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Simultaneous Determination of Electron Density and Electron-Neutral Molecule Collision Frequencys in the Ionospheric D-Region by a Partial Reflection Technique

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Main approaches of simultaneous determination of the electron density and electron-neutral molecule collision frequencys in the ionospheric D-region by means of a partial reflection (PR) technique were considered. In order to obtain more information and to have a more accurate PR technique, its experimental testing was carried out. Using the experimental data, the methods were compared, practical recommendations were given to make more precise an accuracy of obtaining the ionospheric plasma parameters and to widen a height range under study.

1. Introduction

The lowest part of the ionosphere, its D-region, is still remains the poorly investigated one. It is connected both with much difficulty and comparative high cost of experimental investigations and with diversity and intricacy of physical-chemical processes occurring in it. Investigations of the ionospheric D-region both at the middle and high latitudes (obtaining of the information on heigh-time variations in the electron density $N(z,t)$,(where z is the height above the Earth surface, t is the time) are carried out sporadically in rocket measurements conducted by means of sounders or the method of coherent frequencies (see, e.g., [1 – 2]) or using very low-frequency waves (see, e.g., [3]). In order to carry out systematic observations, there is used a PR technique (see, e.g., [4 – 20]) which is one of the basic techniques of studying the ionospheric D-region. A main advantage of the technique consists in the fact that it allows to carry out systematic, long-term and continuous (from some minutes to several days) investigations of the regular height-time variations in the $N(z,t)$ density and in the electron-neutral molecule collision frequencies, $\nu(z,t)$, and plus the parameters of scattering irregularities in the ionospheric plasma under rather a small outlay for scientific research and under acceptable measurement accuracy. Nevetheless usually in practice only the $N(z)$ profile is measured. In order to obtine $N(z)$ values, the model $\nu(z)$ profile is used in the technique, which contributes some error (often large and unknown as those models of the $\nu(z)$ profile are rather inaccurate) to the $N(z)$ profile to be determined.

In order to solve some scientific and a whole number of practicial problems in radio communication, radio navigation, internet systems, etc., one should know both the profiles and their space-time changes, applying acceptable accuracy (the errors in determining the $N(z)$ and $\nu(z)$ values being ≤ 30%). Such a opportunity is enabled by amplitude measuerments used in the PR technique (PR signal amplitudes, $A_{o,x}(z,t)$, of the ordinary «o» and extraordinary «x» polarizations are usually recorded in the whole height range of the ionospheric D-region with a 3 km discreteness; the sounding frequencies used are 2 – 6 MHz). Nevertheless, such capabilities of the technique as to simultaneous determining $N(z,t)$ and $\nu(z,t)$ in the D-region are not yet properly developed. The known methods from [9, 21] are not yet widely used due to a number of reasons. The method from [9] applied when

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sounding the ionosphere by means of one operating frequency does not allow with a required accuracy to obtain information on $N(z,t)$ and $\nu(z,t)$ in the lower ($z \leq 75$ km) and upper ($z \geq 85$ km) parts of the ionospheric D-region due to the method sensitivity to errors in PR amplitude measurements, which were mainly caused by effects of radio noise , errors in the construction of the receiving-transmitting equipment system and by transformation of the magnetoionic components of PR signals in the magnetoactive ionosphere. As a rule the height range investigated is 8-10 km approximately. Applying of the methods from [21] is limited by necessity,of using the multifrequency ionosphere sounding within 2 – 6 MHz.

Using the PR technique in the lower ionospheric D-region, data on variations in the electron collision frequencies, $\nu(z)$, are obtained by means of the known methods [4, 5, 22] which are based on the fact that in this part of the ionosphere (as a rule, these are heights at $z <$ 70-75 km) the differential absorption of the magnetoionic components is small and the approximate equation $a(z) \cong R(z)$ is fulfilled (here $a(z) = < A_x^2(z) > / < A_o^2(z)$ is measured in the experiment, $R(z)$ is the theoretical function depending on the operating frequency ω and longitudinal along the magnetic field of the electron gyrofrequency component ω_L and $\nu(z)$). In this case, one usually obtains $\nu(z)$ values with a required accuracy at one to three heights, i.e. the height range investigated is 3-6 km approximately. The $\nu(z)$ values obtained in this manner are then used to obtain electron density values, for instance, by means of the differential absorption technique [4, 5]. Note that this technique is main for obtaining data on height-time variations in the $\nu(z)$ profile in the lower ionospheric D-region.

In order to extend a height range under study in the ionospheric D-region up to 15 – 25 km, one should develop the new and already existing methods for simultaneous determining $N(z,t)$ and $\nu(z,t)$.

In this paper, in order to increase self-descriptiveness and accuracy of the PR technique, there are suggested new methods for simultaneous determining the electron density and electron-neutral molecule collision frequencies in the ionospheric D-region with their experimental testing; on a basis of the experimental data, there are compared the methods and given practical recommendations as to increasing accuracy when obtaining ionospheric plasma parameters and to widening the height range investigated.

2. Experimental equipment

The experimental investigations were carried out by means of the stationary [23 – 25] and mobile [24, 26] equipment sets for investigating the lower ionosphere by the PR technique at the Radiophysical Observatory of V.Karazin Kharkiv National University in the vicinity of Kharkiv (see Table 1).

Table 1

Coordinates of Radiophysical Observatory of Kharkiv V. Karazin National University

	Geographic		Geomagnetic				
Elevation (m)	Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	Inclination	Declination (W)	L
156	49° 38'	36° 20'	45.37°	118.7°	66° 36.8'	6° 19.6'	~2.0

The main parameters of the PR technique equipment sets when conducting the investigations were as follows: the sounding frequencies of $f = 1.9 - 5$ MHz, the pulse durations of $\tau = 25$ mcsec with the repetition frequency of $F = 1 - 10$ Hz, the pulse power of $P = 100 - 150$ kW, the antenna gain coefficient of $G = 40$.

In the experiments there were recorded the height-time amplitude dependences of the mixed PR signal and radio noise, $A_{sn\,o,x}(z,t)$, put on the films, punched tapes and magnetic tapes from 14 or 22 height levels, beginning with 45 or 60 km every other $\Delta z = 3$ km. In order to select the PR signal amplitudes, $A_{o,x}(z,t)$, there were also recorded the amplitudes of radio noise, $A_{no,x}(t)$, only (2 – 6 samples within 50 kHz) at the time moments preceding the sounding pulse radiation. By means of the mobile equipment complex [24, 26], there were carried out the cycles of simultaneous measurements of the PR signal amplitudes, $A_{o,x}(z,t)$, and the $A_{1,2}(z,t)$ amplitudes at the ortogonal lineary-polarized antennas using the method from [27]. The $A_{sn\,o,x}(z,t)$, $A_{1,2}(z,t)$ and $A_{no,x}(t)$ measurements were made continuously, having their duration of units-dozens of hours.

3. Methods of simultaneous obtaining the electron density and electron-neutral molecule collision frequencies

3.1. Using of amplitude measurements of the average phase difference and the differential absorption of magnetoionic components

Let us consider a method for determining $N(z)$ and $\nu(z)$ profiles in the ionospheric D-region, based on simultaneous measurements of the differential absorption and average phase difference, $<\varphi>$, of the «o» and «x» PR signal magnetoionic components (the measuring time being 5 – 10 min). At the same time, $<\varphi>$ is determined (using the simultaneous measurements of PR signal amplitudes of $A_{o,x}(z,t)$ and amplitudes of $A_{1,2}(z,t)$) at the orthogonal lineary-polarized antennas using the methods from [27] (they allow to determine $<\varphi>$ without fine and complex phase measurements).

A task of simultaneous determining N and ν is solved at two steps.

1. $N(z)$ ***determining.***

For the average phase difference, $<\varphi>$, the expression from [27] is used

$$<\varphi> = <\varphi_o - \varphi_x> = <\arccos\left(\frac{(A_1^2 - A_2^2)(A_o^2 + A_x^2)}{(A_2^2 + A_1^2)A_oA_x}\right). \tag{1}$$

The $<\varphi>$ relationship with the ionospheric parameters, valid for the direct phase measurements as well, is

$$<\varphi> = 2\frac{\omega}{c}\int_0^z (n_o - n_x)dz' + \varphi_2 + \varphi_3 + \Delta\phi, \tag{2}$$

where

$$\varphi_2 = \arctan \frac{5/2\left[C_{5/2}(z_x)z_o C_{3/2}(z_o) - C_{5/2}(z_o)z_x C_{3/2}(z_x)\right]}{z_o C_{3/2}(z_o)z_x C_{3/2}(z_x) + (25/4)C_{5/2}(z_x)z_o C_{5/2}(z_o)},$$

$$\varphi_3 = \arctan \frac{\alpha' \sin\varphi_1}{1+\alpha' \cos\varphi_1},$$

$$\varphi_1 = \frac{x \operatorname{sh} y \cos x - y \operatorname{ch} y \sin x}{y \operatorname{sh} y \cos x - x \operatorname{ch} y \sin x},$$

$$z_{o,x}(z) = \frac{\omega \pm \omega_L}{\nu(z)}, \quad C_p(z_{o,x}) = \frac{1}{\Gamma(p+1)} \int_0^\infty \frac{\varepsilon^p p^\varepsilon}{\varepsilon^2 + z_{o,x}^2} d\varepsilon,$$

$$x = \omega\tau_i(n_o - n_x), \quad y = \omega\tau_i(\kappa_o - \kappa_x), \quad y_{o,x} = \omega\tau_i\kappa_{o,x},$$

$\Delta\phi$ is the initial phase difference of «o» and «x» waves, ω_L is the electron gyrofrequency, $f_L = 2\pi\omega_L$ component, longitudinal along the Earth magnetic field direction, ω is the operation frequency, $n_{o,x}$ and $\kappa_{o,x}$ are the real and imaginary parts of the refraction coefficient, τ_i is the duration of sounding pulses, and α' is the coefficient differing from a unit under simultaneous presence of the mechanisms of scatter and the Fresnel reflection of radio waves (under scattering, $\varphi_3 = \varphi_1$; under reflection, $\varphi_3 = \varphi_1 = 0$).

The $N(z)$ profile calculation is made using formula (2) with account of (1), the expressions for $n_{o,x}$ and $\kappa_{o,x}$ are taken using the generalized model of Sen and Wyller [28]. The model $<\varphi>$ calculations depending on N under different ν values, made for $f = 2.5$ MHz and 5 MHz, have shown that a possible interval of N measurements, having error of $\leq 30\%$ and using this method, covers the D-region by day and the E-layer at night.

The ν account when calculating N has to be carried out at two steps: at first one takes an approximate ν value at a fixed height (for instance, those from the model), then one makes this value more precise according to the methods from [9] briefly described below; after that, a correction for N determining by a method of sucessive approximations is introdused.

2. $\nu(z)$ *determining.*

The methods of determining $\nu(z)$ [9] are based on measuring the differential absorption of the «o» and «x» components of PR signals; there are used the same experimental $A_{o,x}(z,t)$ records and the following expression

$$a(z) = <A_x^2(z)> / <A_o^2(z)> = R(z) \cdot \exp\left[-\int_{z_0}^{z} K(z') \cdot N(z) dz'\right], \tag{3}$$

where $R(z) = \langle|\Delta\varepsilon_x|^2\rangle / \langle|\Delta\varepsilon_o^2|\rangle$ is the relation of the reflection coefficients for the "o" and "x" waves; $\Delta\varepsilon_{o,x}$ stands for the permitivity fluctuations of ionospheric plasma;

$K = 8\omega_p^2 \omega_H \omega / c[(\omega + \omega_H)^2 + \nu^2][(\omega - \omega_H)^2 + \nu^2]$, $\omega_p^2 = e^2 / m \cdot \varepsilon$, $\omega_H = eB_0 m \cos\chi$, $\omega = 2\pi f$, B_0 is the Earth magnetic field induction, χ is the angle between the B_0 vector and the vertical, ε is the electrical permitivity of vacuum, e and m are the charge and mass of an electron, respectively. In this case the error in determining the ν value $\leq 30\%$ under correct account of the measurement errors.

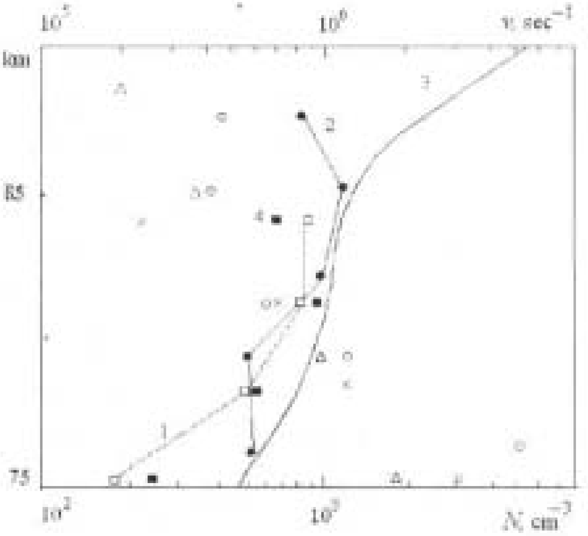


Fig. 1. Height $N(z)$ and $\nu(z)$ profiles obtained from amplitude measurements of $<\varphi>$' and $<a>$ on 04.05.1976 at 15.00 LT near Kharkiv city (curve 1, f = 2.04 MHz) and at 15.17 LT (curve 2, f = 2.19 MHz); $\nu(z)$ is shown by crosses and circles, respectively. Curve 3 is the $N(z)$ profile calculated by means of the model from [10]; curve 4 was obtained using the method from [9] for the experiment with f = 2.04 MHz; the angles show the model $\nu(z)$ profile from [5].

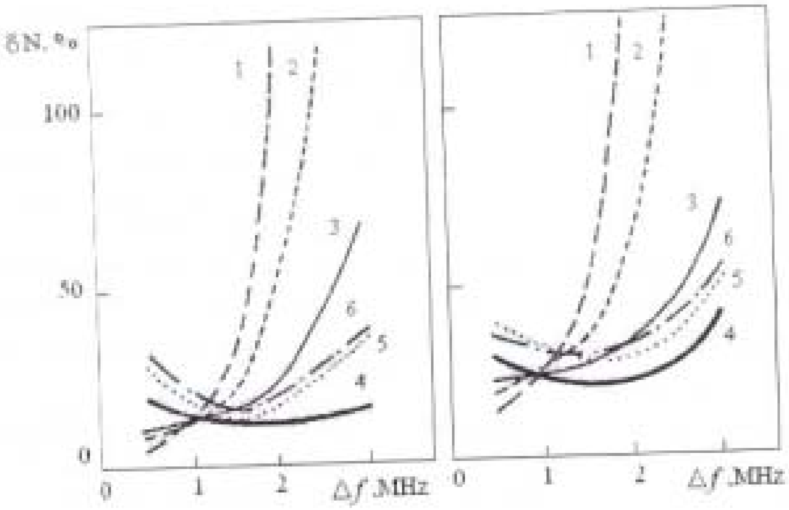
Fig. 1 shows results of the experimental testing of the methods under consideration. The measurements were conducted on 04.05.1976 near Kharkiv City by means of the equipment described in [23]. The height-time dependences of $A_{o,x}(z,t)$ and $A_{1,2}(z,t)$ were recorded from the oscillograph display on to the film, deign – after the digitalization – used to calculate $<\varphi>$ and $<a>$ by means of which there were calculated the $N(z)$ (curves 1 and 2) and $\nu(z)$ profiles (crosses and circles) for the two successive records made at 15.04. – 15.12. LT (f = 2.04 MHz) and at 15.17. – 15.27 LT (f = 2.19 MHz). The Figure shows also an $N(z)$ profile calculated using the same experimental data (for f = 2.04 MHz, curve 4) by means of the methods from [9] using the $\nu(z)$ profile (crosses). This profile, as well as the $N(z)$ profile for f = 2.19 MHz which is not given here, agrees with curves 1 and 2 rather well. We obtained similar results for a number of other records as well. Therefore, by this is meant that the methods considered can be used for systematic investigations.

The model $N(z)$ and $\nu(z)$ calculations made according to these methods and their comparison with the calculations using the method from [4, 5, 9] have shown that the methods suggested are sensitive to the errors to the same extent in the $A_{o,x}(z,t)$ and $A_{1,2}(z,t)$ measurements. Nevertheless, the combined use of both the methods allows to do minimize errors in determining $N(z)$ and $\nu(z)$ in the ionospheric D-region (see, e.g., an example in Fig. 1). In order to extend the height range under study, one should apply simultaneos sounding at 2 or more different frequencies within the 2 – 6 MHz range.

3.2. Using of simultaneous measurements of the differential absorption at two frequencies

It is known that PR signals are a sum of the reflections from all the ionospheric plasma irregularities which are situated in a volume having the vertical size $L = c\tau_i / 2$. The horizontal size of the scattering volume, $\dot{L}_{\perp}$, it set by an aperture of the antenna directivity, θ_A. According to the theory of radio waves scattering in a direction predetermined by the vector $\vec{n}_s$, energy is mainly scattered by the irregularities having a dimension of $l \sim \lambda / 2\sin(\theta / 2)$ where θ is the angle between the wave vectors of an incident and a back-scattered waves. Under the back-scattering, $\theta = \pi / 2$ and $l = \lambda / 2$, (λ is the sounding wave length), i.e. for $f = 2 - 6$ MHz $l \approx 75 - 25$m. For instance, according to [29], the PR signal intensity depends nonlineary versus the sounding frequency f. With this assumption and based on the PR technique one may jointly determine the $N(z)$ and $\nu(z)$ profiles in the D-region on the basis of simultaneous measurements of the differential absorption of the magnetoionic components at two different frequencies f_1 and f_2. There were carried out model calculations of such a possibility of joint determining the $N(z)$ and $\nu(z)$ profiles in the D-region with an error of $\leq 30\%$. The calculations were made as follows: 1) from [29] the typical $N(z)$ and $\nu(z)$ models was prescribed; 2) using formula (3) according to the typical models of $N(z)$ and $\nu(z)$ the value of $a_1(z)$ and $a_2(z)$ are calculated for frequencies f_1 and f_2 from 2 – 6 MHz frequency band and $\Delta f = f_1 - f_2 = 0.5$; 1; 1.5; 2; 3 MHz; 3) distortions $\delta a_{1,2}(z) = 1\%$, 5%, 10%, 20%, 50%, 100% were introduced into the $a_1(z)$ and $a_2(z)$ values; 4) using the $a_1'(z)$ and $a_2'(z)$ values obtained as a result of the previous procedure, the $N'(z)$ and $\nu'(z)$ values were calculated; 5) the errors δN an $\delta\nu$ as $\leq 30\%$ have been prescribed; 6) the height intervals of Δz and Δf were found for which condition 5 was fulfilled as a result of procedures 3 and 4.

Fig. 2 shows an example of the model calculations of the error in determining $N(z)$ depending on Δf for $f = 2.5$ MHz, $\nu_1 = 3 \cdot 10^5$ sec^{-1} and $\nu_2 = 2 \cdot 10^6$ sec^{-1}, the preassigned error $\delta a_{1,2}(z) = 10\%$ and for number of the N values. The model calculations have shown that simultaneous using of the two frequencies with $\Delta f \geq 1$ MHz allows simultaneous determining of $N(z)$ and $\nu(z)$ profiles in the D-region with an error of <30-50%, as a rule, over a height interval of 10 – 12 km. Using of a number of combinations of f_1 and f_2 allows to extend the range investigated up to 15 – 20km. We repeatedly tested these methods.



a)

b)

Fig. 2. Model dependences of the δN error as a function of Δf for $f = 2.5$MHz (ν, sec^{-1}: a) 2 10^6, b) 3 10^5) for some N-values, cm^{-3}: 1 is for 100, 2 for 400, 3 for 800, 4 for 1500, 5 for 2500, 6 for 4000.

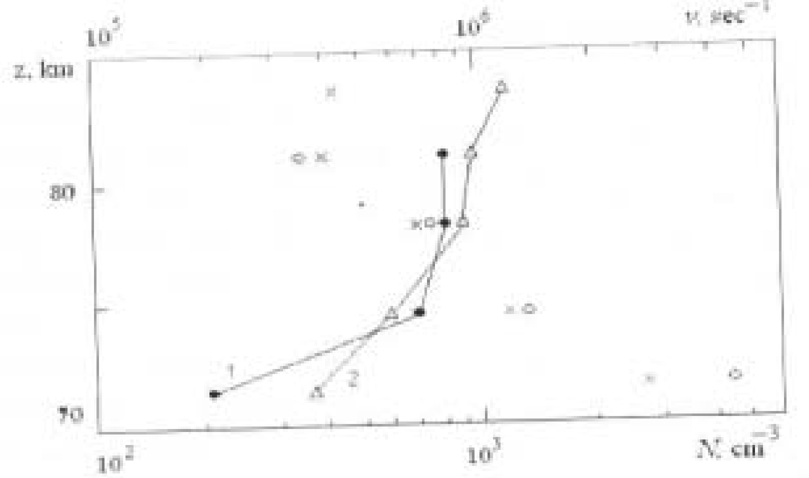


Fig. 3. Comparison of $N(z)$ and $\nu(z)$ profiles measured in the experiment on18.03.1983 within 15.30-15.40 LT: curve 1 is the $N(z)$ profile obtained from the simultaneous measurements of $a_1(z)$ and $a_2(z)$ ($f_1 = 1.885$ MHz and $f_2 = 3.556$ MHz, $\nu(z)$ is shown by circles); curve 2 was obtained using the method from [9] for $f_2 = 3.556$ MHz ($\nu(z)$ is shown by crosses).

Fig. 3 shows an example of the profiles of $N(z)$ (curve 1) and $\nu(z)$ (circles) in the D-region, calculated by means of the methods considered using the data obtained on 18.03.1983 at 15.30 – 15.40 LT near Kharkiv City. The experiments were conducted by means of the two facilities of the PR technique: the mobile [26] and stationary [23] equipment facilities belonging to Kharkiv National University. The $N(z)$ and $\nu(z)$ profiles were calculated by a method of successive approximations similar to that from [9], an equation (3) for $a_1(z)$ was used to obtain $N(z)$, and an equation for $a_2(z)$

finds use to obtain $\nu(z)$; the first $\nu(z)$ value was taken out of the model from [5]; there were used the following operating frequencies: $f_1 = 1.875$ MHz and $f_2 = 3.556$ MHz. For comparison this Figure shows the $N(z)$ (curve 2) and $\nu(z)$ (crosses) profiles obtained by the methods from [9] using the simultaneous measurements of $a_2(z)$ and the cross-correlation coefficient of PR signal intensities, $\rho_{A_x^2 A_o^2}(z)$, at the second frequency. Having checking against the profiles obtained and a number of other similar experiments, which coincide at 75 – 85 km within the measurement error, we may conclude that the considered way of simultaneous obtaining $N(z)$ and $\nu(z)$ can be used to study the ionospheric D-region. Note that in the lower and upper parts of the D-region, the errors in determining $\nu(z)$ are ~ 10 – 100%, which is caused by errors in the methods.

As it was shown from the experimental investigations the main difficulties in using the methods considered consist in the following: 1) not each experiment has simultaneous PR signals coming from the ionospheric plasma ionization irregularities at the two frequencies with $\Delta f \geq 1$ MHz with a required relation of signal/noise, often they are shifted and do not coincide in height; 2) necessity of making measurements at the two frequencies by means of the two PR technique facilities; 3) sensitivity to errors in measuring PR signal amplitudes (which is generally characteristic of the PR technique). Due to this feature, the methods are sporadically applied in the first place to extend the investigated height range (which is important) and to define more precisely the information on $N(z)$ and $\nu(z)$ obtained by other methods.

3.3. Using of reference electron density measurements

The most accurate $N(z)$ profiles in the lower ionosphere may be obtained in rocket experiments by the methods of the impedance sonde [1] or coherent frequencies [2]. At the same time, the error in determining $N(z)$ in the whole ionospheric D-region is $\leq 10\%$ (the main disadvantages of these methods are sporadic conducting of the experiments and their relative high prices). Therefore, it is logical to use the $N(z)$ profiles obtained in the rocket experiments as reference ones. The PR technique measurements carried out simultaneously with the rocket launches (in the rocket launch area) allow to solve a task of simultaneous obtaining the $N(z)$ and $\nu(z)$ profiles in the lower ionosphere: the $N(z)$ profiles obtained in the rocket experiments are used to obtain $\nu(z)$ values according to the differential absorption technique [5, 6] or to the correlation method [9]. Simultaneous using of both the methods allows to reduce methodical errors in calculating $\nu(z)$ values.

The similar experiments (the measurement series) were conducted in 1972, 1974, 1976, 1986 – 1987 near Volgograd City during different seasons (winter, summer, autumn) together with the Institute of Experimental Meteorology (IEM) and Central Aerospace Observatory (CAO) of the USSR State Committee of Hydrometeorology. The PR technique measurements were conducted by means of the mobile equipment [24,26]. Fig. 4 shows an example of results of such experiments: the $N(z)$ profile (curve 1) was obtained by the impedance sonde installed on an MR-12 rocket (the experiment time being 12.00 LT, 01.12.1972); the $\nu(z)$ profile (crosses) was calculated by means of the differential absorption method [5, 6] using data obtained by the PR technique with applying the $N(z)$ profile (curve 1) which in its turn was used to obtain the $N(z)$ value (curve 2) by means of the correlation technique [9]. The $\nu(z)$ and $N(z)$ values obtained correspond to the typical ones for the middle latitude ionosphere, the $N(z)$ profiles (curves 1 and 2) have practically coincided within the error of the methods, their difference in the lower and upper parts, as the analysis of the primary data has shown, has caused by the errors in the $\rho_{A_x^2A_o^2}(z)$ measurements. We used the methods considered for the data processing of the experiments mentioned above. It is important that these methods allow to determine $N(z)$ and $\nu(z)$ profiles in the lower ionosphere with the least error (~10-20%). The main disadvantage is a sporadic character of conducting investigations and fixing to a concrete place of the experiment (the rocket launching site).

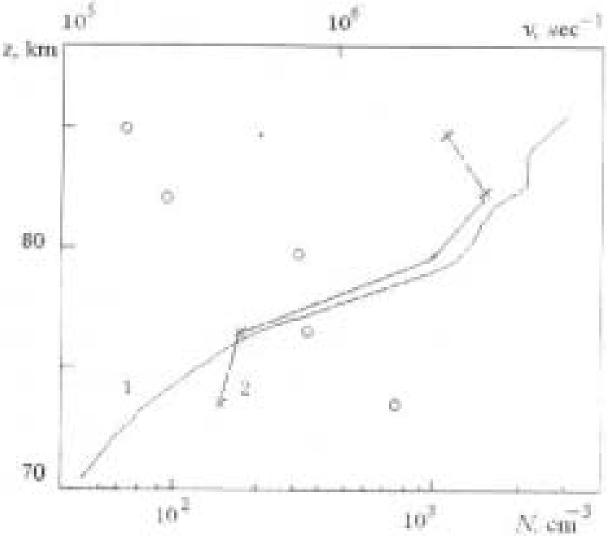


Fig. 4. Height $N(z)$ profiles: curve 1 was obyained by means of impedance sonde on the meteorological rocket at 12.00 LT vear Volgograd City on 01.12.1972; curve 2 was obtained by means of the methods from [9] using the $\nu(z)$ profile (circles) calculated by means of the differential absorption methods from [4, 5] from the PR technique data using the reference electron density profile 1.

3.4. Using of simultaneous measurements of $a\ (z)$ and $\rho_{A_x^2A_o^2}(z)$ at two frequencies

The methods [9] for simultaneous measuring $\nu(z)$ and $N(z)$ on the basis of combined measurements of $a\ (z)$ and $\rho_{A_x^2A_o^2}(z)$ at one frequency do not allow to investigate the whole ionospheric D-region because the using of such "low" frequencies as $f = 2-3$ MHz allows, as a rule, to study the height region of $z \leq 85$ km (with an error of <30-50%); using of such "high" frequencies as $f = 4-6$ MHz allows to investigate (with an error of < 30-50%) the upper ionospheric D-region ($z > 80$ km). Therefore it is logic, for obtaining information on $\nu(z)$ and $N(z)$ profiles in the whole D-region and lowering their errors to carry out simultaneous measurements of $a\ (z)$ and $\rho_{A_x^2A_o^2}(z)$ values at the two frequencies, $f_1 = 2-4$ MHz and $f_2 = 3-6$ MHz. In the case when PR signals at f_1 and f_2 are observed over the same height range (the overlapping part), measurement errors may be reduced.

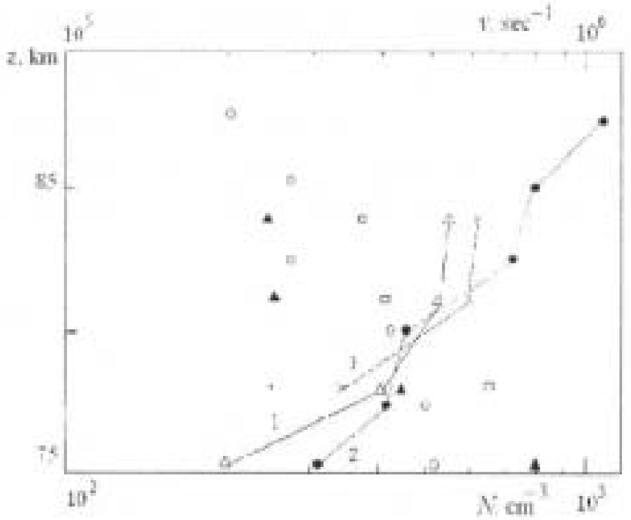


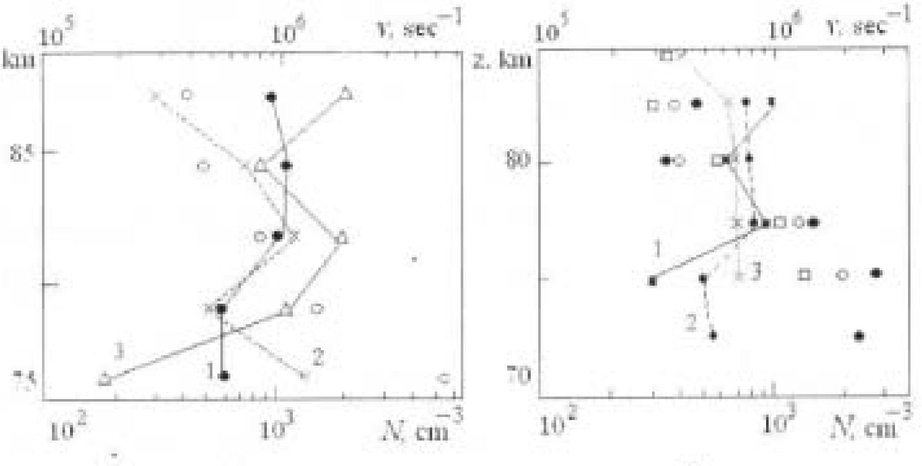
Fig. 5. An example of the $N(z)$ (curves 1 and 2) and $\nu(z)$ (triangles and circles) profiles obtained from the simultaneous measurements of $a\ (z)$ and $\rho_{A_1^2A_2^2}(z)$ at two frequencies of $f_1 = 2.06$ MHz and $f_2 = 2.96$ MHz. Curve 3 (crosses) is the $N(z)$ profile obtained by means of 3.2. method; rhombes show a corresponding $\nu(z)$ profile.

By means of the Kharkiv National Universuty equipment [23 – 26], repeated tests of these methods were carried out, which showed good results. For instance, Fig. 5 shows the $\nu(z)$ and $N(z)$ profiles obtained by the methods considered in the experiment of 19.03.1983 at 16.00 LT near Kharkiv City; the PR signal measurements were conducted at $f_1 = 2.06$ MHz by means of the stationary equipment complex [23] and simultaneously at $f_2 = 3.96$MHz by means of the mobile equipment complex [24] (figures near the curves correspond to the frequencies). It is seen from the Figure that the use of the second operating frequency allowed in the given case to extend the range investigated by 6 km; the $\nu(z)$ and $N(z)$ measurements in the overlapping height range (78 – 84 km) agree rather well. It also shows the profiles of $N(z)$ (crosses) and $\nu(z)$ (rhombs), obtained by means of the methods discussed in 3.2., which agree rather well with the ones discussed above.

4. Comparing of methods

Where it is possible let us compare the methods described on the basis of the experimental data. In 3.2. the methods of determining the $N(z)$ and $\nu(z)$values using the amplitude measurements of $<\varphi>$ and $<a>$ are given. A result of their experimental checking is given in Fig. 6a. In order to compare these methods and those from [9] using the same experimental data (the experiment being conducted on 04.05.1976 at 15.17 LT), the $\rho_{A_1^2A_2^2}(z)$ profile was calculated for $f_2 = 2.19$ MHz. The result was used for calculating (the $\nu(z)$ profile shown in Fig. 1 being used) the $N(z)$ profile (curve 2; curve 1 being the same as that in Fig. 1). The Fig. 6 shows that the calculation results within 79 – 85 km agree rather well; when we have heights lower or higher than this interval, the errors in determining the

$N(z)$ and $\nu(z)$ values are ~10-100%. According to our analysis of the primary experimental data one caused by the errors in both the methods. This Figure shows an $N(z)$ profile (curve 3) calculated using the methods from [30] (for $f_2 = 2.19$ MHz and the $\nu(z)$ profile given in Fig. 1). On the whole, this profile differs from curves 1 – 2, which, as we consider, was caused by violating the assumptions taken as a basis of these methods, which are by no means fulfilled under real conditions.



a) b)

Fig. 6. Comparing of $N(z)$ profiles obtained by means of the PR technique using different methods: a) from measurements of $< \varphi >$ and $< a >$ (curve 1), from measurements of $\rho_{A_1^c A_2^c}(z)$ (curve 2), by means of the methods from [30] (curve 3); b) by means of the methods proposed in 3.1. (curve 1, $\nu(z)$ values are circles) and by means of the methods from [9] for $f_1 = 2.56$ MHz and $f_2 = 3.556$ MHz (curves 2 and 3, $\nu(z)$ values are black circles and crosses).

Let us compare the results obtained by means of the methods discussed in 3.2. and 3.4. In order to do this, we use Fig. 6b showing the $N(z)$ profiles obtained by means of the methods from 3.2. (curve 1) and the methods from 3.4. (curves 2 and 3). The PR signal measurements were made on 18.03.1983 at 12.41 – 12.51 LT at $f_1 = 2.56$ MHz and $f_2 = 3.556$ MHz by means of the mobile and stationary equipment complexes belonging to Kharkiv National University [23–26]. The $\nu(z)$ profiles shown in the Figure are crosses, points and rhombs, respectively. The results given allow us to conclude that the $N(z)$ and $\nu(z)$ profiles obtained from the differential absorption measurements simultaneously at the two frequencies, within 75 – 83 km have the same values as those obtained by means of the methods from [9] (it was done earlier in another experiment: see Fig. 3). The differences in the electron density and electron-neutral collision frequencies at the higher and lower heights were caused by the errors in the $a(z)$ and $\rho_{A_1^c A_2^c}(z)$ measurements. The compared procedures of a great number of other our experiments gave similar results as well.

5. Conclusion

We considered the main methods of determining the electron density and electron-neutral molecule collision frequencies in the ionospheric D-region by means of the partial reflection technique. It was shown that the existing methods do not often allow to obtain the ionospheric parameters with a required accuracy. With the purpose of improving accuracy and increasing information obtained by the PR technique, new methods were proposed and their experimental testing was conducted. On the basis of the experimental data, the methods were compared and present recommendations were given for more accurate obtaining of the ionospheric plasma parameters and for widening of the height range investigated. It was shown that common and simultaneous using of two or more methods (the known and the proposed in the paper) is necessary. It allows to minimize errors in measuring the ionospheric parameters.

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