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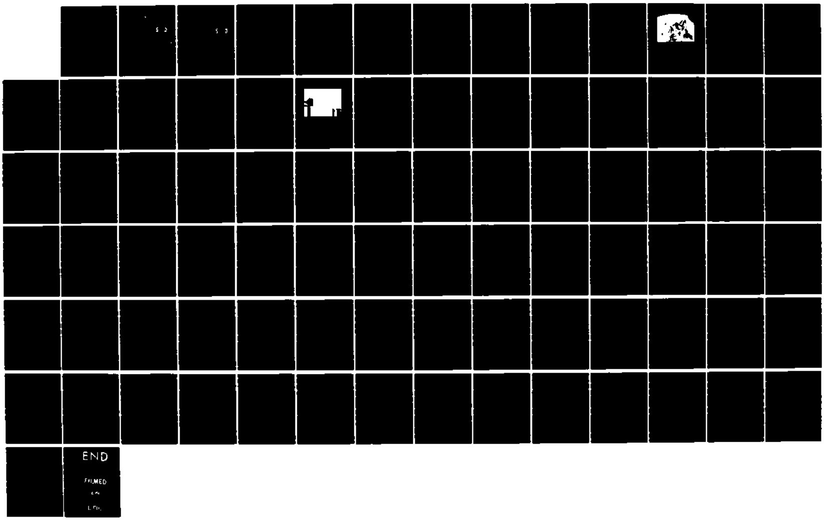

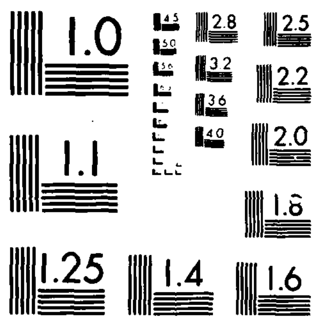

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THE BAT'S EAR AS A DIFFRACTION GRATING

THESIS

William A. Sowell
1st Lt USAF

AFIT/GEP/PH/83D-13

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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(1)

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

William A. Sowell, B.S.
1st Lt USAF
Graduate Engineering Physics

December 1983

Approved for public release; distribution unlimited

Preface

Bats. The word evokes images of caves, vampires, and furry little creatures flitting around at night eating bugs. This common folklore belies the fact that there are over eight hundred species of bats with an amazing diversity of diets, habitats, and echolocation systems (Ref 16). Various species eat pollen, fruit, insects, blood, small animals, or fish. Ranging throughout the world, bats roost in caves and houses, in hollow trees or dense foliage, and under bridges. Their sonar systems vary in complexity from simple clicks used by the fruit bat Rousettus to doppler compensation used by the insectivorous Moustache bat.

From the outset of this project, it became evident that a solid understanding of bat physiology and bio-sonar research would be essential to the success of this thesis. While a literature search provided useful background information on these subjects, a number of people furnished skills, current research data, and other assistance necessary to complete this project. Here I wish to acknowledge some of those people for their valuable support.

First, let me thank Dr. James Simmons of the University of Oregon biology department. The encouragement, current data, and relevant articles that he provided at the beginning of this project were most helpful. Next, I wish to thank Dick Mills, Mike Delaney, and the Cincinnati

Zoo for furnishing live specimens to examine and measure. I am deeply indebted to James Coffey for his attention to detail while fabricating the scale models used in this experiment. Also, I must thank Dr. Richard Cook, my advisor, for his insight and guidance in preparing this thesis.

Finally, to my wife, Laura, I say "I love you" for the sacrifices you've made and your belief in my ability to succeed these past eighteen months.

William A. Sowell

WILLIAM A. SOWELL

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Abstract

The series of parallel evenly-spaced ridges found in most bats' ears are investigated to determine if they are acting as a diffraction grating. A diffraction grating causes a periodic transverse variation of phase or amplitude in an incident wave. Such a device might be useful to the bat in determining a target's relative vertical position.

An experiment using ridged and smooth model ears (of the bat phyllostomus hastatus) was designed. Since the angle of diffraction is related to the angle of signal incidence, it should have been possible to observe periodic variations in amplitude across the frequency sweep received by a model ear.

In calculating the predicted dispersion using the Huygen's-Fresnel principle, it was determined that diffraction could not occur. The data appears to have supported this, and produced two further results. Significant differences in the data between the two model ears suggest a definite relationship between the ridges and the echo-location process. Also, the ears are sensitive to angle of incidence in steps as small as five degrees.

Introduction

1.1 Background

Bats, mammals of the order Chiroptera, use a form of biological sonar to perceive their surroundings, navigate, hunt, and capture prey. A variety of echolocation systems has evolved among the sub-order Microchiroptera, including FM sweep, constant frequency (CF) pulse, doppler shift, and combined CF/FM pulses (Ref 13). These adaptations enable bats to catch flying insects in the open air or in dense foliage, pluck fish from just beneath the water's surface, and snatch small animals from ground clutter or trees. Furthermore, bats can determine the size, shape, texture, relative position, and velocity of their targets to a high degree of accuracy (Ref 11). Because some insects take evasive action upon hearing their predator's cry, certain bat species have developed successful sonar counter-countermeasures (Ref 3:266). Also, it has been determined that bat sonar is extremely resistant to jamming (Ref 4:367).

Since the discovery of echolocation in bats over 40 years ago, many creatures have been found to possess echolocative or ultrasonic capabilities (Ref 8:157-183). A good deal of work is now underway to evaluate and categorize the animals possessed of either of these related talents. Neurological, psycophysical, and acoustical scientists are all working to discover the mechanisms responsible for echolocation.

1.2 Problem Statement

It is no surprise that the outer ear has received the most attention from researchers over the years. It is the most accessible component of the echolocation system. And, while there are as many ear shapes as there are species of bats, one feature is common to almost all bat ears. That is the series of parallel, evenly-spaced, horizontal ridges found on the pinna, as shown in Figure 1.

In a 1961 anatomical study of bat ears, muscles were shown to underly the skin beneath the ridges, but no explanation was offered for their function (Ref 10). One theory suggests that the ridges serve as a matched filter for echo pulse-length compression, but this has not been proven. Another suggestion is that they serve to stabilize the ears in flight. This is perhaps plausible for the long-eared bats, but many bats' ears are very small and induce little drag. Further, some non-flying animals capable of ultrasonic communication have these ridges as well (Ref 9: Plate XIII). None of the explanations offered to date satisfactorily explains the function of these ridges. It is the purpose of this paper to determine if the ridges are acting as a diffraction grating.

Figure 1

Phyllostomus hastatus, the tropical spear-nosed bat used in this experiment. Here, camera angle creates the appearance of downward curvature of the ridges, which cover most of the inside of the pinna. Note the tragus located at the base of the pinna.

1.3 Genesis of the Topic

While reading the book, Life on Earth, the author's advisor became curious about the ridges in the ears of the long-eared bat, Plecotus (Ref 1). A visual similarity between these ridges and an optical diffraction grating was noticed. Then calculations showed an order of magnitude relationship between ridge separation and bat wavelengths (see Table 1). Thus, it seemed possible that the ears were acting as diffraction gratings.

Further studies showed that nearly all bats have ridged ears, but no explanation could be found for the function of the ridges (Ref 14). The ridges were known to be muscles, but why these muscles stood out in a periodic fashion, while other ear muscles did not, was unclear. Considering that bio-sonar evolved in such a highly specialized manner, it seemed probable that the ridges were somehow related to the bat's echolocative abilities.

1.4 Phyllostomus Hastatus

As mentioned earlier, nearly all bat ears are ridged to a greater or lesser degree of prominence. However, the size and shape of bat ears are so widely diversified that no average ear could be identified for this experiment. Thus, the process of selection fell to choosing a bat that was readily available and whose ears were possessed of prominent ridges that were large enough to easily measure. The bat selected was the tropical spear-nosed bat, phyllostomus hastatus, from Trinidad.

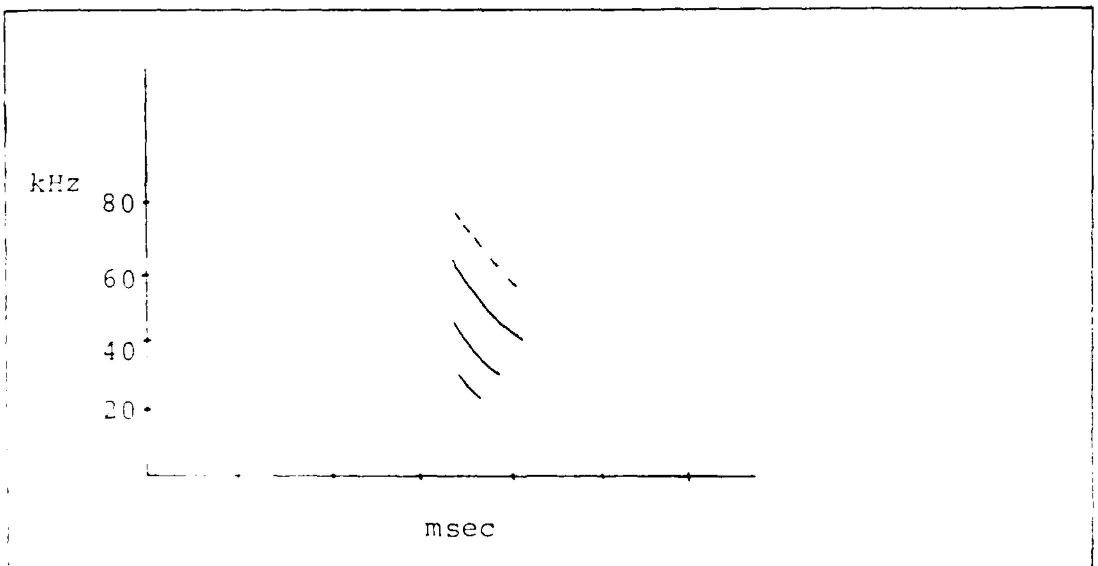
Phyllostomus' ears are approximately 2.4 cm high and contain 12 or more ridges spaced 1 mm apart. The spear-nosed bat emits an FM sweep signal composed of the third,

Table 1

Comparison of Ear-Ridge Spacing
and Emitted Wavelengths of Selected Bats

Bat	Number of Ridges	Spacing (mm)	Wavelength (mm)
Megaderma lyra	7+	0.8	> 4
Tadirada luzonus	8+	2-3	> 7
Plecotus rafinesquii	18+	1	> 7
Plecotus townsendii	10+	1-2	> 4
Hipposiderous galeritus	5+	1-2	> 2.4

fourth, and fifth harmonics of a suppressed fundamental. As shown in Figure 2, the signal consists of a downward sweep ranging from 80 kHz to 30 kHz lasting about 1 msec.



(Ref 12)

Figure 2

Characteristic signal of phyllostomus hastatus.

2. Theory

A diffraction grating may be defined as any arrangement which causes a periodic transverse variation of phase or amplitude in an incident wave. From optics we know that a diffraction grating disperses light, producing fringes of colored or light and dark bands known as a diffraction pattern. Optical diffraction gratings consist of a series of thin, parallel, equidistant slits of the same width in an opaque medium, or similarly, grooves or ridges on a reflecting surface (Ref 5:355). Diffraction is a general characteristic of wave motion, regardless of wavelength. Since the term is most often associated with light, the optics analogy will be used frequently in this paper.

The Huygen's-Fresnel principle of diffraction states that each point on a wavefront acts as the source of a secondary wavelet. The amplitude of the wavefield at any point is the superposition of all the wavelets. When an obstruction is placed in the wavefield, unobstructed wavelets propagate into the geometric shadow and interfere with one another, creating a diffraction pattern. Interference maxima will occur where the path lengths from various sources differ by an integral multiple of the wavelength. The integer multiplier is known as the order of the interference maximum.

Mathematically, the grating equation for reflection can be expressed in this manner

$$d(\sin \theta_n - \sin \theta_i) = n\lambda \qquad (1)$$

$$(n = 0, \pm 1, \pm 2 \ldots)$$

where

d	separation between ridges
n	order
λ	wavelength
θ_i	angle of incidence
θ_n	diffracted angle of n^{th} order

From this equation, one can determine the diffraction pattern to be expected from a flat grating. Figure 3 shows the incoming white light separated into its component frequencies, each of which is diffracted at a unique, predictable angle.

If we assume that a bat's ear-ridges are acting as a diffraction grating, curvatures in the grating surface must be accounted for. The general shape of most bats' ears can be compared to a parabolic cylinder-half. The ridges run around the cylinder while the back of the ear is relatively flat along a line perpendicular to the ridges. In the ideal case, this shape would tend to focus sound

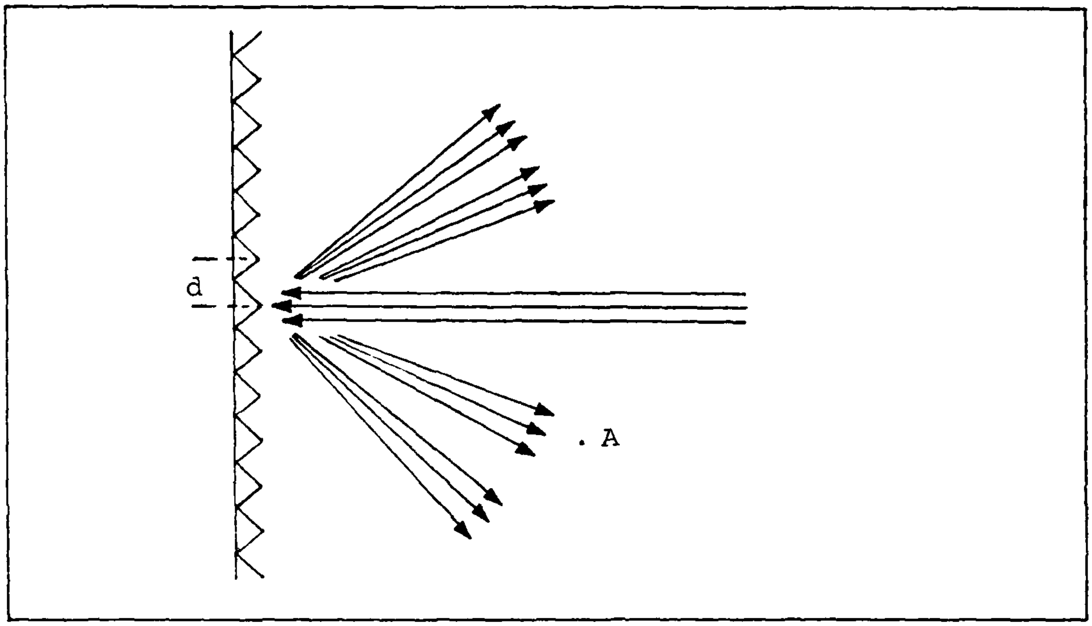


Figure 3.

Diffraction Grating. White light at normal incidence is being diffracted into both the positive and negative orders. Note the dispersion of the individual frequencies.

toward the tragus (Fig. 1), while not changing the shape of the diffraction pattern. To determine the diffraction pattern for a real ear, one could use the Huygen's-Fresnel principle by adding the contributions to a point (in phase and amplitude) from each ridge. This tedious process has not been attempted here, but rather an experiment has been designed to measure the effects, if any, of diffraction from a bat's ear.

3. The Experiment

3.1 Hypothesis

The hypothesis to be tested is that, if a bat's ear does diffract sound, the animal must be employing the dispersion aspect of this phenomenon. This theory is suggested in two ways.

First, dispersion is the most observable characteristic of diffraction that could easily be employed by an echolocator. If a narrow detector is placed at position A in Figure 3, a specific frequency will be detected for a given angle of incidence. Changing the angle of incidence changes the frequency detected at A.

Second, much research suggests that the pinna and tragus impart some direction-coding information to incoming echo pulses (Ref 17). In bats' ears a tragus, located at position A, serves to reflect sound from the pinna to the tympanic membrane (ear drum). Behind the ear drum, within the inner ear, bats have a frequency sensitive basilar membrane. Along the length of this organ are regions responsive to various frequencies. Thus, for a bat emitting and receiving a broadband pulse, a given angle of signal incidence could be detected as a particular frequency.

3.2 Design

A corollary to this for single frequency inputs is that, as the angle of incidence is varied, the amplitude detected at position A varies. This experiment was designed to test the second approach. Two scale model ears were obtained, one with ridges and one without them. The ears (and thus the wavelength range) were scaled up eight-to-one to make use of available audio equipment. This scaling is appropriate, of course, due to the linearity of wave properties.

A mounting device which could be incrementally positioned in both the vertical and horizontal axes was prepared for the models. This unit is capable of providing repeatable angles of incidence in 5 degree steps over a 100 degree range in both axes. Each model was fitted with a microphone (see Appendix A: Equipment List) and mounted in front of the speaker as shown in Figure 4. An audio frequency generator produced sweeps from 3.5 kHz to 10.5 kHz, which were beamed into the ear for each angle of incidence. The signal picked up in the ear was rectified by a diode and recorded on an X-Y plotter for all positions of one ear; then the runs were repeated for the other ear. In this manner, data were collected for over 300 angles of incidence. Each data sheet contains the amplitude response across the frequency sweep for both ears at a given angle of incidence. We can consider that these angles of incidence comprise a matrix of rows and columns. Appendix B contains a sample of this data representing one vertical column and one horizontal row of angles of incidence.

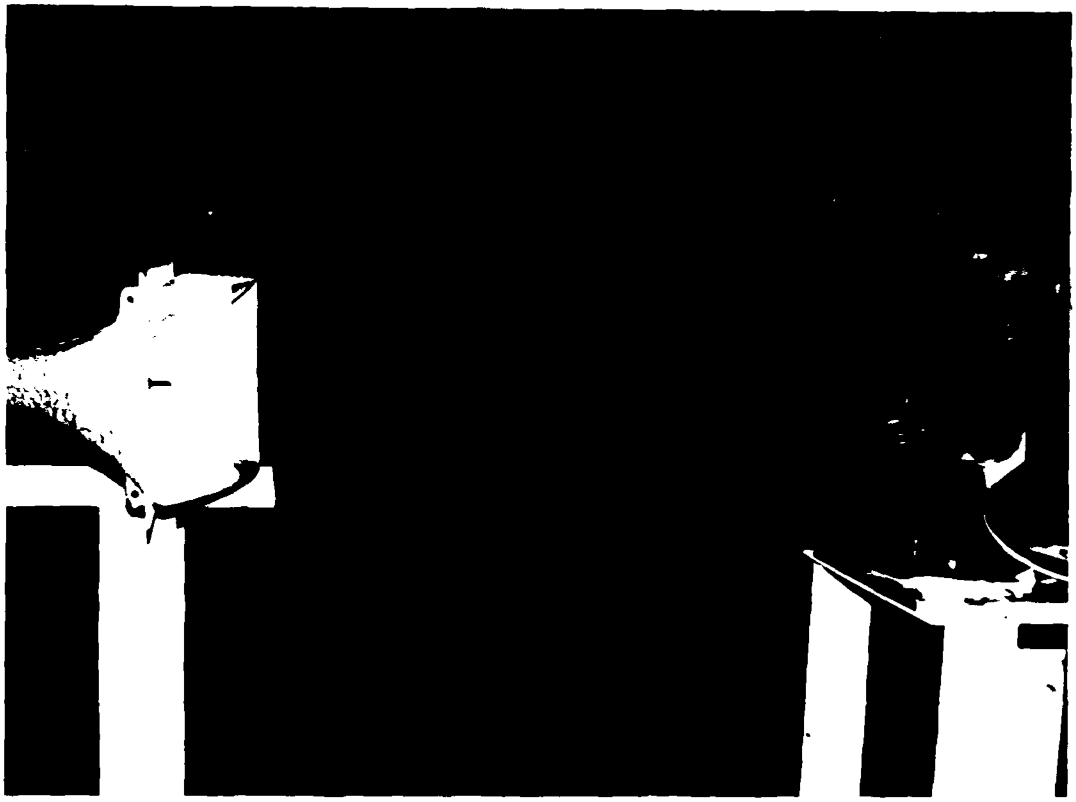


Figure 4

The experimental set-up. This experiment was conducted in an anechoic chamber located in the Bio-Engineering Division of the Aerospace Medical Research Laboratories at Wright-Patterson Air Force Base.

4. Results and Discussion

4.1 The Thesis Question

As is sometimes the case when one asks a question, the answer here is no. The ridges in bats' ears are not acting as a diffraction grating. This result was determined mathematically and confirmed by the data. While this is not the answer hoped for, it is nonetheless a discovery. Furthermore, data from this experiment have provided two other substantial results. These will be explained later, but first let us see how the thesis question was answered.

If a diffraction grating was being used by the bat, it should have been possible to observe periodic variations in amplitude across the frequency sweep detected at the model. In an attempt to calculate the period of this diffraction pattern, the author answered the thesis question. From the grating equation

$$d(\sin \theta_n - \sin \theta_i) = n\lambda \qquad (1)$$

$$(n = 0, \pm 1, \pm 2 \ldots)$$

we get

$$\sin \theta_n = \frac{n\lambda}{d} + \sin \theta_i \qquad (2)$$

Now, given

$$-1 \leq \sin\alpha \leq 1$$

and

$$4\text{mm} \leq \lambda \leq 11\text{ mm} \qquad \text{actual values for this bat}$$
$$d = 1\text{ mm}$$

we find that $\frac{n\lambda}{d} > 4$ for any value of n except 0. For $n = 0$, we find that $\sin\theta_n = \sin\theta_i$. This is the case for specular (or regular) reflection and no dispersion occurs. For all other values of n, we see that the equality in equation (2) does not hold and diffraction cannot occur. This conclusion appears to be supported by the data. While variations in amplitude across the frequency sweep do occur, they are not periodic as predicted by the theory. Measurements of the ear cavity indicate that resonance at various frequencies could be responsible for the observed amplitude pattern. The amplitude pattern for the ridged ear is quite unlike that for the smooth ear, suggesting that the ridges are responsible for the differences. How this is possible is a subject for further investigation.

The next question to be answered is "Under what circumstances might diffraction occur in this ear?" For this bat, either of two conditions could satisfy the diffraction equation. If only every fourth ridge were used, d in equation (2) would equal 4 and diffraction could occur for normal incidence at the bat's highest frequency. If 1 mm wavelengths were employed, λ would equal 1, and diffraction could occur at normal incidence. For diffraction at oblique incidence, either the effective ridge separation or the frequency, or both, would have to be increased still further.

It seems unlikely, however, that these conditions would be met. Most bats' ears contain 12 to 18 ridges. Using every fourth or fifth ridge to effectively increase d would result in only 2 to 4 ridges at a time diffracting sound. Because a grating's resolving power is proportional to the number of ridges involved, a net loss in ability to distinguish frequencies would result.

The alternate solution, a 1 mm wavelength, corresponds to a frequency of over 300 kHz. In this case, we note that the absorption of sound by the atmosphere is proportional to the frequency of the sound. Lawrence and Simmons have shown that atmospheric attenuation of ultrasounds due to absorption at 200 kHz exceeds 8 decibels per meter. This attenuation would greatly limit the useful range of such a system. More importantly, while suitable detection equipment exists, bats have not been recorded at frequencies above 250 kHz.

4.2 Further Results

In addition to answering the thesis question, two other useful results can be gathered from the data. The first is that there is a significant difference in frequency response between the two model ears. Figure 5 shows a characteristic example of these differences. Overall, the ridged ear produced a lower amplitude response than did the smooth ear. Frequencies amplified by the two ears generally differed, especially near 4.5 kHz. Specifically, the smooth ear consistently exhibited a much stronger response near 4.5 kHz than did the ridged ear. These distinct and varying differences lend weight to the idea that the ridges serve some specific function in the process of echolocation.

The second result is an apparent confirmation of the position encoding hypothesis mentioned earlier. There is an observable difference in the response curves between angles of incidence, with seemingly more information present on the ridged trace than on the smooth one. Thus, the pulse signature of each angle of incidence is unique and resolvable in steps as small as five degrees in either the vertical or horizontal plane.

4.3 Validity of the Data

Some of the steps taken to determine the validity and repeatability of this experiment are described here. The data for these tests is located in Appendix C.

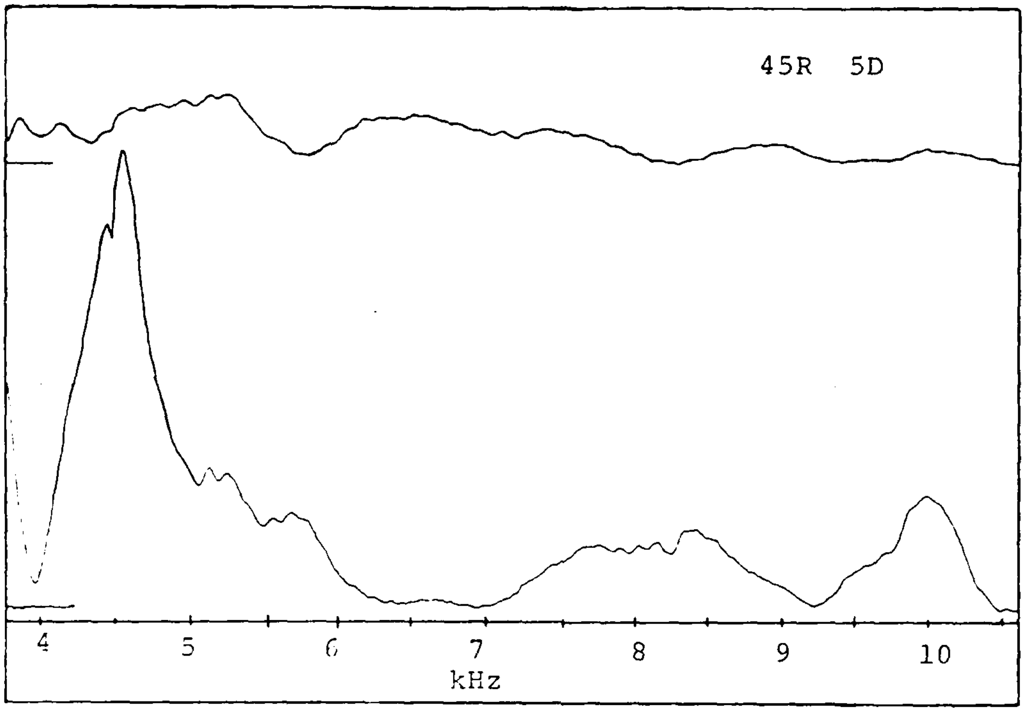


Figure 5.

Sample data sheet. The upper trace is for the ridged ear; the lower one is for the smooth ear. An approximate frequency scale is shown.

Originating from the same mold, the model ears differed only in that the ridges were sanded off and painted over on the control ear. The mounting devices were set up to ensure a fixed separation between speaker and ear throughout the experiment. Positioning of the microphone in the ear canal was arbitrary. Tests showed that a half inch change in position could result in a substantial change in the data recorded for a given angle of incidence. However, the position finally selected was the same for both ears; and once in place, the microphone was not moved until all of the data for an ear was taken. Later on, the microphone was repositioned in each ear and runs were repeated for selected angles of incidence. The data from these tests demonstrates a suitable repeatability of microphone position.

Throughout the experiment, duplicate runs for a given angle of incidence were often made to determine equipment noise levels. Traces such as those on page 30 show that the equipment noise present is easily distinguished from the signal.

Finally, this experiment was conducted in an anechoic chamber to minimize the effects of spurious reflections on outside signals entering the ears.

4.4 Conclusion

Although these tests aren't quantitative in nature, it is felt that they establish an acceptable level of confidence in the experimental procedure and the conclusions drawn. There are, however, several points to consider concerning the applicability of these results to live bats.

The degree of correspondence between the model and the live specimen varies. For example, the density and texture of the model differ from the density and texture of a live bat. These differences result in a different signal absorption level between the model and a real ear, but not between the two models. As a result, the frequencies amplified in the data should not shift for a real ear, but the amplitudes might decrease somewhat.

The animal was measured carefully and reproduced as accurately as possible, but this model represents only one of infinitely many positions that a bat's ear may assume. Because the ridges are muscles, their shape, as well as the shape of the pinna, is certainly variable. This very flexibility allows us to assume that the model represents a valid shape.

The signal sweep used here is not the same as that emitted by the bat. As stated before, though, wave properties are linear. The principle of superposition of waves tells us that any linear combination of waves represents another wave. By this principle, a correspondence between the test signal and the actual signal could be established. However, in this experiment, the necessary phase relationships were not recorded and the correspondence cannot be developed from the data.

Let us summarize the results of this experiment. First, the bat's ear does not diffract sound in the classical sense. Second, the significant differences in the data between the two model ears suggest a definite relationship between the ridges and the echolocation process. Finally, the model ears are sensitive to angle of incidence in steps as small as five degrees. These three points are determined from the data and calculations, and tend to be upheld by the current literature. It is hoped that this experiment will aid others and suggest new approaches in the study of echolocation.

4.5 Recommendations

In order to more accurately study the bat ear using a scale model, the following recommendations are offered. A model of the complete head should be made, with one microphone in each ear. The model should be made of rubber and covered with fur to simulate the density and surface texture of a live bat. In addition, the signals used should approximate those of the actual bat. Dr. Simmons (University of Oregon) is a likely source of phyllostomus hastatus signal information. Signal processing equipment for this endeavor may be available in the AFIT Electrical Engineering Department or in the Bioengineering/Biodynamics Division of AFAMRL. This new experimental configuration would more accurately simulate the bat's signal gathering system. Also, phase differences between signals received in the left and right ear could be studied.

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(19) ----- The complete original data in 11 x 17 inch format is stored in the AFIT Physics Department.

Appendix A

Equipment List

(1) Hewlett·Packard Model 3325A Synthesizer/Function Generator

(2) Hewlett·Packard Model 1220A Oscilloscope

(3) Crown Power Line Two Amplifier

(4) Houston Instrument Omnigraphic 2000 Recorder

(5) Brüel & Kjaer Type 4133 Microphone

(6) Altec Model 291-16B High Frequency Driver

Appendix B

Experimental Data

The original data, recorded on 11 x 17 inch plotter paper, is stored in the AFIT Physics Department. There are over 300 sheets in the original set, each representing a specific angle of signal incidence. These angles range from 45 degrees left to 45 degrees right and from 50 degrees "nose down" to 30 degrees "nose up" in 5 degree steps. The following pages are a representative sample of the data sheets in reduced format. The scale is approximately five-eighths inch equal to 500 kHz, with the corresponding frequencies marked on the first data sheet. One vertical column and one horizontal row of angles of incidence have been included.

Pages 62 through 65 are graphs plotting amplitude response as a function of angle of incidence at a given frequency. The amplitudes are normalized and the frequencies chosen are as shown.

Key

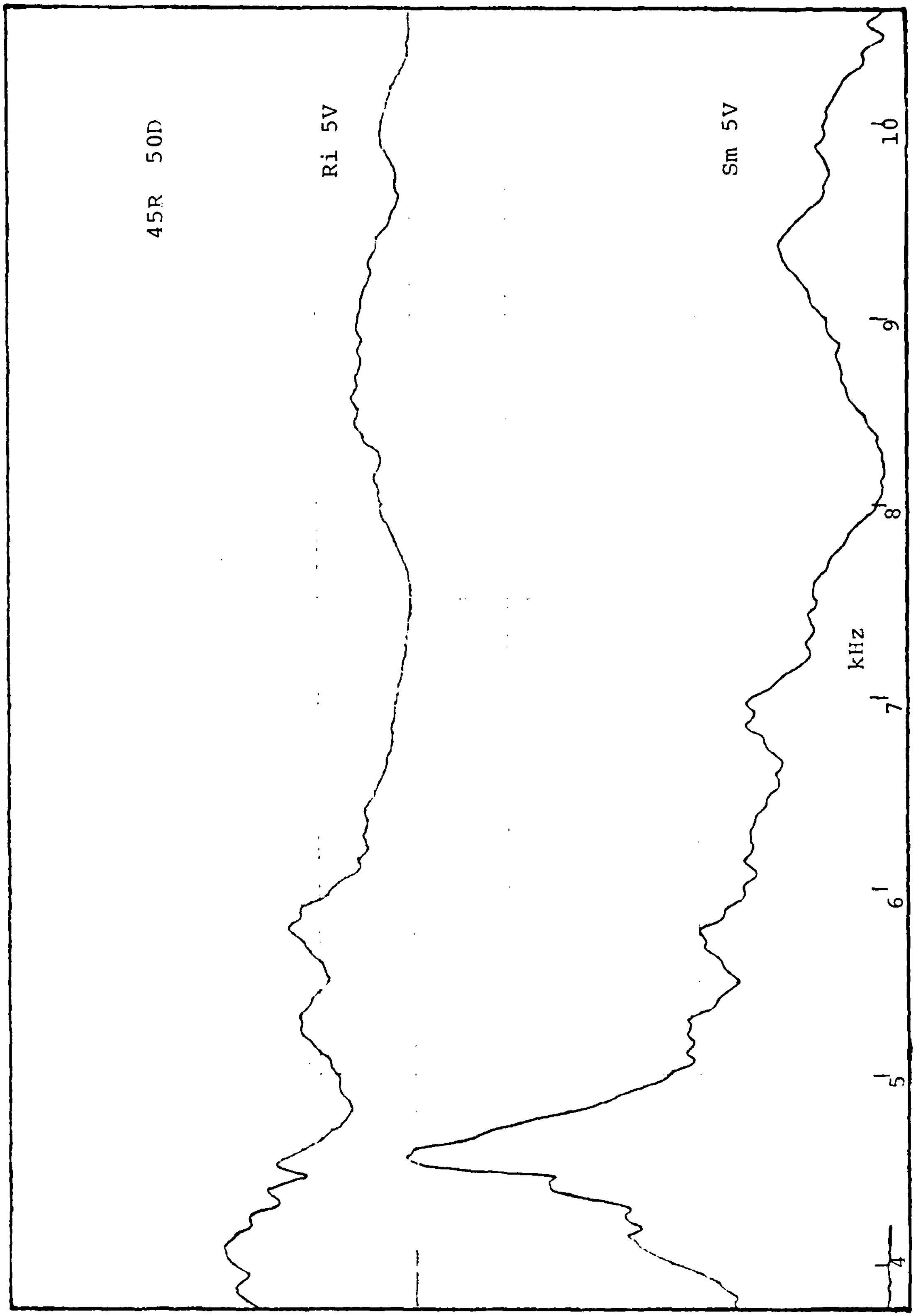
Position Code Example: 45R 25D

This angle of incidence from the bat's perspective is 45 degrees right and 25 degrees down. Figure 4 shows the model centered vertically and horizontally.

Trace Identification Example: Ri 5V, Sm 10V

The traces are labeled with Ri for the ridged ear and

Sm for the smooth one. The numbers represent the voltage applied to the speaker for that run. A higher voltage (and thus speaker volume) was sometimes necessary with the ridged ear in order to record sufficient detail.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Sm 5V
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6
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9
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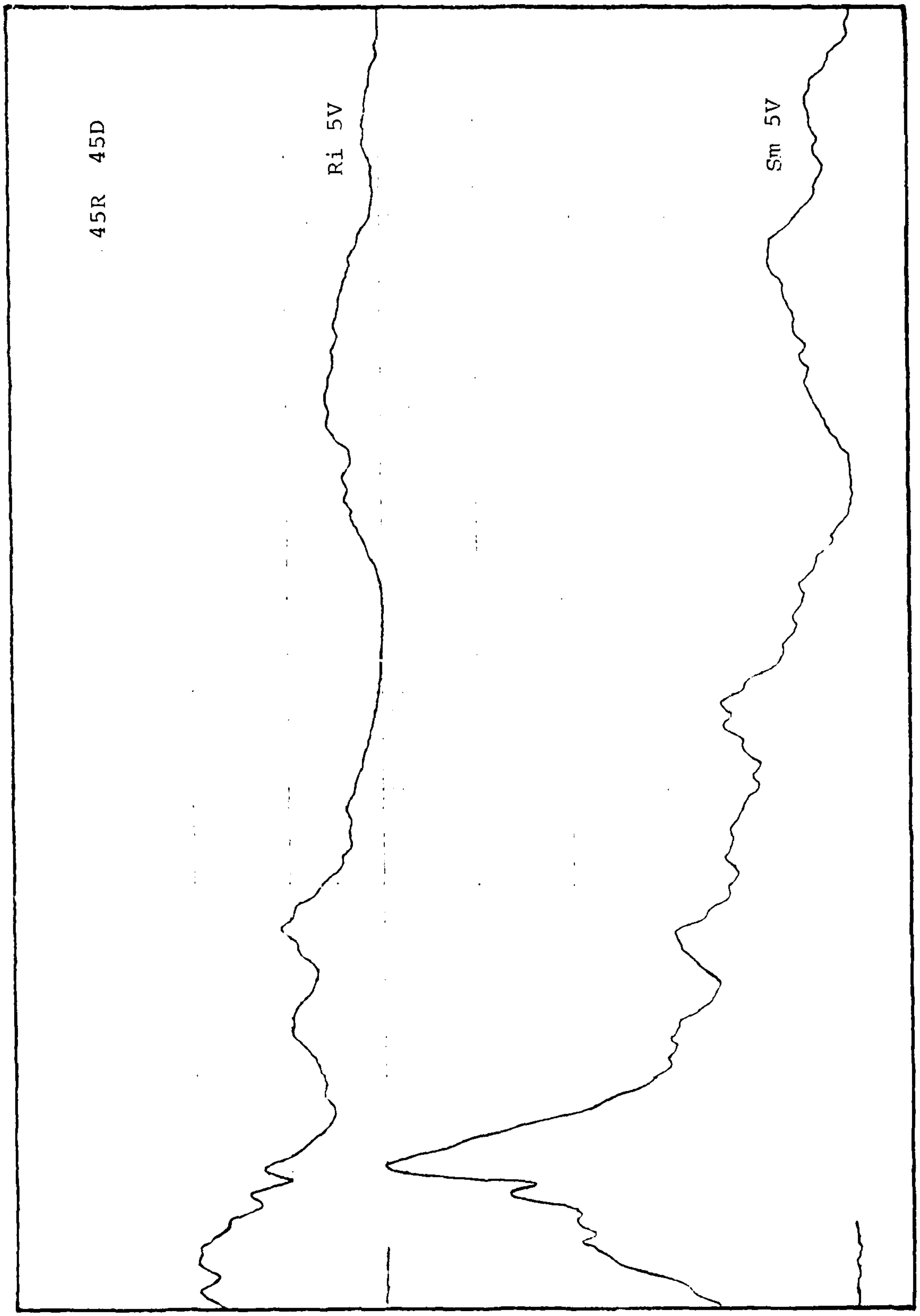
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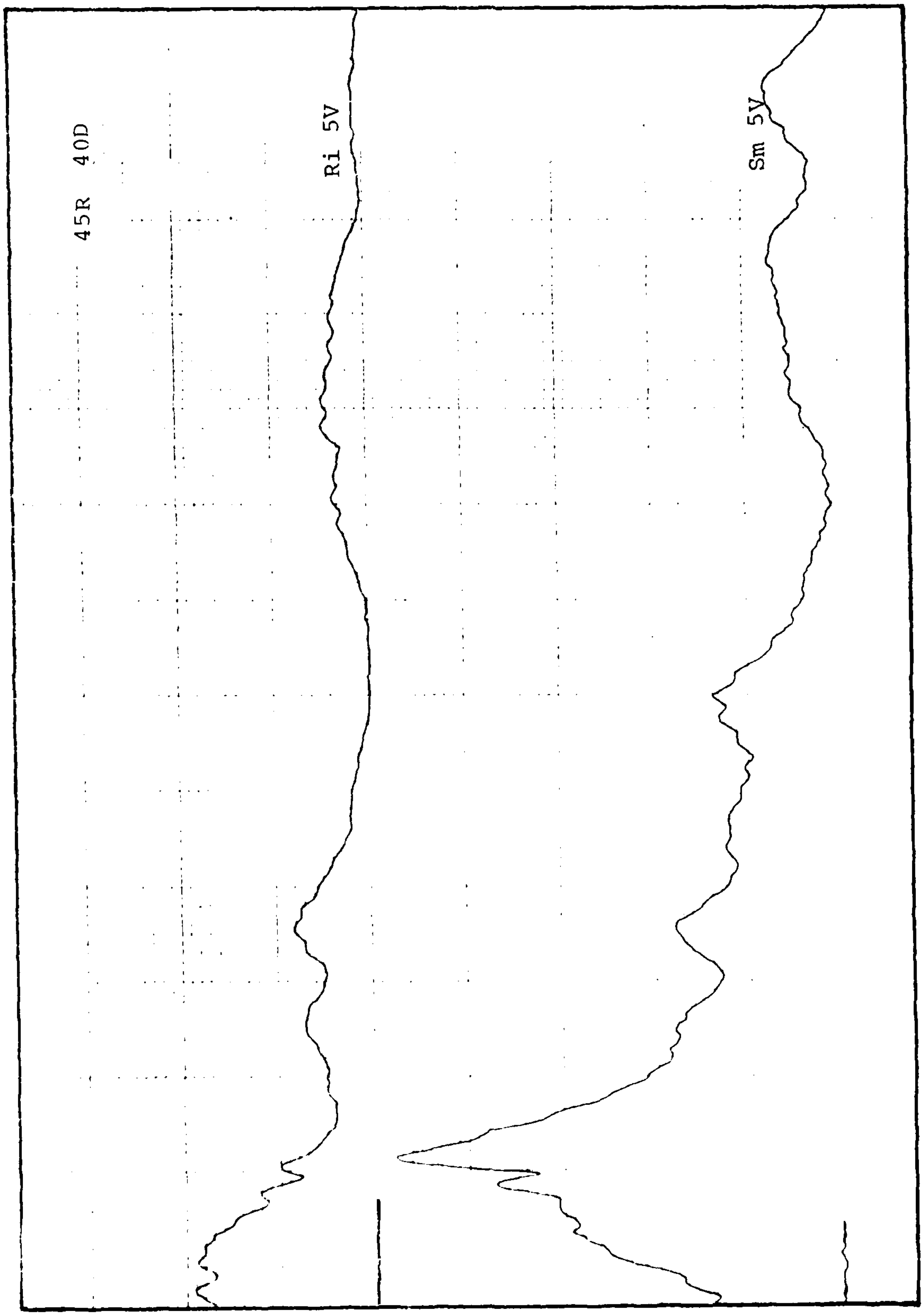
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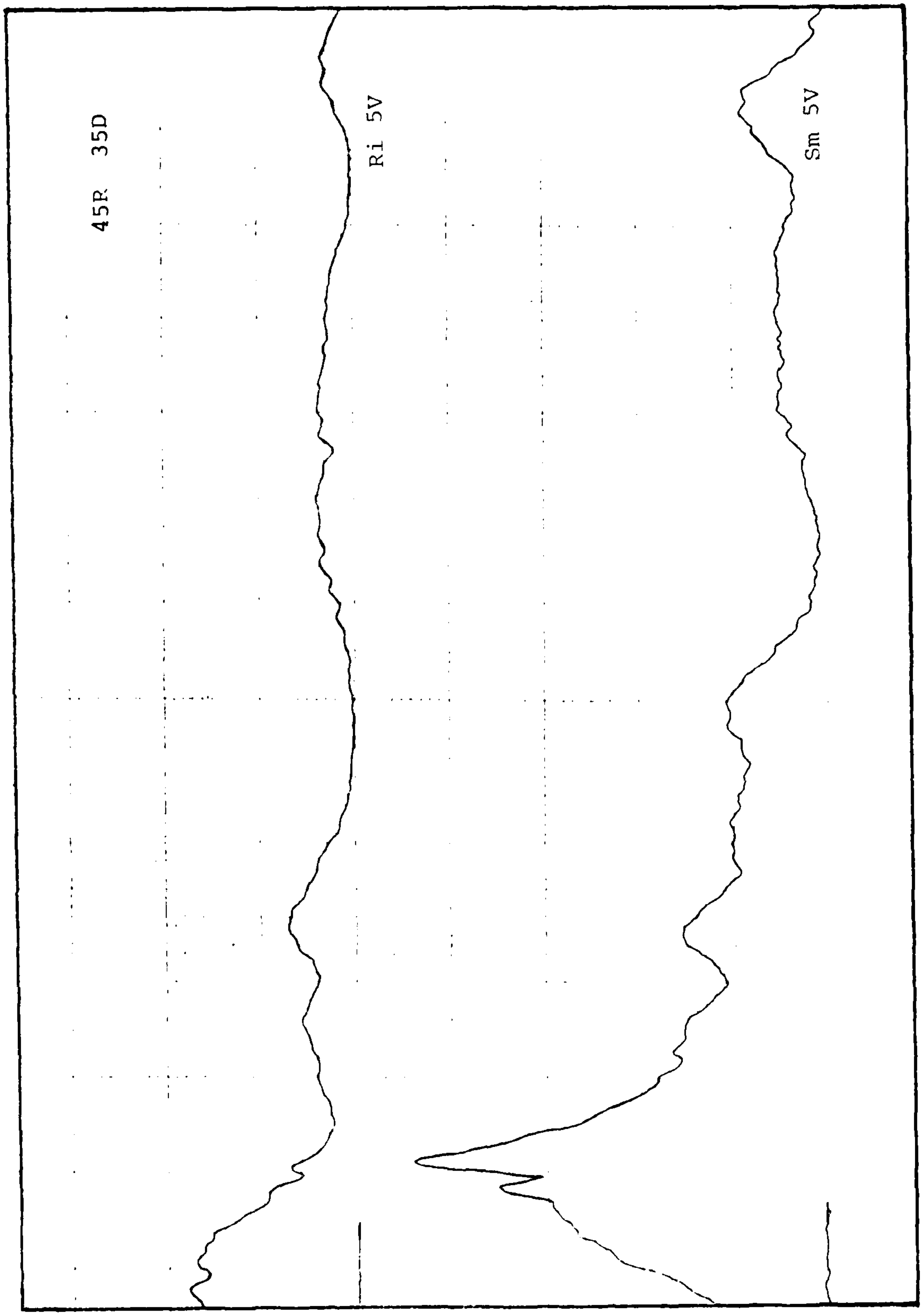
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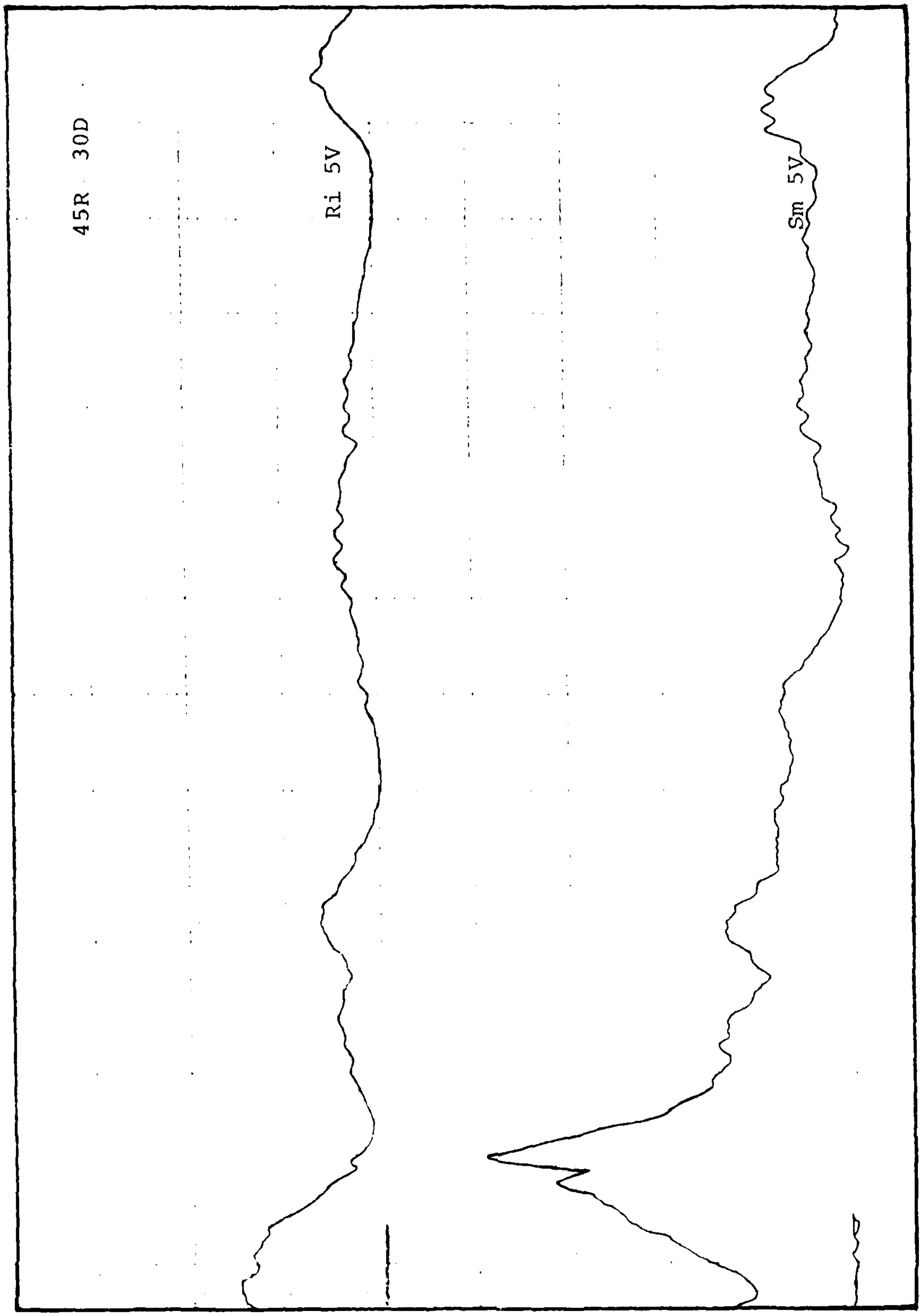
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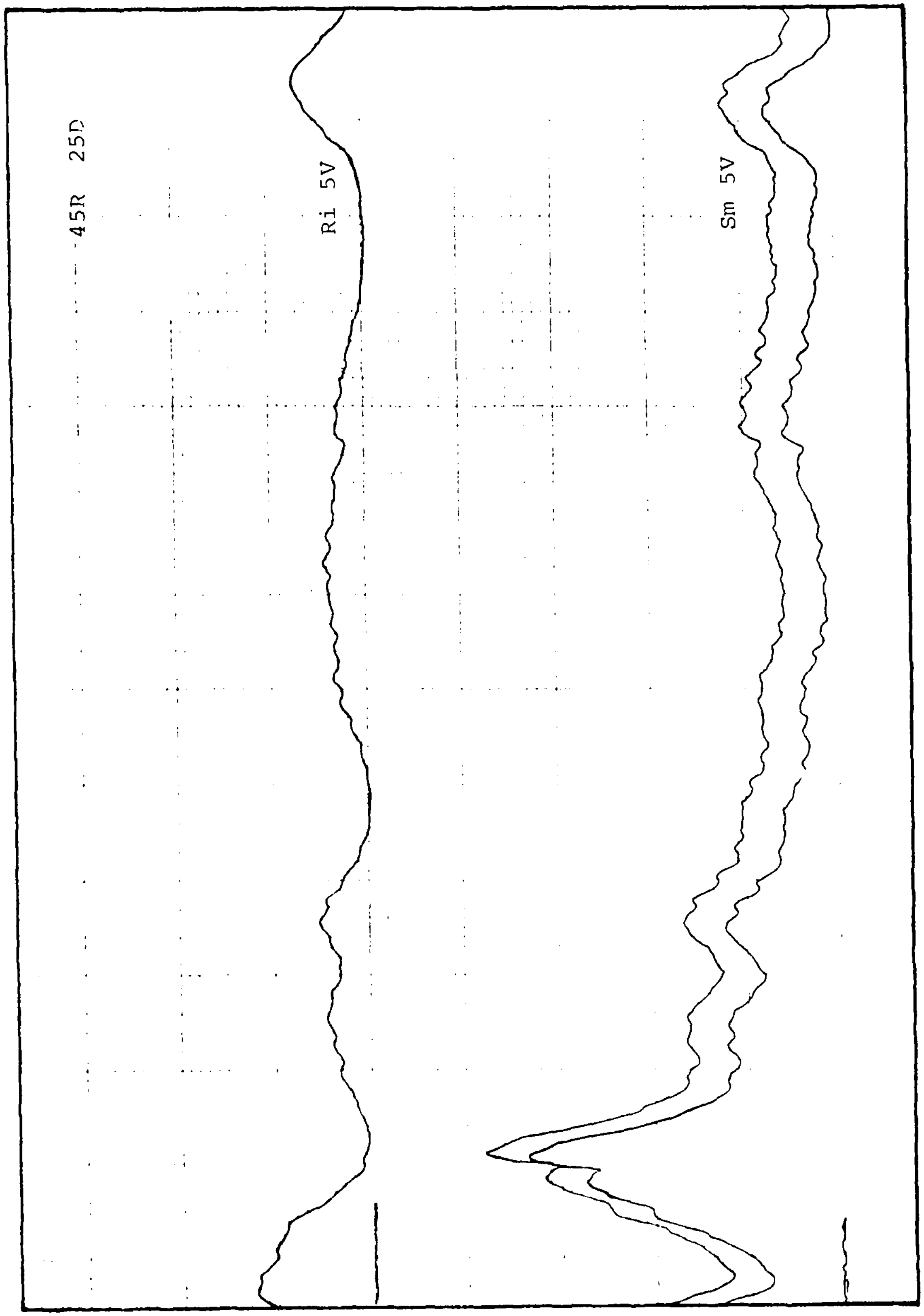
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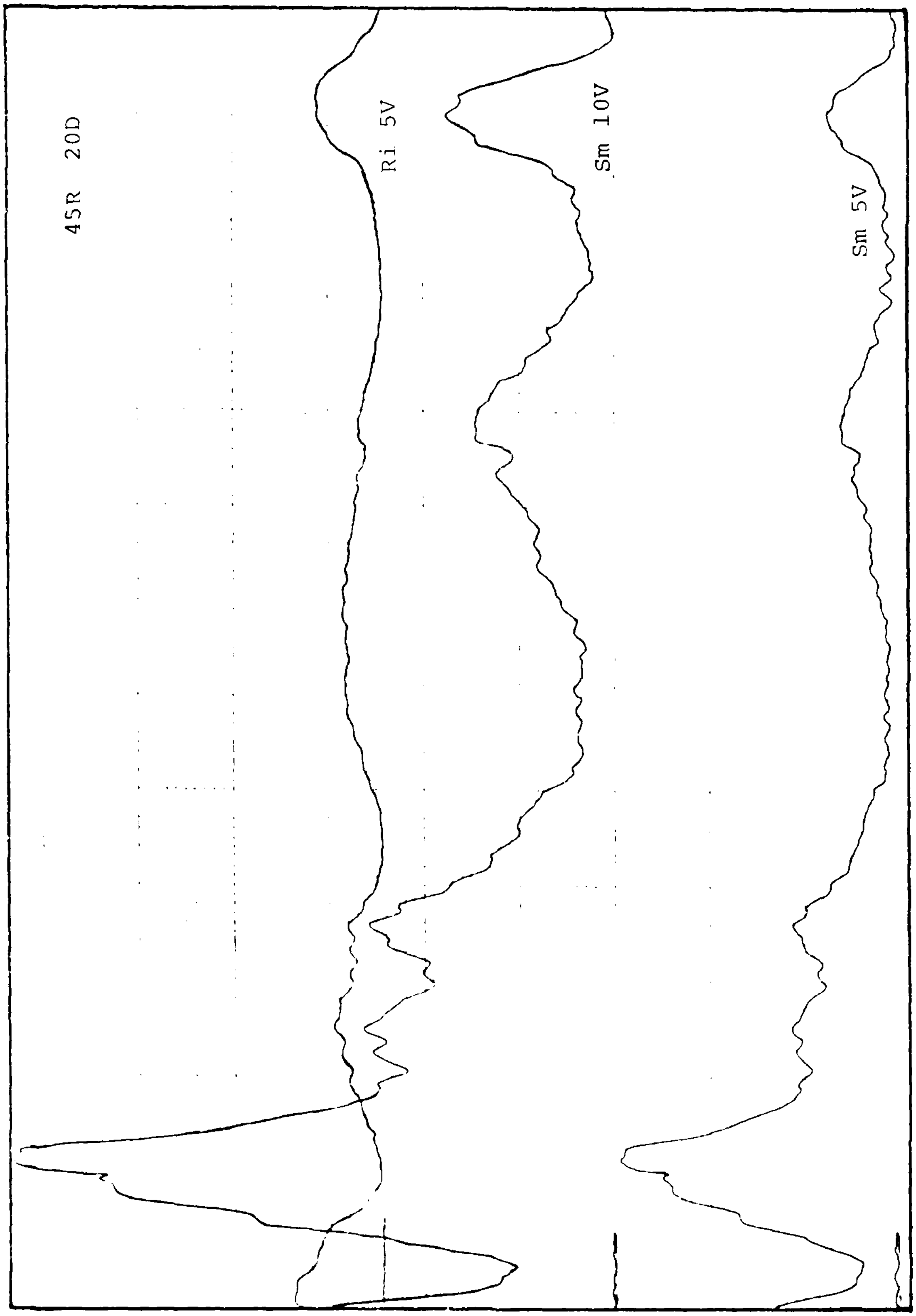
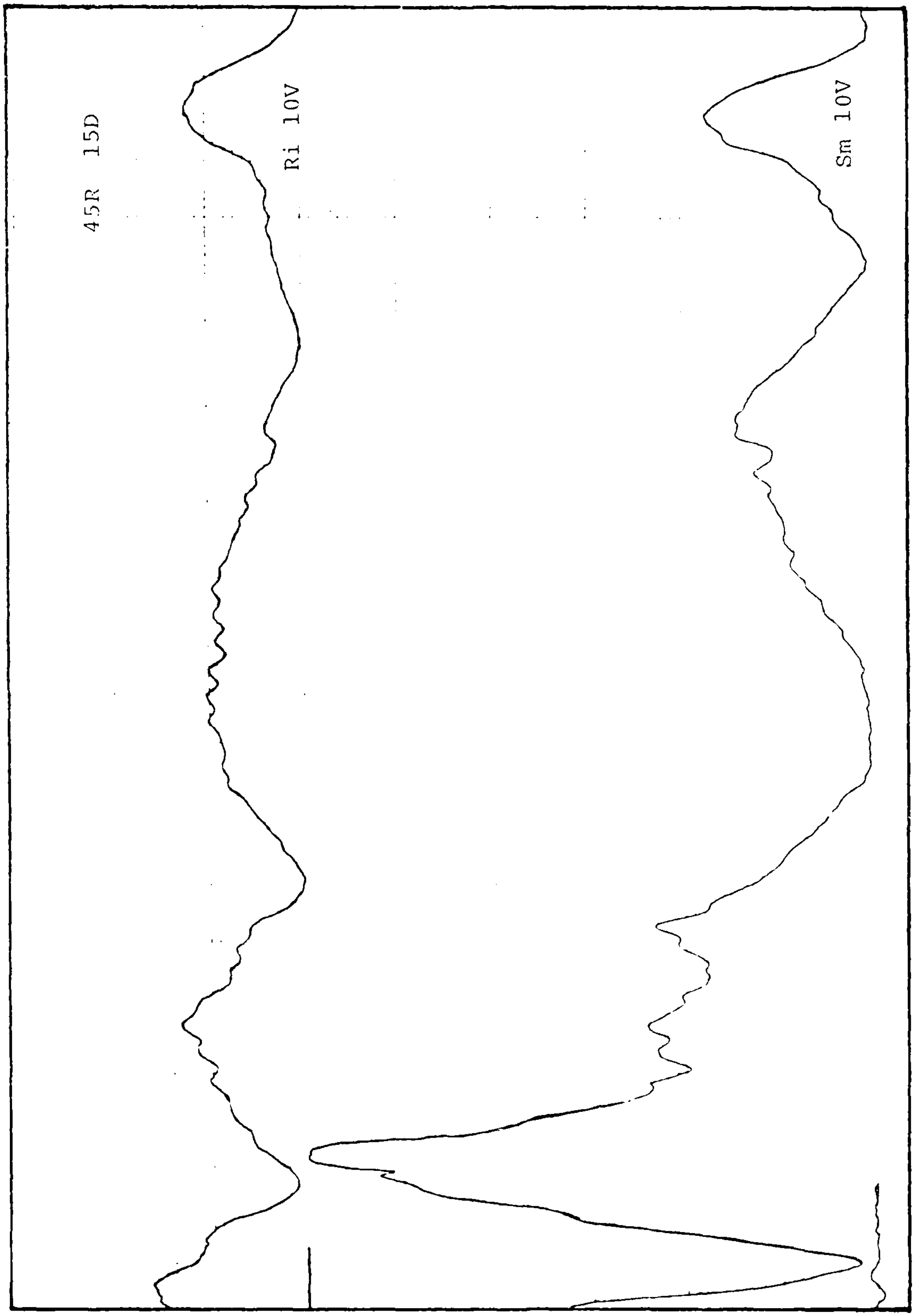
Sm 5V


45R 20D
Ri 5V
Sm 10V
Sm 5V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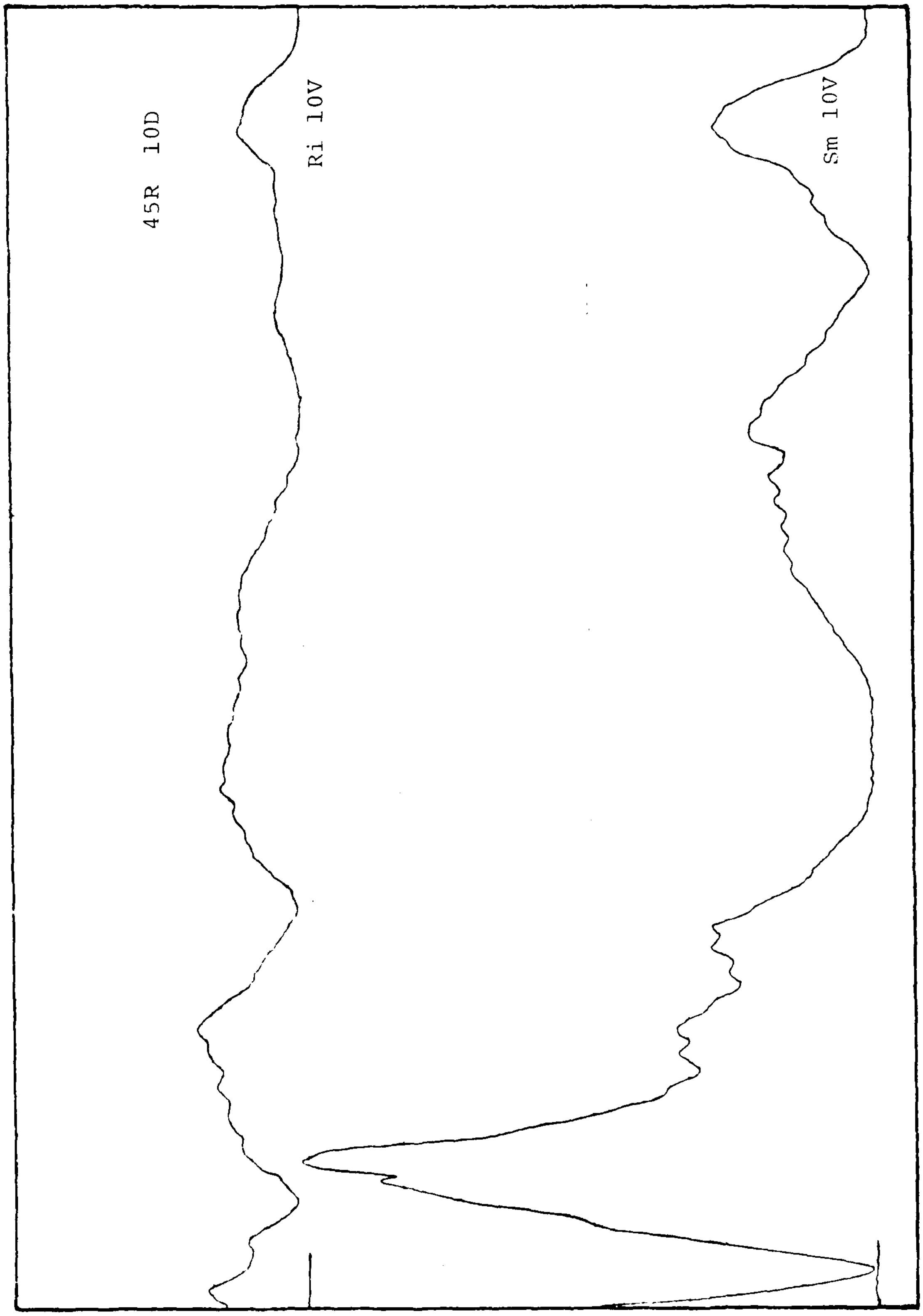
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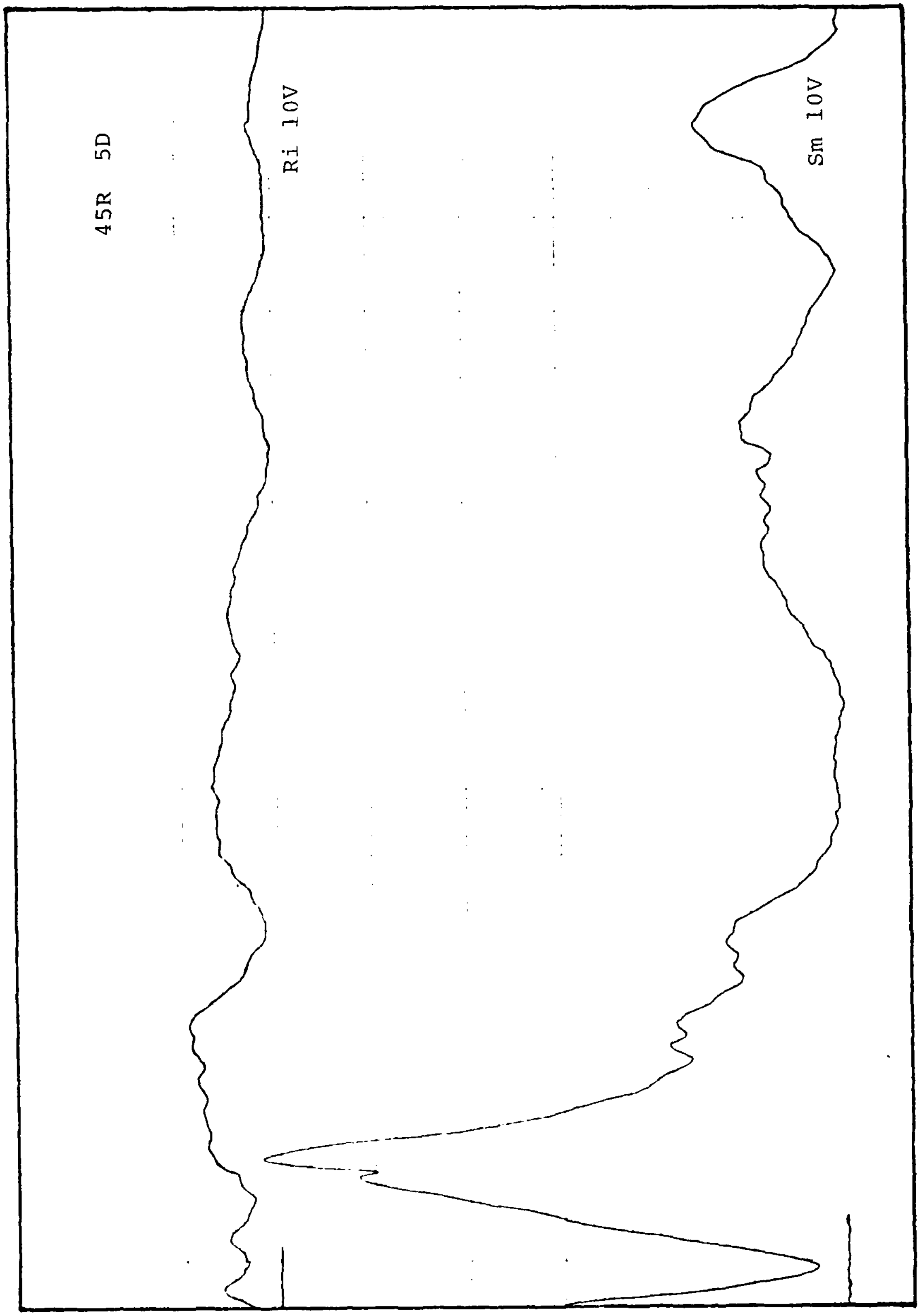
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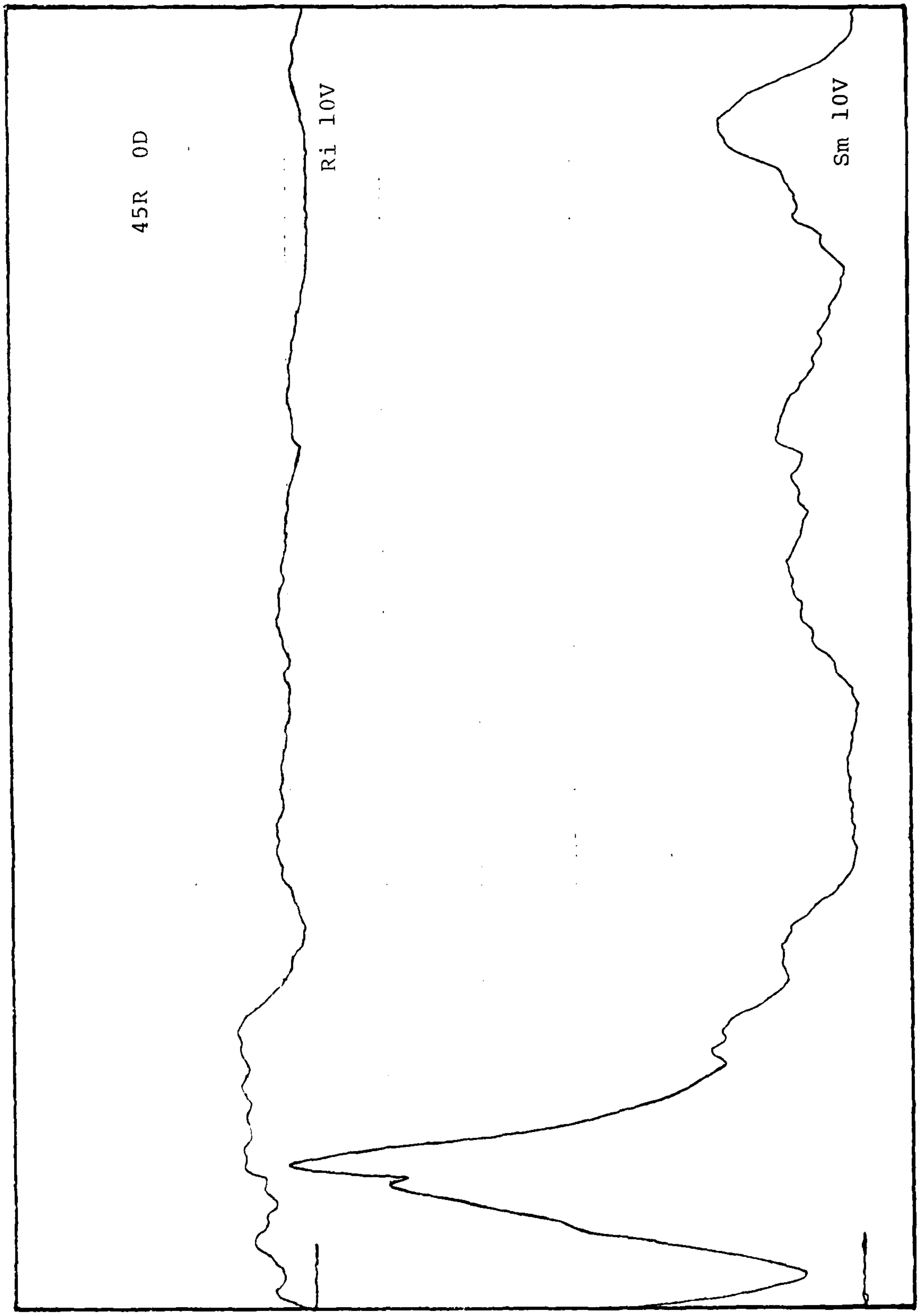
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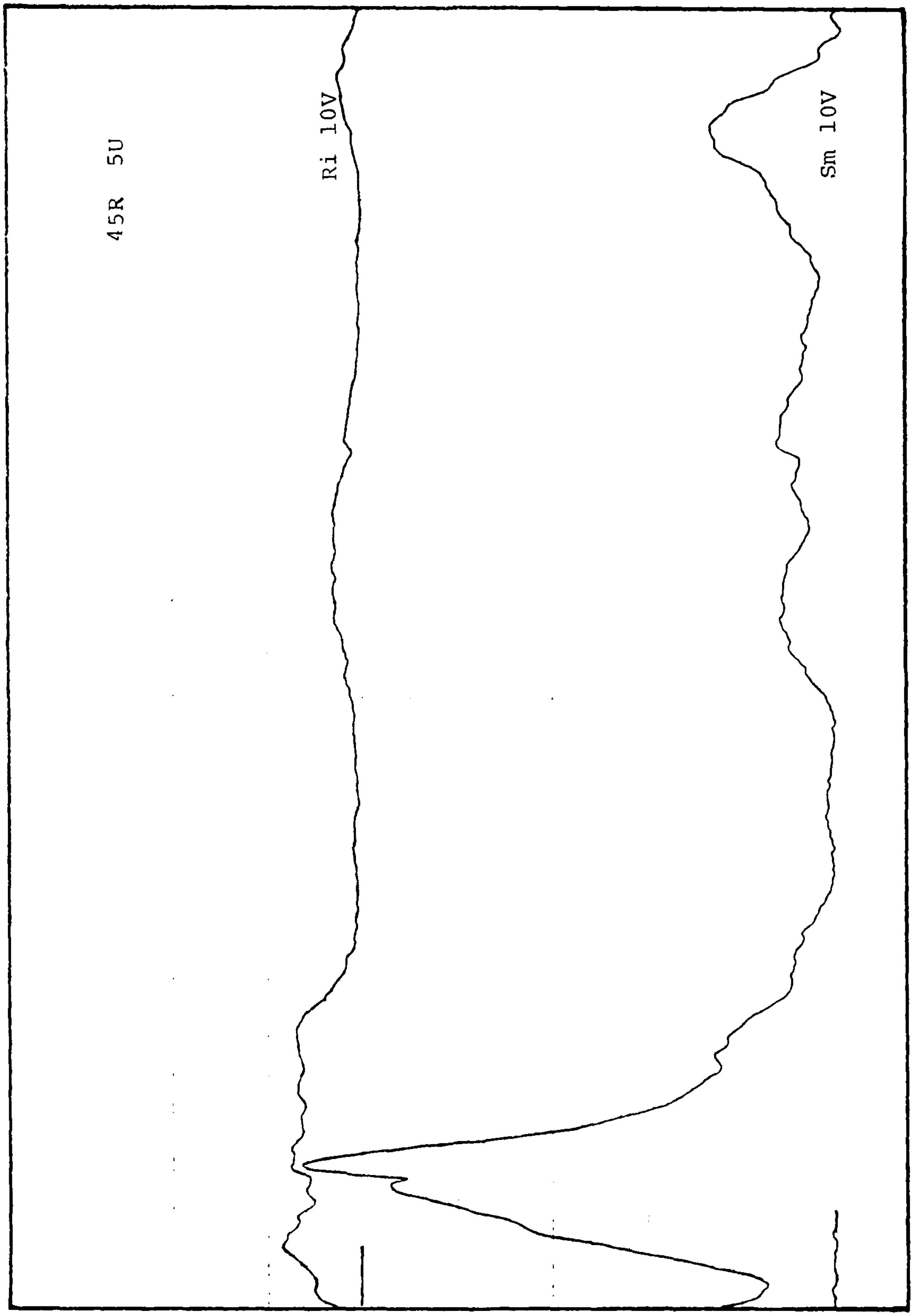
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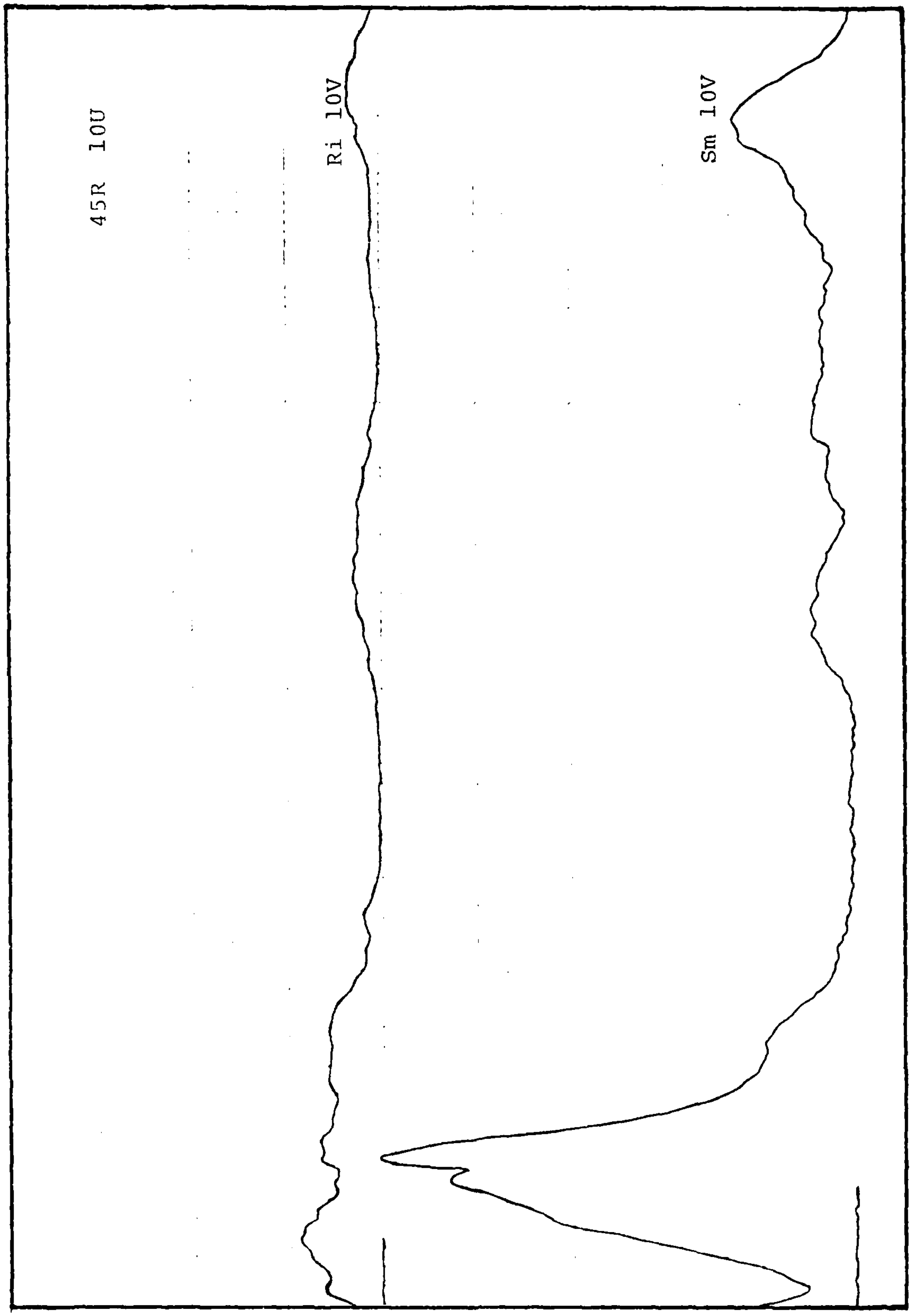
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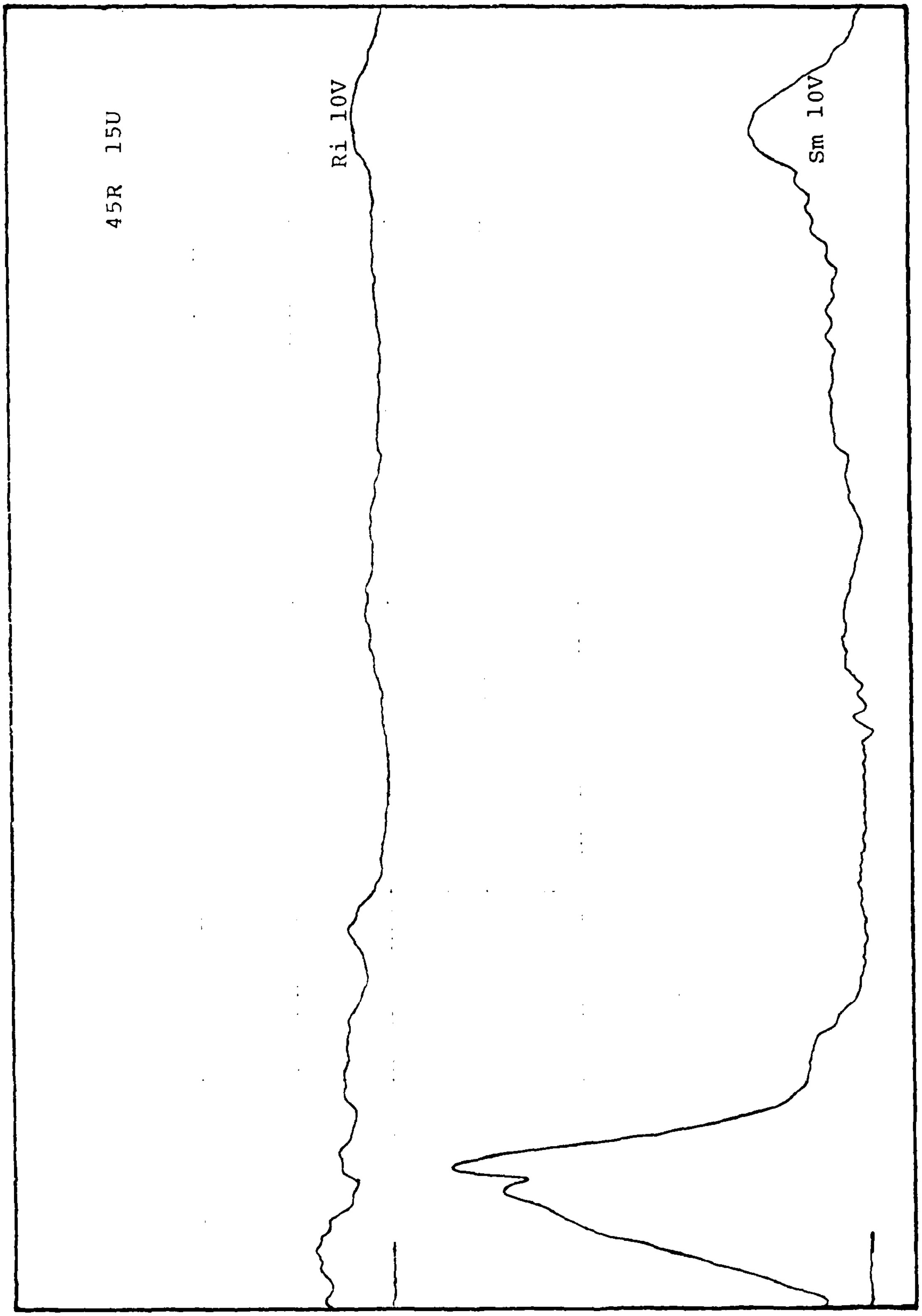
Sm 10V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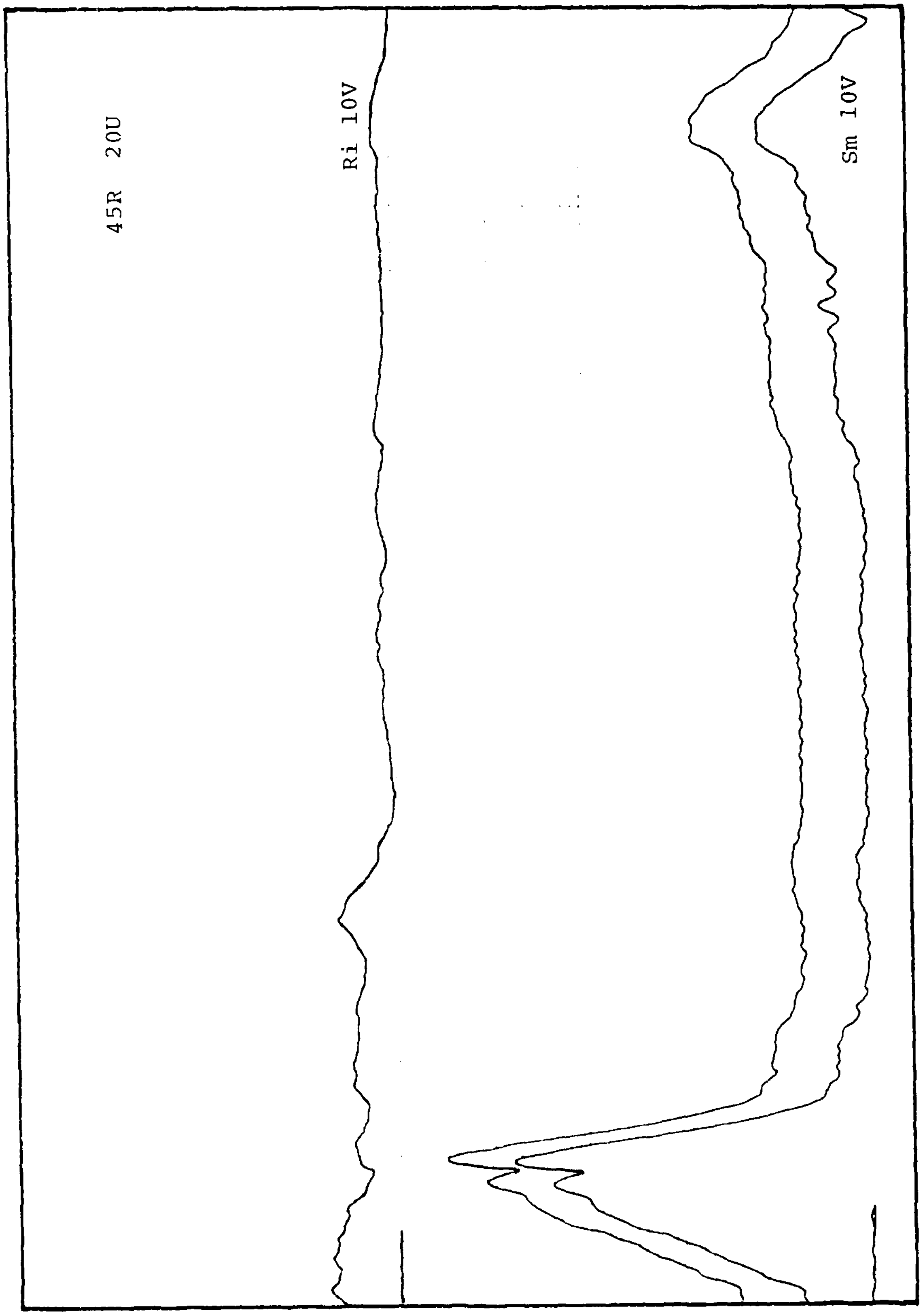
Sm 10V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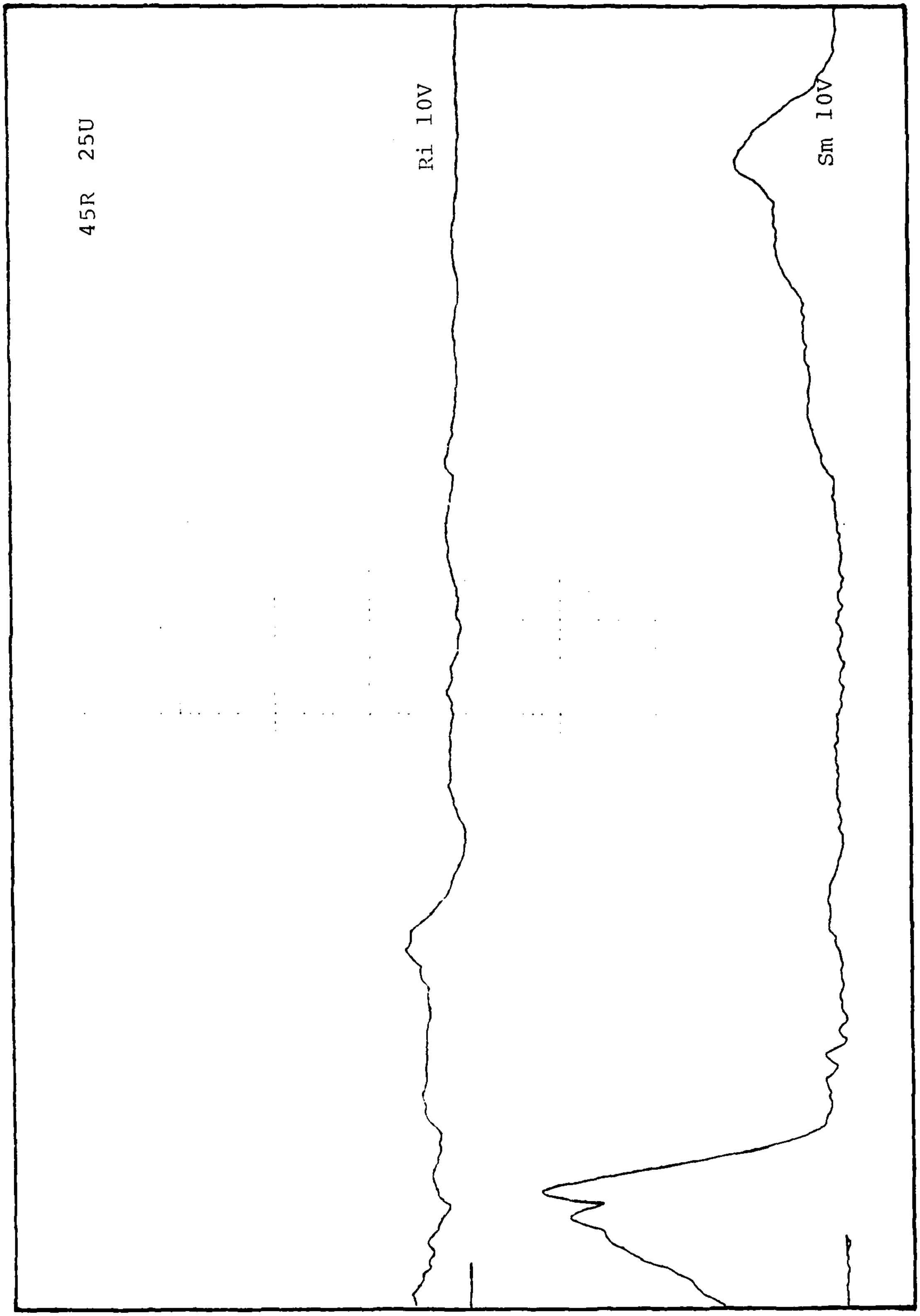
Sm 10V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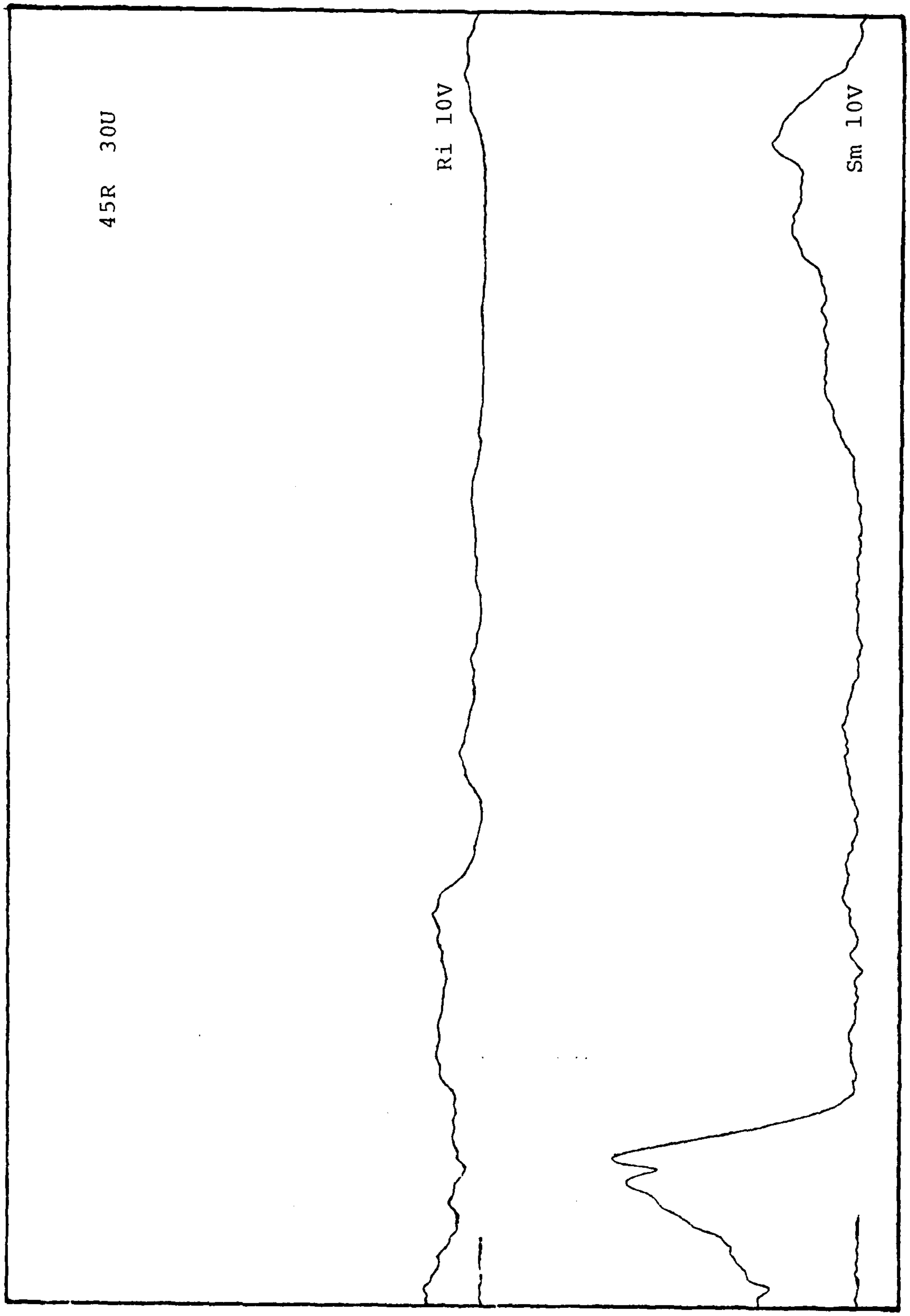
Sm 10V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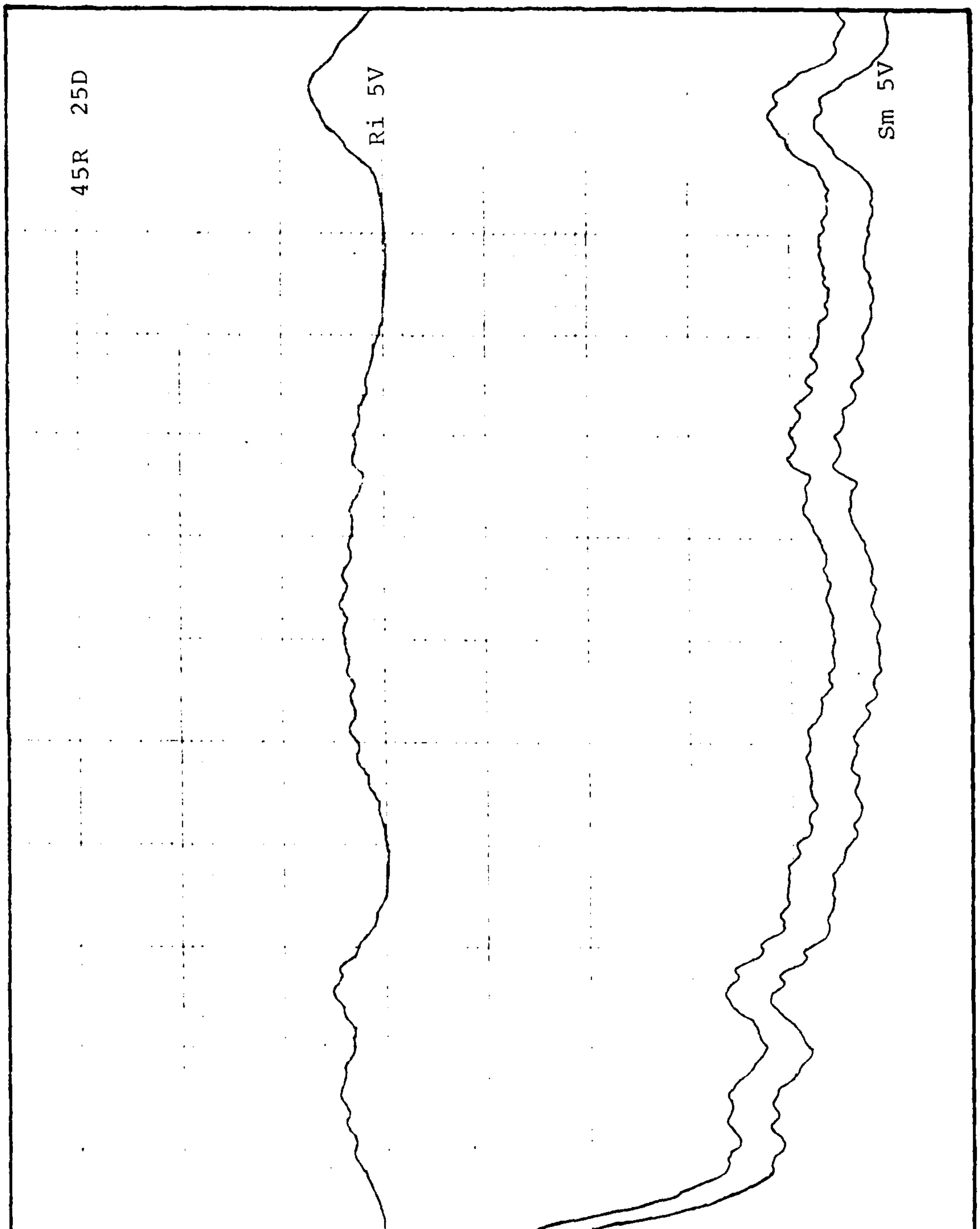
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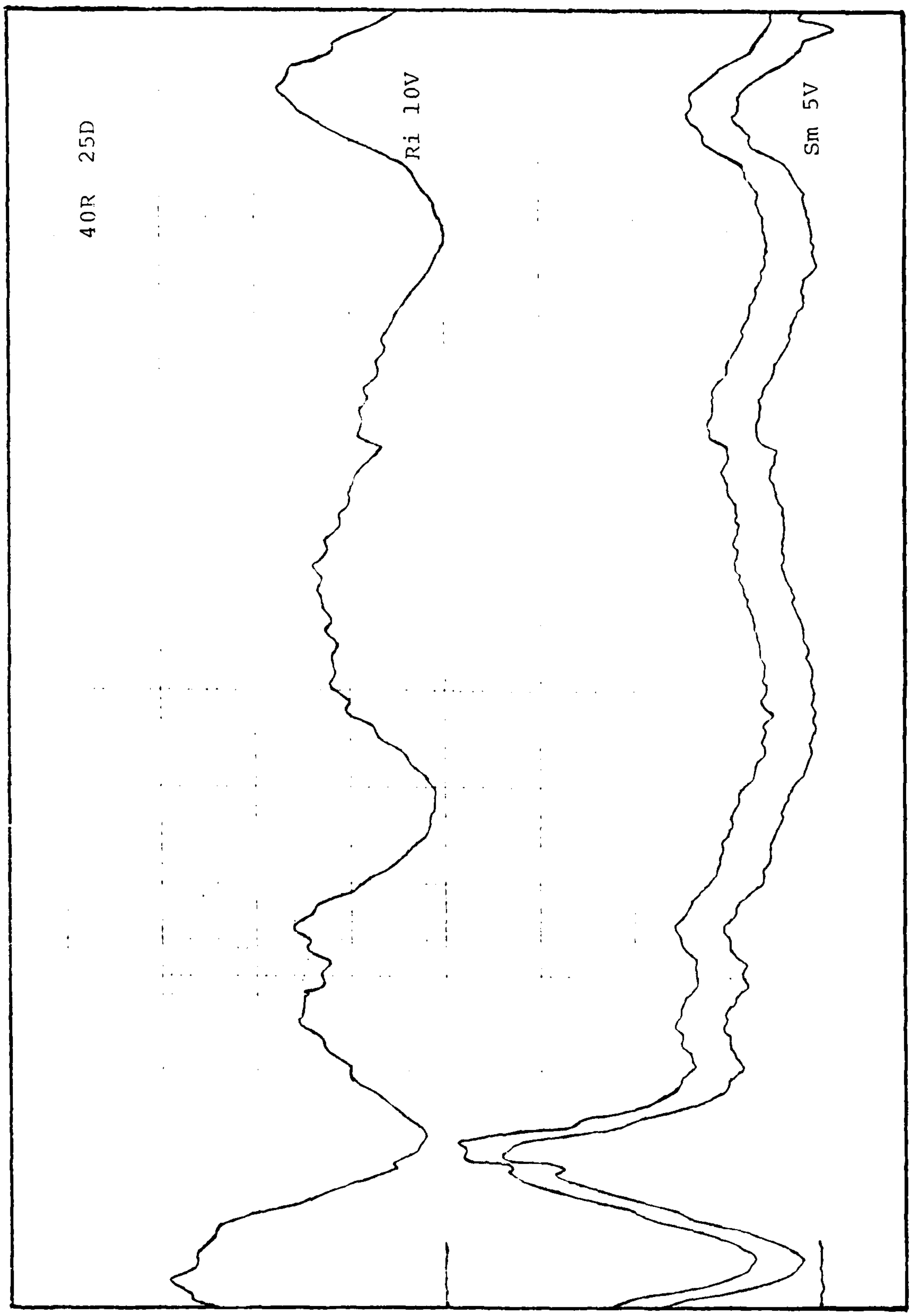
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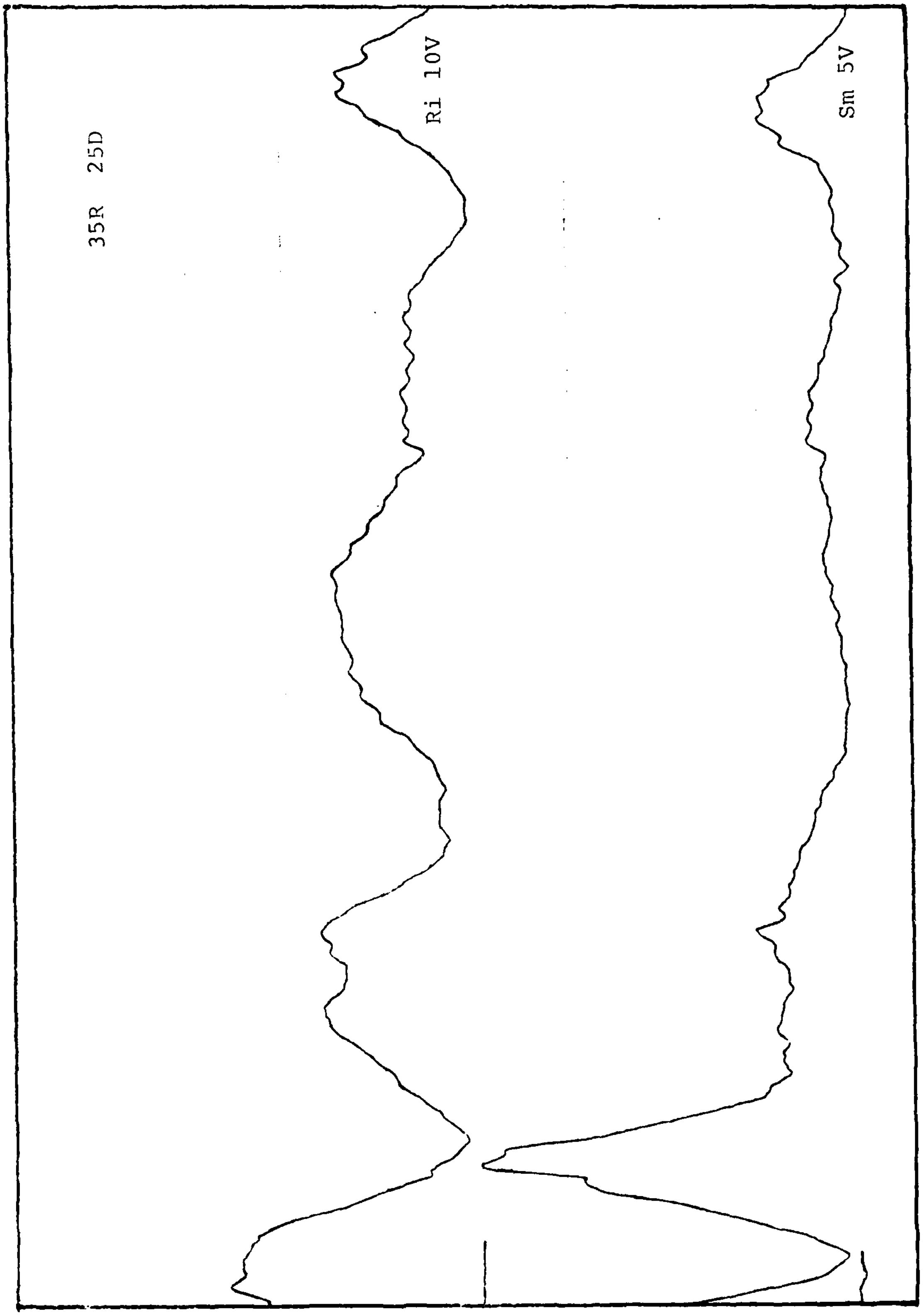

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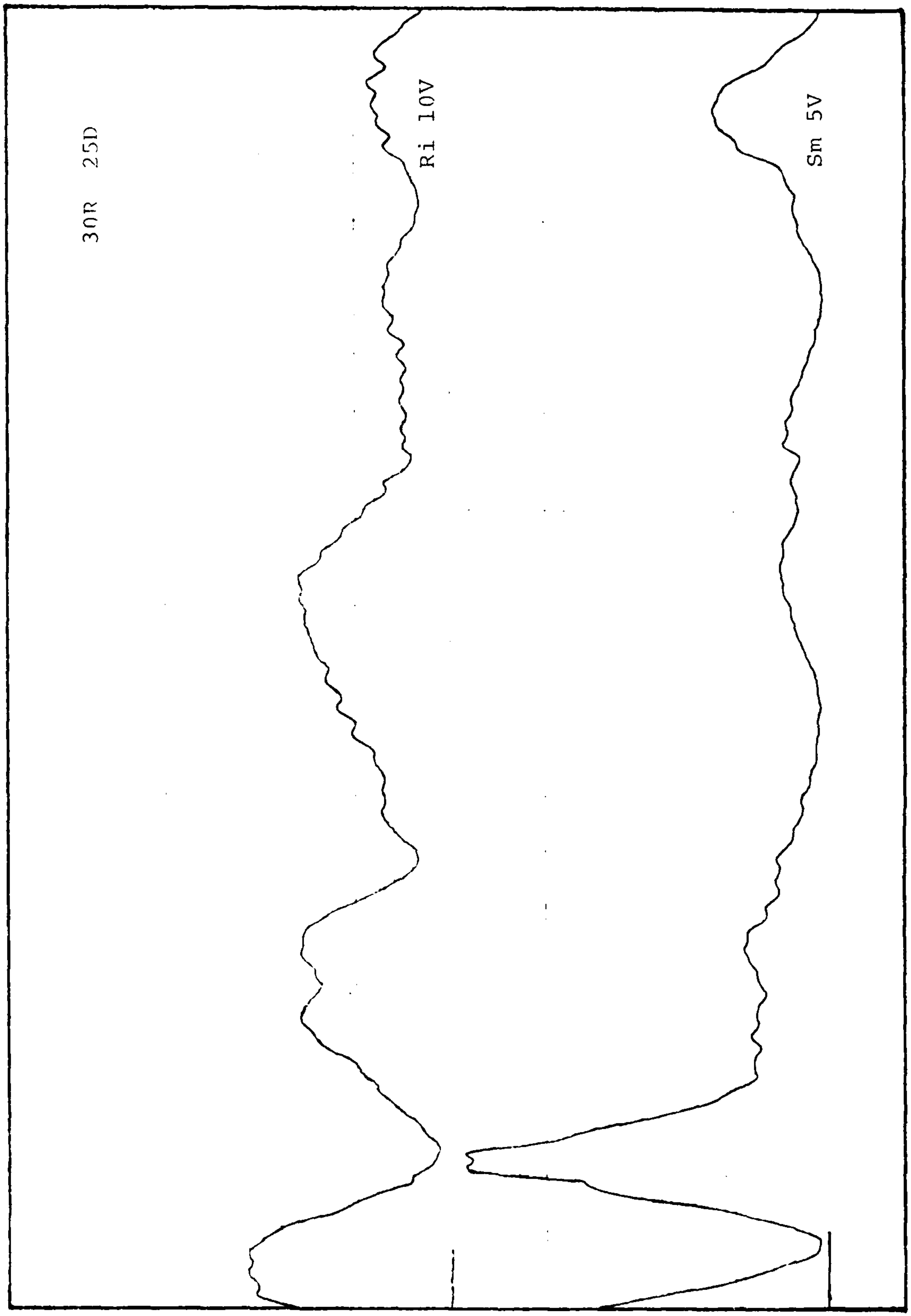
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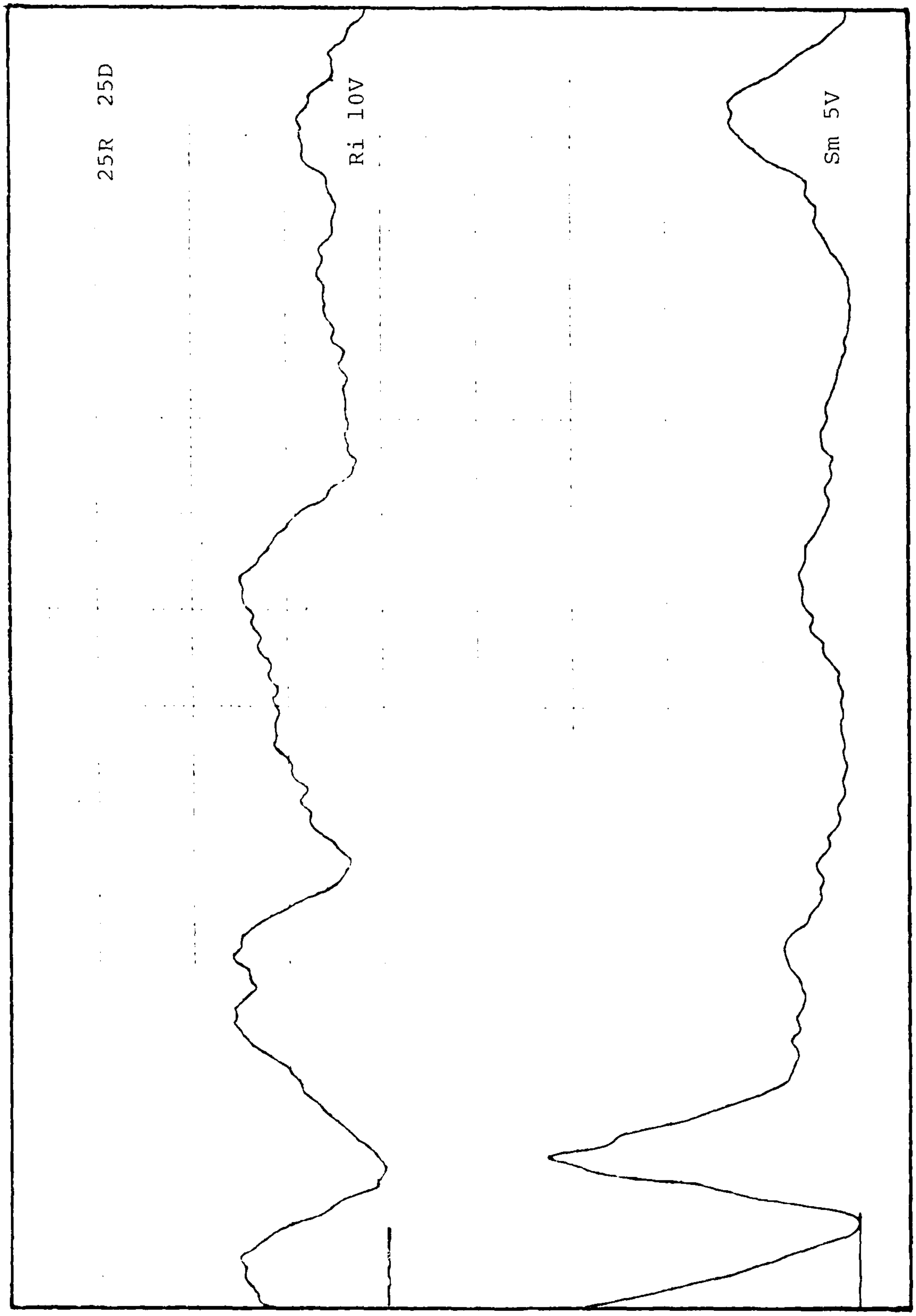
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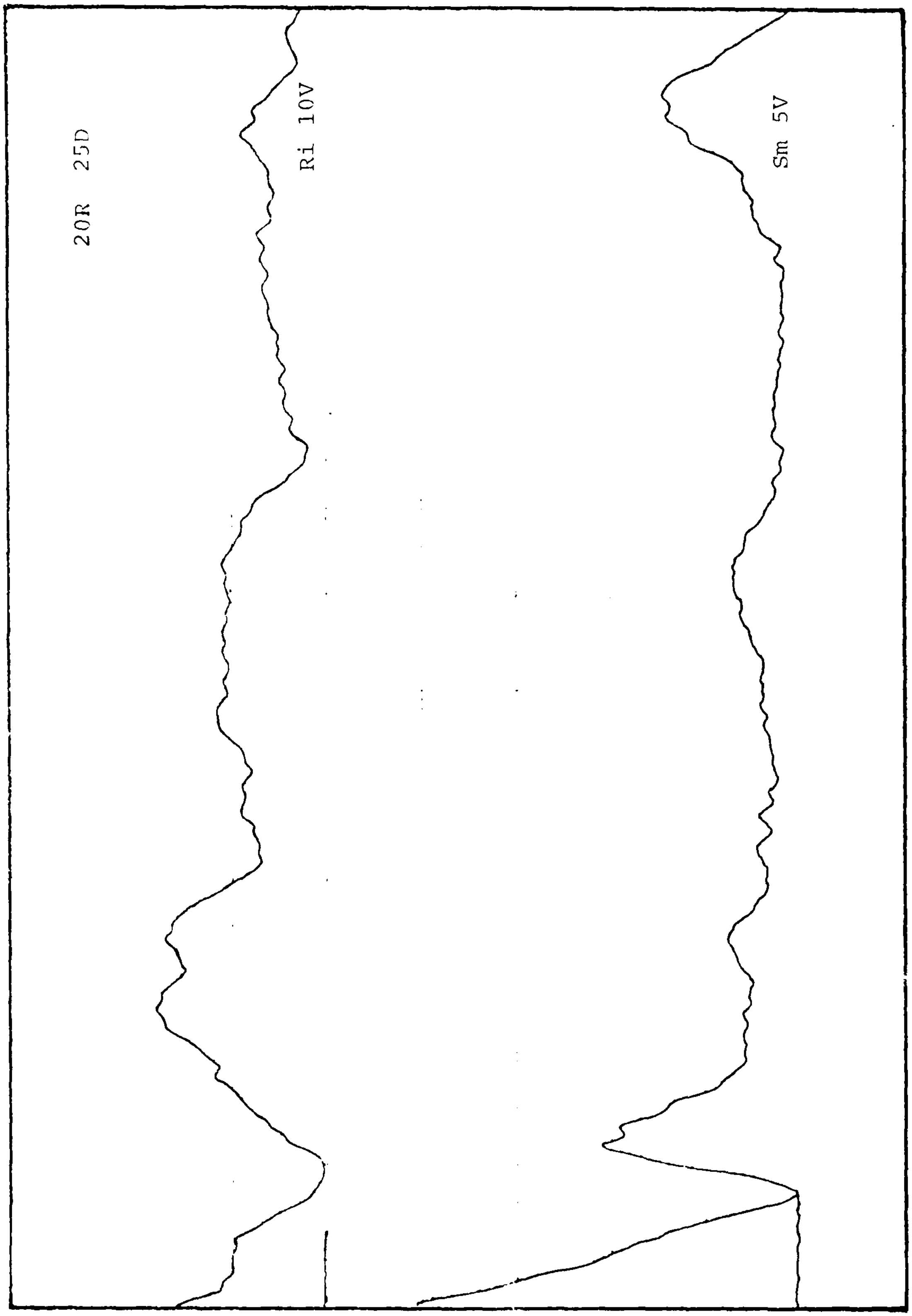
Ri 10V
Sm 5V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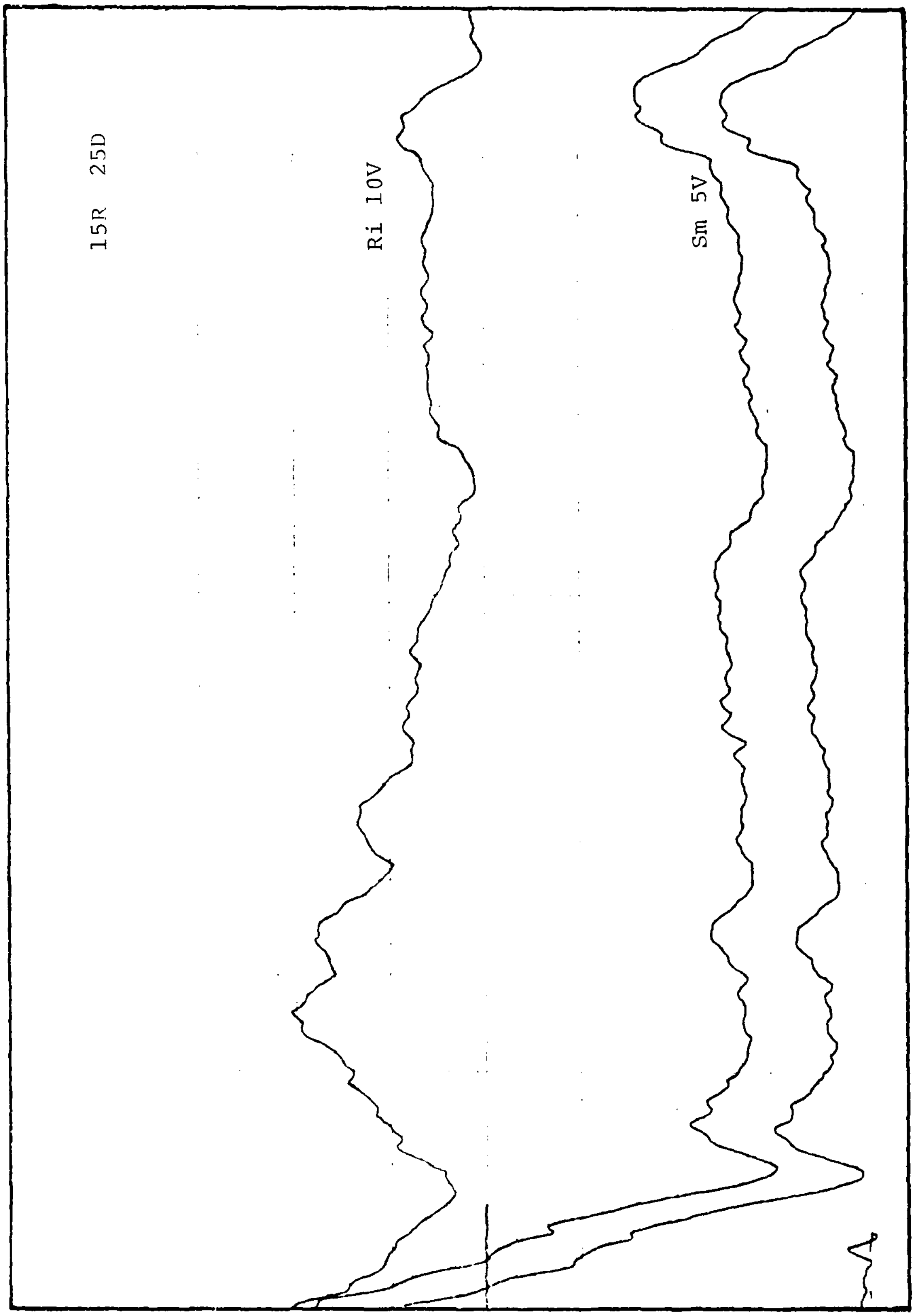
Sm 5V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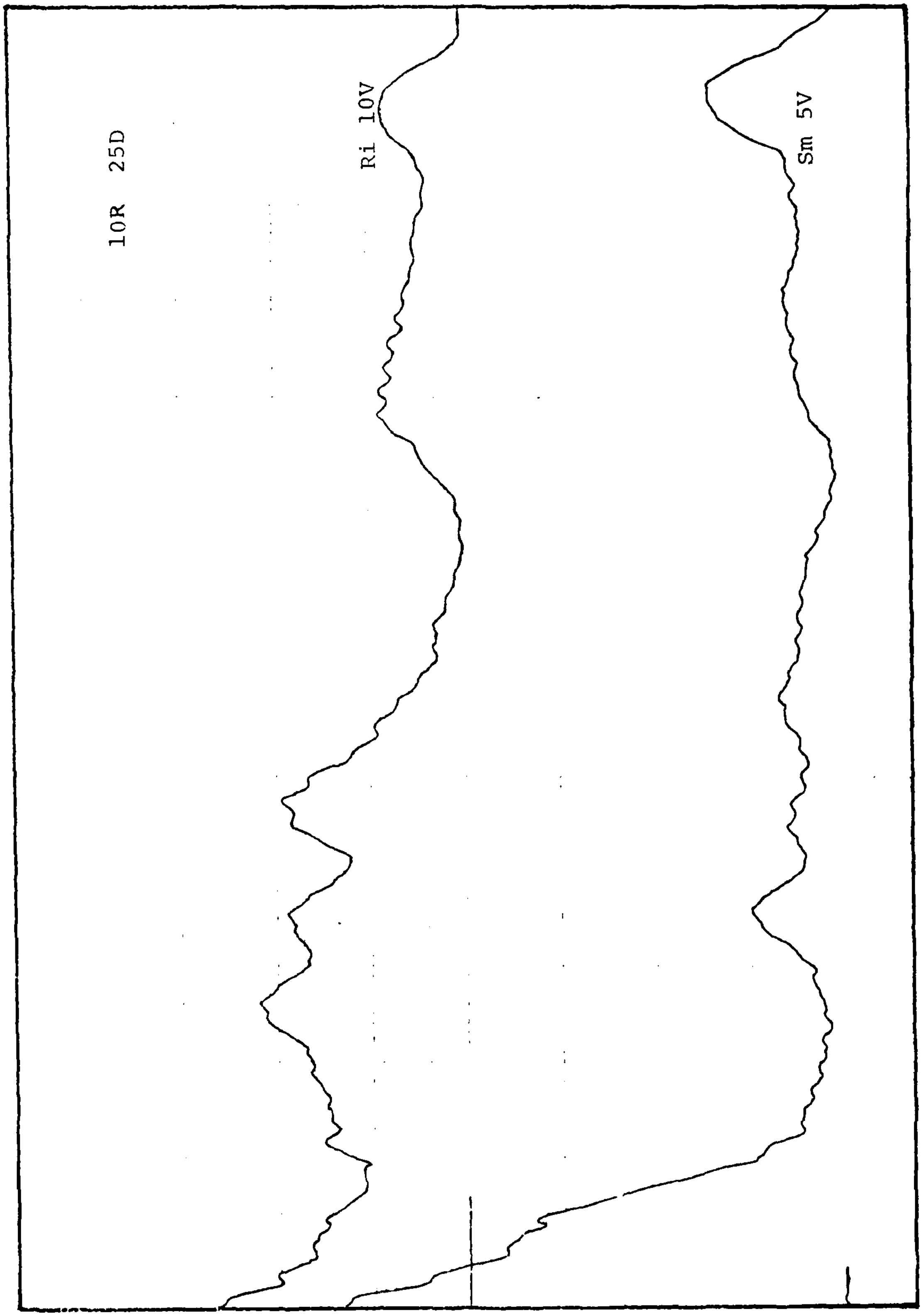
Ri 10V
Sm 5V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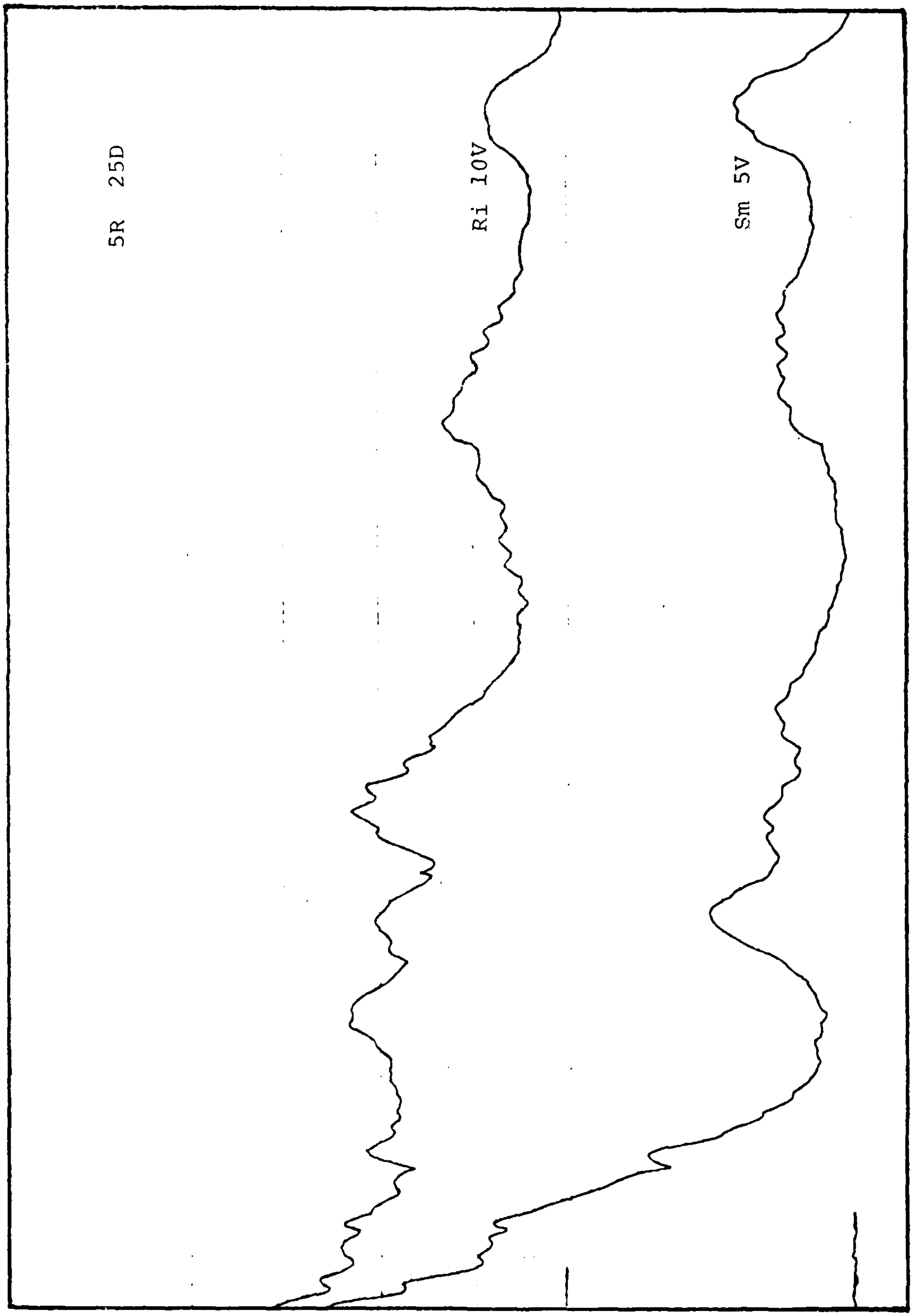
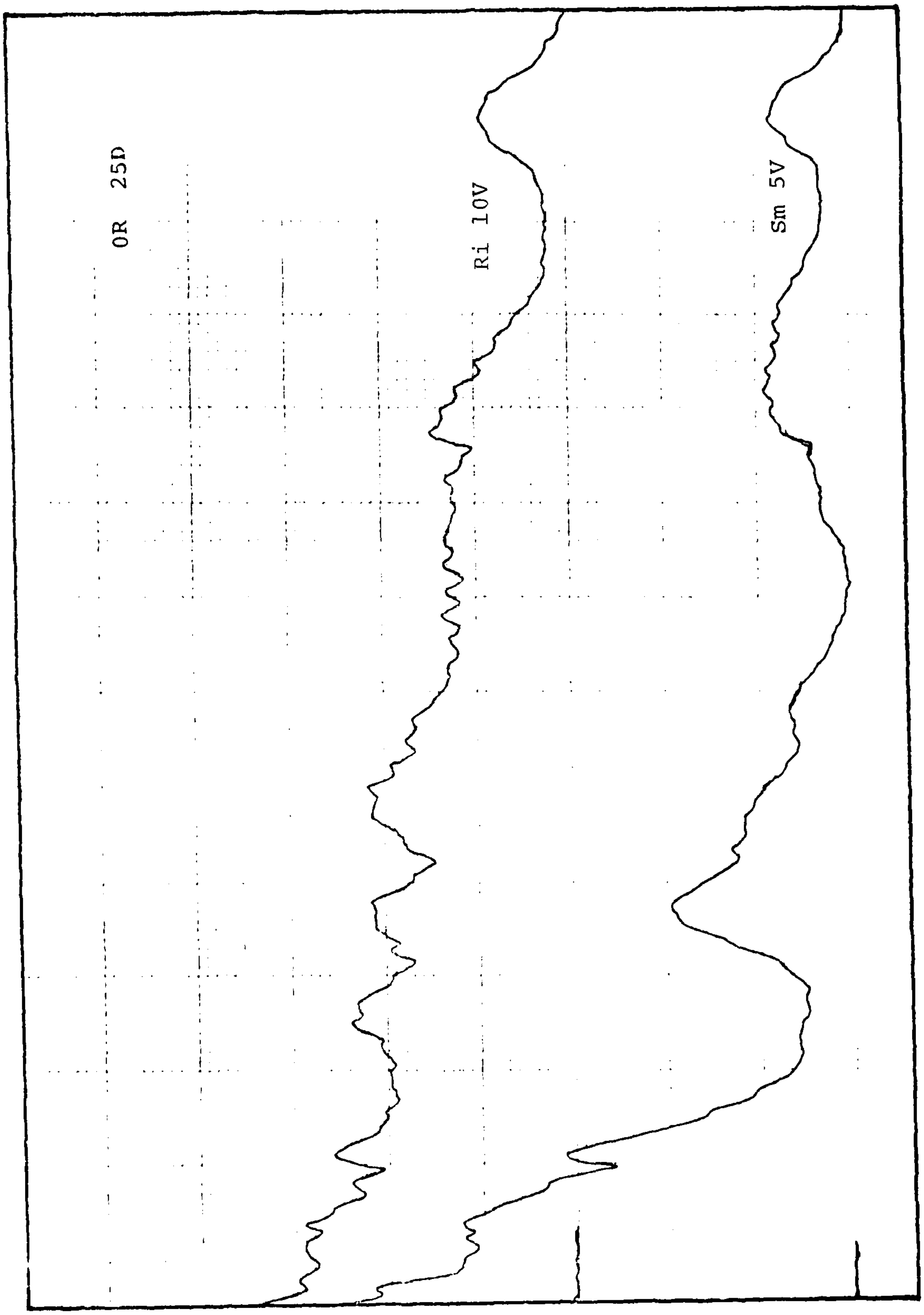
Ri 10V
Sm 5V


5R 25D
Ri 10V
Sm 5V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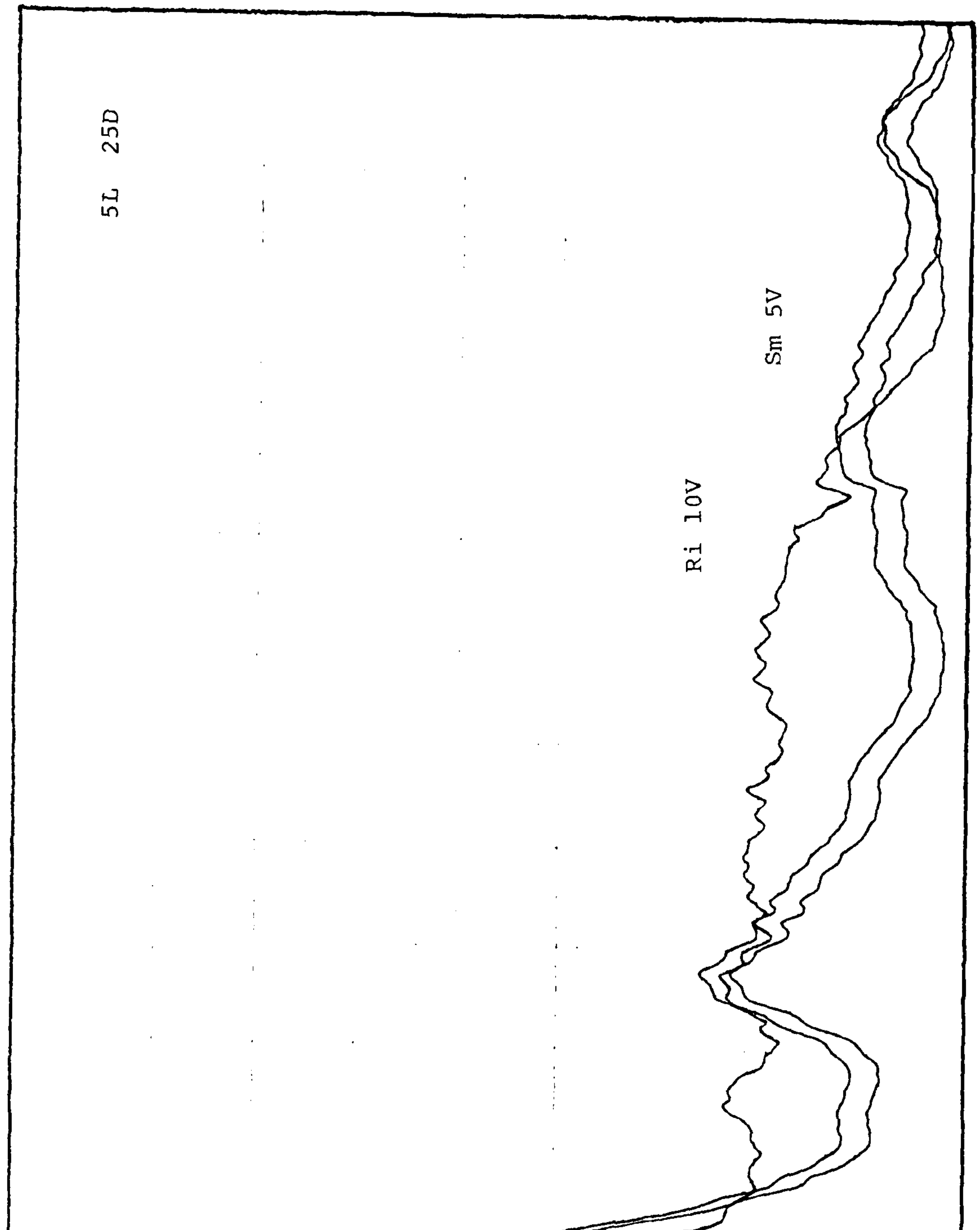
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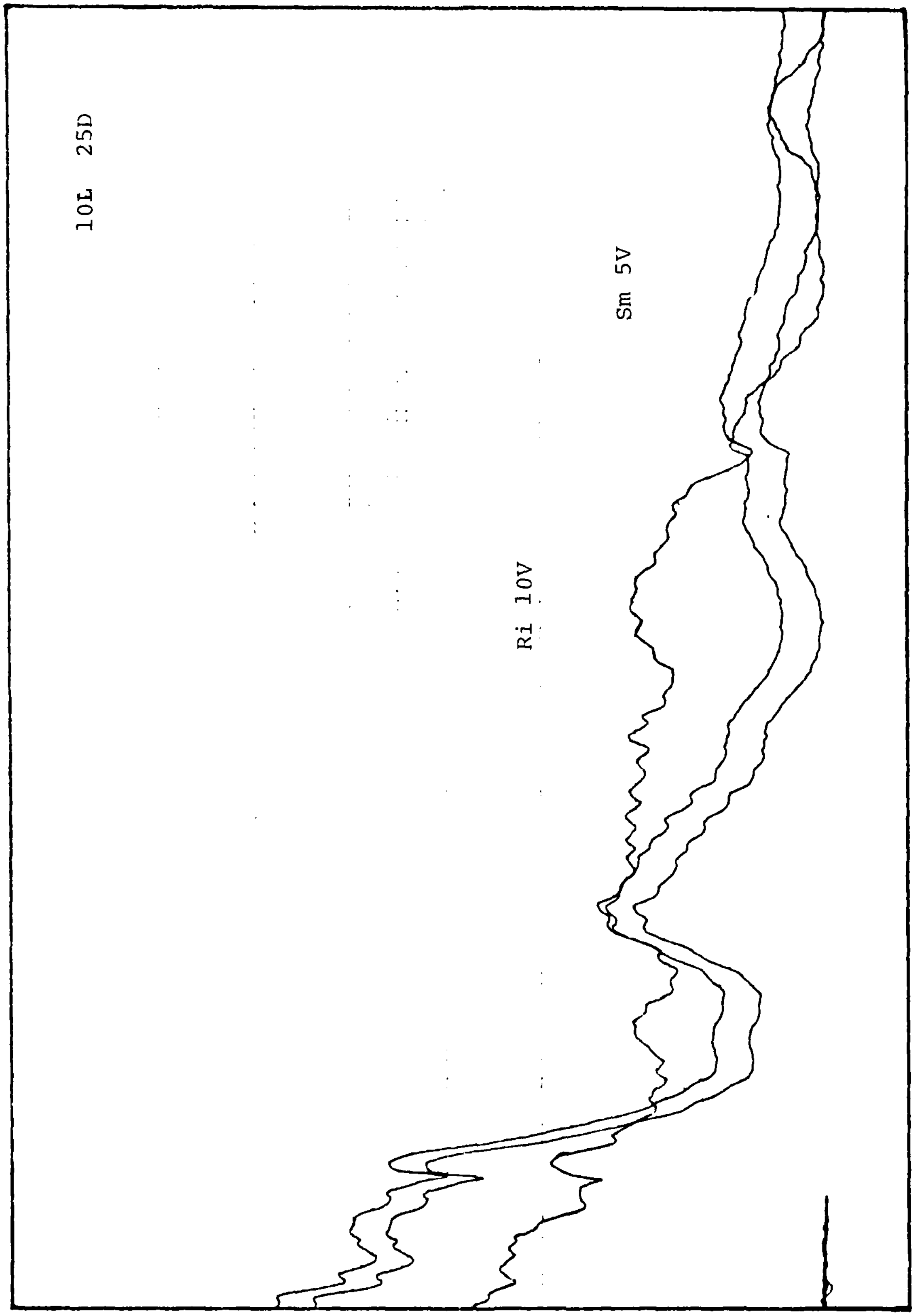
Sm 5V
Ri 10V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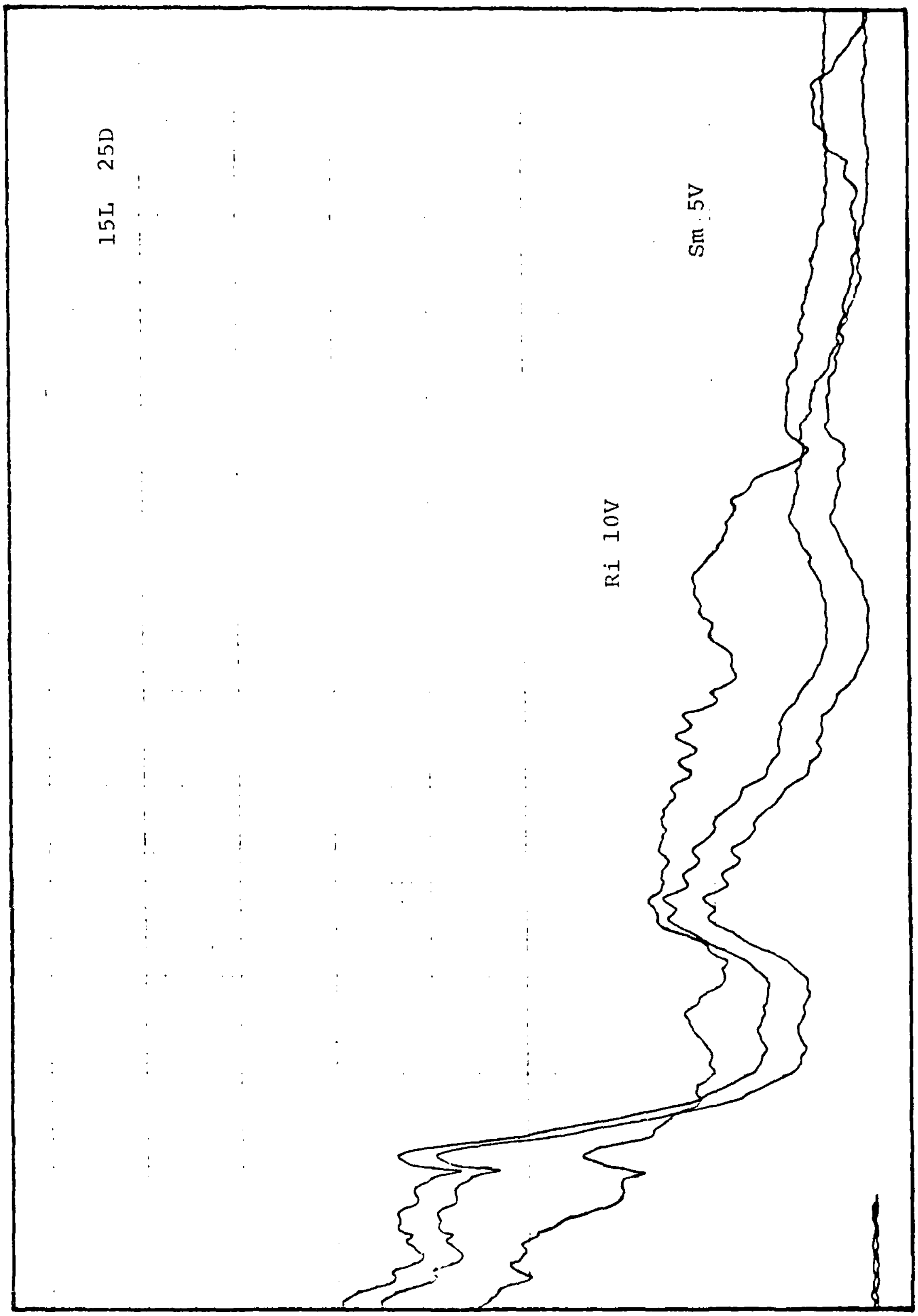
Ri 10V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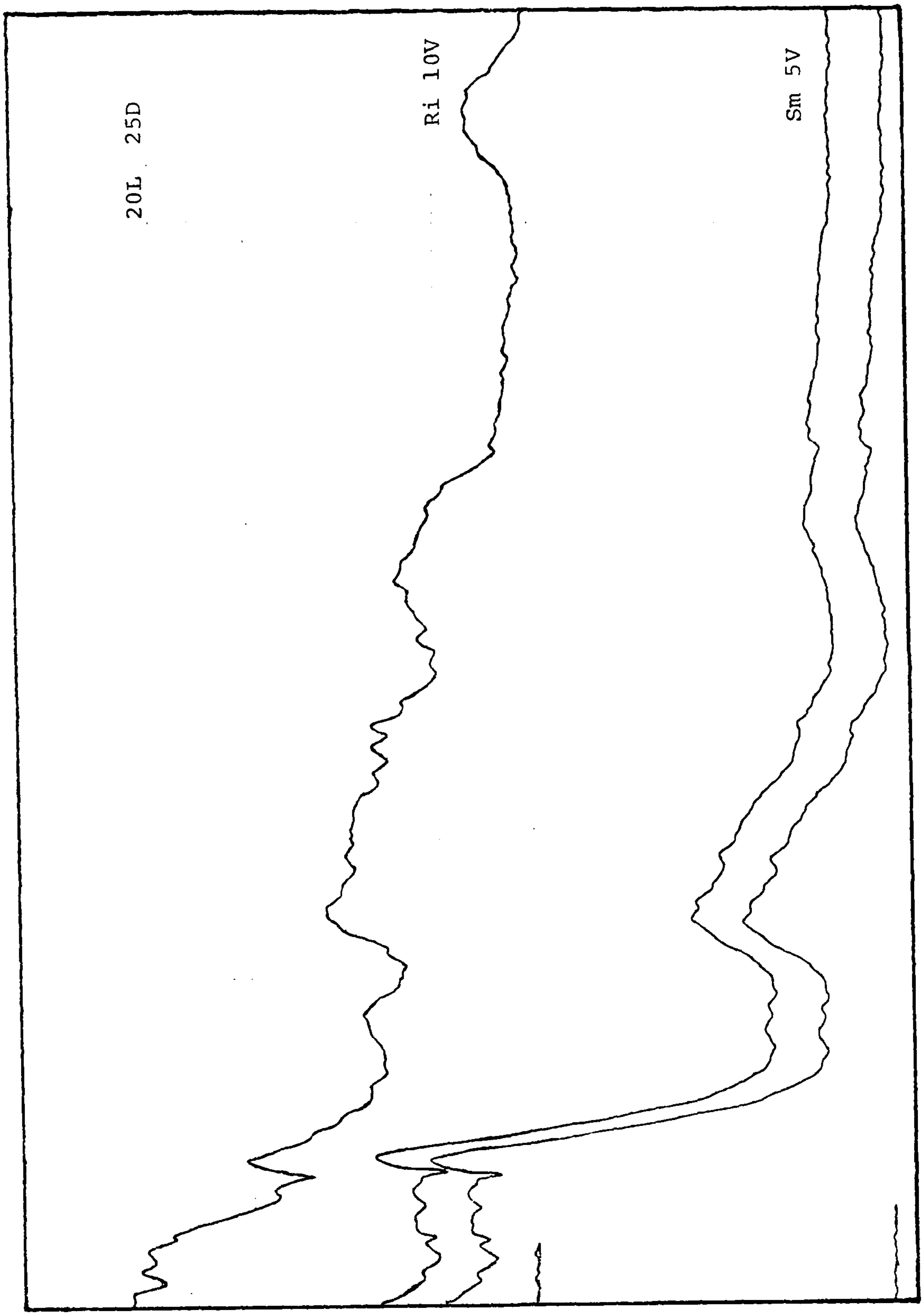
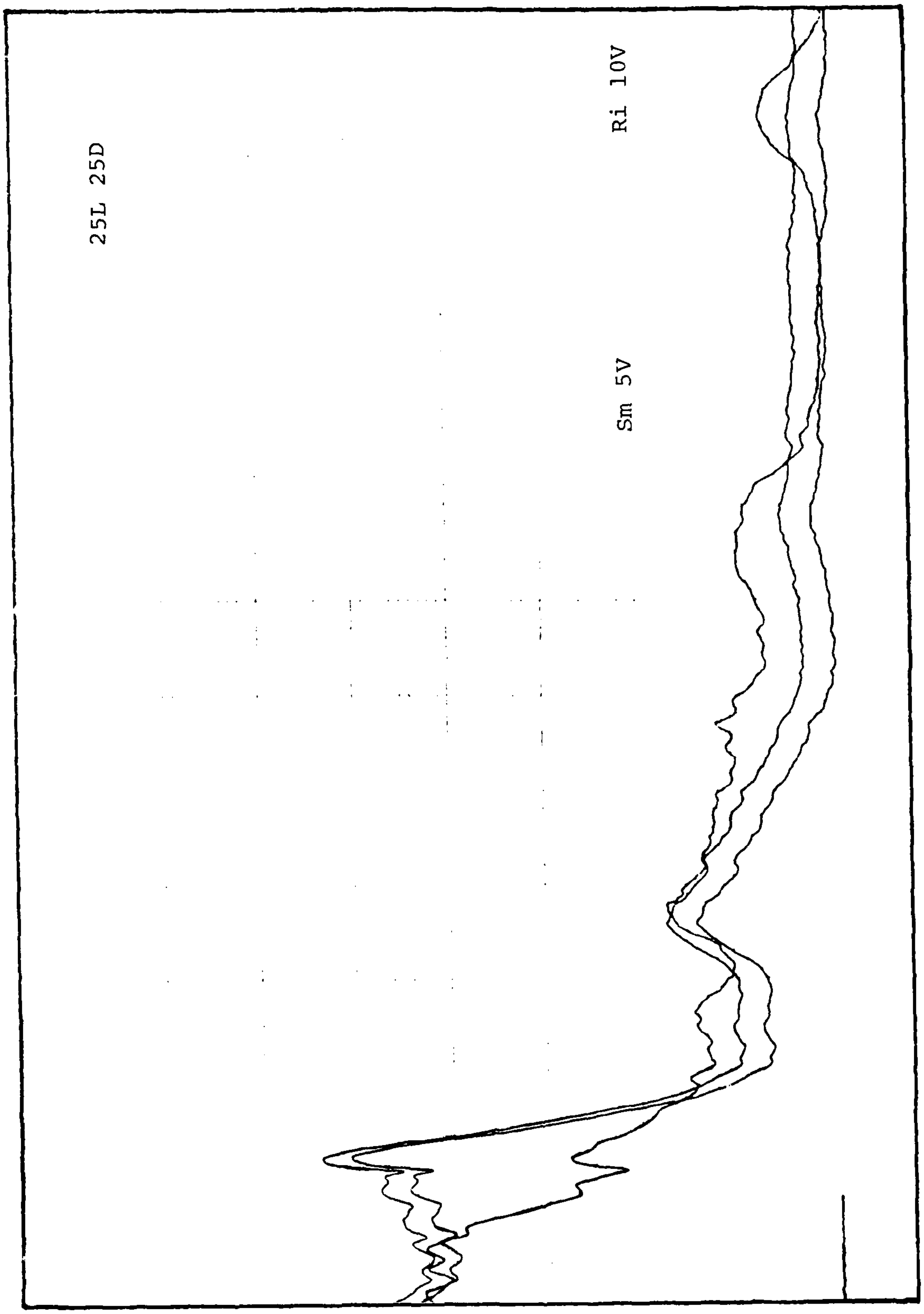
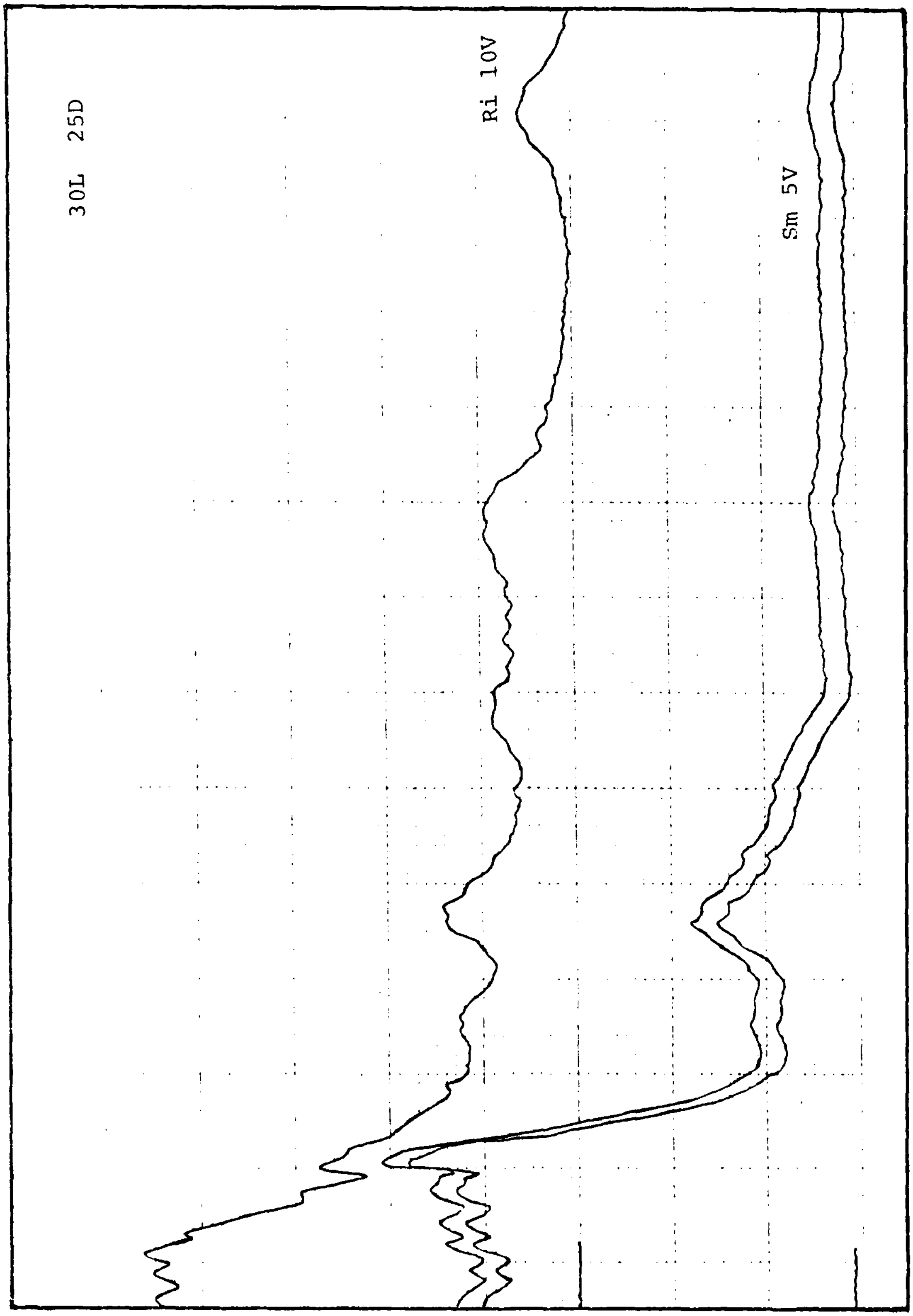
Ri 10V


20L 25D
Ri 10V
Sm 5V


25L 25D
Ri 10V
Sm 5V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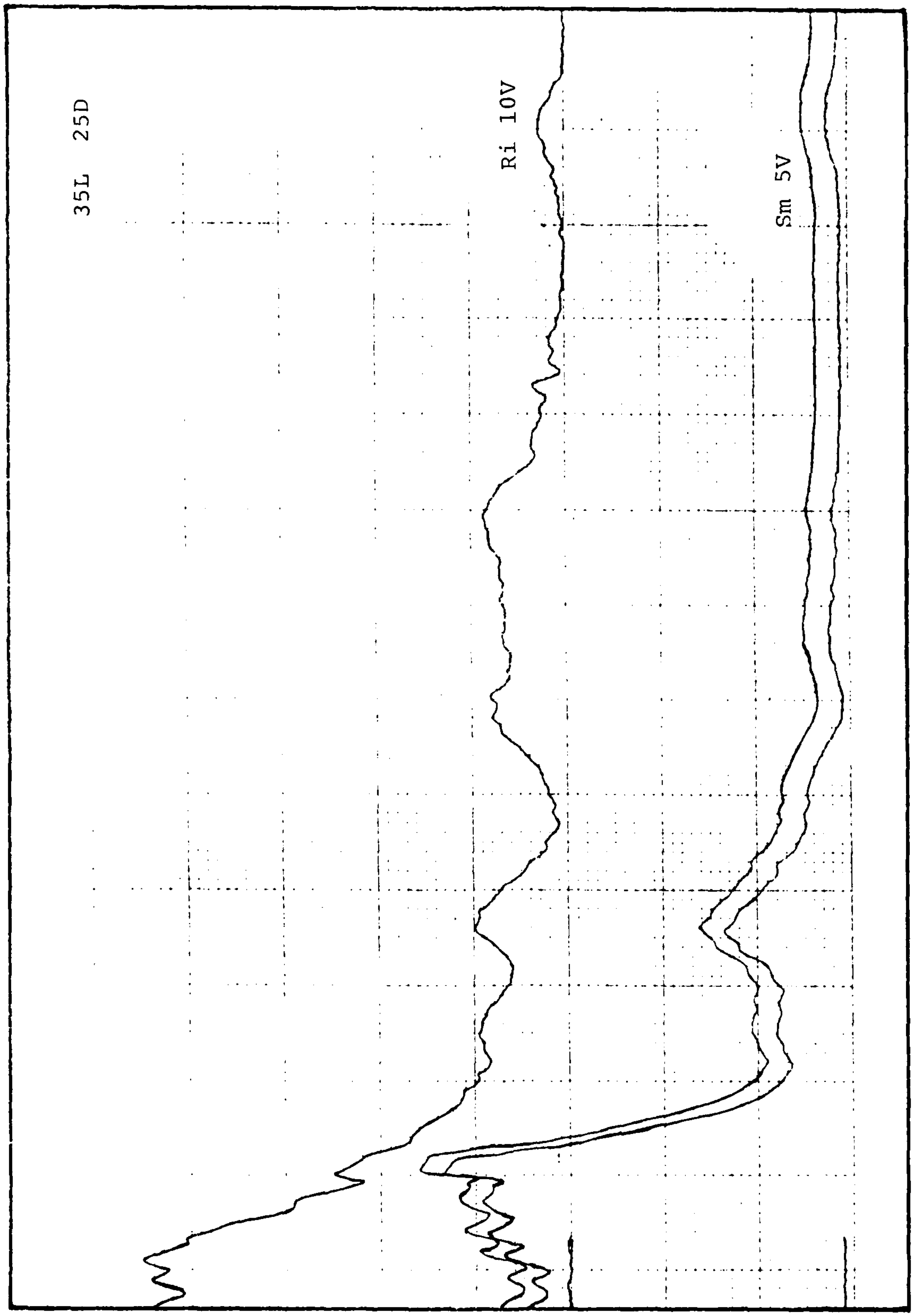
Ri 10V
Sm 5V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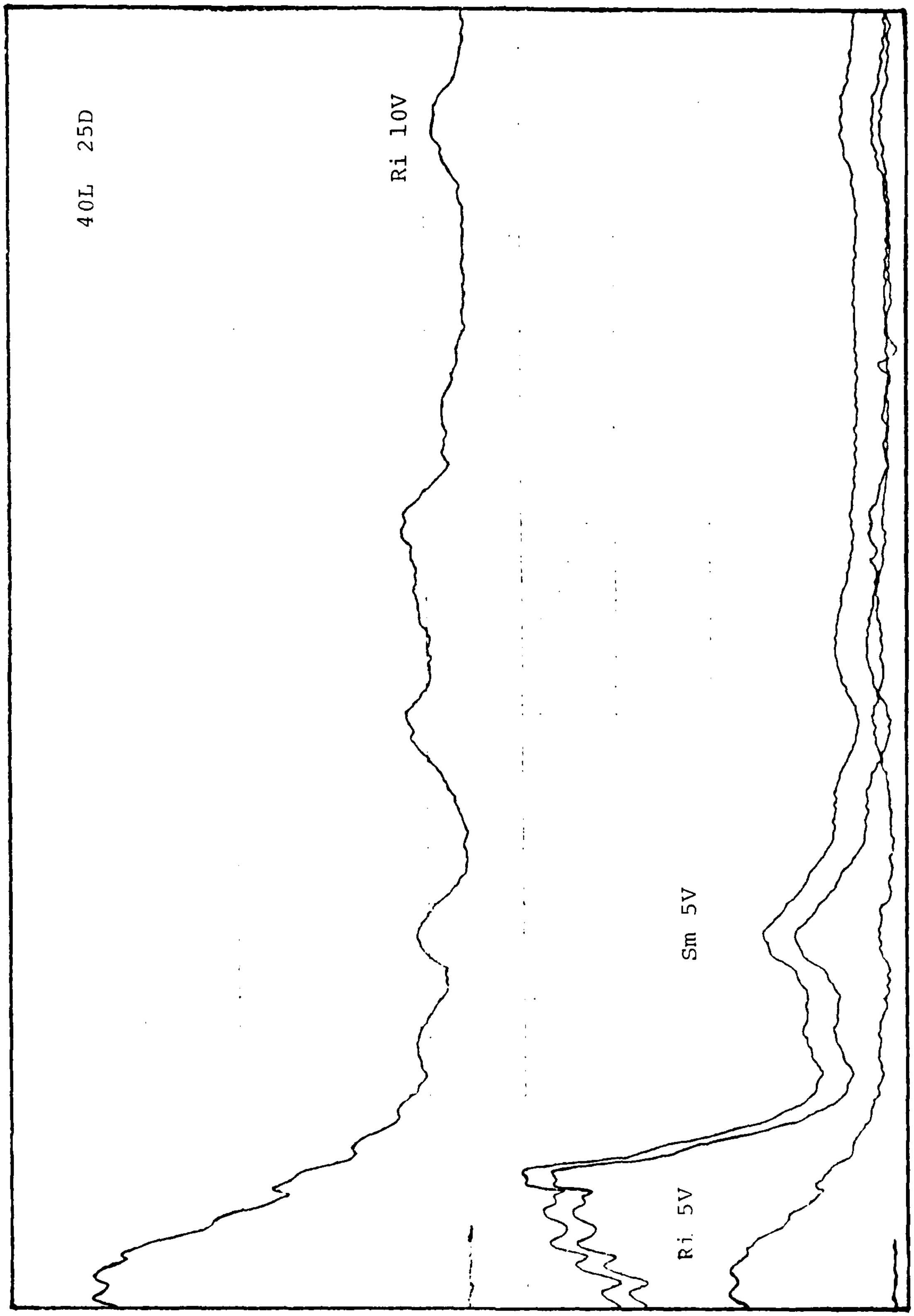
Ri 10V
Sm 5V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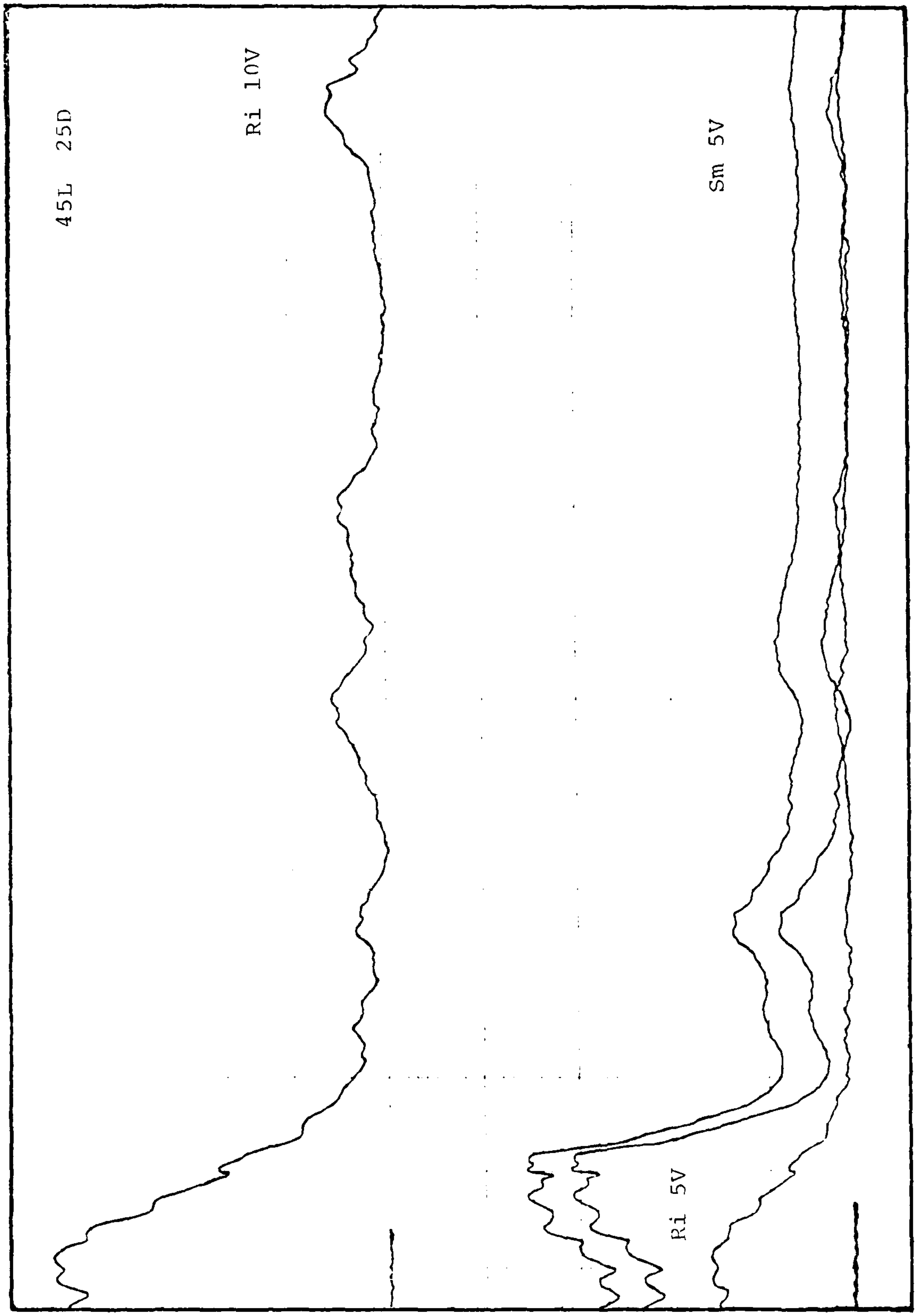
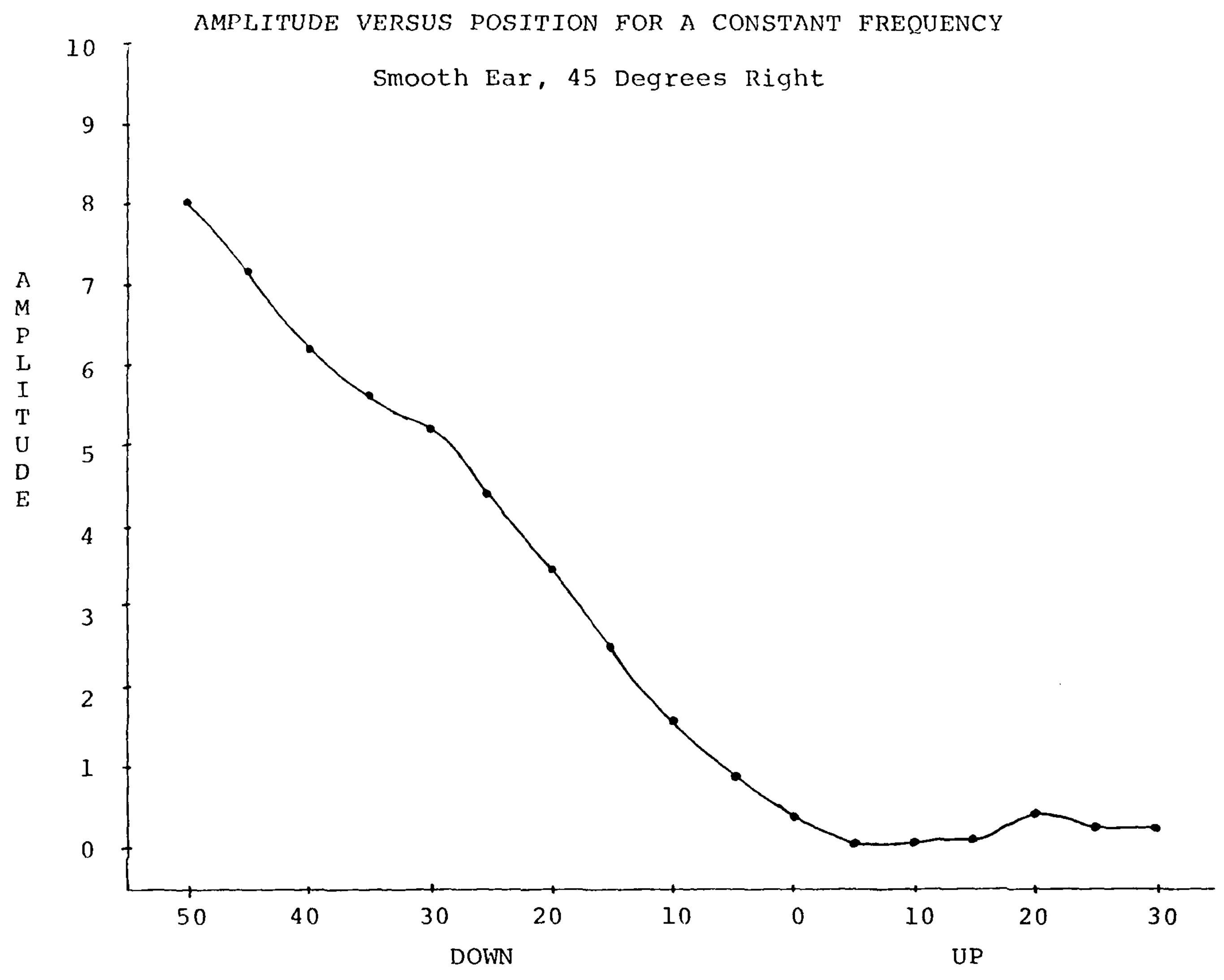
Ri 10V
Sm 5V
Ri 5V

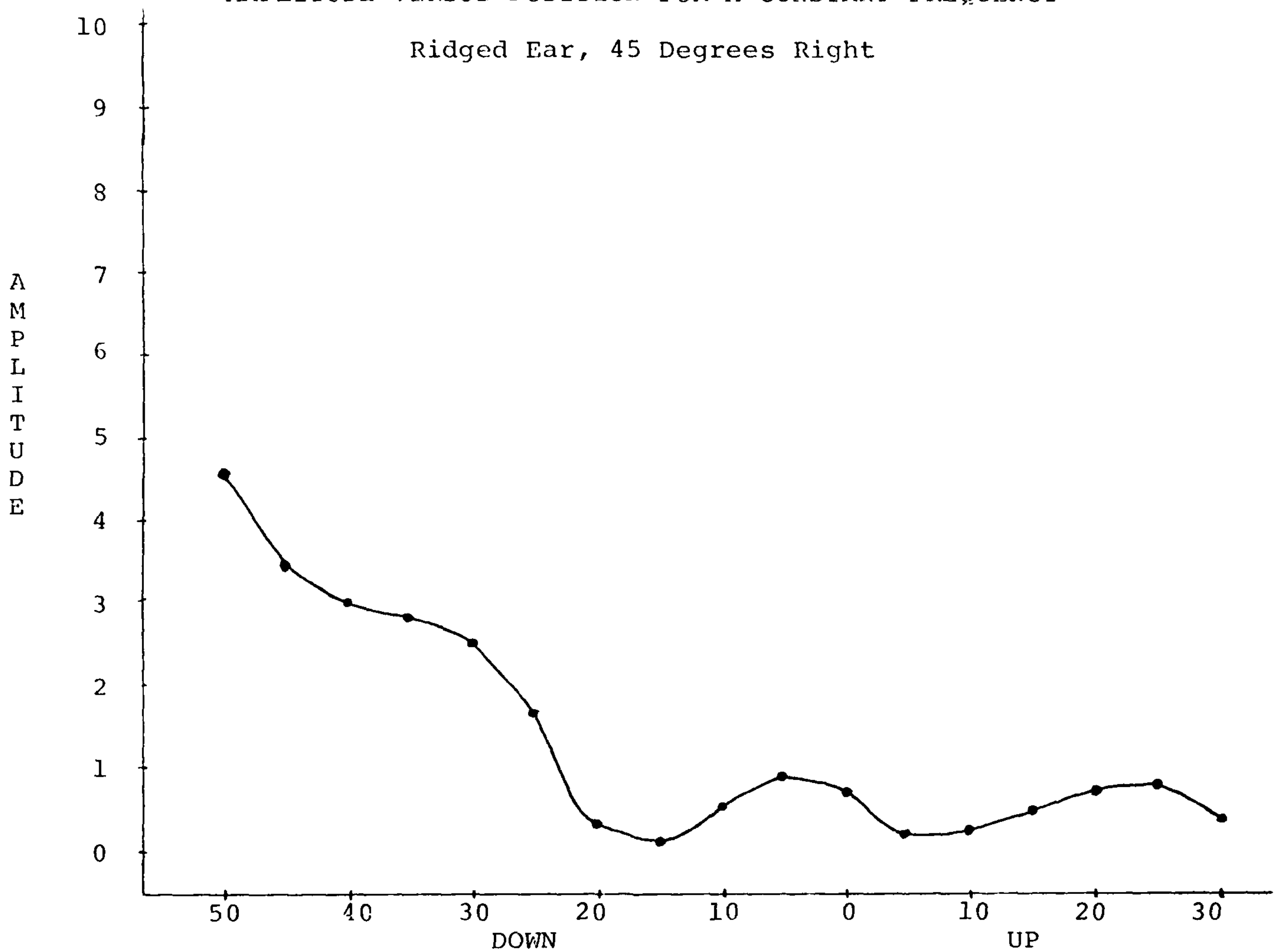

45L 25D
Ri 10V
Sm 5V
Ri 5V

Pages 62 through 65 are graphs showing the model's sensitivity to position at a constant frequency (6 kHz). For both the vertical column and horizontal row of data previously presented, plots are made of amplitude versus position. Pages 62 and 63 represent the model turned 45 degrees to the right of the speaker. Beginning at the left, the model is set at 50 degrees down and is then raised in 5 degree steps until the model is pointing 30 degrees up. Pages 64 and 65 represent the model pointed 25 degrees down. Beginning at the left, the model is aimed 45 degrees right and is then turned in 5 degree steps to the left until 45 degrees left is reached. All values of amplitude are normalized and the same arbitrary scale is used throughout.


AMPLITUDE VERSUS POSITION FOR A CONSTANT FREQUENCY
Smooth Ear, 45 Degrees Right
AMPLITUDE
10
9
8
7
6
5
4
3
2
1
0
50
40
30
20
10
0
10
20
30
DOWN
UP

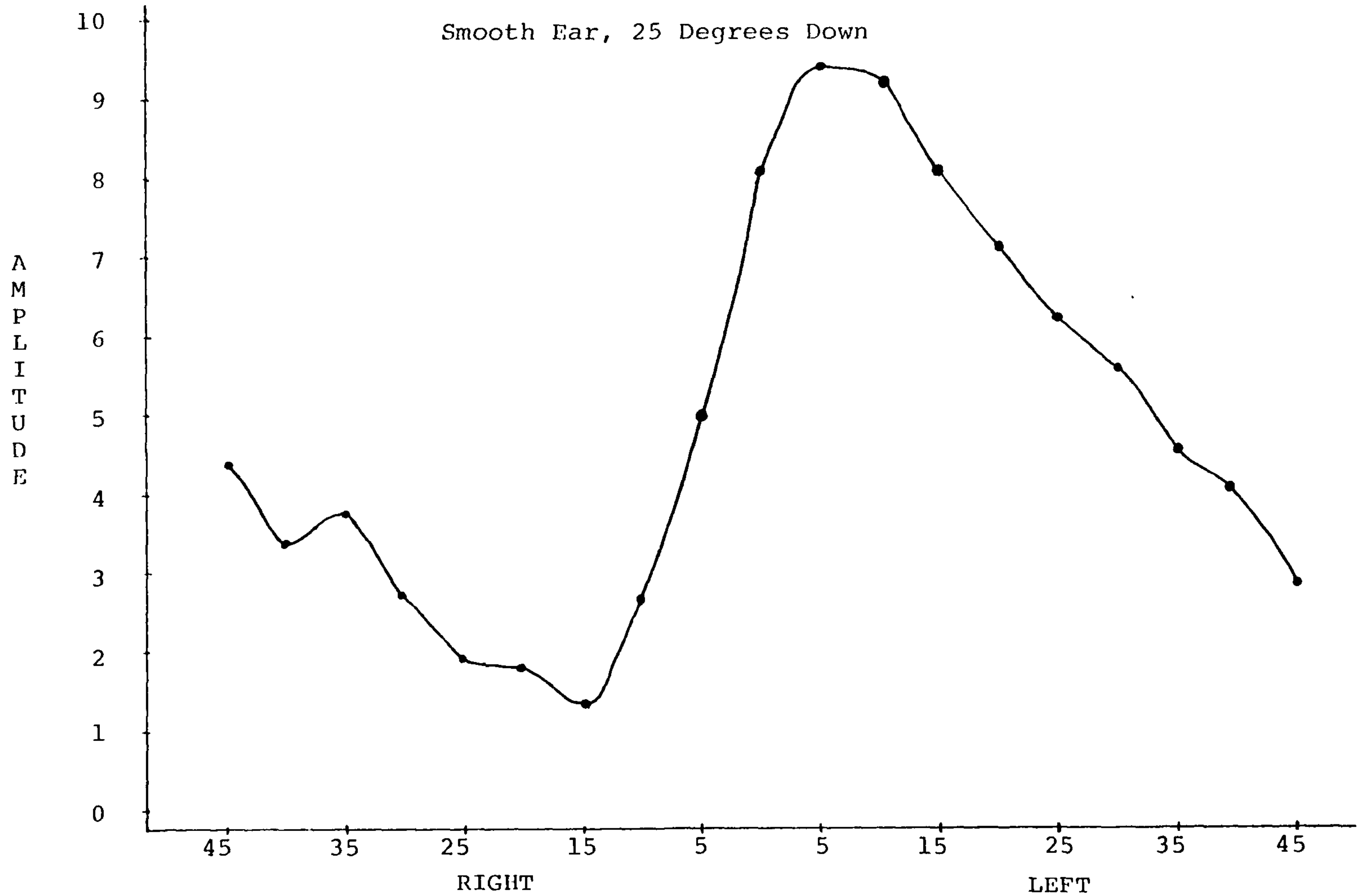
AMPLITUDE VERSUS POSITION FOR A CONSTANT FREQUENCY

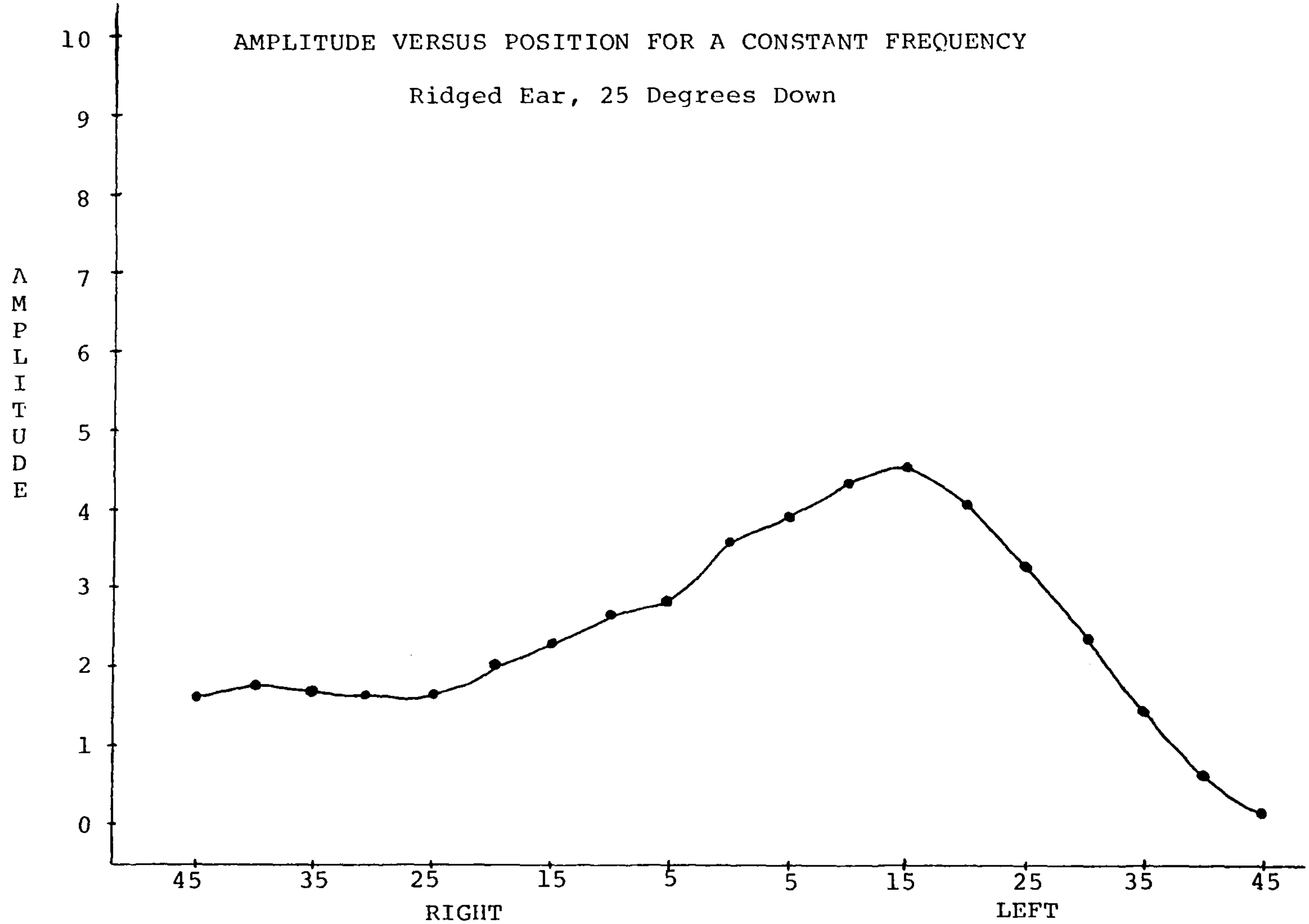
Ridged Ear, 45 Degrees Right



AMPLITUDE VERSUS POSITION FOR A CONSTANT FREQUENCY

Smooth Ear, 25 Degrees Down




AMPLITUDE VERSUS POSITION FOR A CONSTANT FREQUENCY
Ridged Ear, 25 Degrees Down
AMPLITUDE
10
9
8
7
6
5
4
3
2
1
0
45
35
25
15
5
5
15
25
35
45
RIGHT
LEFT

Appendix C

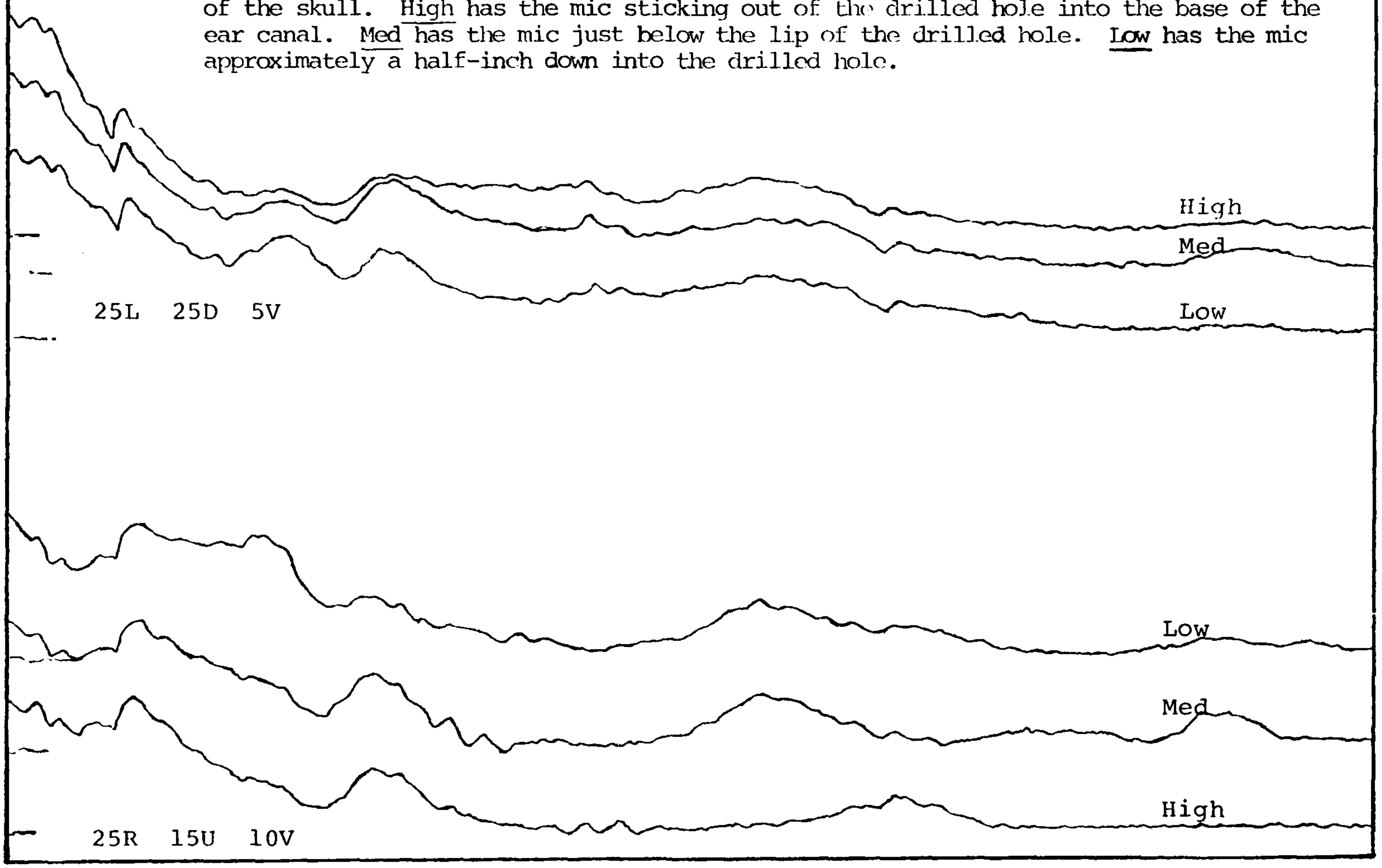
Test Data

Included in the test data are microphone position repeatability tests and response curves for the bare microphone. The first page of each repeatability test shows the response curves for three positions of the microphone in the ear canal. The differences here were not large and a medium position was selected for the runs in each case. The second page of each test shows a trace after the microphone had been removed from and replaced in each ear. These tests demonstrate an acceptable level of repeatability.

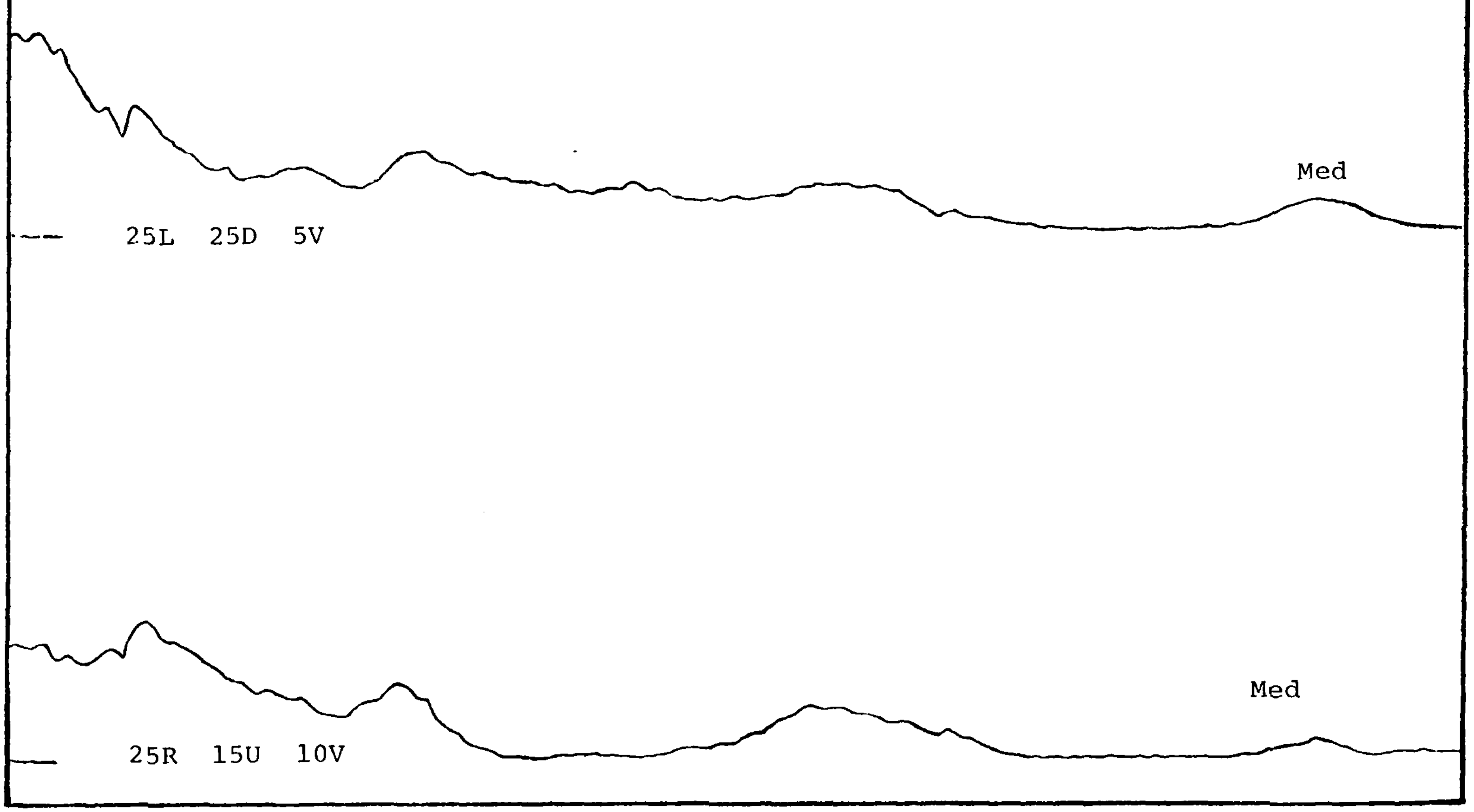
The final two pages are response curves of the microphone with the model ear removed. These curves depart markedly from the nearly flat microphone response curves provided by the manufacturer for sound waves at normal incidence. It seems likely that part of the difference is caused by the mounting device. The mount for the model ear is a 3-sided (box-corner) device, 10 cm on a side, that rotates in the vertical plane. This is supported by a narrow 5 x 25 cm plate affixed to the swiveling horizontal base. The microphone was attached to the ear mount so accurate positions could be determined for each run. Reflections from the exposed metal surfaces could account for the variations in the curves. Since the ear projects above and in front of the mount, such reflections could not occur for the ear tests. It should be noted that there is very little similarity between the bare microphone response curves and the corresponding ridged ear curves, but similarities to the smooth ear curves do exist. Thus, another part of the departure from the manufacturer's curve is the directionality of the microphone and possible anomolies in the sound field. These tests are further evidence that the ridges are responsible for the differences in the curves of the two ears.

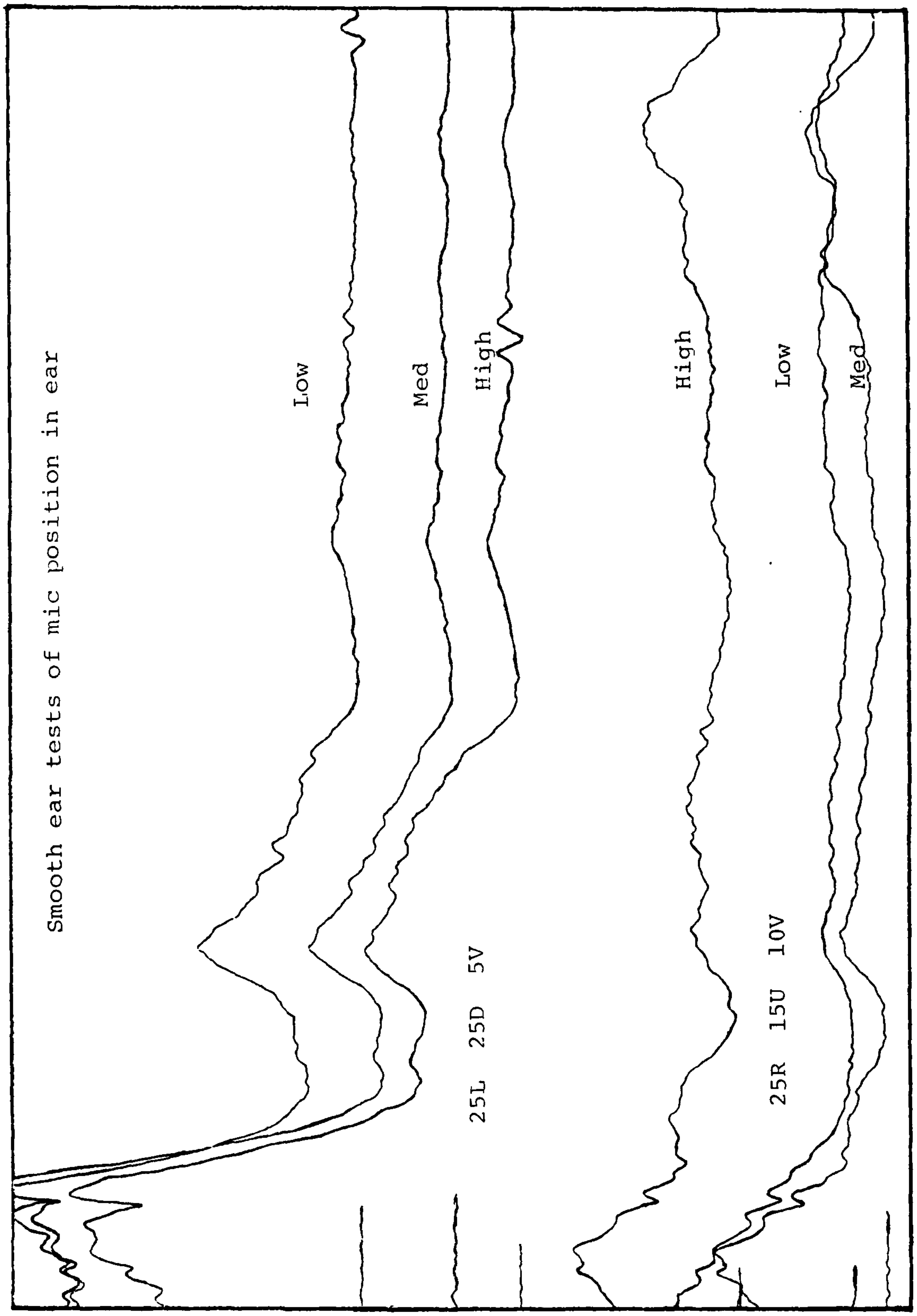
Microphone Position Test -- Ridged Ear

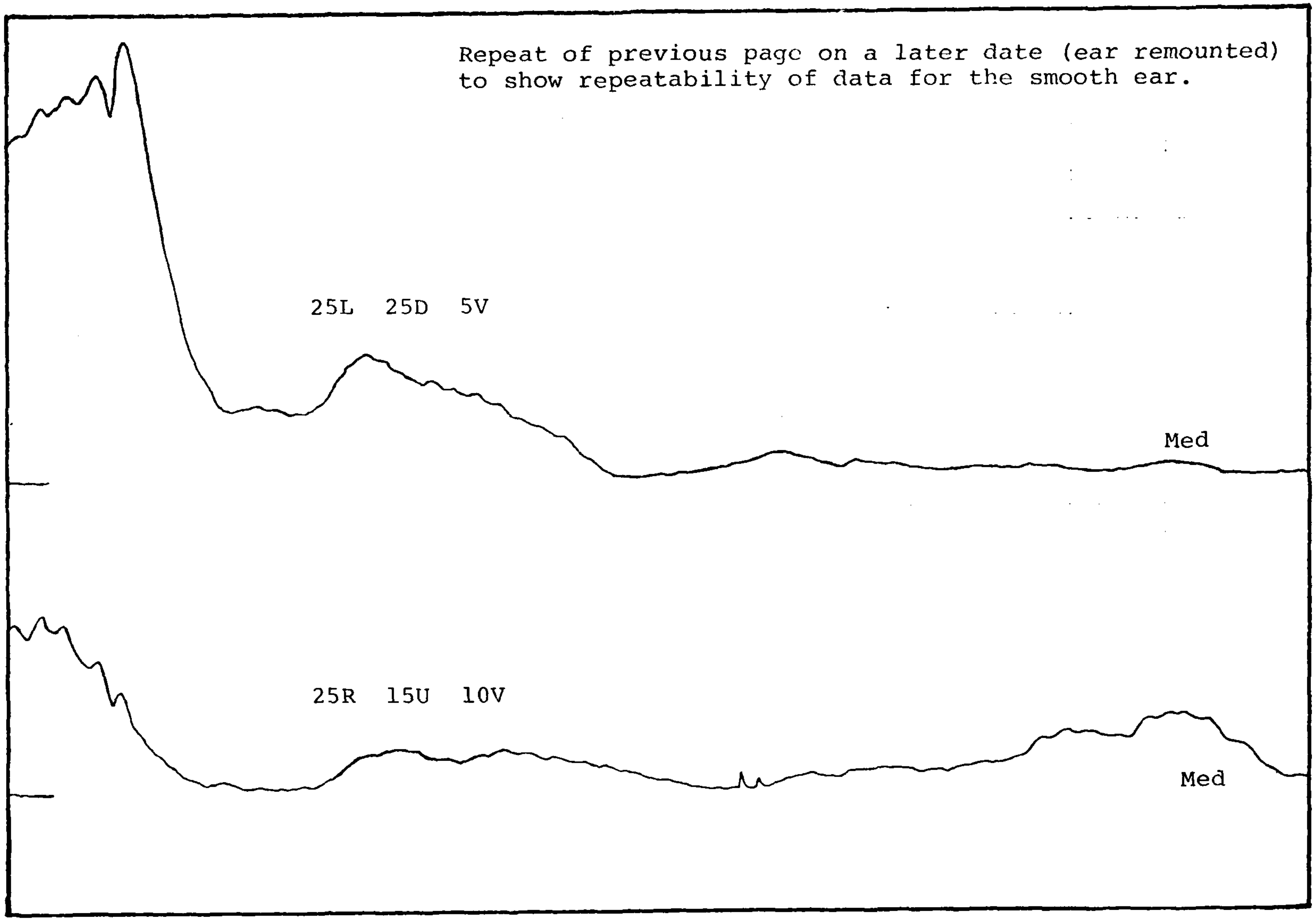
High, Med, and Low represent relative positions of depth in the hole drilled in the base of the skull. High has the mic sticking out of the drilled hole into the base of the ear canal. Med has the mic just below the lip of the drilled hole. Low has the mic approximately a half-inch down into the drilled hole.

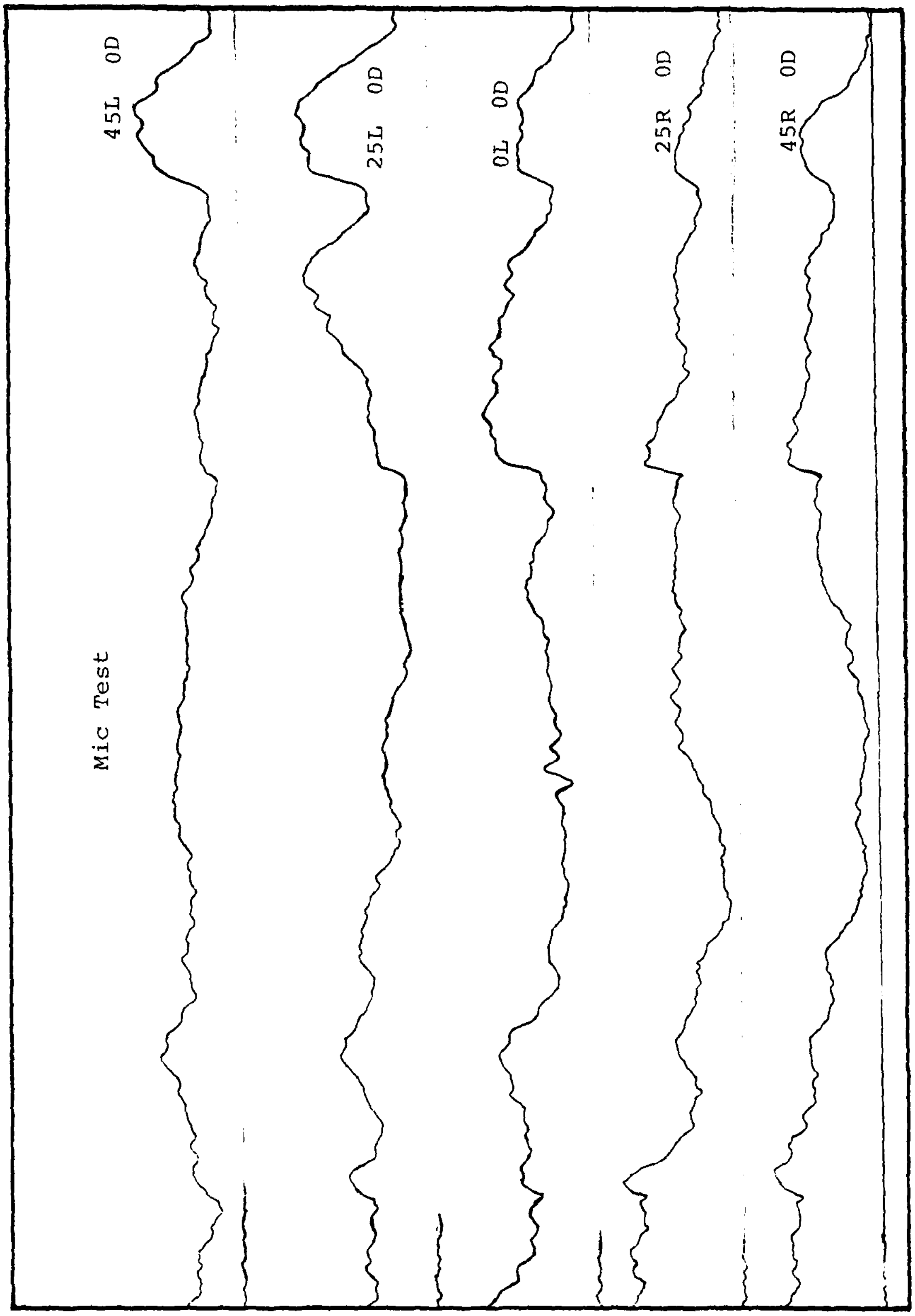


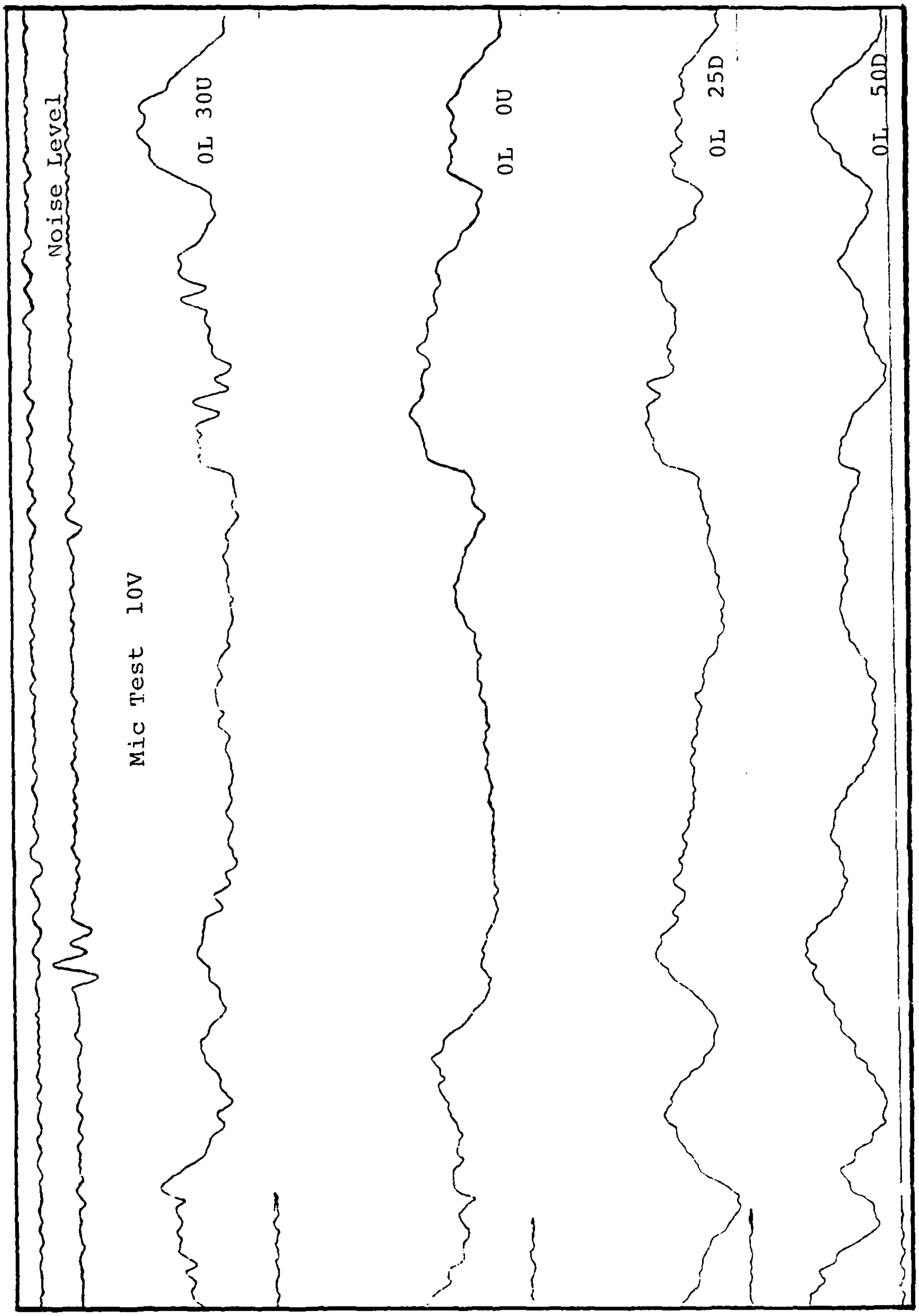
Repeat of previous page at a later date (ear remounted) to show repeatability of data for the ridged ear.




Smooth ear tests of mic position in ear
Low
Med
High
25L 25D 5V
High
Low
Med
25R 15U 10V


Repeat of previous page on a later date (ear remounted) to show repeatability of data for the smooth ear.
25L 25D 5V
Med
25R 15U 10V
Med


Mic Test
45L OD
25L OD
0L OD
25R OD
45R OD



Noise Level
Mic Test 10V
0L 30U
0L 0U
0L 25D
0L 50D

Vita

First Lieutenant William A. Sowell was born on 6 September 1952 in Fairbanks, Alaska. He graduated from high school in Brookings, South Dakota, in May 1970. After two years at South Dakota State University, he enlisted in the Air Force, serving four years as a tail-gunner on B52-H bombers. At the end of his tour in Grand Forks, North Dakota, he returned to SDSU in 1978 and entered the AFROTC program there. He received a B.S. in physics in May 1980 and entered active duty in October of that year. Prior to attending AFIT, he served as a Program Manager in the Support Equipment System Program Office, ASD/AEGA, at Wright-Patterson AFB, Ohio.

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Bats Echolocation

Diffraction Grating

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The series of parallel evenly-spaced ridges found in most bats' ears are investigated to determine if they are acting as a diffraction grating. A diffraction grating causes a periodic transverse variation of phase or amplitude in an incident wave. Such a device might be useful to the bat in determining a target's relative vertical position.

An experiment using ridged and smooth model ears (of the bat

(Continued on Reverse)

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BLOCK 20: Abstract (Cont'd)

phyllostomus hastatus) was designed. Since the angle of diffraction is related to the angle of signal incidence, it should have been possible to observe periodic variations in amplitude across the frequency sweep received by a model ear.

In calculating the predicted dispersion using the Huygen's-Fresnel principle, it was determined that diffraction could not occur. The data appears to have supported this, and produced two further results. Significant differences in the data between the two model ears suggest a definite relationship between the ridges and the echolocation process. Also, the ears are sensitive to angle of incidence in steps as small as five degrees.

END

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