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The UTRAO Periodogram Survey: Preliminary Report for Periods Greater than $9^h06^m08^s$

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Interest in the periodic nature of Jupiter radio bursts has revealed the strong correlation of Jovian activity with the position of both the satellite Io and the central meridian longitude of Jupiter. To investigate the presence of further correlates, we have computed a complete survey of the independent periods greater than $9^{h}06^{min}08^{sec}$. This survey consists of a periodogram investigation of 131 072 trial periods. Further, trial periods between $9^{h}06^{m}08^{s}$ and $4^{h}33^{m}04^{s}$ will be soon investigated.

One complexity of periodogram analysis of Jupiter data is the non uniform rotation of the Jovian longitude system. The jovocentric right ascension of the earth introduces a considerable phase modulation into the occurrence statistics collected by a terrestrial observer. While the removal of this modulation is not difficult, the process will destroy any purely time periodic component of the occurrence statistics, which is the price of revealing any correlate within the Jovian rotation frame.

Since there are two known correlates and this investigation seeks a third, a three correlate statistical model should be used. However, the calculation time for a three correlate model would be such as to discourage a complete investigation. Further, improvement in calculation speed can be achieved by using occurrence times rather than probability. A proper one correlate periodogram requires one to subdivide the argument and calculate both the number of observations and the number of observed radio storms from each interval. If observing time is not evenly distributed over the argument a bias is introduced by using storm times only. This bias is important when short observing intervals are investigated, whereas this study uses an observing catalog so extensive the periodic power of the observing times is severely attenuated, except in the immediate vicinity of 24 hour and 400 day spurious responses. Moreover, ignoring observing time will not decrease the periodic power, and identification of peaks in the periodic power are the object of this investigation.

Method

Each storm is characterized by a starting time, T_s, a duration, T_d, and a Jovocentric right ascension of the earth, JRAE. The phase of each event is then:

$$\Gamma = \omega(T_s - T_{light} - T_{epoch}) - \mathrm{JRAE} + \emptyset_o$$

where T light is the light time to Jupiter, and T_{epoch} is an arbitrary time at which $\emptyset$ = JRAE (T_{epoch}). Likewise the phase duration of the event is

$$\Delta\Gamma = \omega T_D$$

For simplicity, the data are stored in the computer as $T = T_s - T_{light} - T_{epoch}$, $D = T_d$, and $J = (64/2\pi)$ JRAE so that when the phase argument is broken into 64 cells, the cell at the observation start, N, is:

$$64m + n = (64\omega/2\pi)T - J + 1/2 \quad \text{where } n < 64\text{, an integer} \quad m\text{, an integer}$$

and the duration (in cells) is

$$K = (64\omega/2\pi)D + 1/2$$

In practice T, D and J are packed into one computer word and unnormalized multiplies perform the modulo operations. When N has been calculated, position N and K - 1 thereafter in the 64 cell histogram are incremented by one. The result is a histogram of storm occurrence vs. phase of the trial period in a jovocentric rotating coordinate system. When all the data have been entered in this way, the mean and variance of the histogram are calculated, and the quotient of the variance divided by mean squared is saved together with the magnitude of the trial period. This quotient may be calculated

$$\sigma/x^2 = 64\ \Sigma x_i{}^2/\Sigma(x_i)^2 - 1$$

This quantity is an estimate of the power present at the trial period and its harmonics. The nth harmonic is weighted, due to the finite number of cells in the histogram, by the function:

$$\omega(n) = \sin(n\pi/64)/n\pi/64$$

Thus the presence in the periodogram of the 32nd harmonic is diminished by $2/\pi$.

The significance of the amplitude of the periodogram at a given trial period is not quite as simple as the interpretation of the amplitude of the fourier transform of the storm series since unlike the transform, the periodogram also responds as mentioned above to harmonics of the trial period. The concept of duty cycle is applicable to the periodogram interpretation. Fir a given number of cells, n, the data obviously can be no more ordered than to all occur in one cell, which would indicate a maximum duty cycle of 1/n. If we let p be the periodogram response the equivalent duty cycle is 1/(p + 1). To simplify the calculation, the periodogram results were saved as integers after multiplying σ/x^2 by 512. Hence, the equivalent duty cycle is given by 512/(512 + p). The data set used for this periodogram is probably the first with sufficient observing time to show a stronger response to Jupiter than the diurnal period. The equivalent duty cycle of the response to Jupiter's rotation period is 47% while that due to the diurnal period is 52%. The duty cycle interpretation indicates that the histogram which results when the trial period is the rotation period of Jupiter has the same ratio or r.m.s. to mean as a histogram in which Jupiter were always observed active in 47% of the cells and always inactive in the remaining cells.

Data

The data employed in this survey is all from observations at 22.2 MHz. The bulk of it is the Yale observations from the apparitions of 1958 to 1965 inclusive. Also included are DTM 1956 Kodaikanas 1962 to 1965, Goddard 1965 & 1967, and Carnavon 1967. The total observing time is 12318 hours. Storm time is 641 hours, the observing interval is 4152 days; the center of observations is 20 November 1963. During this period the unbiased 2 correlate occurrence probability was 5.06 ± 0.16%.

Analysis of Periodogram

The periodogram contains, as expected, literally hundreds of responses. Many are produced by heterodynes between the known periodicities present in the data. The periods of Io, Earth, Jupiter rotation, Jupiter synodic year, and Jupiter orbital period are all clearly present. To assist the identification of expected spurious responses, a large list of expected heterodynes was calculated and sorted by period. The frequency at which we expect such a response is given by:

$$S(I,J,K,L,M) = \frac{I\nu_{Io} + J\nu_{\oplus} + K\nu_{♃} + L\nu_{sy}}{m} + \nu_{N}$$

where ν_{Io}, $\nu_{\oplus}$, $\nu_{♃}$ are the mean synodic frequencies of Io, Earth and Jupiter, ν_{sy} the frequency of the Jovian Synodic Year, and ν_N the frequency of Jupiter's orbital period. All spurious responses were calculated up to and including order 8, where the order, O is calculated:

$$O = /I/ + /J/ + /K/ + /L/ + /M/ - 1$$

These spurious responses were saved, and the periodogram scanned for peaks, the position of which are saved. Finally we write an ordered list of both spurious and observed responses.

Analysis to date has been limited to manual scans of this list. The list contains over a thousand peaks. Figure 1 (a to h) is an example of several strong responses. This series is the Jupiter subharmonics from 1 (the fundamental) to 8. The spectrum plotted here represents less than 1% of the periodogram survey.

The feature of Figure 1 most readily apparent is that all spurious predictions coincide with observed features and almost all observed features coincide with predictions.

One must employ some caution when claiming to associate an observed response and an artificially generated spurious response. Clearly, we may choose a limiting order of spurious response sufficiently high to assure a near continuum of spurious responses and thus allow every observed response to be associated with a spurious response. Conversely, we may choose an order sufficiently low to leave many "new" periodicies to be announced. Resolution of this problem lies in the development of a technique to predict the magnitude of a given response, and to compare the resulting predicted periodogram to the observed results. This prediction must satisfy most of the observations reported here, and thus a further discussion of the general nature of the periodogram is in order.

The periodogram displays several interesting features: 1) Low order expected spurious responses are not always seen. 2) There are several large responses which are not explained as spurious responses to known periodicities to order 8 as defined above. 3) There are many weaker peaks in the periodogram, and generally these are quite narrow, suggesting association with high order spurious responses. 4) The ratio of the magnitude of the "double side band" modulation due to the 400 day synodic year term varies considerably between different low order spurious responses.

All spurious responses of order 3 or less were scanned to check for the expected peak. Of 93 such spurious responses 48 or about half were not seen. Of these, 35 are negative frequencies, 4 are second order in synodic year and 6 are synodic year - earth products. The remaining three are 2 earth minus Io; and the first subharmonic of Io synodic year, and Earth minus Io. Negative and positive frequencies are symmetric about zero in terms of synodic period but lose the symmetry when corrected to sidereal period. Negative frequencies do not appear in the periodogram unless mixed with one or more other periods.

In the description which follows we use an abbreviated notation to reference a spurious response. A five digit number such as 12345 refers to the response with I = 1, J = 2, K = 3, L = 4, M = 5. Commas will be used if an integer exceeds 9 (e.g. 0, 17, 017 implies I = 0, J = 17, K = 0, L = 4, and M = 7). Note in Figure 1a that 00-101 is not seen while 00101, is the largest response of the periodogram, but that seven of the thirteen identified responses are negative.

When the periodogram is compared to spurious predictions to order 8 several large peaks remain. However, seven of the first eight of these are readily associated with Jupiter subharmonics to higher order. For instance at a sidereal frequency of 3.497349 μHz we find a response, presumably to 001-18 (e.g. order 9) which is 35% of the amplitude of the 00101 principal Jupiter peak. Subharmonics 9, 10, 12, 27, 30 and 43 are also visible. While the latter may seem implausible, its peak coincident to the predicted location to one tenth the width of the principal Jupiter peak (00101). Two of these large peaks are as yet not associated with spurious responses and the search for such associations continues.

The periodogram contains many smaller peaks which are not easily associated with known spurious responses. Often these are very narrow, sometimes a twelfth the width of the principal Jupiter peak, which suggests that these are responses to high order heterodynes. The choice of limiting order is intimately involved in the association of these peaks. We have seen above that a peak of order 43 appears, and that some peaks of order 2 do not. If all spurious responses to order 43 were calculated, the density of spurious peaks would rival the number of trial periods and all features could be associated with close calculated response. The peak detecting scheme used to make the ordered list of calculated and observed responses has a variable sensitivity such that in the presence of very large responses, small responses are passed over. In Fig. 1a for example only five peaks are saved by the peak detecting scanner, whereas thirteen can be both clearly seen and associated with calculated spurious responses.

Since the object of this study is the search for another correlation period, we must not ignore any significant observed response.

An approach more sensitive to the smaller peaks is to plot the entire periodogram together with indication of spurious responses as has been done for the small portions shown in the figure. Then a spurious response generator must be constructed that will calculate a few of lowest order responses that lie near a given peak. Comparison of the strength of such responses to others of similar order should help establish the credibility of the association. Finally, the periodogram displays some moderate but very wide responses. These may be due to periodices in the data which are outside the Jovian rotating frame. We have mentioned above that the correction for jovocentric right ascension of the earth introduces a phase modulation of 0.2 radians to any rotation not associated with the Jupiter frame while removing such a modulation from periods within the Jupiter frame. The wide moderate responses may be caused by non Jovian effects. This should be further investigated by merely running the periodogram program without the phase correction term.

An interesting feature of the subharmonics of the principal period is the variable ratio of side band level. Figure 2 is a plot of the amplitude of the responses 0011m, 0010m, and 001-1m. These are the principal period, and the two side bands produced by the 400 day apparition term. At low order, e.g. m = 1, 2, 3, 4, the principal peak is clearly cominant, while at m 4 the negative side band is greater than the principal response and the positive side band is no longer visible. This behavior must arise from the details of the phase of observations within an apparition. Since such behavior appears on the principal Jupiter response, similar behavior is not unexpected on other responses, and thus while not yet demonstrated in detail, at least qualitatively answers the question (Bigg pt comm.) of why, if the responses proposed to be associated with satellite periods (Bigg 1969) are in fact due to spurious responses, are the opposite 400^d side bands missing (Douglas & Bozyan 1970).

Summary

To reach a firm conclusion regarding the existence of undiscovered periodicities in the Jupiter observations, the following extension of periodogram research should be considered:

1. A Model should be constructed which predicts with some accuracy the amplitude of various intermodulation peaks.

2. The entire periodogram should be plotted together with the location of predicted spurious responses.

3. All remaining peaks should be submitted to an algorithm which finds the nearest two or three lowest order spurious responses, regardless of order and these should be judged as to validity of association.

4. A proper two dimensional periodogram should be run about all remaining periods with observed but unidentified responses.

References

Bigg, E. K. 1969, Astrophys. Letters, 3, 77.

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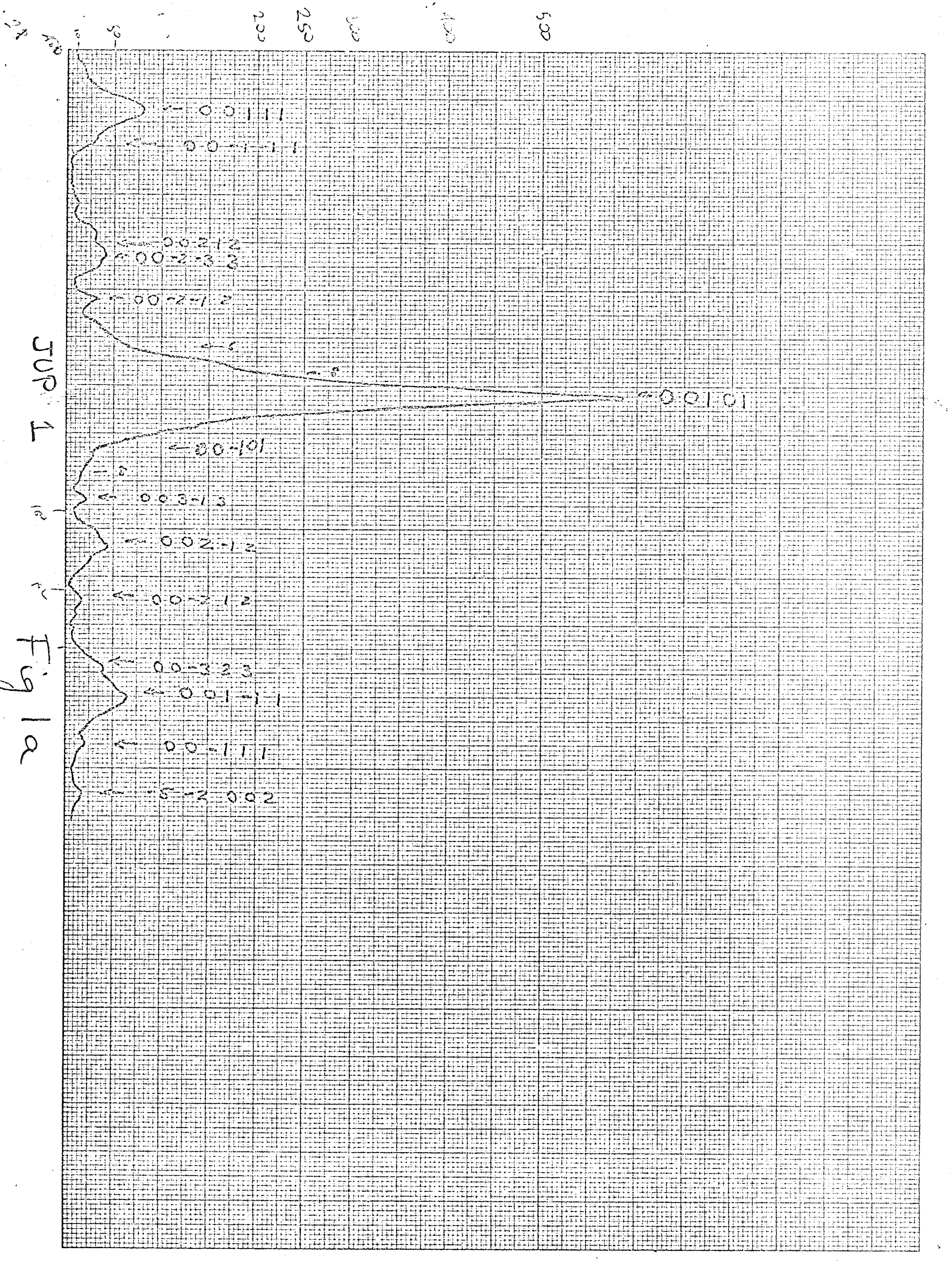

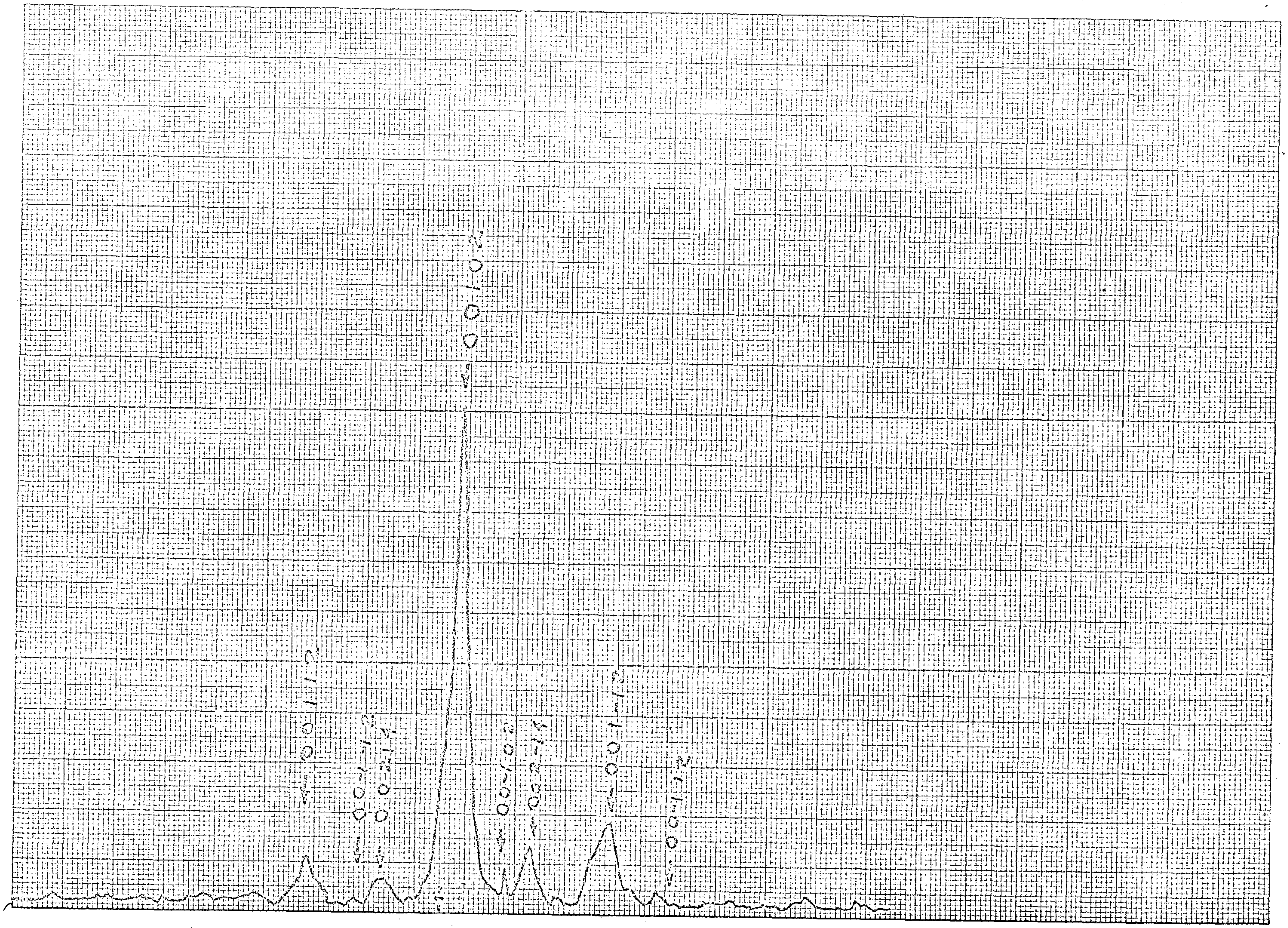

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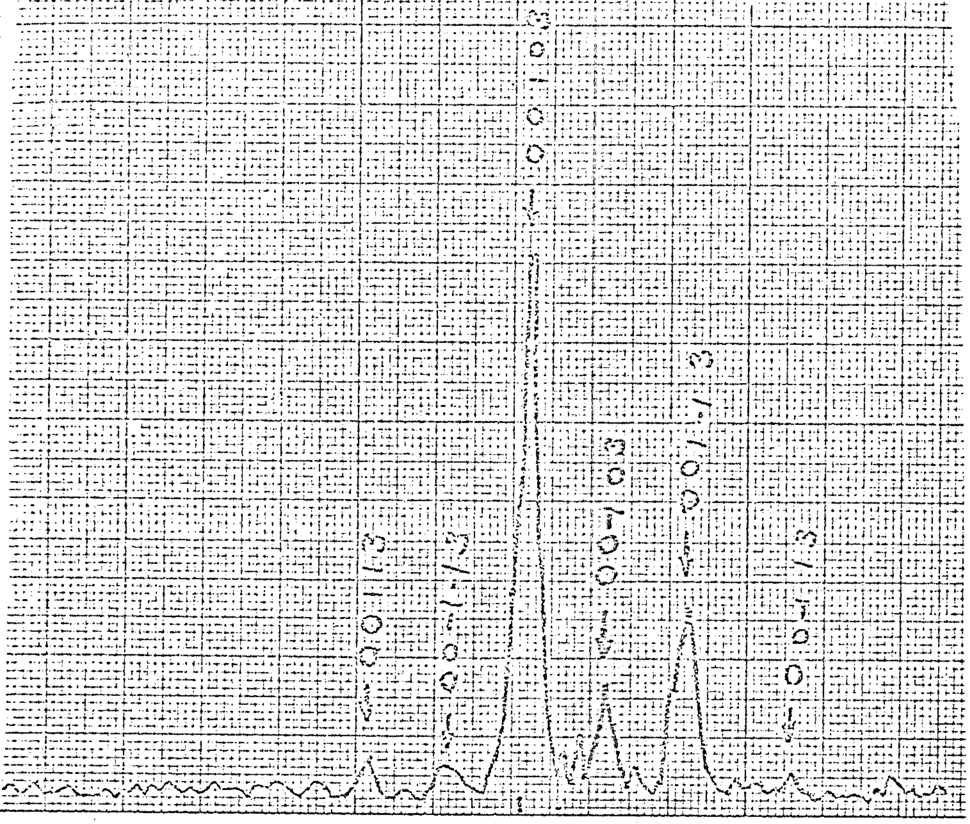
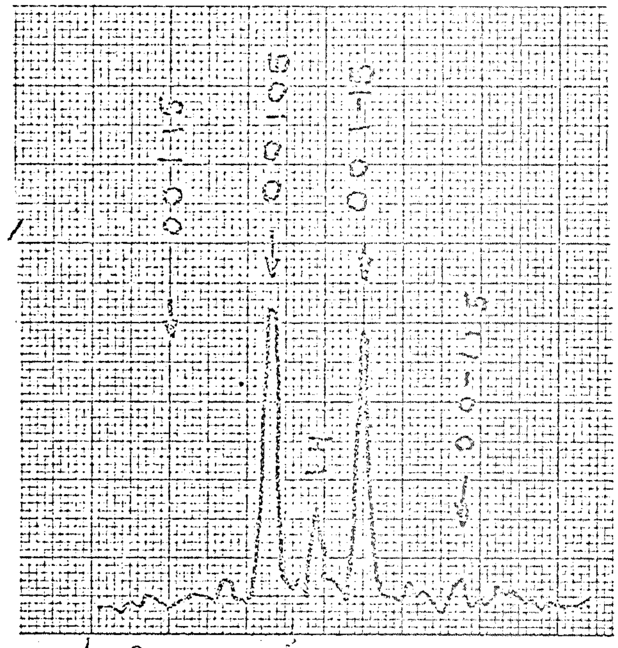
J2 Fig 1b

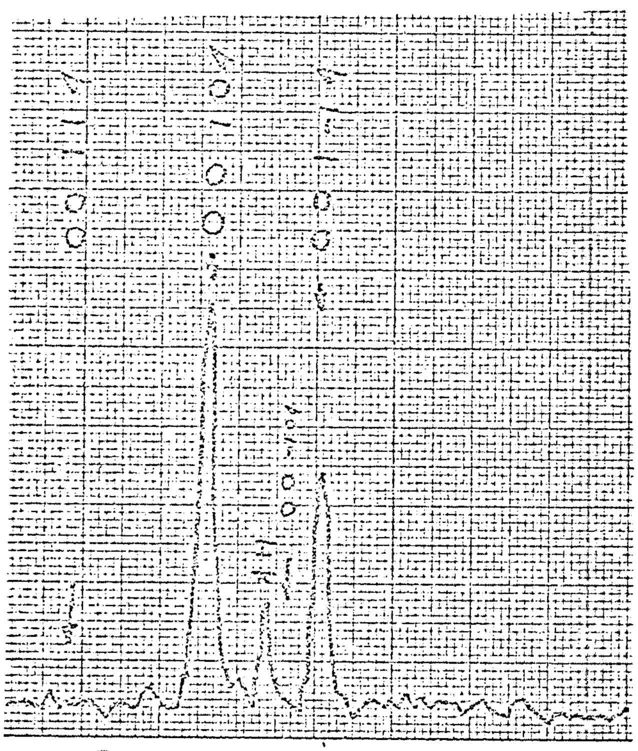


C J3

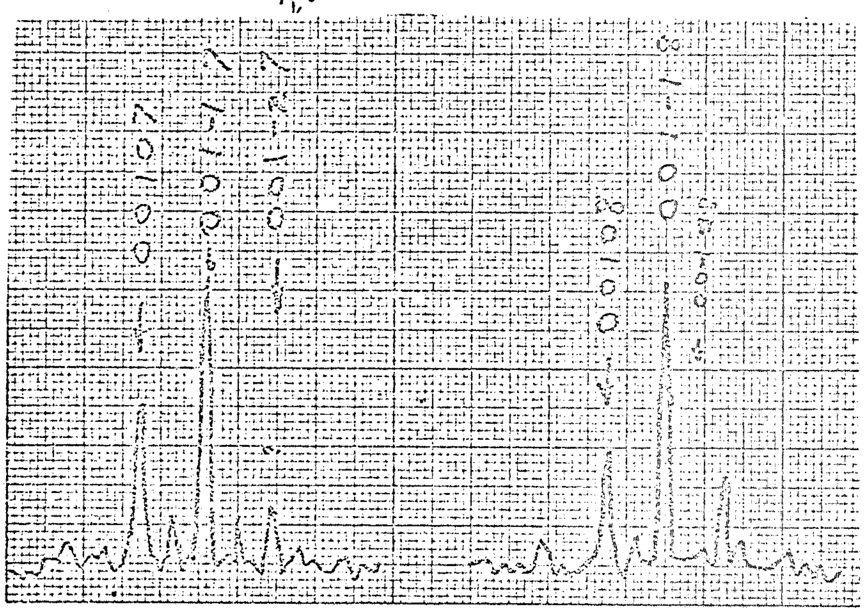


E J5

F J6



D J4



G J7 H J8

Fig 1 C-H

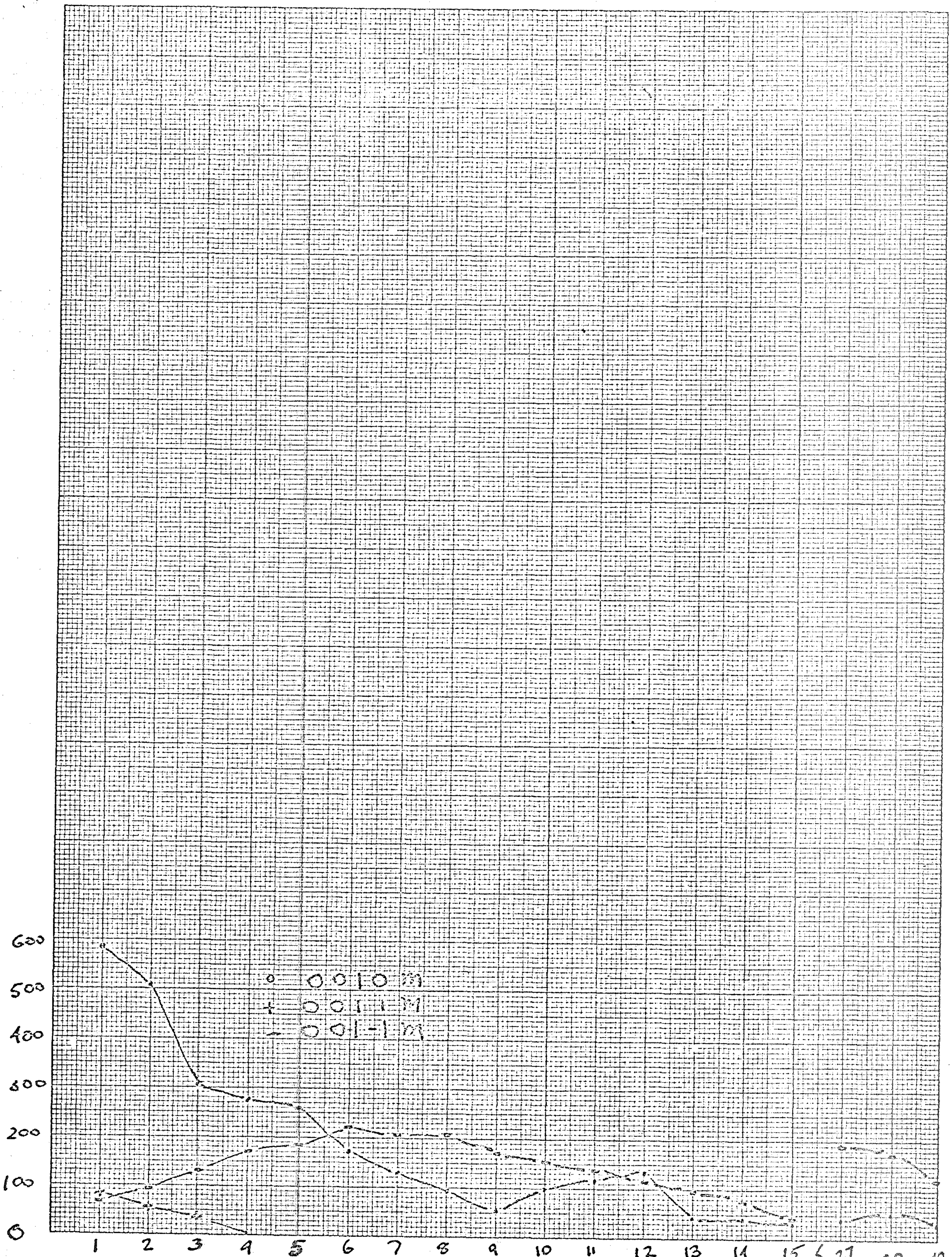

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Fig. 2.