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The Diffraction of Polarized Light from a Laser by a Straight Edge

Robert Lawrence Berger

DIFFRACTION OF POLARIZED LIGHT · BERGER

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THE DIFFRACTION OF POLARIZED LIGHT FROM A LASER BY A STRAIGHT EDGE

By

Robert Lawrence Berger

A Thesis

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Physics

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1963

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

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Thesis committee

Howard C. Bryant
Chairman

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INTRODUCTION

The purpose of this experiment was to determine the effect of polarized light from a highly coherent light source on the diffraction pattern of a metalic straight edge. Two orientations of the polarized light were used: one with the $\vec{E}$ vector of the incident light parallel to the edge of the straight edge and the other with the $\vec{E}$ vector of the incident light perpendicular to the edge of the straight edge. The light source used in this experiment was a ruby laser (Maser Optics, Model 600). The laser produced a beam of very intense, highly coherent, polarized light. Since the light emitted by the laser is not continuous but is pulsed, the diffraction patterns were photographed. The film was developed, and the diffraction patterns were measured on a photodensitometer. In this way intensity as a function of distance perpendicular to the edge of the straight edge and measured along the diffraction pattern was obtained. This data was checked against the classical theoretical predictions.

DETERMINATION OF THE ORIENTATION OF THE $\vec{E}$ VECTOR OF THE LASER BEAM

In order to determine the orientation of the $\vec{E}$ vector of the laser beam with respect to the vertical (i.e., the perpendicular to the plane of the optical bench) a calcite crystal was used as an analyzer. Calcite is a bi-refringent

substance. If a narrow beam of light is incident on the crystal, the beam will be split up into two beams: the ordinary ray (O-ray) and the extraordinary ray (E-ray). These two beams will each be polarized at right angles to each other. A polaroid was used to determine the orientations of the O-ray and of the E-ray for a given orientation of the calcite crystal.

The laser and the calcite crystal were then lined up on the optical bench. The O-ray and the E-ray from the calcite crystal were focused by a lens onto film. The laser was then fired once for each 5° rotation of the calcite crystal. The rotation continued until the O-ray was completely cut out. At this position, 70° clock wise from the vertical, the $\vec{E}$ vector of the laser beam was at right angles to the orientation of the E vector of the O-ray.

METHOD OF OBTAINING THE DIFFRACTION PATTERNS

A red filter was placed on the optical bench in front of the laser in order to filter out any stray pumping light from the flash tubes used to excite the laser crystal. A Gaertner slit was placed in front of the filter and was used to produce cylindrical waves. The cylindrical waves are necessary to produce the diffraction pattern. The slit also cuts down the high intensity of the laser beam. The straight edge (a razor blade) was mounted on the same device that was used to rotate the calcite crystal. Then two exposures were made:

one with the edge of the straight edge parallel to the $\vec{E}$ vector of the laser beam and the other with the edge of the straight edge rotated so that it was perpendicular to the $\vec{E}$ vector of the laser beam. The positions of the Gaertner slit, the straight edge, and the film were carefully measured.

FILM AND DEVELOPER

Kodak Panalure paper was used to check out the set-ups before film, Kodak Panatomic-X, was used. The developer used for both the paper and the film was Kodak Dektol (one part stock solution to one part water for the paper and stock solution for the film). The fixer used for the paper was Mallinckrodt Jiffix (one part stock solution to one part water), and the fixer used for the film was Kodak Rapid Fix (stock solution). A running water rinse and a running water wash were used for both the paper and the film. The times used for developing, rinsing, fixing, and washing were those recommended by the manufacturer. However, in order to obtain a higher contrast between the light and dark fringes than is possible with Dektol, more experimentation with other developers is necessary. It is felt that a higher contrast would result in more accurate measurements of the fringes on the photodensitometer.

THE PHOTODENSITOMETER AND FILM CALIBRATION

A photodensitometer was used to measure the blackening of the film at the fringes and to measure the distance between the fringes. A standard grey plate was used to calibrate the photodensitometer. A grey plate is a photographic material subjected to a series of exposures, each greater by a constant factor (in our case the factor was approximately 2), than the preceding exposure. Each exposure on the grey plate gave an ammeter reading (i) on the photodensitometer. It was assumed that the photocurrent is proportional to the light intensity and that the amplifier is linear. The intensity of the light that produced the first exposure on the grey plate was taken as I_0. The intensities of the light that produced the subsequent exposures were taken as $I_1, I_2, \ldots, I_n$. The relative intensities (I/I_0) of the exposures were then taken as the ratio of the ammeter reading of a given zone to the ammeter reading of the first zone (i'/i_0').

The grey plate was photographed by the same light used to produce the diffraction patterns. The film was developed, and the photographed grey plate was read by the photodensitometer. Again each zone produced an ammeter reading ($i_0, i_1, i_2, \ldots, i_n$ for $n+1$ different exposures). The ammeter reading of the first exposure was taken as i_0. Hence a plot of i/i_0 versus I/I_0 was established from this data. This curve calibrated the film.

However, it was necessary to extrapolate the curve outside the region that included the data points. Thus a "D-log E" curve was plotted. D is the density of the silver deposit in the film, and E is the exposure of the film. D is defined as

$$D = \log \frac{1}{T}$$

where T, the transmission, is defined as

$$T = \frac{\text{transmitted light}}{\text{incident light}}$$

and E is defined as

$$E = I/I_0$$

This curve has a long linear portion. Thus the extropolated portion of the film calibration curve was obtained from the "D-log E" plot.

MEASUREMENT OF THE DIFFRACTION PATTERNS

BY THE PHOTODENSITOMETER

When the diffraction patterns were read by the photodensitometer, the ammeter reading (i) was recorded for each point. It was found that ammeter readings had an upper limit ($i_{SATURATION}$). Thus an ammeter reading (i_0) was chosen for complete transmission, where $i_0 < i_{SATURATION}$. Then i/i_0 was calculated for each point. I/I_0 was then obtained for each point by using the film calibration curve.

However, the meter range was not large enough to measure with any precision the entire diffraction pattern for the original setting of the photodensitometer lamp (at this original

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and E is defined as

$$E = I / I_o$$

This curve has a long linear portion. Thus the extrapolated portion of the film calibration curve was obtained from the "D-Log E" plot.

MEASUREMENT OF THE DIFFRACTION PATTERNS BY THE PHOTODENSITOMETER

When the diffraction patterns were read by the photodensitometer, the ammeter reading (i) was recorded for each point. It was found that ammeter readings had an upper limit ($i_{SATURATION}$). Thus an ammeter reading (i_o) was chosen for complete transmission, where $i_o < i_{SATURATION}$. Then i / i_o was calculated for each point. I / I_o was then obtained for each point by using the film calibration curve.

However, the meter range was not large enough to measure with any precision the entire diffraction pattern for the original setting of the photodensitometer (at this original

setting the ammeter reading $i_0 < i_{SATURATION}$). Thus the ammeter readings were begun at i_0 ($i_0 < i_{SATURATION}$) and continued until almost maximum deflection of the ammeter needle. At that point the photodensitometer lamp was made brighter (i_{LAMP} increased) thus establishing a new $i_0 (i_0'')$. Since T for these two points is the same,

$$\frac{i}{i_0} = \frac{i''}{i_0''},$$

$$i_0'' = i'' \frac{i_0}{i},$$

where i'' is the new ammeter reading for a given point. Thus the ammeter needle is returned to its minimum position, and the measurements can continue.

THEORETICAL EQUATIONS

When the values of I/I_0 for all the points were established, both sets of data were normalized to 1 and plotted.

The theoretical results were plotted using

$$I = x^2 + y^2$$

$$l = v \sqrt{\frac{b \lambda (a+b)}{2a}}$$

where

I - intensity

x - abscissa of the Cornu spiral

y - ordinate of the Cornu spiral

l - distance along the diffraction pattern (perpendicular to the straight edge)

$v = v(x,y)$, distance along the Cornu spiral

a - distance from Gaertner slit to straight edge

b - distance from straight edge to film

λ - wavelength of light used

The theoretical relative intensities were also normalized to 1 using I_{max} as I_0.

Fresnel scalar theory also predicts that the distance from the geometric shadow to the n^{th} minimum is given by

$$d_{min} = A_n \sqrt{\frac{b\lambda(a+b)}{2a}}$$

where

$$A_n \approx \left(\frac{7}{2} + 4n\right)^{1/2}.$$

The distance from the geometric shadow to the n^{th} maximum is given by

$$d_{max} = B_n \sqrt{\frac{b\lambda(a+b)}{2a}}$$

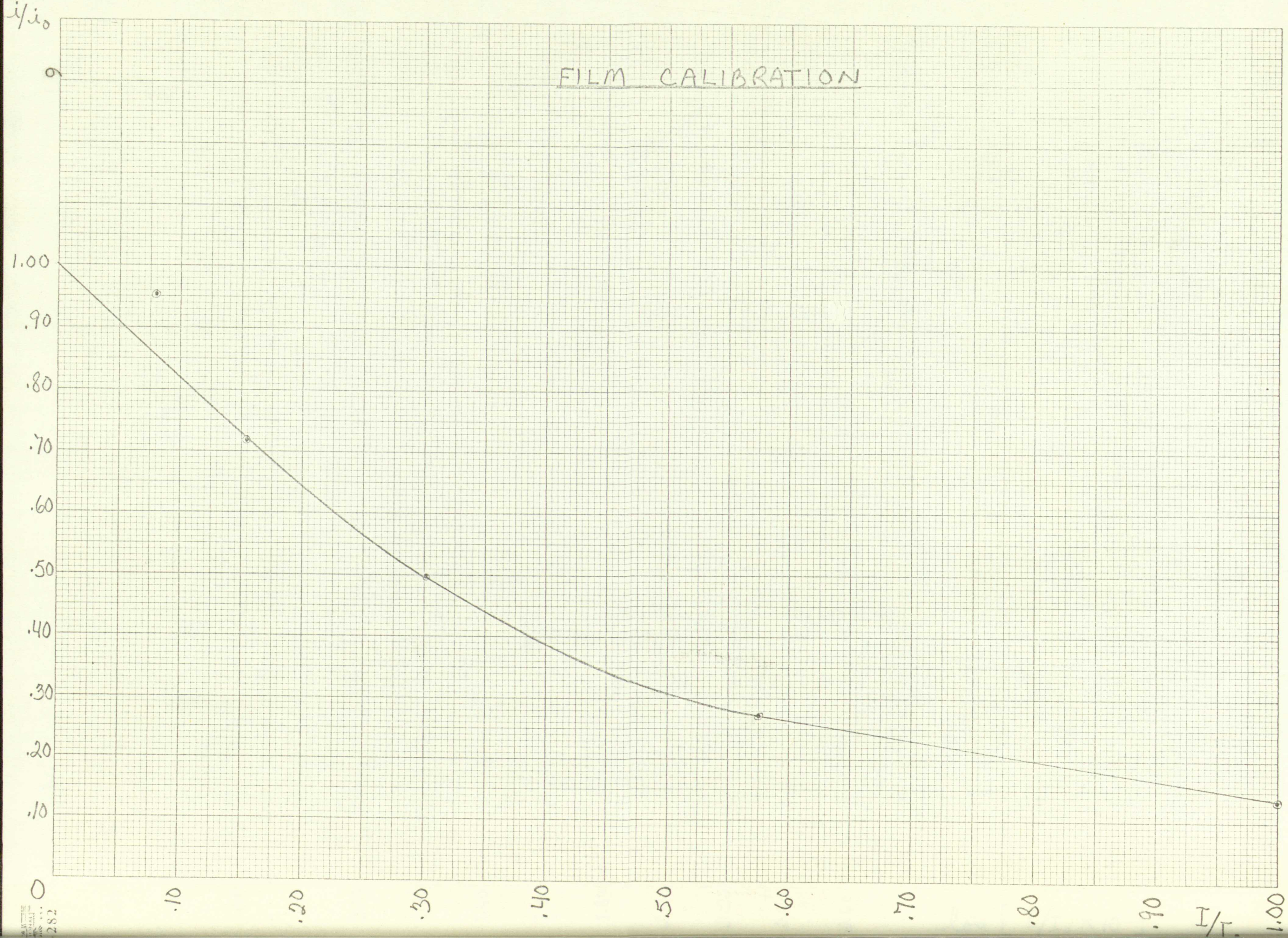
where

$$B_n \approx \left(\frac{3}{2} + 4n\right)^{1/2}.$$

It is easily seen that $\sqrt{\frac{b\lambda(a+b)}{2a}}$ represents the slope (m) of d_{min} versus A_n and of d_{max} versus B_n. Thus these curves were plotted and the slopes (m) were determined for both the parallel orientation and the perpendicular orientation of the $\vec{E}$ vector of the laser beam with respect to the edge of the straight edge. The wavelength (λ) was then calculated from

$$\lambda = \frac{2a}{b(a+b)} m^2 .$$

Thus using the slopes (m) obtained for d_{min} versus A_n and d_{max} versus B_n for the parallel orientation and d_{min} versus A_n for the perpendicular orientation, the wavelength (λ) was found to be 6954×10^{-8} cm. with an estimated experimental error of approximately 1%, since the slope (m) cannot be determined better than 1/2%. Using the slope (m) obtained for d_{max} versus B_n for the perpendicular orientation, the wavelength (λ) was found to be 7003×10^{-8} cm. also with an estimated experimental error of approximately 1%. The manufacturer stated that the wavelength of the laser light was 6943×10^{-8} cm.



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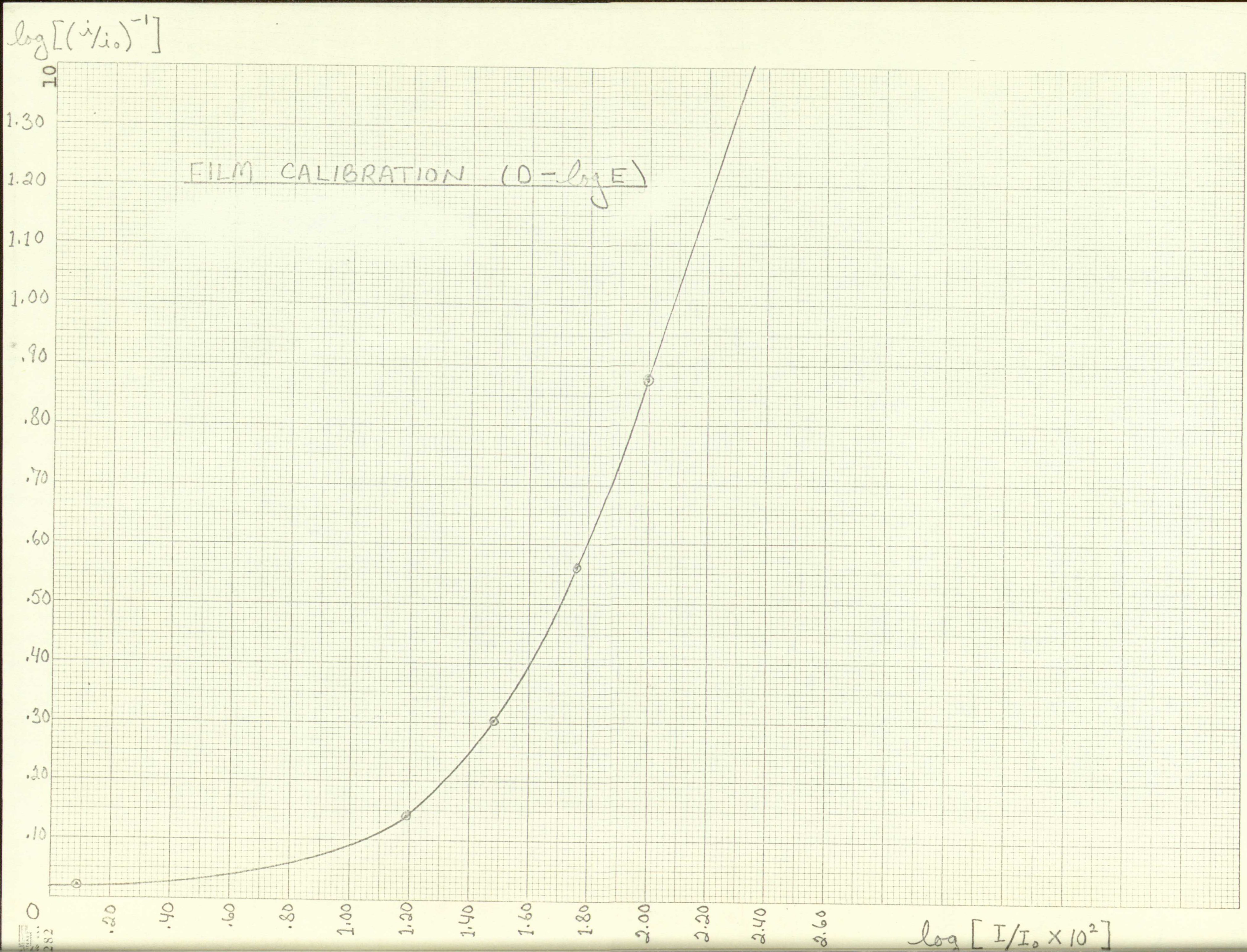

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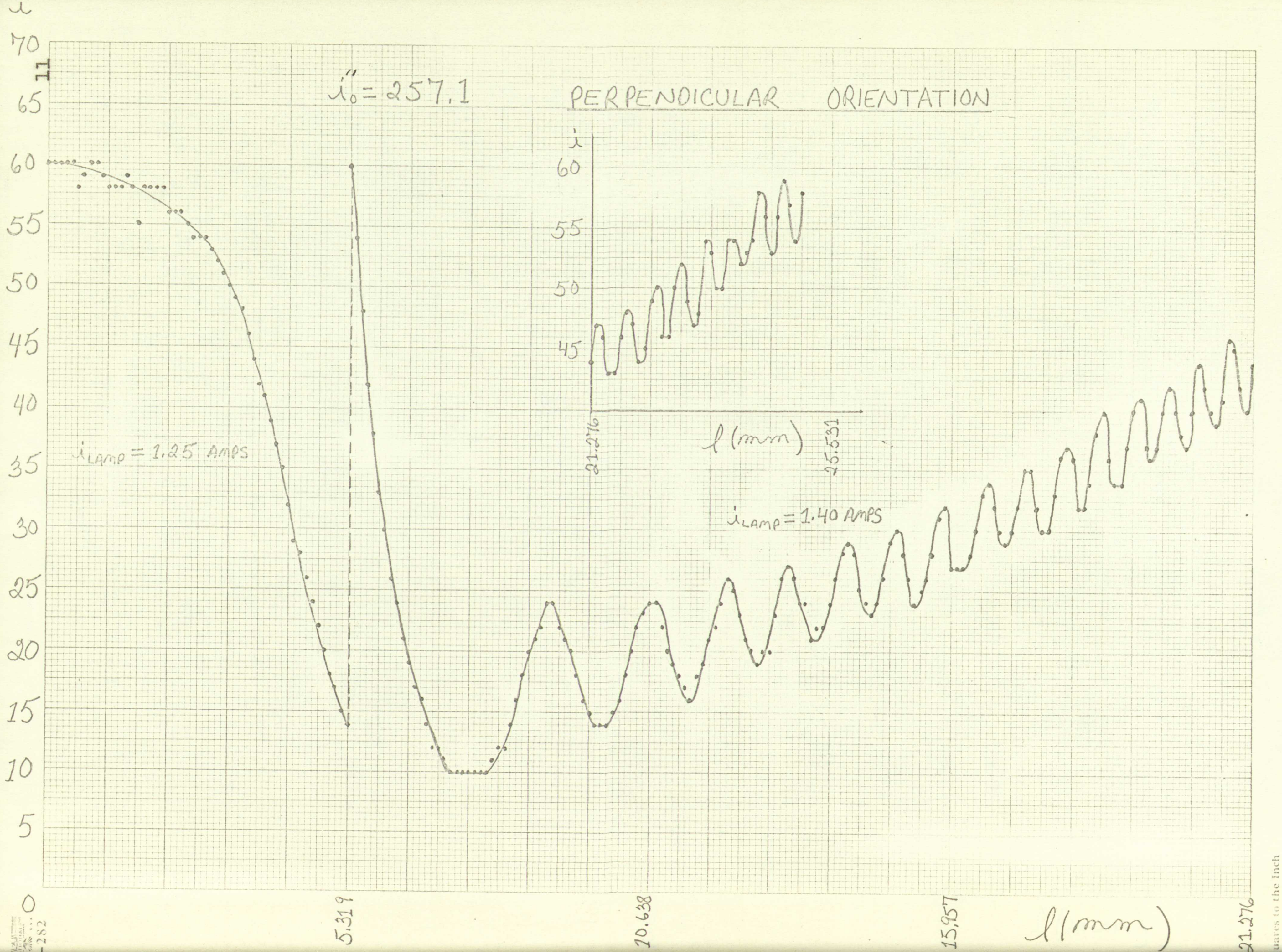
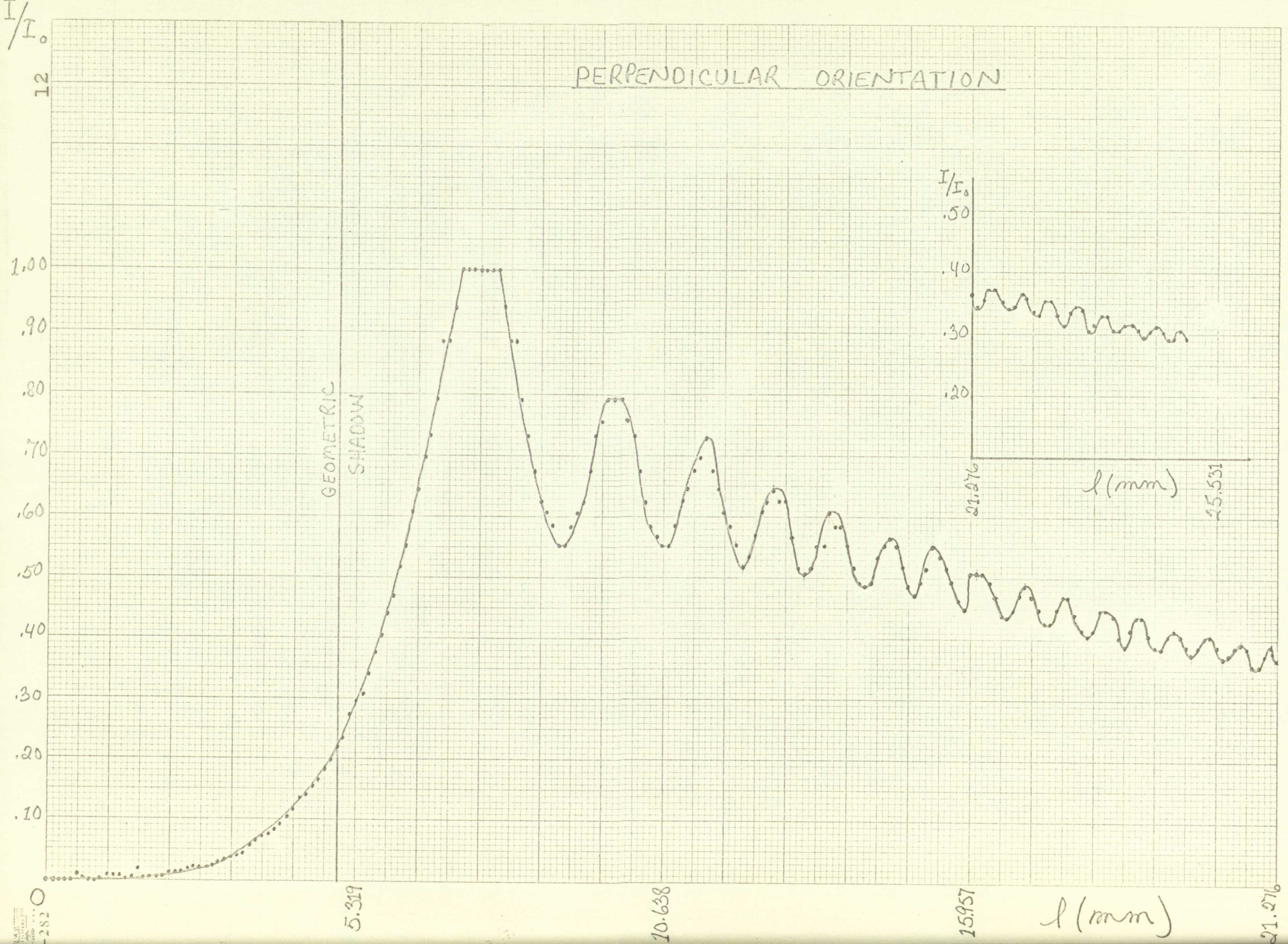


$i_0'' = 257.1$
PERPENDICULAR ORIENTATION
$i_{LAMP} = 1.25$ AMPS
$i_{LAMP} = 1.40$ AMPS
i
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
5.319
10.638
15.957
21.276
l (mm)
21.276
25.531



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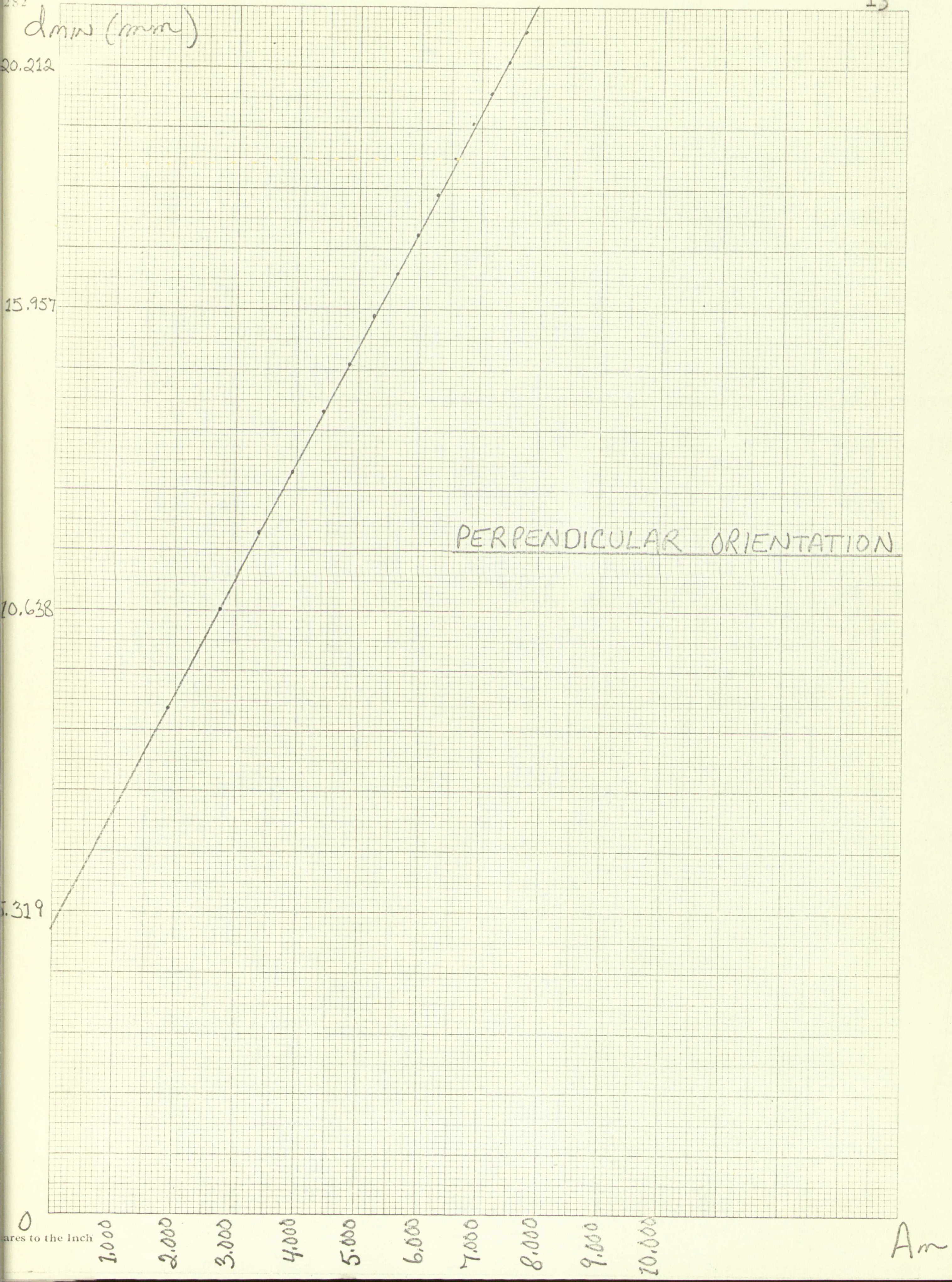
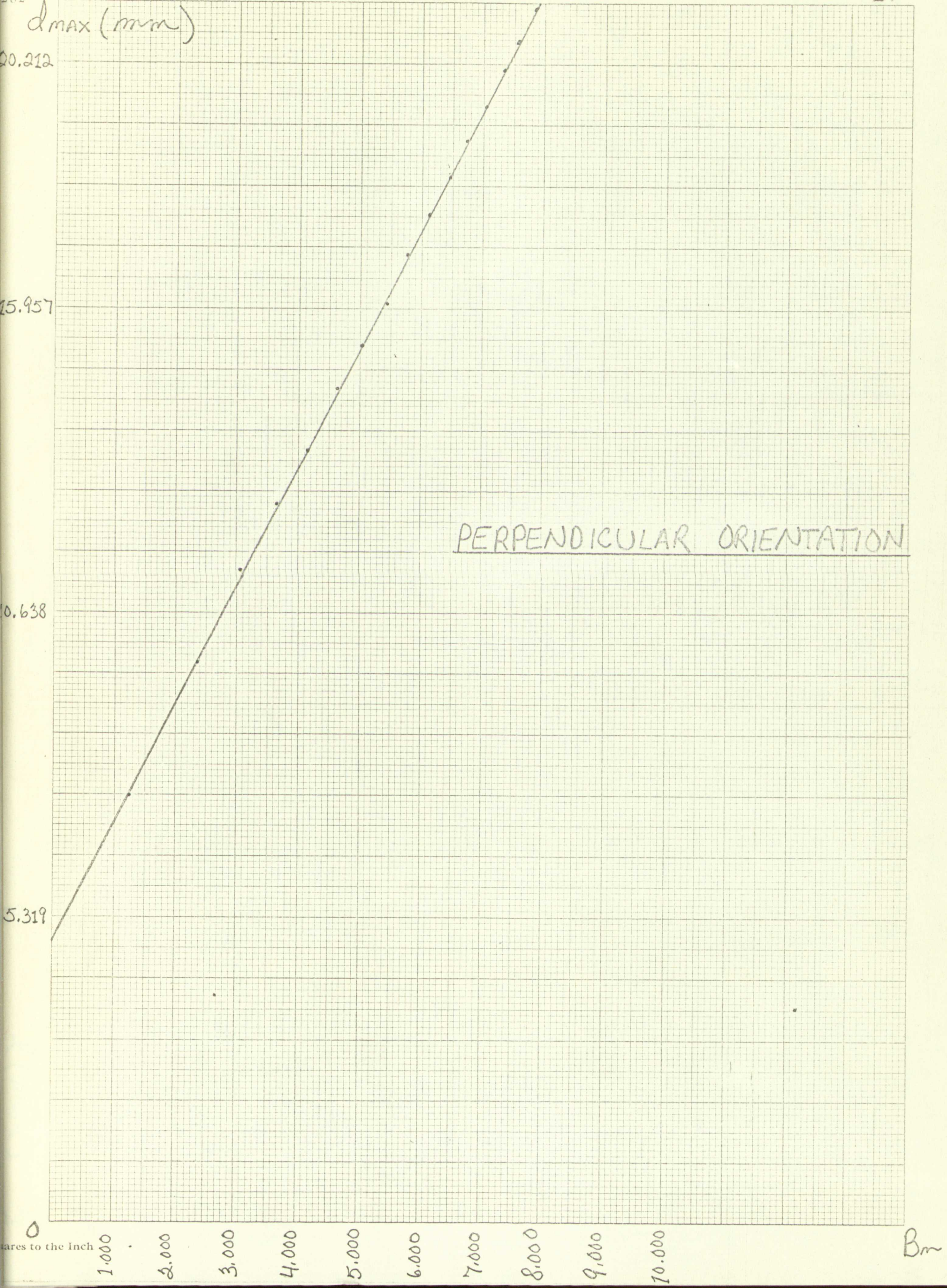
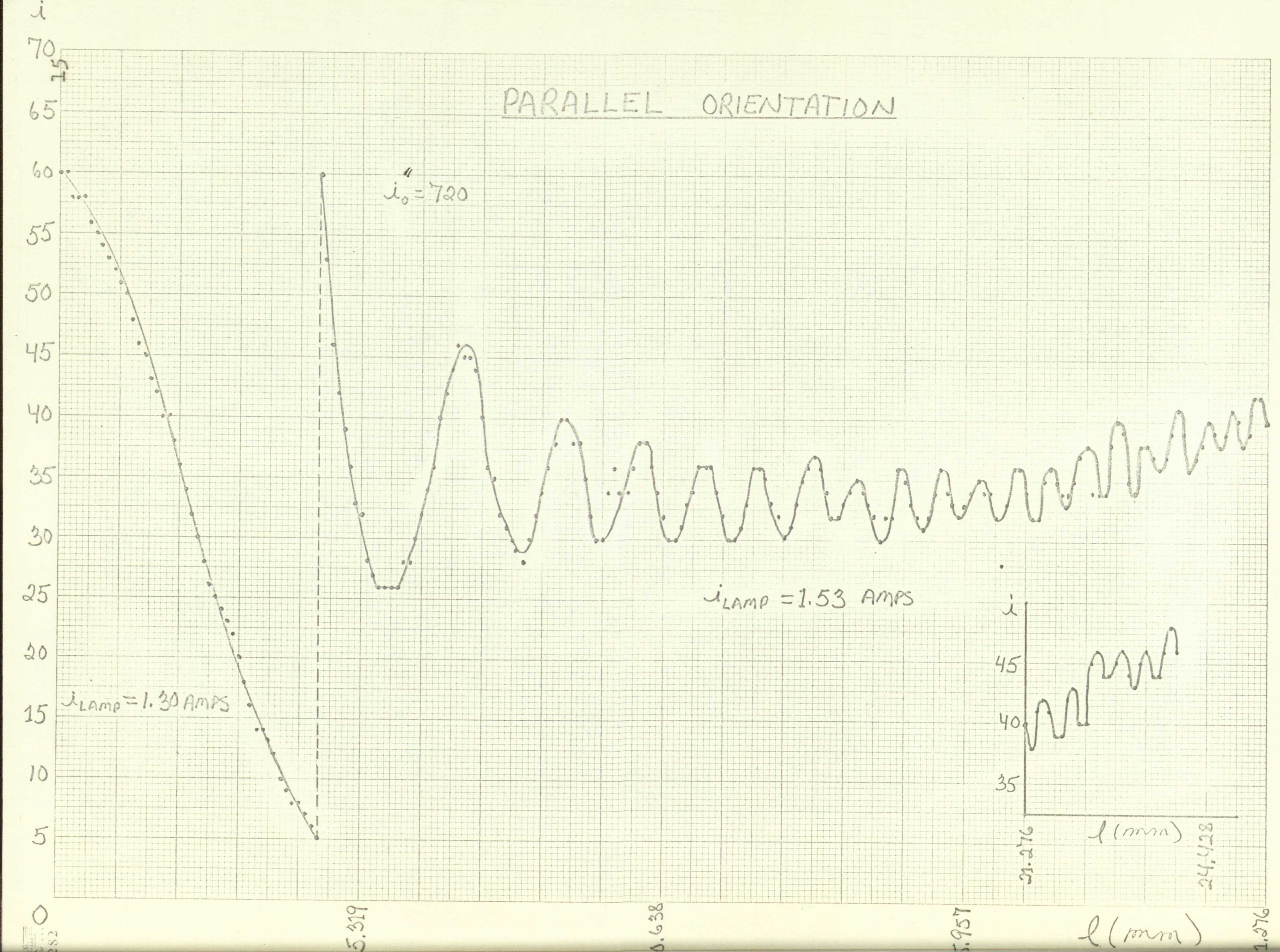
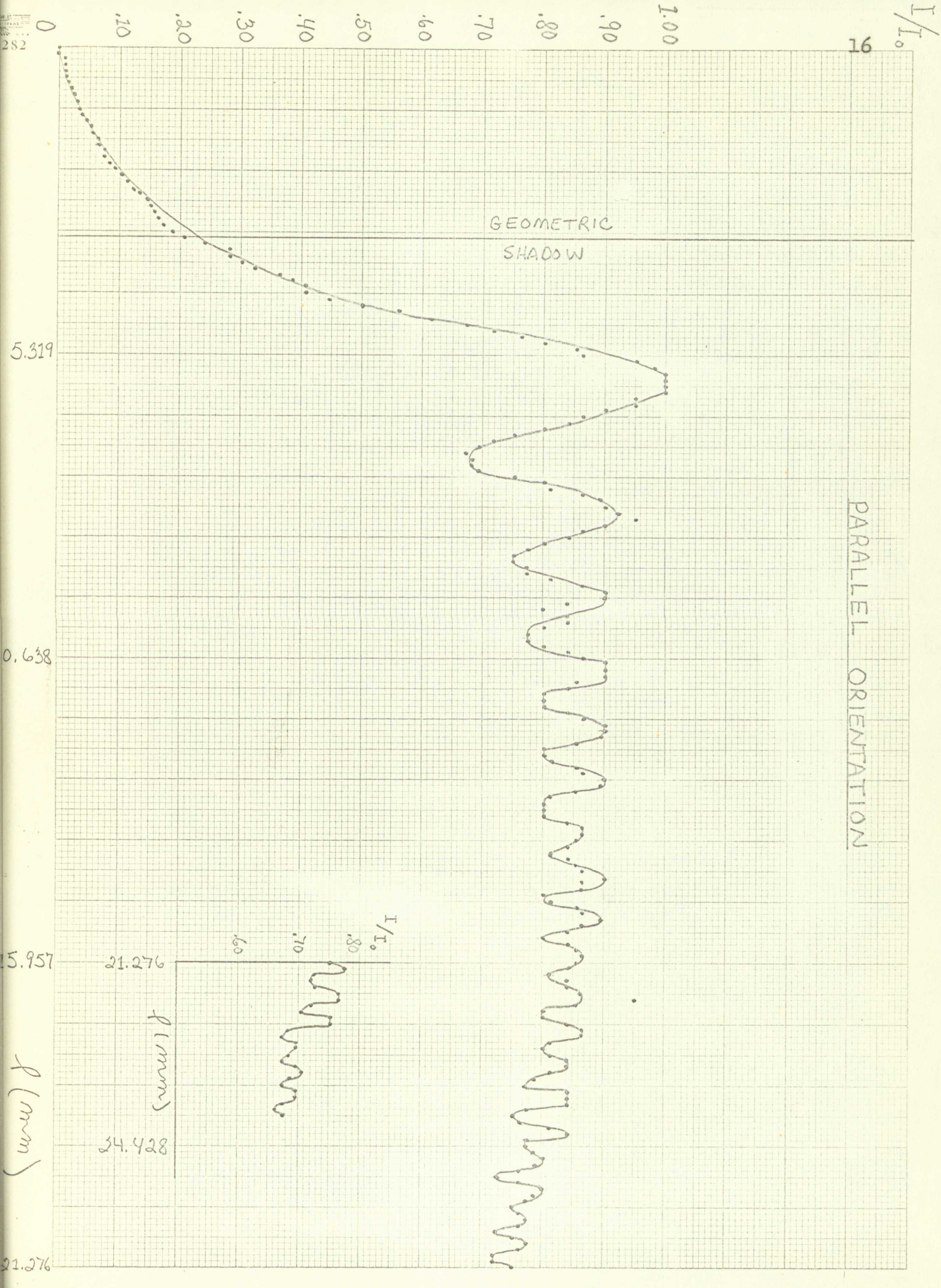
quares to the Inch

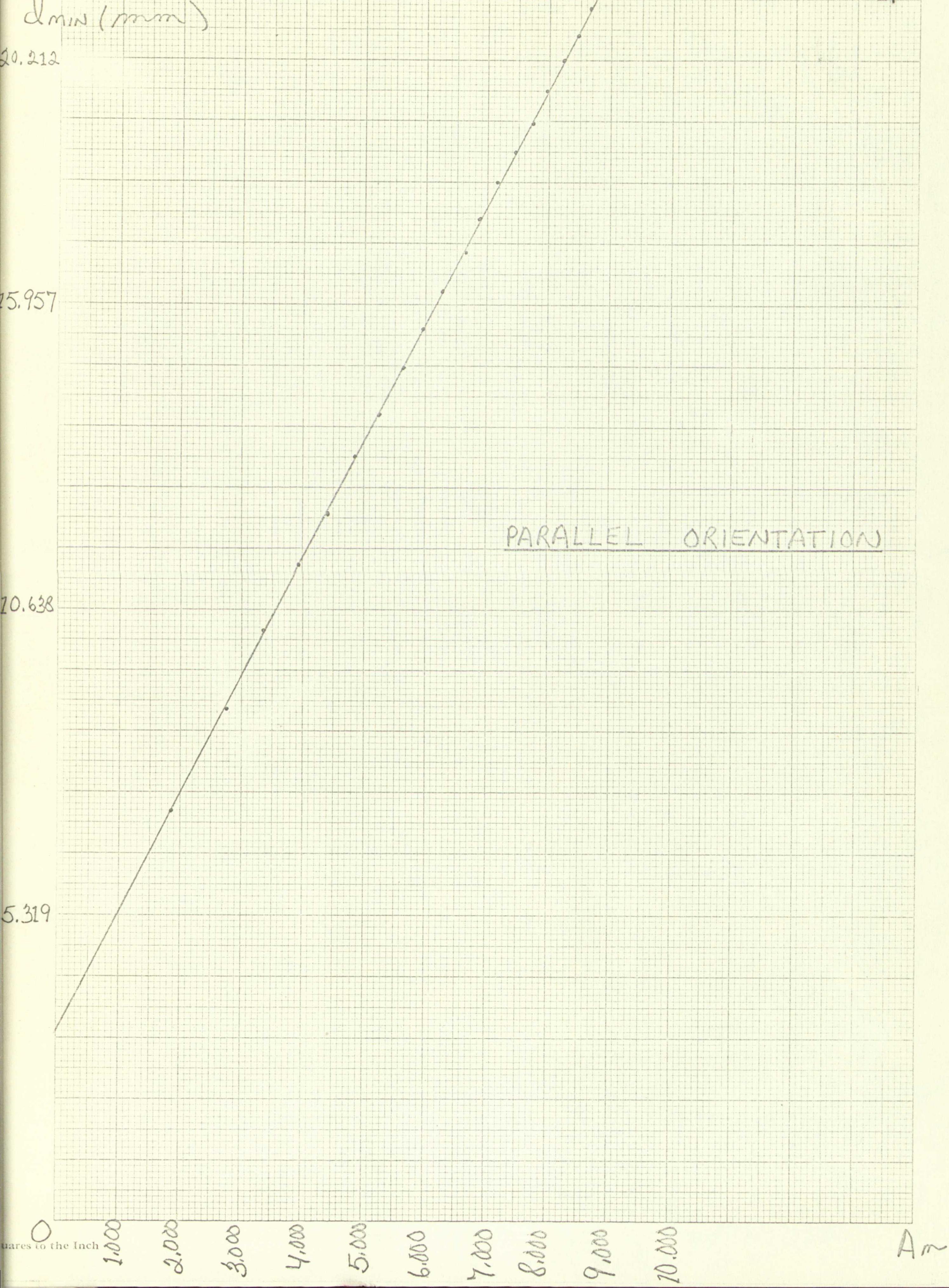

dmin (mm)
20.212
15.957
10.638
5.319
0
PERPENDICULAR ORIENTATION
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
Am


dmax (mm)
20.212
15.957
0.638
5.319
0
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
Bm
PERPENDICULAR ORIENTATION

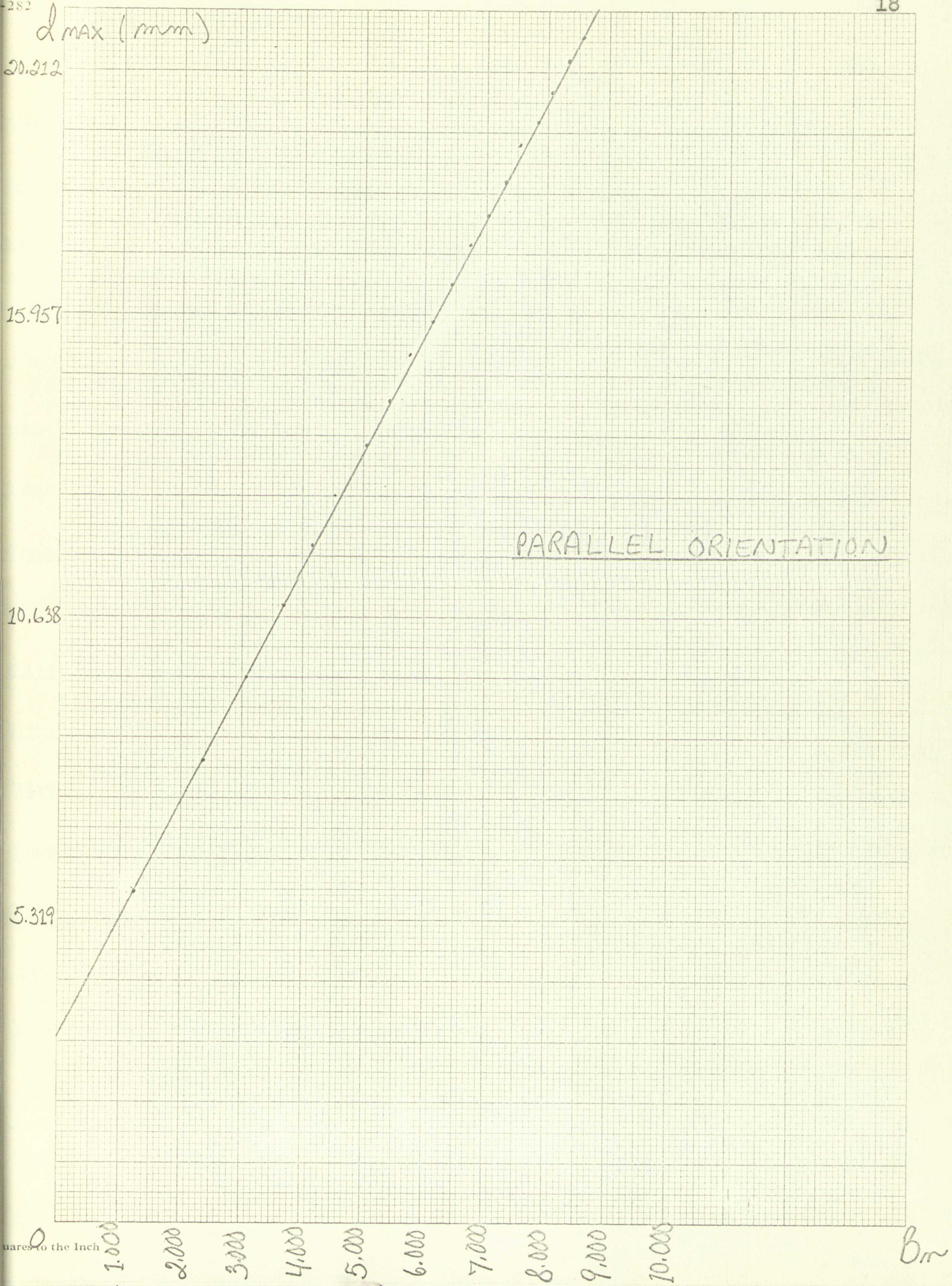


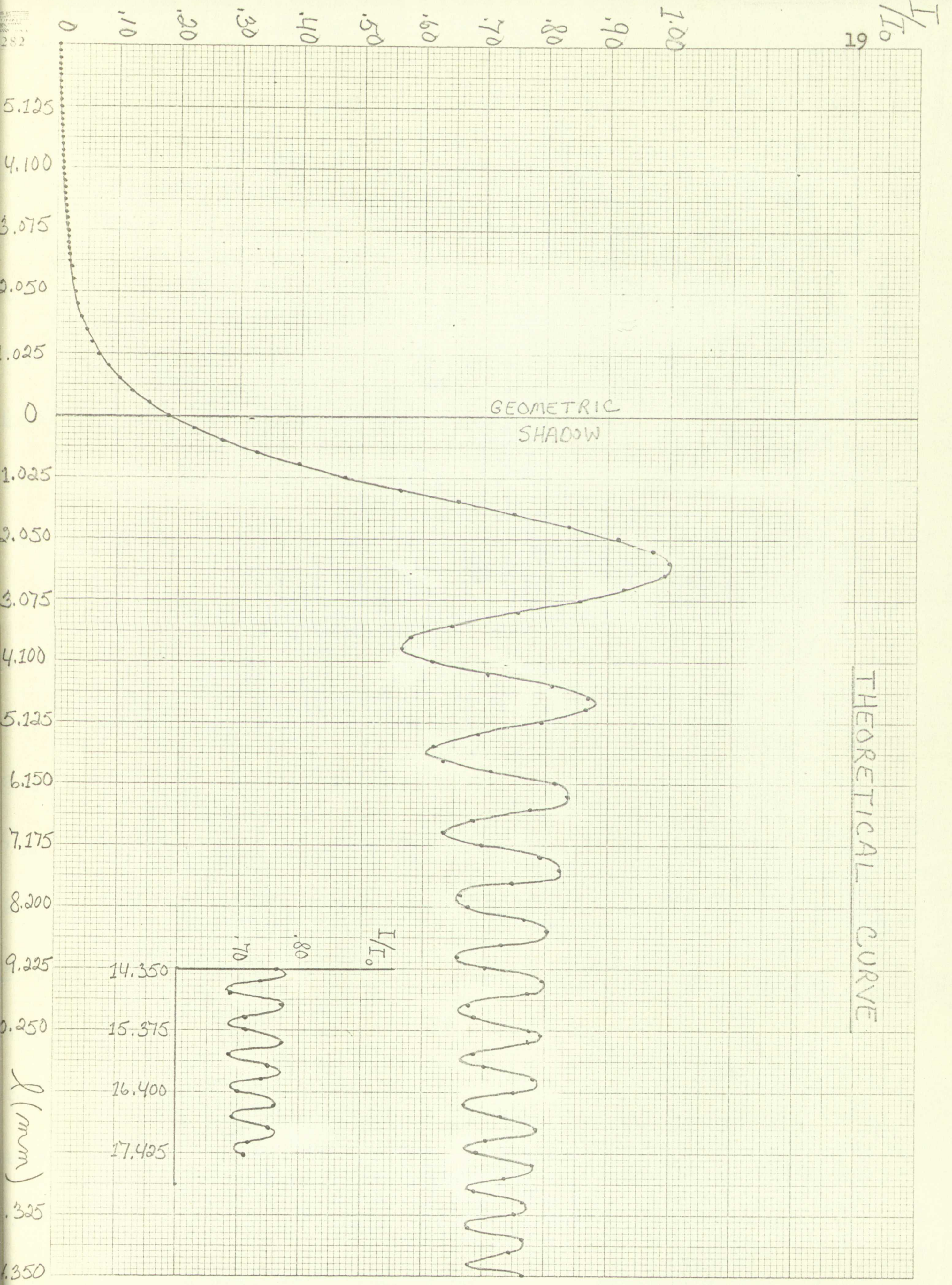
ares to the Inch

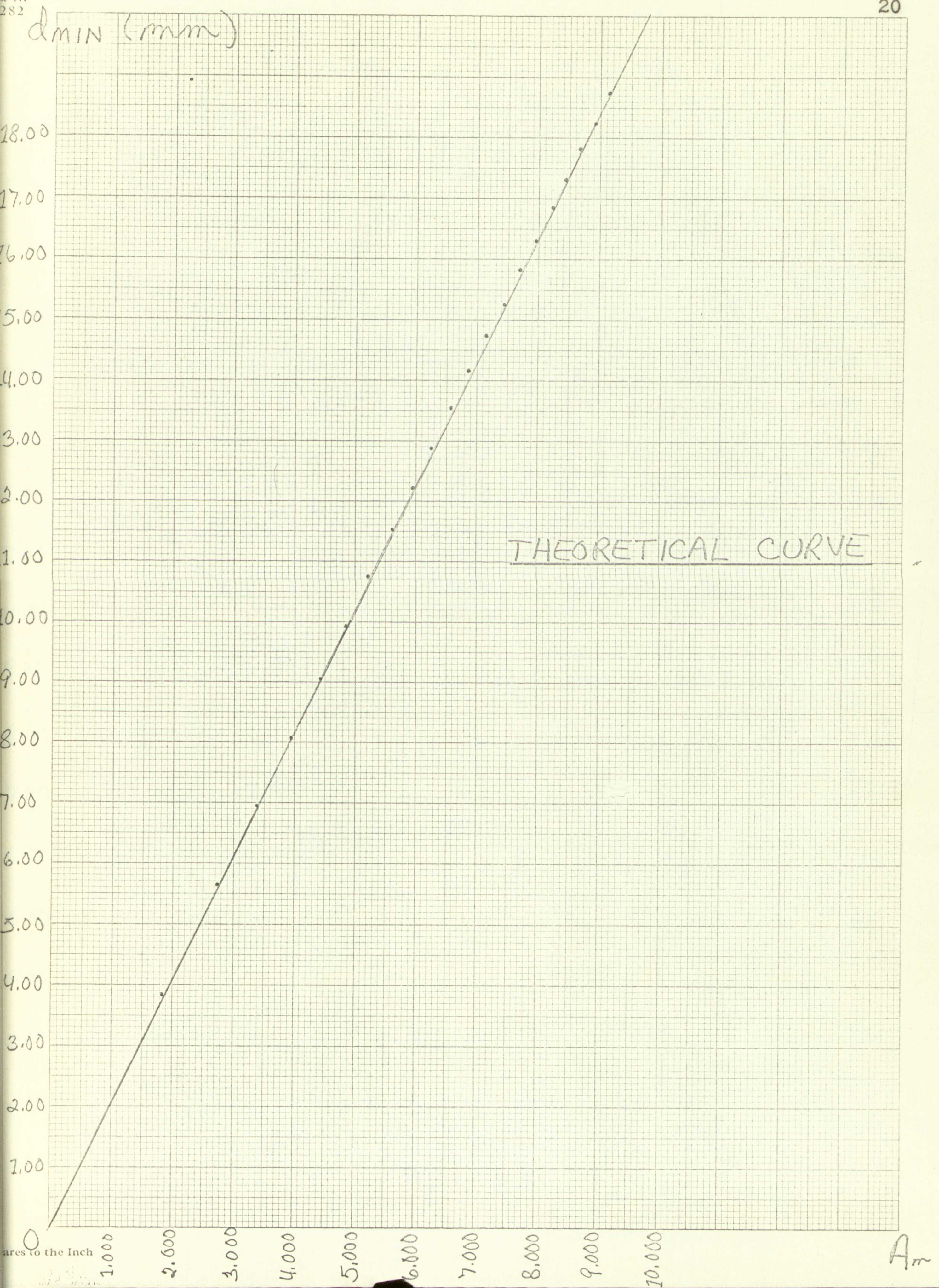

I/I₀
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
GEOMETRIC
SHADOW
PARALLEL ORIENTATION
5.319
10.638
15.957
21.276
ρ (mm)
21.276
24.428
ρ (mm)
.60
.70
.80
I/I₀



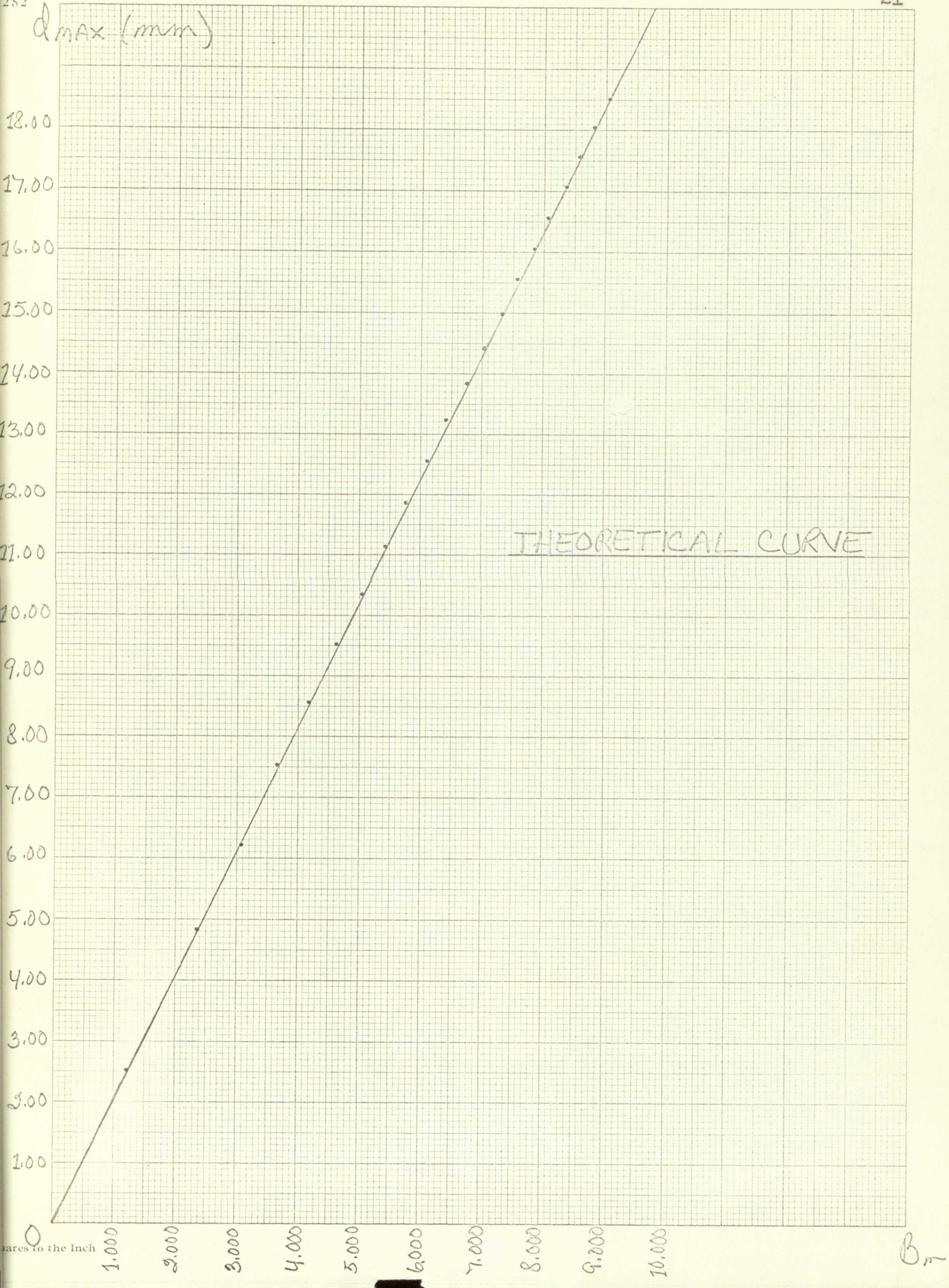
dMIN (mm)
20.212
15.957
10.638
5.319
0
PARALLEL ORIENTATION
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Am


d MAX (mm)
20.212
15.957
10.638
5.319
0
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
Bm
PARALLEL ORIENTATION

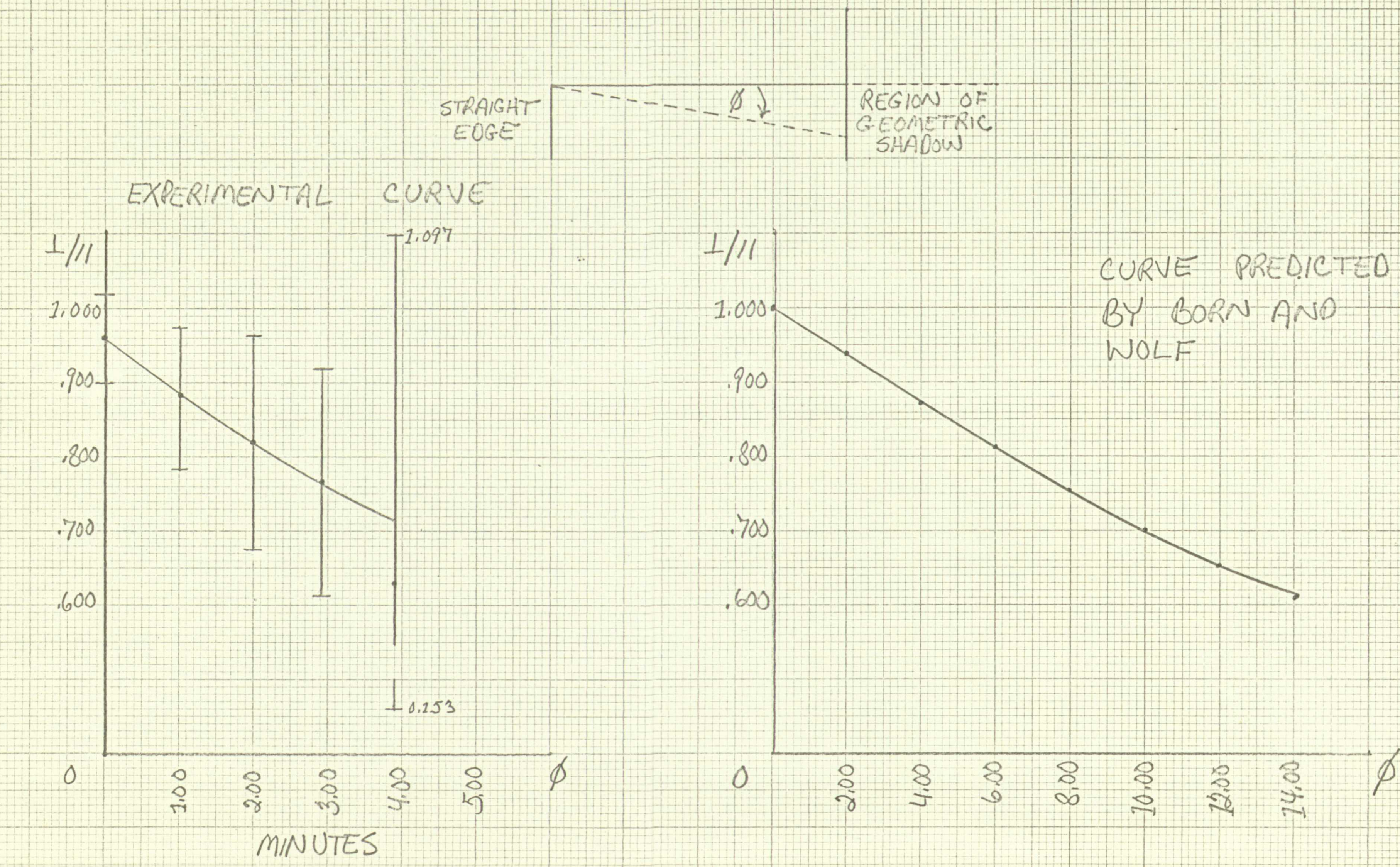

I/I₀
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
GEOMETRIC SHADOW
THEORETICAL CURVE
5.125
4.100
3.075
2.050
1.025
0
1.025
2.050
3.075
4.100
5.125
6.150
7.175
8.200
9.225
0.250
.325
.350
l (mm)
14.350
15.375
16.400
17.425
.70
.80
I/I₀



dMIN (mm)
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
Am
THEORETICAL CURVE


q_{MAX} (mm)
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
THEORETICAL CURVE
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
B_m

RATIO OF INTENSITIES OF THE ⊥ ORIENTATION TO THE // ORIENTATION IN THE GEOMETRIC SHADOW VERSUS ANGLE ϕ



CONCLUSION

It was found that the orientation of the polarized light with respect to the edge of the straight edge had no noticeable effect on the diffraction pattern of the straight edge outside the region of the geometric shadow. The polarization effects appeared in the region of the geometric shadow.[1] The polarization effects in the geometric shadow were more pronounced than those predicted by Born and Wolf. However, the angular extent of light in the geometric shadow observed in this experiment was quite small compared to the angular region of the geometric shadow considered by Born and Wolf. There was also considerable error in the measurements made in the region of the geometric shadow due to the rapid variation in intensity as one progresses into the geometric shadow. It is felt that further investigation of polarization effects in the region of the geometric shadow is necessary.

It was also found that outside the region of the geometric shadow the Fresnel scalar theory predicted the experimental results quite accurately. Thus Fresnel's assumption that a slit placed in front of a light source will itself become a source of coherent light is borne out in this experiment where a highly coherent light source was used.

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[1] Max Born and Emil Wolf, Principles of Optics (New York: Pergamon Press, 1959), p. 575.

It was found that the [illegible]
With respect to [illegible]
effect on the diffraction [illegible]
the region of [illegible]
appeared in the region [illegible]
tion effects in the [illegible]
those predicted by [illegible]
of light in the geometric shadow [illegible]
was quite small [illegible]
shadow constructed by [illegible]
error in [illegible]
shadow due to [illegible]
into the geometric shadow. [illegible]
tion of polarization effects [illegible]
shadow is necessary.

It was also found that [illegible]
shadow the Fresnel [illegible]
sults quite accurately. [illegible]
placed in front of [illegible]
coherent [illegible]
coherent [illegible]

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1 [illegible]
Pergamon Press, 1959, [illegible]

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