MEMOIRS

OF THE

KODAIKANAL OBSERVATORY

M. K. V. BAPPU

Director

VOL. II.

AN ATLAS OF EQUATORIAL IONOGRAMS

BY

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AND

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(Saka 1888-89)

FOREWORD

Vertical soundings of the ionosphere at Kodaikanal have been carried out since 1952. During this period of more than one solar cycle, a large collection of ionograms has been built up and utilized in several research projects that have been executed at this Observatory. Many of these ionograms display several interesting features. It is the purpose of this atlas to make available to ionospheric workers, a collection of ionograms obtained from an equatorial station which depict some of these features.

KODAIKANAL OBSERVATORY,
KODAIKANAL.

M. K. V. BAPPU,
Director.

ACKNOWLEDGEMENTS

The ionograms included in this atlas have been selected out of numerous records obtained during the last ten years through the effort and cooperation of the staff of the Magnetic and Ionospheric section of the observatory. Their contribution is gratefully acknowledged. The compilers are specially thankful to R. V. Subrahmanyan and K. Thanikachalam for their assistance in the preparation of this atlas. One of us (A.K. S.)has been financially assisted in the Scientists' Pool Scheme of the Council of Scientific and Industrial Research, India,

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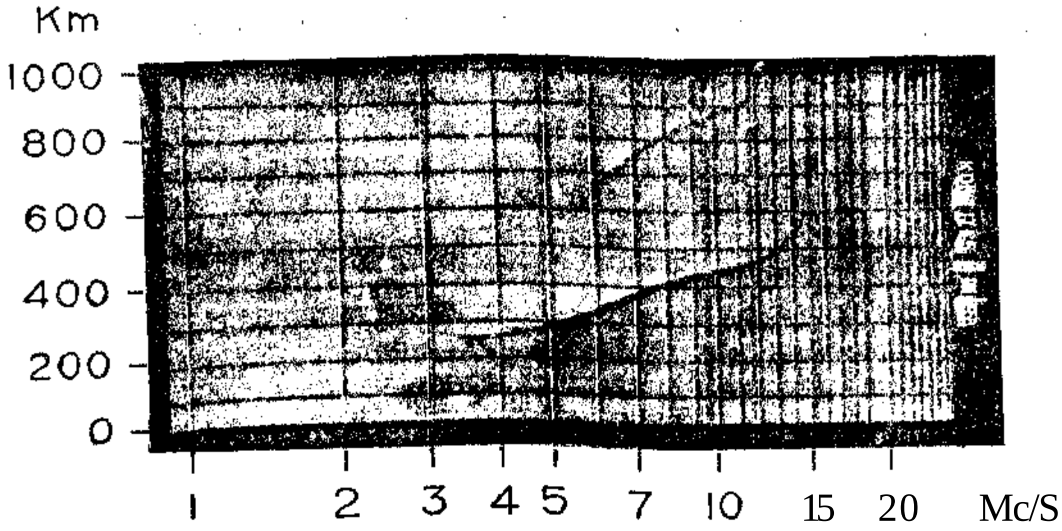
INTRODUCTION

Kodaikanal is situated close to the magnetic equator and many features of the ionosphere at this place are, like those at its southern hemisphere counterpart Huancayo, of special interest. In the course of a period corresponding to almost one solar cycle, a large and valuable collection of vertical incidence ionograms has become available. With the help of ionograms selected from this collection an attempt has been made in Section I of this atlas to illustrate the seasonal as well as solar cycle features In the daytime and nighttime ionograms. Typical records with features characteristic of the equatorial ionosphere such as Spread F, Sporadic E of different types have also been included in this selection in Section I. In Section II, selected ionograms with some unusual features have been reproduced. The last Section contains a few plates illustrating some remarkable changes in the E and F regions associated with geomagnetically disturbed conditions. Interpretations and brief comments have also been included in the compilation.

The times indicated on the ionograms are in Indian Standard Time (82° "5 East Meridian Time). The frequency and height markers are uniformly identical throughout the atlas and these have not been marked in figures on the individual ionograms. A sample ionogram with the frequency and the height scales is reproduced below :



Brief information on the location of the station is given below :

Kodaikanal, Madras State, India.

Geographic Latitude	10°14' N.
Geographic Longitude	77°28' E.
Magnetic Dip	+3° -5
Geomagnetic Latitude	0°*6 N

The C-3 ionosonde is used with two 600 ohm multiple wire delta antennas at right angles, one of these being used for the transmitter and the other for the receiver. The frequency is swept from 1 Me. to 25 Me. in 27 seconds. The regular schedule is one sounding every fifteen minutes. The equipment is normally operated with the following settings :

Pulse width	50 ix sec
Pulse repetition frequency . . .	30 pps.
Height markers	every 100 km
Height range	1000 km

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INTERPRETATIONS

SECTION I.—REPRESENTATIVE IONOGRAMS

Plate 1.—Typical ionograms for noon and midnight conditions during high solar activity. The three sets for winter, summer and equinox indicate that during daytime Fl and F2 layers are not well separated. During equinox nights maximum electron densities are much higher than for the same season during low solar activity.

Plate 2.—Typical ionograms for noon and evening during very low solar activity. Representative ionograms for winter, summer an dequinox conditions indicate that bifurcation of the F layer is distinctly present. During summer days perhaps a 'valley' exists between Fl and F2 layers.

Plate 3.—Illustrates the appearance and disappearance of frequency type Spread F, The echo from the F layer is diffuse, and loses its sharply defined structure near the high frequency end of the trace. This type of Spread F, often called high or medium latitude type, is more often observed in those latitudes.

Plate 4.—Shows a case of range type spread F, commonly observed at low latitude stations. The spread is more or less independent of frequency and no distinct layer structure can be distinguished. Echoes are returned over a wide range of virtual heights and little change of minimum virtual height with frequency is observed.

Plate 5.—A set of ionograms exhibiting both frequency and range type spread F commonly observed at this station.

Plate 6.—Illustrates different types of sporadic E layers observed at KodaikanaL The equatorial type, which is regularly observed a little over 100 km, during daytime, is shown in (a). It is usually transparent and shows scatter, (b) shows a case of intense blanketing sporadic E. Several multiple reflections are observed and echoes from higher layers are almost completely blanketed, (c) shows a sequential type E_s, which appears with cusps around foE and fxE. The cusps are not complete due to deviative absorption. This type of E_s occurs between the minimum virtual height of normal E layer and its height of maximum electron density. This particular case should be classified as h-type, as the flat portion of the E_s trace is higher than that of the E layer. A flat type of E_s which appears during night time is shown in (d).

An Es type layer with a virtual height of 250 km is illustrated in (e). The appearance of the layer at a large virtual height may be due to an increase in range resulting from obli quity. This type is observed, rather infrequently, in the afternoon hours with or without the simultaneous presence of equatorial Es_9

In addition to equatorial E_a in (f), echoes corresponding to a virtual height of about 170 km can be seen at frequencies greater than 10 Mc/s. This may be a transient phenomenon lasting a few seconds or minutes*

In (g) and (h) two cases of slant type E_s are shown. In the type shown in (g), often observed at Kodaikanal, the slant[1] trace appears to have its lower end in the regular E layer near fxE. The other type shown in (h), which emanates from a cusp type E_s near fB, is observed at higher heights with increasing frequency. This type generally appears at high latitudes, but has been found to be present at Kodaikanal on many occasions.

Plate 7.—The ionograms in this plate illustrate the appearance of M and N-type echoes, These echoes arise from the partial transparency of the E_s layer. Assuming the thickness o the E_s layer to be negligible, the virtual heights of the M and N echoes are given by :

$$h'N = h'F + h'E_s$$
$$h'M = 2h'F - h'E_s$$

In (a) and (c) both M and N-type echoes are seen. In (b), only the M-type is present. Contrary to reports from other workers (Smith E. K. and Thomas J. A.; Jour. Atmos. & Terr. Phys. Vol. 13, 1959; pp. 295 to 314) M-type echoes have been found to appear with equatorial E_s at Kodaikanal on many occasions.

Plates 8 *and* 9.—The sequences of ionograms in these plates show the development of the lunar layer, during forenoon (plate 8) and during the evening (plate 9) hours. This type of stratification is very common at this station during periods of low solar activity and is generally absent during very high activity. Like Huancayo (Me Nish A. G. and Gautier T. N.; J. Geophys. Res. 54, p. 181) the stratification occurs approximately at two solar and two lunar hours.

Plate 10.—This set of 8 ionograms shows the development of stratification in the F layer during the main phase of a severe magnetic storm. Similar in nature to the lunar effect, the stratification is recorded at successively greater virtual heights until it is beyond the height range of the ionosonde. The stratification observed in the ionograms here, appeared during a period when the horizontal force of the earth's magnetic field sharply decreased a few hours after the S.C. and the main phase of the storm began.

Plate 11.—During the progress of two solar eclipses that occurred at Kodaikanal during daytime since the ionospheric observations began, the F layer was found to be highly stratified. The plate shows the start of stratification around 0845 hours at a virtual height of a little over 300 km during the solar eclipse of June 20, 1955. This was about 40 mts. after the maximum phase (0.91 at 300 km) of the eclipse. The phenomenon appears to be more or less identical with sunrise effects (plate 12) often recorded at this station. During the progress of the eclipse the quasi-stationary condition is considerably disturbed possibly from large changes in the drift controlled decay term and consequently an intermediate layer makes its appearance. With the end of the eclipse, the electron density in the intermediate layer increases rapidly and the increased retardation in this layer causes the echoes from the pre-eclipse F region to appear from progressively greater virtual heights.

Plate 12.—Illustrates a typical stratification of the F layer often observed around sunrise time. A cusp appears in the F layer trace and gradually moves up. This phenomenon generally occurs on mornings following a magnetic storm when the pre-sunrise N_mF2 and $h'F_2$ are large. Although some oblique incidence effects may be present, particularly in the east-west plane, at these hours, we believe these as genuine cases of stratification. This is supported by the true height profiles from 0545 to 0700 hrs (plate 12a) deduced from these ionograms. With sunrise new ion-production occurs at a height lower than the night time level of NMax of the F layer. The movement of the cusp is due to increasing group retardation produced by the post sunrise ibnization.

Plate 13.—Shows a case similar to plate 12, but with the nighttime scatter present. The scatter is gradually blanketed out by the new ionization formed below the scattering region.

Plates 14 *and* 15.—These plates demonstrate disturbances of travelling type in the F layer trace. In plate 14, a cusp appears in F2 layer trace at 1115; it decends gradually to the low frequency end of Fl layer trace. In plate 15, a cusp is formed in the Fl trace at 0945, followed by a second cusp in the F2 trace. Both of them then move up. The lower one does not move beyond the regular F1-F2 cusp. The cusp in F2 trace, however, proceeds to the maximum frequency of F2. Some of the echoes appear to be oblique, although it is not possible to say which ones. The oblique echoes most probably originate from horizontal gradients of ionization which move over the station as travelling disturbances.

Plate 16.—Illustrates a case of travelling disturbance in which the distortion is noticed only in the extraordinary ray trace. Similar echoes are quite often seen in Kodaikanal ionograms.

SECTION II

Plates 17 *and* 18.—Show two cases where the heights of the F2 layer were very high. Plate 17 shows this for a period of low solar activity. In this case the maximum electron density of the F2 layer was not much greater than that for the Fl layer. There was probably a 'valley' between Fl and F2, as indicated by the cusp between Fl and F2 going to infinity. Plate 18 shows the occurrence of high F2 layer for a sunspot maximum period. The F2 layer has a much larger maximum electron density than F1. Ionograms in plate 18 were obtained when a moderate S.C. type magnetic storm, was in. progress. The sunspot minimum cases, represented in plate 17, are, however, not infrequent on undisturbed days.

Plates 19 *and* 20.—Illustrate two cases where sudden and rapid changes in the height and shape of the F2 layer were observed. At 0830 and 0832 (plate 19) a large separation between, ordinary and extraordinary traces at the high frequency end indicates some oblique incidence effect. Electron densities of both Fl and F2 layers increase sharply within a period of half-an-hour. In plate 20 occurrence of a sudden change in the height of the F2 layer is shown.

Plate 21.—The ionograms indicate a disturbance in the F2 layer not associated with a magnetic disturbance. A well defined additional cusp is found to have formed in the F2 layer.

Plate 22.—Illustrates a case where spread echoes were obtained from Fl and F2 layers during daytime.

Plates 23 *and* 24,~-~These two plates illustrate a case of disturbance in the F layer lasting for some hours. Transient echoes, probably at oblique incidence, are seen at various heights in several ionograms *{e.g.* 1215 in plate 23). M and N type echoes are also seen after the appearance of sequential E_s from 1406 in plate 24.

Plate 25.__Four sequential E_s traces are seen at 0815, two of which are either blanketed or they merge forming intense sequential E_s with ordinary and extraordinary ray traces, giving multiple as well as M and N type reflections. The four sequential E_s traces may be from two different E* strata both situated above the minimum virtual height of the normal E layer.

Plates 26, 27 *and* 28.—Illustrate three cases of occurrence of sequential type E_s at unusually large heights. They also show group retardation at the high frequency ends which is unusual. The layers also appear to move up gradually to heights of 250 km or above. They are probably not oblique considering the duration of their presence. Multiple hops and M echoes in plate 28 also indicate that the echoes are likely to be from a layer, vertically overhead. An M type echo (from 2 h'F—100) at 1915 in plate 27 indicates the presence of a E_s layer at about 100 km which could be transparent from below but reflecting at the top.

Plate 29.—Each one of the two ionograms in this plate shows diffuse short range echoes at certain frequencies, which show a range scatter. The minimum range was about 30 km. They are not due to any external disturbances as they are not seen below the ground pulse. Attempt to ascribe the echoes to some fault in the equipment has also failed. They appeared for several weeks in only two specific periods of operation of the ionosonde at Kodaikanal, namely, January, 1954 and again in the summer of 1957. This occurrence was confined only to day time.

SECTION III

Plate 30.—The normal F region in these latitudes during the progress of a magnetic storm becomes stratified, thick and high. A set of ionograms obtained at intervals of quarter of an hour during the main phase of a moderately severe magnetic storm, which commenced on the previous day, are reproduced here to illustrate rapid changes involving distortion and stratification of the layer. Since the stratification lasts for some time and two hops echoes appear at twice the virtual height the stratification cannot be ascribed to oblique paths and travelling disturbance.

Plate 31.—During the main phase of a magnetic storm, sudden disappearance and reappearance a little later of the equatorial type of E_s has often been noticed to occur, several times in the course of a day (Bhargava B. N. and Subrahmanyan R. V.; J. Atmos. & Terr. Phys. Vol. 20,1961, p. 81). The ionograms in this plate are reproduced here to illustrate this.' The disappearance of E_s at 1300 hrs took place during the magnetic storm of 17th—18th February 1958, the horizontal force of the earth's field being subnormal during the day on the 18th February.

Plate 32.—The occurrence of Spread F and abnormal maintenance of ionization in equatorial regions after sunset is well known. However, during magnetic storms, not only is the spread F, a normal daily feature at these latitudes, particularly prominent during high solar activity, absent but the maximum ionic densities are abnormally large throughout the night. The ionograms reproduced here were obtained during a moderately severe storm which commenced on 1310 hrs. I.S.T. on 17th March 1958. The critical frequency of the F layer at 0500 was 11*2 Mc/s. as against the monthly median value of 8.6 Mc/s. In the absence of production, the electron loss appears to be more than compensated for near the peak by downward movement of ionization and large values of N_mF2, therefore, persist throughout the night.

Plate 33.—A sequence of early morning ionograms during the main phase of a severe S. C. type of magnetic storm. A disturbance possibly resulting in oblique incidence echoes started at 0500 hrs. At 0600 there is weak second hop echo but a layer appears corresponding to virtual height of 600 km. The F layer also appears to be stratified. The 0615 hrs ionogram is very complex both in one hop echoes as well as multiple echoes which do not quite correspond in virtual height to two and three hops. Apparently rapidly moving tilts exist in the isoionic surfaces towards more than one side of the station.

Plate 34.—A sequence of very unusual ionograms recorded in the afternoon hours during the main phase of an S. C. Storm that started on the previous day. At 1345 hours the peak of production appears at an unusually low height resulting in rapid increase in the ionic densities below the level of maximum ionization. With the increase of retardation the virtual height of the pre-disturbance layer increases considerably (1400 hrs.to 1530 hrs), The disturbance was associated with large changes in the height, shape and maximum ionic density of the F layer. It is quite likely that some oblique echoes may be present but the explanation above appears to be more plausible than the one based entirely upon travelling disturbances,

PLATE I

SUNSPOT MAXIMUM CONDITIONS'

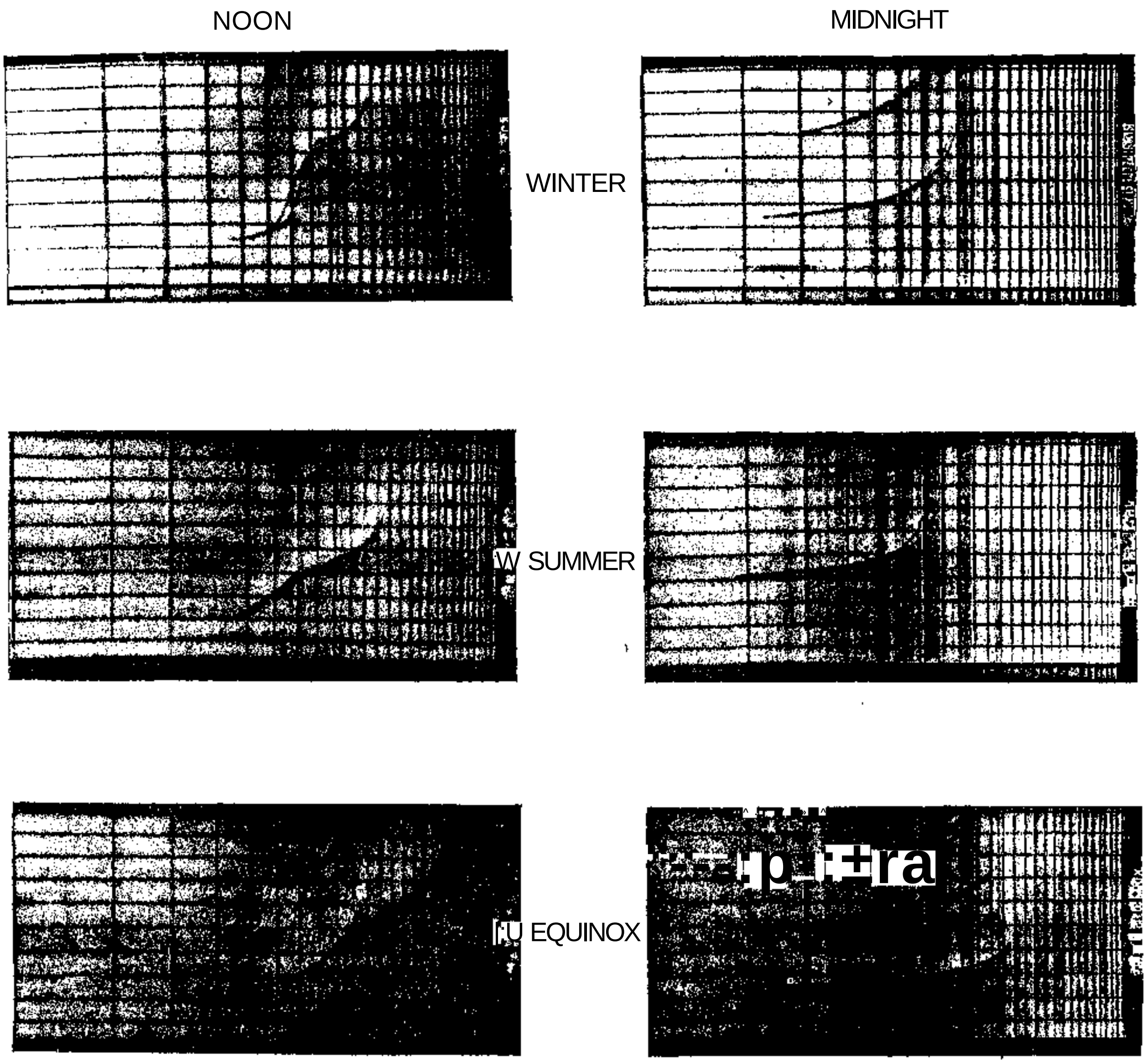

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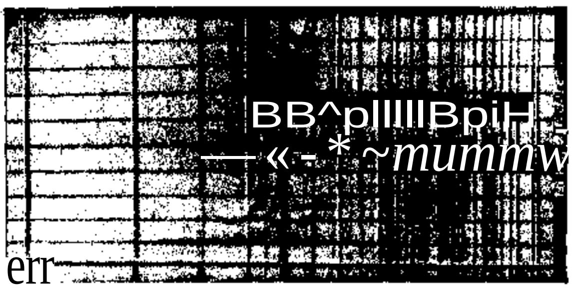
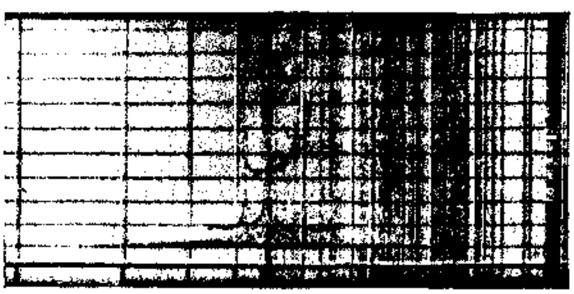
PLATE 2

SUNSPOT MINIMUM CONDITIONS

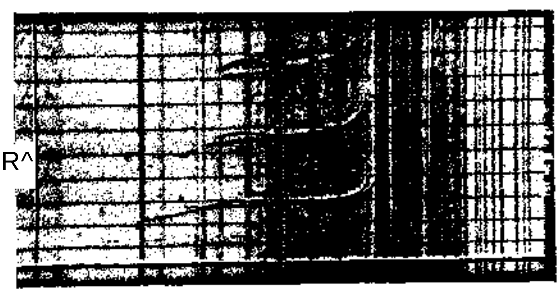
NOON | 1800



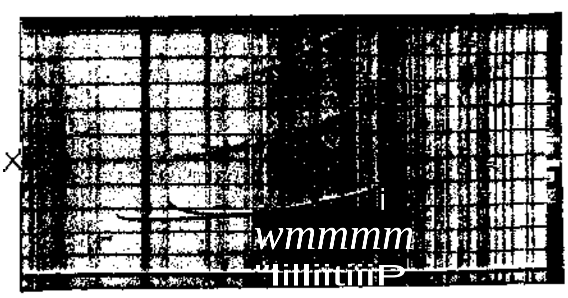
WINTER



SUMMER



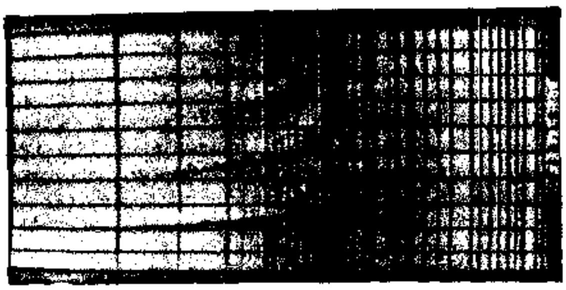
EQUINOX



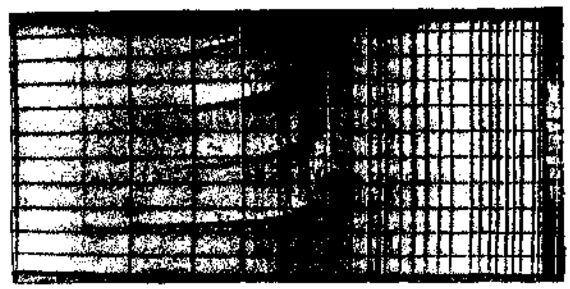
L S6t Q I d 3S

1700

0430



0445



0450

0000

GIQO

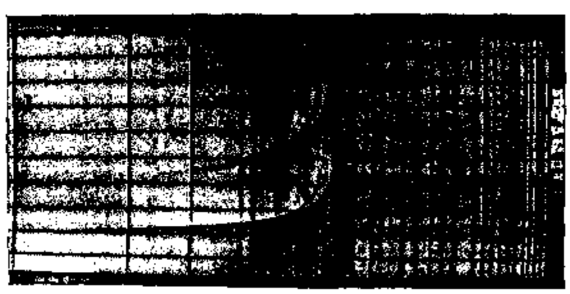
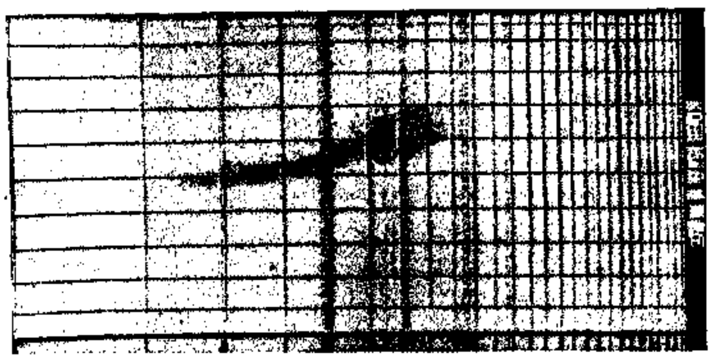


PLATE 4

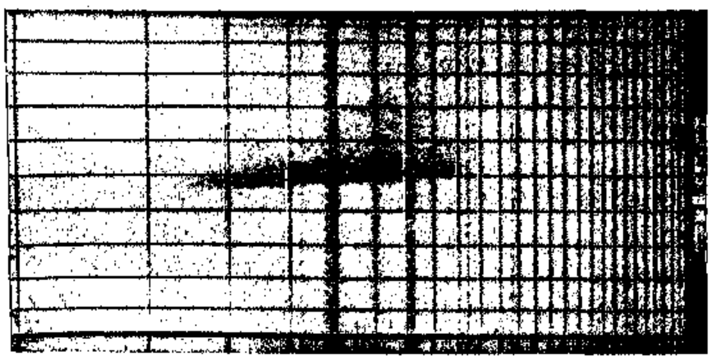
FEB. 15, 1958

2M5



2130

2145



2200

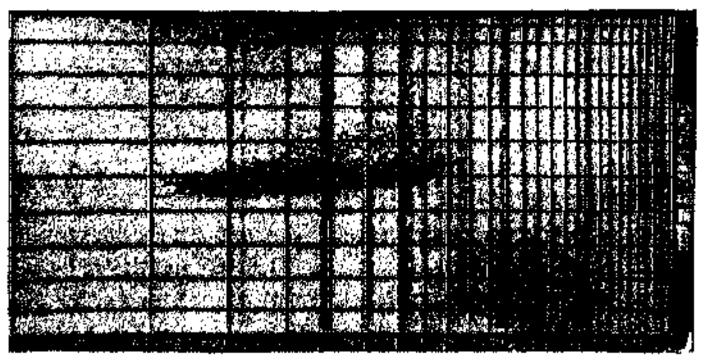
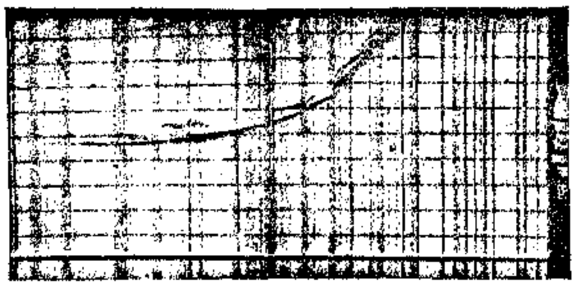


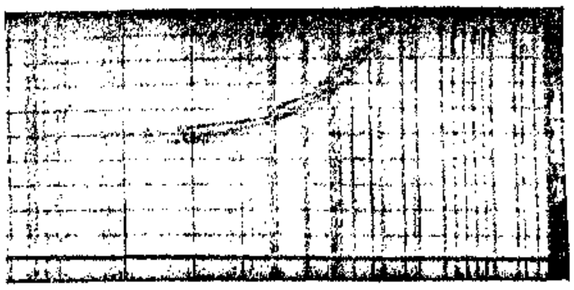
PLATE 5

NOV. 12, 1956

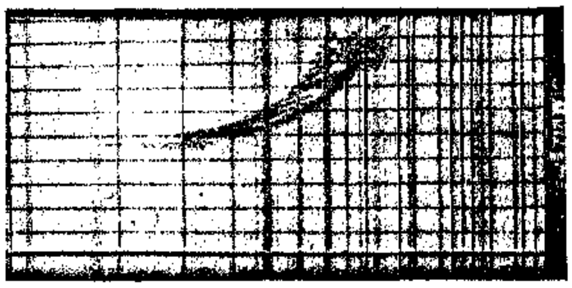
1915



1930



1945



2000

2015

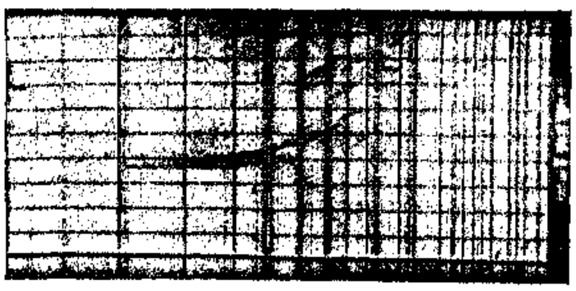


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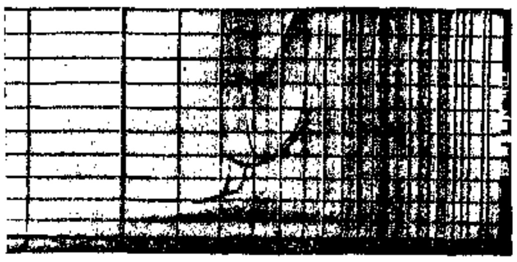
PLATE 6

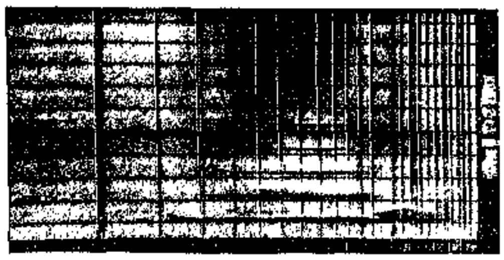
AUG. 26, 1953 1030

(a)



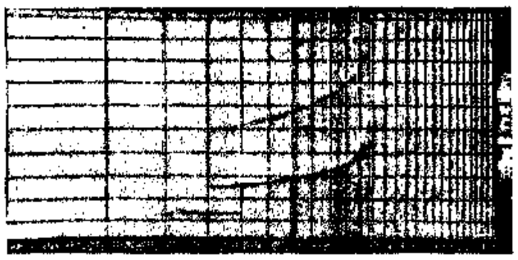
SEPT. 2, 1959 1545

(b)



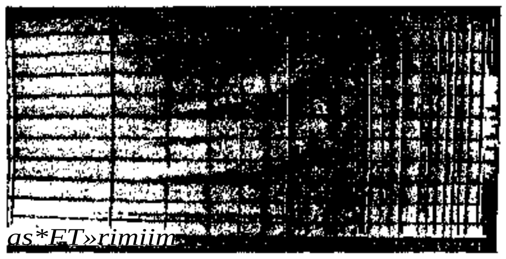
MAR. 30, 1958 0740

(c)



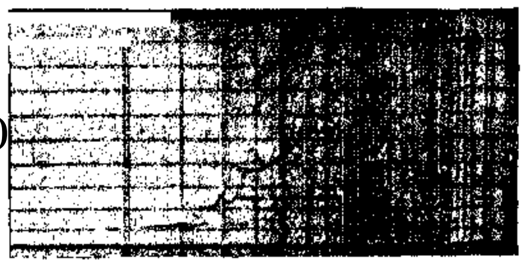
OCT. I, 1957 0300

(d)



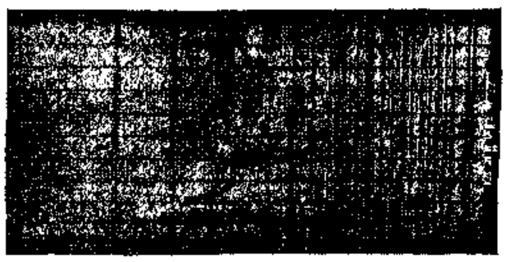
JUL. 3, 1953 1445

(e)



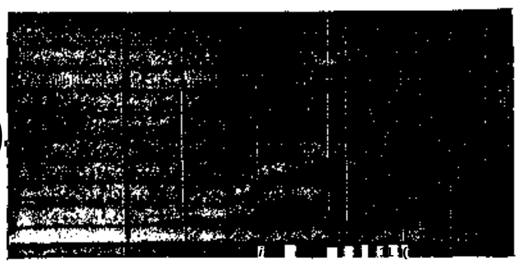
JAN. 3, 1954 1045

(f)



MAR. 4, 1956 1330

(g)



JAN. 8, 1954 1515

(h)

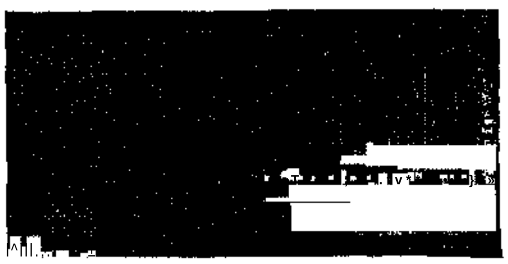
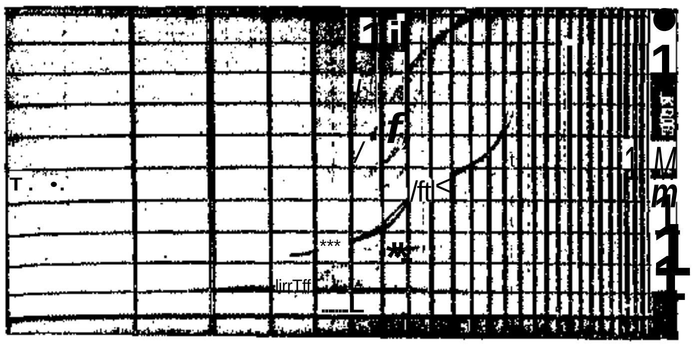


PLATE 7

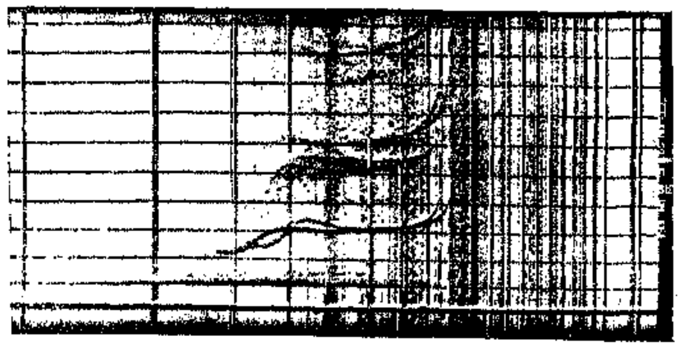
DEC. 16, 1957 1110

(a)



JUN. 22, 1954 1700

(b)



JUN. 22, 1954 1600

(c)

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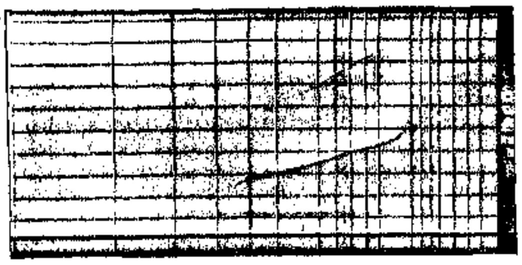
PLATE 8

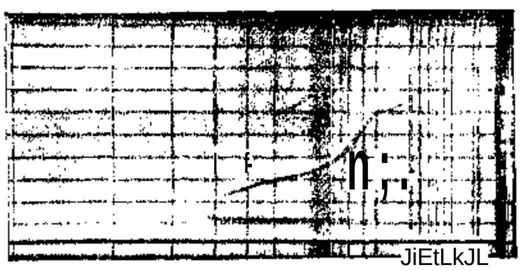
APR. 29, 1956

1000



1030

1100



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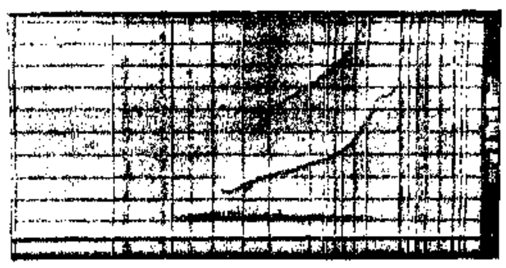

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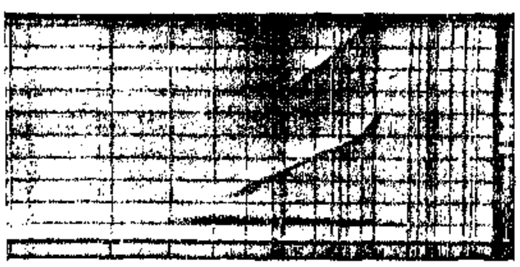

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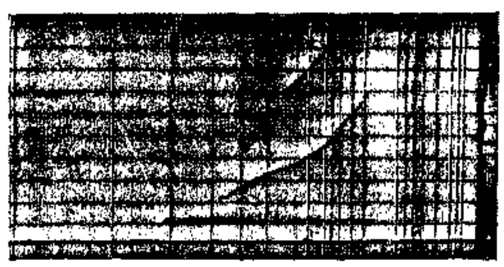

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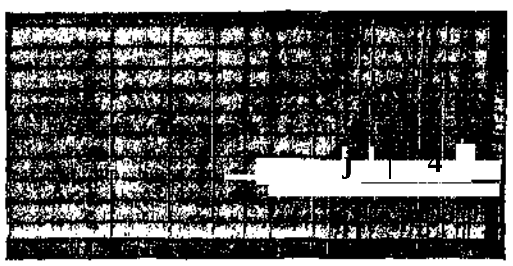


PLATE 9

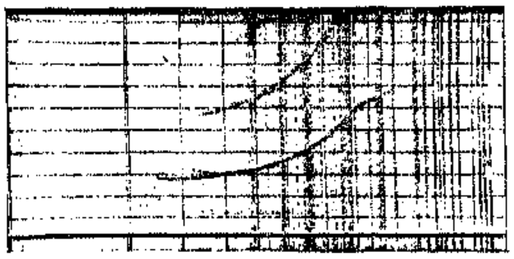
MAR. 4, 1956

1700

1715

1730

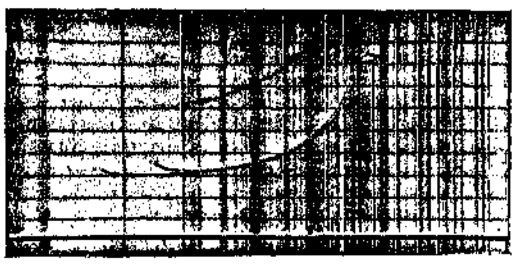
1745



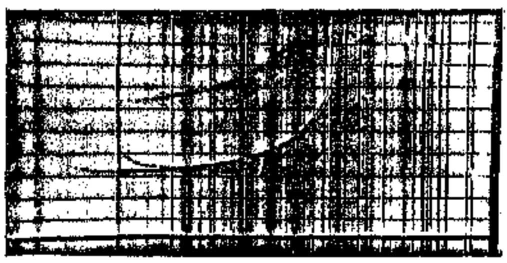
1800

1815

1830



1845

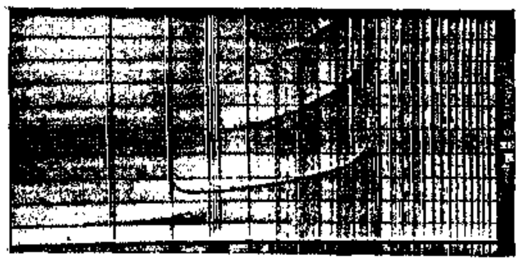


7—5 D. A.B.Kodai/64.

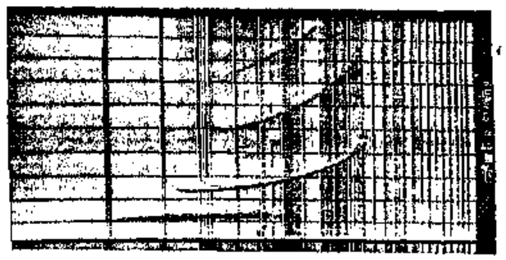
PLATE 10

NOV. 28, 1959

0800

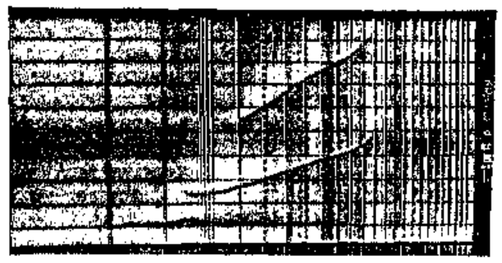


0815



0830

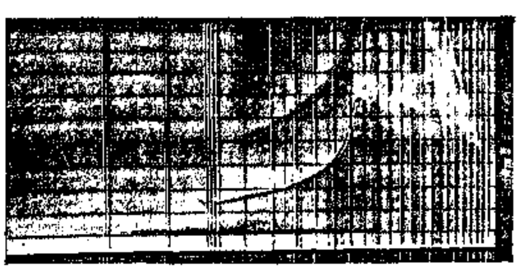
0845



0900

0915

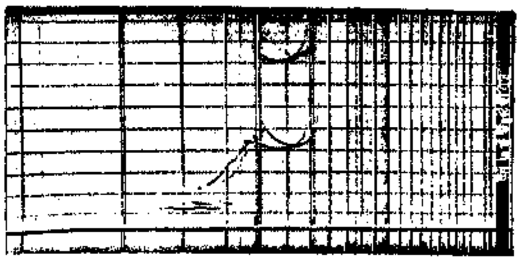
0930



0945

PLATE II

JUNE 30, 1953



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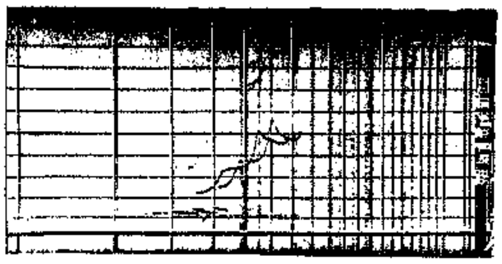

0900

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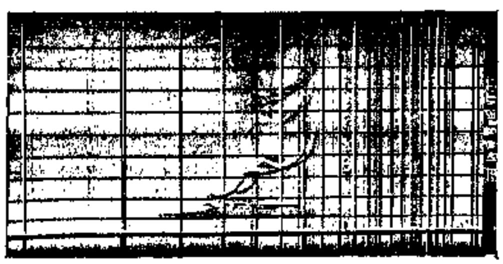
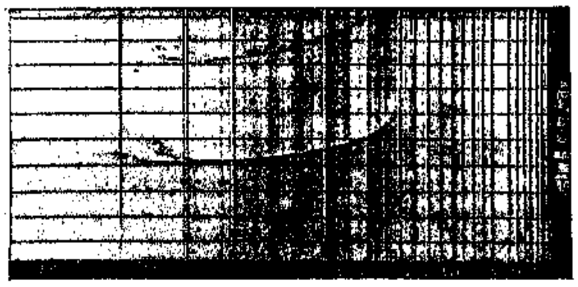
0935

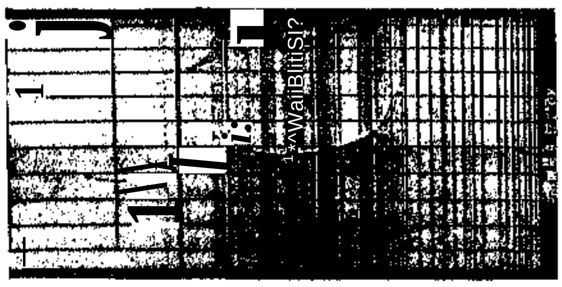


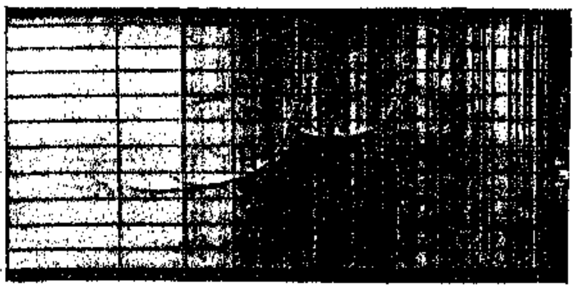
0945

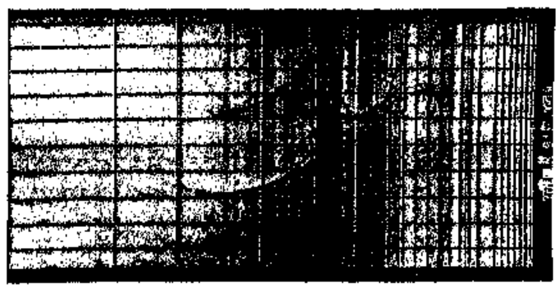
T E 12

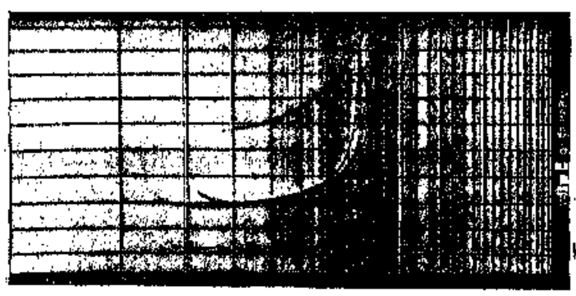
3, 1858











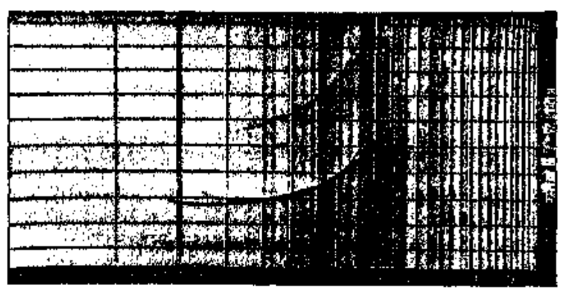
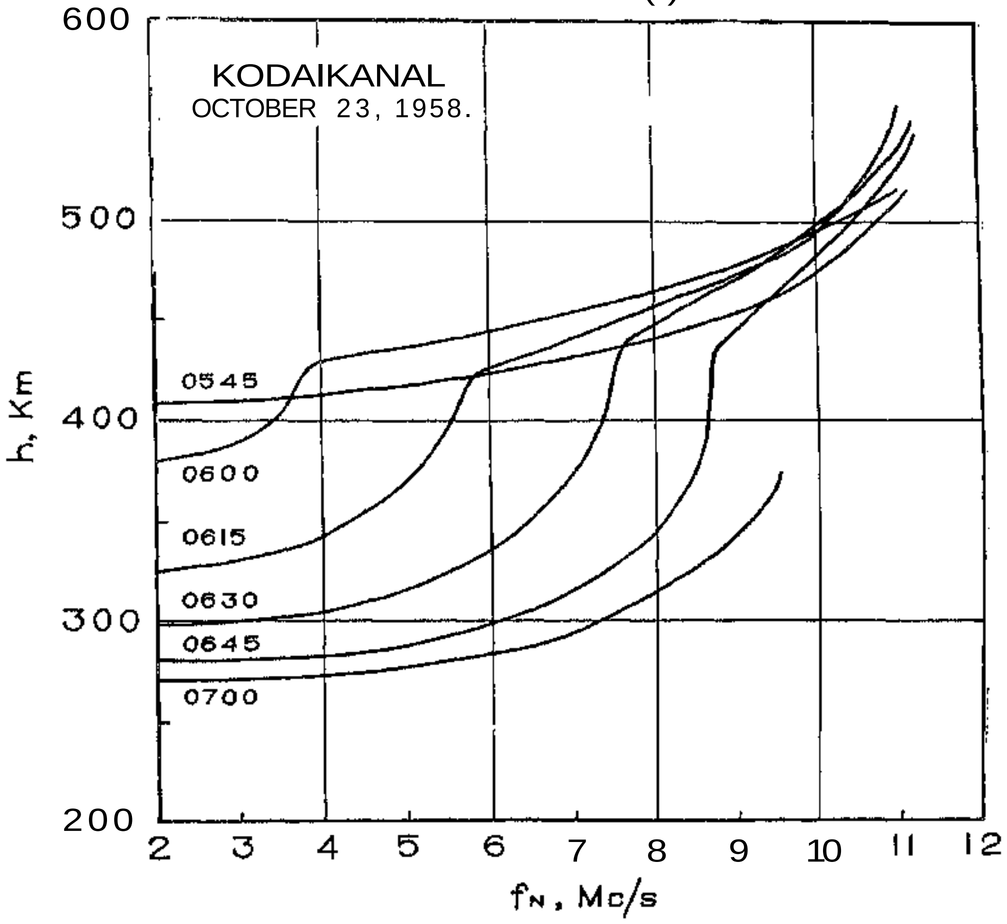


PLATE 12 (a)

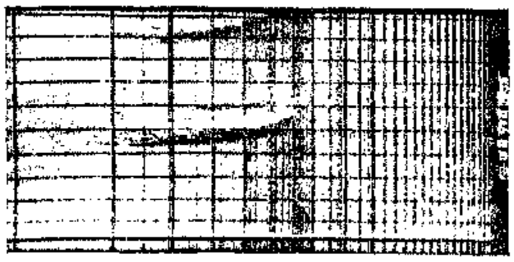


True height profiles deduced from ionograms shown in Plate 12.
(underlying ionization has been neglected.)

PLATE 13

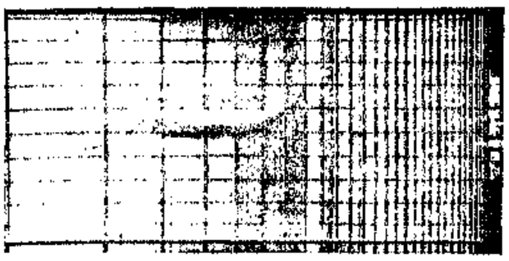
DEC. 12, 195 7

0550



0554

0600



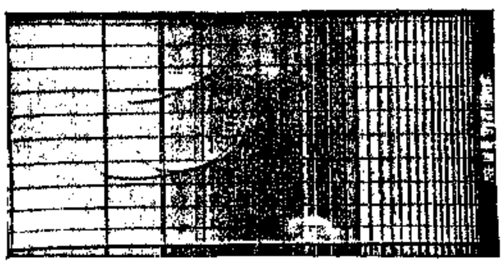
0602

0606

0610

0615

0630

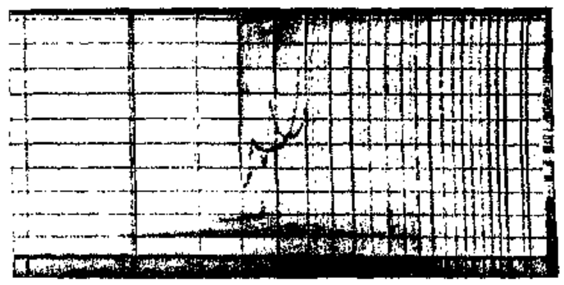


pI VTE I7

C Q6i '82 '3 30

1115

1130



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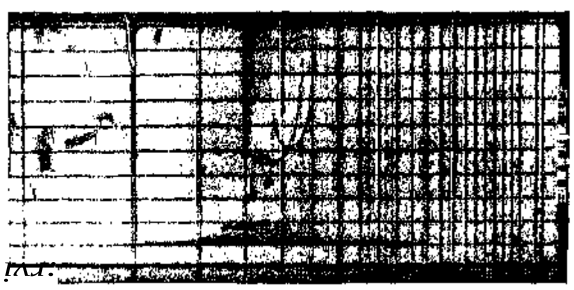

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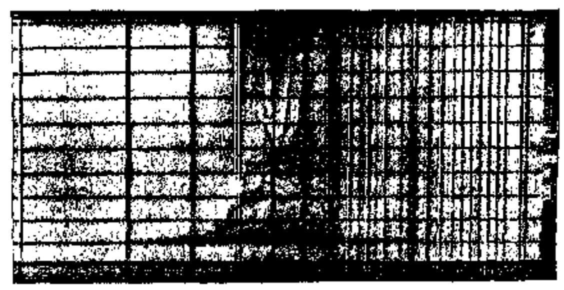


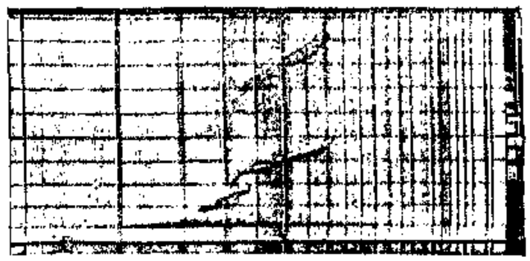
1215

PLATE 15

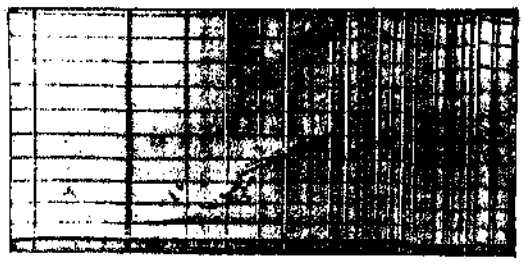
JUN. *A*, 1953

0945

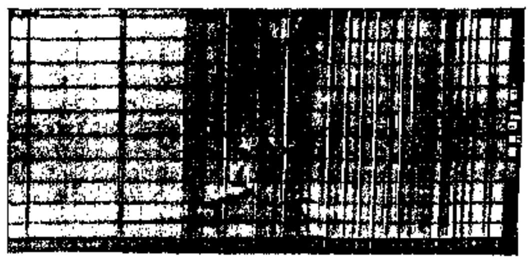
1000



1015



1030



1045

1100

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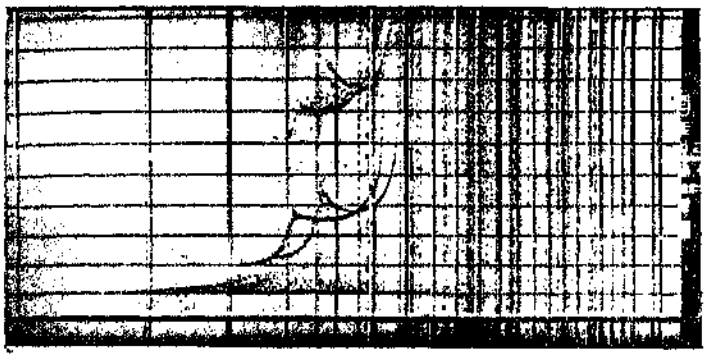
PLATE 16

JAN. 9, 1954

1445



1500

1515

1530

11-5D. A. B.Koclai/64.

PLATE (7

JUL. 31, 1954

1030

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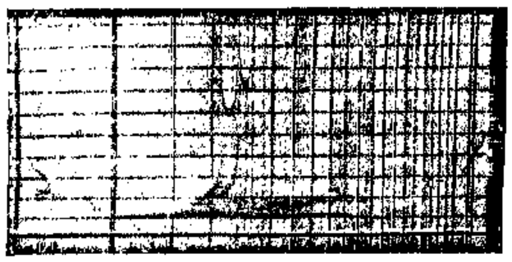
1100

1115



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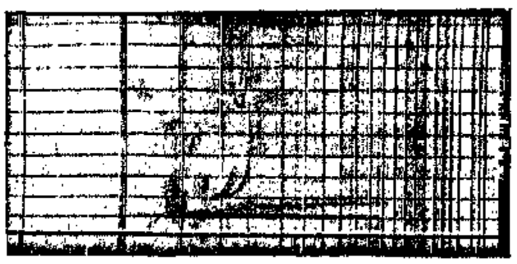
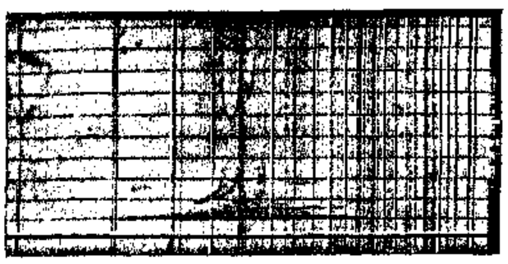
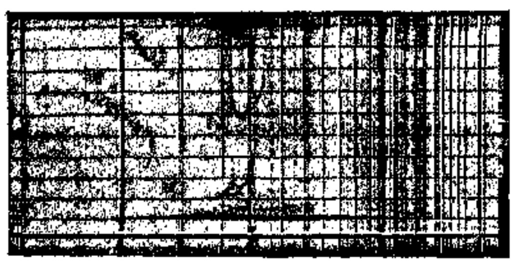


1145



1200



1215

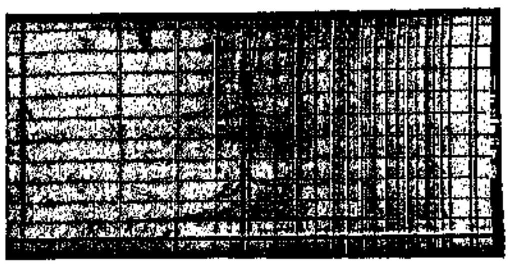
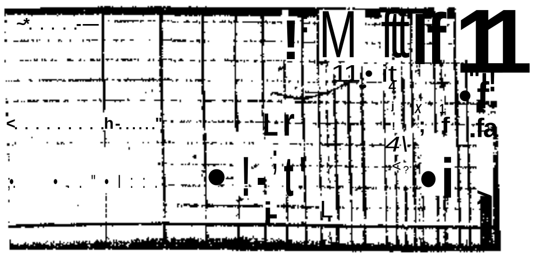


PLATE 18

JAN. 3, 1957

1300

1315



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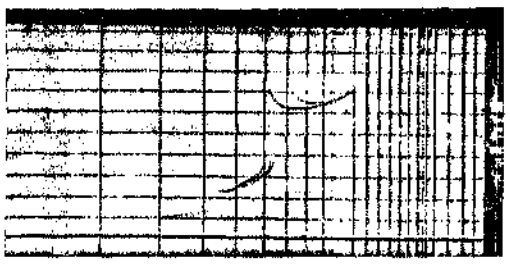

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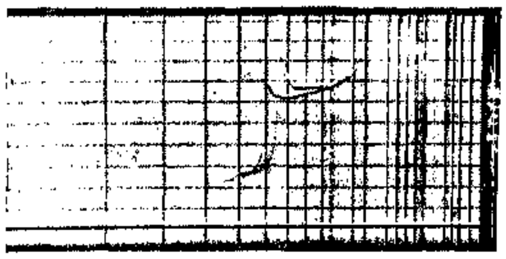

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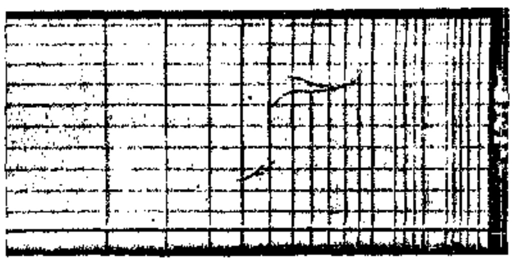

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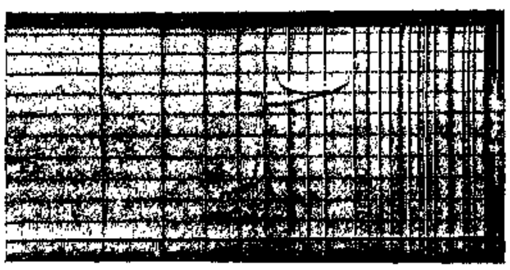
1430



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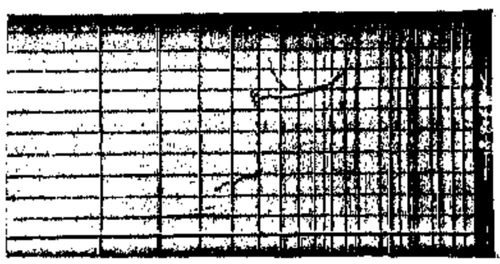
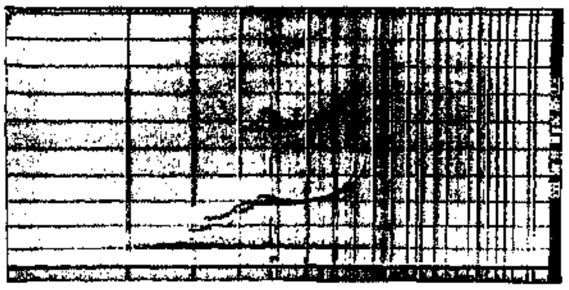


12—5 D. A. B. Kodai/64.

PLATE 19

MAY 26, 1953

0815



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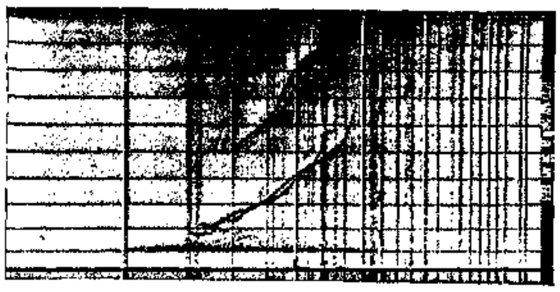
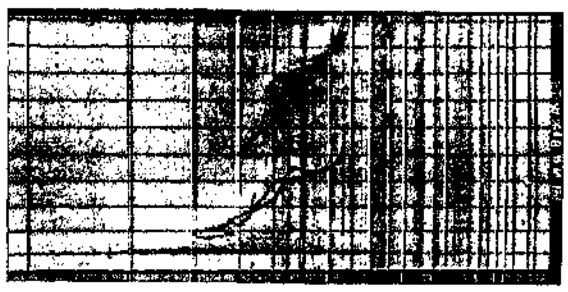


0832

0835

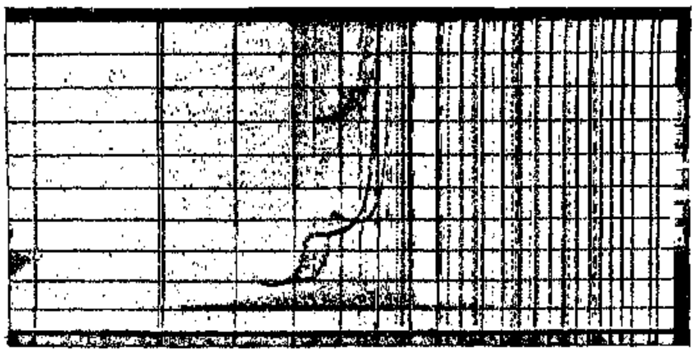


0845

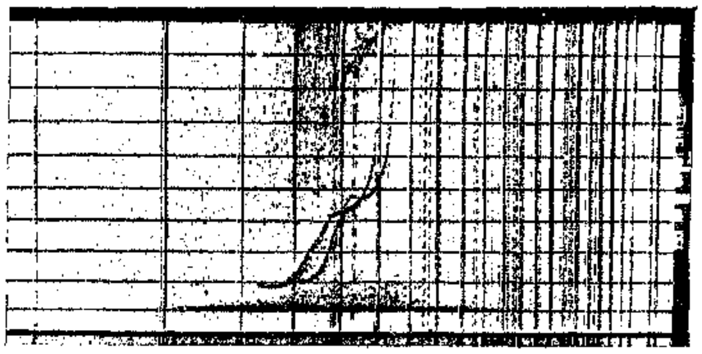
PLATE 20

AUG. 19, 1953

0945



1000



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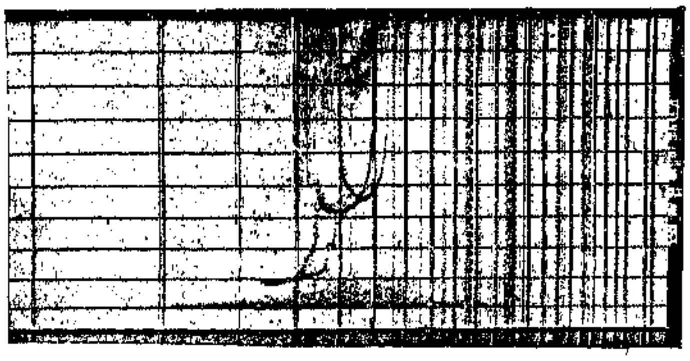
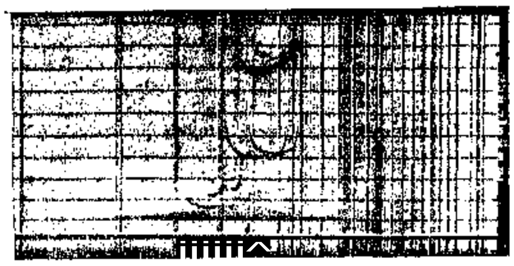


13—5 D. A. B. Kodai/64.

PLATE 21

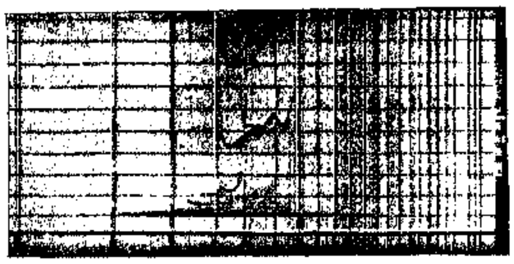
JUL. 3, 1954

1015

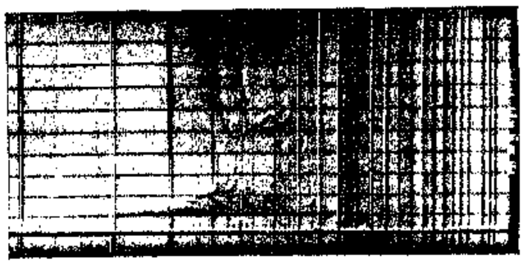


1030

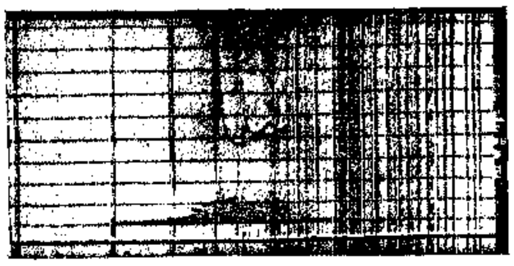
1045



MOO



1101



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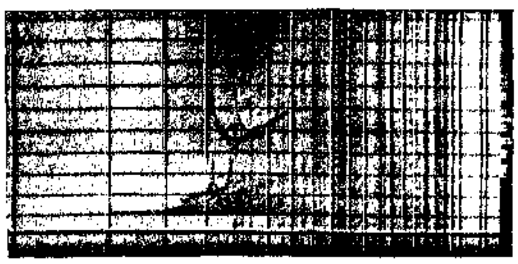


1130

PLATE 22

JUL. 6, 1954

1045

1100

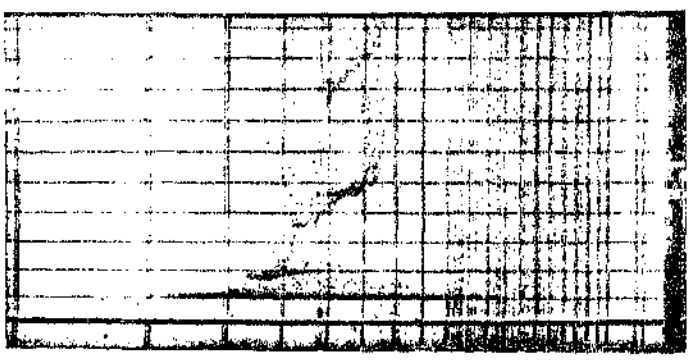
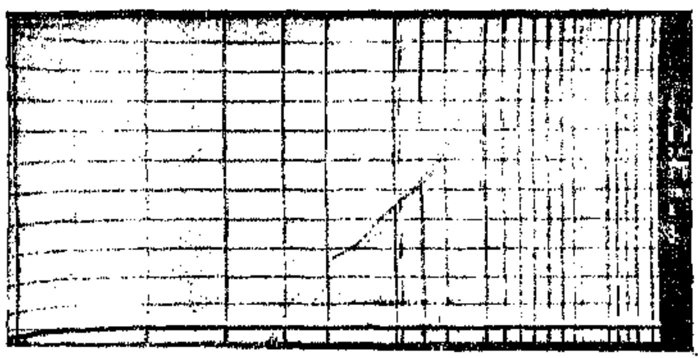


PLATE 23

JAN. 8?, 1954

15 30

JUN. 8, 1957

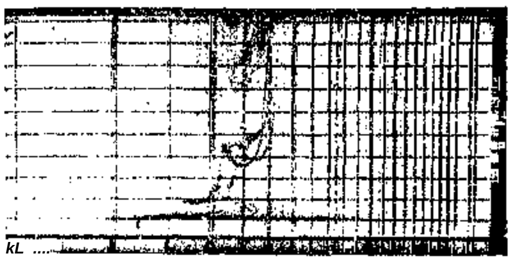


14—5D. A. B. Kodai/64

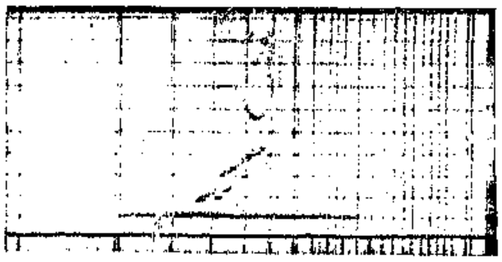
PLATE 24

DEC. 25, 1953

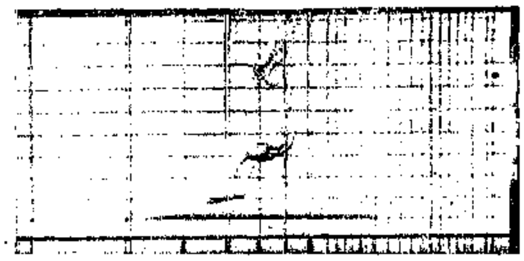
1130



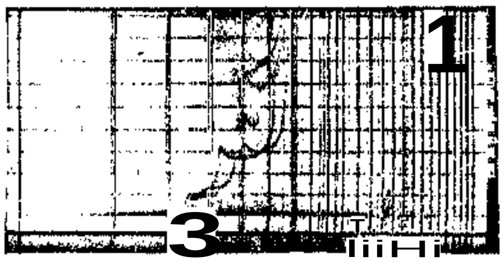
1145



1200



1215



1230

1245

1300

1315

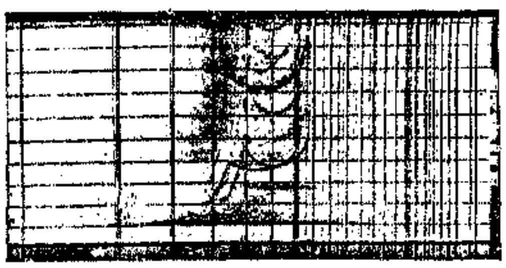
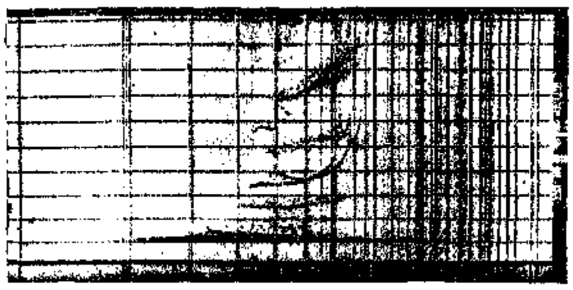


PLATE 25

DEC. 25, 1953

1330



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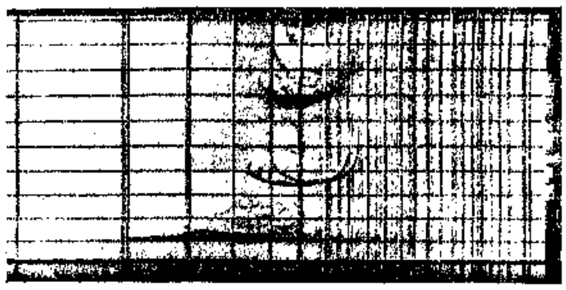

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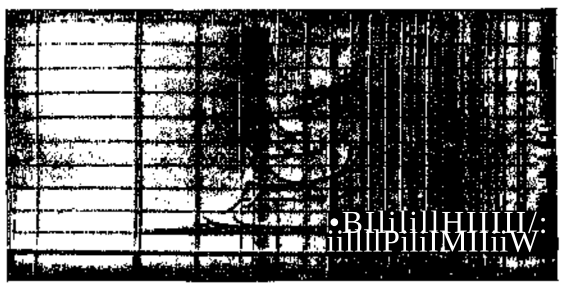
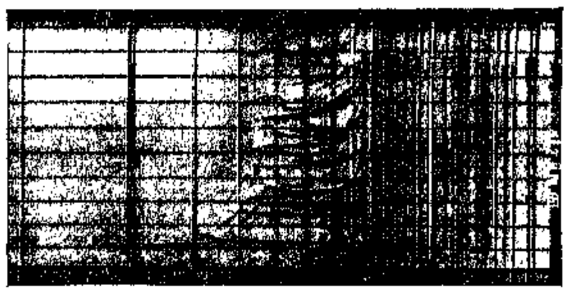
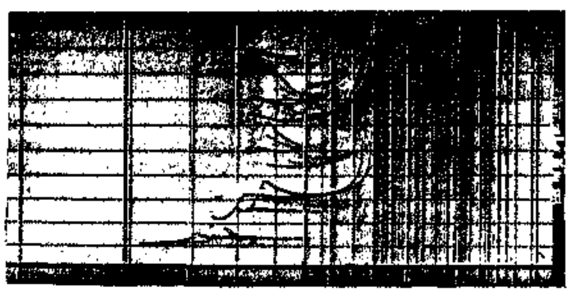


1415



1430



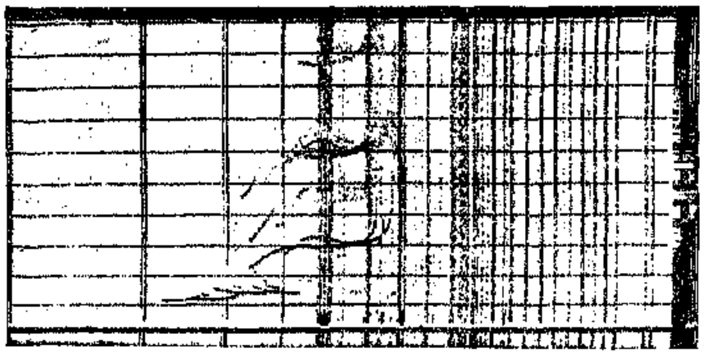
1445

15—5D. A.B.Kodai/64.

PLATE 26

JUN. 11, 1954

0815



0830

0845

0900

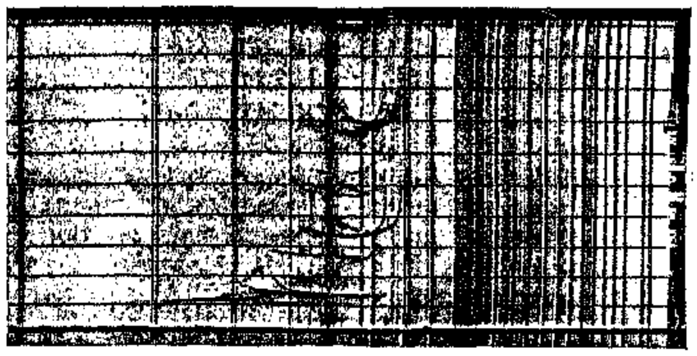
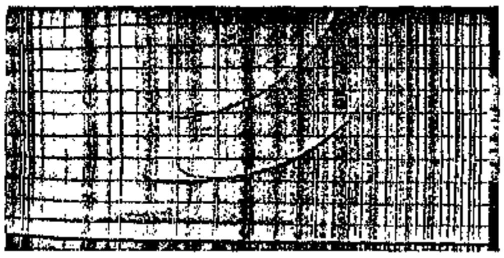


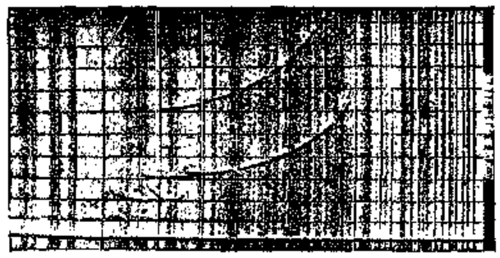
PLATE 27

AUG. II, 1957

1815

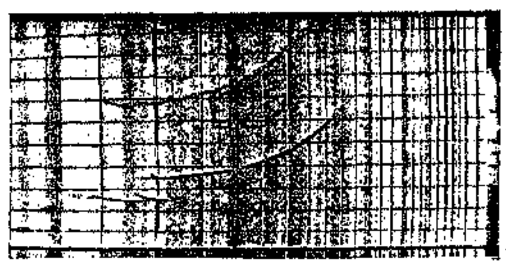


1830

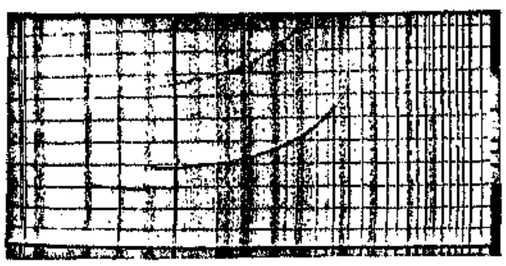


1845

1900



1915



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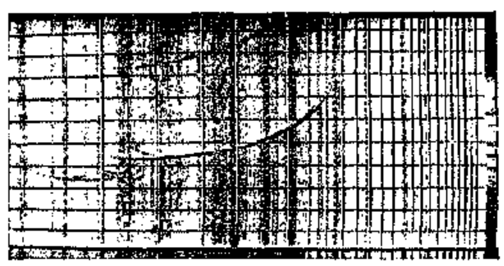
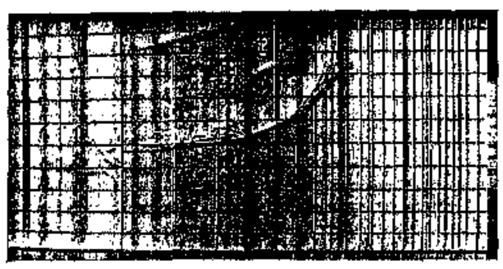


1945

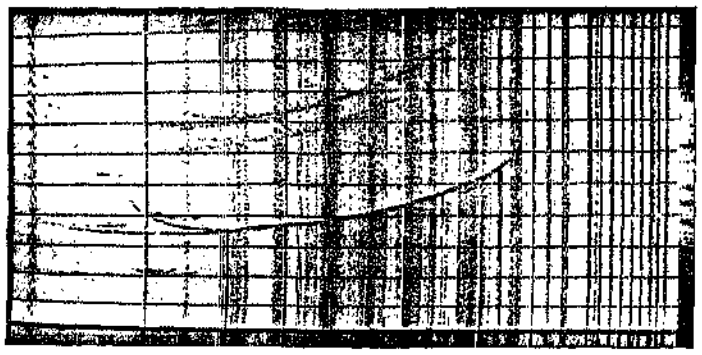


16—5 D. A. B. Kod.ai/64.

PLATE 28

AUG. 3, 1957

1915



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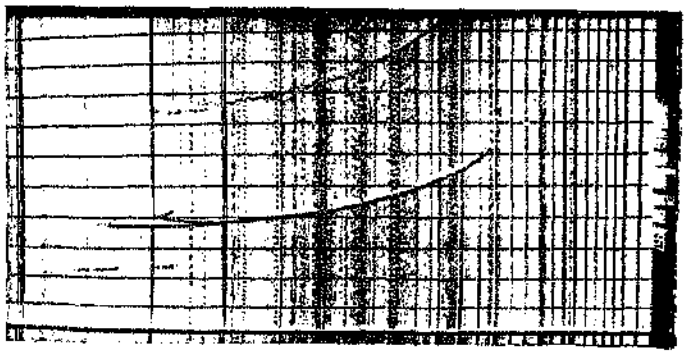

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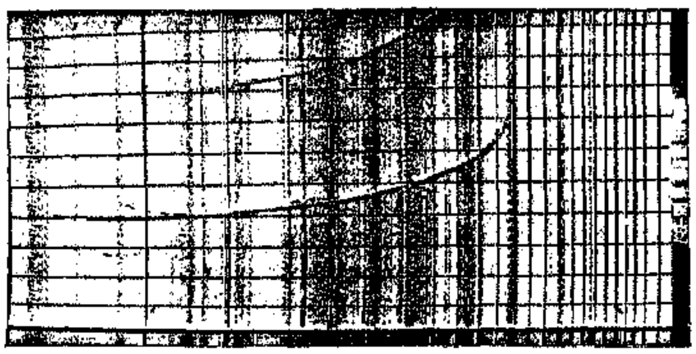
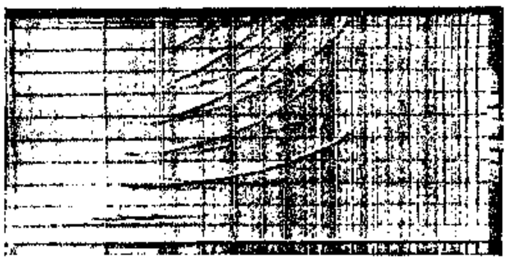


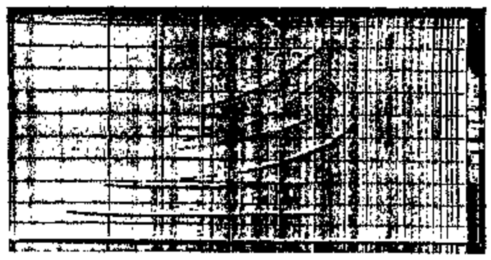
PLATE 29

JUL. 29, 1957

1830

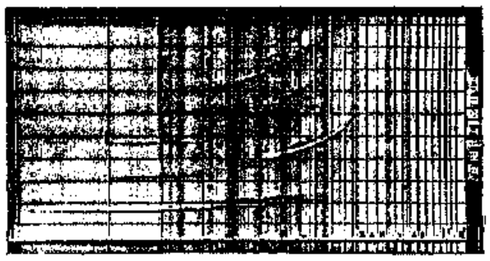


1845

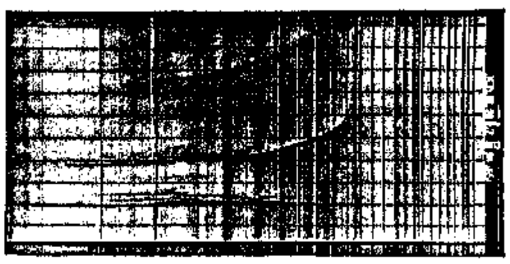


1900

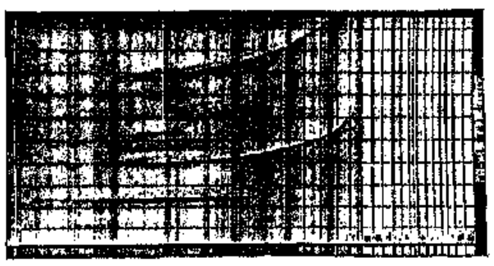
1915



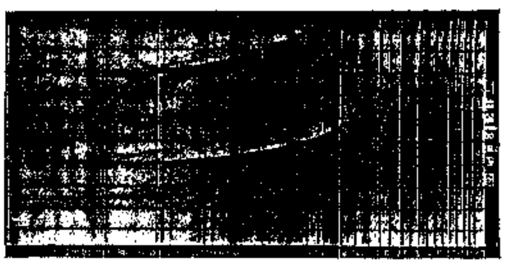
1930



1945



2000

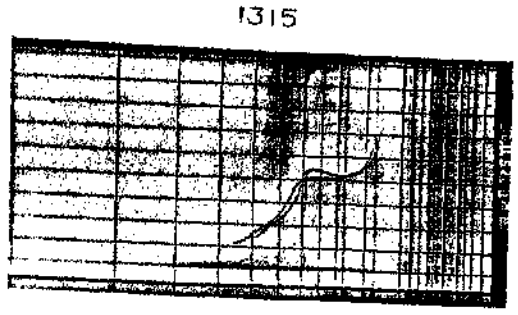


17—5D. A. B.Kodai/64.

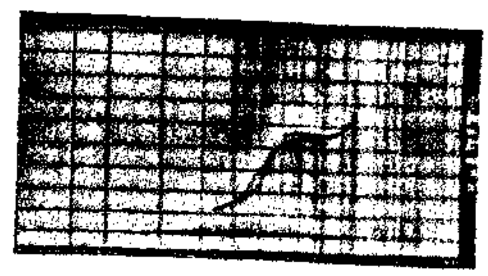
PLATE 30

JUL. 5, 1957

1315

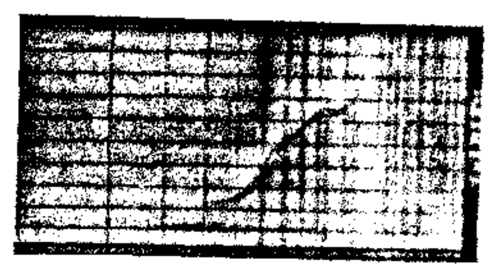


1330

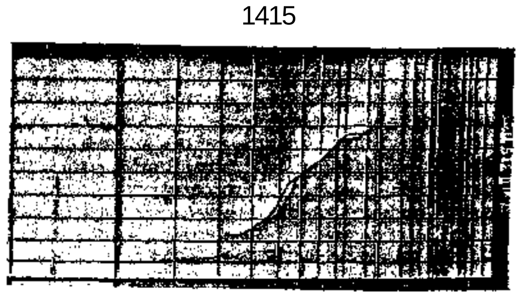


1345

1400

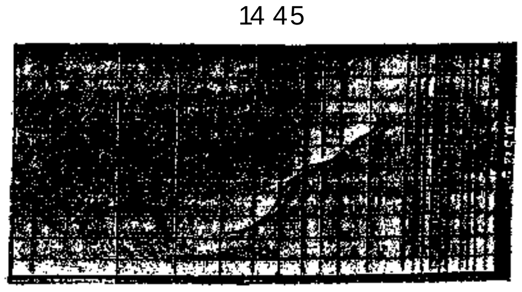


1415



1430

14 45



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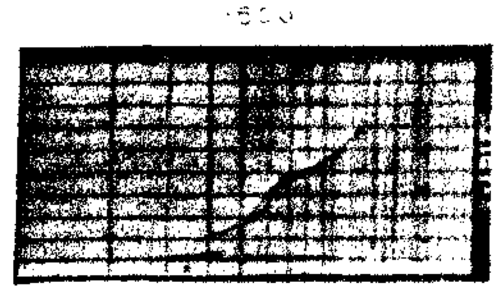


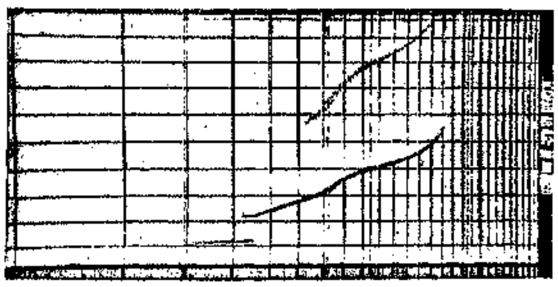
PLATE 31

FEB. 18, 1958

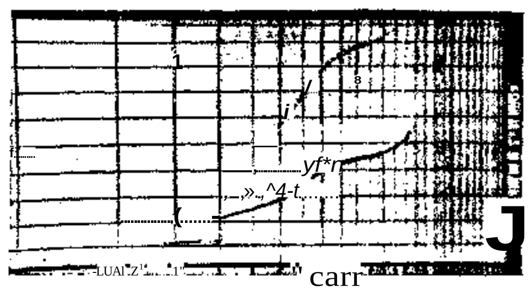
1200

1300

1400

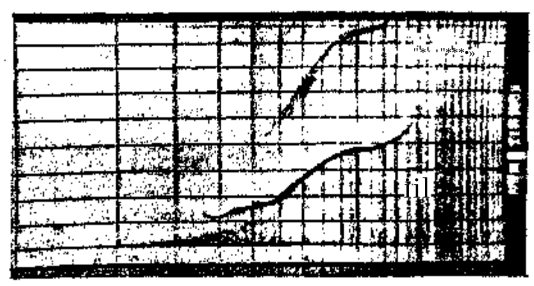


1500



1515

1530

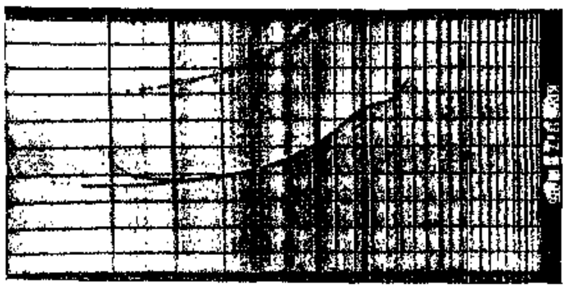


18—5D. A. B.Kodai/64.

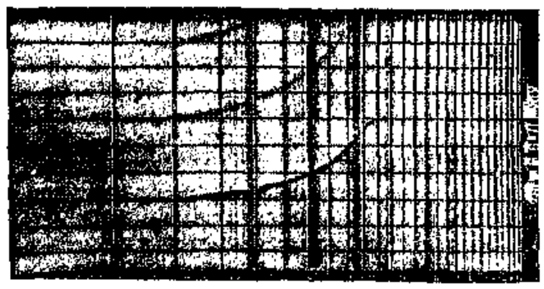
PLATE 32

MAR. 17-18, 1958

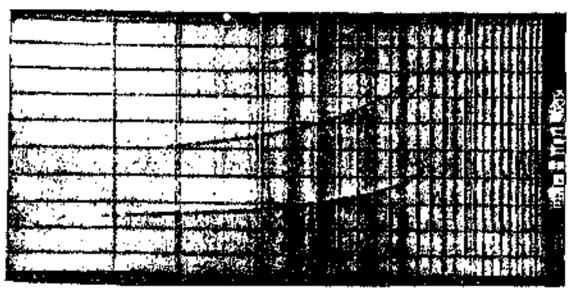
1900



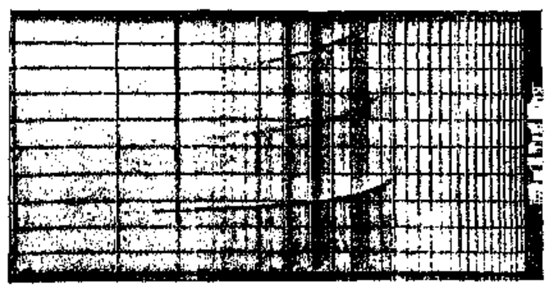
2100



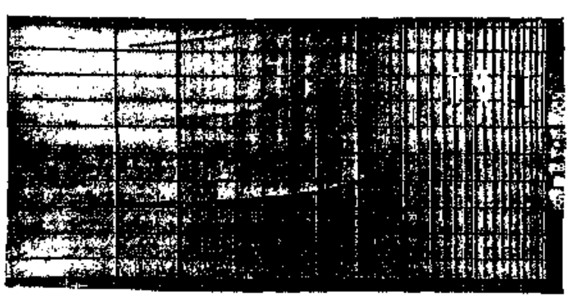
2300



0100



0300



0500

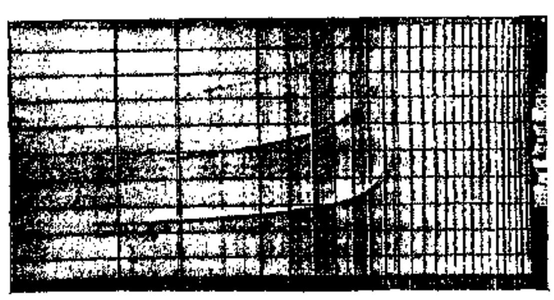
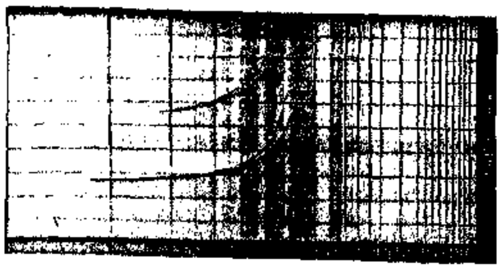


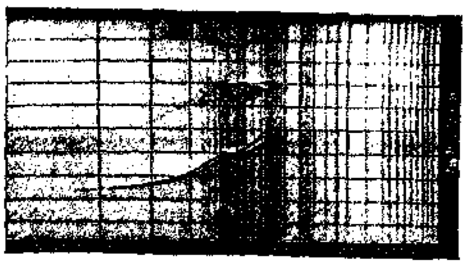
PLATE 33

OCT. 7, 1960

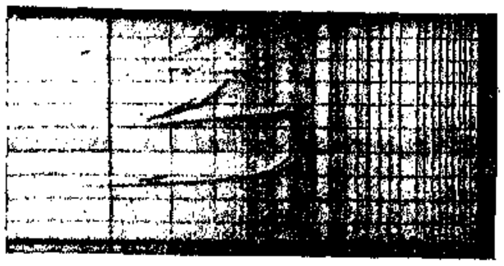
0500



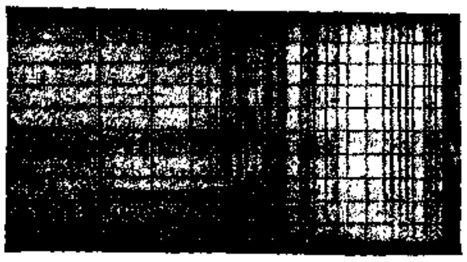
0515



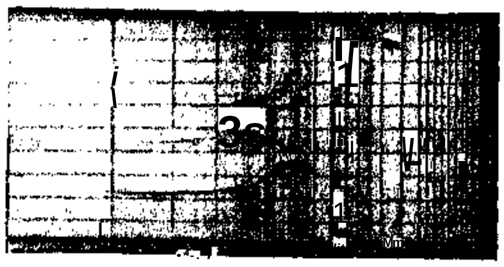
0530



0545



0600



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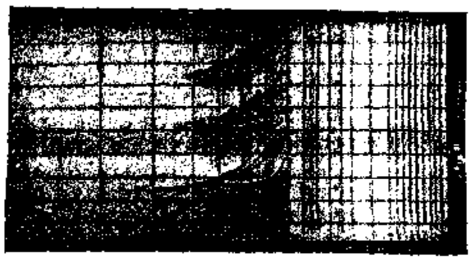

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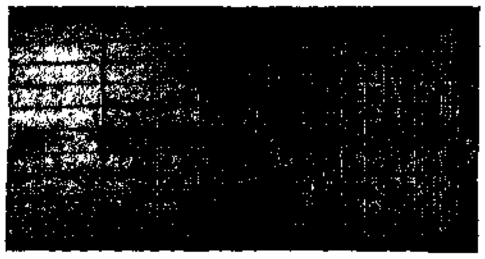
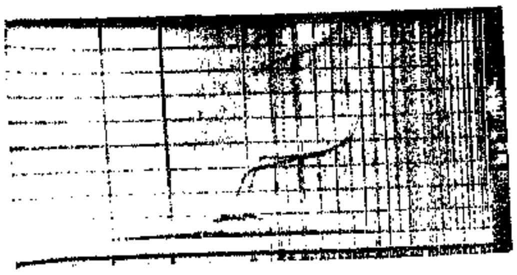


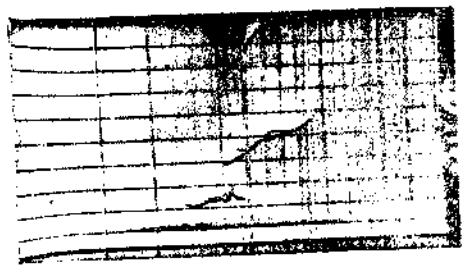
PLATE 34

JUL. 27, 1961

1345



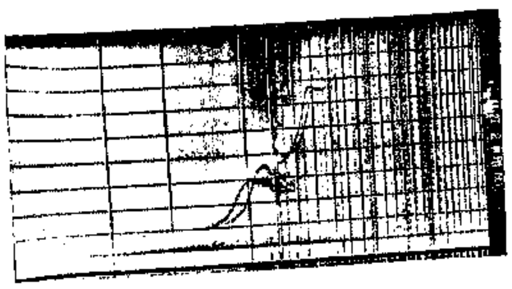
1400



1415

1430

1445



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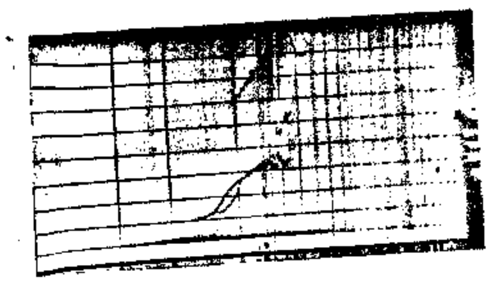

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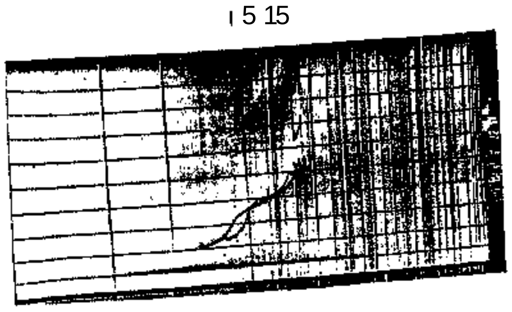
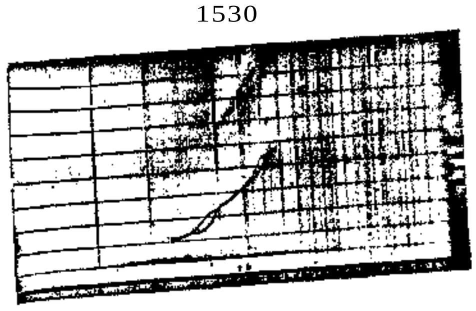


1530



GIPK—S4-5 D. A. B. & Kodai/64—13-3-68-350