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1. Introduction

In carring out the experiments with the use of electron accelerators (electron guns) installed on board the rocket it's necessary to know the rocket electrical potential relative to the environment of Φ , since the real energy of injected electrons $E = E\ accel - e\Phi$, where E accel is the energy determined by the accelerator device.

The value of potential Φ is determined mainly by the injected electron beam intensity (i.e. the gun current) and the electron flow to the rocket surface from the environment, in turn, depending on Φ and can not be accurately calculated.

It was the first rocket experiment (1969) with the electron accelerator [I] when the current pulses $\sim$ 0,5A and duration $\sim$ 1 sec were injected to the ionosphere. To secure the rocket body neutralization a depoying metallized "umbrella" of large area was used due to which the rocket cross-section collecting the neutralizing charges from the environment was considerably increased. In [I] it is mentioned that the potential - value Φ in this experiment was low, that can be explained by the "umbrella" efficiency.

In the second experiment (Echo-1-2,3, 1970) the injection current pulses were only ~ 70 mA with the duration 0,016 s. In this case potential Φ did not exceed 200 V [2] .

In Soviet-French experiment Araks which has been prepared and carried out under the joint guidance of R.Z.Sagdeev, I.A.Zhulin and F.Cambu the program of accelerator operation provided for the injection pulses with two durations: 2.56 sec and 20 msec. For this experiment the metallized "umbrella" was not used for the neutralization; a power cesium plasma generator was installed on board the rocket "Eridan", which, however, was switched on only during a part of the flight. Therefore, the high values of Φ could be assumed (in any case when the plasma generator was switched off).

In rocket experiments [1-3] for potential Φ determining a method of the retarding potential analyzer was used, while in Echo-2 experiment it was Langmuir probe method [4] . In experiment [1] the retarding potential value was changed from 0 to 2000 v for 70 msec, in Echo- 1 experiment [2-3] from 0 to 8750 v in accordance with the specific program the gun operation mode ~~and~~ during one cycle of the retarding potential change for 1 sec there were ten pulses of the injection current with the duration 16 msec (or one pulse of injection current with the duration of retarding voltage change ~ 0.5 sec). Under such operating conditions of the analyzer and gun only a comparatively rough estimate of Φ value can be made and no conclusions can be made on time variations during one pulse of the injection current.

The use of rather long current pulses (τ =2.56 sec) in

Araks experiment enabled one to choose the duration of the cycle of the analyzing voltage T/n, where n is the integer, so that to determine ϕ n-times for one long current pulse, and to a certain degree, to follow the dynamics of ϕ variation for T time. The present paper gives the results of ϕ determining at different altitudes during the flight of "Eridan" rocket on January, 26, 1975.

2. Method of measurement and instrument

On board the rocket "Eridan" at the distance of ~ 1 m from the injector two flat identical analyzers with the retarding potential were installed (Fig.1) with the normals under an angle of 90° to each other, as well as to the rocket and injector axis.

The analyzer represents a flat paralled device consisting of the collector 2 and the grid system. Grid 1 is the analyzing one. The sawtooth retarding the electrons voltage is supplied to this grid relative to the body. A maximum voltage value of one analyzer is ~ 300 v, and of second is ~3000 v.

Fig.2a gives the plots of the retarding voltage time variations. Collector currents and analyzing voltages were recorded each 30 msec; at the moments of measurement the analyzing voltages, the whole variation period of which was ~ 0.6 sec, had the following values on January, 26, 1975.

Table 1

$V_R^{max} \sim 300$ v:	314	295	273	254	225	193	168	136	110	86	67	45	30	20	17	14	12	9
$V_R^{max} \sim 3000$ v:	3140	2950	2730	2540	2250	1930	1680	1360	1100	860	670	450	300	200	140	120	90	

The external grid 4 was under the body potential, grid 3 was supplied by not high positive voltage +40 v, to prevent the ionospheric ion hit to the analyzer with $\varphi \lesssim 0$ (in the intervals between gun pulses). The grid 6 nearest to the collector so called suppressive grid served as the suppression of photo- and secondary emission. A group of grids 5 screens the collector off the varying electric field formed by the analyzing grid 1.

Dynamic range of the measured collector currents is $10^{-10} - 10^{-6}$a; the time of reading establishement did not exceed $2 \cdot 10^{-4}$sec.

At each given moment of time only those electrons could reach the collector 2 the energies of which E exceed the retarding potential V_R.

In preparing the experiment the following simple model of phenomena was supposed (this model proved to be a very idealized): during the flight the rocket is surrounded by the cold ionospheric plasma (the electron temperature 0.1-0.2 ev), electron fluxes around the rocket with energies $E > e\varphi$ are negligably small (lower than the amplifier sensitivity level~ 10^{-10}a). As the accelerator is operating the rocket body should be charged to some positive φ potential and under the effect of the rocket electric field ionospheric electrons will take $e\varphi$ energy at the analyzer input. As long as there is the negative voltage on the grid 1 $|V_R| > \Phi$ ionospheric electrons can not reach the collector. With $|V_R| \lesssim \Phi$ the instrument is "opened", the collector current is sharply increased to Im value depending on the concentration of ionospheric electrons $n_e(h)$ and Φ value. Then it is recorded as long as $|V_R| > \Phi$ condition is brought about again. Note that if $n_e \sim 10^5 cm^{-3}$, Te ~ 0.2 ev and Φ =0, then Im value should be $\sim 4.10^{-7}$a; for Φ =100 v and the same parameters of the surrounding ionospheric plasma - $\sim 10^{-5}$a. Fig.2 gives a diagrams of dependence of V_R on t and expected dependences of I on t (2a) and of I on V_R for one cycle of V_R variation (2b).

As it was mentioned above the accelerator operation program for the experiment on January 26, 75 involved periodic injection of beam pulses I_{inj}=0.5A with the duration τ_1 =2.56 sec and the injection angle α =0° (α is the angle between the large rocket axis and the injected electron beam), as well as the injection of the beam current short pulses with the same value and the duration $\tau_2 = 2.10^{-2}$sec and with the injection angle $\alpha = 0^\circ$, 70° and 140° (Fig.3).

It is likely that during the long pulses Φ potential can be either more than Φ value during the short pulses or they will be equal.

Besides, there wasn't cause to expect that the electrons with energies $\sim$ 15 kev and $\sim$27 kev injected under the angle 0° to the rocket axis will hit to the analyzers which are located sufficiently lower than the injector (the analyzer normals to aperture made up the angle 90° with the injector axis). The generator of V_R voltage was synchronized with the operation of the electron gun programming unit so that during each long pulse four retardation curves were measured by use each analyzer.

It is seen from Table 1 that the minimum retarding voltage with which the analyzer collector current was measured was 9 v, consequently electrons with energy $E < 9$ ev were not recorded for given experiment.

In the present paper only those measurements are analyzed which were made during the long injection pulses when the measurement frequency (30 hz) was enough for obtaining the detailed retardation curves.

3. The measurement results and discussion

During the whole flight on January, 26, 1975 the collector currents in the analyzers were recorded only at the moments of injector operation. Fig. 3 presents the examples of telemetry records for $\alpha = 0°$ and $\alpha = 140°$. Time is varied from the right to the left. Fig 3a corresponds to 142-145 seconds of the rocket flight when the mean energy of injected electrons was 27 kev the beam current 0.5 a and the plasma generator was operating. Fig.3b shows an example of instrument operation for 283-287 sec. when the injection energy was approximately ~ 15 kev under unvariable other conditions and Fig.3c shows the same as Fig.3b but with the plasma generator being switched off (321 to 326 sec). It's seen from Fig.3 that in varying the injection energy from 27 kev to 15 kev as well as in switching on and off the plasma generator the shape of the retardation curves recorded for the long pulse duration does not practically change.

The fact that in pauses between pulses the currents of the analyzers decreased to zero evidences apparently that the process(es) of the rocket neutralization due to the surrounding plasma conductivity were extremely fast. Unfortunately, it is impossible to take the time moments of the currents appearing and disappearing in the analyzers after the beginning and the end of this gun operation, respectively, with an error less than 30 msec according to the available telemetry records because the currents of these abalyzers being recorded with 30 msec period and the injector operation with I msec interval. All this makes the body potential determination impossible at those periods when the accelerator injected short pulses (τ_2 =20 msec) since at the pulse moment each analyzer gave a reading for the current appropriate to a fixed value of the retarding potential V_R, only.

Fig.4 presents the retardation curves obtained in time of long current pulses of the accelerator at different altitudes during the flight. Two scales for the retarding voltage correspond(ing) to the two different analyzers of electrons are plotted along X-axis and the currents along Y-axis; the retardation curve for the analyzer with $V_R \lesssim 300$ v are shown by solid line and for one with $V_R \lesssim 3000$ v by dotted line. The currents values are limited by the range from 10^{-9} to 10^{-6}a. It can be seen from Fig.4 that the stepwise increases of the currents occur within 10^{-7} to 10^{6}a when the retarding potential decreases.

According to mentioned - above the values of retarding potential at the moments of these stepwise increases of the collector currents conforms to the value of the rocket potentials relative to the environment.

The ionospheric plasma density slightly changed and amounted to about $10^5 cm^{-3}$ within the considered range of altitudes according to the data taken by the ionospheric station being under operation during the launch on the island of Kergelen as well as to the results of the wave measurements carried out of the nose cone*) jettisoned from the "Eridan" rocket during the flight. As it has been noted above the collector current I of the analyzer opened for ionospheric electrons must be in this case from about 10^{-7}a to $\sim 10^5$a depending on φ .

Fig.5 shows the examples of the retardation curves recorded by the analyzer with $V_R \lesssim 300$ v at the periods of long pulses with injection energy of 15 kev. Each sequence of four dependences conforms with single pulse. Some of these retardation curves were obtained in case of the plasma generator being switched on (5a and 5b) and some of them for the switched off generator (5b and 5c).

As seen from Fig.4 and 5 in all the cases the sharp current spike in the both instruments, when the current reaches the value $I \gtrsim 10^{-6}$a, is observed for $V_R < 300$ v. It means that the value φ did not exceed 300 v during the considered flight time.

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*) Dr. Lavernya kindly made these results available to us.

The current spikes are not so steep as it can be expected starting from the idealized model described above (to which Fig.2 corresponds). The steepness degree of these spikes seen on the retardation curves indicates to some heating of electrons as compared with their temperature in the unperturbed ionosphere. In addition, the significant fluxes of electrons recorded for $|V_R| > \Phi$ (up to $|V_R| > 10\Phi$ in many cases) is a feature of most of the retardation curves (unexpected in preparing of the experiment). The current spike I with $|V_R| \sim \Phi$ is probably masked in the recording of these electrons when it becomes less sharp and the spread of the fixed values of Φ increases.

The analysis of the electron fluxes with energies $E > e\Phi$ and the discussion of their probable origin are the subject of [5] .

As follows from Table 1 the step in changing voltages of both analyzers is almost similar within the range $V_R \sim 150$ to 250 v of the retarding voltages. It results from Fig.4 that within the V_R changing between two sequential telemetry points the values of Φ determined from the data of these analyzers coincide though the conditions $|V_R| \sim \Phi$ are accomplished in both analyzers unsimultaneously. It means that during the period the analyzing voltage variation the value Φ is not practically changed.

It is seen from Fig.5 that the character of the retardation curves for $h > 160$ km is practically independent of altitude. The current I growth front variations up to $I_m \gtrsim 10^6$a evidently reflect the time fluctuations of ionospheric electron fluxes to the rocket with energies $E > e\varphi$. After the plasma generator being switched off these fluctuations increased whereas the values of V_R for which the sharp rise of the current $I_m \gtrsim 10^{-6}$ a is observed remained to be the same (see Fig.5b). At heights h 125 km the slight increase of the values $|V_R| \sim \varphi$ is observed and then with the height decreasing the potential rather sharply drops.

The stable value of φ is evidently rather quickly set up after the injection beginning ($t_{set} \lesssim 30$ msec). It should be noted that during the experiment [1] the collector current delay equal to about 100 msec relative to the injection current beginning (or its end) was observed. But in this case electrons with energies of about 6 ev and smaller were recorded that couldnot be observed in this experiment.

The spread of φ- values obtained during one long pulse is obviously associated with the injection current variations and (or) with the inaccurate determination of the moment of the collector current jump due to the relatively rare telemetry points in measuring the current and the retardation potential V_R.

Fig.6 gives the altitude variation of φ value. The mean values of φ for each long beam pulse determined from the results of eight measurements (four recordings for each analyzer) are equal to about 150 v at altitudes h higher than 125 to 130 km; φ values being practically independent of the situation whether the plasma generation is switched on or off.

As follows from [1] Hess et al. noted that φ values during their measurements were rather low but they did not give the particular values; in Echo-2 experiment the potential did not exceed 100 v [4] .

With the altitude decreasing (from h ~ 125 km) significantly decreases of potential indicates to the improvement of the rocket neutralization conditions. The altitude variation of Φ shown in Fig.6 gives grounds for the assumption that at altitudes of about 125 km in the process of neutralization noticeable changes occur. The questions about neutralization in the ionosphere of a body with the high energy potential were considered in [6-8] . Beard and Johnson [6] ignored the influence of the geomagnetic field on gathering charges by a body. Parker and Murphy [7] analyzing the trajectories of particles in the constant electric and magnetic fields showed that the presense of the geomagnetic field leads to the equation

$$I \leq \left[1 + \left(\frac{4\Phi}{\Phi_0}\right)^{1/2}\right] I_0$$

where I_0 is a current gathered by a body from the ionosphere (the body cross-section perpendicular to the magnetic field) without injection; I is a current gathered by a body for Φ potential, $\Phi_0 = \frac{m\omega_c^2 a^2}{2e}$

$\omega_c = eB/m$ is a gyrofrequency; a is a body radius; e and m are a charge and mass of electron, respectively.

This equation and the values: $\Phi \sim 150$ v and $a \sim 30$ cm used in this experiment, indicate to the fact that the current of ionospheric electrons incoming on to the body with such a potential for $n_e \sim 1.5 \times 10^5 cm^{-3}$ in the Parker and

Murphy model is about by two orders less than the injection current equal to 0.5 A.

Linson [8] assumed that due to the ionospheric plasma turbulence and the electrical field electrons possibly come on to a body along the trajectories normal to the magnetic field; however, this possibility is not proved but postulated only.

The results obtained on 26.1.1975 during Araks experiment described above show that there is a mechanism (or mechanisms) ensuring the gathering of ionospheric electrons with the current summarized over the total rocket surface of the order of ampere (since the value Φ did not increase during the long beam pulse). Probably there was not only the gathering of the ionospheric electrons but also of electrons created as a result of some ionization processes caused by the beam; it most likely occured at altitudes lower than ~125 km where with the altitude decreasing Φ - potential significantly reduces in spite of n_e fall in the ionosphere. The drop of Φ in turn, should decrease the rocket gathering of ionospheric electrons.

4. Conclusion

During Eridan rocket flight on January 26, 1975 following the ARAKS experiment program, the altitude dependance of the electric rocket potential relative to the environment was determined.

In this flight the value of Φ did not exceed 300 v; at altitudes h lower than ~125 km Φ decreased; at $h \gtrsim$

125 km Φ was comparatively stable (~ 150 v).

2. The time for the Φ potential establishment was not higher than 30 msec (30 msec is a period of the recording of the analizer data).

3. During the gun operation near the rocket electrons hoter than thase in the undisturbed ionosphere were observed.

4. The plasma generator work slightly influenced on the rocket Φ -electric potential.

5. The measurements results of the Φ altitude variation indicate to the fact that at altitudes $\lesssim$ 125 km the process of the neutral upper atmosphere ionozation most likely existed due to the injected electron beam; such a process took possibly place at altitudes $\gtrsim$ 130 km (or certain process resulting in the gathering of ionospheric electrons across the geomagnetic field).

6. By means of the instruments for potential measuring the electron fluxes with energy $E > e\Phi$ were also observed; the results of these observations are not discussed in the present paper (see [5]).

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Figure captions

Fig.1. The analyzer scheme.

Fig.2. The variation of analyzing voltage V_R during the time (2a) and assumed dependence of collector current on V_R.

Fig.3. The examples of TM-information.

Fig.4. The current-voltage characteristics on changing of analyzing voltage V_R from ~ 0 to ~300 v; and from ~ 0 to ~3000 v.

Fig.5. The current-voltage characteristics at different altitudes on changing V_R from ~ 0 to ~300 v.

Fig.6. The altitude variation of the rocket potential φ.

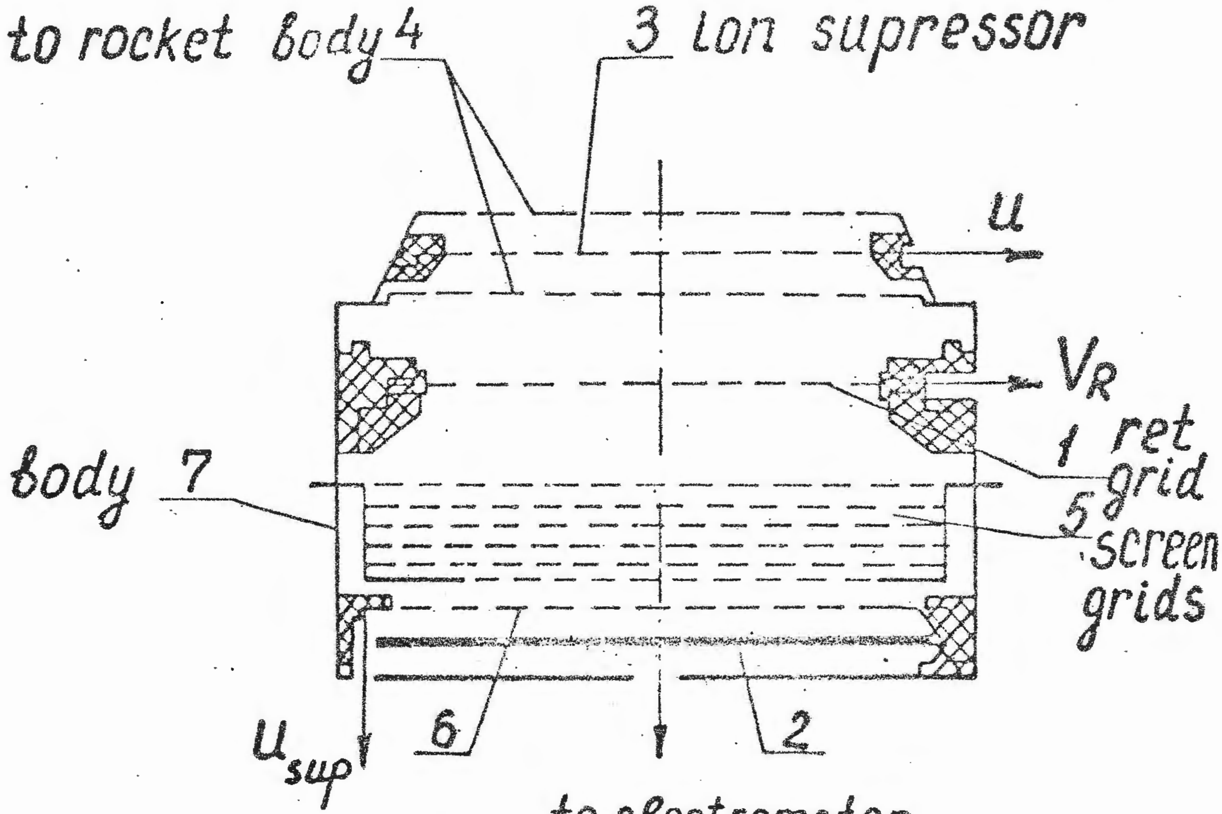

to rocket body 4
3 ion supressor
u
V_R
1 ret grid
body 7
5 screen grids
u_{sup}
6
2
to electrometer

Fig. 1

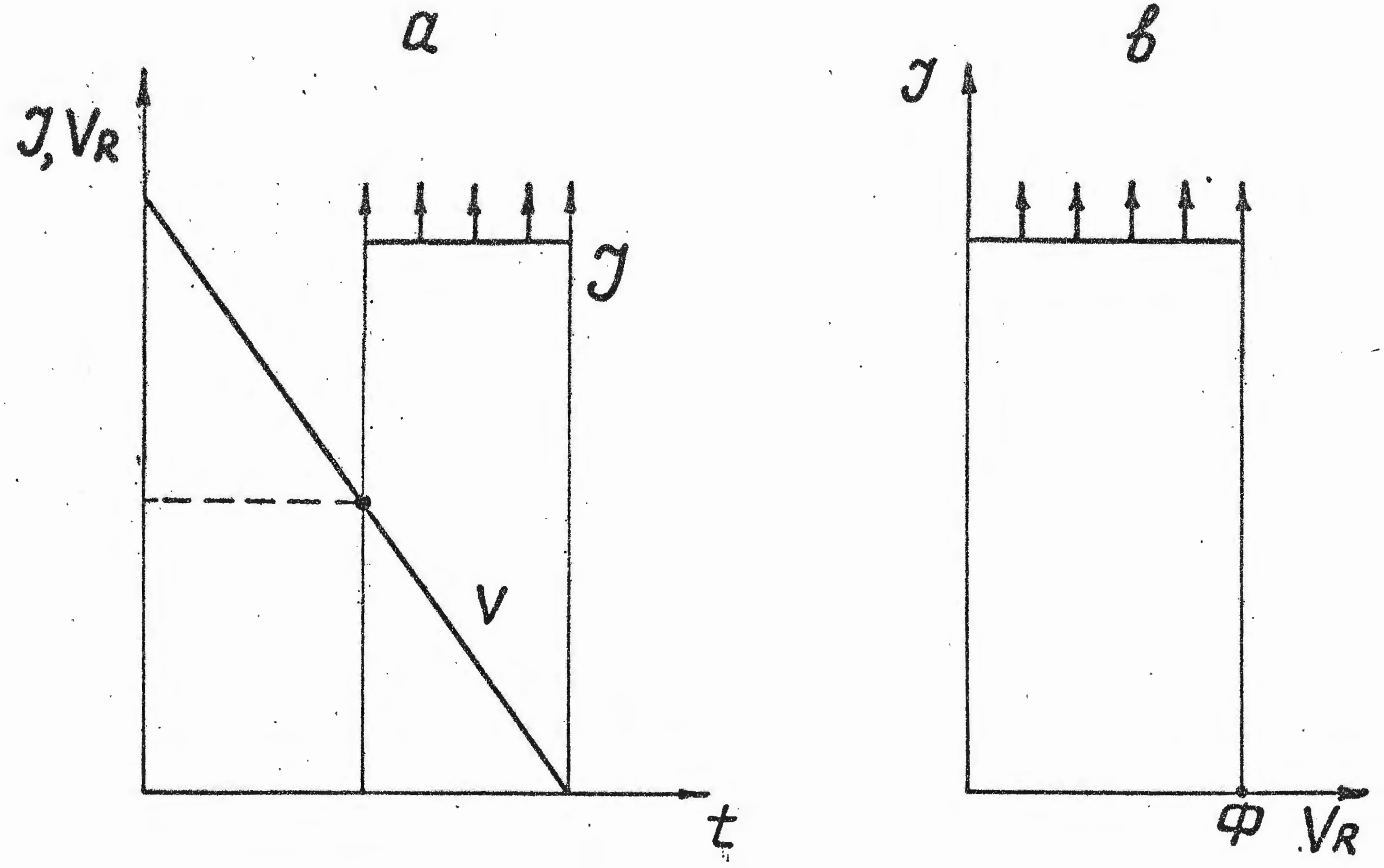
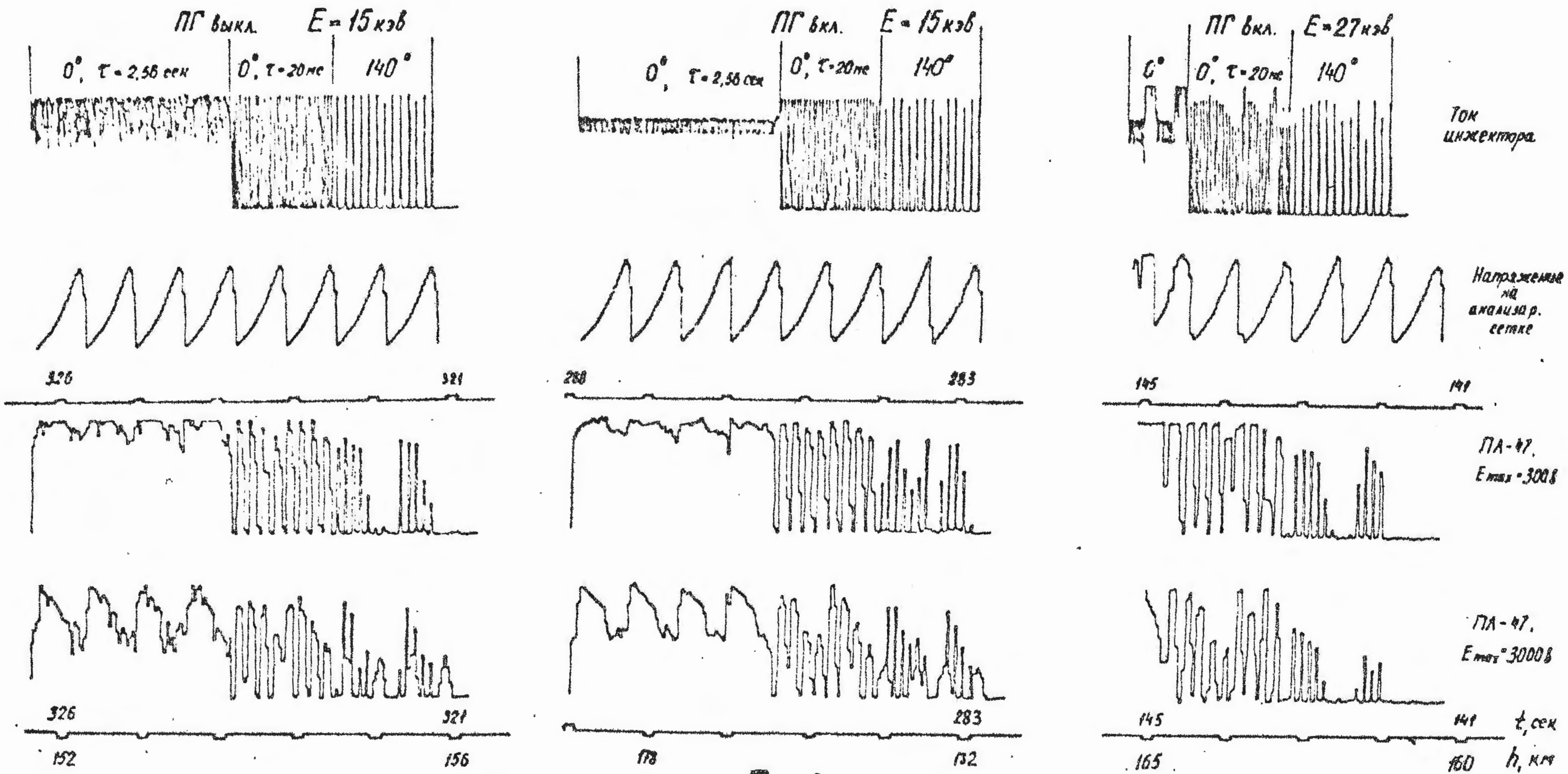


Fig. 2


ПГ выкл.
E = 15 кэв
0°, τ = 2,56 сек
0°, τ = 20 мс
140°
ПГ вкл.
E = 15 кэв
0°, τ = 2,56 сек
0°, τ = 20 мс
140°
ПГ вкл.
E = 27 кэв
0°
0°, τ = 20 мс
140°
Ток инжектора
Напряжение на анализ. р. сетке
ПЛ-47, Emax = 300 в
ПЛ-47, Emax = 3000 в
326
321
288
283
145
141
t, сек
152
156
178
182
165
160
h, км
Fig. 3

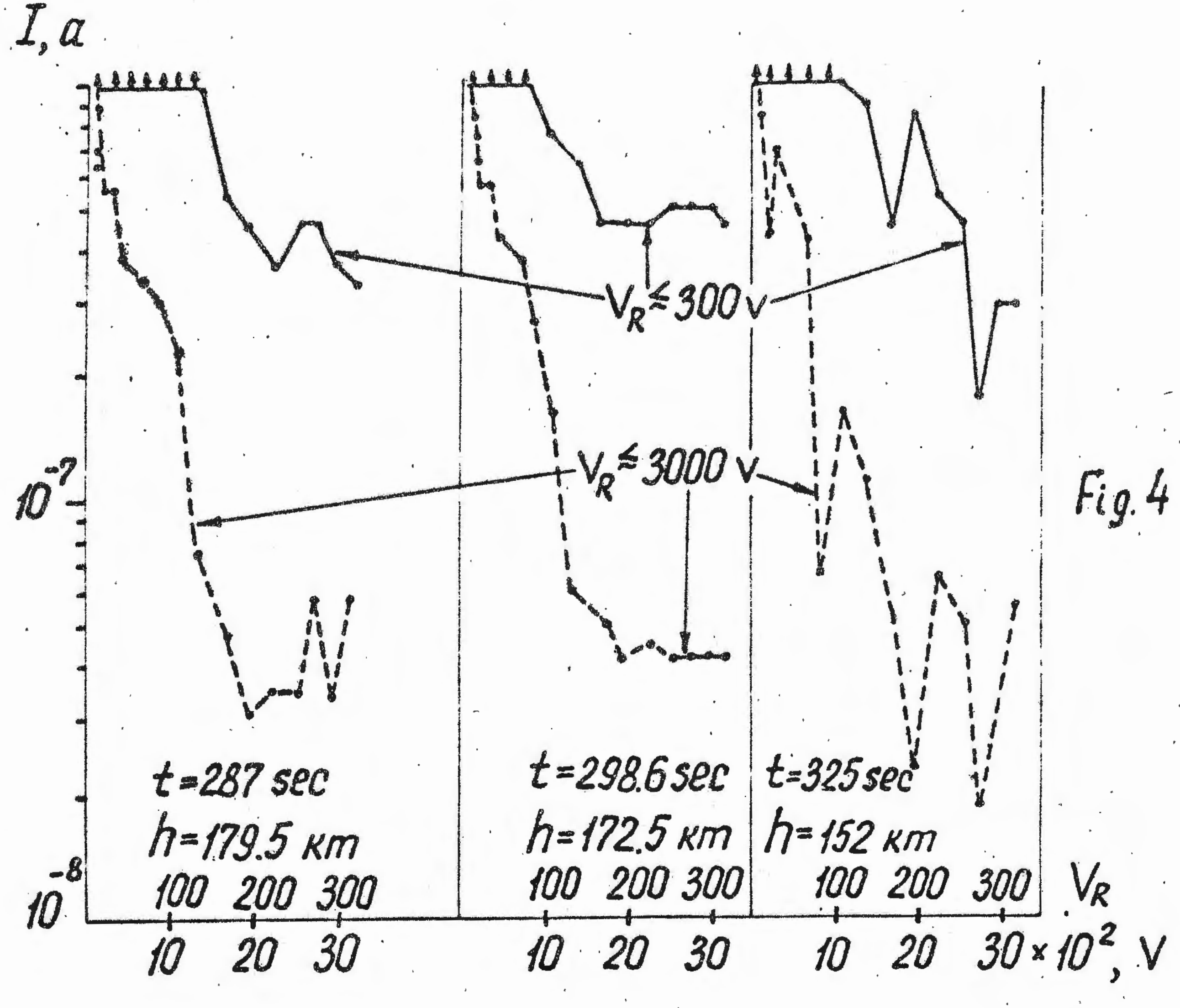

I, a
10^{-7}
10^{-8}
$V_R \leq 300$ V
$V_R \leq 3000$ V
t=287 sec
h=179.5 km
t=298.6 sec
h=172.5 km
t=325 sec
h=152 km
100 200 300
10 20 30
V_R
30×10^2, V

Fig. 4

a. P.G. switched on

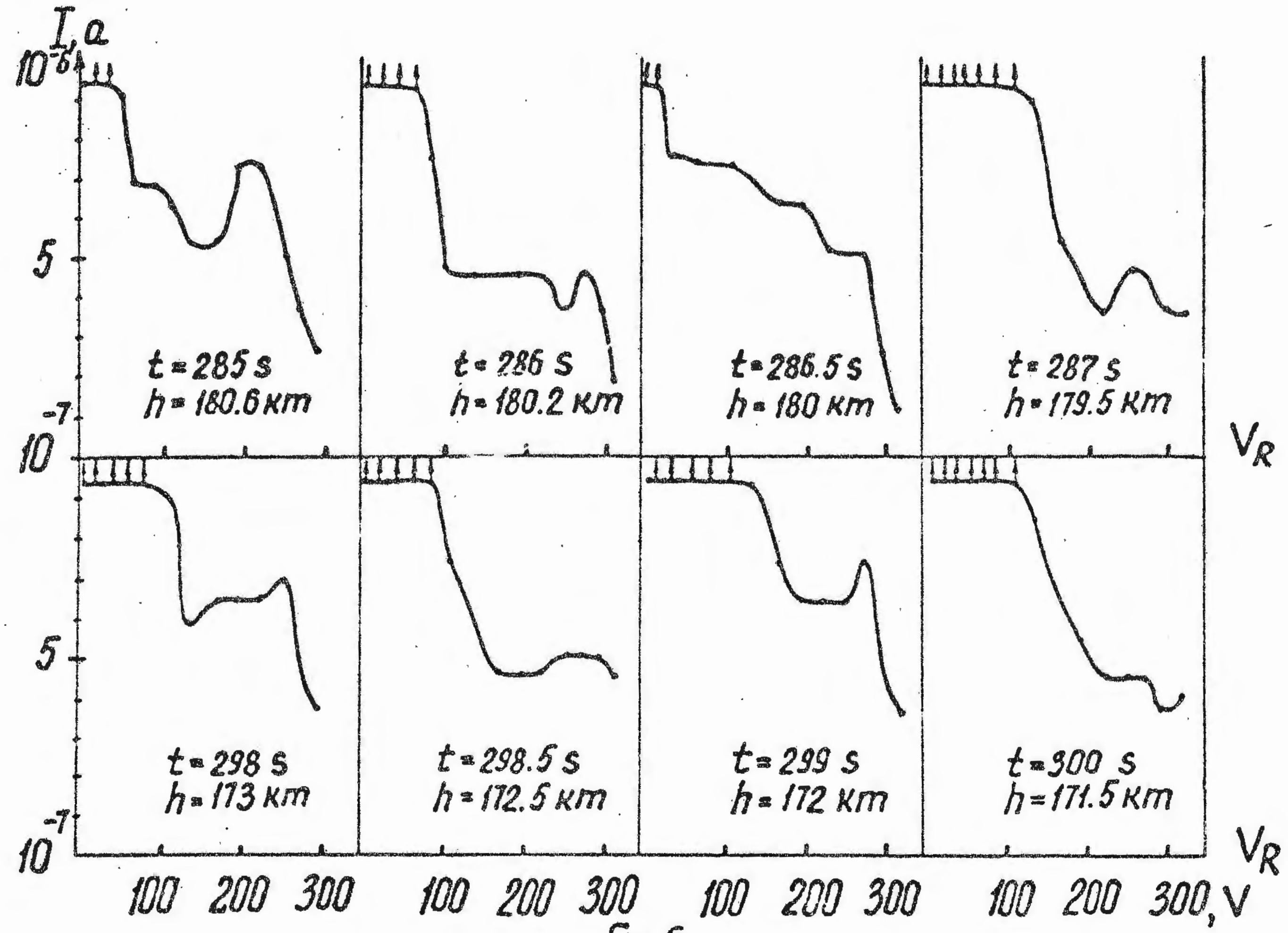


Fig. 5a

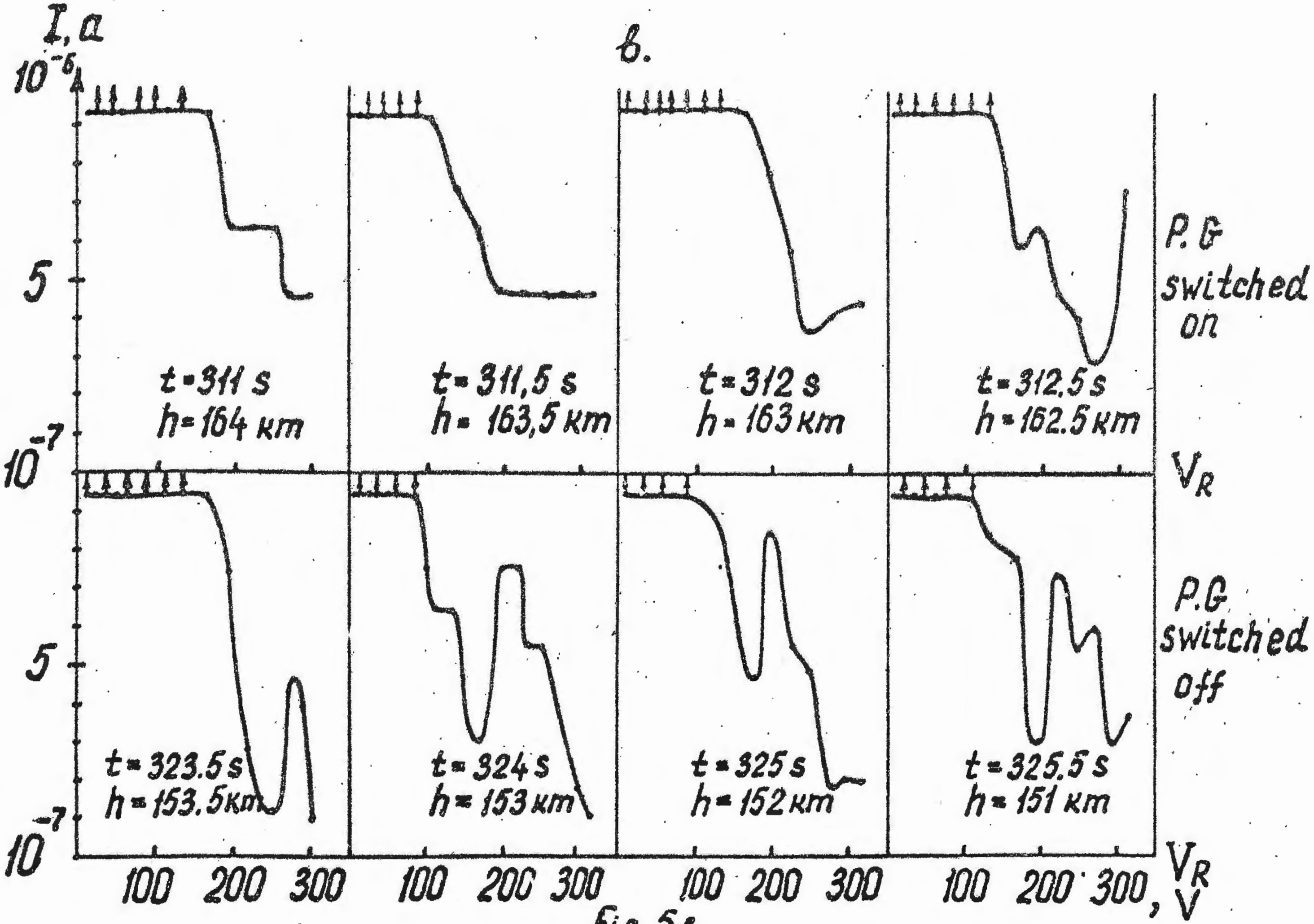
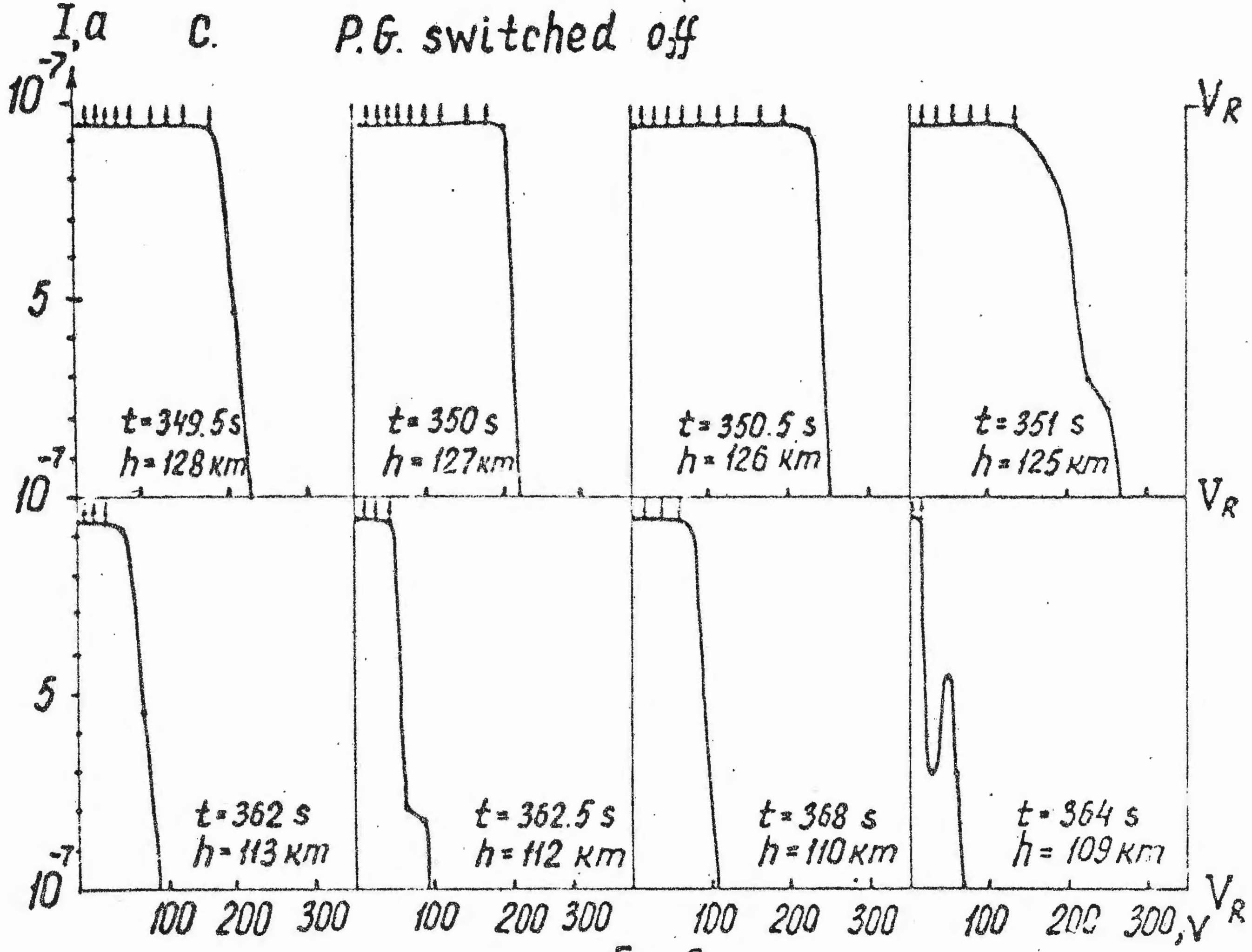

I, a
в.
10^{-6}
5
10^{-7}
t = 311 s
h = 164 km
t = 311,5 s
h = 163,5 km
t = 312 s
h = 163 km
t = 312.5 s
h = 162.5 km
P. G switched on
V_R
5
10^{-7}
t = 323.5 s
h = 153.5 km
t = 324 s
h = 153 km
t = 325 s
h = 152 km
t = 325.5 s
h = 151 km
P.G switched off
100 200 300
100 200 300
100 200 300
100 200 300
V_R, V

Fig. 5в.



I,a
c.
P.G. switched off
10^-7
5
10^-7
5
10^-7
V_R
V_R
V_R
t=349.5 s
h=128 km
t=350 s
h=127 km
t=350.5 s
h=126 km
t=351 s
h=125 km
t=362 s
h=113 km
t=362.5 s
h=112 km
t=368 s
h=110 km
t=364 s
h=109 km
100 200 300
100 200 300
100 200 300
100 200 300,V

Fig. 5c

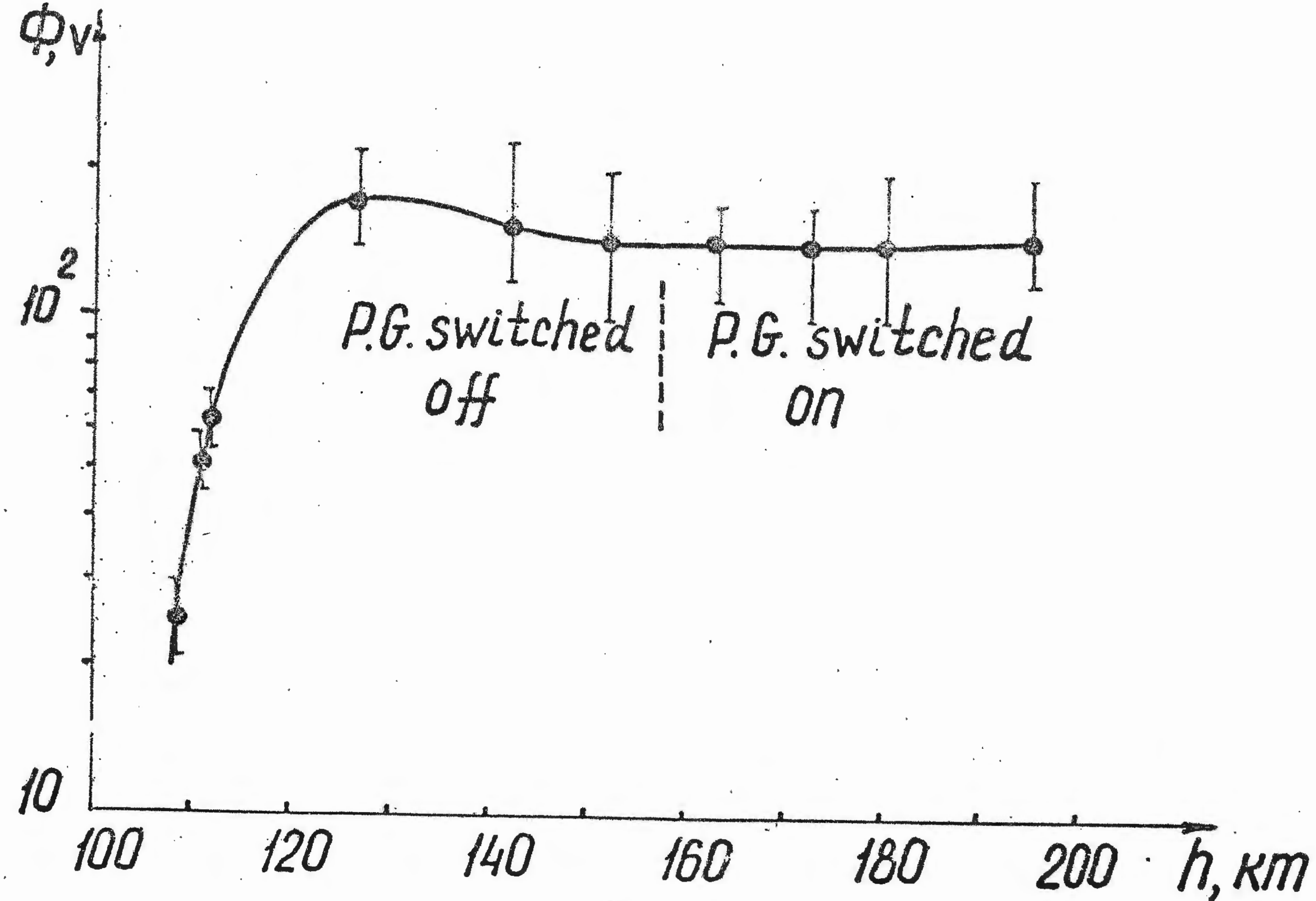

Φ, v
10²
10
100
120
140
160
180
200
h, km
P.G. switched off
P.G. switched on

Fig. 6

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