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EMPIRICAL MODELING OF TIME AND ALTITUDE VARIATIONS OF ELECTRON-NEUTRAL MOLECULE COLLISION FREQUENCIES IN THE IONOSPHERIC D-REGION

A.M. Gokov[1,♦] & O.F. Tyrnov[2]

[1]*S. Kuznets Kharkiv National University of Economics, 9a Nauka Ave., 61166 Kharkiv, Ukraine*

[2]*V. Karazin National University of Kharkiv, 4 Svoboda Sq., Kharkiv, 61022 Ukraine*

♦Address all correspondence to: A.M. Gokov, E-mail: 19amg55@gmail.com

There are considered and analyzed basic particularities of the time and altitude distribution of the electron-neutral molecule collision frequencies in the undisturbed mid-latitude ionospheric D-region obtained on the basis of long-term systematic experimental studies near the city of Kharkiv, Ukraine and episodic target observations near Volgograd, Russia performed using the methods of partial reflections and rocket based impedance probe.

KEY WORDS: *ionospheric D-region, methods of partial reflections and probe impedance, model of electron-neutral molecule collision frequencies*

1. INTRODUCTION

In order to solve quite a number of scientific and application problems of telecommunication, radio navigation, internet systems etc. it is necessary to know with the acceptable accuracy (the error of δN, $\delta\nu \leq$ 30%) two profiles: of the electron concentration $N(z,t)$ and the electron-neutral molecule collision frequency $\nu(z,t)$, along with their time and space variations. Studying of variations of the profiles $\nu(z,t)$ in the lower ionosphere is performed using different techniques (see, for example, [1–5]). However, known in the references measurements of the profile $\nu(z,t)$ are performed separately and very often with a great deal of error and without full description of the conditions for performance of the observations concerned. There are a few desired measurements. Some researchers (see, for example, [1]) are using the averaged profile $\nu(z,t)$ considering that both daily and seasonal as well as the latitude variations of $\nu(z,t)$ do not exceed 20% in the D-region. However, at present, there is no commonly accepted opinion related to variations of the $\nu(z)$ -profile in the D-region. For that reason there exists no reliable model of time and altitude variations of $\nu(z,t)$. Several models of $\nu(z,t)$, which are built mostly on the basis of the atmospheric pressure profile $p(z)$ of this or that model of the standard CIRA atmosphere are usually used for solving of various problems in the references. The data of rocket studying of $p(z)$ are normally applied for building of experimental models of the $\nu(z)$-profiles. In a number of papers (see, for example, [3,6,7]) it is demonstrated that often, during the periods of regional particularities in the behavior of the atmosphere, for example, at stratospheric warmings, at propagation of the acoustic gravity waves (AGW) etc. strong variations of temperature and pressure occur at the altitudes of 70 to 100 km; they attain 80…100%. Therefore, similar variations of $\nu(z,t)$ should be expected at the above altitudes. Consequently, there increases the value of measurements of the $\nu(z)$ -profiles performed under different conditions. During the recent decades in order to study variations of $\nu(z)$ in the lower ionosphere it is more and more often applied the partial reflections (PR) (see, for example, [1,2,4,8,9]), which allows simultaneous obtaining of the $N(z)$ and the $\nu(z)$-profiles in the D-region with the acceptable accuracy.

The results of empirical modeling of time and altitude variations of the electron-neutral molecule collision frequencies in the ionospheric D-region are provided in the paper on the basis of the long-term systematic experimental studies near the sity of Kharkiv and episodical purposed observations near Volgograd performed by the methods of PR and the probe impedance (PI) using the rockets.

2. RESULTS OF EMPIRICAL SIMULATION

Studying of possible variations of $\nu(z)$ in the D-region was performed using three different methods based on the observations made in two mid-latitude regions during different seasons of the year – near the cities of Kharkiv and Volgograd. Variations of $\nu(z)$ in the middle and upper parts of the ionospheric D-region (at the altitudes of $z \geq 75$ km) were studied using the techniques considered in [2,10] (the measurements were performed with the help of the PR technique only), and during the joint measurements using the PR methods (the duration of registrations for obtaining of the $\nu(z)$-profile was 10 minutes) and the IP method using the rockets [6,7]. Variations of $\nu(z)$ were studied in the lower part of the D-region (at the altitudes of $z < 75$ km) using the techniques considered in [11].

2.1 Daily Variations

The studies near Kharkiv were performed based on the observations made by the PR method during different seasons of the year. In this case the altitude profiles $\nu(z)$ are calculated with the error of $\leq 30\%$ using the techniques related to simultaneous measurements of the differential absorption $a(z)=\langle A_x^2(z)\rangle / \langle A_0^2(z)\rangle$ and the correlation coefficient $\rho_{A_o^2 A_o^2}(z)$ of the magnetic ion components of the PR-signals developed in the papers [2,10]. Total number of daily cycles (during the daytime) of the processed and analyzed measurements was 9. From 4 to 8 profiles of $N(z)$ and $\nu(z)$ were obtained during each measurement cycle. Simultaneous measurements of the lower ionosphere parameters by the PI method using the rockets [6] and by the PR method with the help of the mobile radio-physical complex [12] were performed near Volgograd on 19–20.08.1976. The profiles $N(z)$ were measured during the rocket experiments with the error of $\leq 10\%$ and used for obtaining of the profiles $\nu(z)$ under the differential absorption technique by the PR method based on the measurements of $a(z)=\langle A_x^2(z)\rangle / \langle A_0^2(z)\rangle$. The error of the $\nu(z)$-profiles obtained in that manner was not exceeding 20%.

Let us consider the examples of variations of $\nu(z)$ in the medium and upper parts of the D-region (at the altitudes of $z \geq 75$ km). Figure 1 provides the examples of the $\nu(z)$-profiles obtained at different zenith angles of the Sun during the daytime on 11.06.2003 in the summer season on the basis of simultaneous measurements near Kharkiv and on 19–20.08.1976 near Volgograd.

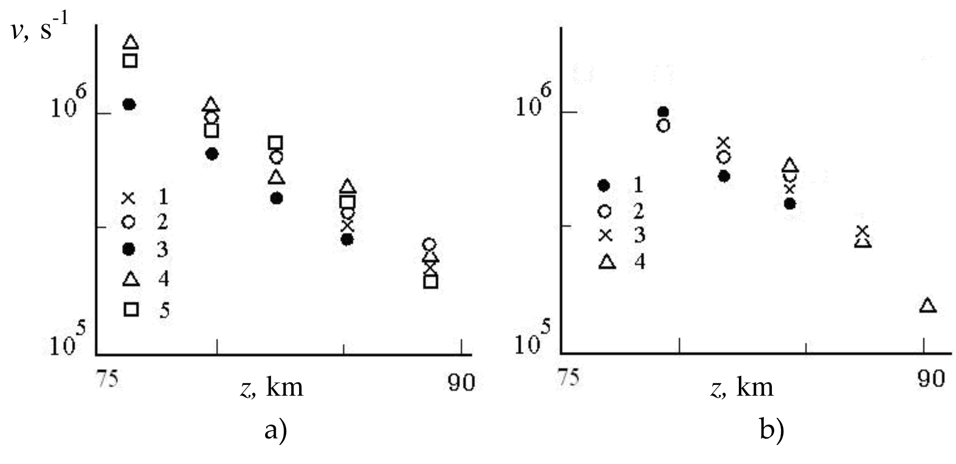


FIG. 1: Variations of $\nu(z)$ in summer during the day at middle latitude of z > 75 km (local time – LT): a – near Volgograd, 20.06.1976: 1 – 09:10 a.m., 2 – 11:47 a.m., 3 – 06:30 a.m.; 19.06.1976: 4 – 11:51 a.m., 5 – 5:18 p.m.; b – near Kharkiv, 11.06.2003: 1 – 09:30 a.m., 2 – 11:30 a.m., 3 – 1:30 p.m., 4 – 3:30 p.m.

Shown in Fig. 2 are examples of the $\nu(z)$-profiles obtained at different zenith angles of the Sun during the daytime in summer (19.08.2006 and 01.08.2008) and in winter (05.02.2003 and 28.01.2004) near Kharkiv.

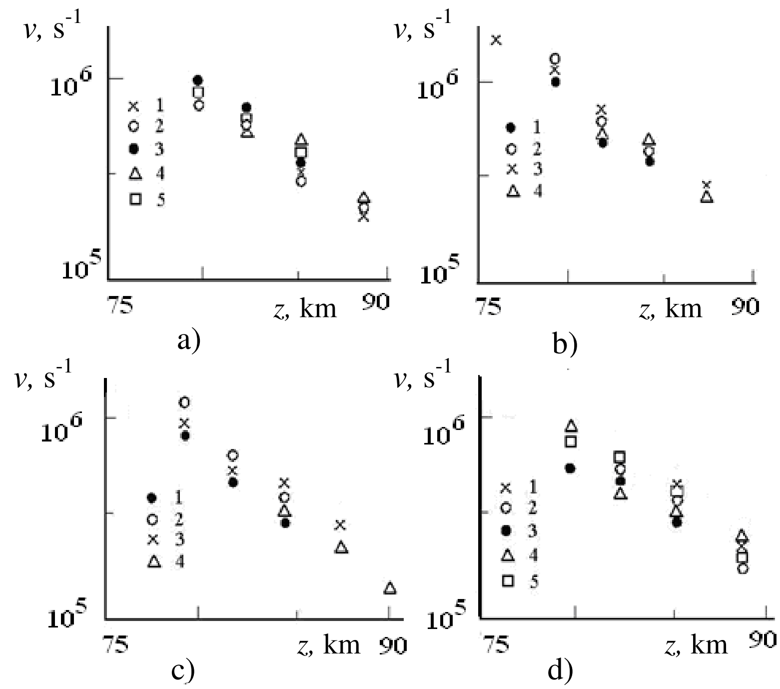


FIG. 2: Variations of $\nu(z)$ in summer during the daytime in middle latitude, z > 75 km (local time – LT): a) 01.08.2008: 1 – 09:00 a.m., 2 – 11:40 a.m., 3 – 1:30 p.m., 4 – 3:30 p.m., 5 – 5:30 p.m.; b) 19.08.2006: 1 – 09:30 a.m., 2 – 11:30 a.m., 3 – 1:30 p.m., 4 – 4:30 p.m., and in winter: c) 05.02.2003: 1 – 09:50 a.m., 2 – 11:30 a.m., 3 – 1:30 p.m., 4 – 3:00 p.m., 5 – 4:20 p.m.; d) 28.01.2004: 1 – 09:40 a.m., 2 – 11:30 a.m., 3 – 1:30 p.m., 4 – 3:00 p.m.

The above examples illustrate variations of $\nu(z)$ during the daytime (depending upon the zenith angle of the Sun) in the upper part of the mid-latitude D-region at $z \geq 75$ km. The differences between the values of $\nu(z)$ obtained in various mid-latitude regions, as it is evident from Fig. 2, do not exceed the measurement error values, that is we may consider that regional discrepancies in the variations of $\nu(z)$ in the undisturbed mid-latitude D-region are absent. Nevertheless, they are possible during the periods of some regional disturbances.

In order to determine the regional distinction it was performed a comparison of the profiles $N(z)$ and $\nu(z)$ obtained simultaneously and at the same value of the zenith angle of the Sun with the help of measuring of the ionospheric parameters by the PI method using the rockets [6] and with the help of the PR method near Volgograd (the geographical latitude was 48.4° N) and with the help of the PR method near Kharkiv (the geographical latitude was 49.9° N). In the first case the profiles $\nu(z)$ were obtained based on the techniques considered in [10,11] on the basis of measurements by the PR method using the profiles $N(z)$ obtained by the PI method during the simultaneous rocket experiments.

Table 1 provides the results of such measurements for the experiments performed on 29.10.1995.

As it is evident from the presented examples and other results, which are not provided in this paper, the regional dependence of the electron-neutral molecule collision frequencies is absent at the altitudes $z \geq 75$ in the mid-latitude lower ionosphere while the regional distinctions occur in $N(z)$ and they can be wieving clearly.

TABLE 1: Comparison of the profiles $N(z)$ and $\nu(z)$ obtained in different regions

z, km	Kharkiv (10:20 a.m. LT)		Volgograd		Kharkiv (11:00 a.m. LT)		Volgograd	
	N, cm^{-3}	$\nu \cdot 10^{-7}$, s^{-1}	N, cm^{-3}	ν x10^{-7}, s^{-1}	N, cm^{-3}	ν x10^{-7}, s^{-1}	N, cm^{-3}	ν x10^{-7}, s^{-1}
72			240	0.181	210		280	0.192
75	420	0.128	590	0.115	510	0.101	650	0.111
78	680	0.087	780	0.071	720	0.078	870	0.069
81	890	0.038	1010	0.045	910	0.032	970	0.040
84	1210				1450			

Variations of $\nu(z)$ in the lower part of the D-region (at the altitudes $z < 75$ km) were investigated on the basis of the measurements performed with the help of the PR method only using the techniques of [10] with the error of $\leq$ 30%. As an example, Fig. 3(a) provides the variations of $\nu(z)$ near Kharkiv during the daytime on 14.12.1984, and Fig. 3(b) shows the variations of $\nu(z)$ during the day on 19.03.1983.

These examples along with the results of other experiments show that variations of the profile $\nu(z)$ in the undisturbed mid-latitude D-region are insignificant during the daytime, they are within the limits of the measurement errors performed by the PR method ($\leq$ 30%), i.e., the dependence of the electron-neutral molecule collision frequencies upon the zenith angle of the Sun $\nu(z,\chi)$ is also absent at the altitudes of $z < 75$ km.

2.2 Seasonal Variations

Probable seasonal variations of $\nu(z)$ at $z \geq 75$ km were studied, as before, upon the measurements with the help of the PR method near Kharkiv and during the joint measurements near Volgograd by the PI method using the rockets [6] and by the PR method with the help of the mobile radio-physical hardware complex [12]. In the first case the values of $\nu(z)$ are obtained jointly with the profiles $N(z)$ based on the technique described in [2,10], in the second – the $N(z)$-profiles measured by the PI method using the rockets were applied for obtaining the profiles $\nu(z)$ based on the differential absorption technique [13].

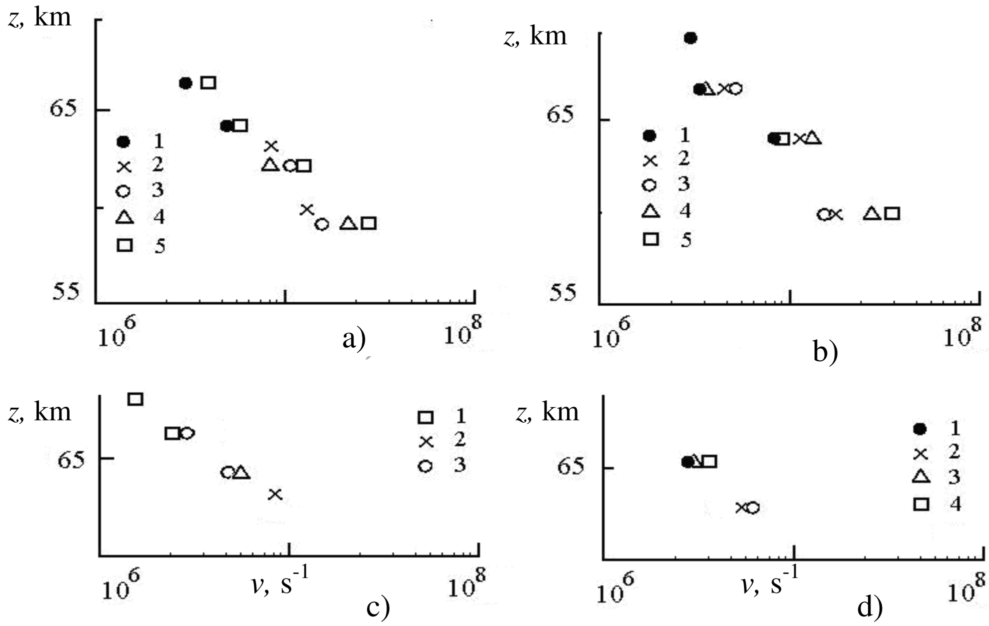
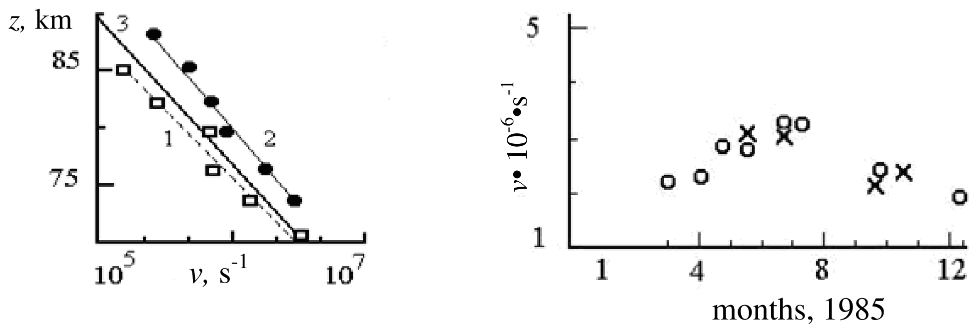


FIG. 3: Variations of $\nu(z)$ in the lower part of the D-region during the day at the middle latitude near Kharkiv (local time LT): a) 14.12.1984: 1 – 10:00 a.m, 2 – 11:01 a.m., 3 – 1:07 p.m., 4 – 2:00 p.m., 5 – 3:30 p.m.; b) 19.03.1983: 1 – 09:03 a.m., 2 – 10:00 a.m., 3 – 11:42 a.m., 4 – 4:30 p.m., 5 – 4:00 p.m.; c) 28.01.2004: 1 – 10:00 a.m., 2 – 12:00 p.m., 3 – 2:00 p.m.; d) 05.02.1998: 1 – 10:00 a.m., 2 – 12:00 p.m., 3 – 1:30 p.m., 4 – 3:30 p.m.

Figure 4(a) shows the altitude $\nu(z)$-profiles obtained at about noon local time during the joint measurements using the PR and IP methods during the rocket experiments near Volgograd under the undisturbed conditions in summer: 19.06.1976 at 11:51 a.m. LT (the dots) and in winter: 01.12.1972 (the rectangles). Solid line in Fig. 4(a) denotes the $\nu(z)$-profile obtained on 01.12.1972 using the method of pulse cross-modulation (CM) at 12:00 p.m. LT near Moscow [9]. It is apparent that the summer values of ν exceed the winter ones by approximately 1.6 times (the difference between the values of $\nu(z)$ obtained by the PR and CM methods is about 30% that is evidently stipulated by the errors of the methods).

Figure 4(b) provides the dependence of the values of $\nu(z)$, obtained using the PR method near Kharkiv (the circles) and near Volgograd (the crosses) during different seasons (the profiles $\nu(z)$ are obtained based on the technique considered in [13], the values of $\nu(z)$ are provided for the altitude of 78 km). The values of $\nu(z)$ measured in two mid-latitude points match within the limits of the measurement errors. This example is also illustrating possible seasonal variations of $\nu(z)$ in the mid-latitude D-region.



a) b)

FIG. 4: Examples of seasonal variations of the electron-neutral molecule collision frequencies in the mid-latitude D-region

Seasonal variations of $\nu(z)$ in the lower part of the ionospheric D-region (at the altitudes of $z < 75$ km) were investigated only based on the measurements performed with the method of PR near Kharkiv using the techniques of [8,11]. The error in measuring $\nu(z)$ was not exceeding 30%. The results of calculations for two seasons (there were performed the calculations of the values of ν for the altitude range of $z = 60\ldots66$ km) are provided in Table 2. They confirm availability of possible seasonal variations of the electron-neutral molecule collision frequencies in the lower part of the D-region (see, for example, [4,5]): the summer values of ν_1 exceed the winter ones ν_2 by approximately 1.4…1.6 times.

TABLE 2: Average values of the collision frequencies for summer and winter conditions

z, km	ν_1 **(summer)**	ν_2 **(winter)**	ν_1 / ν_2	$\langle \nu \rangle$
60	$0.403\ 10^8$	$0.274\ 10^8$	1.47	$0.339\ 10^8$
63	$0.250\ 10^8$	$0.154\ 10^8$	1.62	$0.202\ 10^8$
66	$0.174\ 10^8$	$0.164\ 10^8$	1.07	$0.169\ 10^8$

2.3 Latitude Variations

To determine the possible latitude variations of $\nu(z)$ in the D-region it is performed the comparison of the averaged $\langle\nu(z)\rangle$ -profiles obtained using the techniques developed in the paper [2] upon simultaneous measurements of the differential absorption $a(z)$ and the correlation coefficients of the squares of amplitudes of the PR-signals $\rho_{A_o^2 A_x^2}(z)$ using the PR method du-ring the daytime at the middle latitude on 31.07.1981 near Kharkiv (the geographical latitude is $\varphi = 49°38'$) and at the high latitude 02.07.1977 near Murmansk ($\varphi = 69°$). The results are presented in Fig. 5. The circles in this Figure denote the averaged upon 5 realizations $\langle\nu(z)\rangle$-profile for the middle latitude, the dots is averaged for the high latitude (the averaging was performed upon 6 registrations uniformly distributed during the daytime). Vertical sections determine the spread of the obtained data; solid lines define the assessment of the spread for the experimental profiles of the collision frequencies under the undisturbed conditions, which assessment was obtained by the author after examining the reference source data measured experimentally with the help of different techniques.

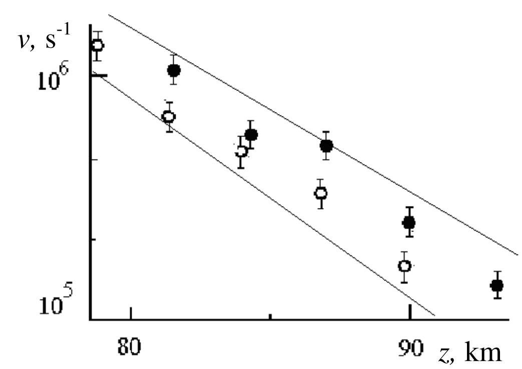


FIG. 5: An example of latitude variations of the electron-neutral molecule collision frequencies in the ionospheric D-region

From Fig. 5 it is evident that the differences between the $\langle\nu(z)\rangle$-profiles are small, although the values of $\nu(z)$ for the high latitude are slightly exceeding the values of $\nu(z)$ for the middle latitude (both averaged and individual ones). The spread of the experimental profiles of the collision frequencies under the undisturbed conditions obtained on the basis of examining the reference sources is substantially higher. It is stipulated, primarily, by the measurement errors and, apparently, by possible latitude variations of the collision frequencies. It should be noted that the issue of possible latitude variations of the electron-neutral molecule collision frequencies in the undisturbed lower ionosphere still remains open by now. Studying of such variations is a costly and complicated problem to be solved, therefore, the results provided above represent a vital importance.

Studying of possible variations of the electron-neutral molecule collision frequencies in the D-region during the periods of some natural disturbances occupies a special position among the ionospheric investigations.

This problem is very complicated. This is reasoned both due to complexity of performing the necessary experiments and to absence or insufficient accuracy of the known calculation techniques for the collision frequencies. On the other hand, knowing of such variations is necessary both for correct interpretation of the observation results and for solving the application and scientific problems.

2.4 An Example of Investigation of Possible Variations of the Electron Collision Frequencies in the Mid-Latitude Ionospheric D-Region during a Heavy Thunderstorm

Let us consider separate results of experimental studies of possible variations of $\nu(z)$ in the mid-latitude D-region during a heavy thunderstorm and during the disturbance periods of the mesospheric electric fields (see, for example, [14]). An attempt was made to experimentally study possible variations of $\nu(z)$ in the lower part of the D-region during a heavy thunderstorm. With that purpose on 06.08.1986 near Kharkiv there were performed with the help of the PR method the measurements of amplitudes of the PR-signals $A_{o,x}(z,t)$ and $A_{so,x}(z,t)$ in 10–minute cycles after each 30 minutes starting from 9:30 a.m. till 4:30 p.m. LT. In the vicinity of the observation point (the range is equal to approximately several kilometers) the thunderstorm lasted for about the time period from 10:30 a.m. till 12:10 p.m. LT; the sources of thunderstorms were traced at the ranges of several kilometers during the entire day. A typical feature for the above experiment was in the fact that in all the cases there were recorded distinct PR-signals from the altitudes of 63…84 km. The signal-to-noise ratio exceeded, as a rule, the value of 2…10. We note that under the undisturbed conditions similar PR-signals are recorded in the lower D-region by the equipment provided by V. Karazin Kharkiv National University in 1…2% of cases approximately. This allowed obtaining the values of the electron collision frequencies in the lower part of the mid-latitude D-region on the basis of the technique from [8,10,11] using the correlation $R_{0,x}(z,t) = \langle A_x^2 \rangle / \langle A_{no}^2 \rangle = R(\nu)$. The calculation error for ν amounted to less than 30…40%. Shown in Fig. 6 are provides the results of calculations of ν for the altitude z = 63 km (marked as 1). The shaded area denotes the time of the thunderstorm. The data marked in the Figs. 2 and 3 correspond to the values of ν obtained during other thunderstorms. It is evident from Figure 6 that during the thunderstorm the values of the electron-neutral molecule collision frequencies ν at z = 63 km increase by 1.5…1.7 times approximately. The difference between the values of ν obtained during the periods of different thunderstorms results, apparently, from the difference in the nature of the thunderstorms and the difference in the conditions in the ionosphere and the atmosphere during the above periods.

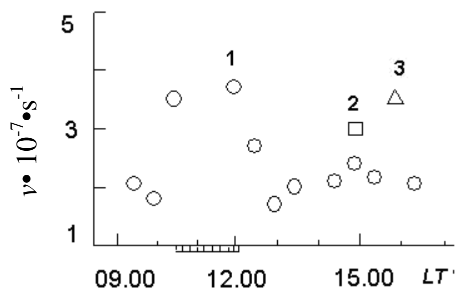


FIG. 6: Variations of the electron-neutral molecule collision frequencies at the altitude z = 63 km in the mid-latitude D-region during the periods of thunderstorms: 1 - 6 August 1986; 2 - 22 August 1986; 3 - 3 June 1987

3. CONCLUSIONS

The empirical model of time and altitude variations of the electron-neutral molecule collision frequencies $\nu(z)$ is built in the undisturbed ionospheric D-region. It is determined that regional discrepancies in the variations of $\nu(z)$ in the undisturbed mid-latitude D-region are absent, however, they are possible at certain regional disturbances. It is also determined that variations of $\nu(z)$ in the undisturbed mid-latitude D-region are insignificant during the daytime, they lie within the limits of the measurement errors using the PR method ($\leq$ 30%), i.e., the dependence of the electron-neutral molecule collision frequencies upon the zenith angle of the Sun $\nu(z,\chi)$ is absent. The results of experimental studies witness for availability of the seasonal and latitude variations in the mid-latitude D-region: the summer values of $\nu(z)$ exceed the winter ones by 1.4…1.6 times approximately.

Despite the limited experimental data the above results provide for both quantitative and qualitative characteristics of the time and altitude variations of the electron-neutral molecule collision frequencies in the D-region. However, they can be used as a preliminary model of seasonal variations of $\nu(z)$ in middle latitudes and specified by other targeted measurements.

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