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LOW FLUX SIMULATION

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Research Directorate
AIR FORCE SPECIAL WEAPONS CENTER
Air Force Systems Command
Kirtland Air Force Base, New Mexico

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(Prepared under Contract AF 29(601)-4604 by Dr. Ralph W. G. Wyckoff of the University of Arizona and Dr. D. C. Miller, Philips Electronic Instruments, A Division of Philips Electronics and Pharmaceutical Industries Corporation, Mount Vernon, New York)

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HEADQUARTERS
AIR FORCE SPECIAL WEAPONS CENTER
Air Force Systems Command
Kirtland Air Force Base
New Mexico

ABSTRACT

Experiments were made to determine the feasibility of constructing a pulsed source of soft X-rays of flux levels of at least 1 cal/cm^2 in sub-microsecond times with photon energies between 1 and 5 Kev. The design and operation of the X-ray tube are presented for a circular capacitance bank of series-parallel units having a total capacity of 54 μf with maximum voltage rating of 4 Kv, and for another capacitance bank of 6.4μf with a maximum voltage rating of 13 Kv. Anode pulsing was carried out, since the X-ray yield with pulsed cathode was found to be invariably inferior. Semiquantitative measures of the dependence of X-ray intensity on voltage have been made by finding areas of equal blackening in different photographs. Opinions are further developed on the possibility of producing a pulsed soft X-ray flux of the order of 1 cal/cm^2.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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Director, Research Directorate

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FOR AND IN THE ABSENCE OF
JOHN J. DISHUCK
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DCS/Plans & Operations

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1.0 Introduction

This is a report of work done under Contract No. AF29(601)-4604 carried out for the Air Force Special Weapons Center, Kirtland Air Force Base. It describes experiments made to determine the feasibility of constructing a pulsed source of soft X-rays of flux levels of at least 1 cal/cm^2 in times from 5×10^{-8} to 20×10^{-8} seconds, the X-ray hardness corresponding to photon energies between 1 and 5 kev. Since this feasibility depends on the efficiency with which soft X-rays can be generated, we have measured the output of an X-ray tube under normal conditions of operation and compared this with theoretical expectations and with the pulsed output of the same tube.

2.0 Experimental

X-ray pulses were generated in a demountable X-ray tube constructed for the purpose and made in such a way that either or both the anode and cathode could be insulated for high voltage. It was evacuated by a pumping system (shown in Fig. 1) consisting of a Consolidated CMF 300 diffusion pump backed by a suitable forepump. The vacuum, as measured by an ionization gauge, was of the order of 10^{-5} mm.

As Fig. 2 indicates, the X-ray tube itself is a brass box five inches (5") on a side with a wall thickness of 3/8". This shape was chosen to permit easy modification of tube components. It has performed satisfactorily at the energy levels of the present experiments but changes in design might be needed if much higher energies were to be applied. Exchangeable anodes consisting of blocks of metal could be fitted into a copper shaft passing through and soldered onto the ceramic high-tension insulator. The tube wall in the neighborhood of the anode was sheathed with lucite to prevent the discharges from the anode shaft which otherwise occurred when the condenser bank was fired. The cathode assembly was attached to ceramic insulators soldered into the removable cover plate of the tube. In preliminary experiments, the cathode consisted of a straight length of tungsten wire lying in the axis of a hemicylindrical copper shield. Later, this simple type of cathode was replaced by a coiled filament surrounded by a cylindrical focusing shield of brass screening; it was dimensioned to give a focal spot of ca. 7 mm diameter. Undoubtedly, a more intense and controlled source of electrons, if one were needed, could be obtained by biasing this shield. Tungsten wires of various diameters through 20 mil were tried as filaments but it was found that an adequate electron supply could be had from 8 mil wire.

Because of the low yields of continuous radiations from X-ray tubes operated at low voltages, experiments have been made with targets of gold, as a typical heavy metal, and of aluminum and magnesium. The K excitation potentials of aluminum and magnesium, 1.56 and 1.30 KV respectively, correspond to radiation within the desired energy range; the gold spectrum excited at the voltages we have used includes a relatively strong M spectrum (corresponding to ca. 3.4 KV) (Chart 1).

The experiments were restricted to those which could be made with condensers loaned for the purpose by the Kirtland Air Force Base. They have been sufficient to establish the efficiency of excitation of the X-ray pulses these condensers have generated.

Two banks of condensers were employed (Fig. 3). One consisted of a circular bank of series-parallel units having a total capacity of 54 μF and a maximum voltage rating of 4 KV; this was used as supplied. The other, assembled in Tucson from units provided from the Base, had a capacity of 6.4 μF and a maximum voltage rating of 13 KV. The banks were charged by rectified and smoothed high voltage supplies which could be operated with either terminal grounded; one of these supplies was also used for the continuous operation of the X-ray tube. The condenser banks were fired with vacuum switches loaned by the Base. In the lower voltage experiments the discharge was triggered by an auxiliary spark passed between the terminals of the partially evacuated switch. In the experiments above 3.5 KV the banks wered fired by pumping the switch until breakdown occurred.

Duration of the pulsed discharge through the X-ray tube was measured with a Type No. 507 Tektronix oscilloscope condenser coupled to an electrode of the X-ray tube.

A preliminary attempt was made to measure the energy in the X-ray output with thermistors, following a suggestion from Capt. Marvin C. Atkins, Physics Division, Research Directorate, Air Force Special Weapons Center. It was found that only the smallest thermistors would have the requisite sensitivity, and these unfortunately could not be supplied by the manufacturers in time. Hence, we were compelled to limit our measurements of X-ray outputs to photographic records standardized by counts of quanta identified through pulse-height and spectrometer measurements. The photographic records consist of photographs of the pulsed outputs made through a series of aluminum foils used as attenuators (Fig. 5). The energy contents of the pulses were obtained by finding the exposure times necessary to give the same patterns of blackening when the X-ray tube was operated continuously under conditions of measured X-ray output.

3.0 Results

The first series of experiments was designed to determine whether the condenser banks could be discharged promptly through the X-ray tube. In these early trials, the circular bank was charged to potentials up to 3 KV above ground and the cathode was a linear filament; no effort was made to measure the X-ray output. With inadequate heating currents through the cathode wire, the condenser bank either did not fire when triggered or was left with a residual charge after a manifestly prolonged period of gradual discharge. With higher currents through the tungsten and the oscilloscope probe given the (ca. 50 $\mu\mu$F) capacity required for an integrated response, the recorded potential of the anode during discharge of the bank through the X-ray tube appeared as in Fig. 4. Here an abrupt rise is followed by a decline whose shape is in part at least attributable to the oscilloscope circuit. X-rays characteristic of the target can be produced only as long as the potential exceeds the critical excitation voltage, which for aluminum is 1.56 KV; in the photograph of Fig. 4 this potential is exceeded for a period of not more than 0.2 microseconds. In later experiments, when the X-ray outputs were being measured, it was found that the yield invariably was reduced when the oscilloscope probe was attached. Although we were unable to prevent the mis-match in circuitry thus apparent, it seems reasonable to conclude that the X-ray pulses we have been measuring have had durations of the order of a microsecond.

In a second set of experiments, a comparison was made between the performance of the tube (a) when the filament was continuously heated and the condenser bank discharged through the anode (as before) and (b) when the bank, permanently connected to the anode, was discharged by electrons from a filament through which a second condenser bank was discharged. This second method of producing X-ray pulses was tried because it seemed to offer the possibility of an especially high electron yield. Such an output has not proved to be necessary, and since the X-ray yield with pulsed cathode has invariably been inferior, the experiments now to be described were all carried out by anode-pulsing.

Studies were next made to provide a basis for measuring the X-ray yields. As indicated earlier, these studies consisted of (a) counting photons emitted by the X-ray tube under continuous operation, (b) determining the energy associated with these counts and (c) finding out the dosage of continuously produced X-rays that would cause the same photographic blackening as a given pulsed discharge. A voltage of 5 KV was used because, as will be shown later, it provides an adequate yield of aluminum K X-rays only slightly contaminated by white radiation. The number of X-ray quanta produced per second when the tube was fed from a stabilized constant voltage supply was measured through a tube window 1/4" in diameter sealed with one layer of 1/4 mil mylar. Air-absorption was avoided by bringing the mylar covering of an end-window flow proportional counter into contact with this tube window. The counter was filled with P-10 gas at atmospheric pressure, connected through a pre-amplifier to a Philips circuit panel and operated at voltages that permitted the unequivocal pulse-height identification and counting of the X-ray quanta. Under these conditions when the X-ray tube was passing 0.1 ma at 5 KV and six 1/2 mil layers of aluminum had been inserted between the counter and the tube window,

$$1.35 \times 10^4 \text{ quanta/sec.}$$

were counted.

Measurements later to be described established the amount of radiation transmitted through each of these aluminum sheets in turn. In this way, and by adding one additional mylar sheet, it was easy to ascertain the unobstructed flux of quanta through the X-ray tube window. Transmission through the first aluminum foil was low (20%), owing to the presence of some very soft radiation; thereafter, succeeding layers had the constant transmission of about 27% indicative of an essentially monochromatic beam. If the aluminum foils had been exactly 1/2 mil thick, the computed transmission for aluminum K radiation would be 32%. Measured transmission of the mylar film was 55%.

The flux of X-ray quanta and of their energy can be calculated as follows:

Since 1.35×10^4 counts/sec. are registered after passage through six aluminum plus two mylar sheets,

1.15×10^8 counts/sec. pass through the unobstructed

1/4" X-ray tube window. This amounts to

$$3.66 \times 10^{8} \text{ counts/sec./cm}^{2} \text{ at the tube window.}$$

Allowing for a calculated 87% efficiency of the counter, this represents

$$4.20 \times 10^{8} \text{ counts/sec./cm}^{2}.$$

The energy associated with one quantum of aluminum K radiation is $Ve=1.49 \times 10^{3}$ volts $\times 1.60 \times 10^{-19}$ coulombs, or

$$2.38 \times 10^{-16} \text{ joules (J).}$$

The energy flux at the position of the window of the X-ray tube then is

$$1.00 \times 10^{-7} \text{ J/sec./cm}^{2}.$$

Photographic blackenings were recorded after the 1/4" X-ray tube window and its mylar covering had been replaced by a cassette faced with a series of 1/2 mil aluminum foils ranging between one and 10 in number. Using standard X-ray film, it was shown that the same pattern of blackening was produced (a) by the pulsed discharge of the 6.4 μF bank charged to 5 KV and (b) by the output of the X-ray tube continuously operated at 0.1 ma and 5 KV for a period of 30 seconds. The energy associated with this blackening is thus $30 \times 1.05 \times 10^{-7}$ J/sec./cm^{2}, or

$$3.00 \times 10^{-6} \text{ J/cm}^{2}, \text{ or } 0.72 \times 10^{-6} \text{ cal/cm}^{2}.$$

The energy stored in the bank to produce this blackening is $\frac{1}{2}FV^{2}=80$ joules. Compared with the 15 joules required to give the same blackening under continuous operation, the pulsed operation thus has a relative efficiency of 15/80=18.7%. This reduced efficiency corresponds roughly to the part of the discharge (Fig. 4) taking place at more than 1.56 KV (the excitataion potential of aluminum). It undoubtedly is higher when higher voltages are used.

The yield as thus measured is about a millionth of the desired yield. Existing knowledge does not suggest how pulsed operation of an X-ray tube can be made more efficient than continuous operation, and since it obviously would not be feasible to employ a condenser bank having a million times the capacity of the one used here, factors must be sought which could significantly increase the yield as measured above.

It is well known that X-ray output rises rapidly with exciting voltage when this voltage is near the excitation potential for characteristic radiation, as in the present case. We have, therefore, made experiments to gain some idea of the practical limits to this increase. These consist in photographic records of the X-ray pulses obtained; and these have, as before, been interpreted through measured yields of the X-ray tube operated continuously. In general, the experimental arrangement was that already described but we have here employed an X-ray tube window with the smaller diameter of 0.013", chosen to reduce the load on the counting circuits. The counter was also different--a standard Philips flow proportional counter altered to bring its mylar window into contact with the X-ray tube window. To keep from overloading the circuits at 10 KV, tube currents were reduced to from 15 to 50 μA. Table I gives the results of an experiment in which the tube current was 0.050 ma and the beam was attenuated through one mil of aluminum. The aluminum counts were made using a pulse height window broad enough to include the entire peak. "Total Counts" indicates the integrated output of the circuit. We have verified that they include all X-ray quanta entering the counter by observing that at a low base-line setting, the number of counts does not materially increase as the voltage is raised to the Geiger region. The observed five-fold increase in the aluminum radiation (Table I and Chart 3) is in good agreement with earlier measurements and with the predictions of theory. The corresponding eight-fold rise in the total count is an index of the increasing amount of white radiation with voltage. The Total/Al ratio of 1.16 points to the spectral purity of the output at 5 KV; the increasing importance of the white radiation at higher voltages is apparent in the ratio 1.75 that applies at 10 KV. Nevertheless, as Chart 2 indicates, white radiation remains a relatively insignificant component of the spectrum at this voltage. The rise in white radiation with voltage is further demonstrated by the data of Table II which were accumulated to calculate the unattenuated output of the tube. Here the constant transmission of the aluminum foils measured at 5 KV contrasts with the steadily increasing transmission at 10 KV due to spectral inhomogeneity.

Photographs of X-ray yields have been made as before with the condenser bank charged at a series of voltages between 1.5 and 10 KV (Fig. 5). By finding areas of equal blackening in the different photographs, one can obtain a semi-quantitative measure of the way the intensity of the X-ray pulse increases with voltage. Thus, the blackening through four foils of aluminum produced by the 5 KV pulse is about equal to that of the 10 KV pulse after passage through ten foils. Reference to Table II shows that this result would be expected if the ratio of white to characteristic aluminum radiation is the same in the pulse as in the continuously generated beam. As Chart 3 indicates, the output of aluminum radiation is still rising sharply with increasing voltage at 10 KV. Existing data suggest that for the 45^{o} target used in the present experiments, a maximum will be reached at ca. 15 KV and that at this voltage the efficiency will be of the order of ten times that at 5 KV.[1]

Only a few exploratory observations have been made with magnesium and with gold targets. As would be expected, the X-ray output from the magnesium target is considerably less than that from aluminum, but otherwise pulsed magnesium X-rays are as easy to produce as those of aluminum. The other light metal that could be used to produce X-rays within the desired energy range is silicon (excitation potential = 1.84 KV); with it the efficiency could be twice to three times that attainable with aluminum. The output of the gold target is harder to analyze quantitatively. Blackening from a 5 KV pulse was a little less than that from a 5 KV aluminum pulse but the photographic effect of the 10 KV gold pulse was far greater than that of the 10 KV aluminum pulse. This is in accord with spectrometer data recently obtained (Chart 4). Although we were unable to analyze the results with gold more fully, we have compared them with a calculated efficiency for white radiation, assuming that the relations prevailing for harder X-rays are valid here too. If the peak voltage across the tube is set at 2.5 KV, the hardest X-rays excited have a wave length of 5.0 Å; and the white spectrum excited at this voltage will have a maximum at ca. 7.5 Å--not far from the wave length of the aluminum K lines. A well known expression for the efficiency (ϵ) of production of white radiation from a target of atomic number N is:

$$\epsilon = 1.1 \times 10^{-9} NV,$$

where V is the exciting voltage. For a gold target (N = 79) excited at 2,500 volts, $\epsilon = 2.16 \times 10^{-4}$; in other words, for an input of one J/sec. at this voltage the white X-rays should have an energy flux of 2.16×10^{-4} J/sec., or 0.52×10^{-4} cal/sec. According to the geometry of our experimental arrangement, the energy flux at the X-ray tube window should be ca. 1/284 of the total output assuming a symmetrical distribution within the hemisphere bounded by the plane of the target face. Thus, the energy flux of the white radiation from gold at the tube window calculates out to be

$$1.83 \times 10^{-7} \text{ cal/sec./cm}^2 \text{ - input.}$$

This is to be compared with the measured 0.48×10^{-7} cal/sec./cm^2 input for aluminum radiation excited at 5 KV. This comparison implies a considerably greater efficiency of production of white radiation from a heavy element at these voltages, but it is not an efficiency which, like that of the characteristic radiation, can be improved by raising the voltage without a drastic hardening of the total X-ray output.

4.0 Conclusion

From the foregoing, an opinion can now be developed as to the possibility of producing a pulsed soft X-ray flux of the order of one cal/cm^2. If we assume for convenience in calculation that a condenser bank delivering 20,000 joules is the largest that it would be practical to use for this purpose, the present experiments indicate that under 5 KV operation it should deliver a flux of aluminum K radiation (under the geometrical conditions of our setup) of

$$0.72 \times 10^{-6} \text{ cal/cm}^2 \times 250 = 1.8 \times 10^{-4} \text{ cal/cm}^2.$$

Excitation at 15 KV would permit a ten-fold gain to yield a flux of[1]

$$\text{ca. } 1.8 \times 10^{-3} \text{ cal/cm}^2.$$

Changes could be made in the tube that would lead to a further gain of approximately ten-fold. Thus, the target-window distance could be considerably reduced from the present 6.7 cm; and experiments have shown that increasing the angle of incidence of the electrons on the target face from 45° will at least double the flux at 5 KV. These, together with the use of silicon in the target, should result in a flux of

$$\text{ca. } 2 \times 10^{-2} \text{ cal/cm}^2.$$

The best chance of augmenting this yield, short of the discovery of a radically different and more efficient means of X-ray production, seems to lie in bringing the target face more or less normal to the electron beam.[2] There are indications that if this is done, efficiency of characteristic soft X-ray production may continue to rise from 15 KV until a voltage in the neighborhood of 40 KV has been reached. If this is true, it could result in as much as a further 15-fold enhancement in output, to yield a flux of

$$\text{ca. } 0.3 \text{ cal/cm}^2.$$

This is a value within striking distance of the objective defined in the present contract. There are, of course, a number of problems that might arise as the X-ray flux mounts towards such a value. It would require a considerable amount of further work to find out if they were important and to test the validity of extrapolations upon which the above estimate has been based. The requisite experiments appear relatively straightforward.

REFERENCES:

[1]See also M. A. Blochin, Physik der Röntgenstrahlen, p. 104 (VEB Verlag Technik, Berlin 1957); Dolby, R.M., Brit. J. Appl. Phys. 11, 64 (1960).

[2]Work being carried out by Dr. R. W. G. Wyckoff, Department of Physics, University of Arizona, Tucson, Arizona; also Worthington and Tomlin, Proc. Phys. Soc. A69, 401 (1956).

5.0 TABLE I

COUNTS AT VOLTAGES BETWEEN 5 KV AND 10 KV

KV	WATTS	Al COUNTS	TOTAL COUNTS	Al COUNTS PER W	TOTAL COUNTS PER W	TOTAL Al K
5	0.25	480/sec	557/sec	1920/sec	2230/sec	1.16
6	.30	1072	1310	3680	4360	1.22
7	.35	1920	2610	5480	7450	1.36
8	.40	2900	4300	7260	10750	1.48
9	.45	3840	6330	8530	14100	1.65
10	.50	5000	8780	10000	17540	1.75

6.0 TABLE II

TOTAL COUNTS AND TRANSMISSIONS AT 5 KV AND 10 KV

NO. OF Al FOILS	TOTAL COUNTS FOR 5 KV, 0.5 W		TOTAL COUNTS FOR 10 KV, 0.5 W	
	COUNTS	TRANSMISSION	COUNTS	TRANSMISSION
1	1.49×10^4/sec	- -	2.93×10^4/sec	- -
2	.407	27.3%	1.00	34.3%
3	.128	31.5	.41	40.9
4	.033	25.8	.22	53.8
5	.0088	26.7	.138	62.2
6	- -	- -	.094	68.5
7	- -	- -	.066	70.6
8	- -	- -	.049	74.6
9	- -	- -	.038	77.8
10	- -	- -	.030	77.9

Fig. 1

Fig. 2

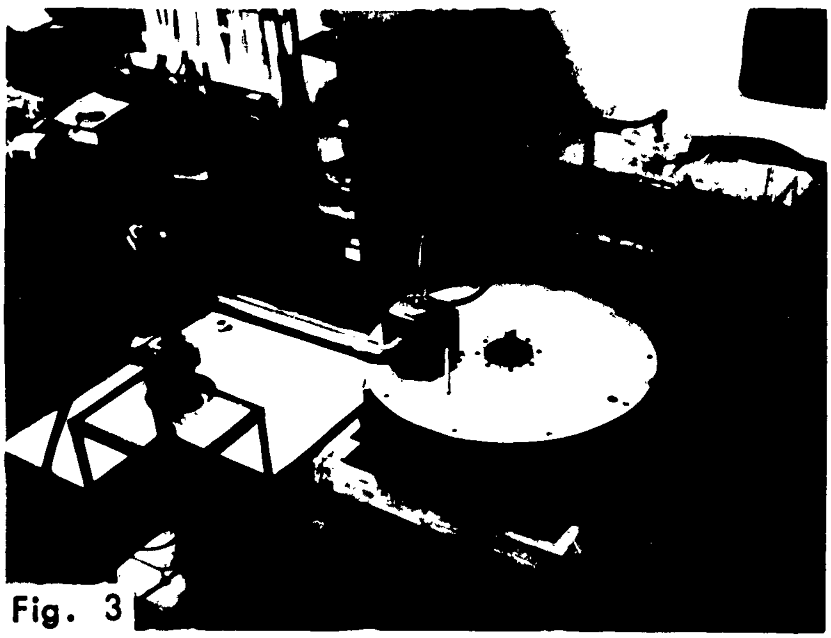


Fig. 3

2.6 KV pulsed discharge
through X-ray tube
Abscissa - 0.5 micro sec./div
Ordinate - 500 volts/div

Fig. 4

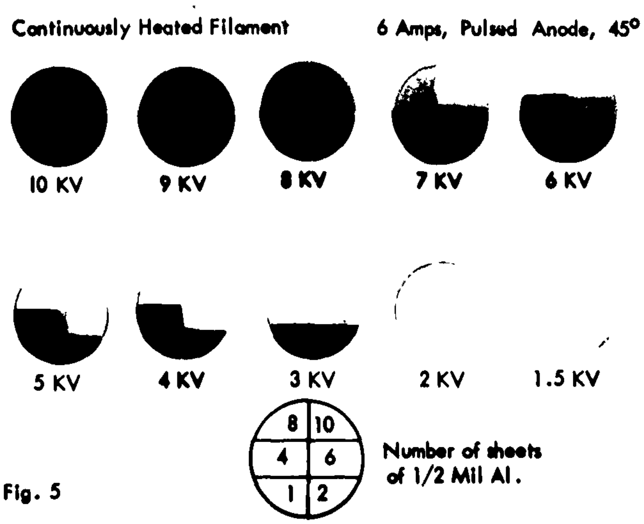
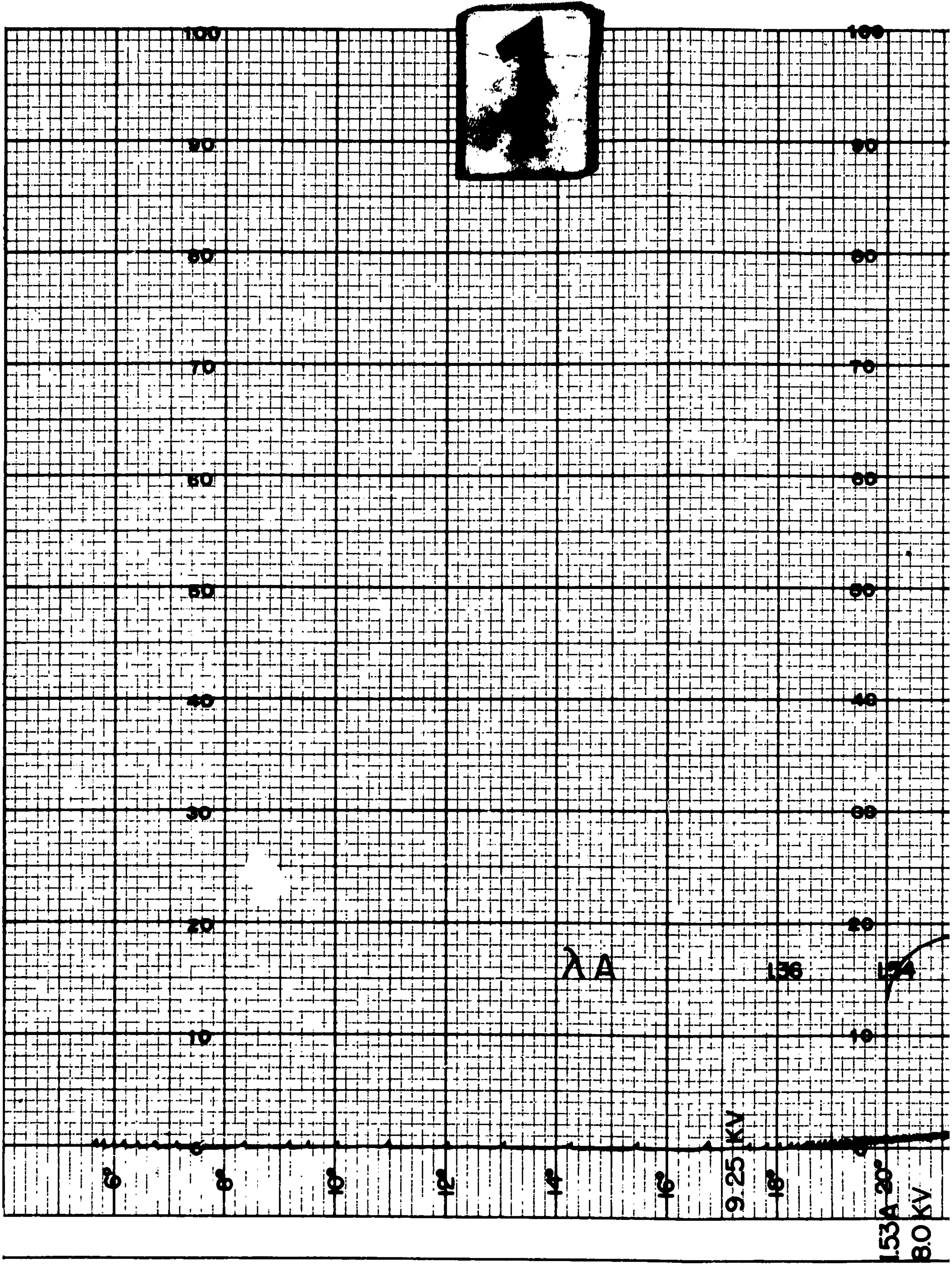
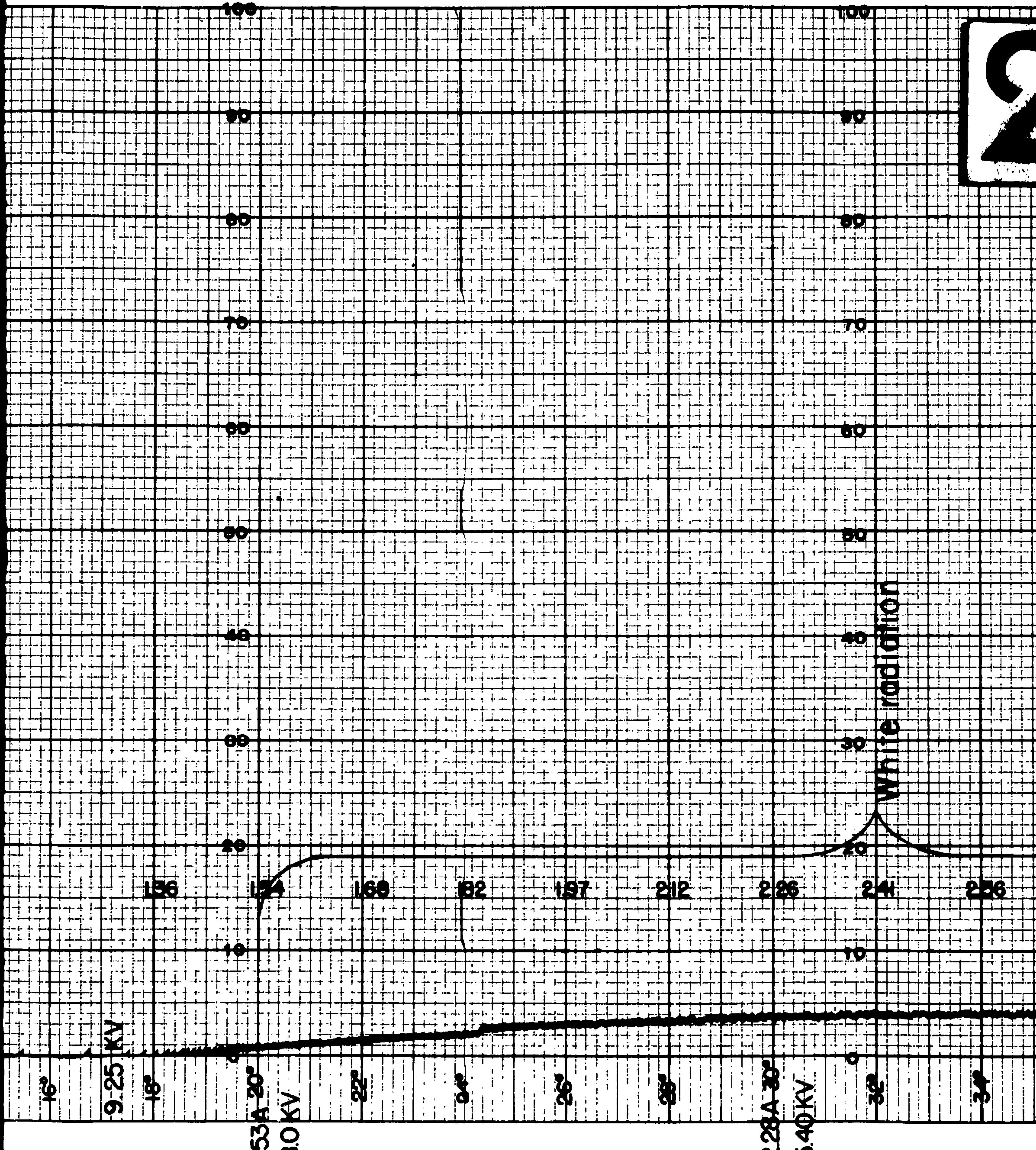
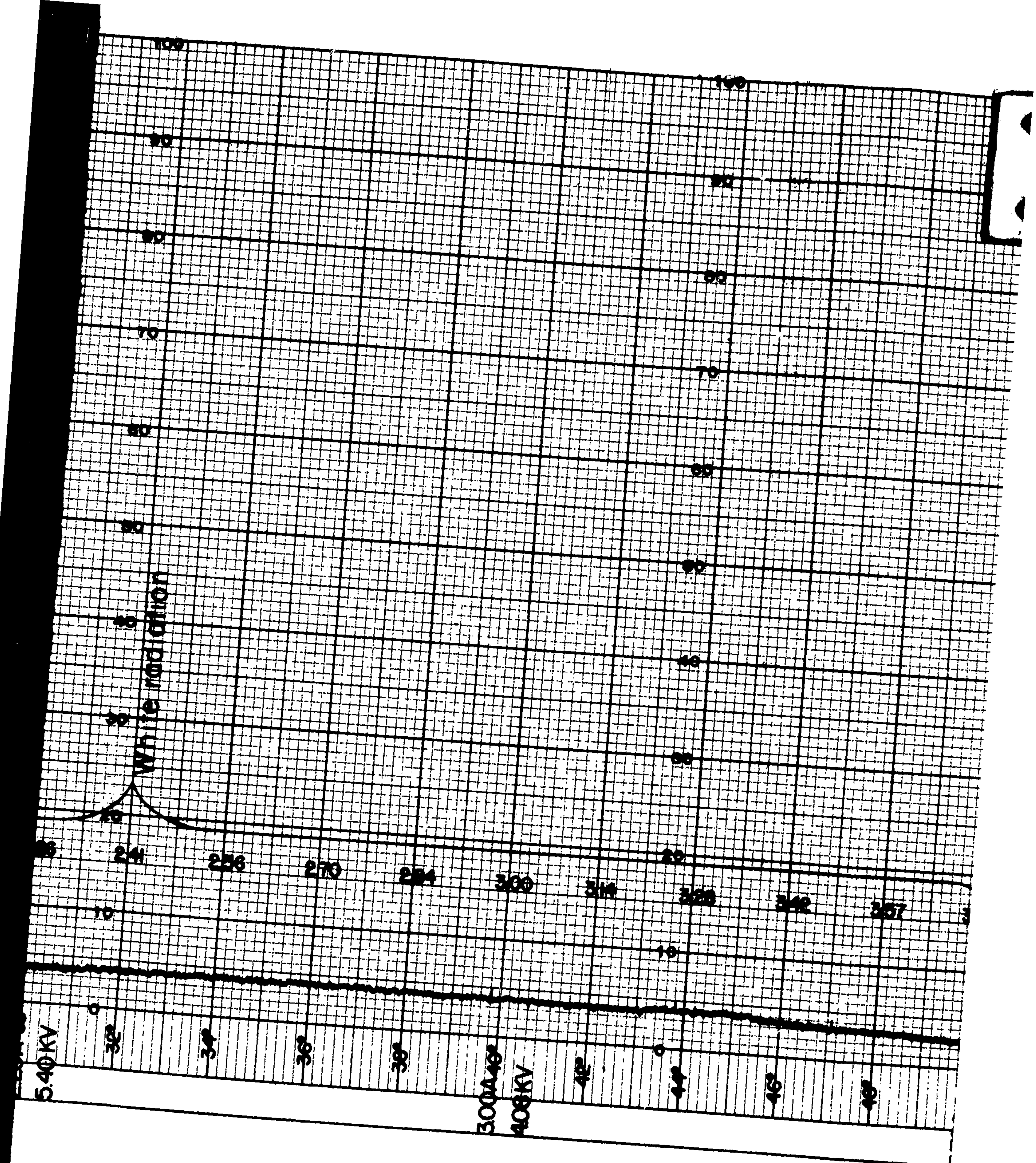


Fig. 5


100
90
80
70
60
50
40
30
20
10
λA
1.36
9.25 KV
1.53A
8.0 KV
6°
8°
10°
12°
14°
16°
18°
20°


2
White radiation
1.56
1.54
1.68
1.82
1.97
2.12
2.26
2.41
2.56
9.25 KV
1.53A 20°
8.0 KV
2.28A 30°
5.40 KV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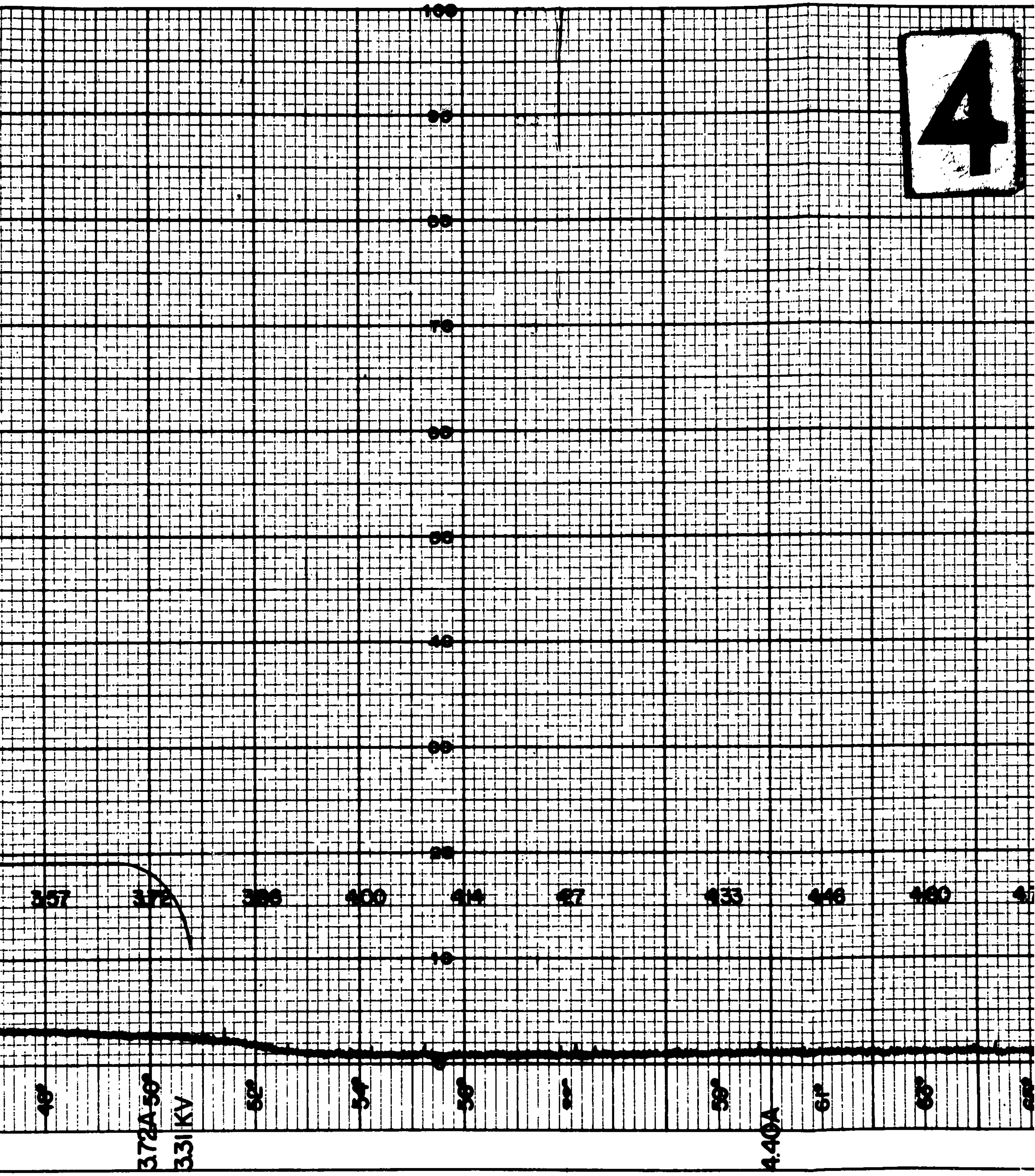
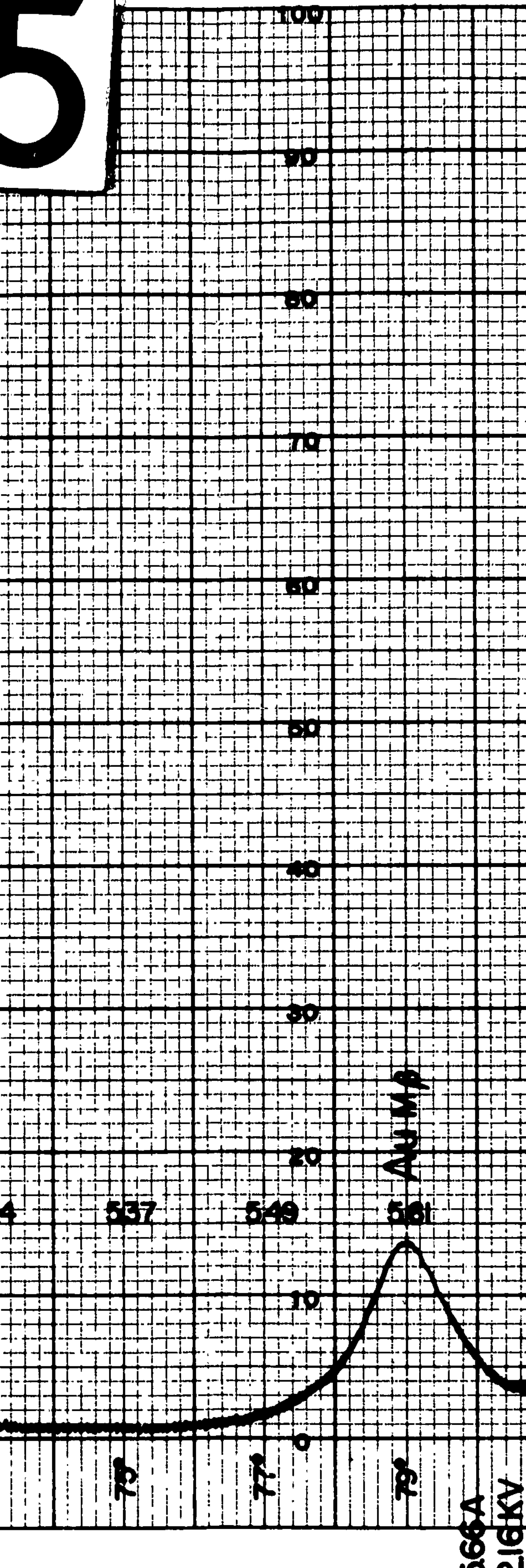
256
270
284
300
314
328
342
357
5.40KV
3.00A46°
4.08KV


4
100
90
80
70
60
50
40
30
20
10
357
372
386
400
414
427
433
446
460
3.72A 50°
3.31 KV
4.40A

5


100
90
80
70
60
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40
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20
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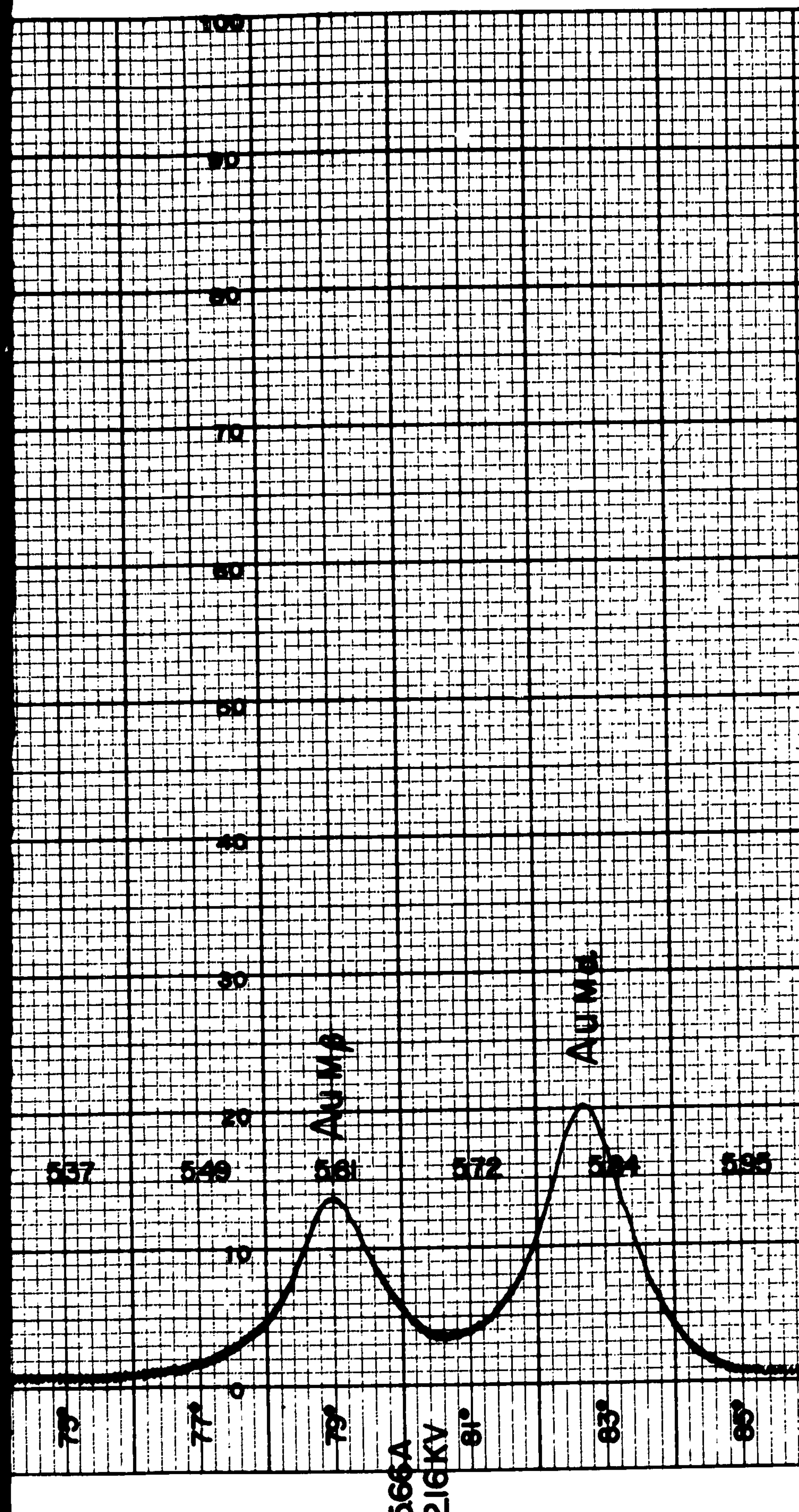
Au Mβ
537
549
561
75°
77°
79°
5.66A
21.6KV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90
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40
30
20
10
0
Au Mβ
Au Mα
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549
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572
584
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75°
77°
79°
81°
83°
85°
5.66A
21.6KV

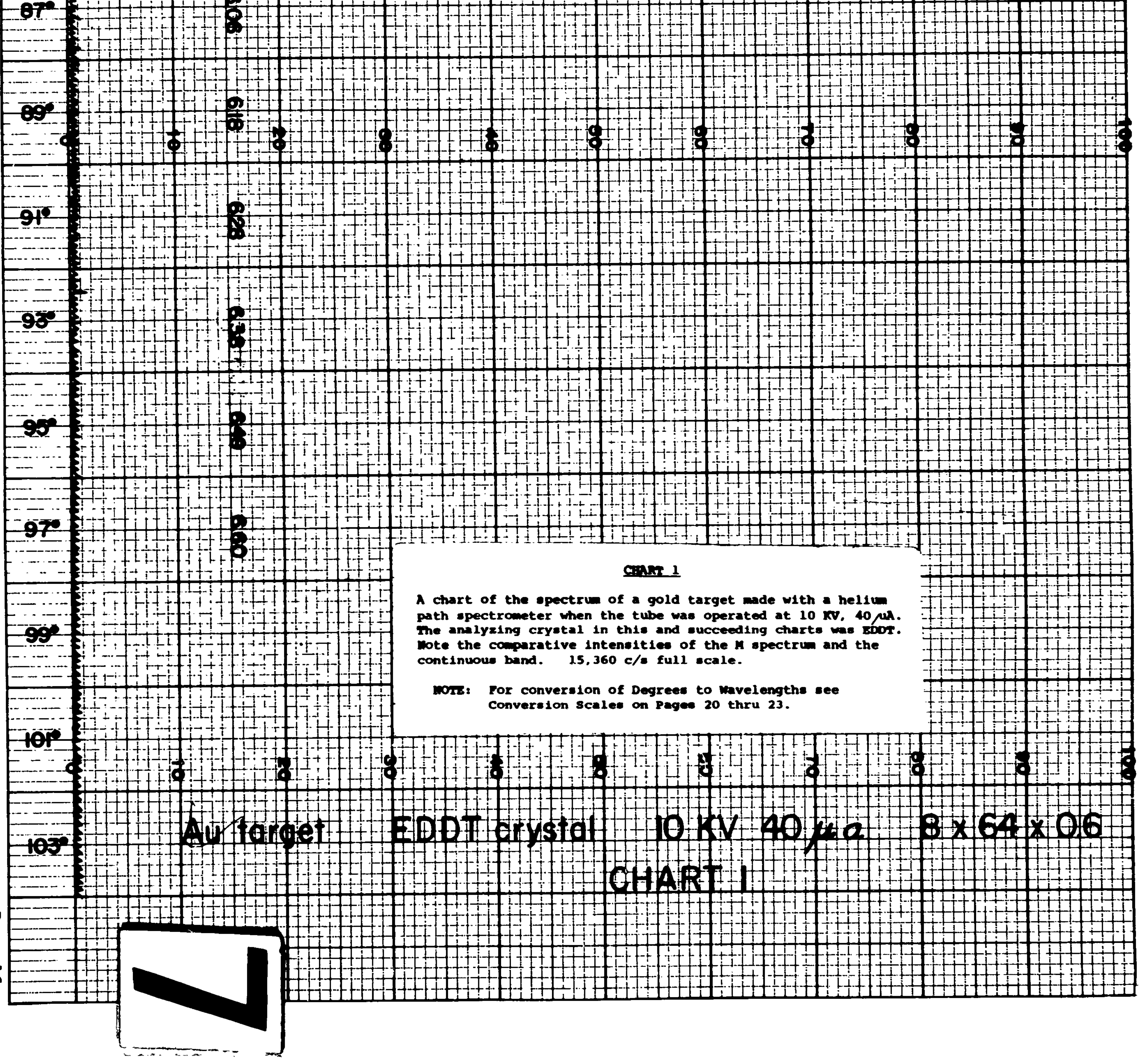
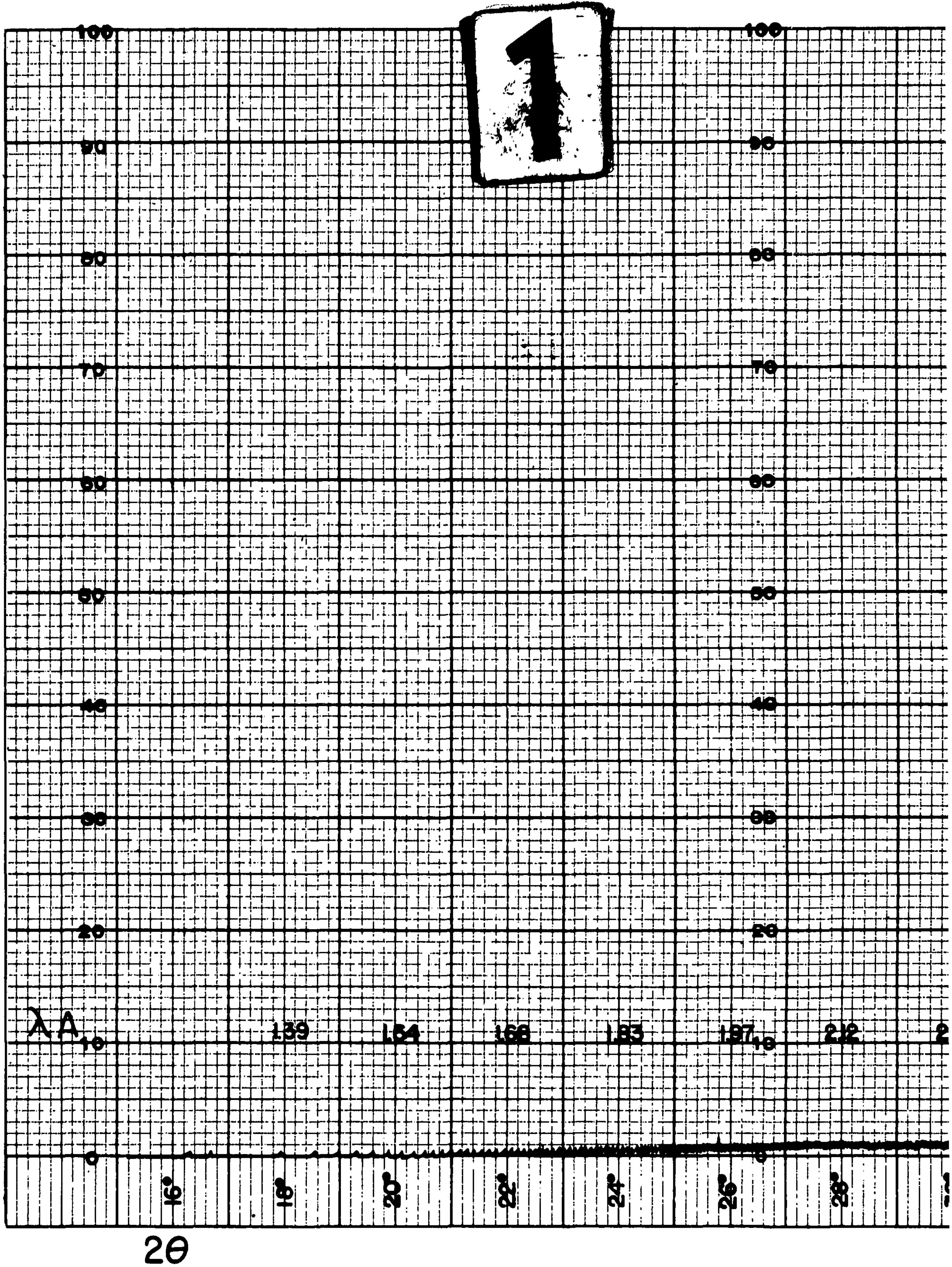
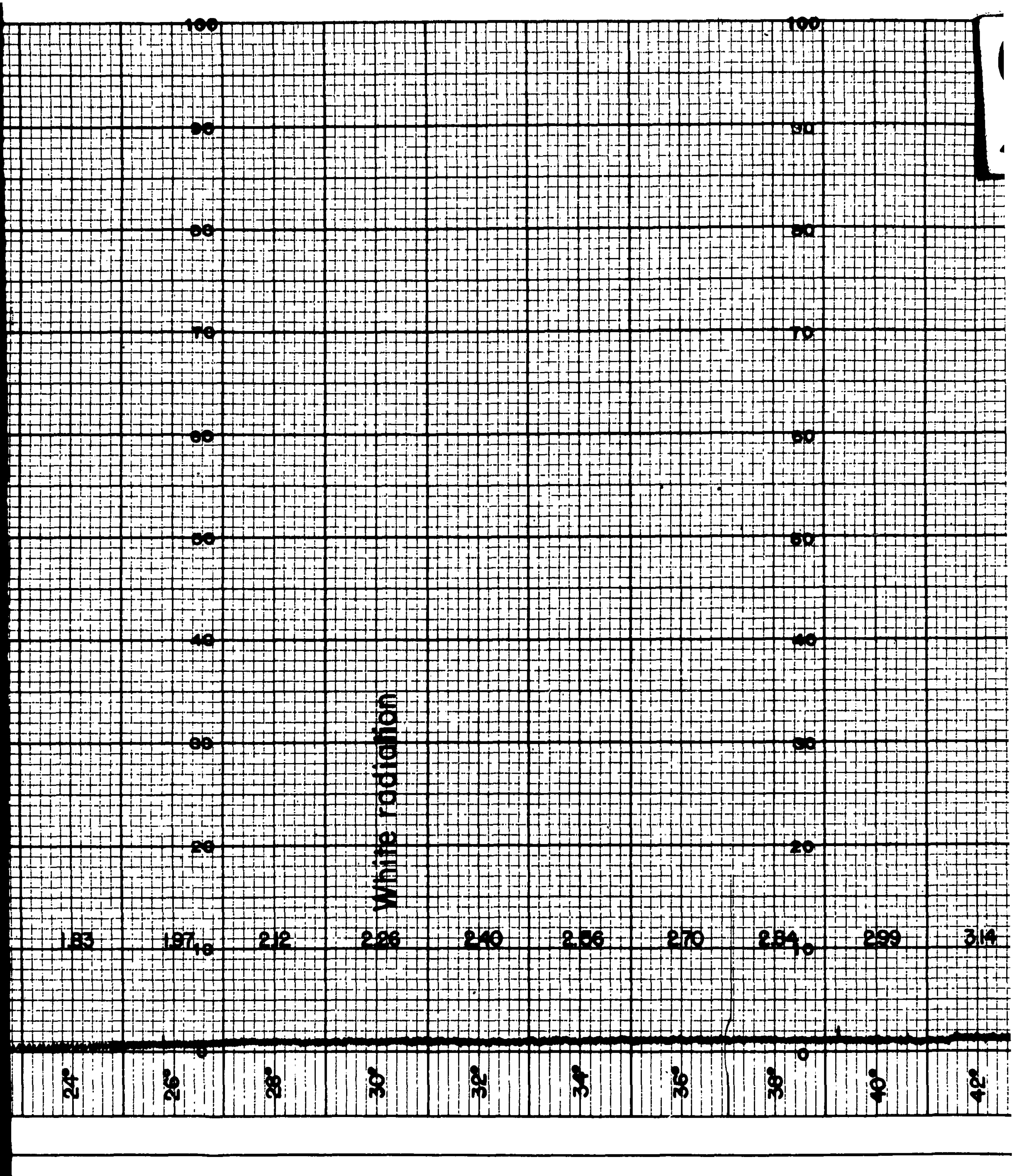


CHART 1

A chart of the spectrum of a gold target made with a helium path spectrometer when the tube was operated at 10 KV, 40 μA. The analyzing crystal in this and succeeding charts was EDDT. Note the comparative intensities of the M spectrum and the continuous band. 15,360 c/s full scale.

NOTE: For conversion of Degrees to Wavelengths see Conversion Scales on Pages 20 thru 23.


1
100
90
80
70
60
50
40
30
20
λA 10
1.39
1.54
1.68
1.83
1.97
2.12
0
16°
18°
20°
22°
24°
26°
28°
2θ


White radiation
1.83
1.97
2.12
2.26
2.40
2.56
2.70
2.84
2.99
3.14
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26°
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30°
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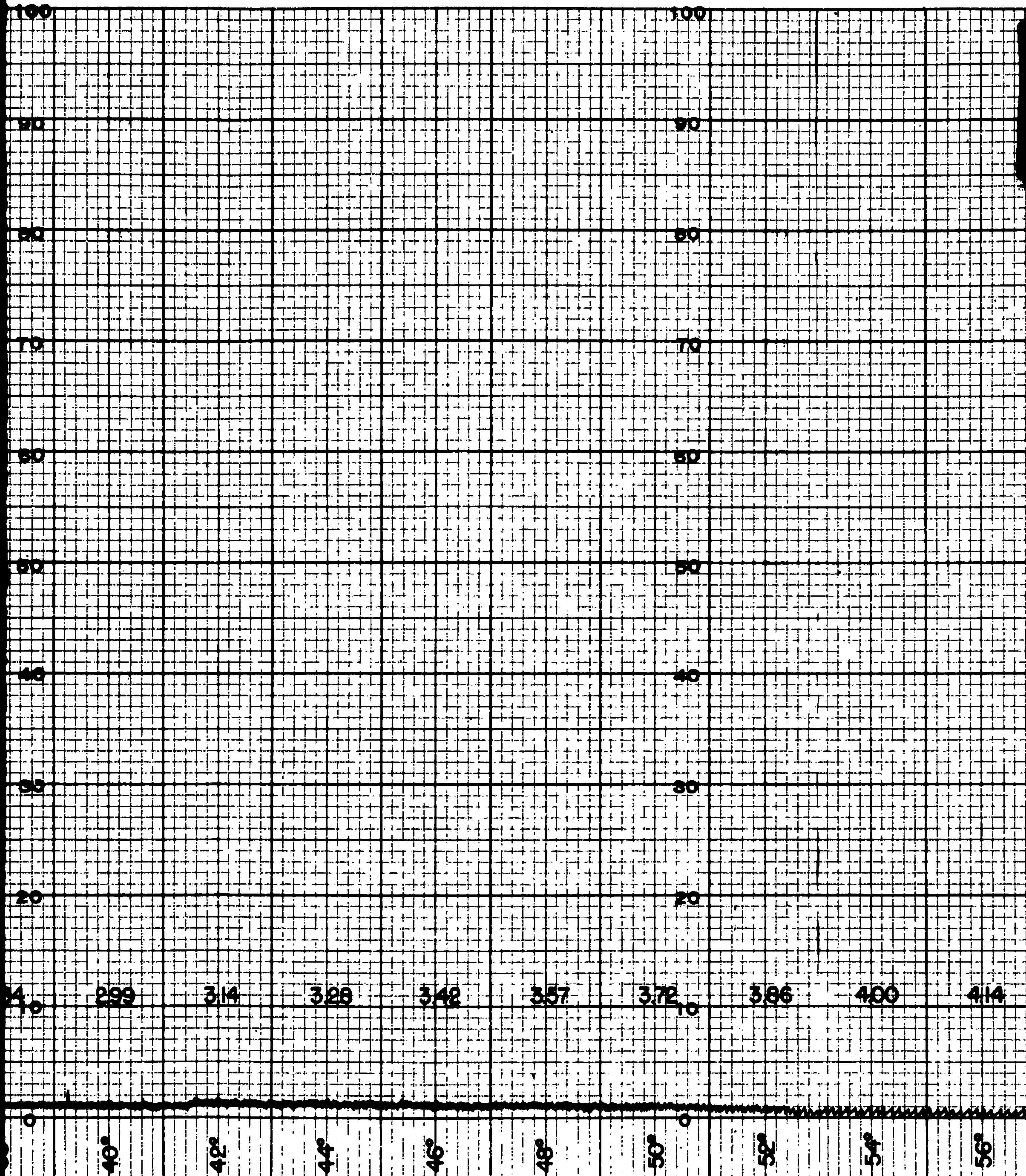
34°
36°
38°
40°
42°



100
90
80
70
60
50
40
30
20
10
0
2.99
3.14
3.28
3.42
3.57
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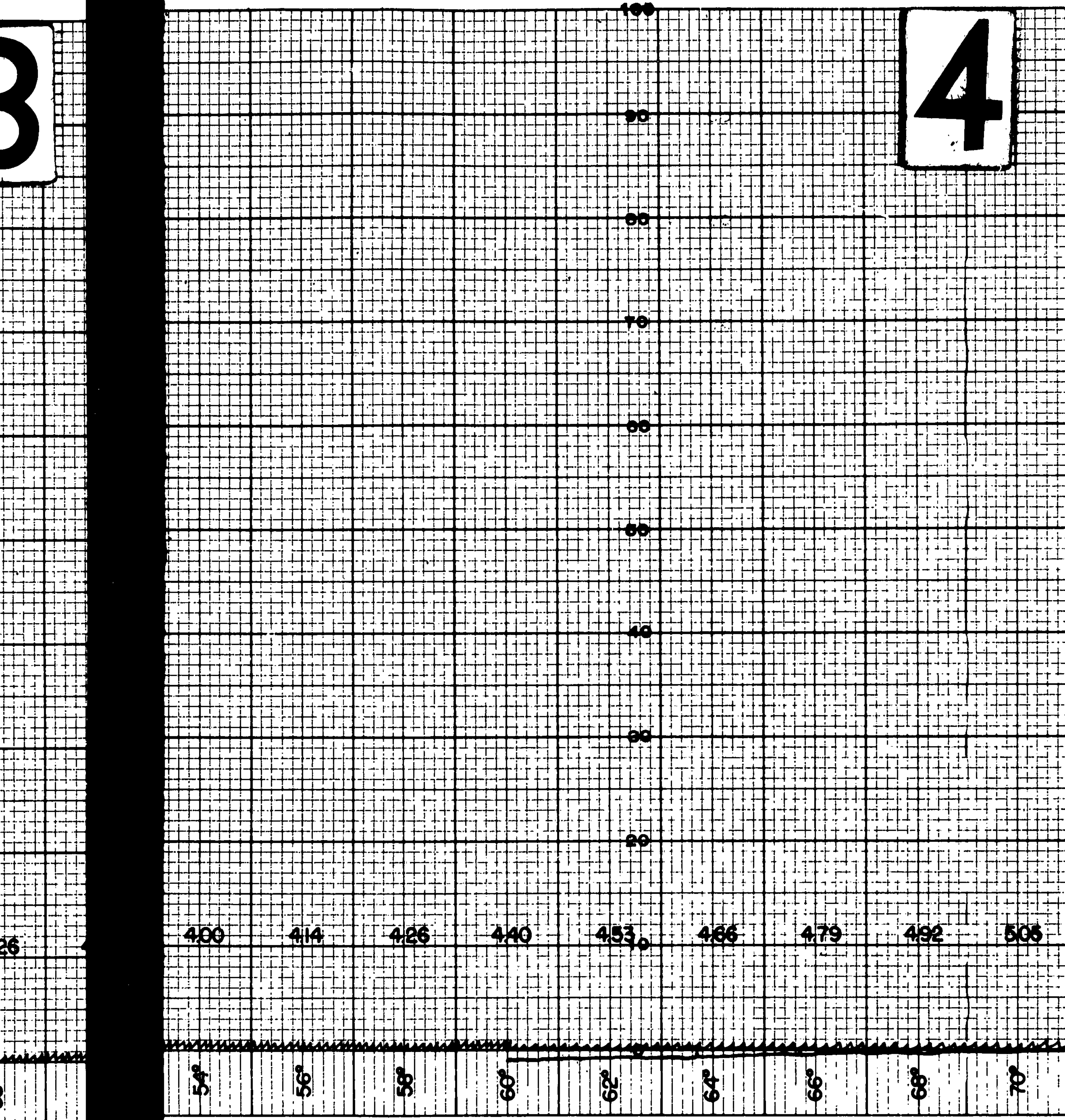
50°
52°
54°
56°



4
100
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60
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40
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20
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4.00
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4.66
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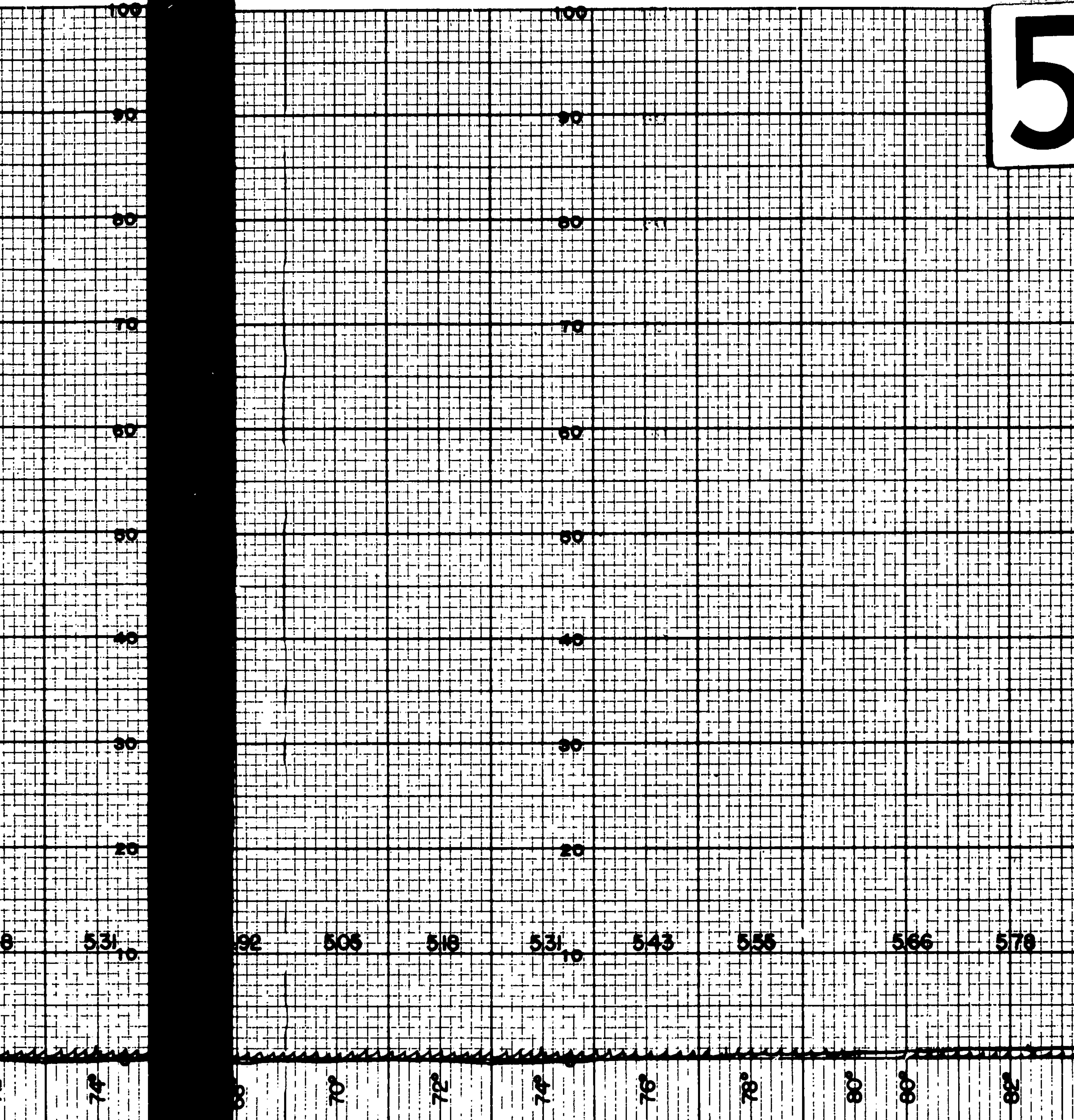
5.05
54°
56°
58°
60°
62°
64°
66°
68°
70°

5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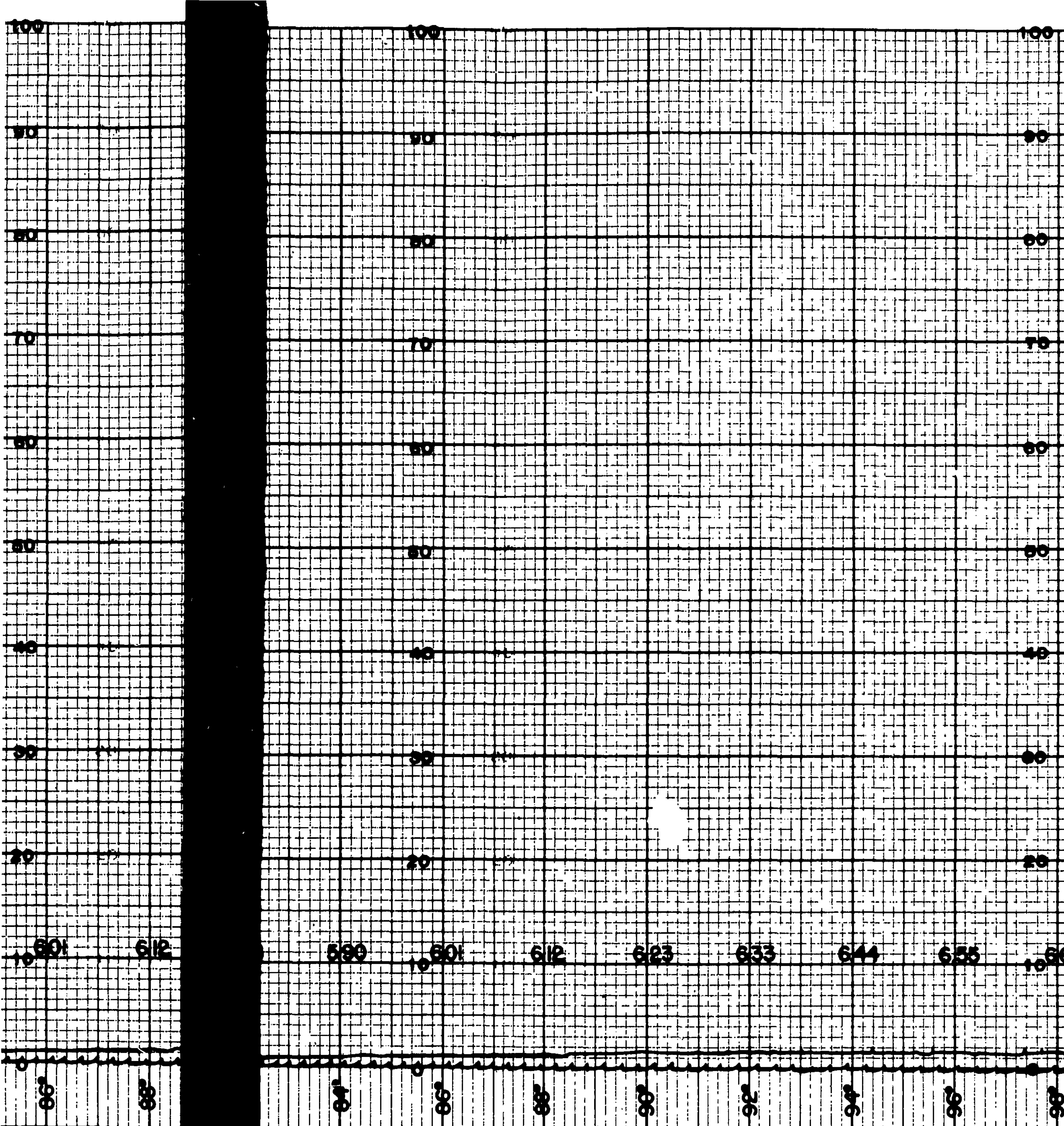
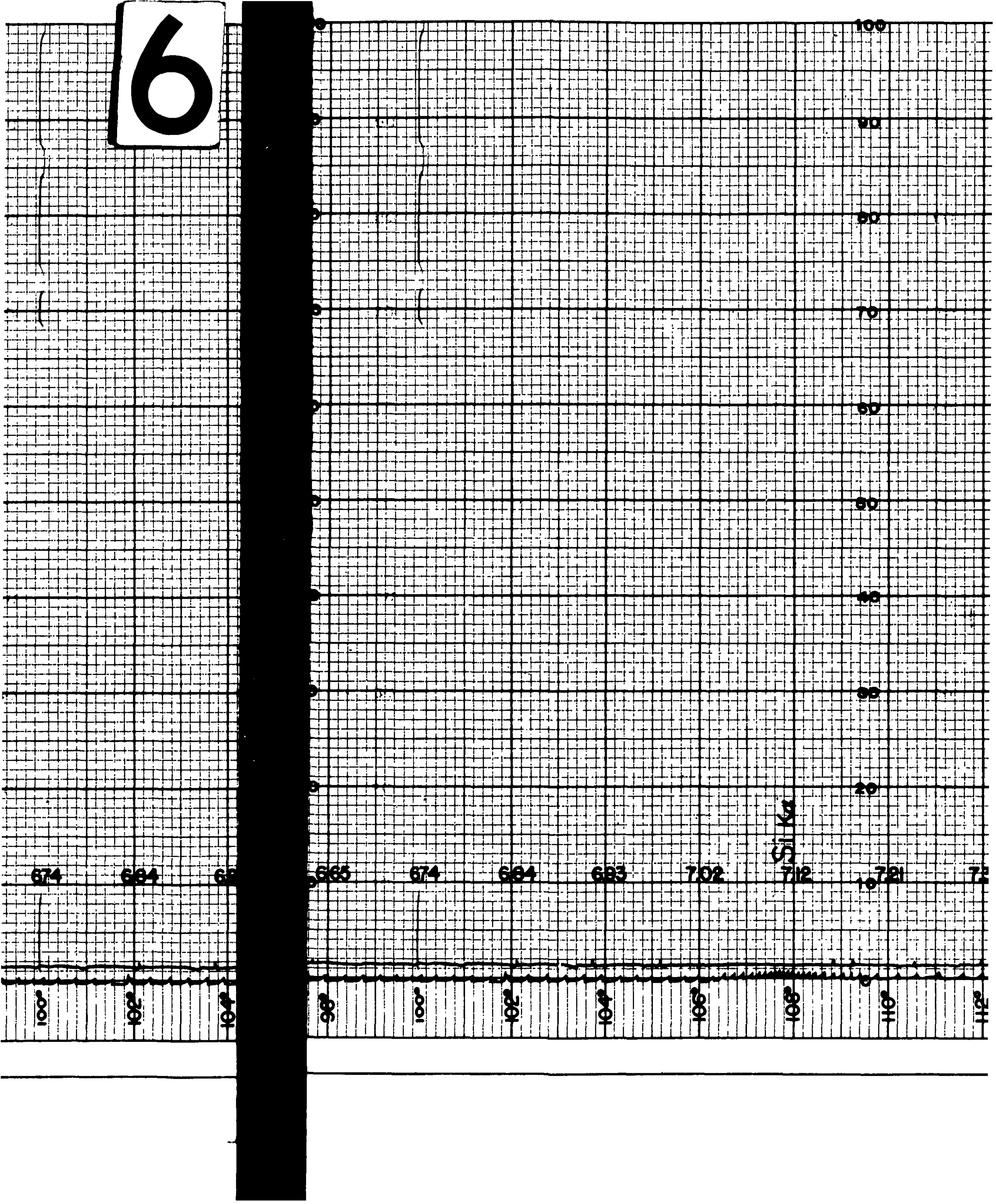
80
70
60
50
40
30
20
10
5.31
5.06
5.18
5.31
5.43
5.55
5.66
5.78
74°
70°
72°
74°
76°
78°
80°
80°
82°

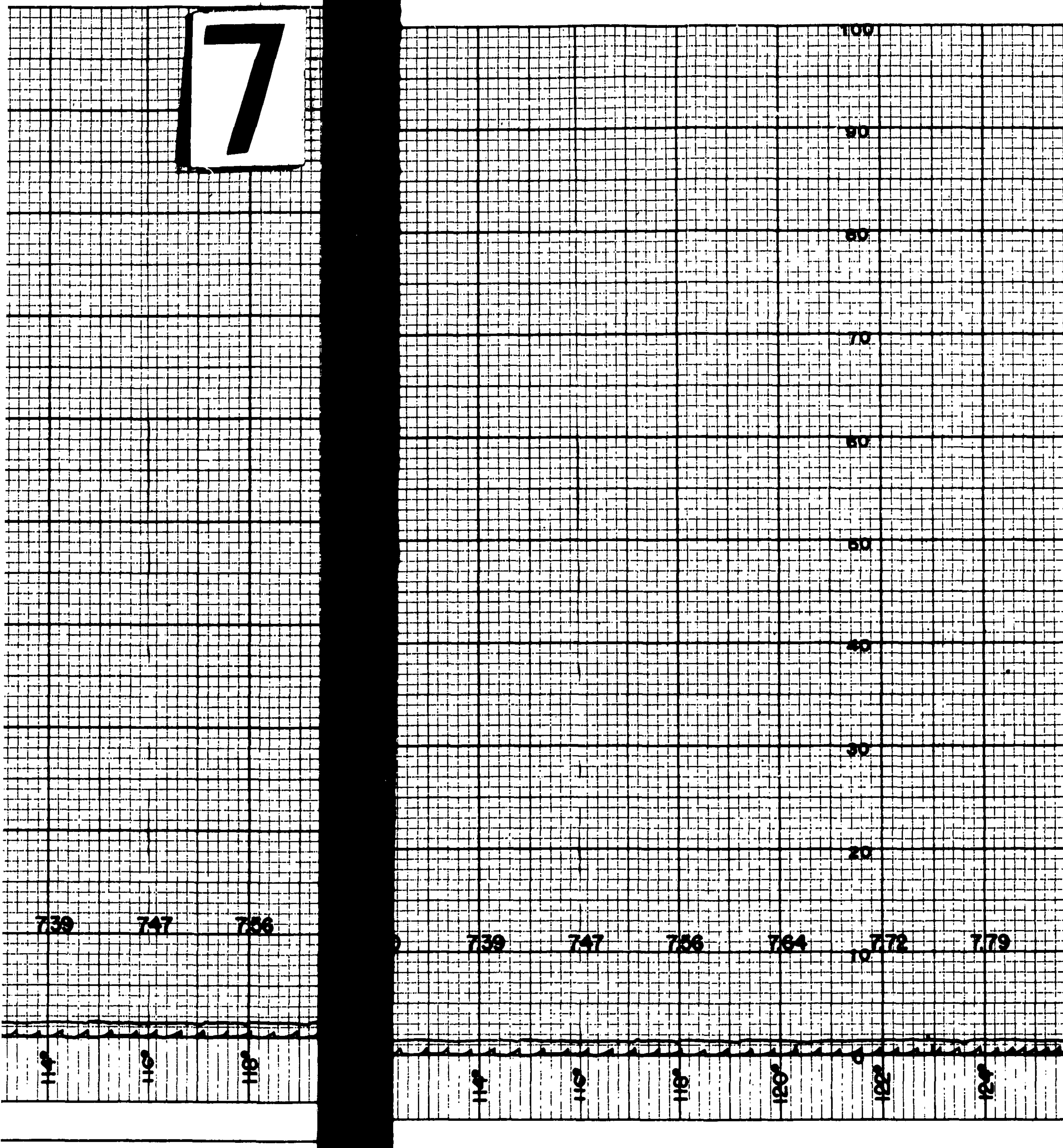


100
90
80
70
60
50
40
30
20
10
0
5.90
6.01
6.12
6.23
6.33
6.44
6.55
84
86
88
90
92
94
96
98



6
100
90
80
70
60
50
40
30
20
10
674
6.84
6.65
674
6.84
6.93
7.02
7.12
7.21
Si Kα
100°
102°
104°
98°
100°
102°
104°
106°
108°
110°
112°

7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90
80
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60
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20
10
0
739
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118°
120°
122°
124°

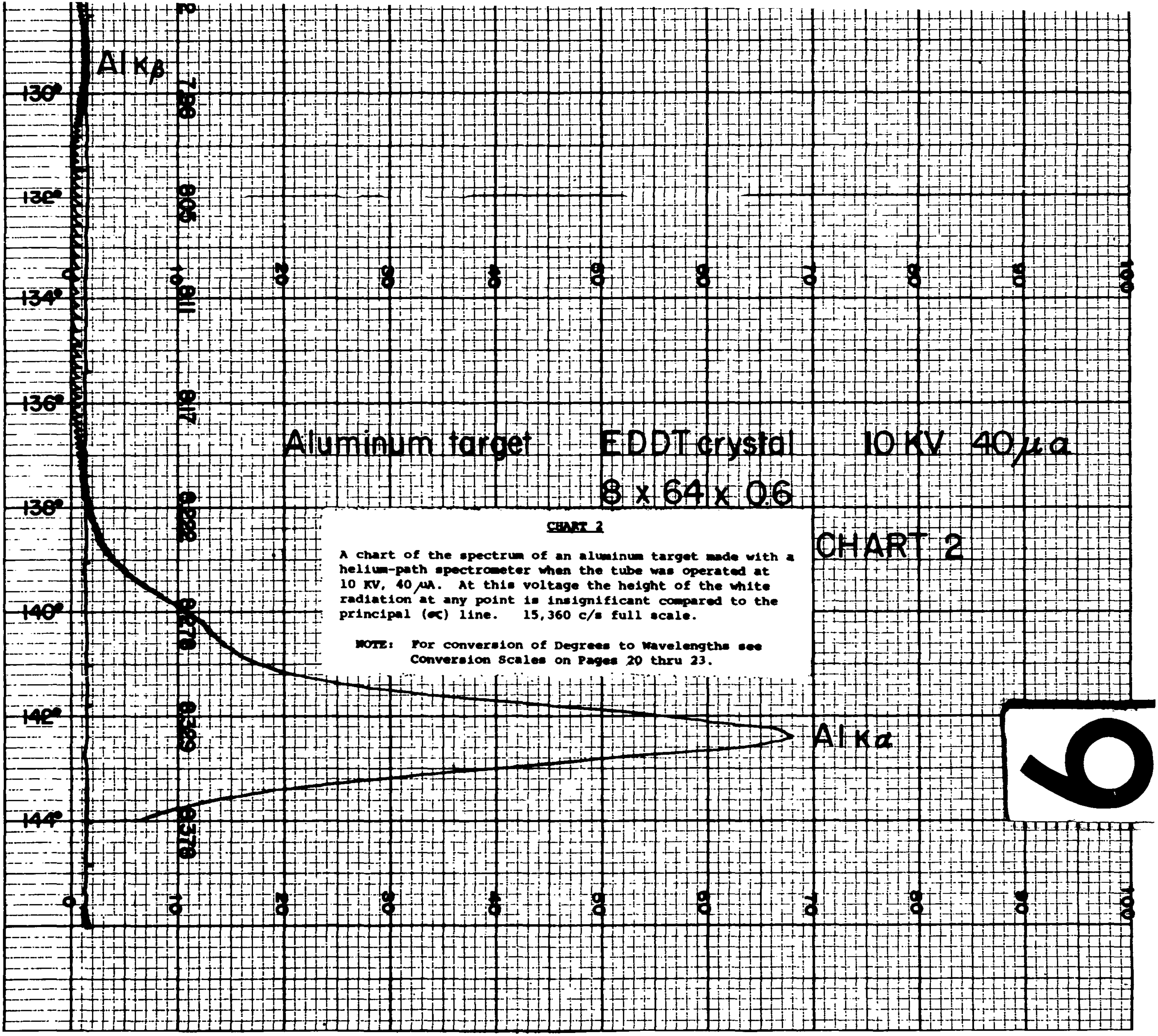


CHART 2

A chart of the spectrum of an aluminum target made with a helium-path spectrometer when the tube was operated at 10 KV, 40 μA. At this voltage the height of the white radiation at any point is insignificant compared to the principal (α) line. 15,360 c/s full scale.

NOTE: For conversion of Degrees to Wavelengths see Conversion Scales on Pages 20 thru 23.

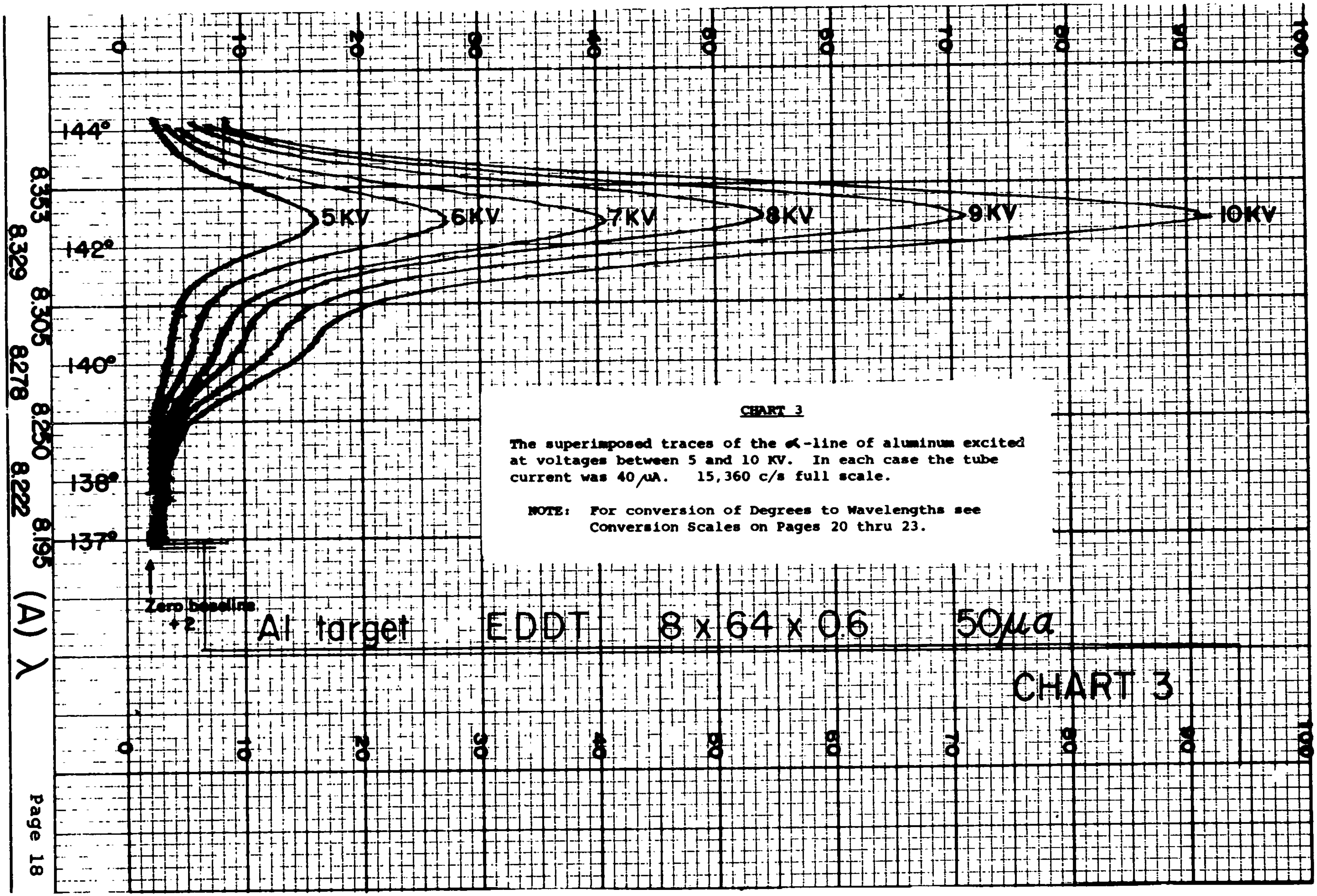
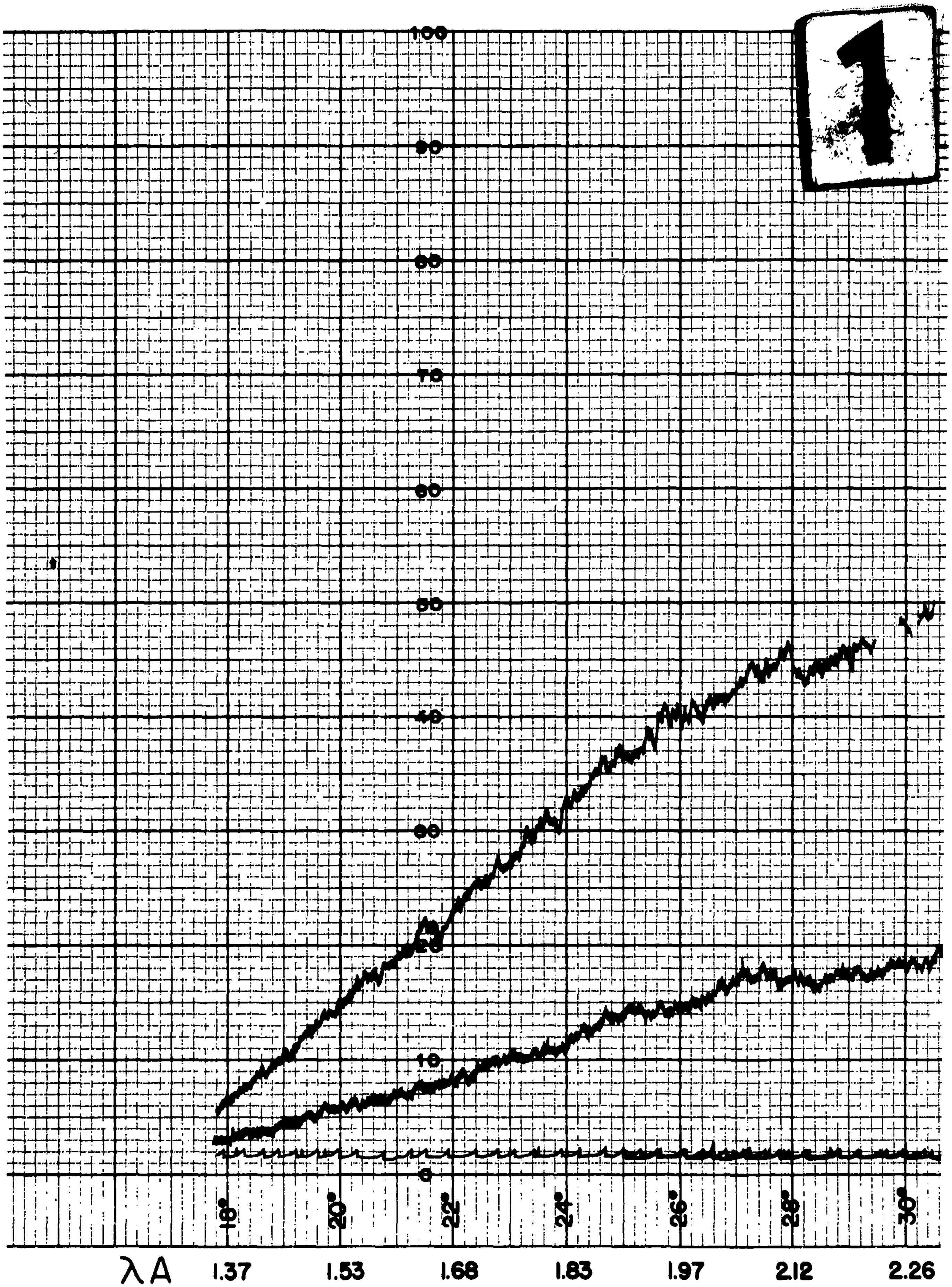
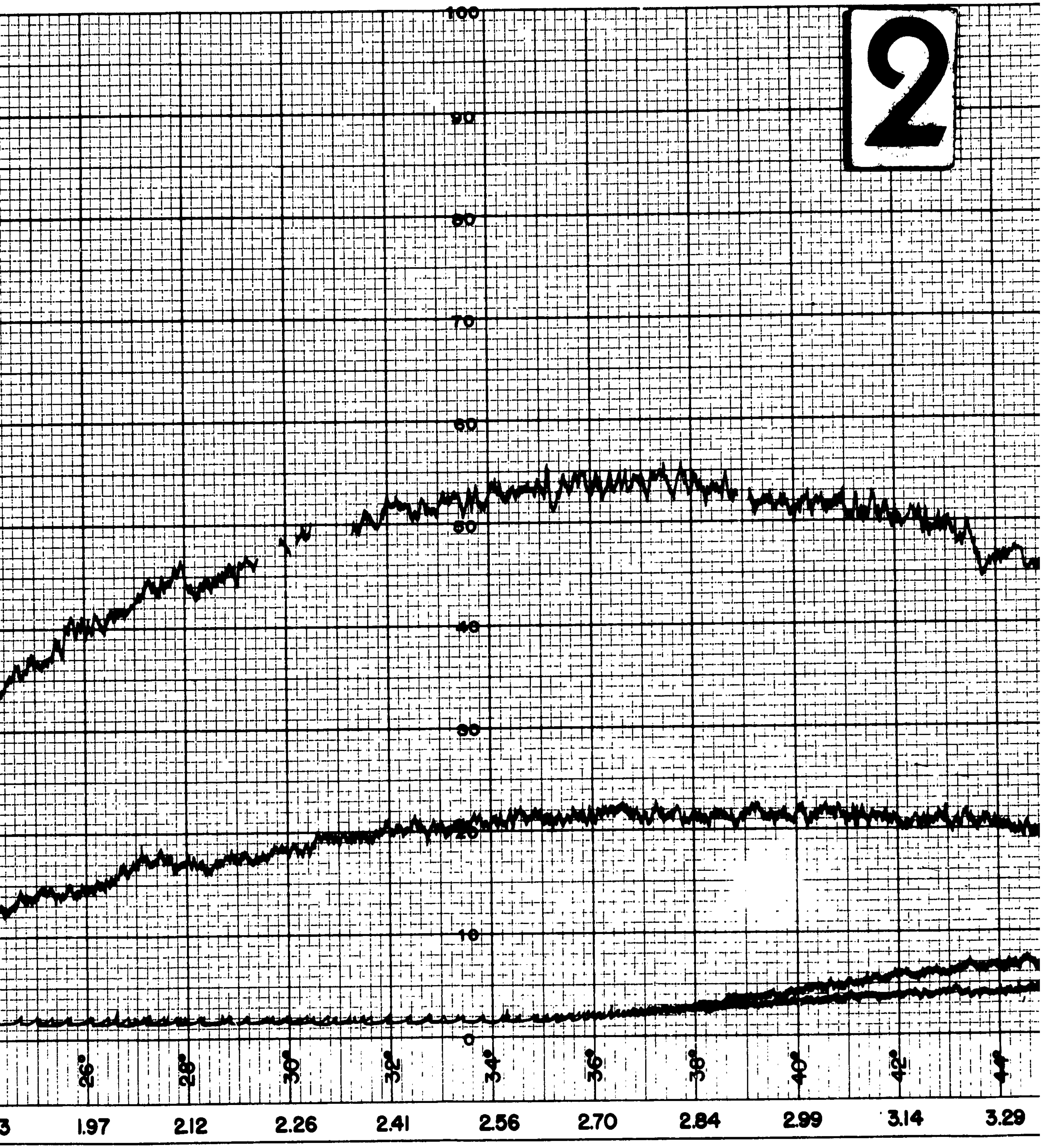


CHART 3

The superimposed traces of the α-line of aluminum excited at voltages between 5 and 10 KV. In each case the tube current was 40 μA. 15,360 c/s full scale.

NOTE: For conversion of Degrees to Wavelengths see Conversion Scales on Pages 20 thru 23.


1
100
90
80
70
60
50
40
30
20
10
0
18°
20°
22°
24°
26°
28°
30°
λA
1.37
1.53
1.68
1.83
1.97
2.12
2.26


2
100
90
80
70
60
50
40
30
20
10
0
26°
28°
30°
32°
34°
36°
38°
40°
42°
1.97
2.12
2.26
2.41
2.56
2.70
2.84
2.99
3.14
3.29

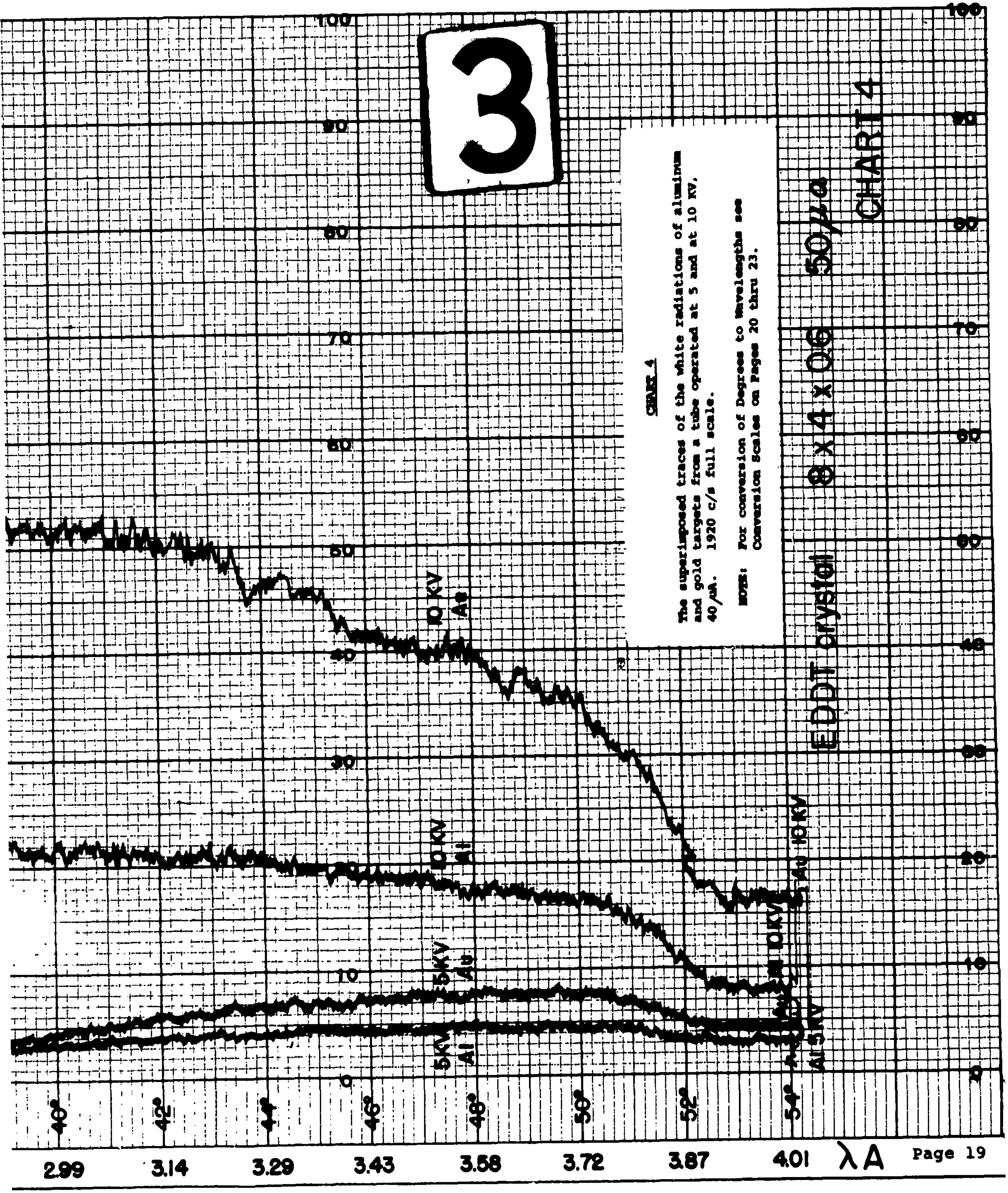
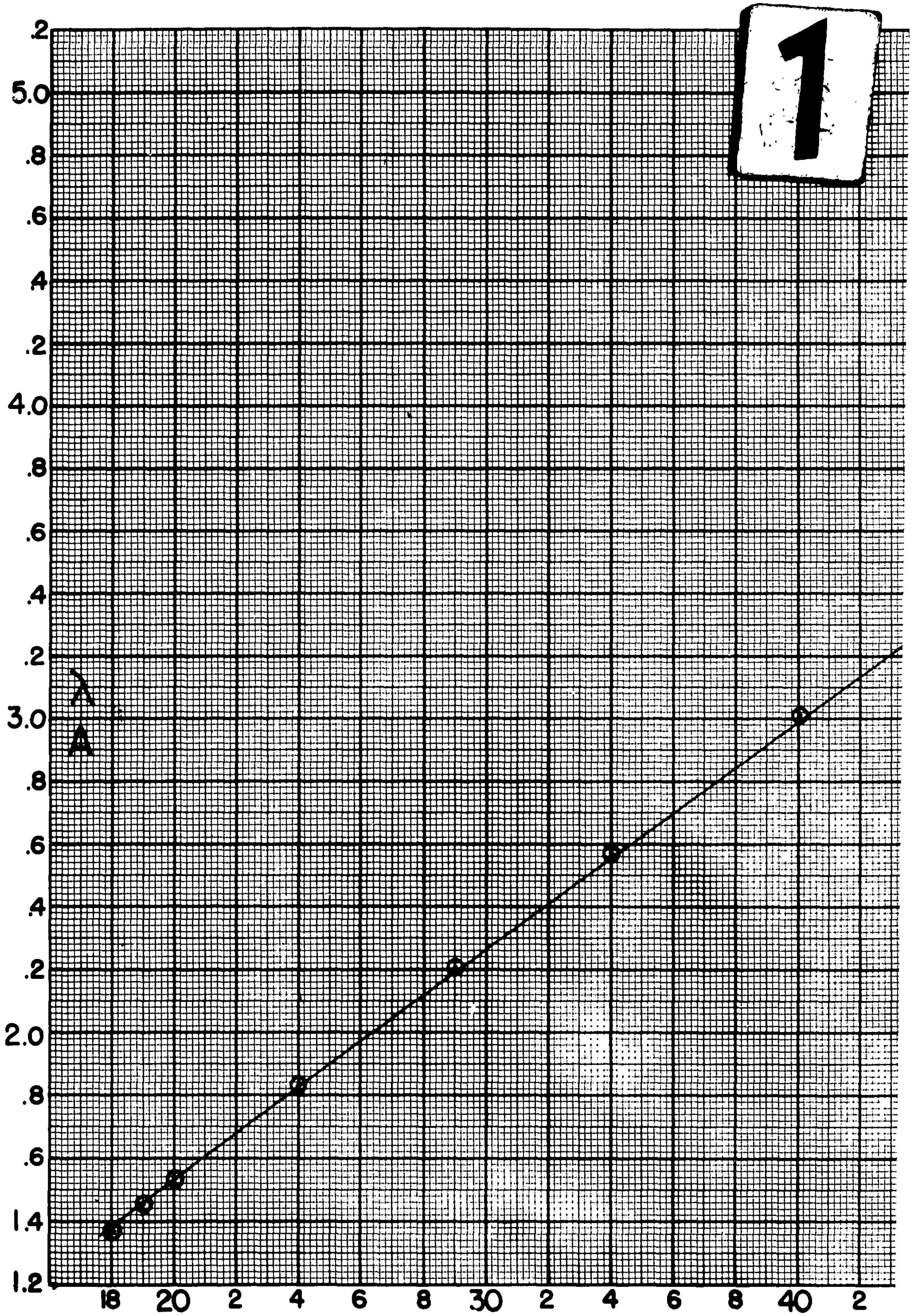
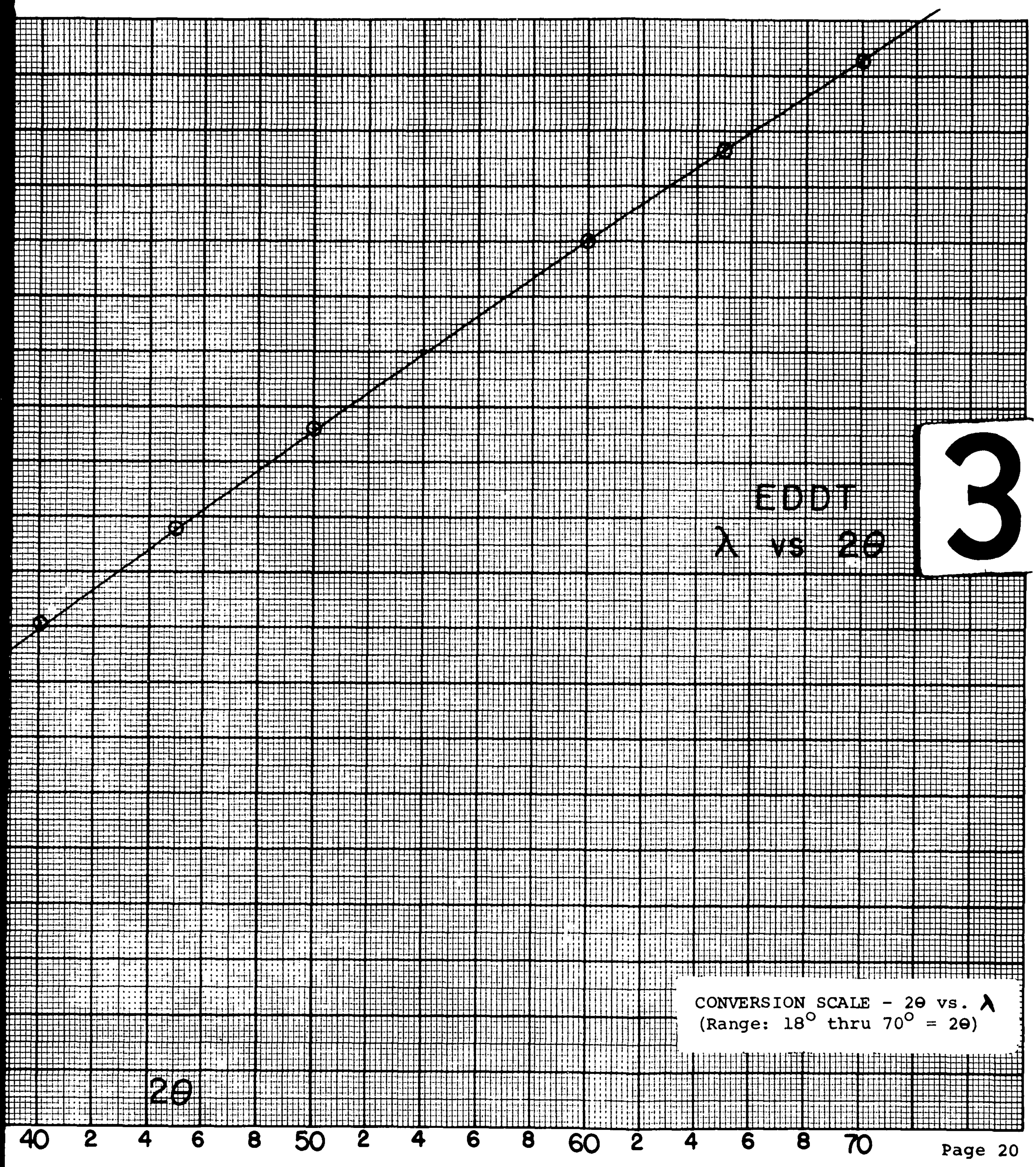


CHART 4

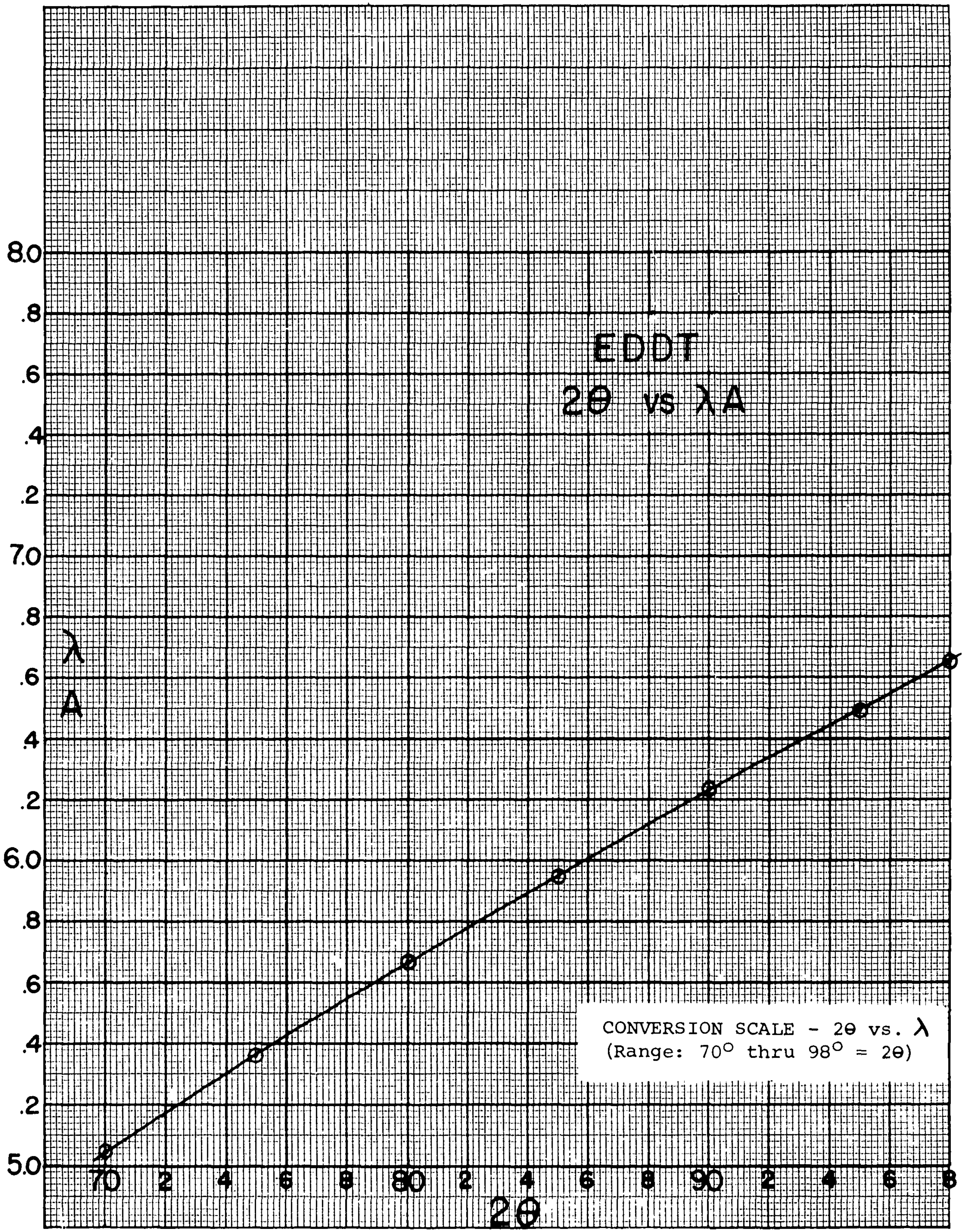
The superimposed traces of the white radiations of aluminum and gold targets from a tube operated at 5 and at 10 KV, 40/μA. 1920 c/s full scale.

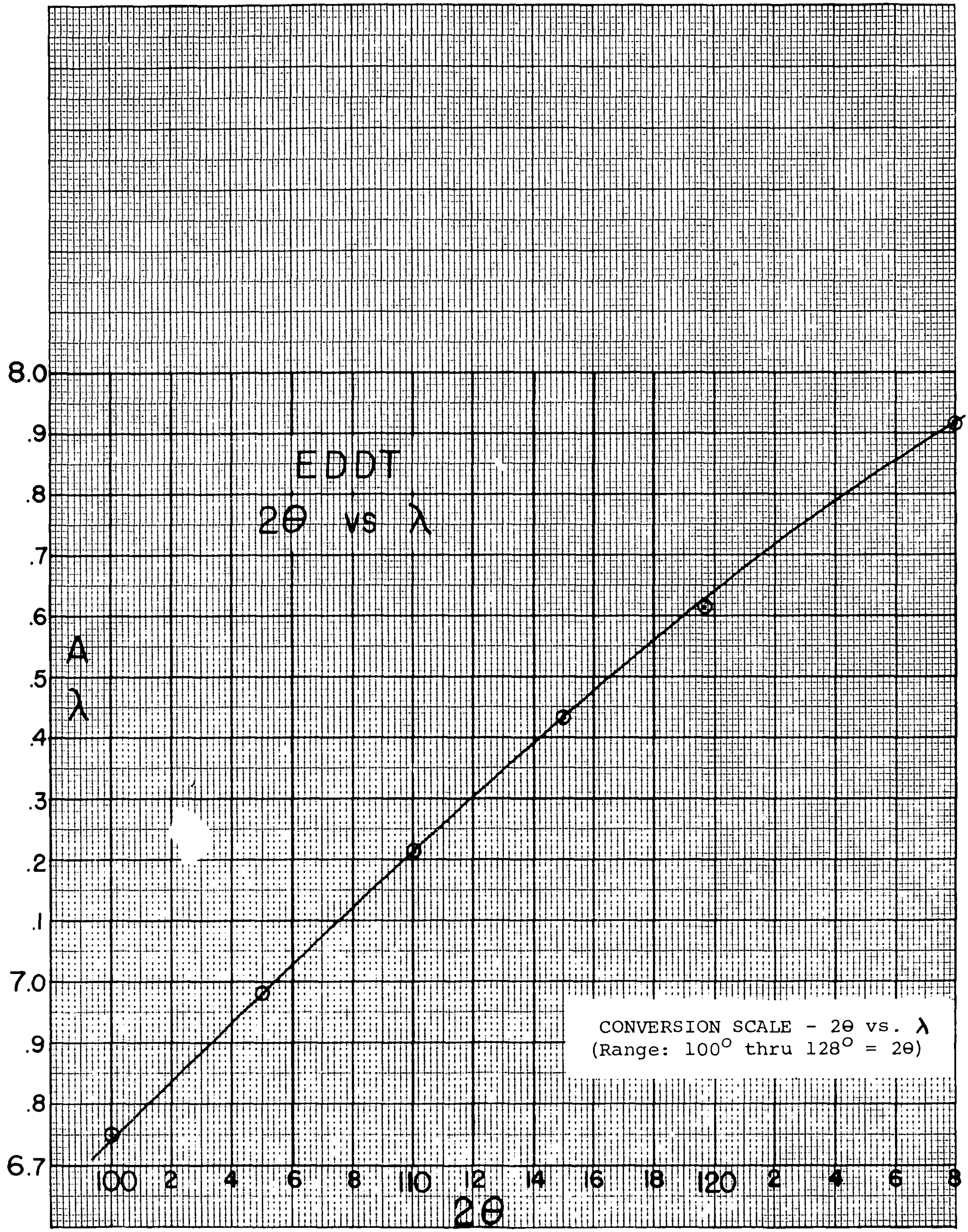
NOTE: For conversion of Degrees to Wavelengths see Conversion Scales on Pages 20 thru 23.

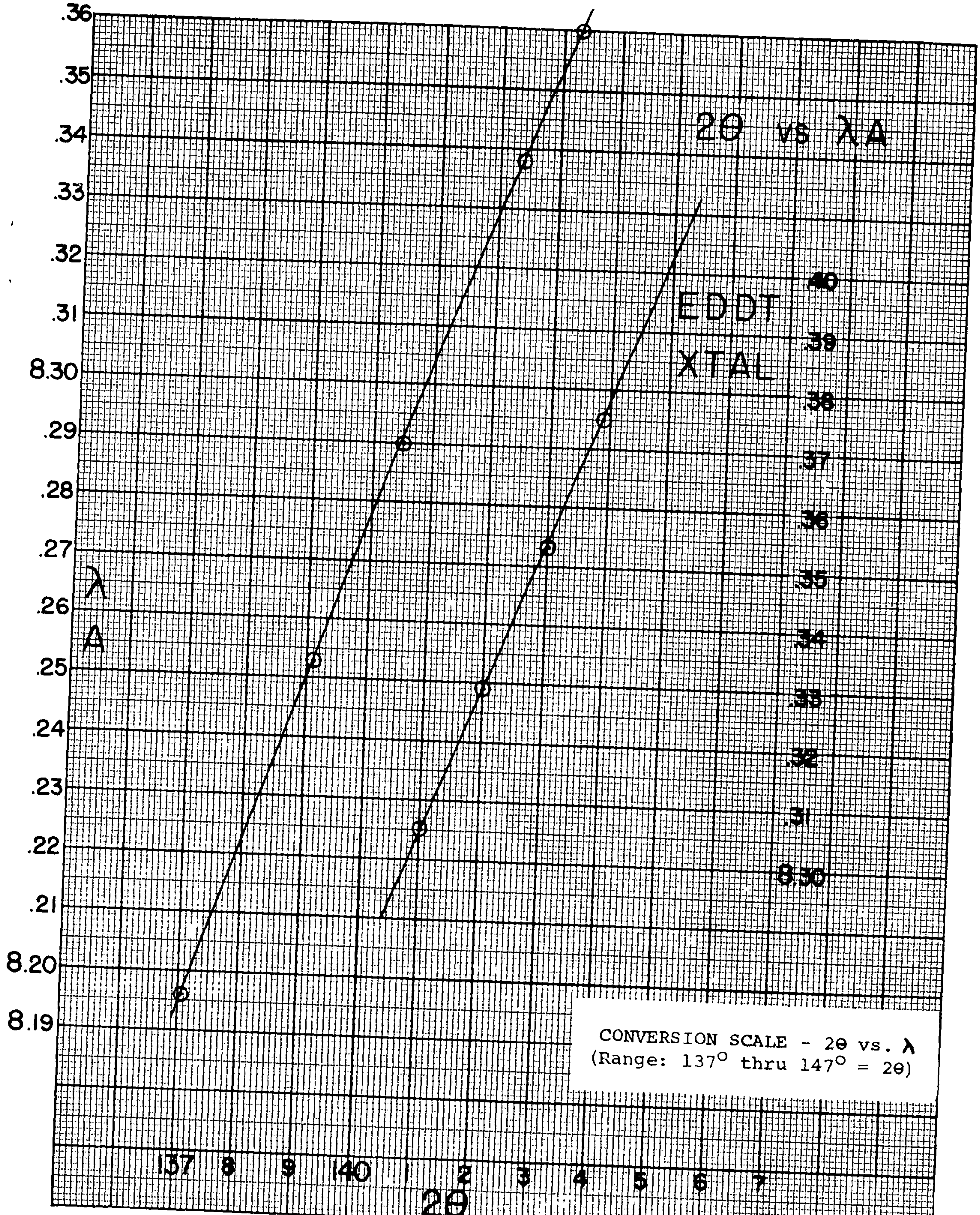

1
.2
5.0
.8
.6
.4
.2
4.0
.8
.6
.4
.2
λ
Å
3.0
.8
.6
.4
.2
2.0
.8
.6
1.4
1.2
18
20
2
4
6
8
30
2
4
6
8
40
2



3
EDDT
λ vs 2θ
CONVERSION SCALE - 2θ vs. λ
(Range: 18° thru 70° = 2θ)
2θ
40 2 4 6 8 50 2 4 6 8 60 2 4 6 8 70


EDDT
2θ vs λA
λ
A
8.0
.8
.6
.4
.2
7.0
.8
.6
.4
.2
6.0
.8
.6
.4
.2
5.0
70
2
4
6
8
80
2
4
6
8
90
2
4
6
8
2θ
CONVERSION SCALE - 2θ vs. λ
(Range: 70° thru 98° = 2θ)


EDDT
2θ vs λ
8.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
7.0
.9
.8
6.7
A
λ
100
2
4
6
8
110
12
14
16
18
120
2
4
6
8
2θ
CONVERSION SCALE - 2θ vs. λ
(Range: 100° thru 128° = 2θ)



CONVERSION SCALE - 2θ vs. λ
(Range: 137° thru 147° = 2θ)

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Unclassified Report

Experiments were made to determine the feasibility of constructing a pulsed source of soft X-rays of flux levels of at least 1 cal/cm^2 in submicrosecond times with photon energies between 1 and 5 Kev. The design and operation of the X-ray tube are presented for a circular capacitance bank of series-parallel units having a total capacity of 54 μf with maximum voltage rating of 4 Kv, and for another capacitance bank of 6.4 μf with a maximum voltage rating of 13 Kv. Anode pulsing was carried out, since the X-ray yield with pulsed cathode was found to be in-

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3. X-radiation -- simulation
4. X-ray emission
5. X-ray sources

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