CO_2 Laser Cold Cathode Study

NASA Grant NGR-21-002-216

January 1972

TECHNICAL
RESEARCH
REPORT

(NASA-CR-122441) CO2 LASER COLD CATHODE STUDY Progress Report U. Hochuli (Maryland Univ.) Jan. 1972 27 p CSCL 20E

N72-27550

Unclas
G3/16 35352

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Progress Report for NASA Grant #21 002 216

Introduction

Up to the present there are no reliable sputter free cold cathodes for the CO_2 laser available that yield lifetimes in excess of 10000 hours from small gas volumes. (For our purpose we define a gas volume of 100 cm^3 for a 1W CO_2 laser as small). Although general considerations enable us to predict the group of cathode materials that are going to be most likely successful we are faced with a lack of detailed understanding of the surface physics and chemistry taking place on the cold cathode surface of a CO_2 laser. In our opinion only a systematic approach to this problem is justified. Such an approach involves the study of a relatively large number of different cathode materials and will most likely yield more than one solution. It would be enormously wasteful to build lasers for each different cathode material. Discharge tubes are sufficient to elliminate all the unsuccessful approaches. The more successful ones can be further screened by using gas analysis methods to monitor some of the constituents of the CO_2 gas mixture. Considering the number of variables involved we realize that over a hundred discharge tubes have to be fabricated and tested. This necessitates facilities to produce alloys, cathodes and discharge tubes. All of these discharge tubes have then to be tested for their electrical characteristics and the more successful ones have to undergo gas analysis.

During the past five months we have developed our facilities to the point where we can cast an alloy, fabricate it into a cathode and have that particular cathode working in a discharge tube all within one to two man days of work. This time span does of course exclude particular alloys that are very difficult to handle. In this case it often takes more than one week to overcome the difficulties involved.

Description of the facilities

A RF generator with 3 KW output power is used as the heat source for melting. The components of the alloy can be heated in graphite crucibles that are easily machined in our shop into suitable shapes. Zirconia crucibles can be substituted to melt alloys prone to carbon contamination. In this case the alloy has to be heated by direct induction in the metal itself or indirectly by placing the Zirconia crucible in a tantalum sleeve. In order to avoid oxidation problems the crucible is surrounded by a quartz sleeve that can be evacuated with a turbo molecular pump and back-filled with argon if so desired. We have also fabricated very small crucibles by drilling suitable holes into Zirconia slugs. The necessary diamond core drills were available from research on very stable laser structures concurrently conducted for the Navy.

The alloys, cast into suitable slugs or droplets have then to be machined directly into cathodes or first rolled out into sheet form. Unfortunately we did not find a suitable local manufacturer willing and able to provide this service in a reliable way and with the necessary short turnover time required. We had therefore no other choice than to do it ourselves with the rolling facilities of the center of materials research at the University of Maryland.

The cathodes using the alloy in sheet form are then bent into cylinders with a crimp seam. A suitable end cap at the rear of the cathode cylinder confines the discharge. These end caps are formed by dies we designed and fabricated in house. The cathode necks are protected from high current densities by standard ceramic collars used in neon sign electrodes. The four normalized cathode designs used are shown in figure 1. The discharge tube type incorporating these cathodes is shown in figure 2. The gas volume in these tubes is purposely kept low at 25 cm^3. Chemically inert and shiny plantinum sheet anodes allow to visually observe cathode sputtering deposits that reach the anode. These anodes can usually be cleaned with hydrofluoric acid and reused several times in rebuilt tubes. More stubborn deposits are removed with abrasive paper and anodes of bad appearance are remolten and the platinum reused for the fabrication of new ones.

So far we have built over 70 discharge tubes with cathodes from the 8 pure elements Pt, Pd, Au, Ag, Cu, Co, Ni, Re and with cathodes from alloys using the elements mentioned and also including Mn, Sn, In, Zn, Cd.

Our electrical test facilities were increased to the point where we can run and monitor 32 discharge tubes simultaneously.

Gas Monitoring

We decided that infrared absorption spectroscopy was a suitable preliminary approach to monitor the CO_2 as well as the CO content of the most promising discharge tubes. This method requires only the permanent attachment of an absorption cell to the discharge tube. Compared with gas analysis by a mass spectrometer the absorption cell method requires no gas depletion and no seals that have to be broken. A further advantage is the fact that the 4.6μ CO line can be observed without the resolution problems between N_2 and CO both with a mass around 28 gr per mole. The optical method has the drawback that it is less sensitive and does not allow to passively monitor the O_2 content. This is due to the fact that the symmetrical O_2 molecule has no resultant electrical dipole matrix element for vibrational transistions originating from the ground state.

We have so far built six absorption cells of 8.4 cm path length, Fig. 3, using Kodak's Irtran 2 windows. Indium sealing techniques were used to join the windows to the Pyrex cell body. The 20 mm ID of the cells accommodates the beam of a DigiLab FTS 14 interferometer and the length was a compromise between cell gas volume and absorption. A partial CO_2 pressure of 5 Torr corresponds roughly to a peak absorption of 10% in the 4.3μ CO_2 band. To a similar pressure of CO corresponds only an absorption of about 1.7% around 4.6μ. The spectrum, taken with a slit width of 4 cm^{-1}, is shown in Fig. 4.

Results

Considering the time scale involved the results we have can only be of a preliminary nature. Nevertheless some of the discharge tubes do extremely well for a gas volume of only 25 cm^3 or roughly one half the gas volume used in a 1W laser. This statement is especially true for the discharge tubes using silver and silver compound cathodes. Their characteristics are shown in figures 5 to 7. The pure silver cathode has run for more than 5000 hours and shown an almost unchanged discharge characteristic. Most investigation would claim a 5000 hour laser with this result. We are far more critical. Visual inspection shows slight anode deposits and a flickering cathode spot that would result in a noisy laser. The flickering can be controlled by lowering the current density and maintaining at the same time the proper cathode temperature. This still leaves us with the slight but existing anode deposit problem. These deposits are due to the attraction of negative ions by the anode. This negative ion formation is efficiently suppressed by adding copper to the silver cathode. So far we have 3 discharge tubes with such cathodes running. A representative characteristic is shown in figure 6.

Considering all the different cathode properties desired we took the risk to build a laser with such a cathode without prior knowledge of its life expectation. Because of a slightly different surface treatment the laser cather produces more cathode deposits than the other 3 similar cathodes. So far the laser is performing very well, see figure 8, but 1000 hours is only a short testing period. The fact that the same techniques resulting in a good discharge tube have also produced a good laser is very significant. This correlation gives confidence that our approach, namely to gain first experience with discharge tubes, so far has been a sound one.

The next important cathode material is copper. Fig. 9 shows the characteristic of a tube with such a cathode. This is the cleanest discharge tube we have so far built. The anode looks still clean and cathode sputtering is almost nonexistant. We do however notice gas clean up on Fig. 9.

Fig. 10 shows the performance of a gold-copper alloy cathode. We hope that this cathode will reduce the gas clean up problem of the pure copper cathode and at the same time preserve its cleanliness. These assumptions seem to hold for the first 500 hours tested.

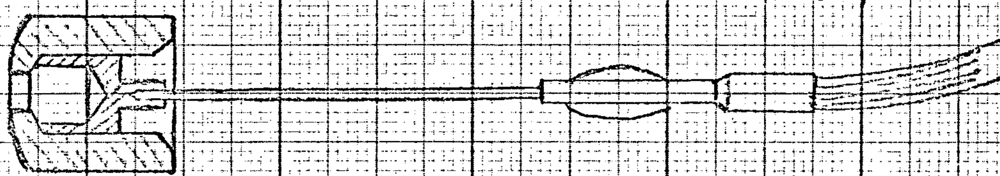
The next 8 figures show discharge characteristics of tubes with pure Pt, Pt-Cu, Pt-Ag and Pt-Au cathodes. So far these results are not satisfactory. Most of these cathodes sputter and all have too rapid gas clean up. Raising cathode and wall temperatures especially under the sputtering deposits may help to let the trapped gas diffuse back out.

Finally, on figures 19 and 20, we have the performance of two nickel cathodes with different current densities. Comparing these characteristics with some of our results clearly show that we are gaining a much better understanding of the problem.

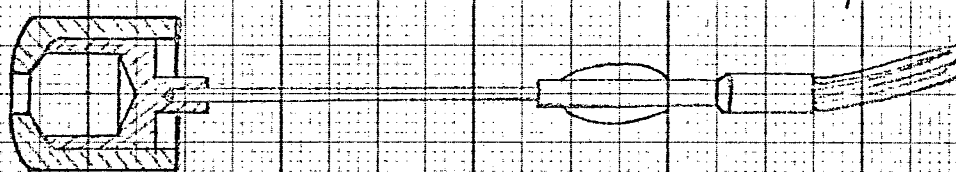
The discussion of our results has been kept extremely short. Time is needed to verify some of our ideas as well as to optimize the parameters of the most promising cathodes.

Cathode Types

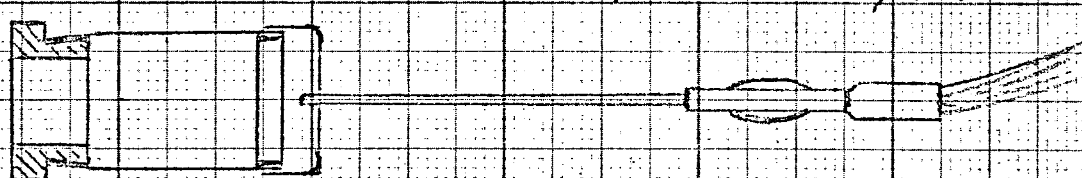
Type 1LX 3.5mm ID
X mm max. depth



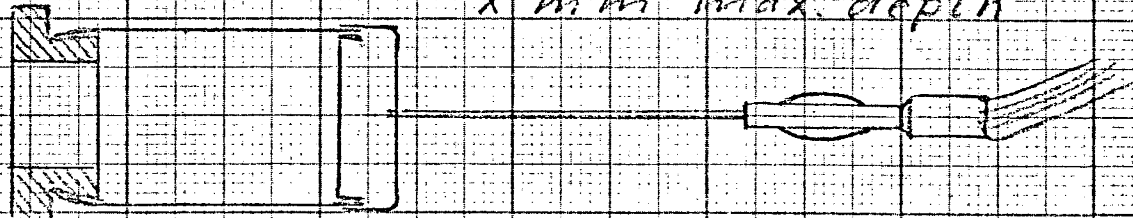
Type 2LX 5 mm ID
X mm max. depth



Type 3LX 8.5mm ID
X mm max. depth



Type 4LX 11.3 mm ID
X mm max. depth



1/2"

Fig. 1

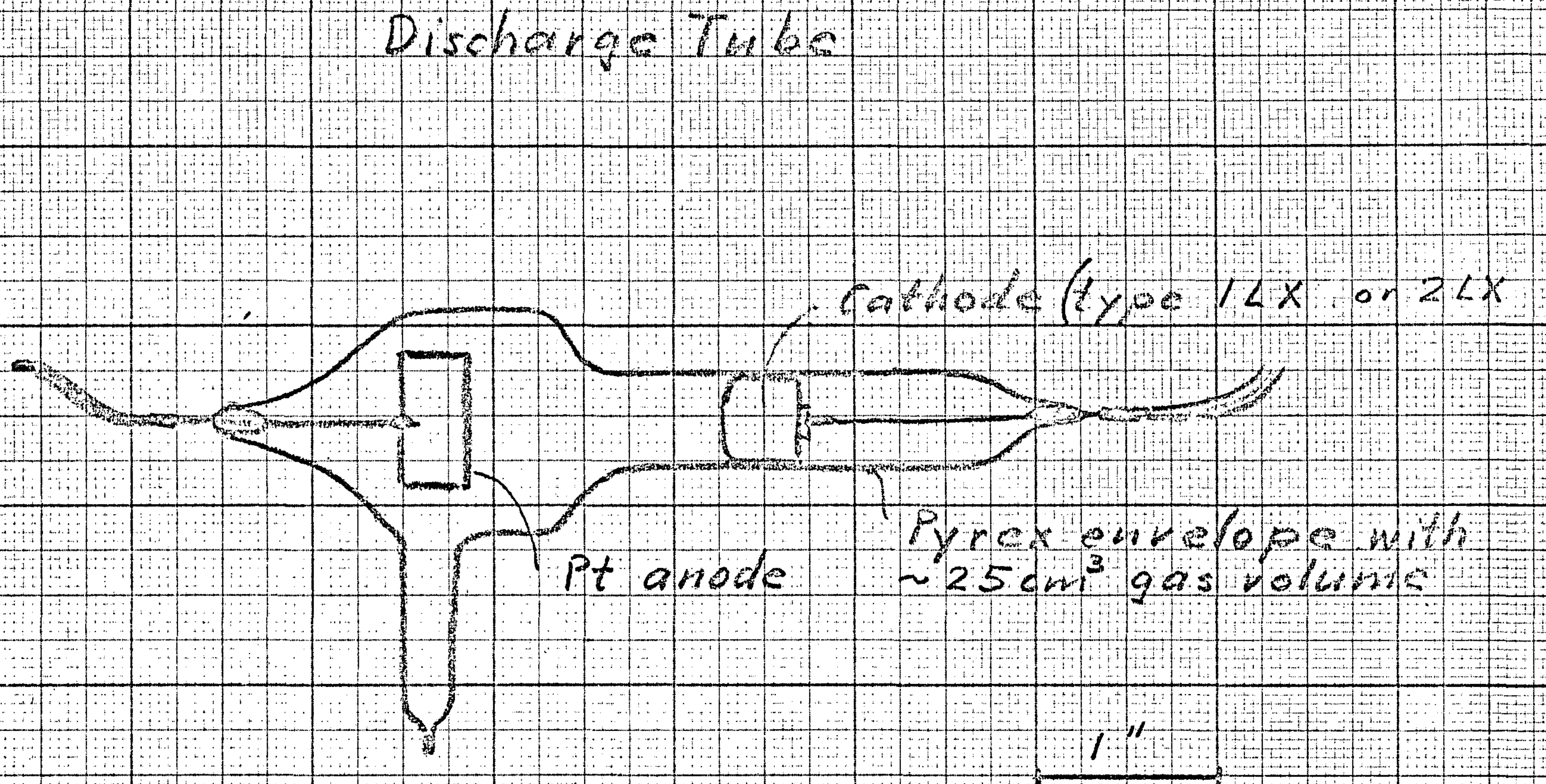

Discharge Tube
Cathode (type 1LX or 2LX)
Pt anode
Pyrex envelope with
~25 cm³ gas volume
1"

Fig 2

Infrared Absorption Cell

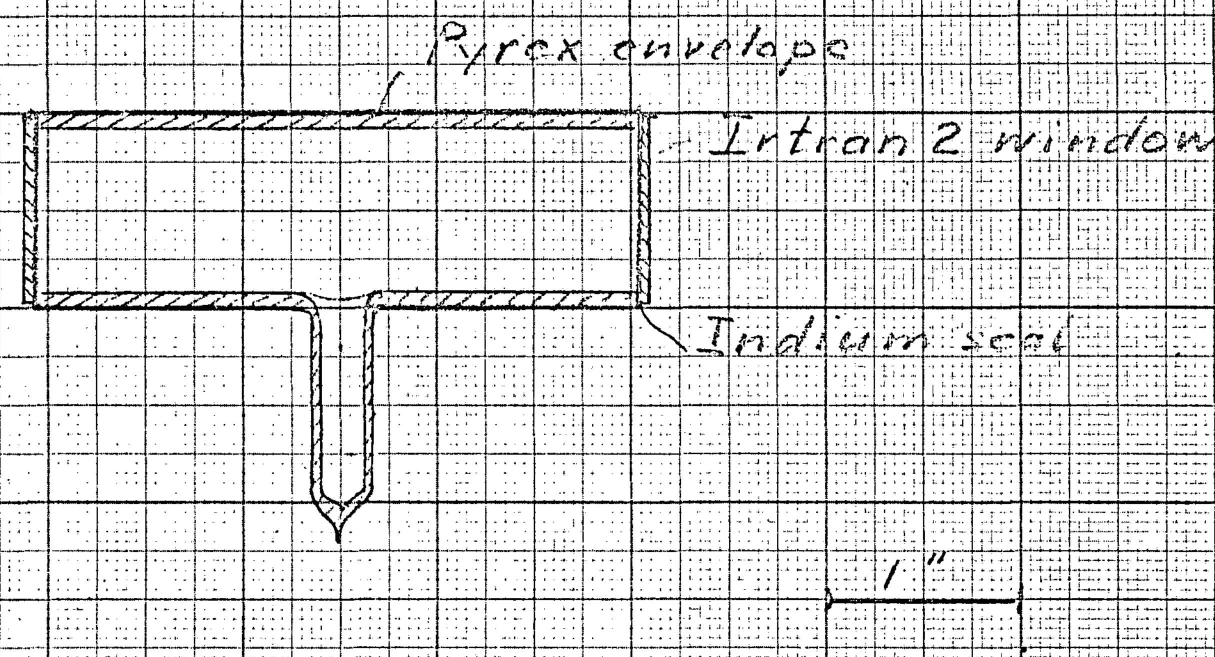


Fig 3

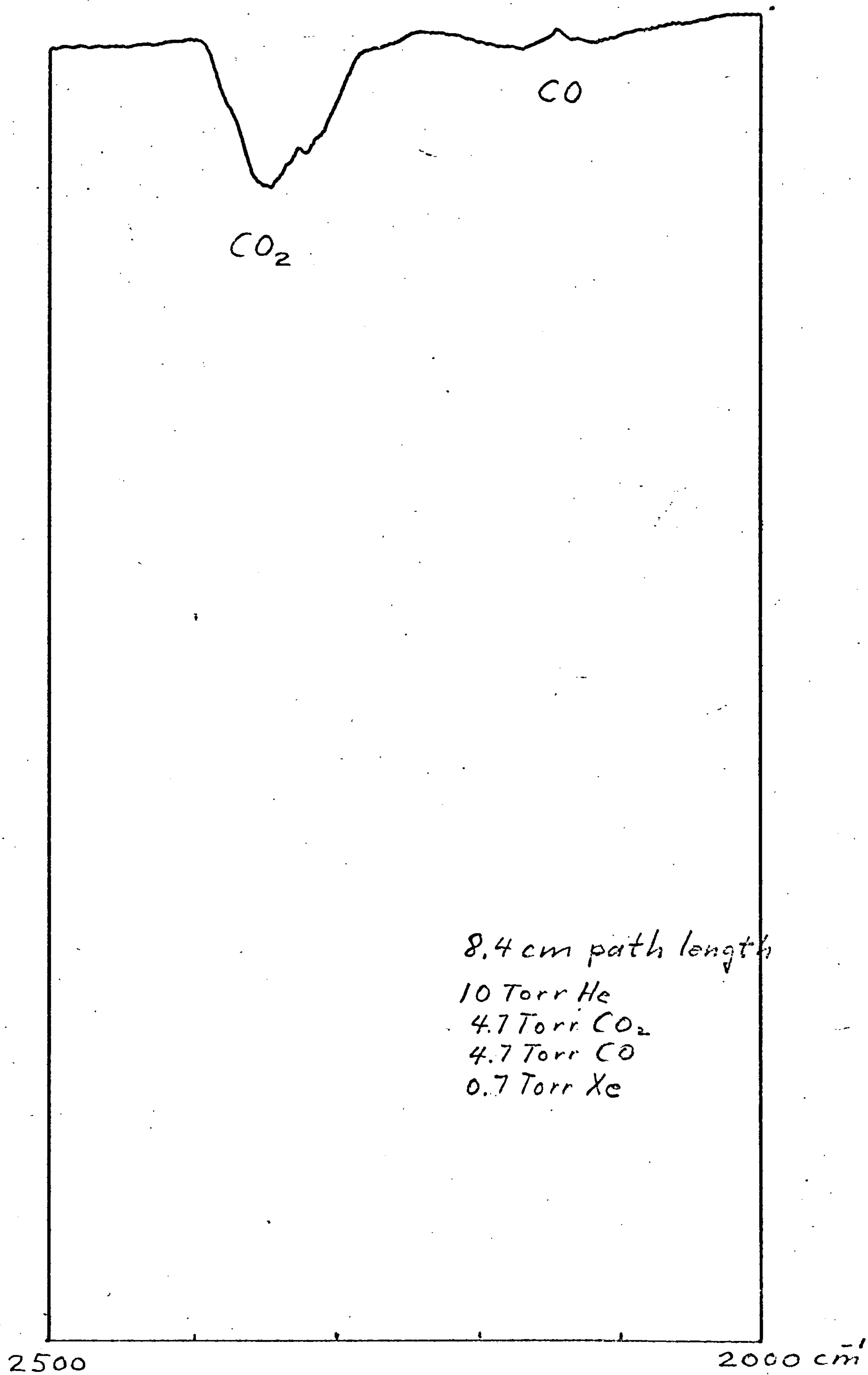

CO
CO_2
8.4 cm path length
10 Torr He
4.7 Torr CO_2
4.7 Torr CO
0.7 Torr Xe
2500
2000 cm^{-1}

Fig. 4

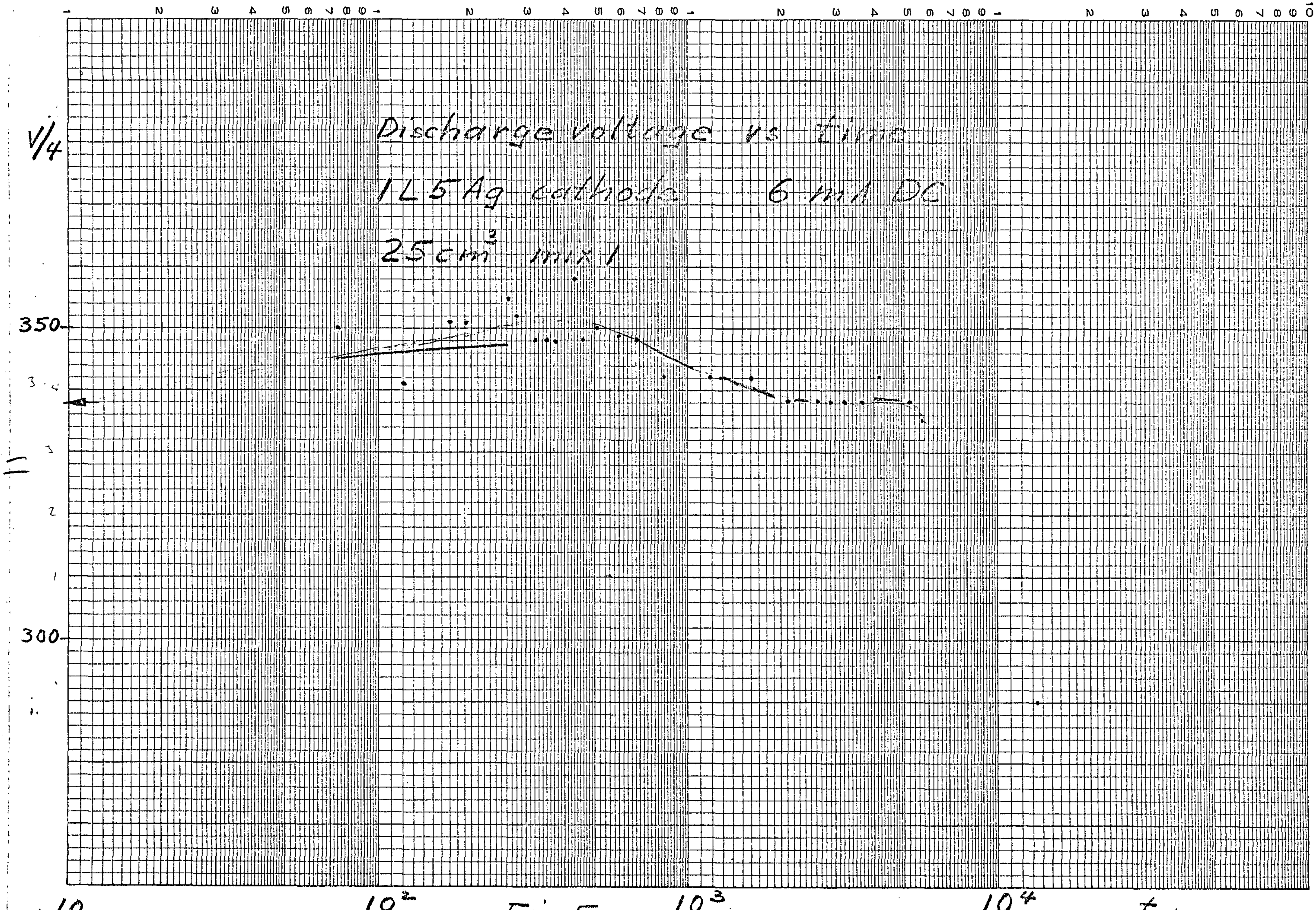

Discharge voltage vs time
1L5 Ag cathode 6 mA DC
25 cm² mix 1
V/4
350
300
10
10²
10³
10⁴
t hours

Fig. 5

NO. 340-L410 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
4 CYCLES X 10 DIVISIONS PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

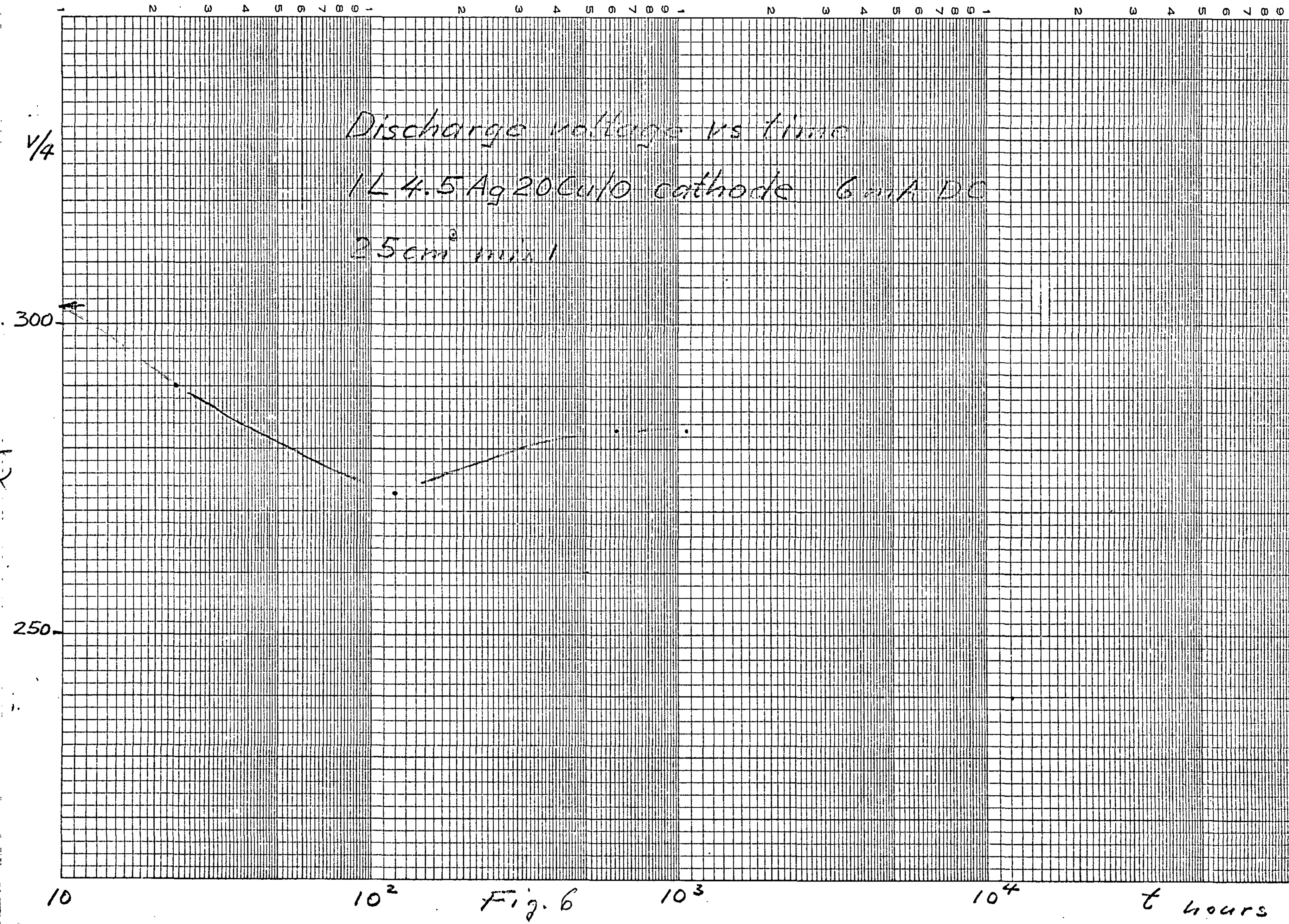


Fig. 6

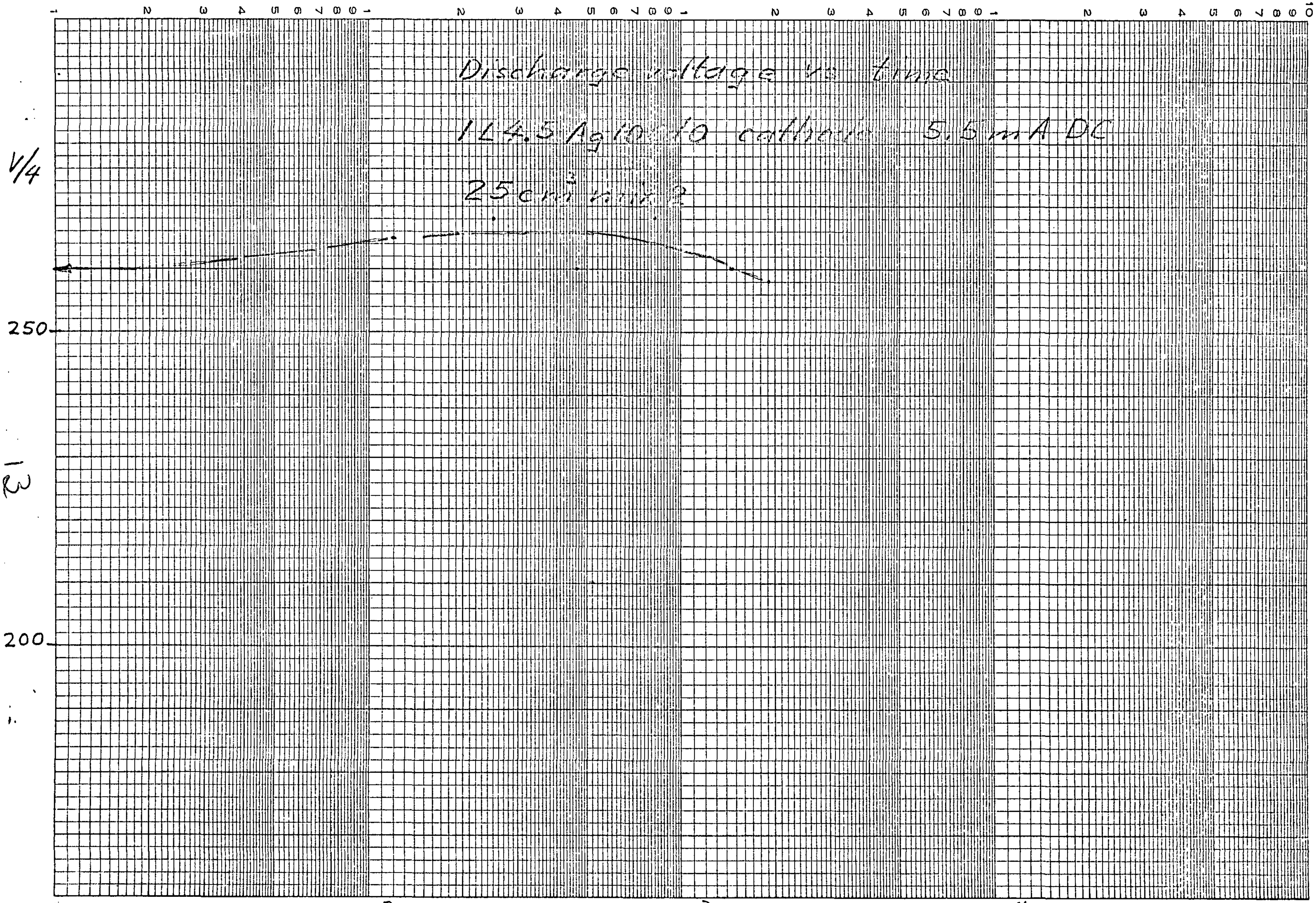


Fig. 7

NO. 340-L410 DIETZGEN GRAPH PAPER
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4 CYCLES X 10 DIVISIONS PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

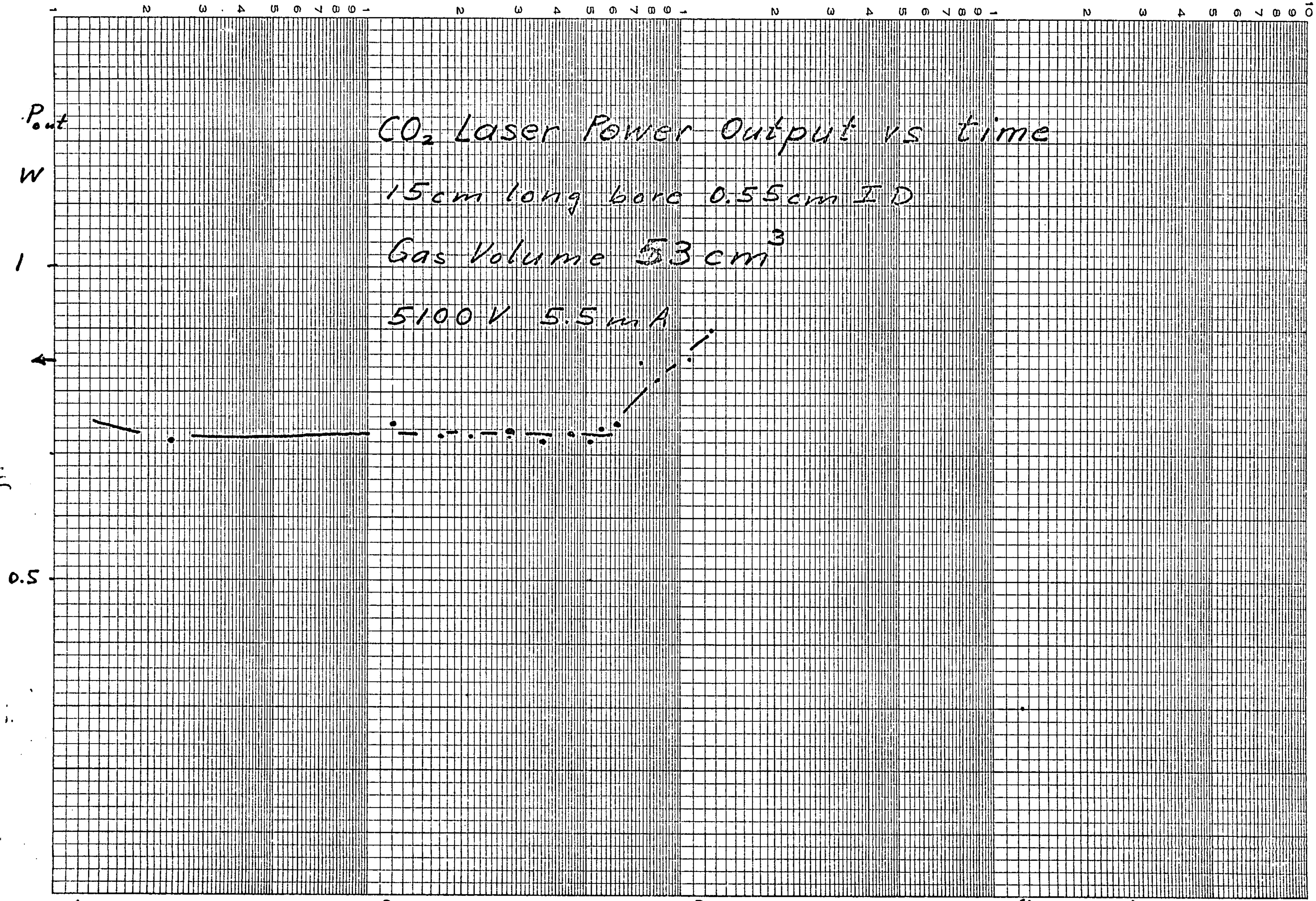

Fig. 8

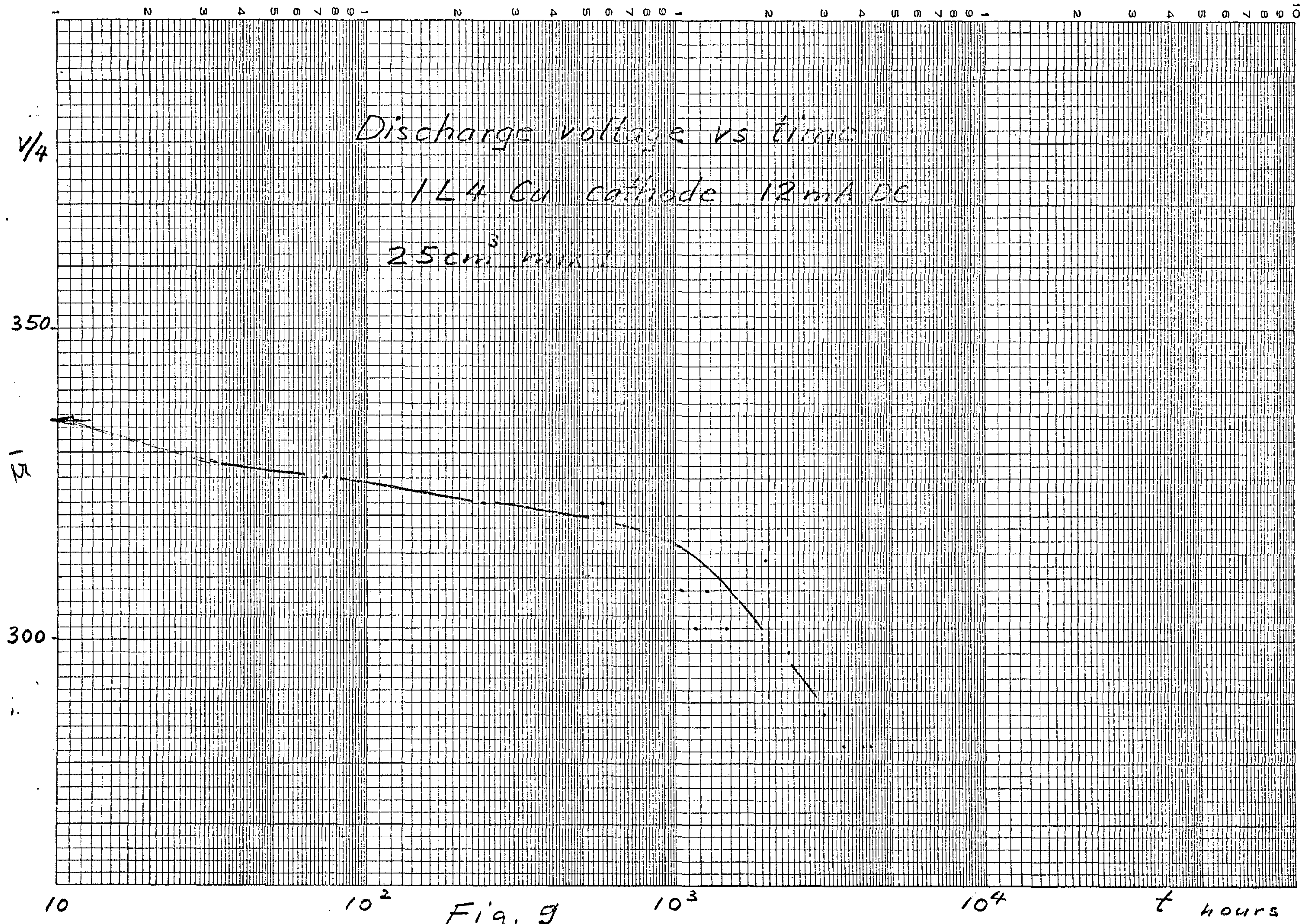
Discharge voltage vs time
1L4 Cu cathode 12mA DC
25cm³ min
V/4
350
15
300
10
10²
10³
10⁴
t hours

Fig. 9

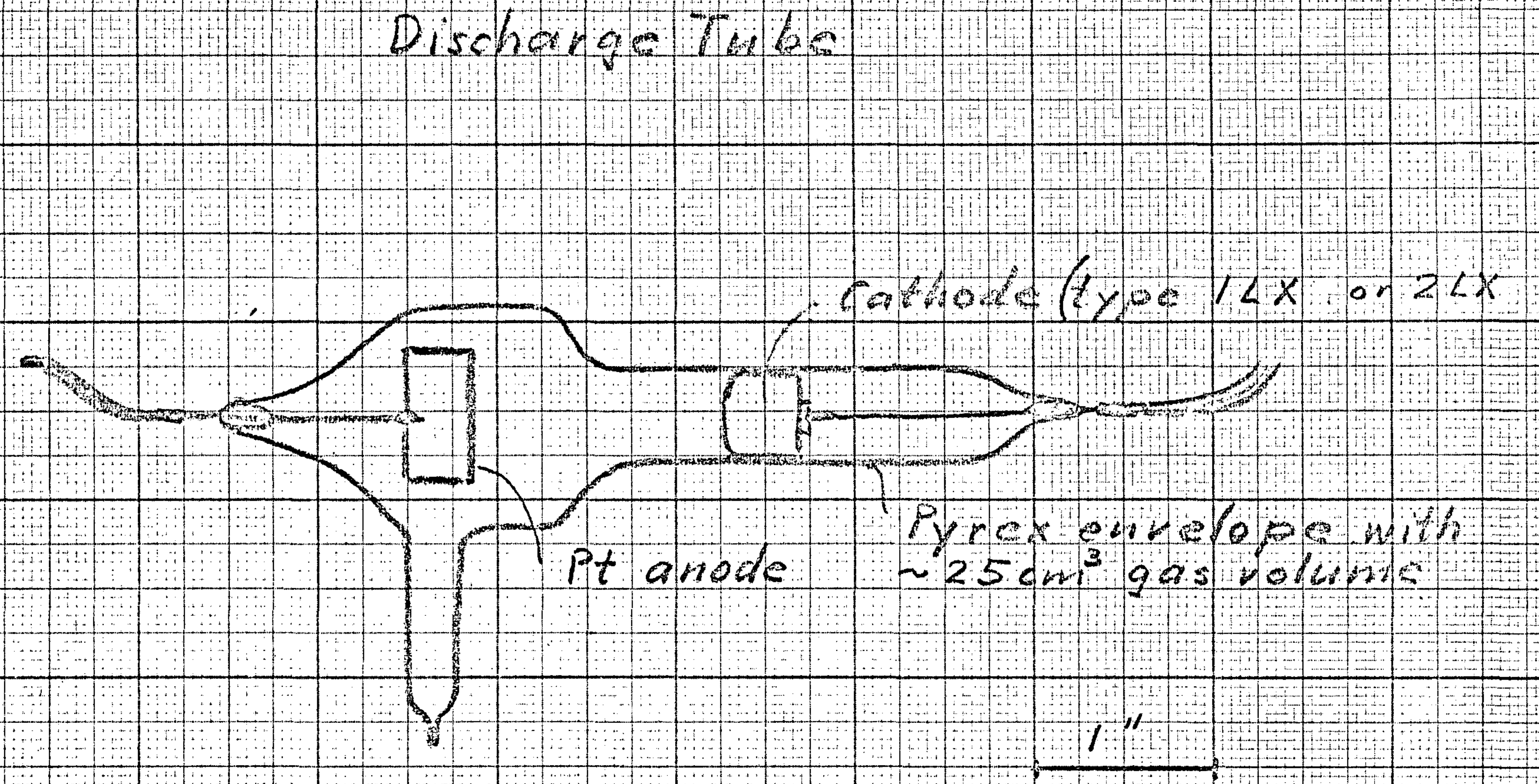
Discharge Tube
Cathode (type 1LX or 2LX)
Pt anode
Pyrex envelope with
~25 cm³ gas volume
1"

Fig 2

Infrared Absorption Cell

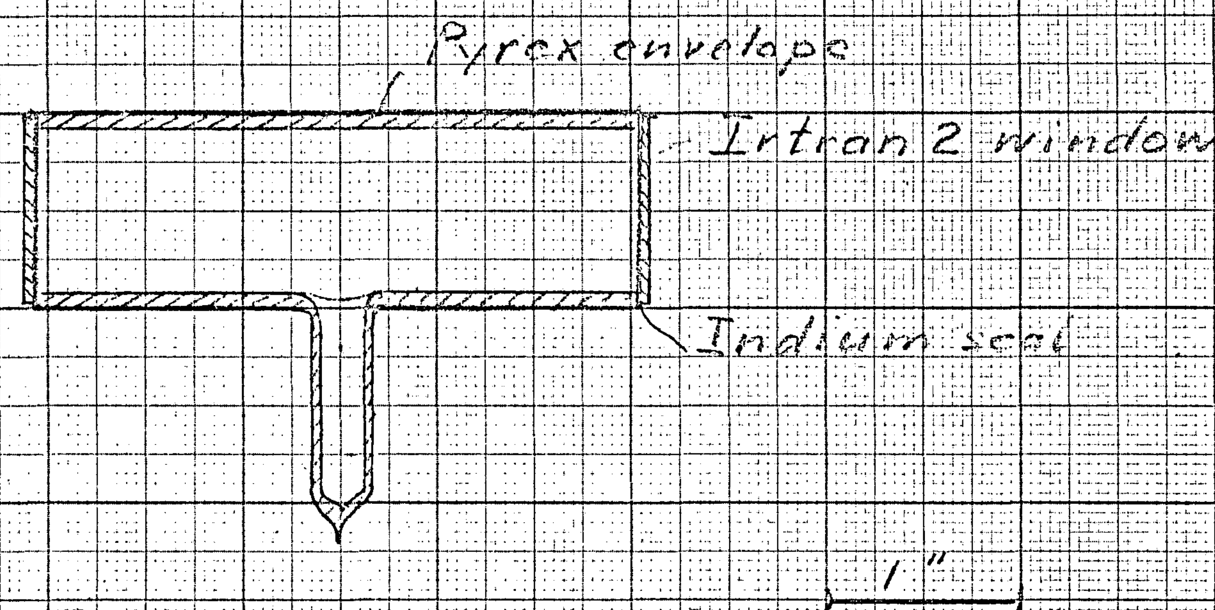

Fig 3

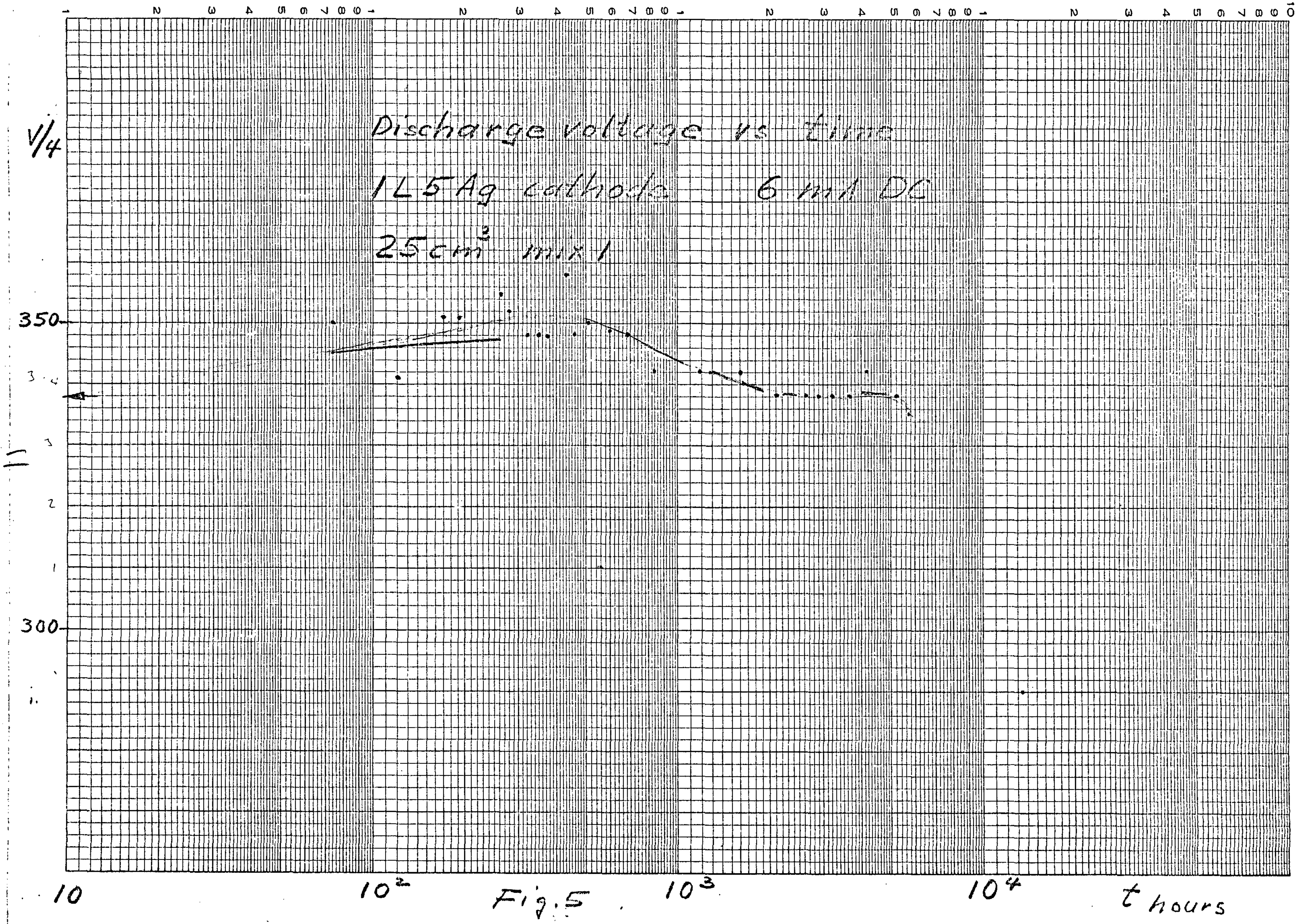
Discharge voltage vs time
1L5 Ag cathode 6 mA DC
25 cm² mix 1
V/4
350
300
10
10²
10³
10⁴
t hours

Fig. 5

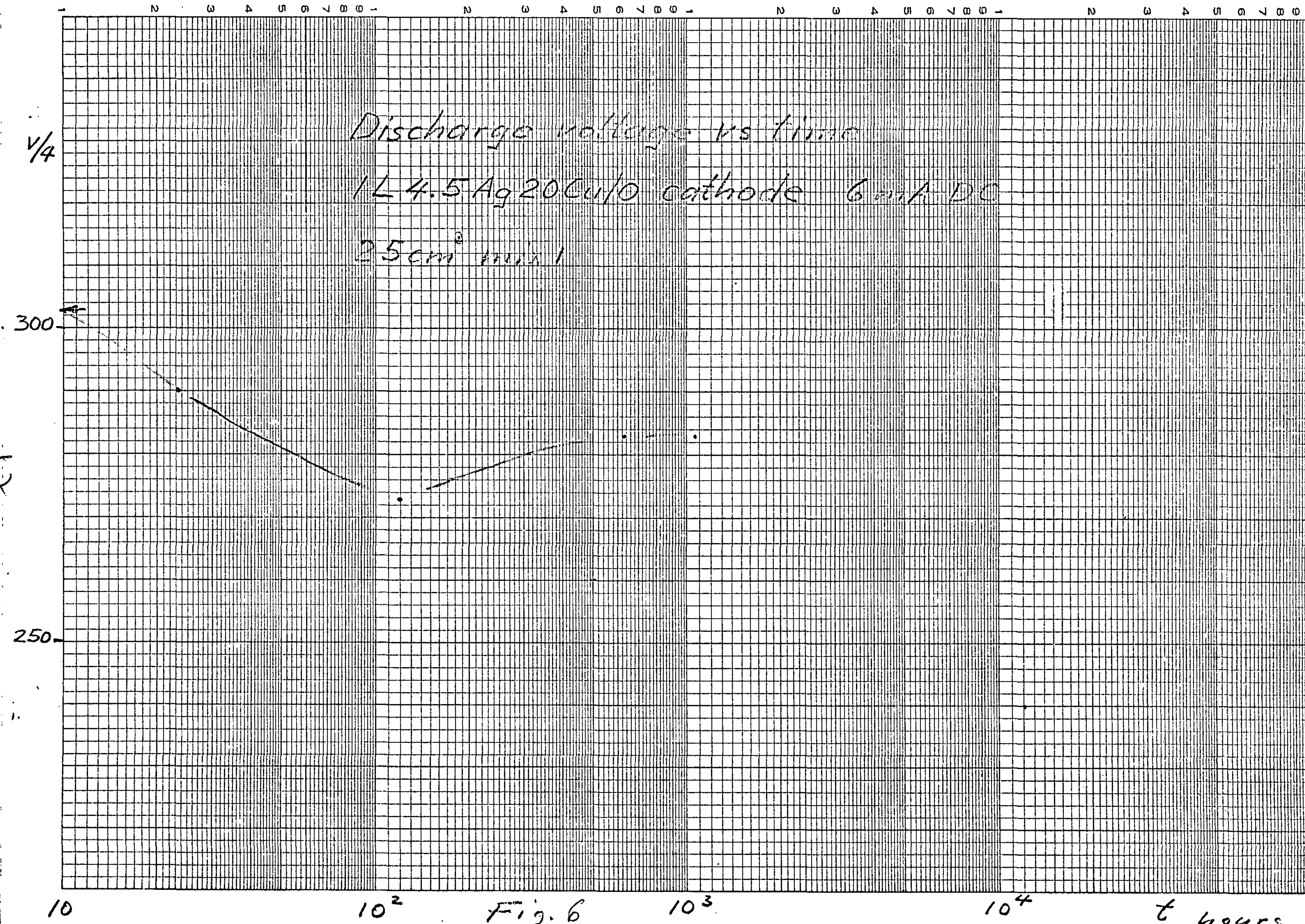
Discharge voltage vs time
1L 4.5Ag20Cu/0 cathode 6 mA DC
25cm² run 1
V/4
300
250
10
10^2
10^3
10^4
t hours

Fig. 6

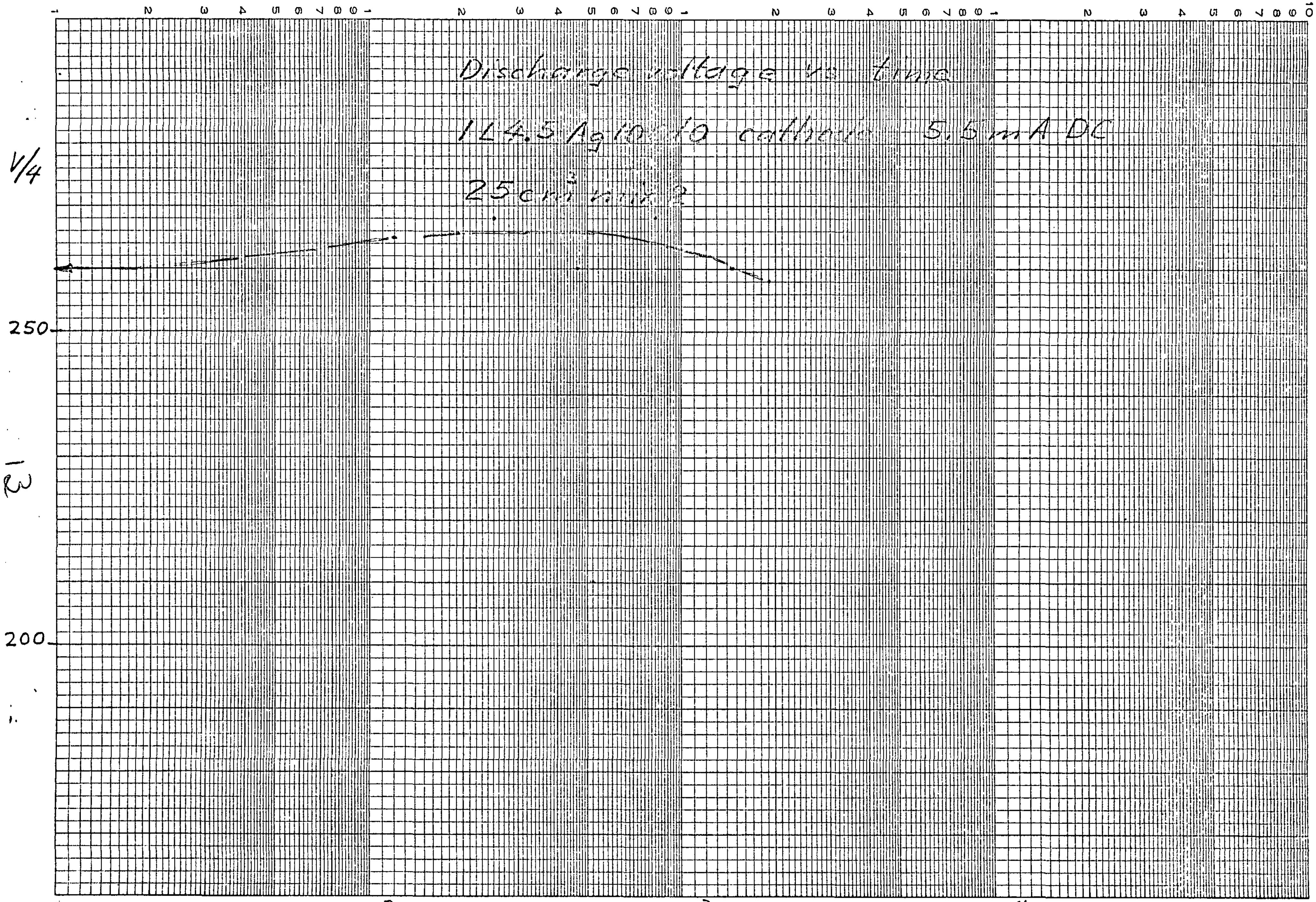
Discharge voltage vs time
1L4.5 Ag/10 cathode 5.5 mA DC
25 cm² unit 2
V/4
250
200
10
10^2
10^3
10^4
t hours

Fig. 7

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4 CYCLES X 10 DIVISIONS PER INCH

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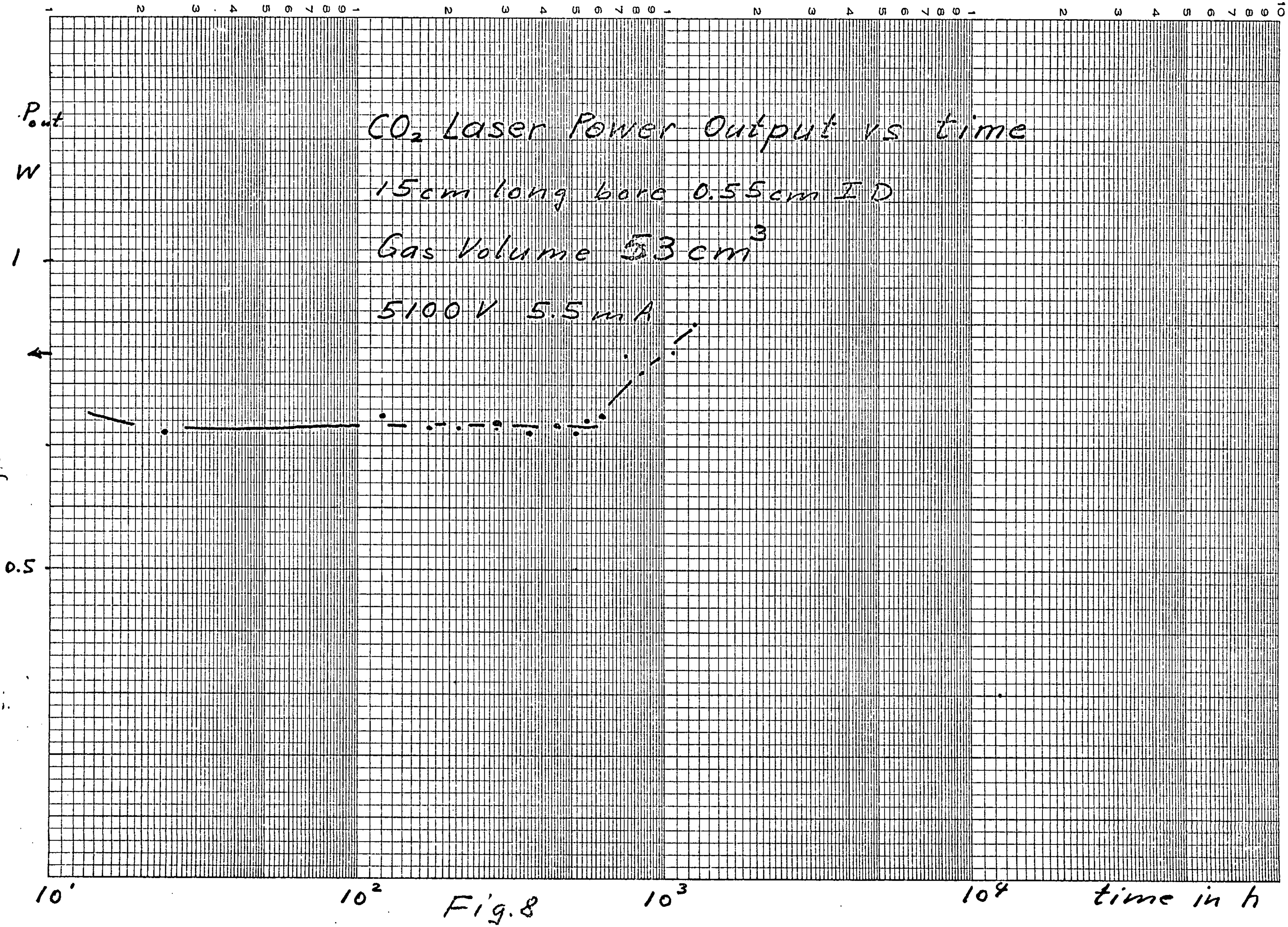

Fig. 8

14

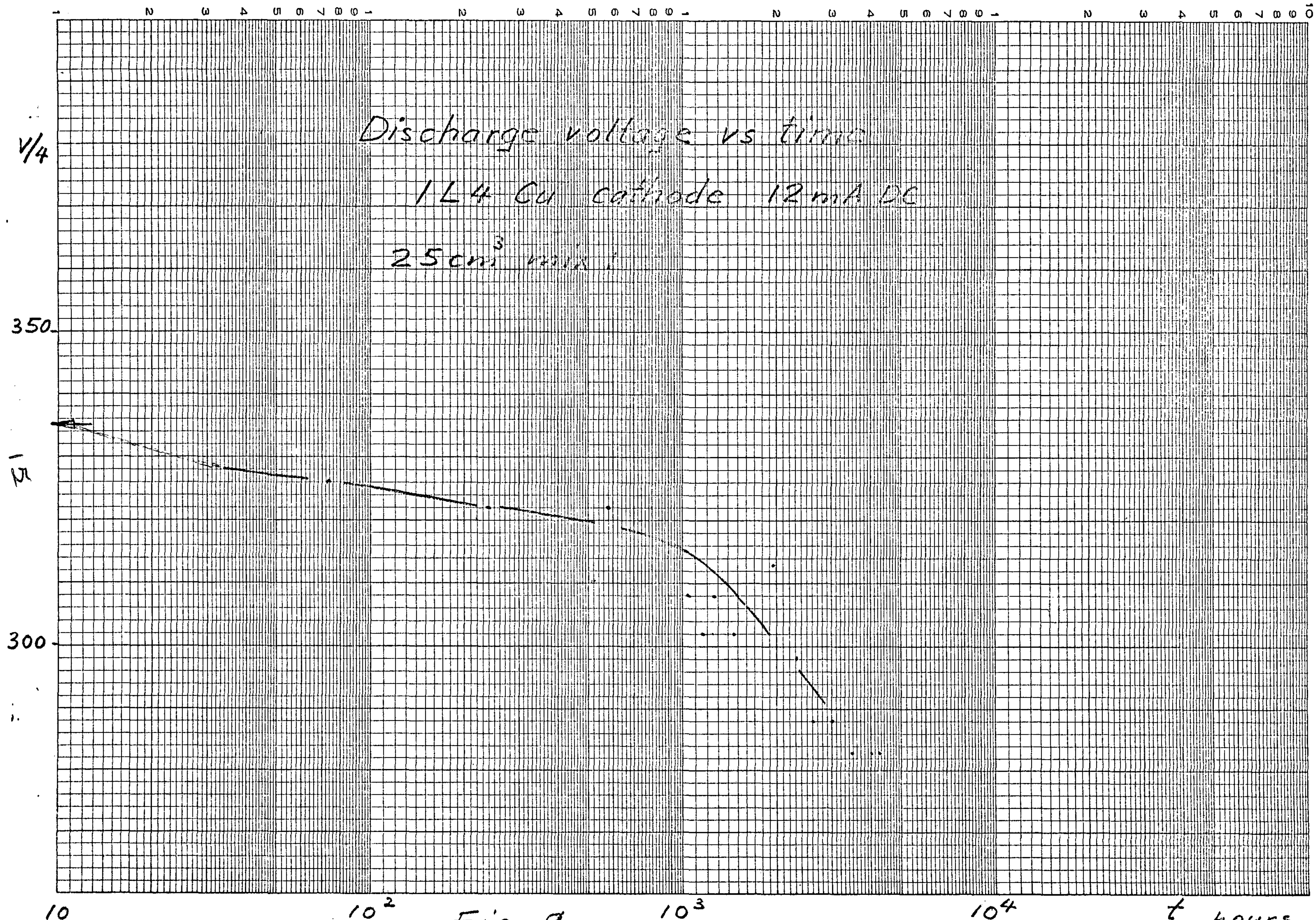
Discharge voltage vs time
1L4 Cu cathode 12 mA DC
25 cm³ min
V/4
350
15
300
10
10²
10³
10⁴
t hours

Fig. 9

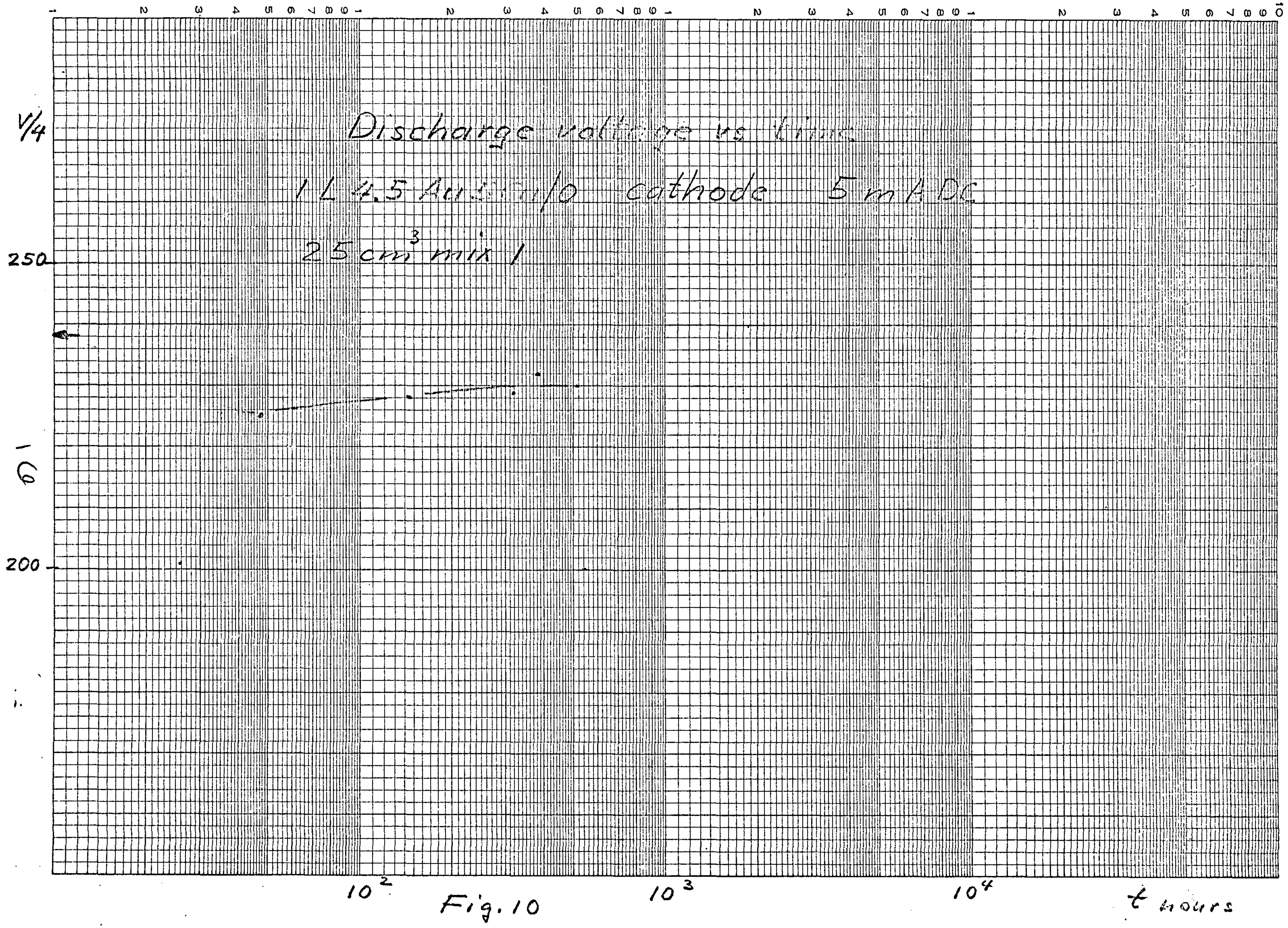
Discharge voltage vs time
1 L 4.5 Au ... /0 cathode 5 mA DC
25 cm³ mix 1
V/4
250
16
200
10²
10³
10⁴
t hours

Fig. 10

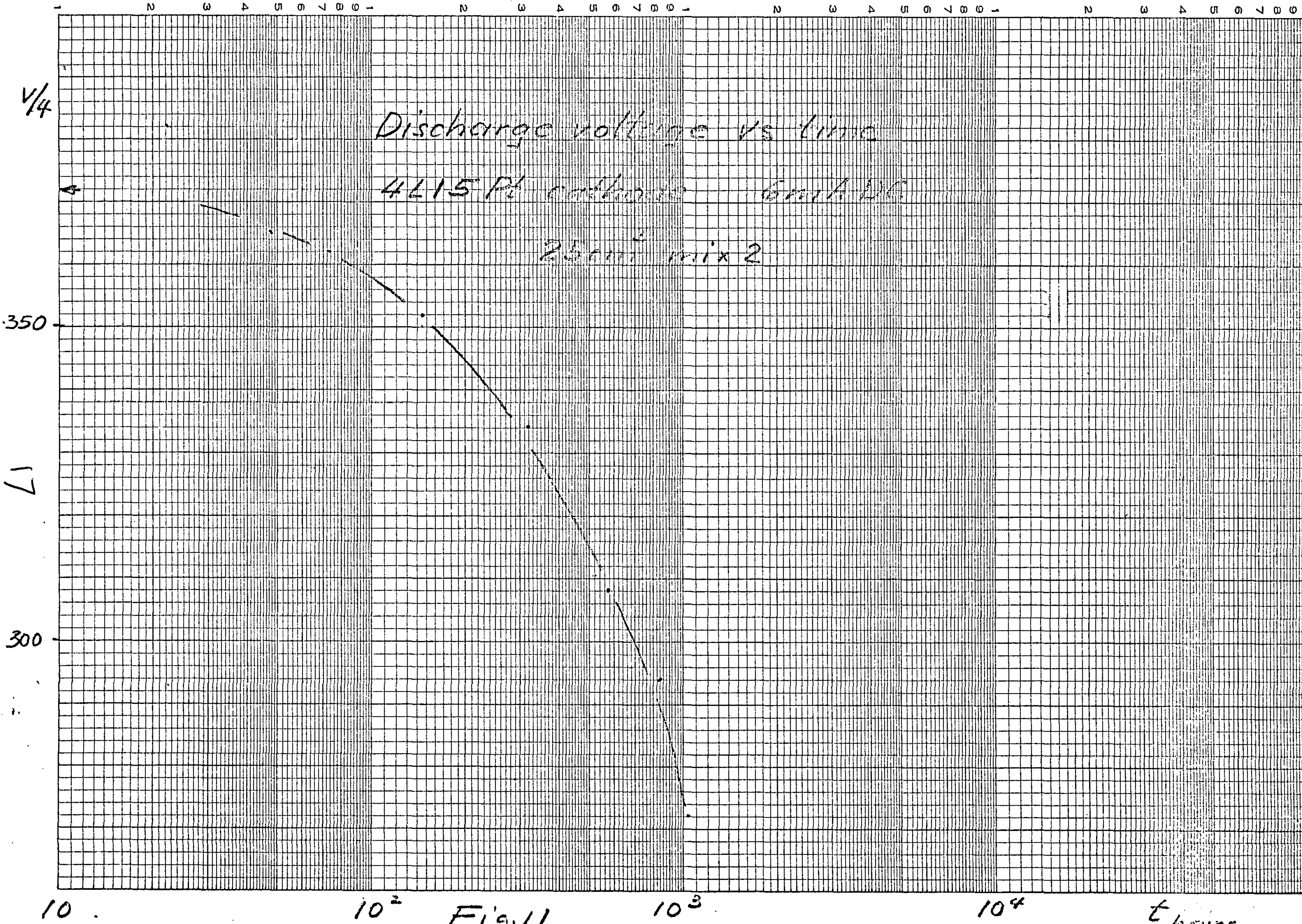
V/4
Discharge voltage vs time
4L15 Pt cathode 6mA DC
25cm² mix 2
350
300
10
10²
10³
10⁴
t hours

Fig. 11

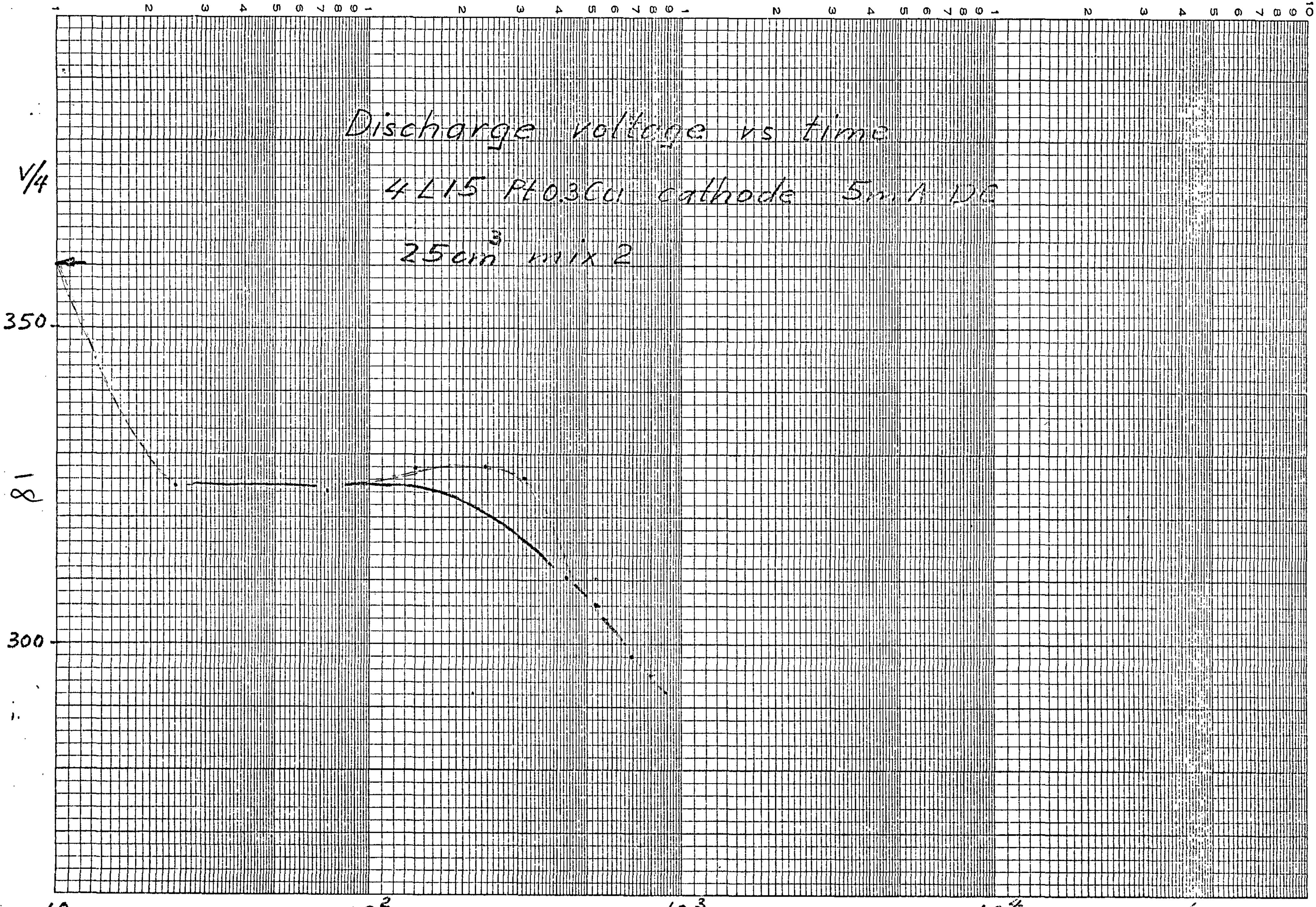
Discharge voltage vs time
4L15 Pt0.3Cu cathode 5mA DC
25cm³ mix 2
V/4
350
18
300
10
10²
10³
10⁴
t hours

Fig. 12

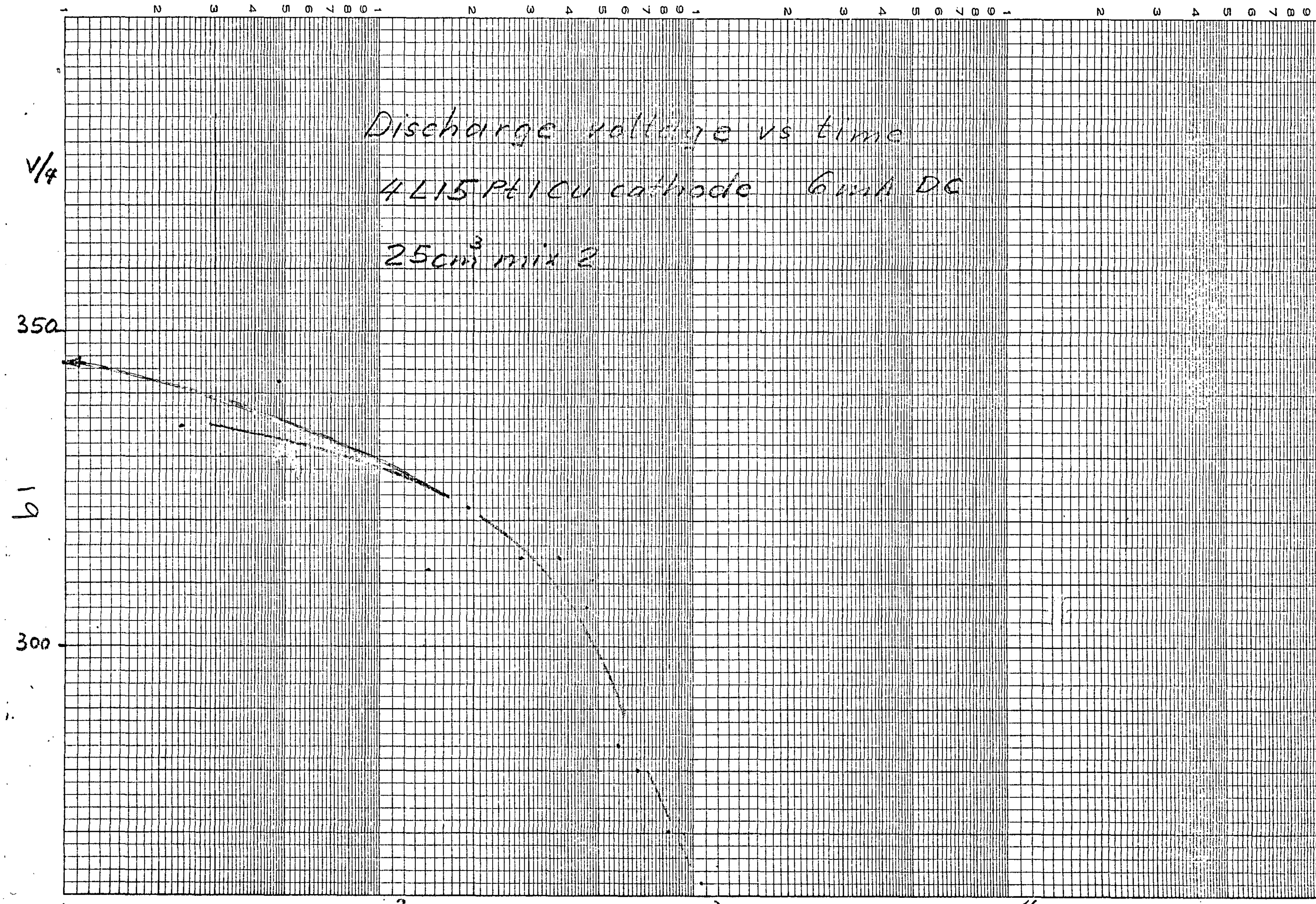
Discharge voltage vs time
4L15 Pt/Cu cathode 6mA DC
25cm³ mix 2
V/4
350
300
10
10²
10³
10⁴
t hours

Fig. 13

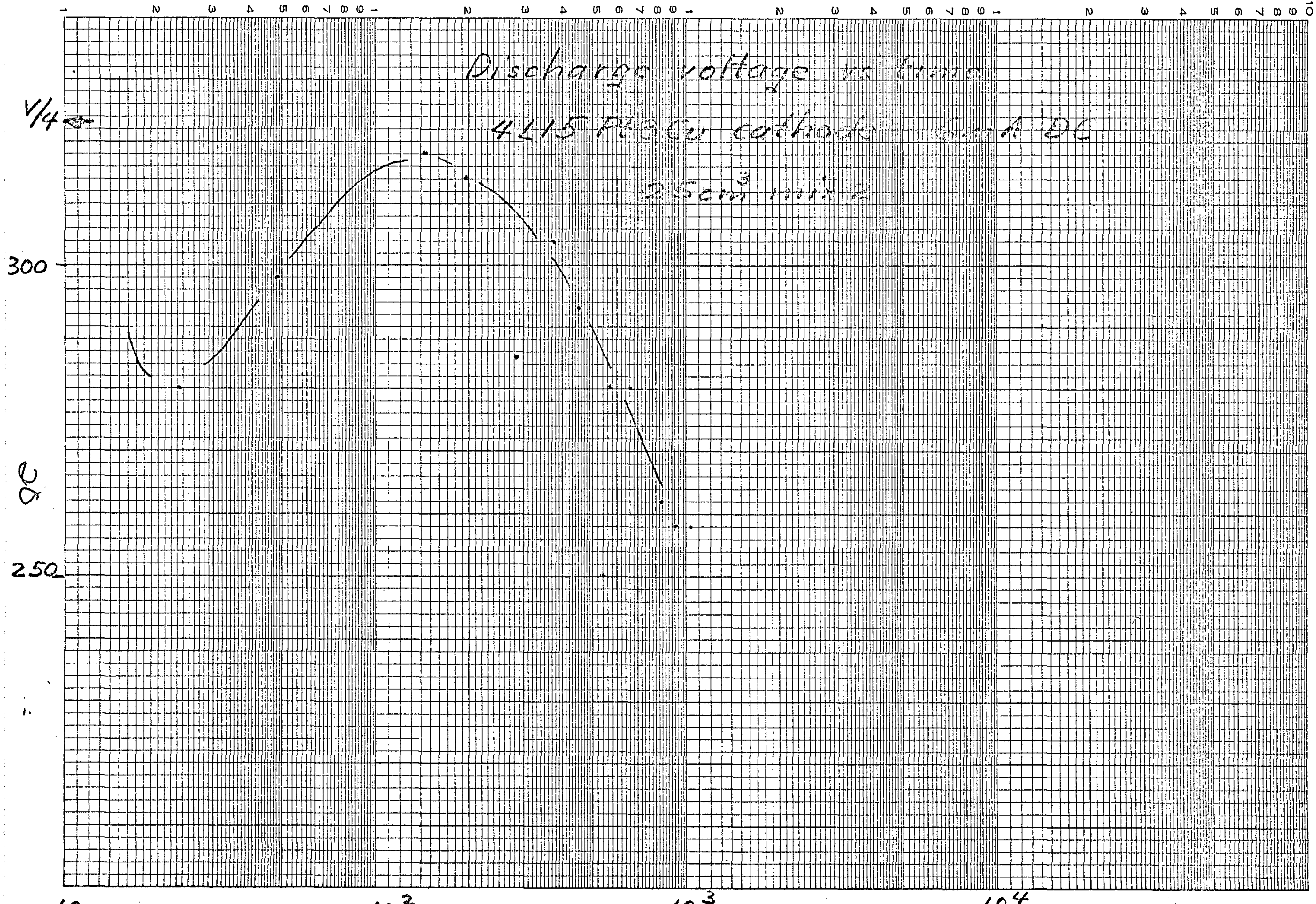
Discharge voltage vs time
4L15 Pt-Cu cathode mA DC
25cm³
V/4
300
250
10
10²
10³
10⁴
t hours

Fig. 14

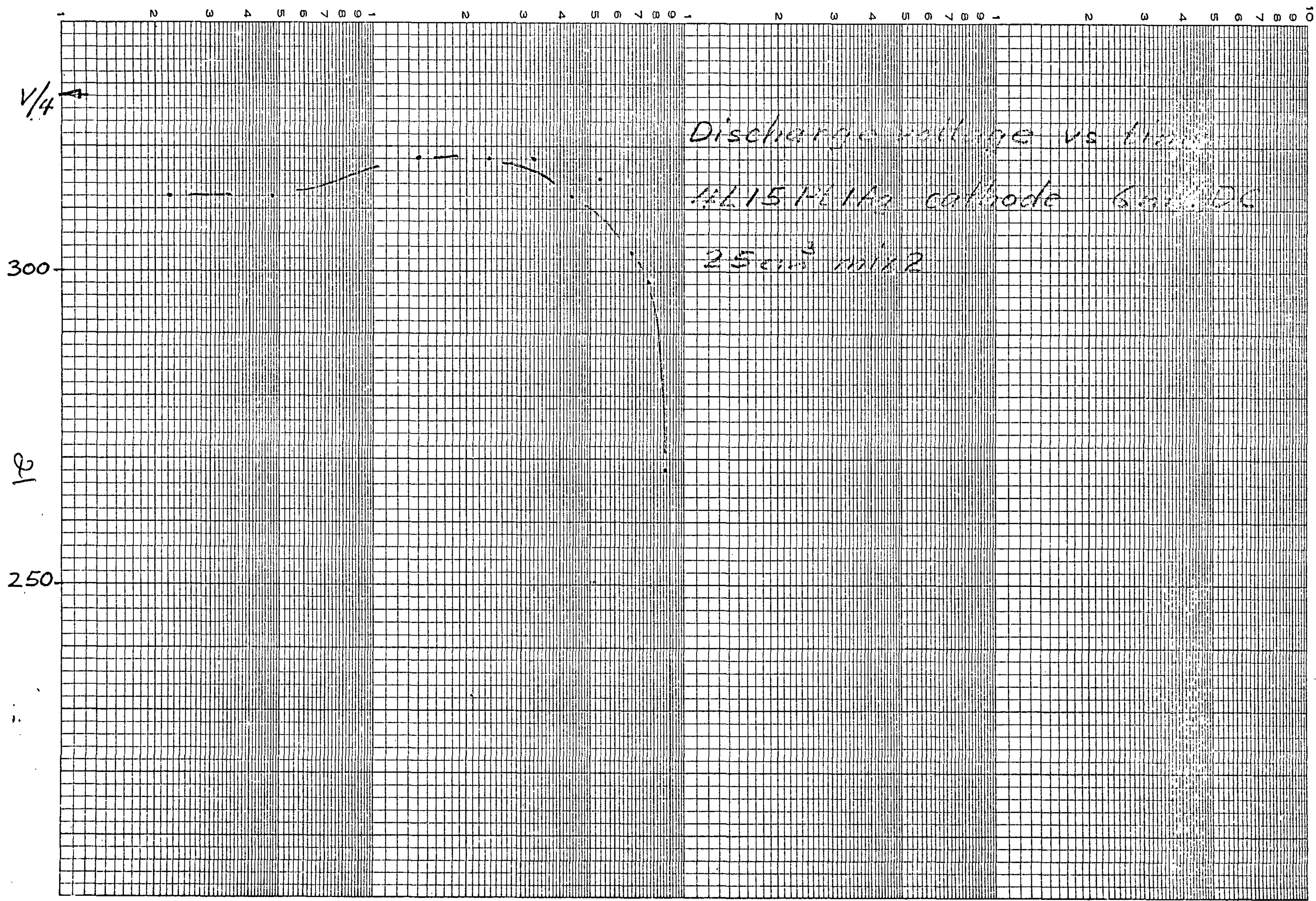
V/4
300
250
Discharge voltage vs time
#L15 Pt Ag cathode 6ma DC
25cm³ mix 2
10
10²
10³
10⁴
t hours

Fig. 15

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SEMI-LOGARITHMIC
4 CYCLES X 10 DIVISIONS PER INCH

EUGENE DIETZGEN CO.
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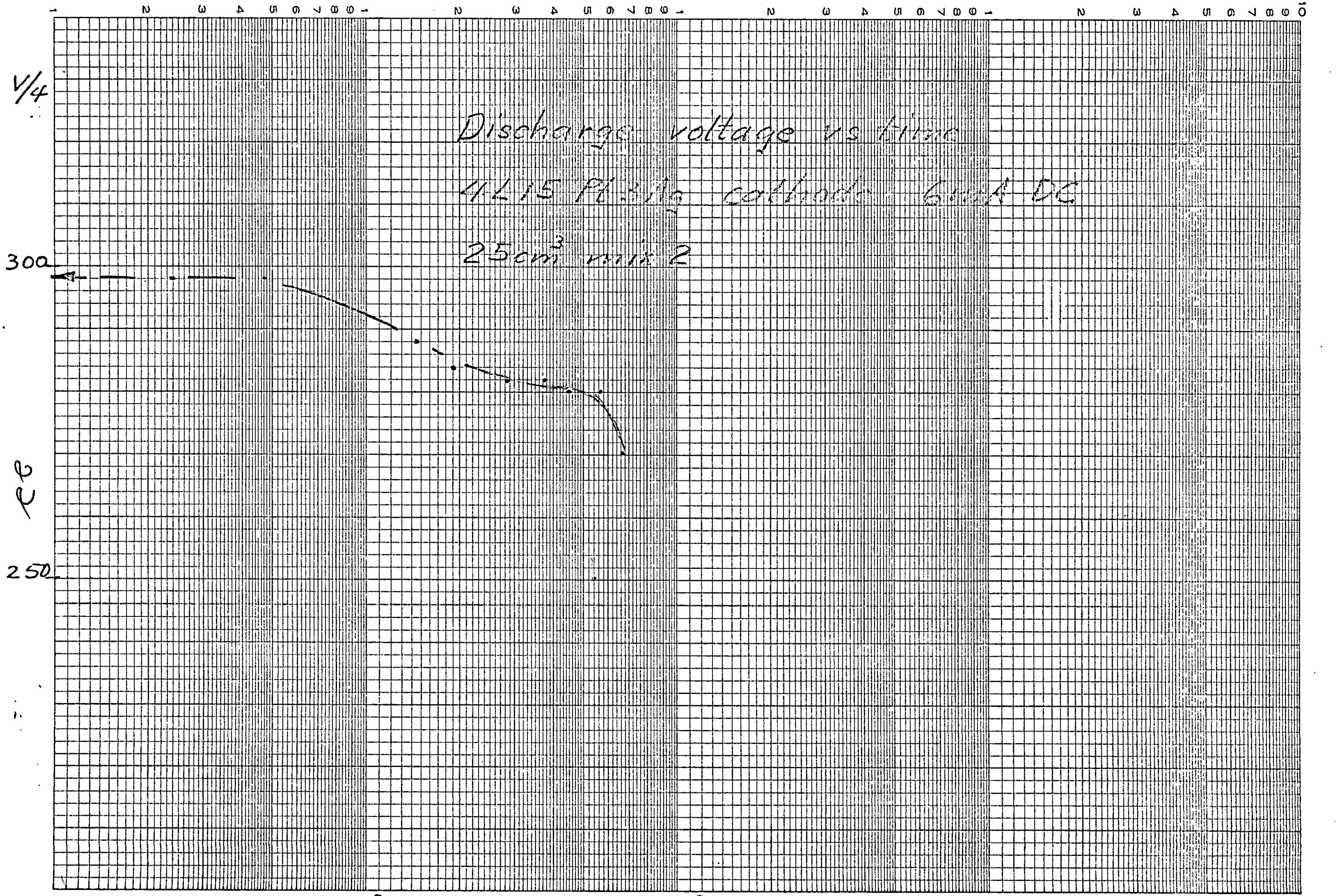

Fig. 16

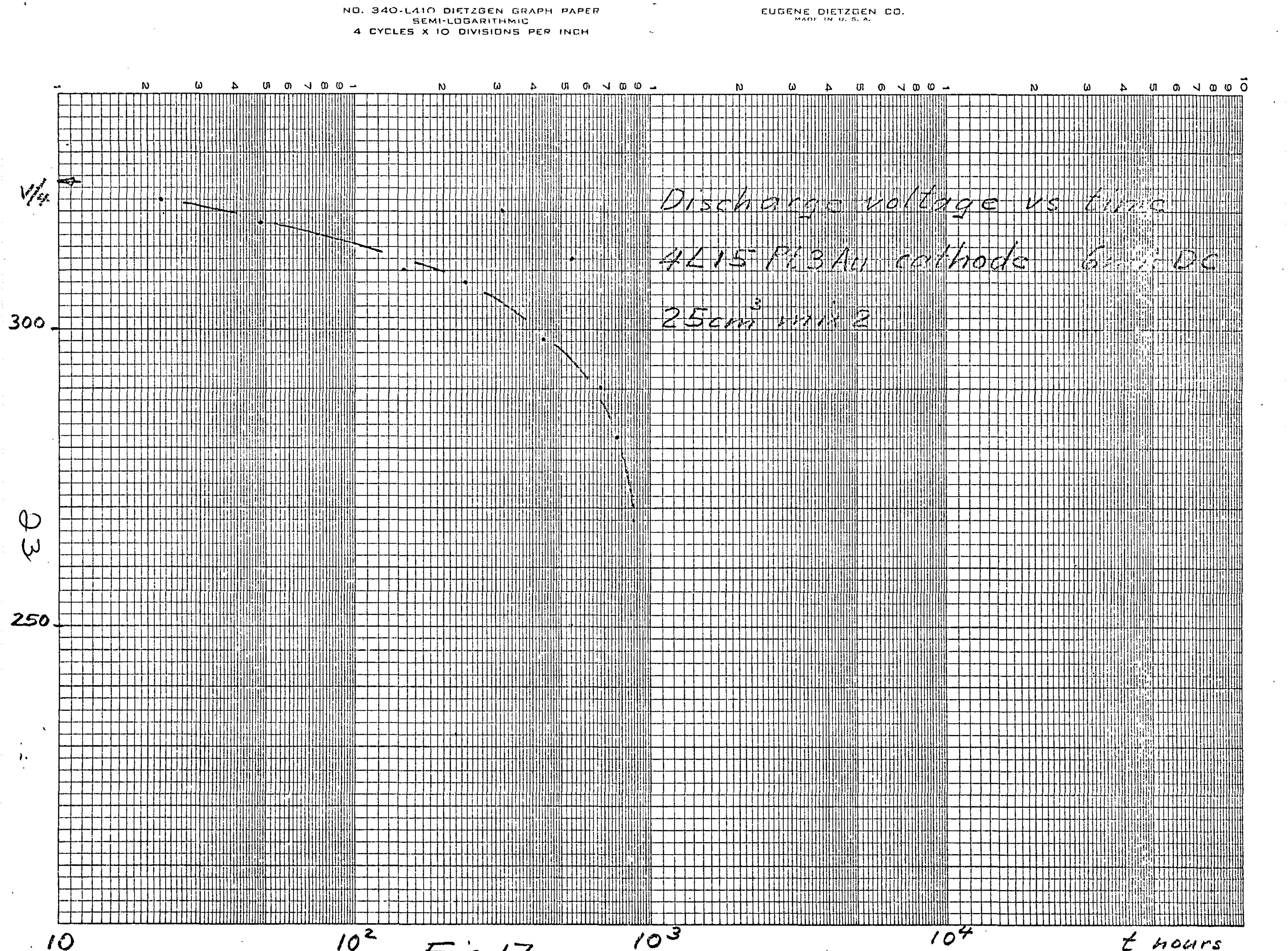
NO. 340-L410 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
4 CYCLES X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.
Discharge voltage vs time
4L15 Pt3Au cathode
25cm³ unit 2
V/4
300
250
10
10²
10³
10⁴
t hours

Fig. 17

NO. 340-L410 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
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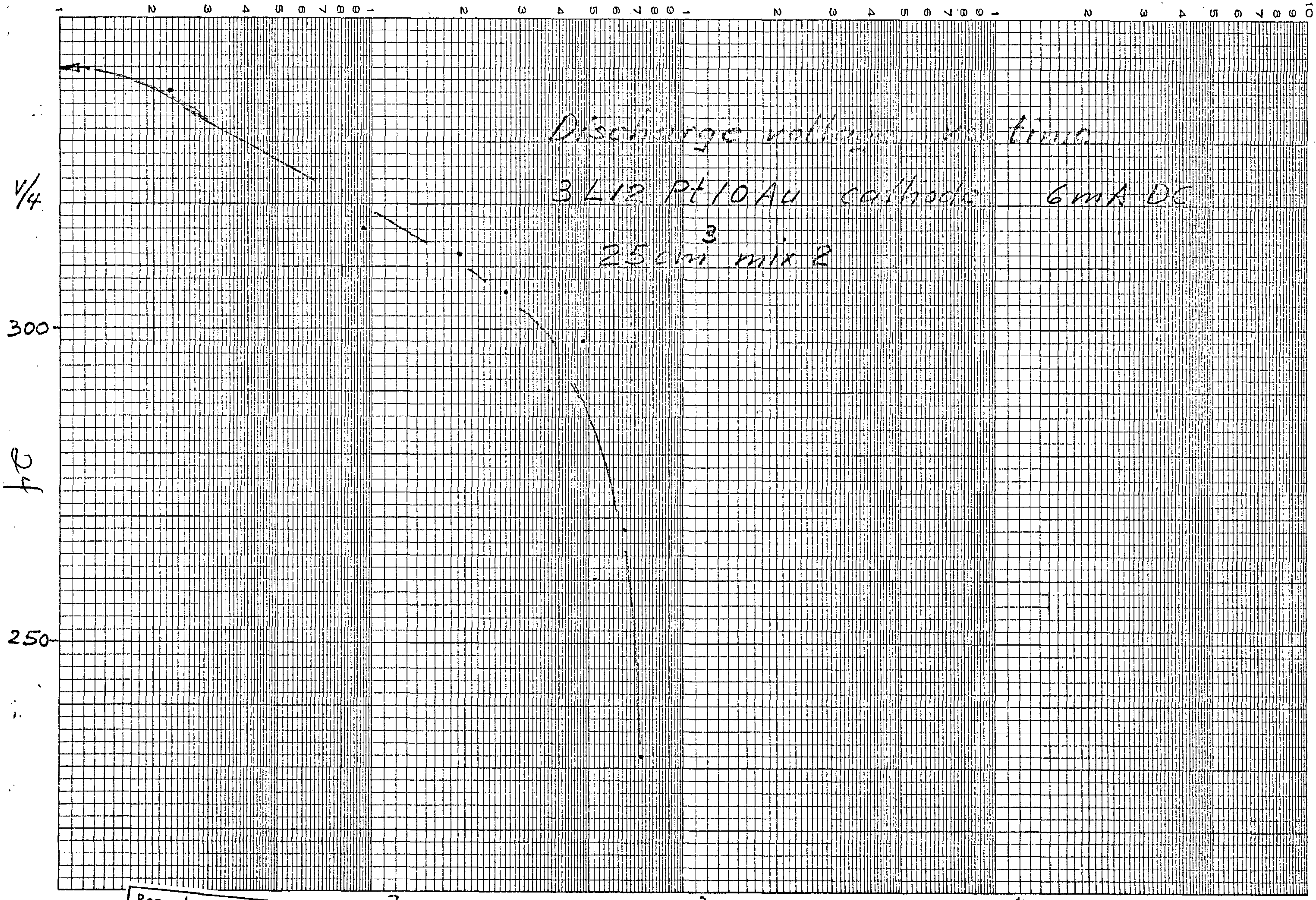

Fig. 18

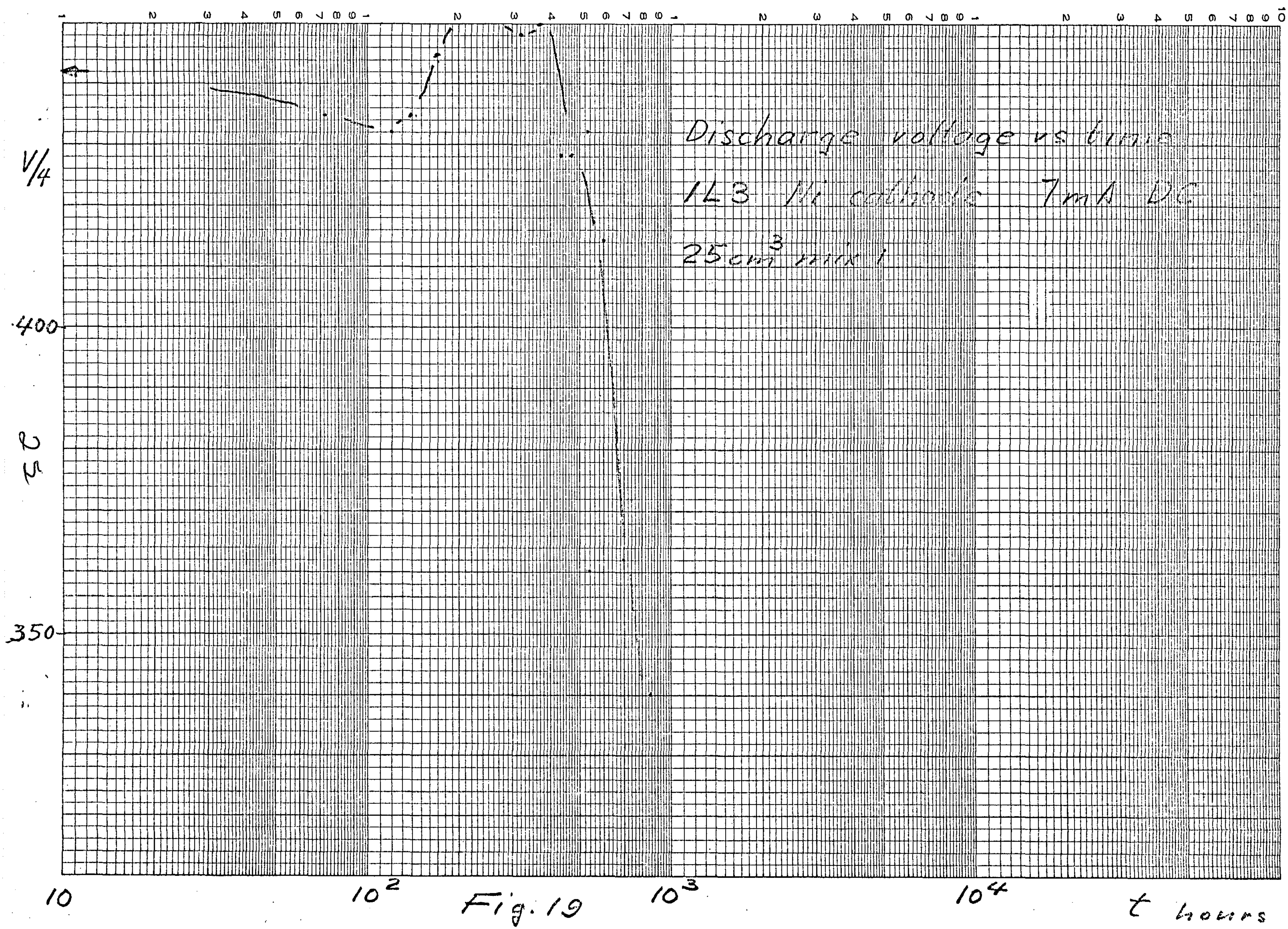
Discharge voltage vs time
IL3 Ni cathode 7mA DC
25cm³ mix 1
V/4
400
25
350
10
10²
10³
10⁴
t hours

Fig. 19

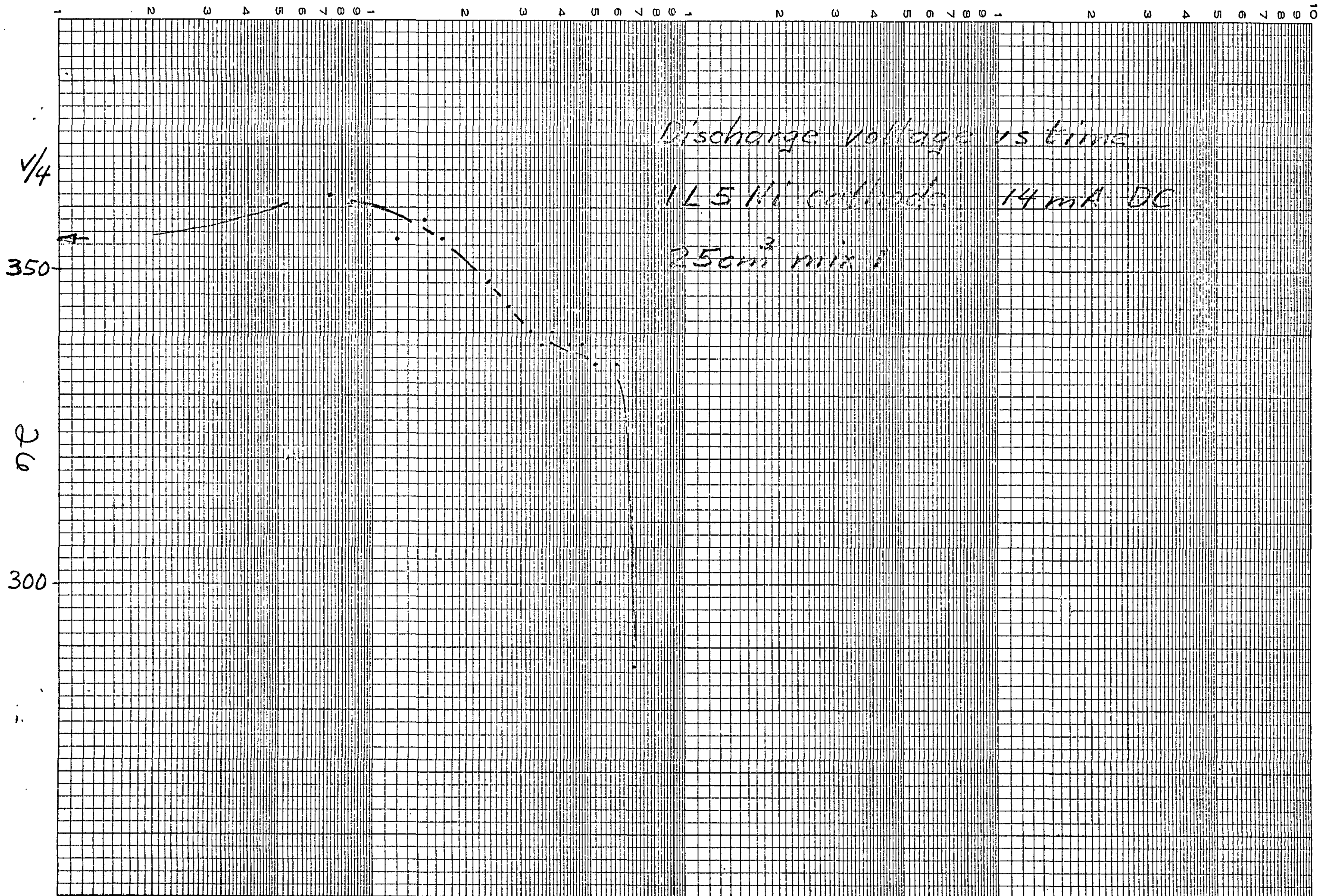
Discharge voltage vs time
1L5 W cathode 14mA DC
25cm³ mix I
V/4
350
300
10
10²
10³
10⁴
t hours

Fig. 20