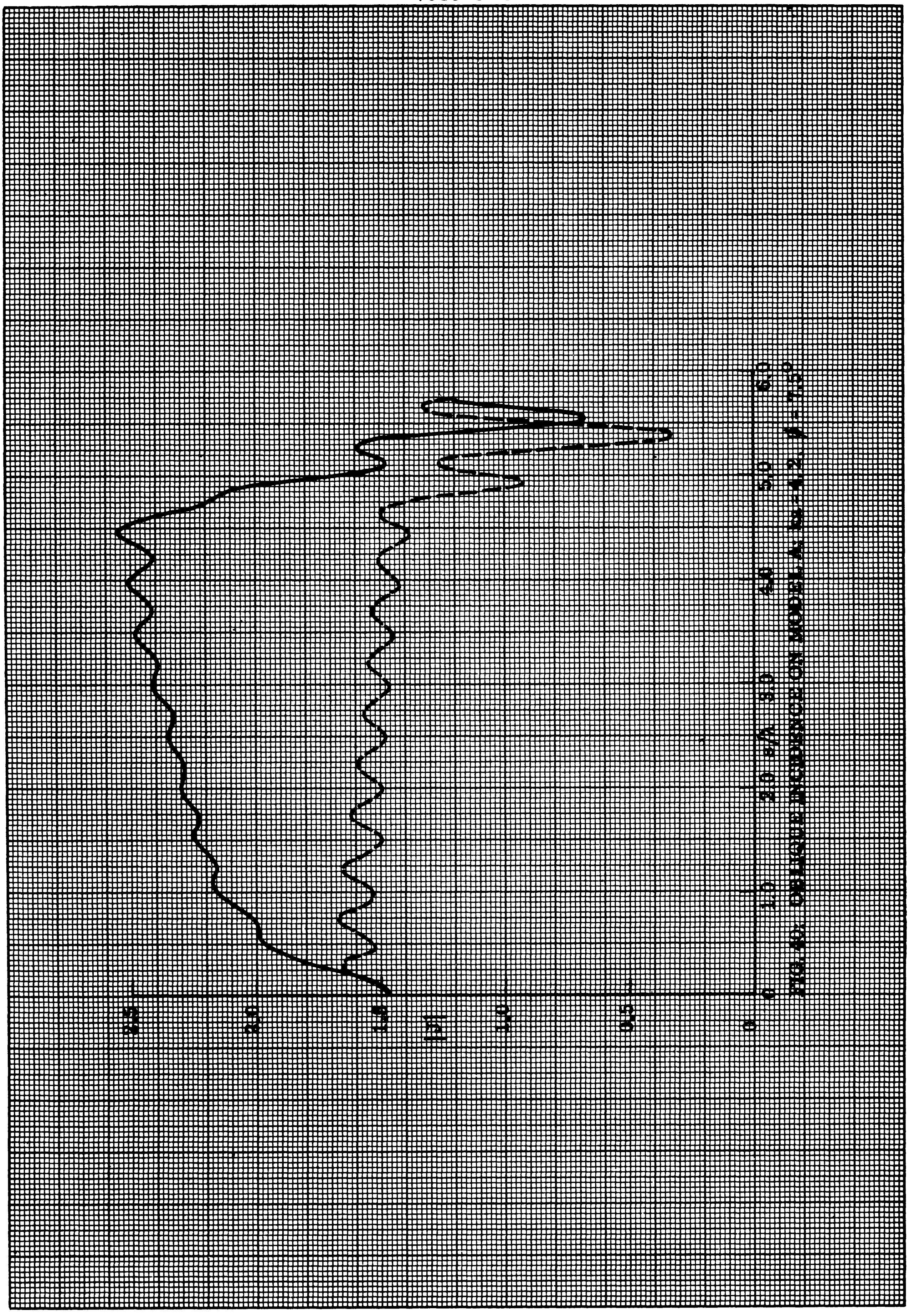



FIG. 40: OBLIQUE INCIDENCE ON MODEL A, $ka = 4.2$, $\phi = 7.5^\circ$

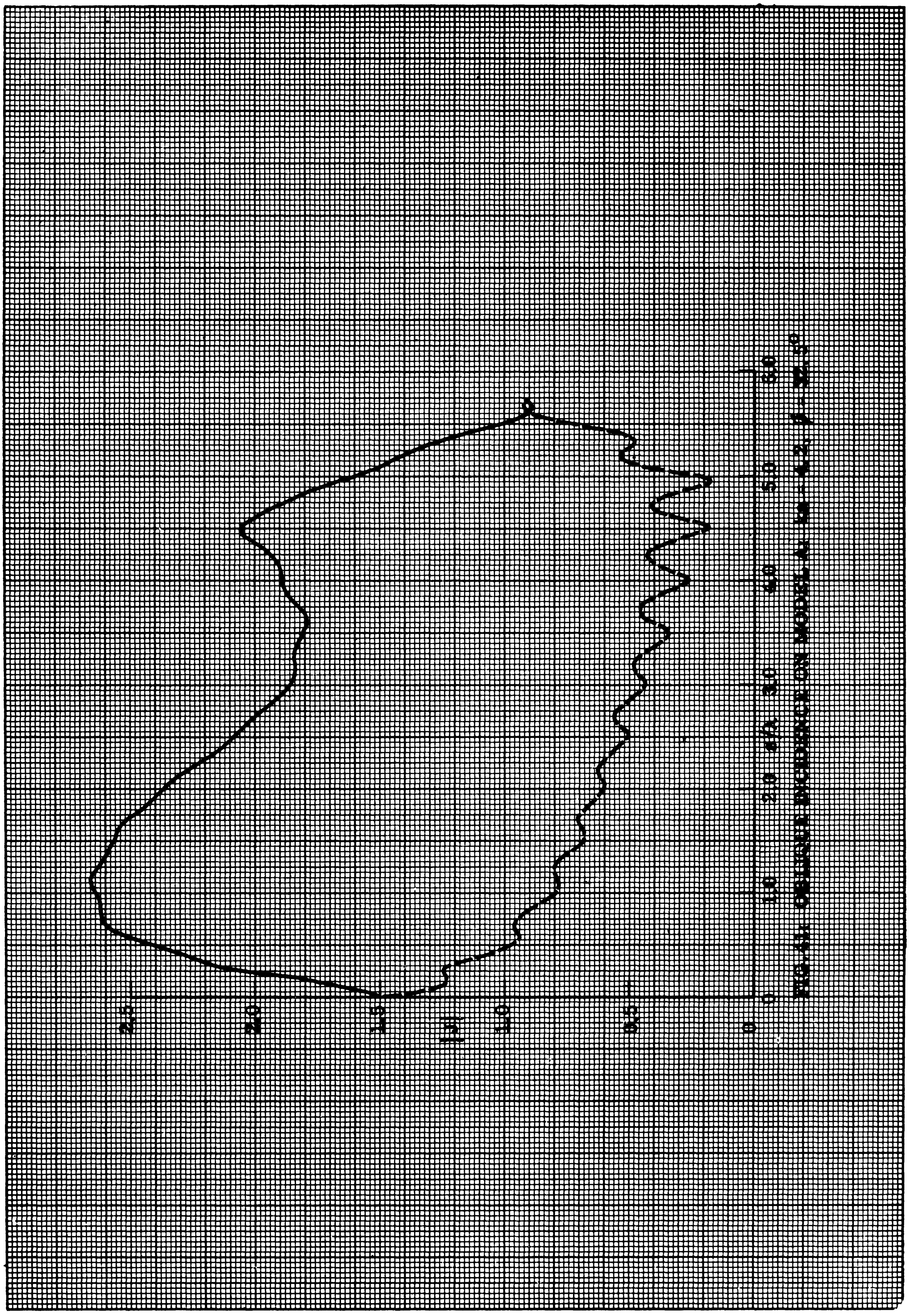



FIG. 41: OBLIQUE INCIDENCE ON MODEL A, ka = 4.2, β = 37.5°

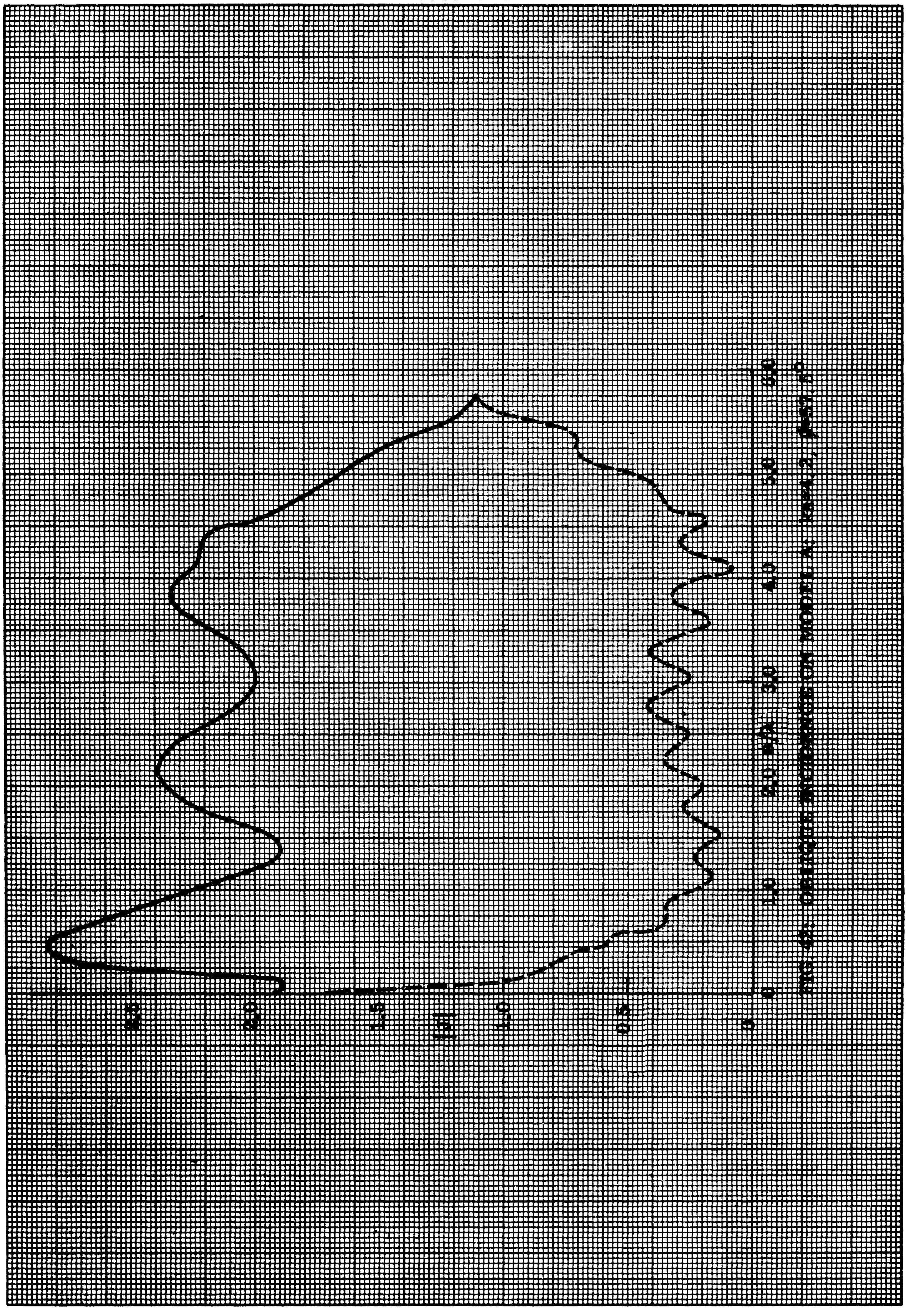



FIG. 42: OBLIQUE INCIDENCE ON MODEL A: ka=4.2, β=57.5°

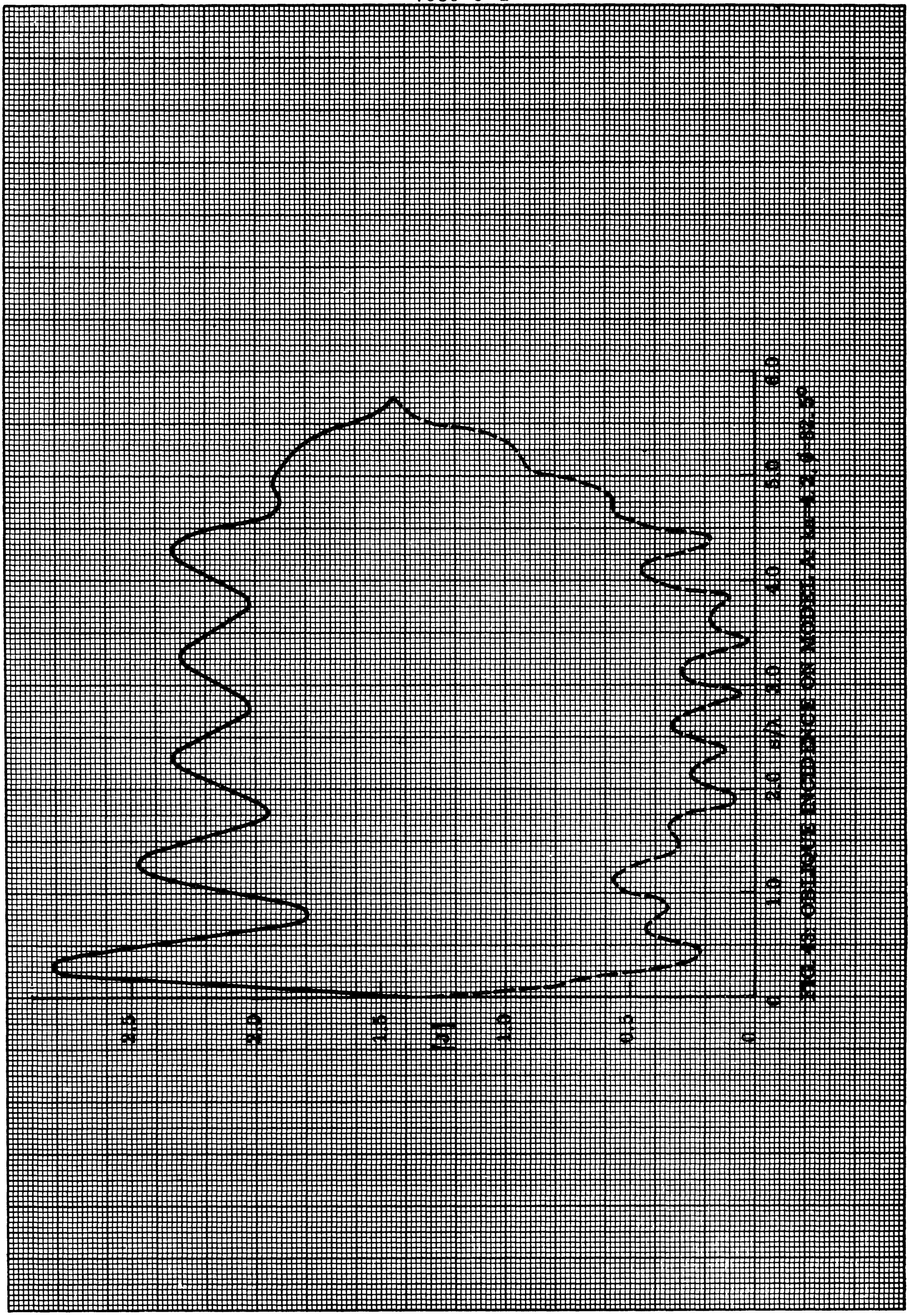
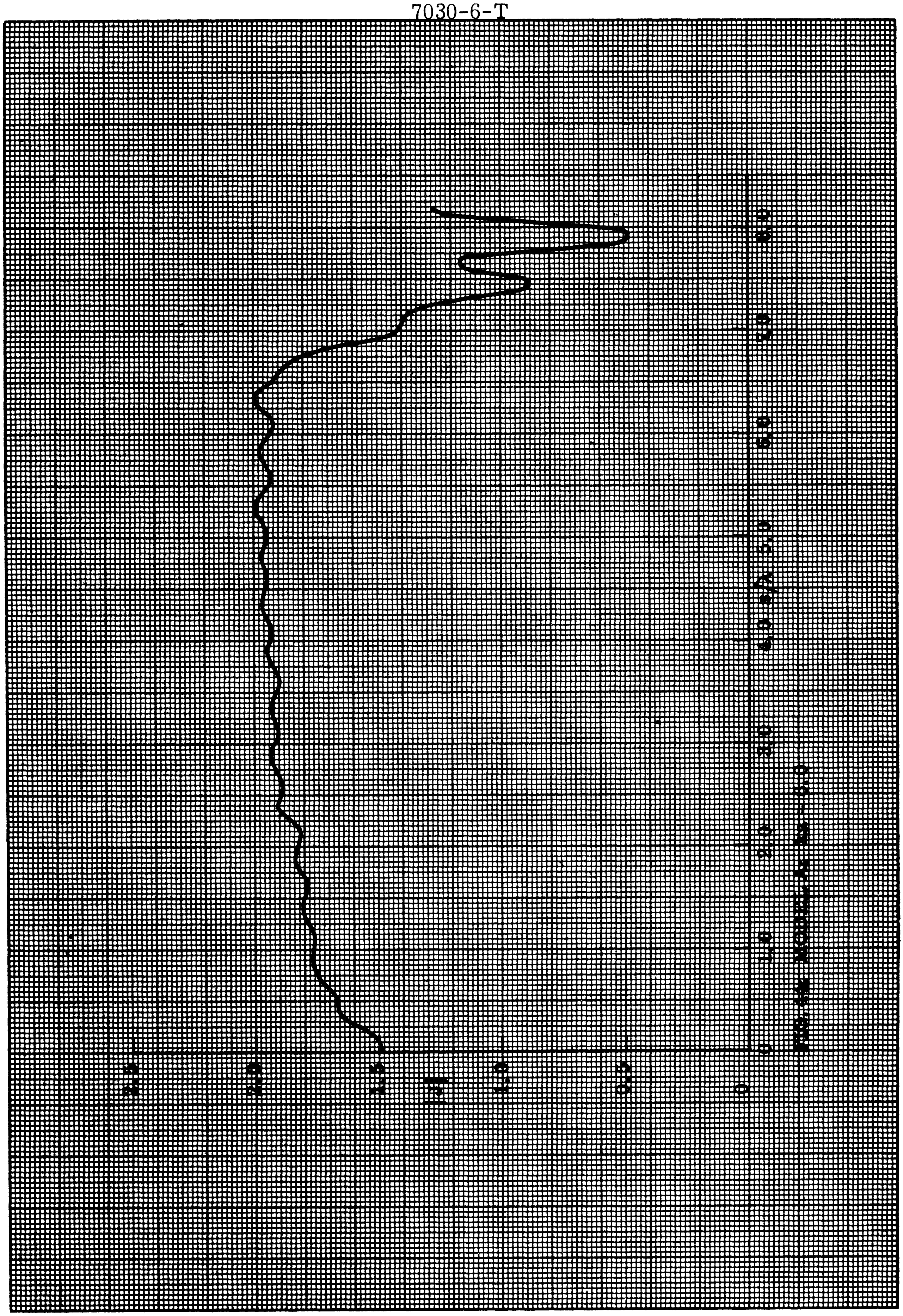
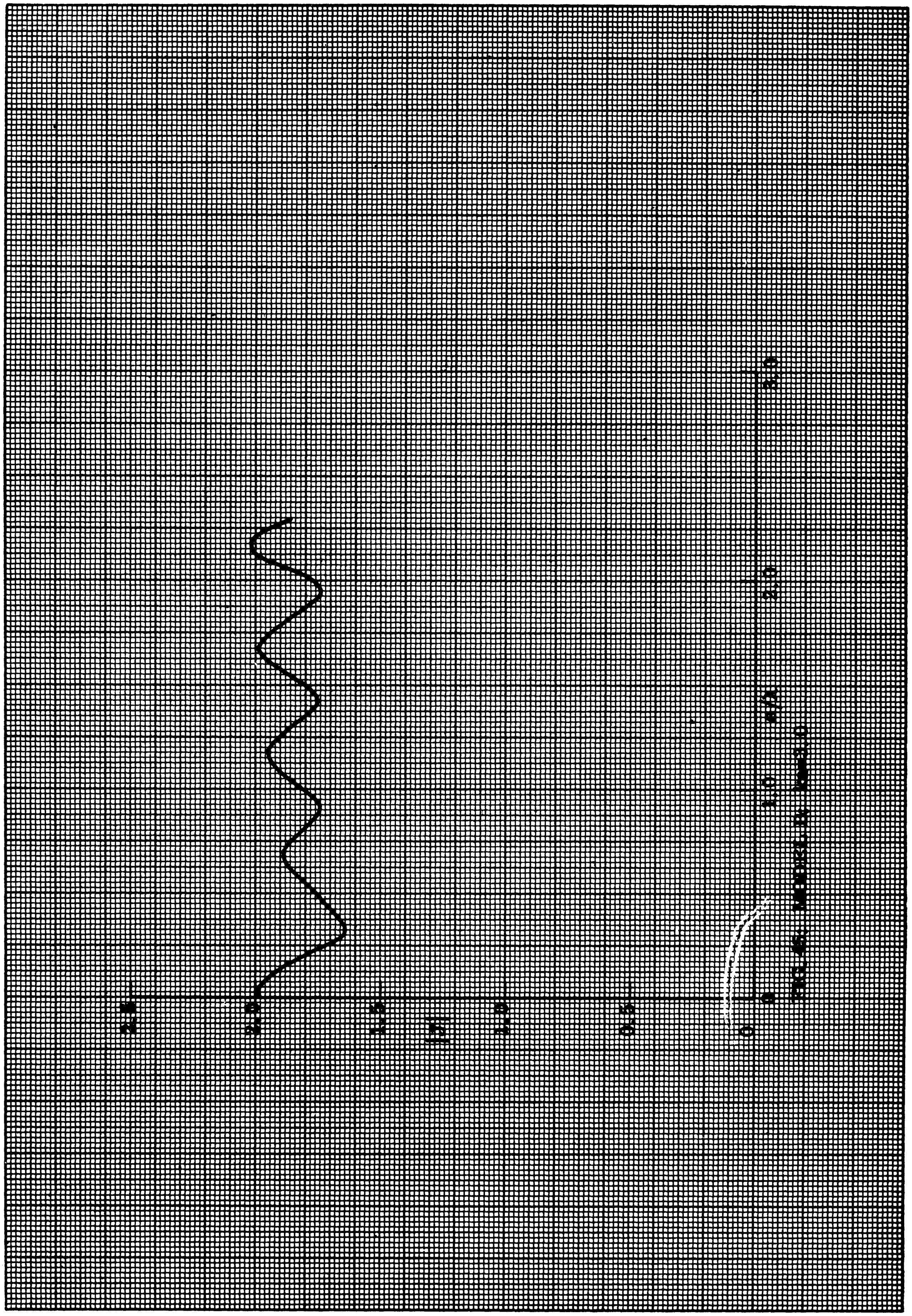



FIG. 43: OBLIQUE INCIDENCE ON MODEL A; ka=4.2, θ=52.5°


0
1.0
2.0
3.0
4.0
s/λ
5.0
6.0
7.0
8.0
2.5
2.0
1.5
|Γ|
1.0
0.5
0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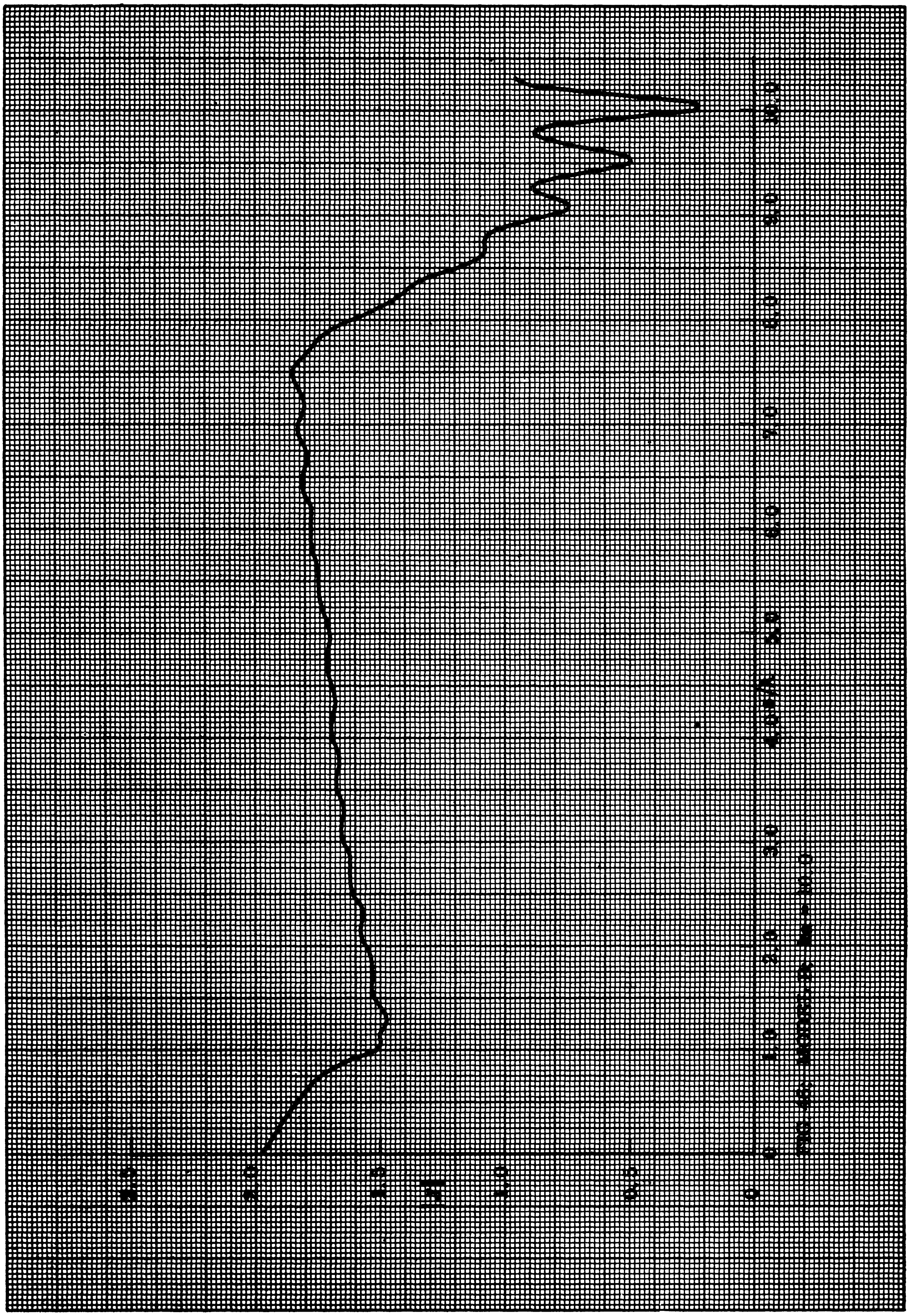
2.0
1.5
1.0
0.5
0
1.0
2.0
3.0



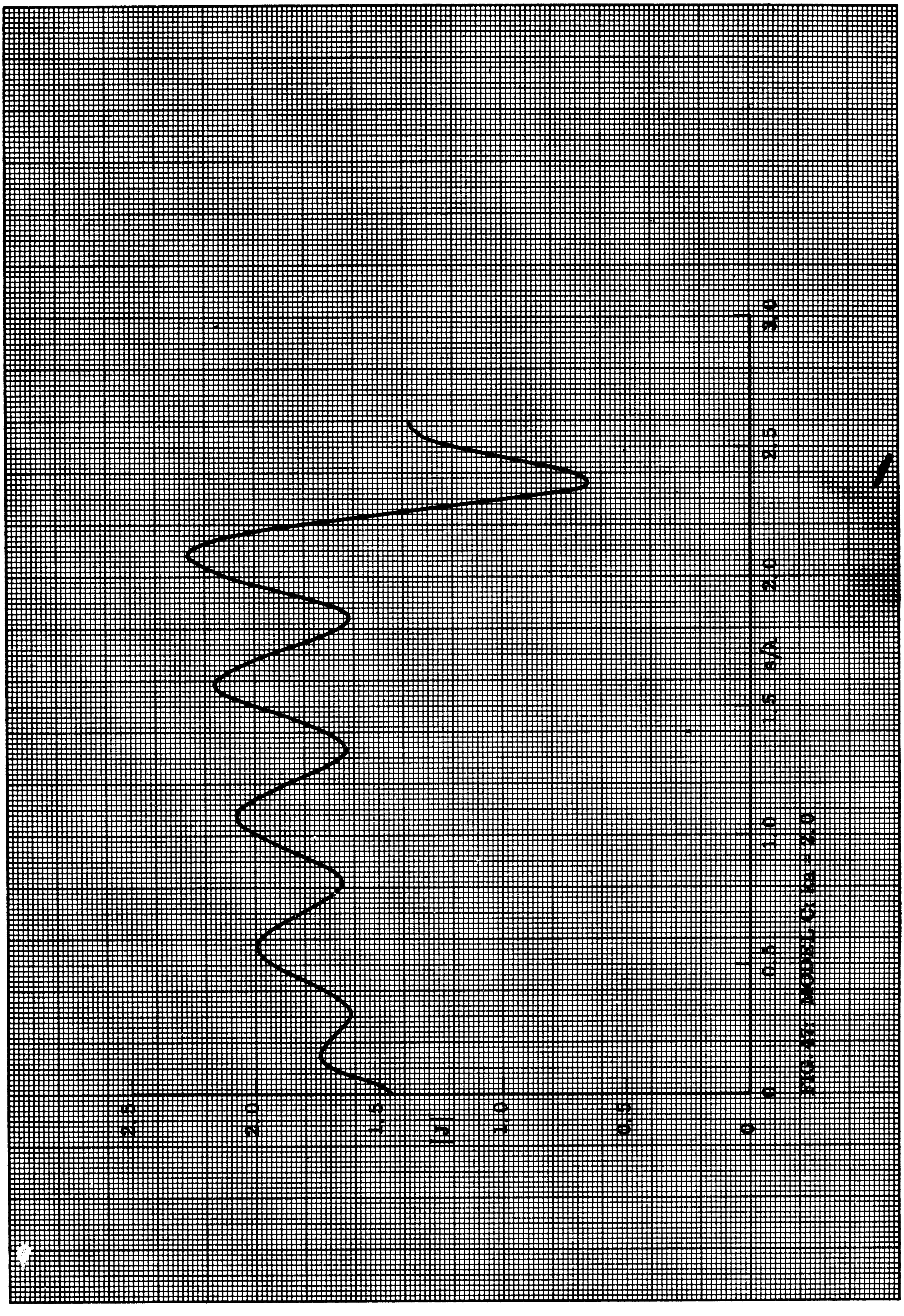



FIG. 43: MODEL C: ka = 2.0

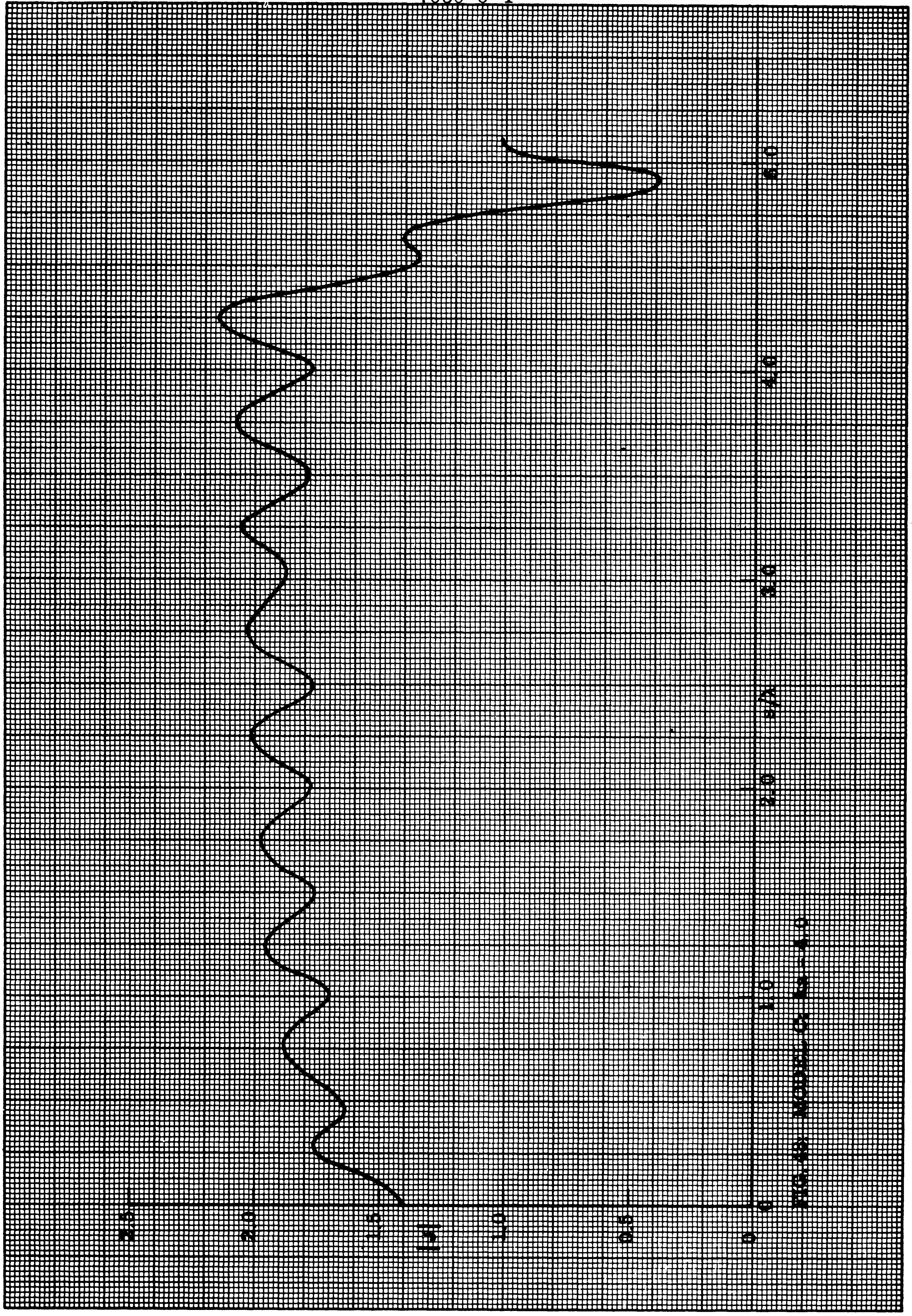



FIG. 45: MODE C, ka = 4.0

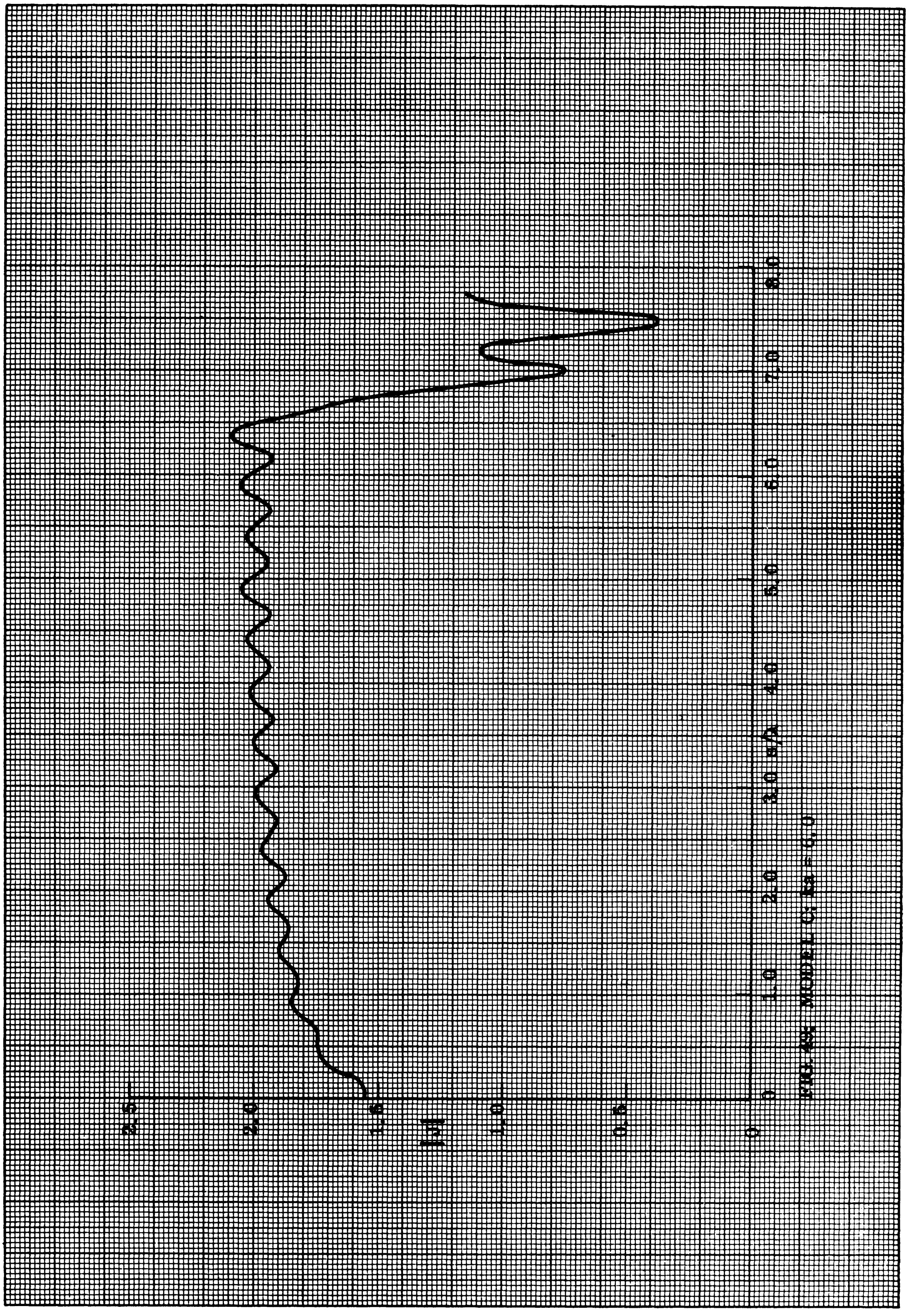



FIG. 49: MODEL C; ka = 6.0

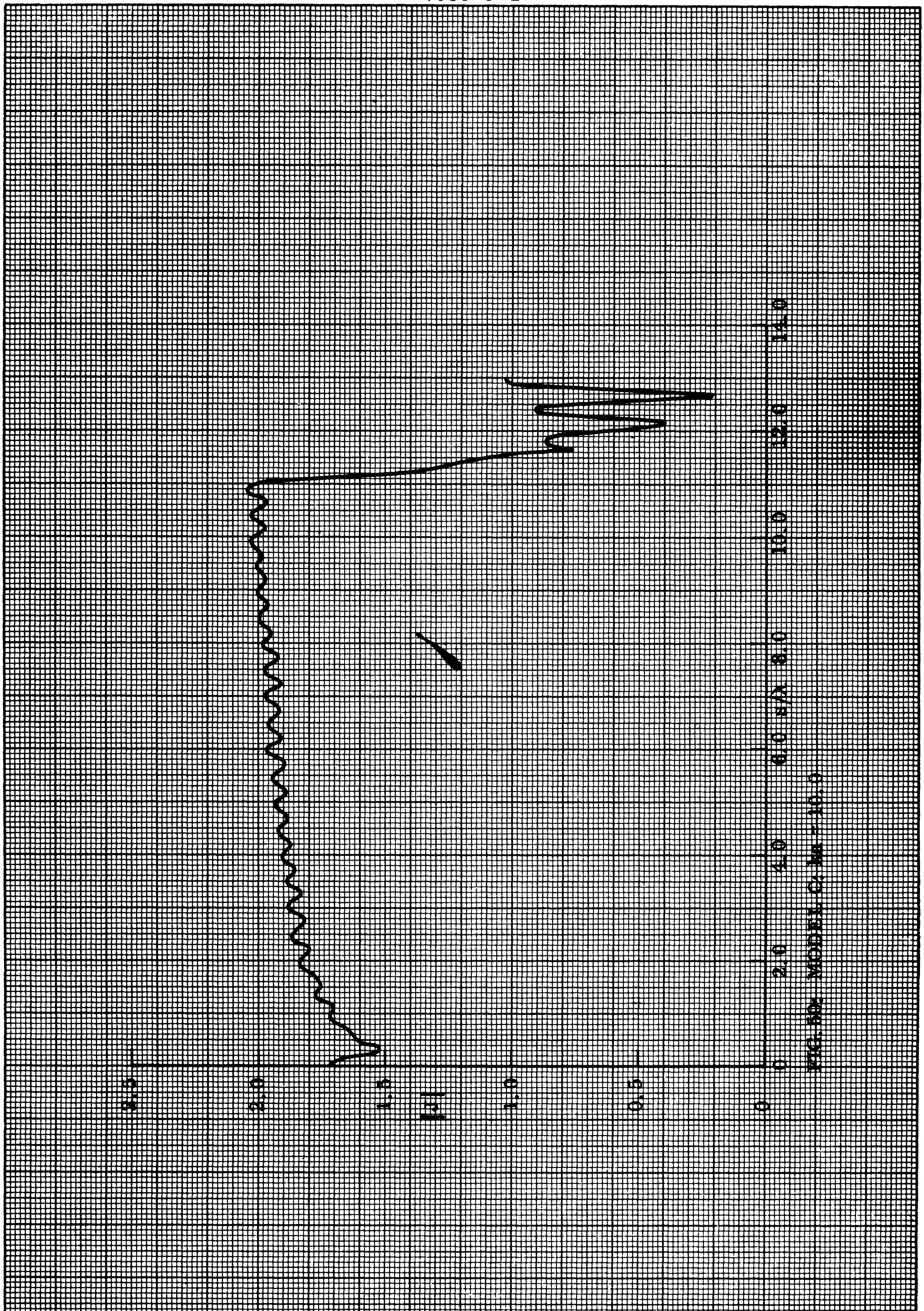



FIG. 50: MODEL C: ka = 10.0

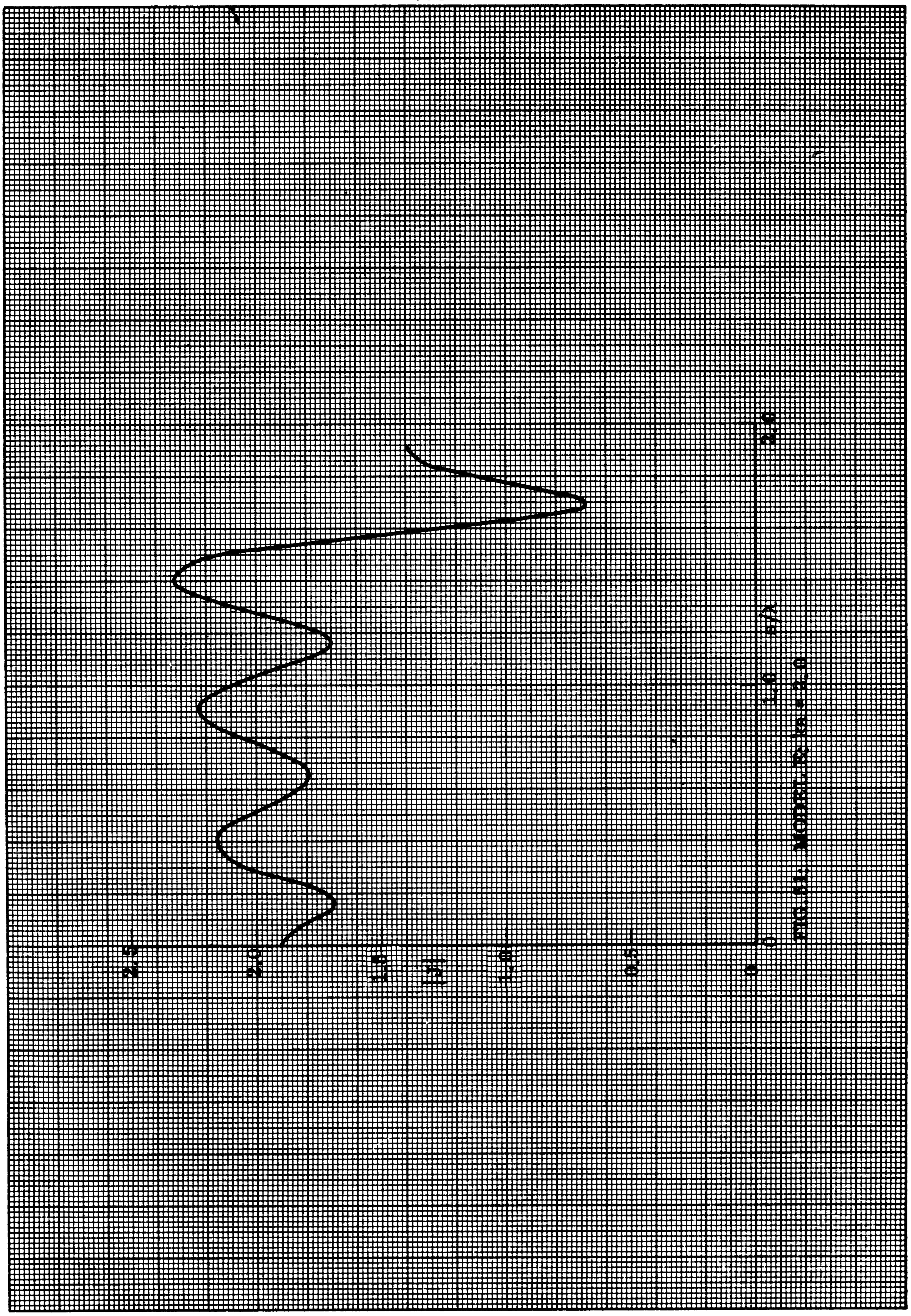
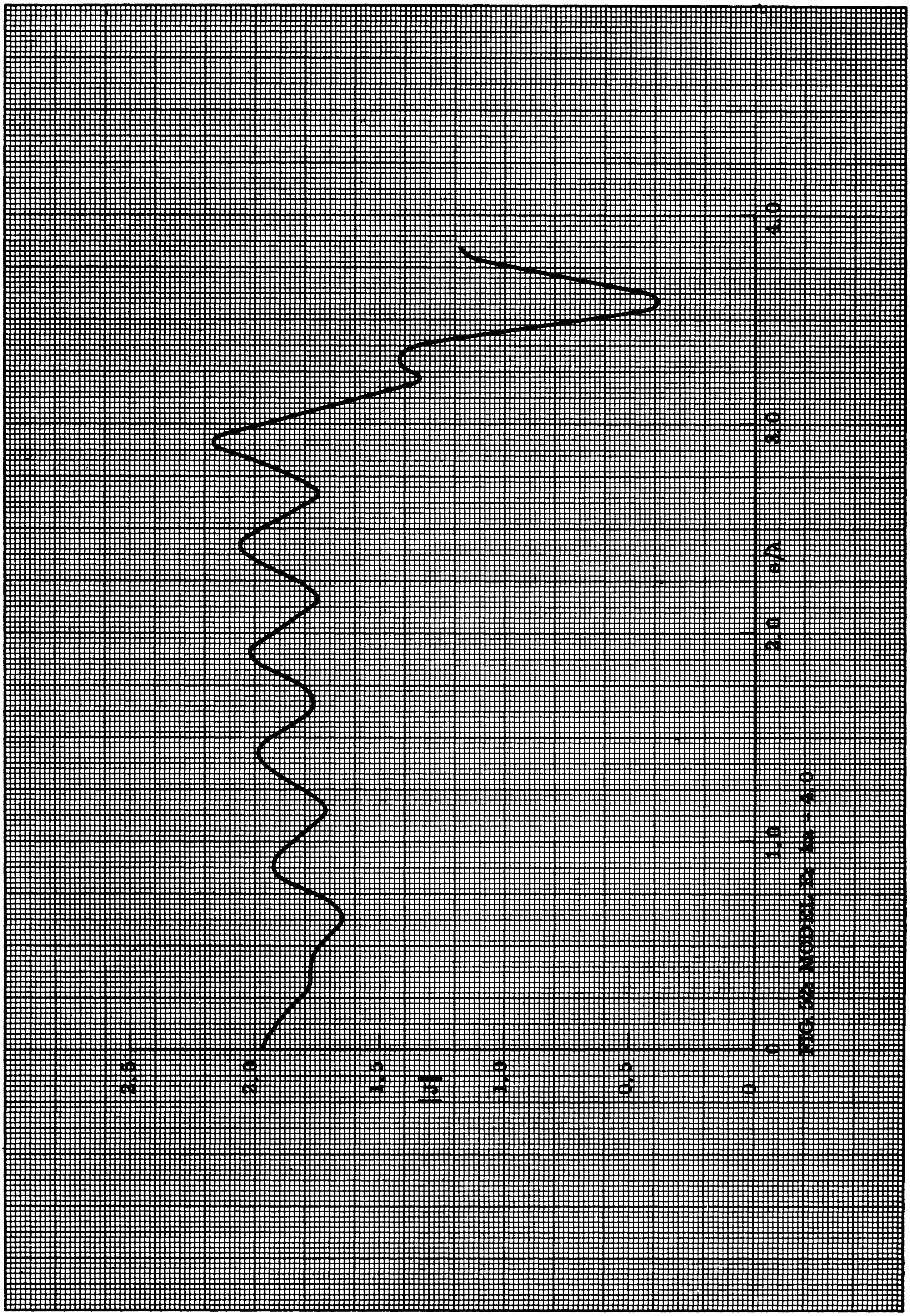
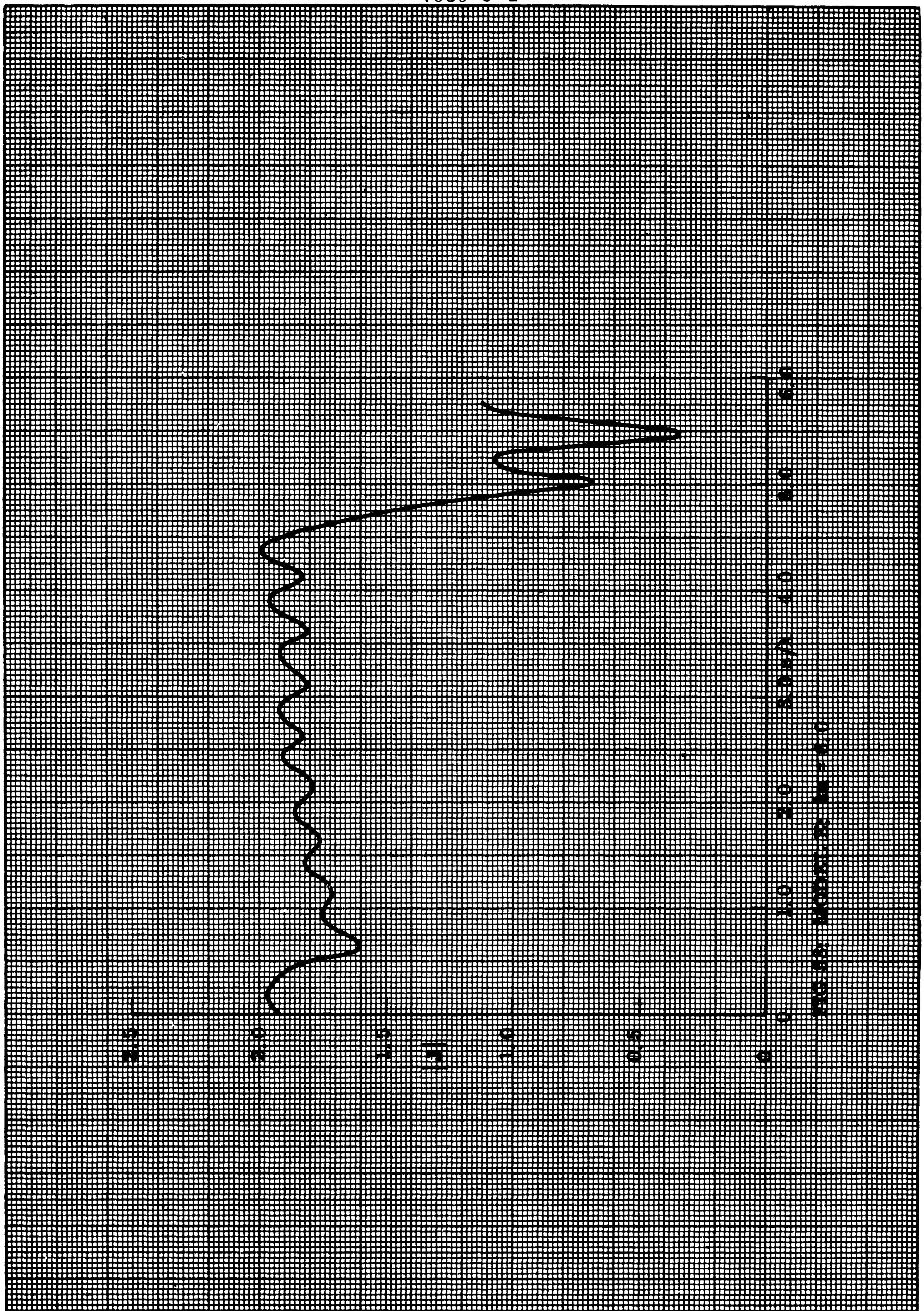



FIG. 31: MODEL B, ka = 2.0


2.5
2.0
1.5
1.4
1.0
0.5
0
0
1.0
2.0
s/λ
3.0
4.0


0
1.0
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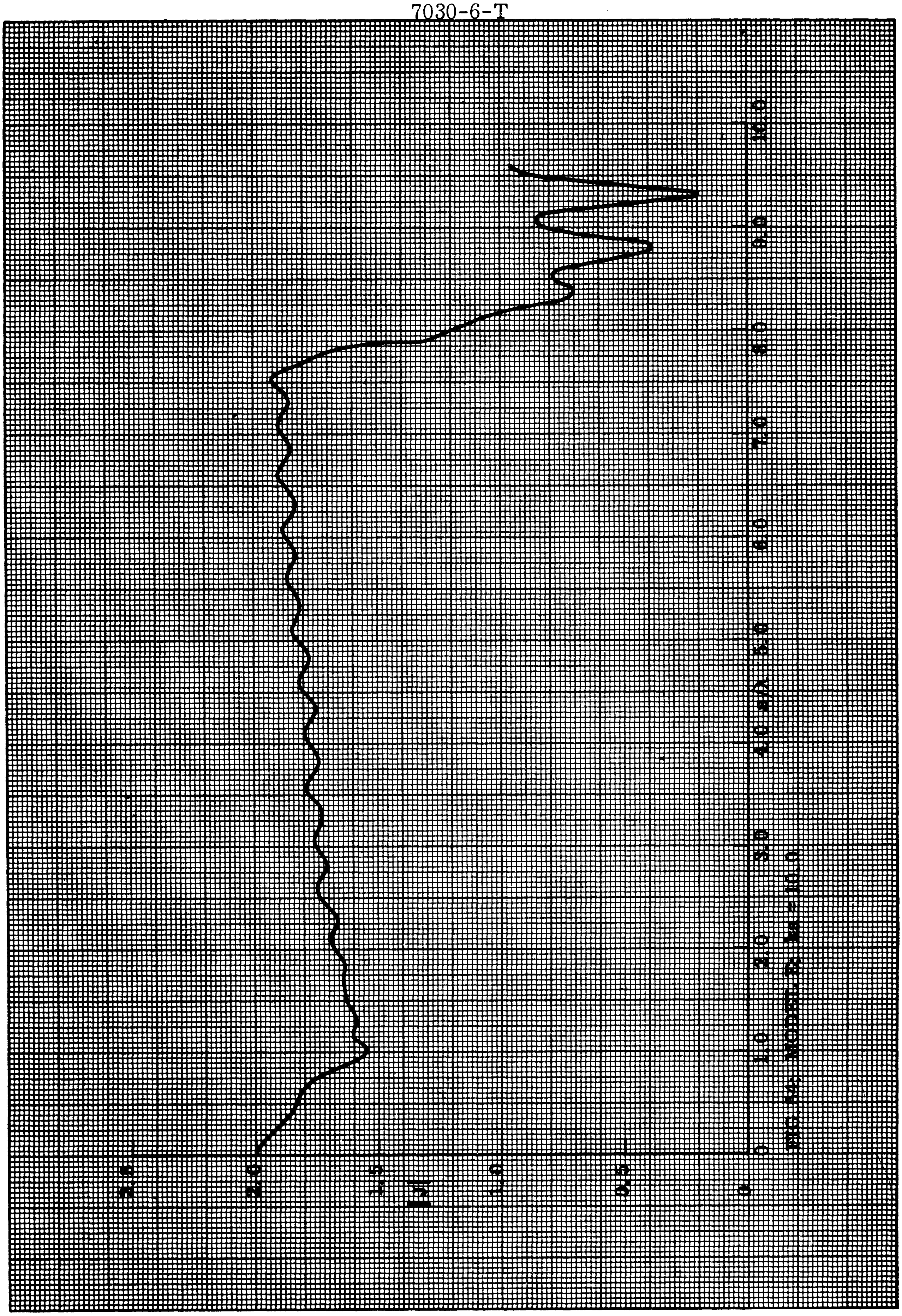
3.0
4.0
5.0
6.0
2.5
2.0
1.5
1.0
0.5
0


0
0.5
1.0
1.5
|E|
2.0
2.5
0
1.0
2.0
3.0
4.0 x/λ 5.0
6.0
7.0
8.0
9.0
10.0
FIG. 34. MODEL E, ka = 10.0

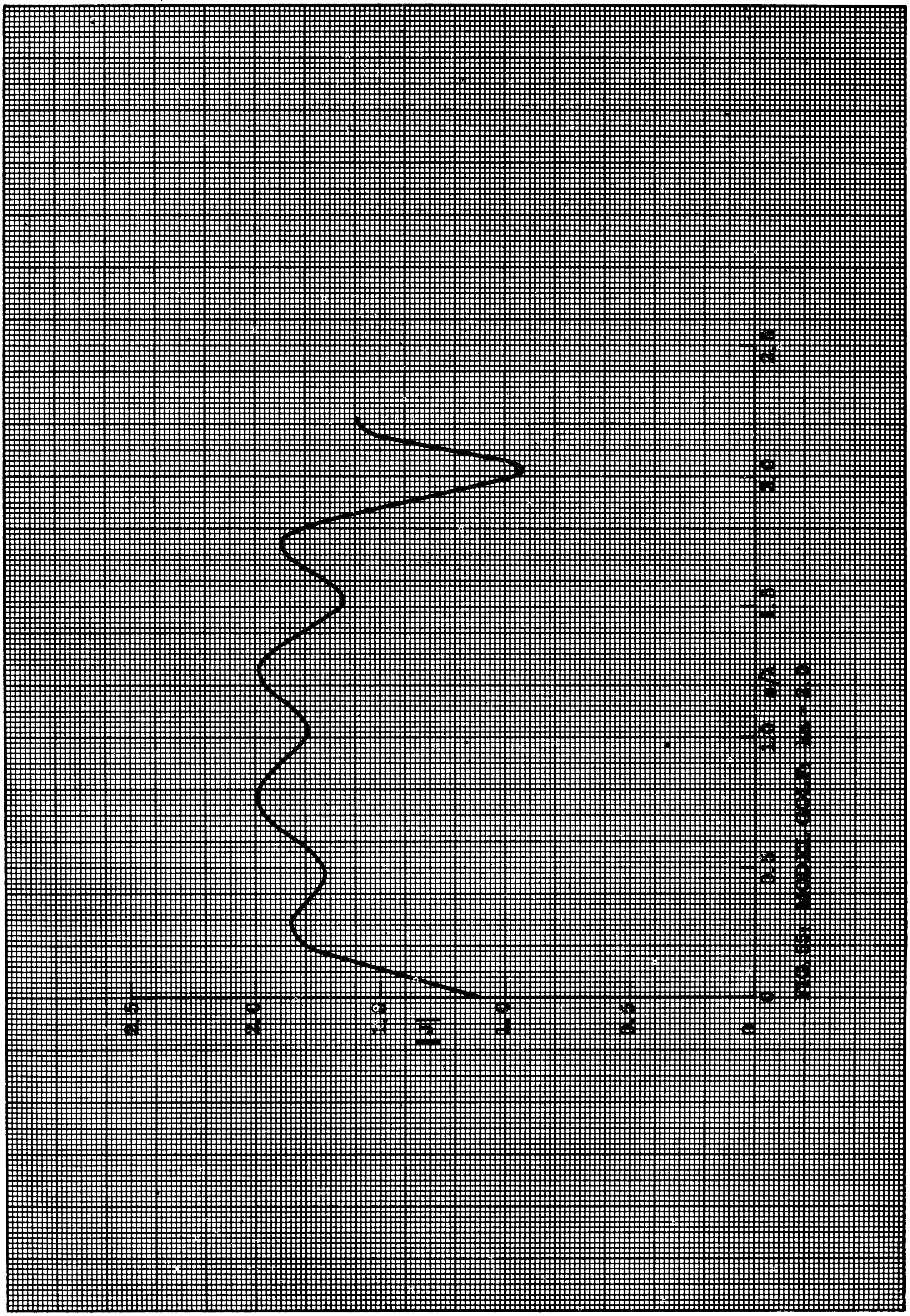



FIG. 65: MODEL GCL, ka = 2.5

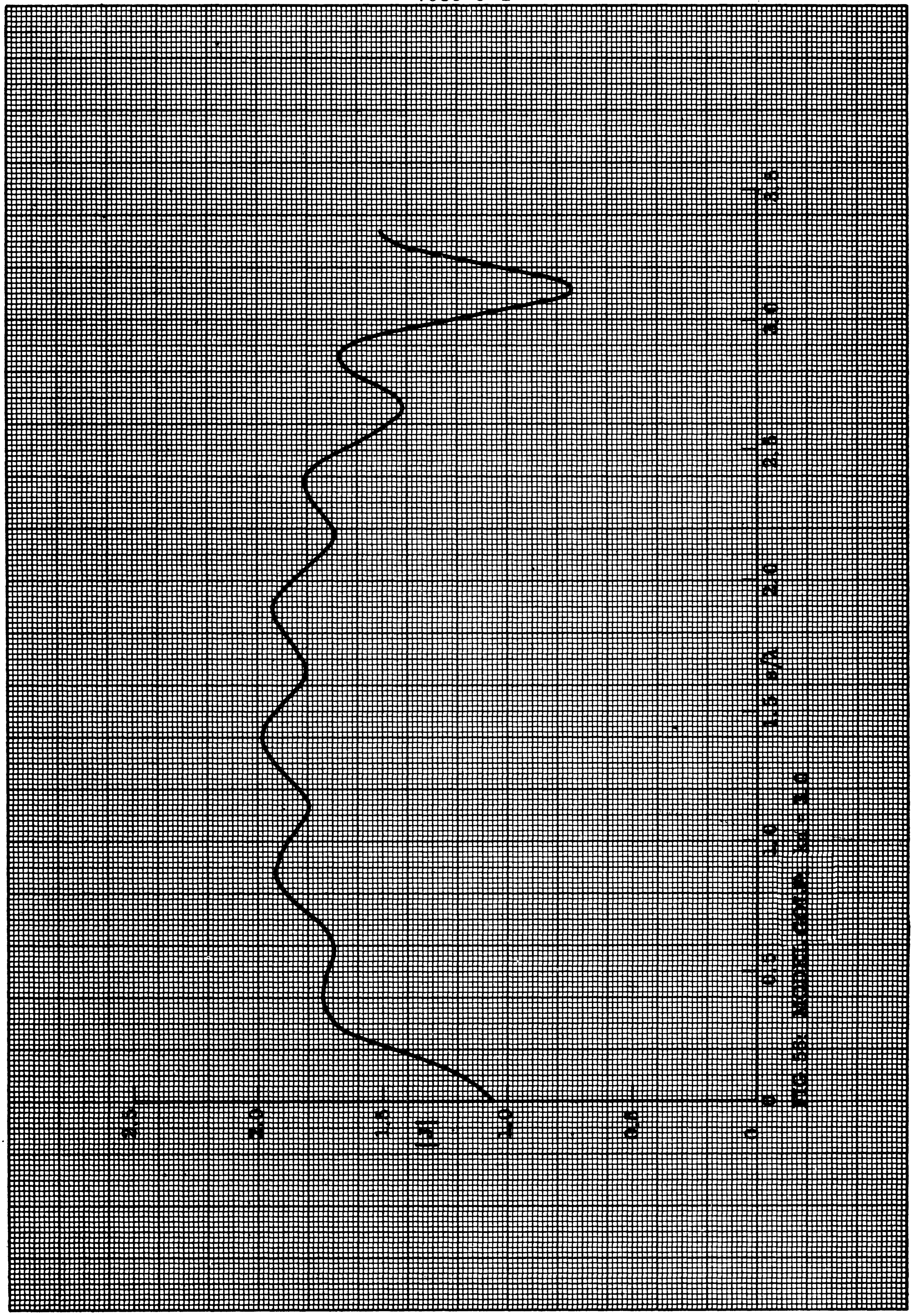
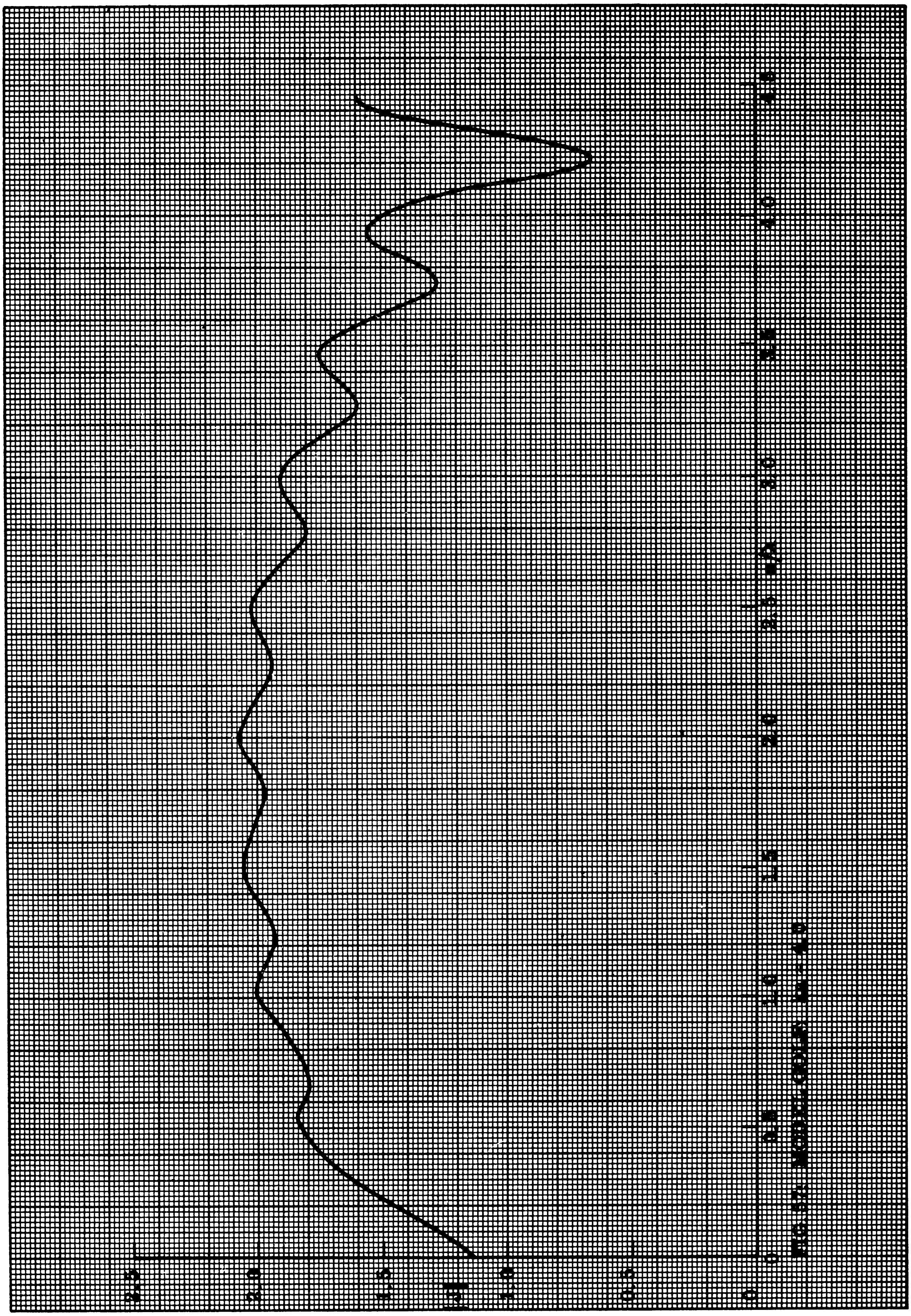
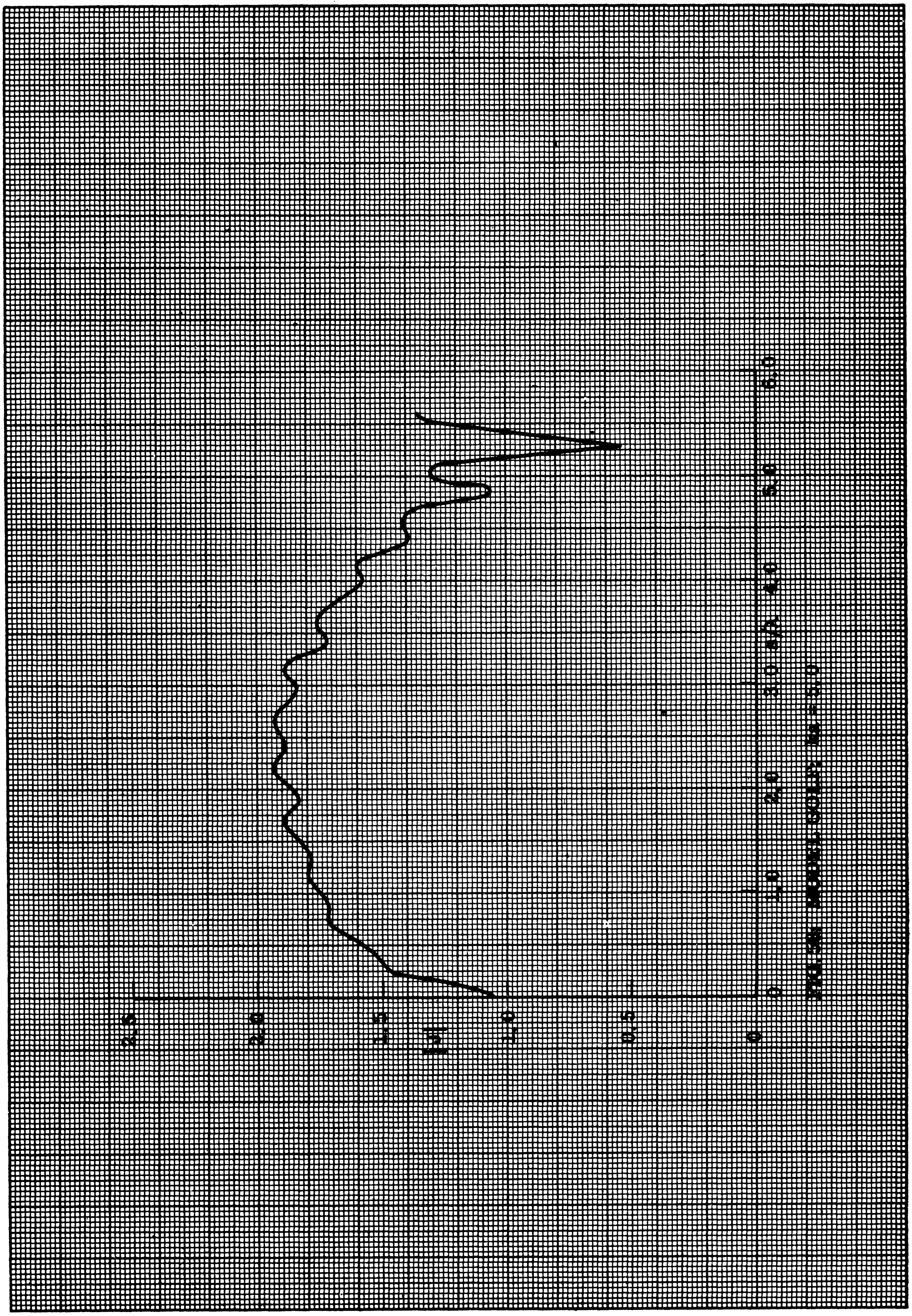



FIG. 58: MODEL CMLB, $ka = 3.0$


0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
0.5
1.0
1.5
2.0
2.5


0
1.0
2.0
3.0 d/λ
4.0
5.0
6.0
0
0.5
1.0
|E|
1.5
2.0
2.5

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Technical Report

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Senior, Thomas B. A.

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
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| December 1965 | 68 | 3 |

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13. ABSTRACT

In the course of a recent study of the currents excited on the surfaces of various metallic objects by an incident plane wave, the surface fields have been measured for a number of cone-sphere-like objects. The prime purpose in making these measurements was to provide a basis for the development and checking of formulae for predicting the scattering behavior through approximations applied to the surface fields, and the conclusions reached from analyses of the data are described elsewhere+. Although it is realized that the results of such 'interpretative' studies are not everybody's 'cup of tea', it is felt that the experimental data itself may be of somewhat wider interest, and could be of particular value to those concerned with the verification of digital computer methods for the derivation of the surface field from the appropriate integral equations. A selection of the surface field traces has therefore been assembled and is presented.

+Senior, T. B.A. and L. P. Zukowski (1966), "The Interpretation of Some Surface Field Data," The University of Michigan Radiation Laboratory Technical Report No. 7030-8-T. UNCLASSIFIED .

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