SPACE RESEARCH INSTITUTE

Academy of Sciences, USSR

Д-222

K.I.Gringauz, N.M.Shutte

ENERGY SPECTRA OF ELECTRONS WITH ENERGIES 3 KEV PROBABLY ACCELERATED IN INTERACTION OF THE INJECTED ELECTRON BEAM WITH THE IONOSPHERIC PLASMA IN ARAKS EXPERIMENT

Moscow

INSTITUTE FOR SPACE RESEARCH
ACADEMY OF SCIENCES OF THE USSR

Д-222

K.I.Gringauz, N.M.Shutte

ENERGY SPECTRA OF ELECTRONS WITH ENERGIES 3 KEV PROBABLY ACCELERATED IN INTERACTION OF THE INJECTED ELECTRON BEAM WITH THE IONOSPHERIC PLASMA IN ARAKS EXPERIMENT

1976

Introduction

During the preparation of the measurements of the rocket electric potential relative to the environment within the Araks experiment program (carried out under the leadership of R.Z.Sagdeev, I.A.Zhulin and F.Cambu) [1] the authors had known the data of rocket experiments with electron accelerators, made by Hess et al. [2] and Winckler et.al. [3, 4] . The rocket potentials in these experiments were defined by means of electron retarding potential analysers up to 2 kev [2] , and up to 8 kev [3, 4] .

The detailed data of the retarding potential analizers experimental results has not been published; a very brief information on these data was given in [2 - 4] .

In [2-4] there was no information on registration of electrons with energies $E > e\Phi$ (where Φ is rocket potential relative to surrounding media) by means of retarding potentials analizers during electron accelerators operation. However , in the paper [5] published in 1975 after the carring out of the Araks experiment it's noted that in the Echo-1 experiment electrons with the wide energy spectrum from energies more than $e\Phi$ have been recorded during injection using the electrostatic analyzers and solid-state detector. The aim of this report is to present and to consider the results of the registration of electrons with energy $E > e\Phi$ by the analyzer with retarding potentials obtained during the Araks experiment on 26.I.1975. The experimental data given below refers to the descending part of the rocket trajectory where the electron accelerator operated quite stable.

2. Measurement results

During the injection of long electron beam pulses along the rocket axis with energies $E_1 \sim 15$ kev and $E_2 \sim 27$ kev the wide-angle analyzers of electrons with retarding potentials $V_R \lesssim 3$ kev recorded integral energy electron spectra with energies $E > e\Phi$; such electrons were not recorded within the intervals between the pulses of the injection currents.

Fig. 1 shows the samples of the retardation curves (dependencies of the electron analyzer collector current on retarding voltage) obtained during the injection current pulses with the duration $\tau = 2.56$ sec and $\alpha_{iy} = 0°$. The retarding curves at the Fig. 1a top side correspond to the injection energy $E_2 \sim 27$ kev when the plasma generator is switched on (vertical arrows directed downwards indicate the moments when the electron injection began or stopped in the middle of the retarding voltage cycle). The other curves of Fig.1 correspond to the injection energy $E_1 \sim 15$ kev when the plasma generator is switched on (1a-1b) and off (1c-1d).

It is seen from Fig.1 that the injected electron energy change practically does not influence the recorded spectra shape. If the recorded electron fluxes are time-independent the retardation curves cannot have maxima and minima for any shape of their differential energy spectrum. It means that the extremumpoints on the retardation curves indicate to time fluctuations of the recorded fluxes. In this case both spectra and these fluctuations are evidently not associated with the rocket rotation (the period of which was 0.5 sec). It can be noted that the recorded electron flux fluctuations are higher for the plasma generator switched off than on. It's also seen from Fig.1 that when the rocket flight altitude becomes lower than ~ 160 km with the further lowering of h, the retardation curves essentially vary and the recorded electron fluxes with $E \sim 1000$ to 3000 v begin decreasing and when $h < 125$ km they practically disappear. In this case at ~ 140 to 125 km the essential time variations are observed: during one retarding voltage cycle the electron fluxes with energies 2 to 3 kev appear and disappear (see Fig.1c and 1d).

Fig. 2a shows the altitude dependences of collector currents corresponding to the various values of the retarding potentials V_R. Here the time fluctuations of the retardation curves (see Fig.1) were averaged, and each point plotted is averaged over the four retardation curves corresponding to one long pulse of beam current; the point height refers to time of the middle of this pulse

Fig.2b (obtained as a result of processing the data of Fig.2a) shows the altitude dependences of the averaged electron fluxes on one cm^2 of the analyzer apperture within the different energy ranges presented on the figure. It is seen from Fig.2b that at h $\gtrsim$ 160 km the fluxes in all energy ranges do not practically change with altitude and from h $\sim$160 km and below the fluxes in these ranges begin to decrease sharply and at $\sim$ 125 km they disappear.

Fig.3 gives the differential energy spectra of recorded electrons with energies $E > e\varphi$. In Fig.3a the spectra are plotted based on the data of the two retardation curves, for which the time fluctuations of electron fluxes were insignificant. One of them relates to h $\sim$180 km, the other – to h $\sim$165km (values of h refer to the moments of the start of the given retardation curve measurements).

Fig.3b shows the averaged differential energy spectrum of electrons with $E > e\varphi$ plotted by the data of ten retardation curves measured within 180 to 160 km. In this case the time fluctuations of the single characteristics were averaged automatically.

The comparison of Fig.3a and 3b shows that the main peculiarities of the single differential energy spectra referred to the altitudes given in Fig.3a are typical.

3. Discussion

The absence of the recordings of electrons with energies $E > e\varphi$ in the pauses between the injected electron pulses at all altitudes of the Eridan rocket flight indicates to the fact that their appearance is associated with the injector operation. Since the energies of these electrons $E \lesssim 3$ kev it is clear that they are not the electrons injected by the accelerator with energies either ~ 15 kev or ~ 27 kev.

As it was noted earlier the data [5] on the recordings during the injection pulses in Echo-experiments of electrons with the continuous energy spectrum from zero to injection energy were published after the Araks experiment fulfilment. In the cases of electron injection under 90° angle to the rocket axis the location of detectors and injector allowed the authors of [5] to suggest that the observed electrons are caused by multiple scattering of injected electrons from the rocket body in the process of their Larmor rotation. The possibility to explain the effects observed in these cases by the atmosphere scattering at the rocket flight altitudes is rejected in [5] since with the altitude increasing from 100 to 300 km the atmosphere density varied by 10^4 times and the electron fluxes observed – by 10 times only(it should be noted that such a decreasing with altitude of electron fluxes scattered from the rocket also needs, from our point of view, an additional explanation). The observed fluxes intensity was also sufficiently higher than the value defined by the possible Coulomb scattering [6].

The authors of [5] note that with the injection of electron pulses upwards along the rocket axis (as in the measurements on-board the Eridan rocket described above in Sec.2) it is impossible to explain the observation data by scattering from the rocket; and in this case it can be explained by instabilities occuring in interaction of the injected electron beam with the surrounding plasma [7] .

We think that the data given in the previous section of this paper give an evidence in favor of suggection that the electrons with energies $E > e\varphi$ recorded during the Araks experiment on 26.1.1975 really occur as a result of interaction of the injected electron beam with the ionospheric plasma. These electrons undoubtedly are not scaterred from the atmosphere or the ionospheric plasma because as it is seen from Fig.2 the electron fluxes with all registered energies sufficiently decrease with the altitude lowering (achieving at $h \lesssim 120$ km the values less than the instrument sensitivity threshold) whereas the neutral atmosphere density considerably increases with decreasing the altitude and the ionospheric plasma concentration during the flight on 26.1.1975 at 90 to 200 km varied slightly. Fig.4 shows the altitudinal distribution of the neutral atmosphere density over Kergelen taking into account the season and diurnal time according to the 1966 USA Standard atmosphere model, n_e electron concentration following the measurement data of the ionospheric station on Kergelen on 26.1.1975, n_e*) using the wave measurement data on the nose cone separated from the Eridan rocket and plasma frequency based on the same data.

It is also obvious that the observed height dependence of electron fluxes, $e\varphi < E < 3$ kev cannot be explained by the

---

*) the ionospheric plasma characteristics according to the wave measurement data are kindly presented by Dr.Lavergnat

scattering from the rocket body. In our opinion, the fact that energy spectra of recorded electrons do not change their shape when the injection energy changes from 27 kev down to 15 kev (see Fig.1a) does not confirm the assumption that the neutral atmosphere is strongly ionized by the injected beam at heights of $\gtrsim 130$ km. We suppose that electron acceleration in the process of beam instability development during interaction of beam with ionosphere plasma can serve as a source of electron fluxes under discussion.

The spectra shape independence on height in the range $\sim 155 - \sim 140$ km with the plasma generator ~~is~~ switched off can be related to the fact that plasma frecuency ω_p (fig.4) at this heights is practically constant. It means that under unvariable conditions of the injection that take place when $\alpha_{inj} = 0$, the conditions for the instability development and, accordingly, their influence on the ionospheric plasma remain constant. The decreasing of energies and fluxes of these accelerated electrons as the rocket gets the region of lower altitudes can be associated with the influence of the increasing frequency of collision with neutrals.

Since the character and the degree of the development of the beam instability depends greatly on the beam current value and the efficiency of the statistic accelerating of particles depends on such parameters as the type of excited waves the frequency of plasma waves and their energy density, it can be hoped that the obtained differential spectra of the observed electrons, on the one hand, and the wave measurement results carried out during the Araks experiment, on the other hand, will be useful for identification of the processes which resulted in their occurence.

4. Conclusion

1. The wide-angle electron analyzers with retarding potentials installed on board the Eridan rocket for measuring the potential Φ of the body during the accelerator operation recorded electron fluxes from the environment with energies $e\Phi < E < 3$ kev. Within the pauses between the injection current pulses such fluxes were not observed.

2. The recorded electron fluxes with energies $E > e\Phi$ beginning with $h \sim 160$ km decreased as the altitude lowered; near $h \lesssim 120$ km they dropped to the value lower than the instrument sensitivity threshold.

3. The observed spectra character practically did not vary with the injected electron energy variation from 27 kev to 15 kev.

4. After the plasma generator was switched off the observed flux time fluctuations increased.

5. The altitudinal dependence of these electron fluxes does not allow their origin to be explained by the atmospheric scattering, the Coulomb scattering or by the multiple scattering from the rocket body during Larmor rotation of injected particles.

6. Probably, the occurrence of the observed electron fluxes with energies $E > e\Phi$ is caused by the acceleration

of electrons of the ionosphere plasma by the electromagnetic and electrostatic waves which occured as a result of the beam instability development in process of interaction of the electron beam injected from the rocket with the ionospheric plasma. The particle concentration in the recorded electron fluxes energy range is $(10^{-6}$ to $10^{-7})$ n_e, where n_e is the electron concentration in the ionosphere surrounding the rocket.

References

1. K.I.Gringauz, N.M.Shutte. Altitude changes of the electrical potential of the "Eridan" rocket during Araks experiment, Preprint Space Res.Inst., 1976.
2. W.N.Hess, M.C.Trichel, T.N.Davis, W.C.Beggs, G.H.Kraft, E.Stassinopoulos, E.J.R.Maier. J.Geophys.Res., 76, 6067, 1971.
3. J.Winckler. Space Sci.Rev., 15, 751, 1974.
4. J.Winckler. J.Geophys.Res., 40, 729, 1974.
5. J.R.Winckler, R.L.Arnoldy, R.A.Hendrickson, J.Geophys. Res., 80, 2083, 1975.
6. C.Israelson, J.R.Winckler. J.Geophys.Res., 80, 3709, 1975.
7. D.C.Cartwright, P.J.Kellogg. J.Geophys.Res., 79, 1439, 1974.

Figure captions

Fig.1. Energy spectra of electrons with $e\phi < E < 3$ kv, during the electron beam injection for $\alpha_{inj} = 0°$ and $\tau_{inj} = 2{,}56$ sec.

Fig.2. The altitude dependences of electron fluxes with $E \sim 1 \div 3$ kv.

Fig.3. The differential energy spectra for the altitu des $\sim 160 - 180$ km.

Fig.4. The altitude dependences of the fundamental ionospheric parameters (n_e , ω_p , ρ) during Eridan rocket flight I.26.1975.

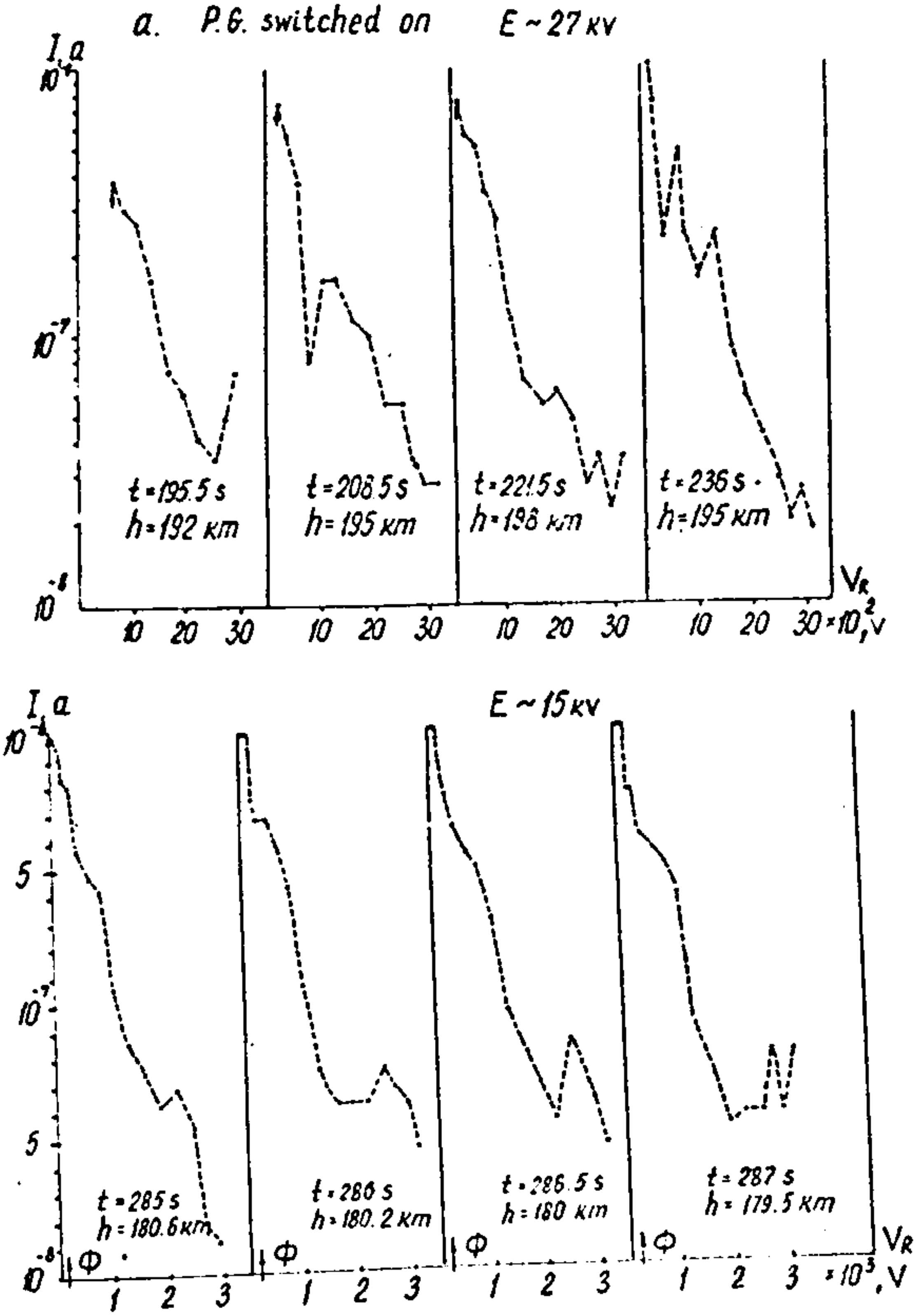
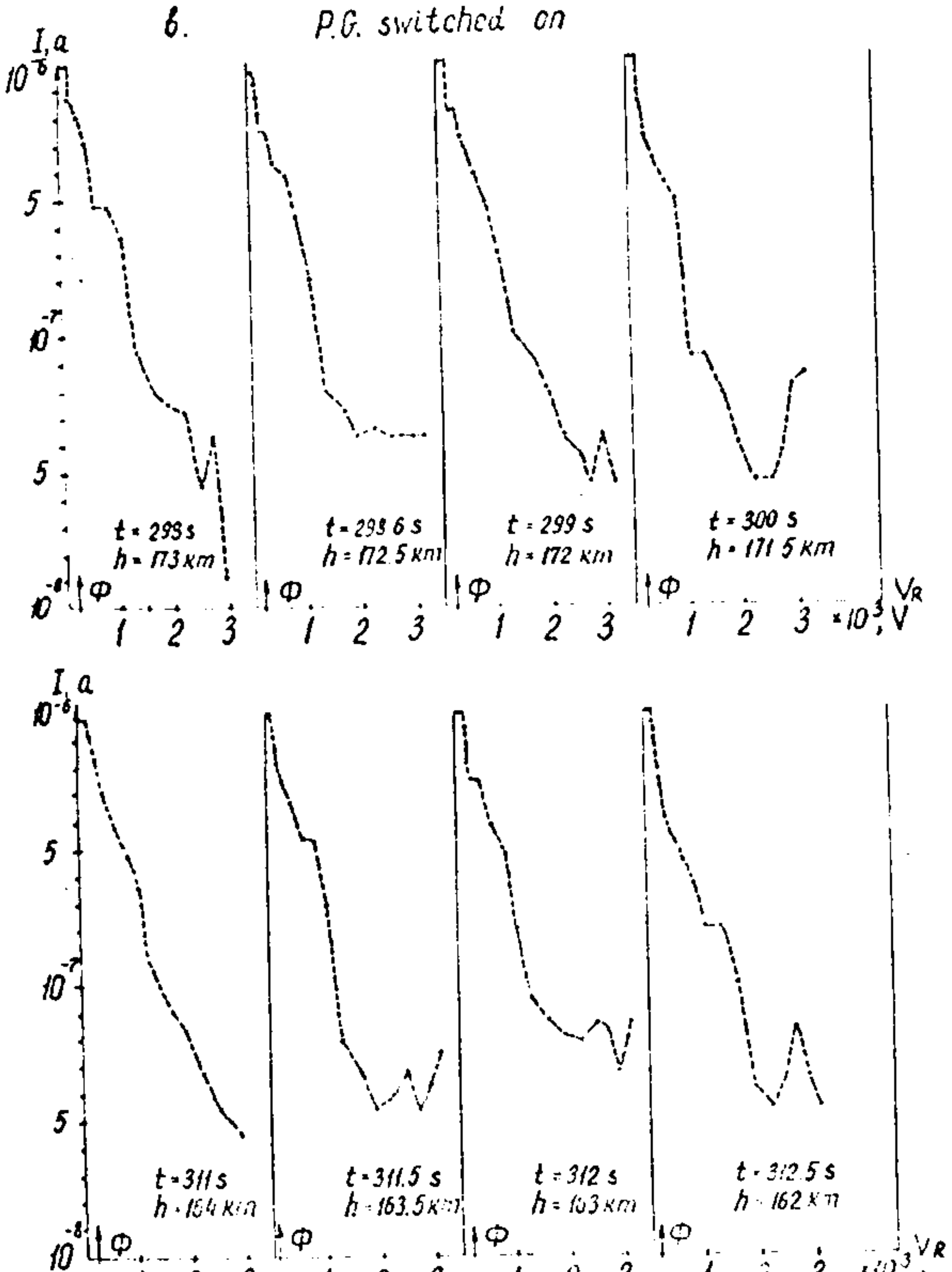

a. P.G. switched on E ~ 27 kV
I, a
10^{-6}
10^{-7}
10^{-8}
t = 195.5 s
h = 192 km
t = 208.5 s
h = 195 km
t = 221.5 s
h = 198 km
t = 236 s
h = 195 km
10 20 30
V_R
$\times 10^2$, V
E ~ 15 kV
I, a
10^{-6}
5
10^{-7}
5
10^{-8}
Φ
t = 285 s
h = 180.6 km
t = 286 s
h = 180.2 km
t = 286.5 s
h = 180 km
t = 287 s
h = 179.5 km
1 2 3
V_R
$\times 10^3$, V

Fig. 1a



б. P.G. switched on

Fig. 1б.

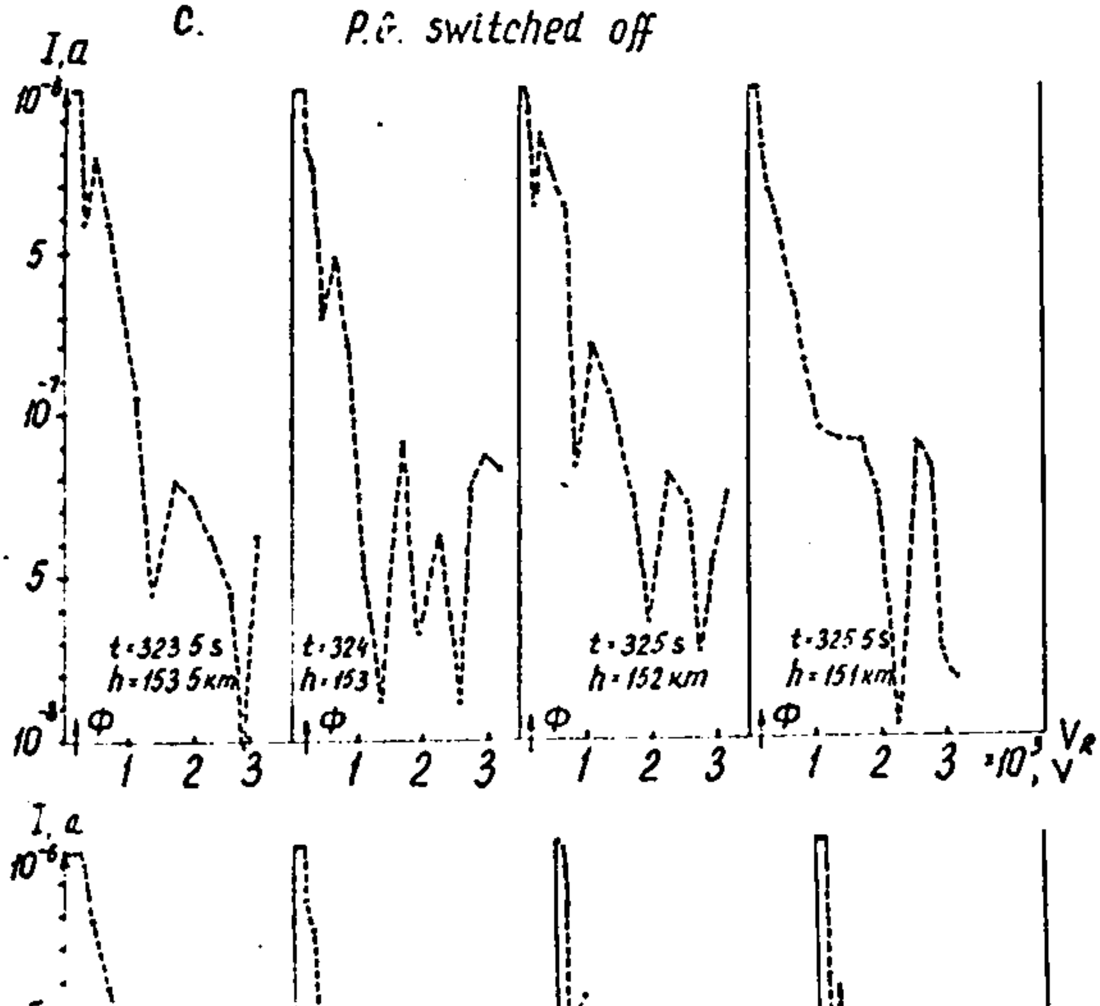

c.
P.G. switched off
I, a
10^-6
5
10^-7
5
10^-8
Φ
1
2
3
×10^3, V
V_R
t = 323.5 s
h = 153.5 km
t = 324
h = 153
t = 325 s
h = 152 km
t = 325.5 s
h = 151 km
t = 336.5 s
h = 143.5 km
t = 337 s
h = 142.5 km
t = 337.5 s
h = 142 km
t = 338 s
h = 141 km

Fig. 1c

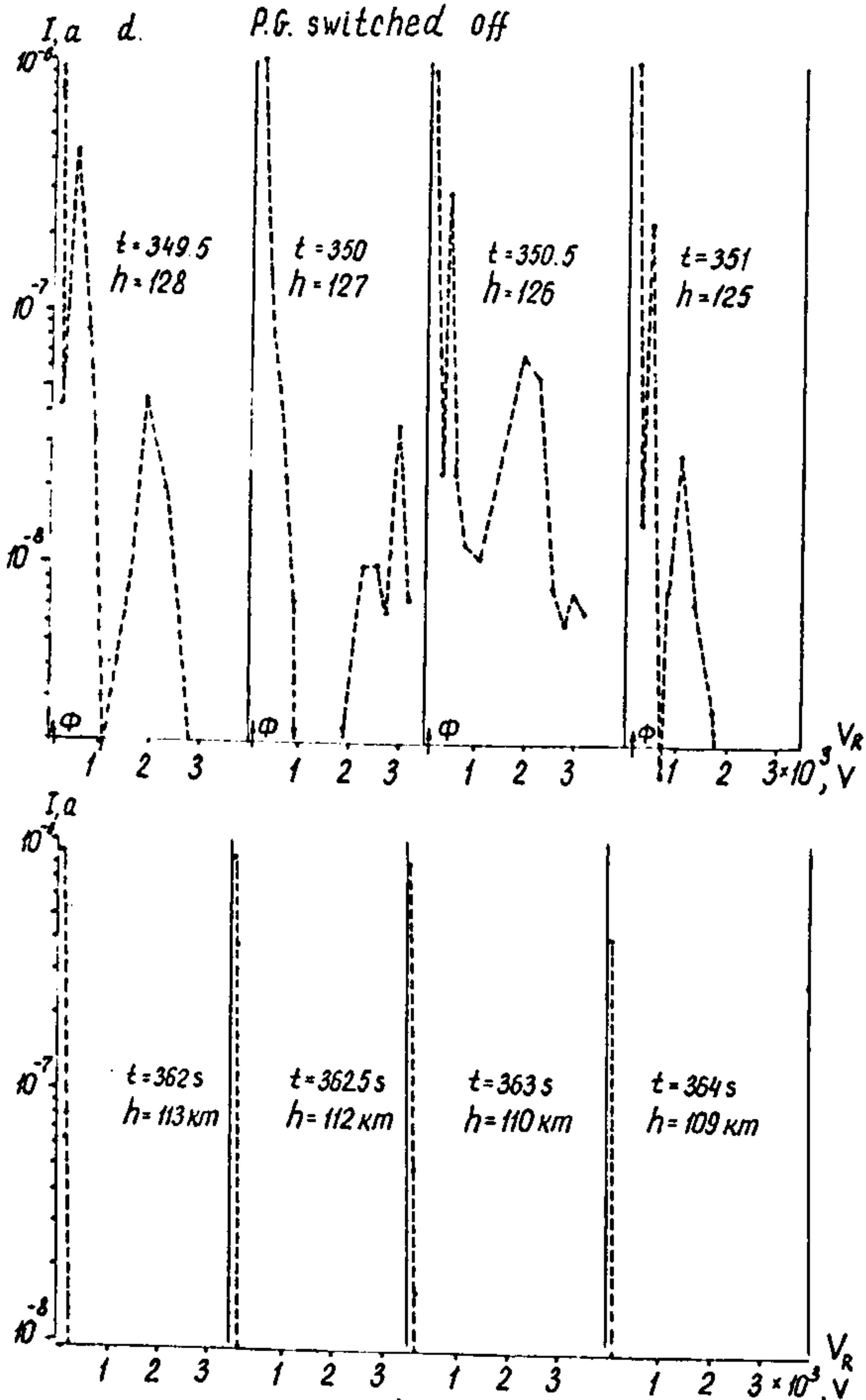

I, a
d.
P.G. switched off
10⁻⁶
10⁻⁷
10⁻⁸
Φ
t = 349.5
h = 128
t = 350
h = 127
t = 350.5
h = 126
t = 351
h = 125
1 2 3
V_R
3×10³, V
I, a
10⁻⁶
10⁻⁷
10⁻⁸
t = 362 s
h = 113 km
t = 362.5 s
h = 112 km
t = 363 s
h = 110 km
t = 364 s
h = 109 km
1 2 3
V_R
3×10³, V

Fig 1d

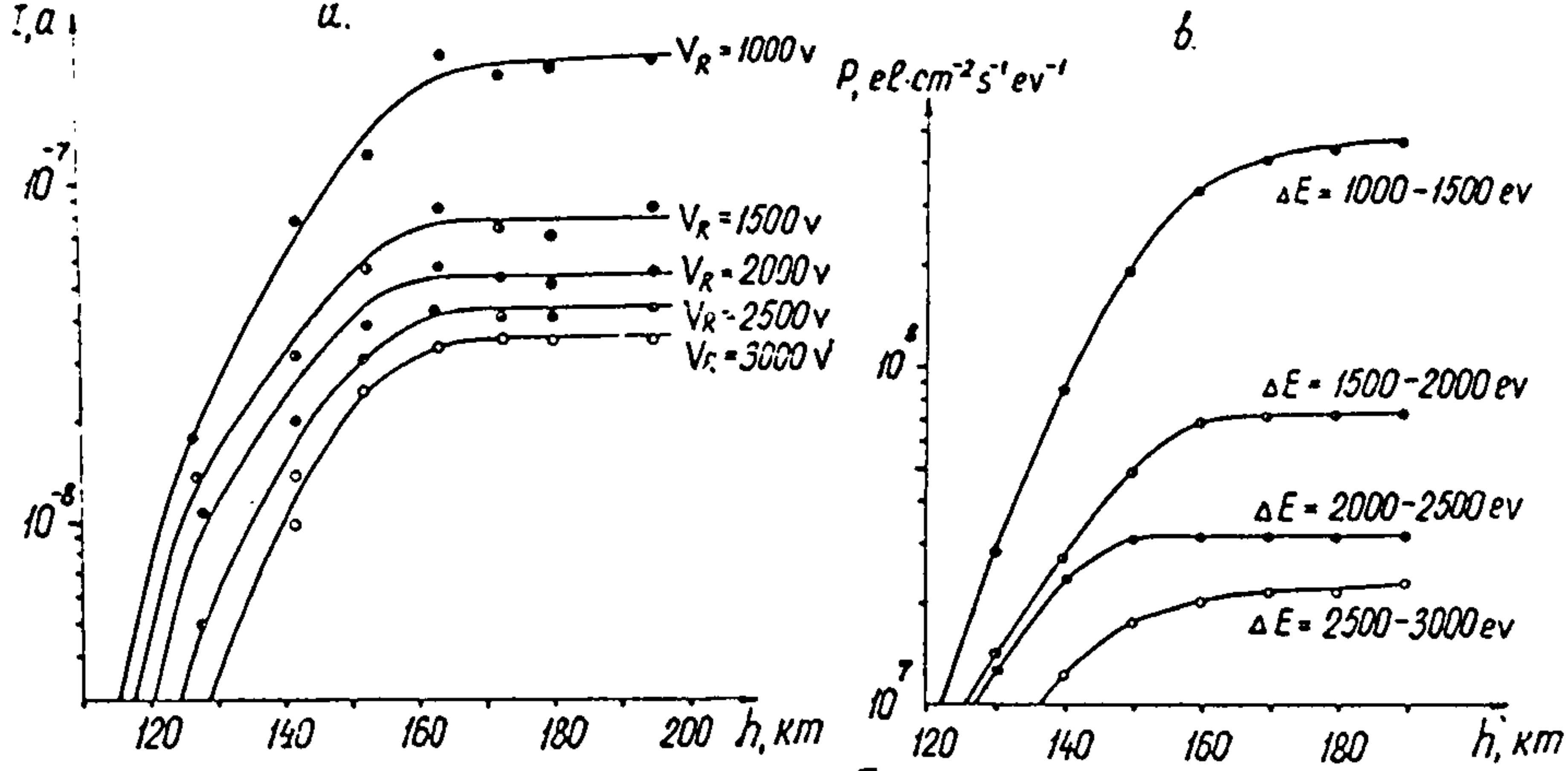

I, a
a.
10^{-7}
10^{-8}
V_R = 1000 v
V_R = 1500 v
V_R = 2000 v
V_R - 2500 v
V_r = 3000 V
120
140
160
180
200
h, km
b.
P, el·cm^{-2}s^{-1}ev^{-1}
10^{8}
10^{7}
ΔE = 1000-1500 ev
ΔE = 1500-2000 ev
ΔE = 2000-2500 ev
ΔE = 2500-3000 ev
120
140
160
180
h, km

Fig.2

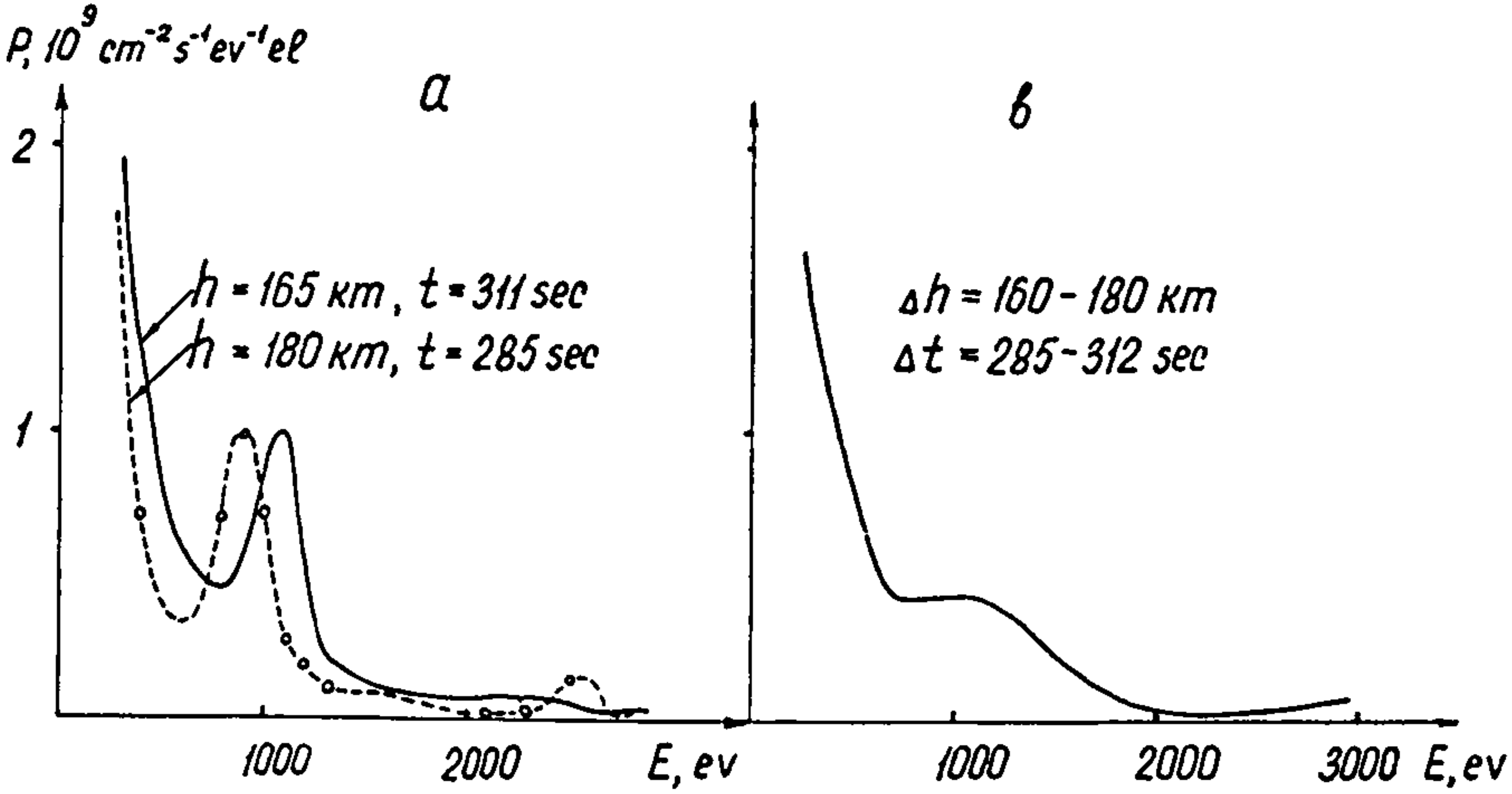

P, 10^9 cm^{-2}s^{-1}ev^{-1}el
a
2
1
h = 165 km , t = 311 sec
h = 180 km, t = 285 sec
1000
2000
E, ev
в
Δh = 160 - 180 km
Δt = 285-312 sec
1000
2000
3000
E, ev

Fig. 3

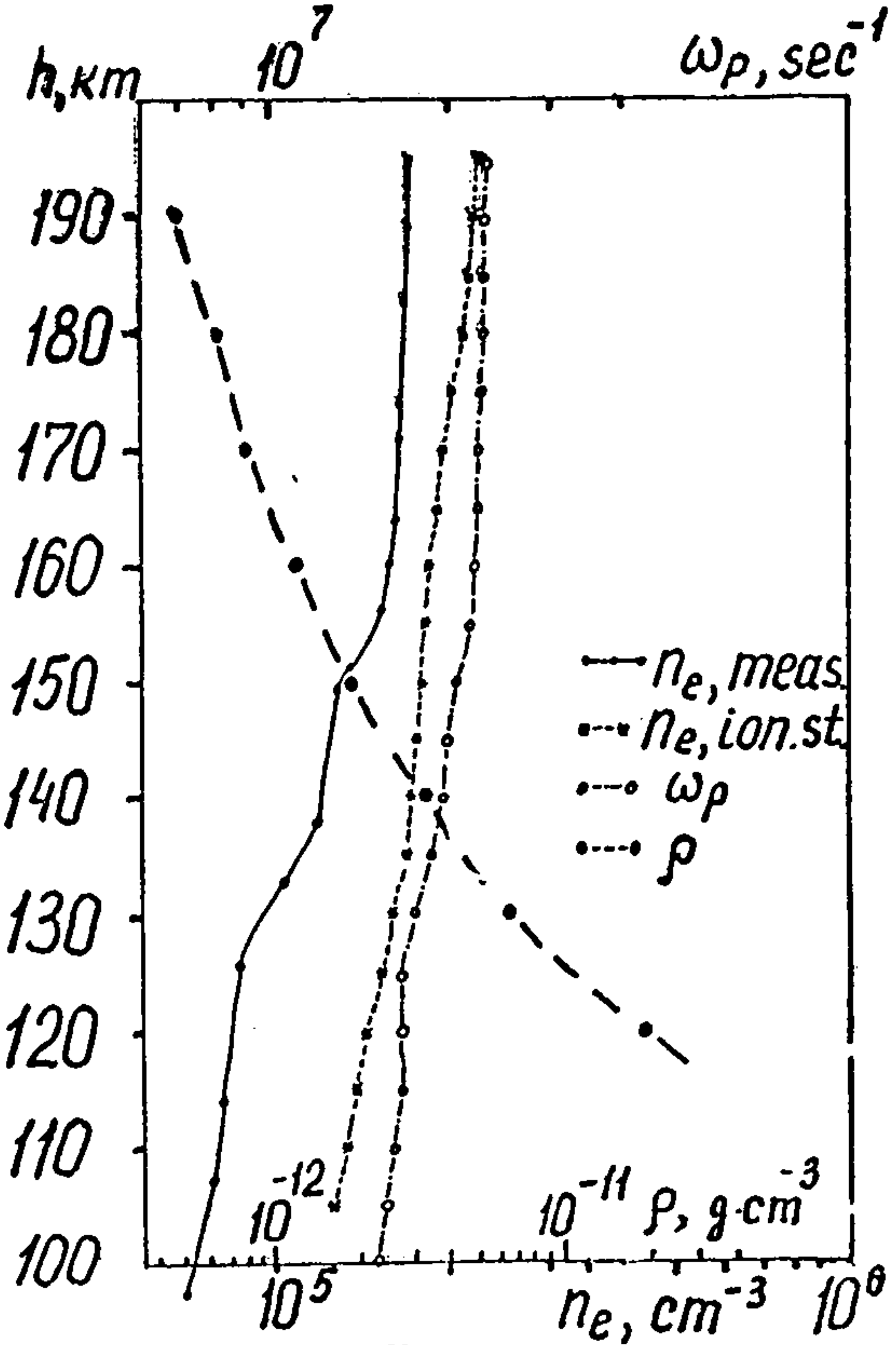

h, км
10^7
ω_p, sec^{-1}
190
180
170
160
150
140
130
120
110
100
n_e, meas.
n_e, ion.st.
ω_p
ρ
10^{-12}
10^{-11}
ρ, g·cm^{-3}
10^5
n_e, cm^{-3}
10^6

Fig. 4

055(02)2 Отпечатано в ИКИ АН СССР

Т-09716 Подписано к печати 27.4.76

Заказ 619 Тираж 110 Объем 0,8 уч.-изд.л.