INSTITUTE OF PLASMA PHYSICS

NAGOYA UNIVERSITY

OBSERVATION OF ELECTROSTATIC ENVELOPE SOLITONS IN A PLASMA

Tadao Honzawa

IPPJ-258 September 1976

RESEARCH REPORT

NAGOYA, JAPAN

Abstract

Observational results on electrostatic envelope solitons excited in a plasma are described. Pump frequency adopted here was comparable with the ion plasma frequency. Envelope solitons were observed to be formed in a group. The number of solitons per group was found to have a countable value up to 16 under a suitable condition. The number of solitons was also observed to be strongly dependent on such parameters as the pump and modulation frequencies, the amplitude of the applied rf voltage, plasma parameters and so on.

Recently a number of theoretical works have been reported on the formation of envelope solitons in collisionless plasmas.[1,2] Experimental studies on the interaction of a laser beam[3] or an rf field[4] with an inhomogeneous plasma have shown that electronic envelope solitons, where the pump frequency is comparable with the local electron plasma frequency, can be formed as a result of the trapping of laser light or rf field by plasma cavitons.[4] However, in so far as we know, no one has experimentally shown that ionic envelope solitons, where the pump frequency is comparable with the ion plasma frequency, can be formed in a plasma. In this paper we want to report our experimental study on the formation of such ionic envelope solitons. Here, many data on relations between the number of solitons per group and various parameters are presented.

Experiments were carried out with a double plasma device[5] at the Institute of Plasma Physics, Nagoya University, which consists of a chamber (50 cm dia. and 80 cm long) and an inner small chamber (40 cm dia. and 40 cm long), as shown in Fig.1. Since the "target" and "driver" plasmas were generated by two different power-supplies and separated by a negatively biased grid G, the two plasmas could be independently controlled. The target plasma used here was characterized as follows; electron temperature $T_e \simeq 0.7$ eV, ion temperature $T_i \simeq 0.2$ eV and plasma density $n_e \simeq 2 \times 10^8$ cm^{-3}. The space potential of the plasma was observed to be as low as - 15 V, though the chamber was grounded, whereas the static potential of the driver plasma before the application of rf voltage was nearly 0 V. So we could always observe an ion stream with a kinetic energy around 15 eV in the target plasma region, which seemed to play an important role in the formation of envelope solitons. For the excitation of envelope solitons an amplitude-modulated sinusoidal rf voltage with a maximum amplitude up to 13 V and a frequency from 500 to 900 kHz was applied to the driver plasma. The frequency of the modulation was in the range from 3 to 30 kHz. Detection of the excited waves was made from electron saturation current by the use of a Langmuir probe, which was axially movable. As the electron and ion plasma frequencies for the target plasma used here are estimated to be about 100 MHz and 0.5 MHz respectively, all the excited waves are thought to belong to ion waves rather than electron waves. Throughout this experiment argon gas was used at a pressure around 3×10^{-4} Torr. Under such a condition the mean free paths for ion-neutral collisions, which are most predominant, are estimated to be comparable with the size of the chamber.

Under a suitable condition an amplitude-modulated wave excited in the target plasma is possibly broken into some small packets because of the modulational instability,[1] and hence the shape of its envelope becomes like a train of beads. Observational results tell us that the breaking of the wave envelope always occurs in the vicinity of the position, at which the amplitude of the wave has a maximum value, and that the breaking takes place in the region close to the intermediate grid G ($x < 1$ cm). Some informations on the spatial evolution of the wave envelope excited in the target plasma can be obtained from such a picture as shown in Fig.2. We can see in this figure that initial small perturbations rapidly develop to envelope solitons with considerable amplitude during propagation. It is also noted that at a large distance the amplitudes of solitons gradually decrease because of some damping effects, for example, Landau damping. In Fig.2 the carrier wave signal is smoothed out, because all signals were displayed by synchronizing with the modulation wave. If we synchronize with the carrier wave, then photographs like Fig.3(b) can be easily obtained. Even if the amplitude of the applied rf field and the frequencies of the carrier and modulation waves are kept constant, the wave envelope changes its shape depending on the rate of modulation. Fig.4 shows that there is a threshold in the rate of modulation for the formation of envelope solitons.

The number of solitons per group was found to be determined by a way of the initial breaking due to the instability and to depend on the frequencies of both the carrier and modulation waves, the amplitude of the externally applied rf voltage, various plasma parameters and so on. If we select suitable parameters, many solitons , as shown in Fig.5, can be formed in a group. The observed relation between the soliton number and the frequency of the carrier wave for various values of the modulation frequency, when other parameters were kept constant, is demonstrated in Fig.6. From this figure we can say that a larger number of solitons are formed for a lower modulation frequency, and that for a fixed modulation frequency more solitons are obtained for a higher carrier frequency. Data were also obtained on the relation between the soliton number and the period of the modulation wave for a fixed value of the carrier wave, as shown in Fig.7. This figure indicates that the soliton number increases roughly in proportion to the period of the wave. By varying the amplitude of the externally applied rf voltage it was found that the relation between the soliton number and the carrier wave frequency for a fixed modulation frequency was affected by the amplitude change (see Fig.8). Moreover, we could observe that, even if the frequencies of both the carrier and modulation waves were kept constant, the soliton number could be changed by changing plasma parameters. Observation of the dependences of the soliton number on heater currents and discharge voltage in the target plasma region indicated that the soliton number was little affected by the changes of these quantities. On the other hand, the soliton number was found to depend on heater currents and discharge voltage in the driver plasma region and the potential of the intermediate grid (see Fig.9). All the quantities described in the latter case are the ones exerting an important effect upon the characters of the ion stream injected from the driver to the target. Therefore it is expected from the above results that the ion stream plays an important role in the formation of envelope solitons and the determination of the soliton number. On the other hand, the propagating velocity of an envelope soliton (equal to the group velocity) could be measured to be as high as 1×10^6 cm/s by means of the time-of-flight method. This velocity is comparable with those of streaming ions observed in the target plasma. This fact also makes us imagine that the existence of an ion stream is probably necessary for the formation of envelope solitons observed in this experiment.

The author wishes to thank Prof. K. Matsuura, Prof. Y. Kato and Dr. N. Asano for valuable discussions. He is also grateful to Dr. M. Inutake for helps in the performance of this experiment.

This work was carried out under the collaborating research program at the Institute of Plasma Physics, Nagoya University, Nagoya.

References

1. V.I.Karpman and E.M.Krushkal', Zh. Eksp. Teor. Fiz. 55, 530 (1968) (Sov. Phys. JETP, 28, 277 (1969))
2. T.Taniuti and N.Yajima, J. Math. Phys. 10, 1369 (1969) There are many other papers.
3. B.H.Ripin, J.M.McMahon, E.A.McLean, W.M.Manheimer and J.A.Stamper, Phys. Rev. Lett. 33, 634 (1974); L.M.Goldman, J.Soures and M.J.Lubin, Phys. Rev. Lett. 31, 1184 (1973). This is only a partial list.
4. H.C.Kim, R.L.Stenzel and A.Y.Wong, Phys. Rev. Lett. 33, 886 (1974); H.Ikezi, K.Nishikawa and K.Mima, J. Phys. Soc. Japan 37, 766 (1974)
5. R.J.Taylor, K.R.MacKenzie and H.Ikezi, Rev. Sci. Instrum. 43, 1675 (1972)

Figure Captions

Fig.1. Schematic picture of apparatus.

Fig.2. Spatial evolution of the wave envelope during propagation. Here x is the distance from grid to probe.

Fig.3. (a) Wave envelope. (b) Amplitude-modulated carrier wave. This was taken under the same condition as the case (a).

Fig.4. Dependence of the shape of the wave envelope on the modulation rate. Here the amplitude of the applied rf voltage and the frequencies of the pump and modulation are kept constant.

Fig.5. Examples of sequences of many solitons.

Fig.6. Relation between the soliton number and the frequency of the carrier wave for various values of the modulation frequency.

Fig.7. Relation between the soliton number and the period of the modulation wave for a carrier frequency.

Fig.8. Effect of the amplitude change of the rf voltage on the relation between the soliton number and the carrier wave frequency.

Fig.9. Dependence of the soliton number on the potential of the intermediate grid.

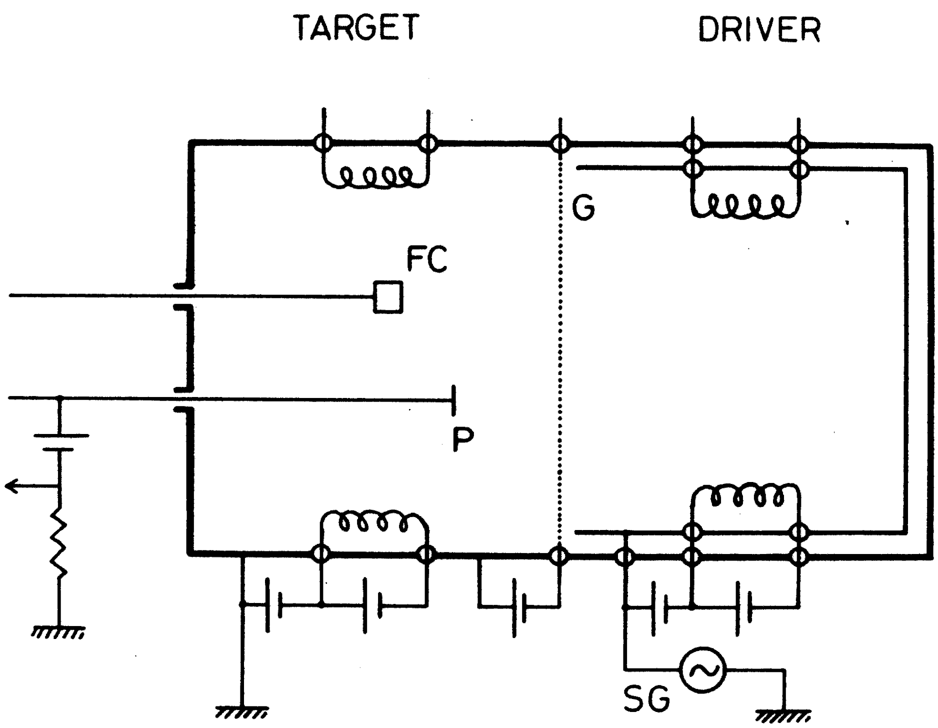


Fig. 1

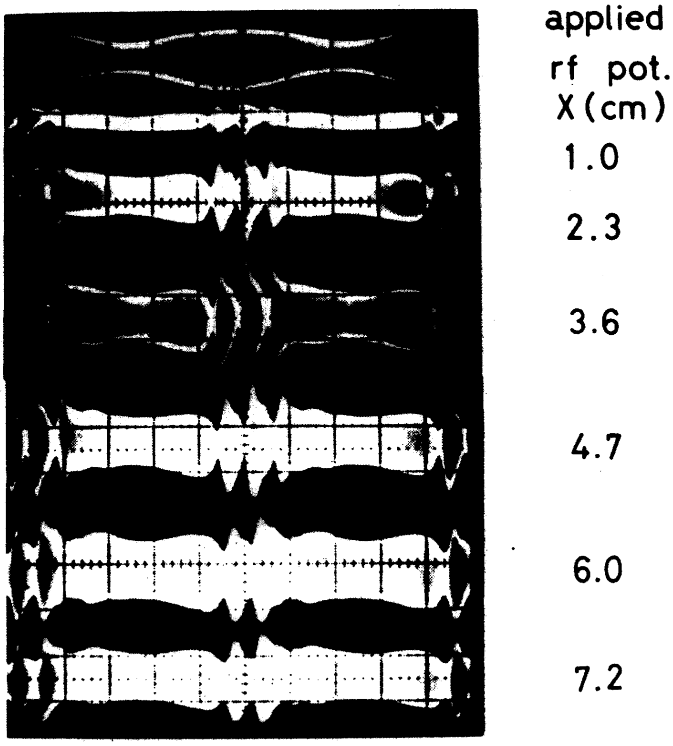


Fig. 2

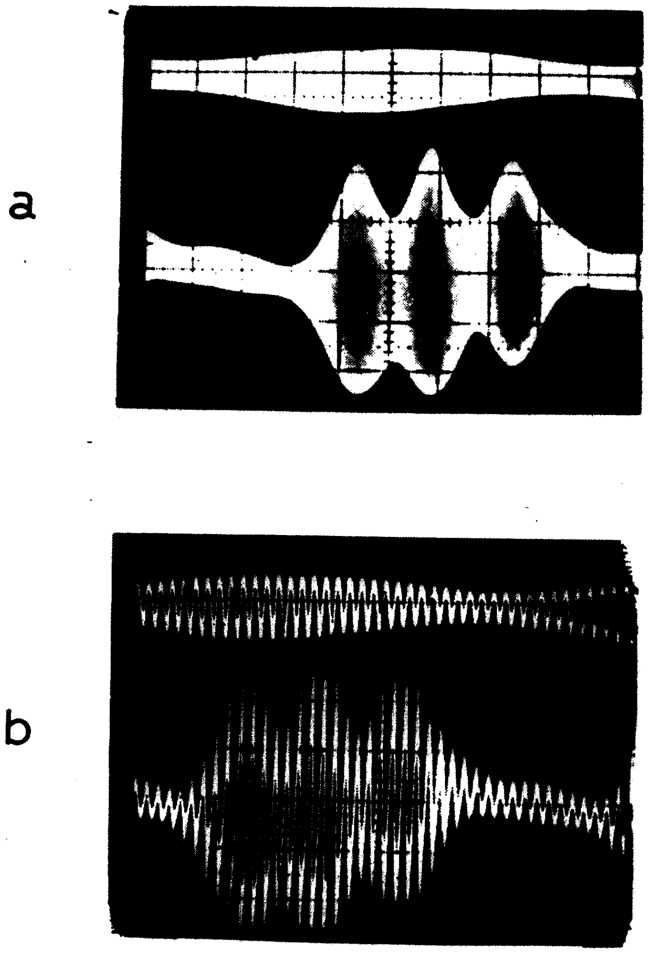


Fig. 3

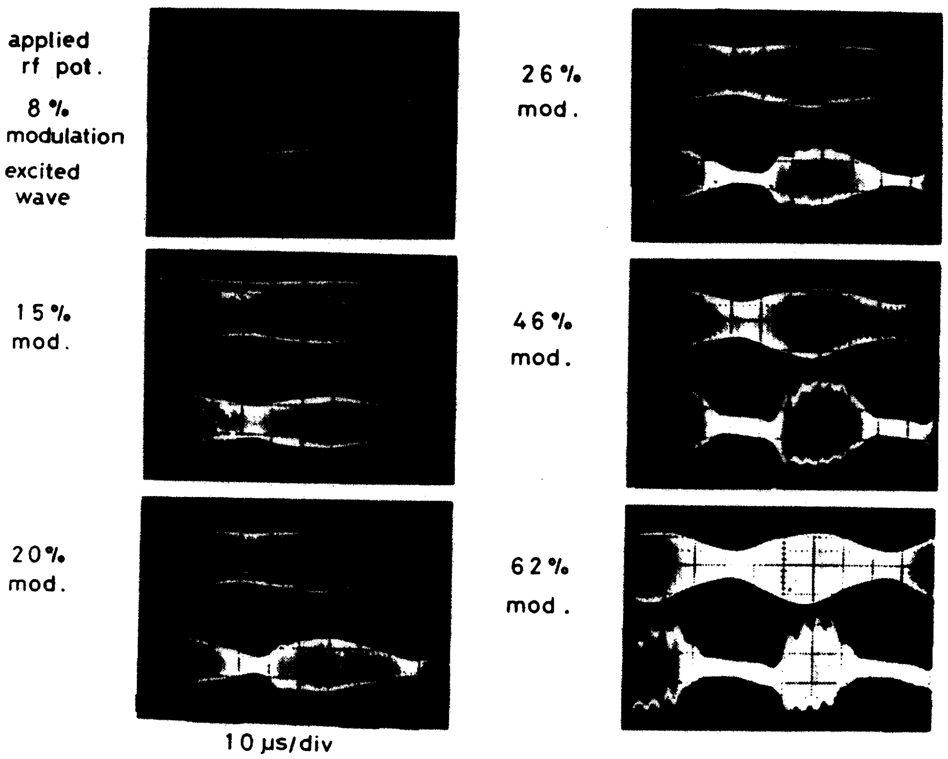

applied
rf pot.
8 %
modulation
excited
wave
15 %
mod.
20 %
mod.
10 µs/div
26 %
mod.
46 %
mod.
62 %
mod.

Fig. 4

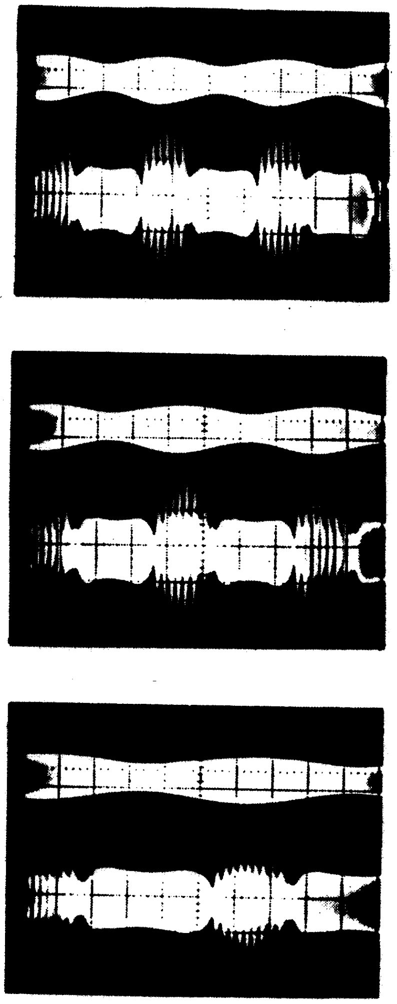
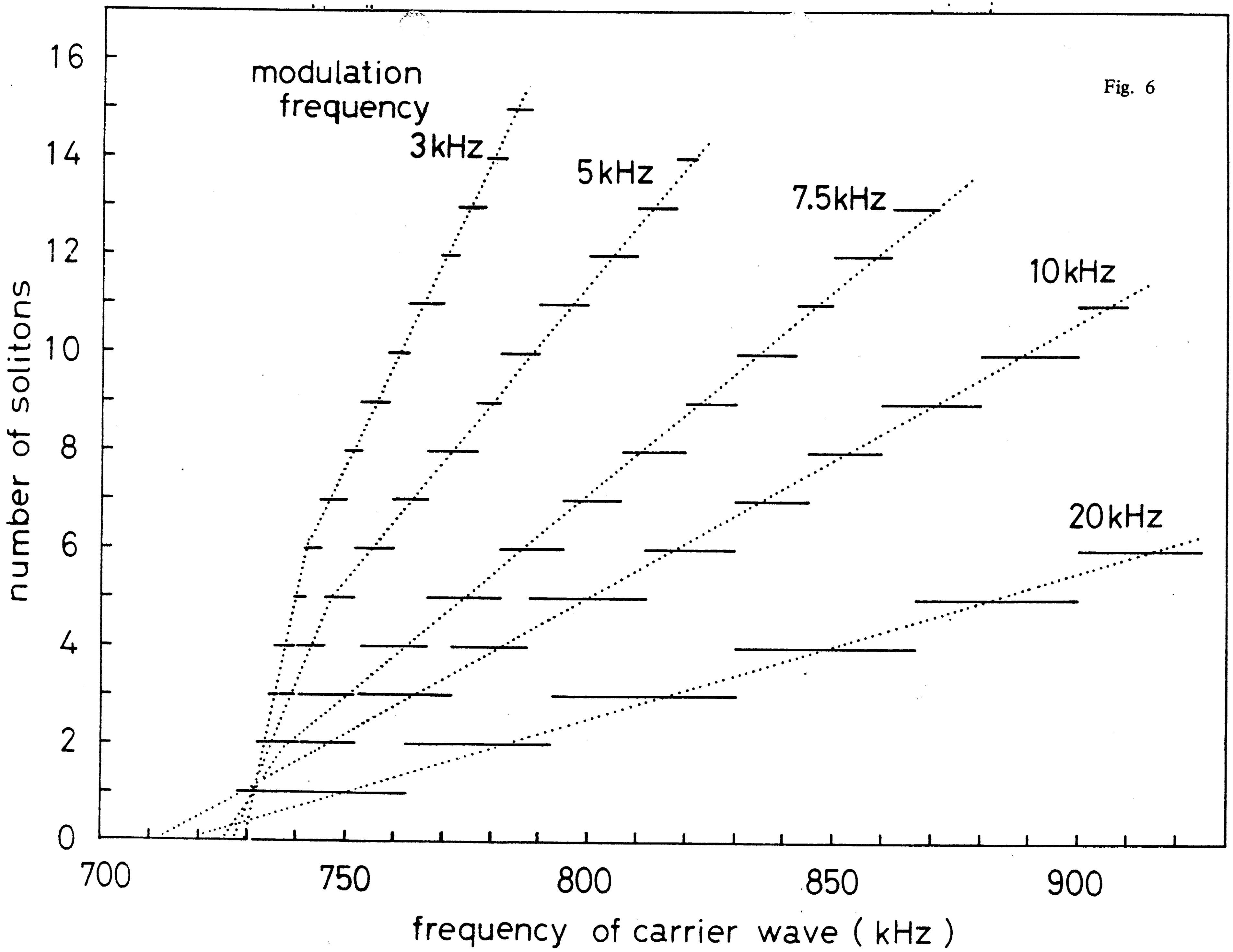


Fig 5

Fig. 6


modulation frequency
3kHz
5kHz
7.5kHz
10kHz
20kHz
number of solitons
0
2
4
6
8
10
12
14
16
700
750
800
850
900
frequency of carrier wave (kHz)

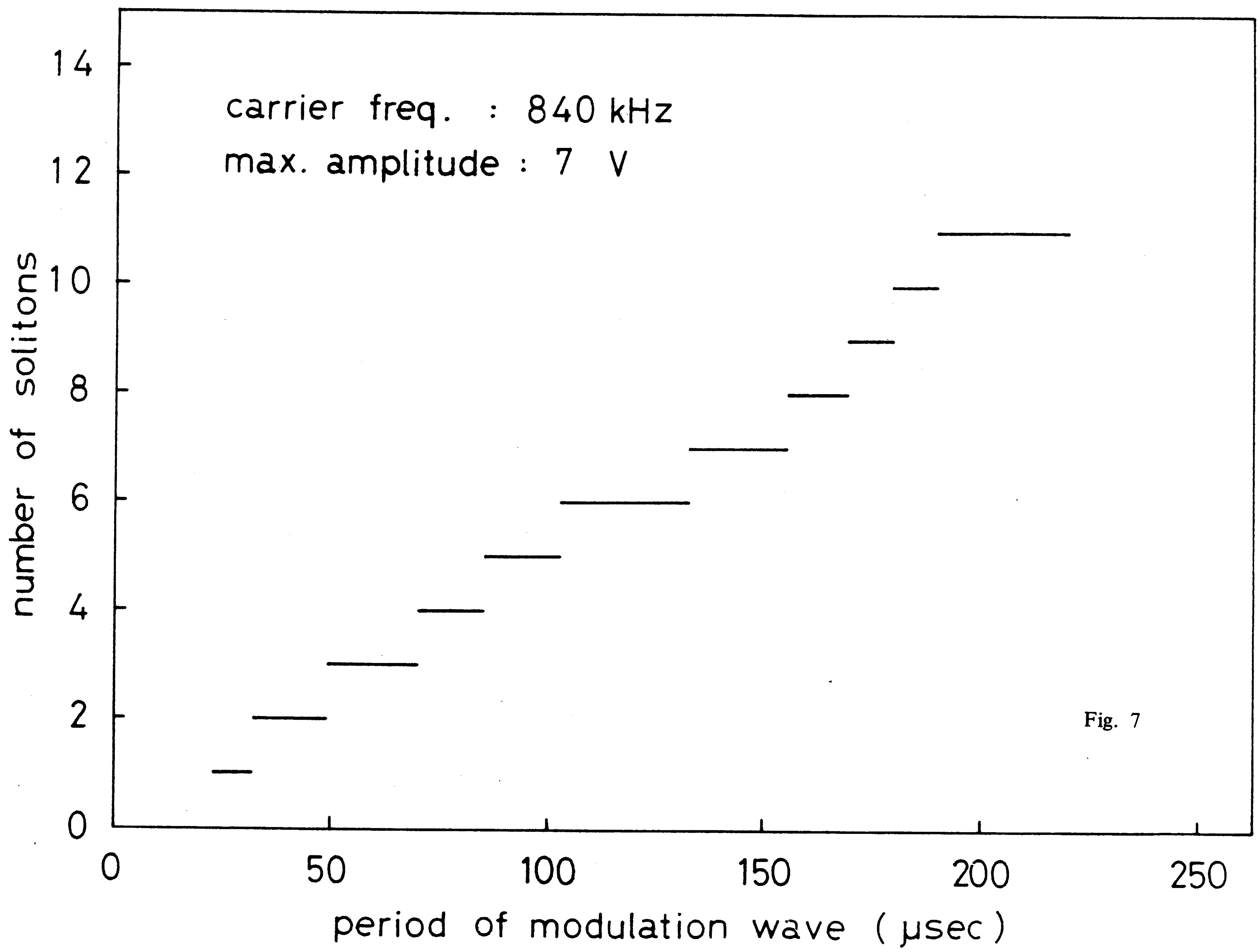
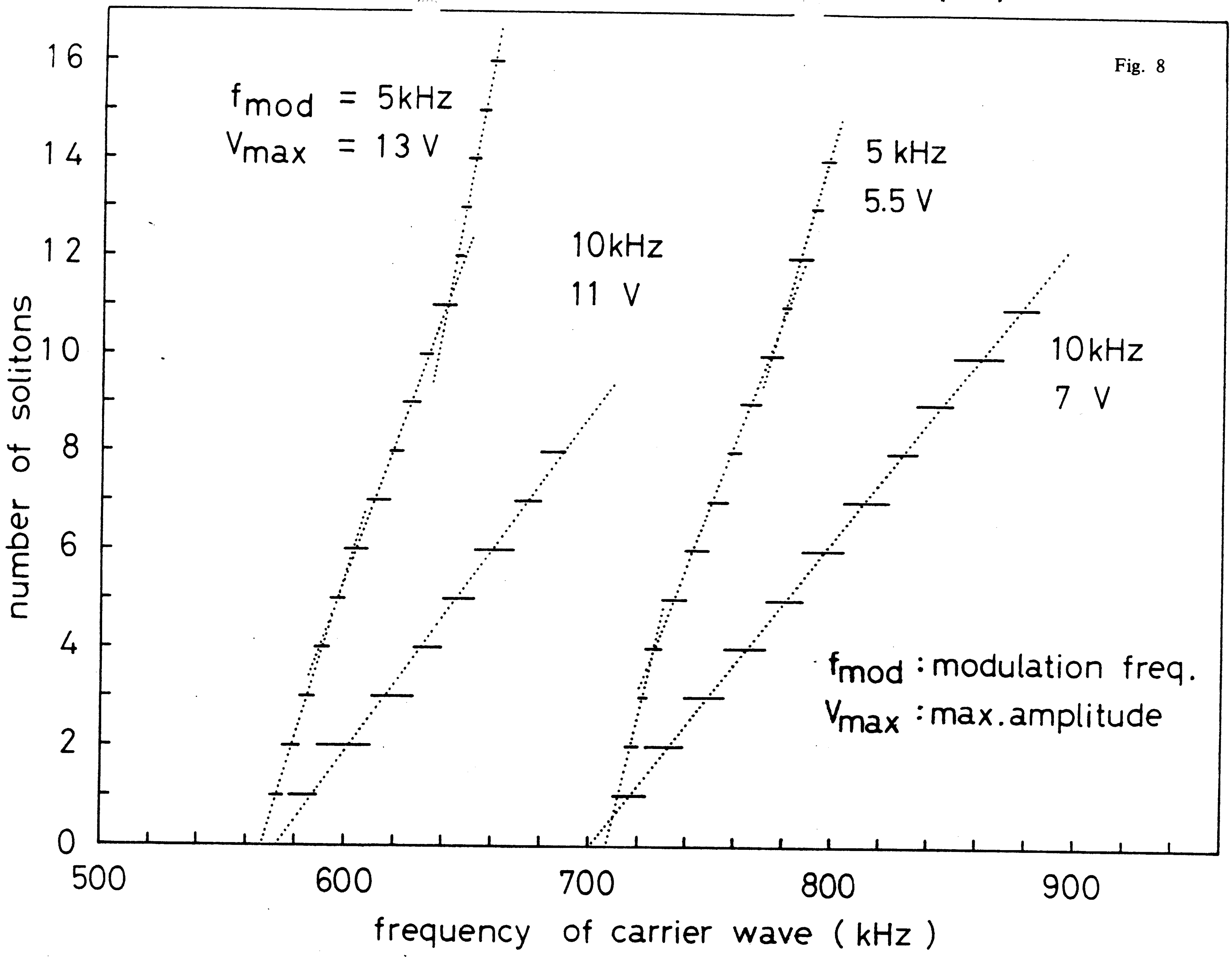

carrier freq. : 840 kHz
max. amplitude : 7 V
number of solitons
0
2
4
6
8
10
12
14
0
50
100
150
200
250
period of modulation wave (μsec)

Fig. 7

Fig. 8



fmod = 5kHz
Vmax = 13 V
10kHz
11 V
5 kHz
5.5 V
10kHz
7 V
fmod : modulation freq.
Vmax : max. amplitude
number of solitons
frequency of carrier wave (kHz)
0
2
4
6
8
10
12
14
16
500
600
700
800
900

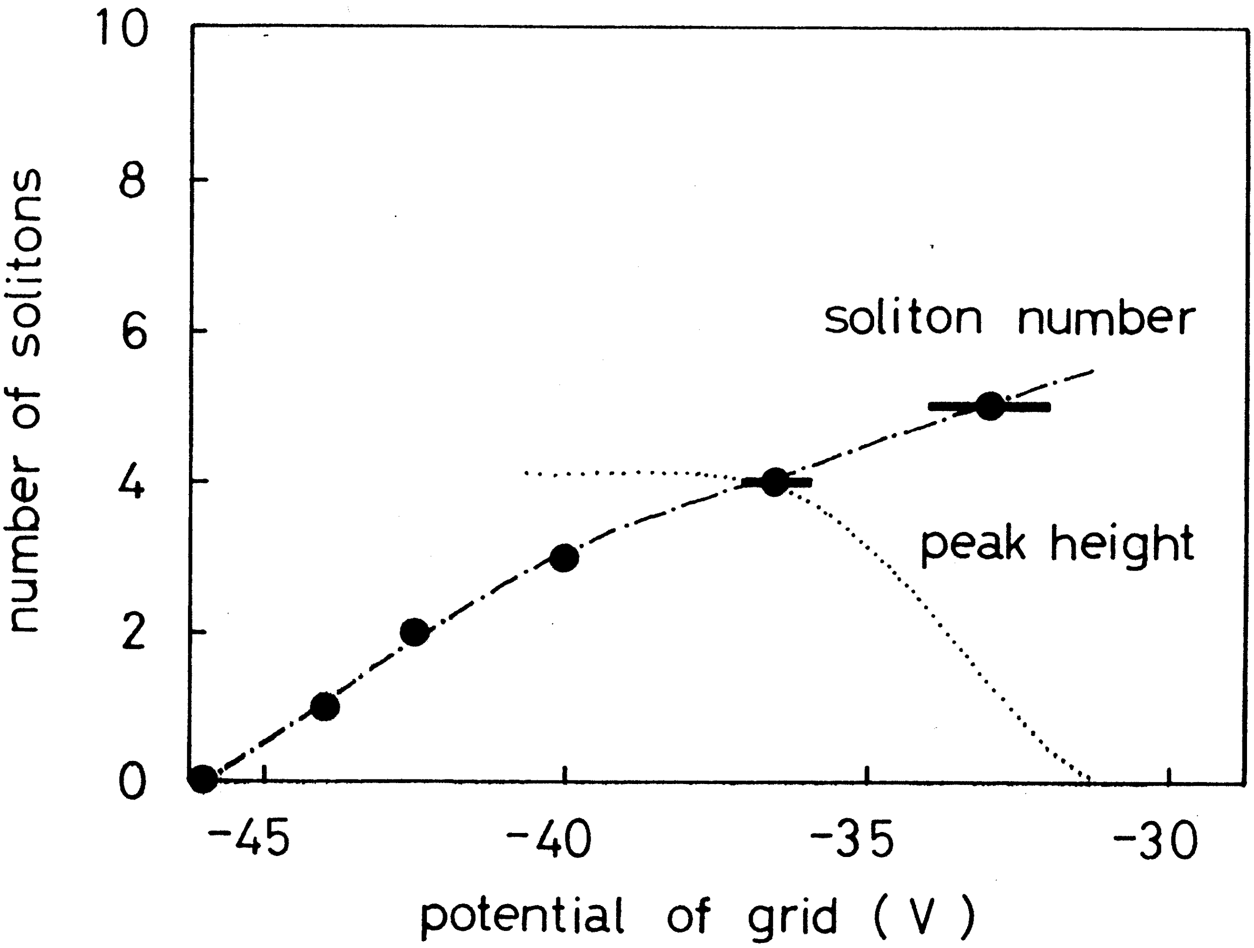

10
8
6
4
2
0
number of solitons
soliton number
peak height
-45
-40
-35
-30
potential of grid (V)

Fig. 9

OBSERVATION OF ELECTROSTATIC ENVELOPE SOLITONS IN A PLASMA

Tadao Honzawa

IPPJ-258 September 1976

Further communication about this report is to be sent to the Research Information Center, Institute of Plasma Physics, Nagoya University, Nagoya 464, Japan.

Permanent address : Department of Electronic Engineering, Utsunomiya University, Utsunomiya, Japan.