THE CHANGE OF DIFFUSION PROCESSES FOR $O^+ + N_2 \rightarrow NO^+ + N$ REACTION IN THE IONOSPHERIC F REGION DURING THE SOLAR ECLIPSE OVER KHARKOV

by

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Research on solar eclipses has been a very importance in detecting short and medium-scale changes in the ionosphere. In this paper, the relationship between the changes in self-diffusion coefficients of the $O^+ + N_2 \rightarrow NO^+ + N$ reaction with the solar eclipse of March 29th, 2006 in Kharkov, Ukraine (49.6° N and 36.3° E) was investigated for 202, 252, and 303 km. The results of the research showed that self-diffusion coefficients increases with the increase of ionospheric altitude in each three days and the maximum diffusion value is reached at 303 km on 29th of March. It can be said that results of effects of solar eclipse in Turkey on ionosphere, results of the study of the experimental measurement and obtaining results of our study are consistent with one another.

Key words: *ionosphere, chemical processes, Kharkov incoherent scatter radar, solar eclipse, diffusion*

Introduction

Solar eclipse offers a unique opportunity to study the ionospheric and dynamic processes related to the sudden changes that will be occurred especially during and after the eclipse [1]. The ionosphere structures are degenerated due to solar eclipse, and many researchers have conducted different models, theories and observations researches on the ionospheric response to solar eclipse. The importance of solar radiation on ionization has demonstrated by theoretical investigations of the ionospheric response to a solar eclipse [2, 3]. In order to investigate the effect of solar on the ionosphere, several theoretical models on the behavior of the atmosphere during the solar eclipse were developed [4-8]. Studies have been conducted on the investigation of the changes in ionospheric behavior during solar eclipse [9]; in addition, the Incohorent Scatter Radar, located near Kharkov city, Ukraine has also been used extensively to study the effect of solar eclipse on the ionosphere [10-15].

Solar eclipse provides a potential to the investigations of important events such as photoionization and dynamic processes in the ionosphere due to sudden changes in solar radiation. The dynamic processes during an eclipse are significantly depends on changes in daily, solar and geophysical variations. Changes in neutral gas release and photoionization cause sudden perturbation of the natural structure of the ionosphere. Further, observation and investigation of ionospheric structure during solar eclipse have contributed extremely to the understanding transport, dissociation, recombination, diffusion, collisions, production and loss processes as well as radio propagation [1].

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The diffusion subject has been studied by many authors as theoretical and experimental in the ionosphere plasma [16]. Diffusion event in the ionosphere was first suggested by Hulburt, but the equations he put forward are partially incorrect. In 1945 Ferraro published work which is now accepted as the basic paper on the diffusion. Rishbeth [17] performed a study regarding how production, loss, diffusion and electromagnetic drift change for determine the daytime F_2 region under equilibrium conditions. The general expression for thermal diffusion and diffusion correction factors in an ion was made by Pavlov and Pavlova [18] for multicomponent partially ionized plasma. Dominguez was used Bohm-type coefficient of diffusion with quantum mechanical methods in plasma. The diffusion coefficient was calculated by many authors for not only electron but also minor ions as the frequency independent for mid-latitudes in the ionosphere plasma [16].

The solar is the most important factor in controlling the electron density mechanism in the ionosphere; in addition, reactions are also important in explaining the increase and decrease of electron density in the ionosphere. Therefore, the investigation of reaction processes for O^+ ion, which density is almost close to electron density, will contribute to the understanding of the loss and production processes in the ionosphere. One of the most important reactions involving the loss of O^+ in the ionosphere [19]:

$$O^+ + N_2 \rightarrow NO^+ + N$$

In this study, diffusion coefficient calculations for the aforementioned reaction, one of the basic reactions controlling the ionization density in the ionospheric F region, were made. In these calculations, both the data obtained from Kharkov incoherent scatter radar (ISR) and the thermospheric NRLMSISE-00 model was used.

General information for the solar eclipse and the ISR

The March 29, 2006, eclipse was partial for Ukraine, since the maximum coverage of the solar disk was 77.4%. The eclipse was observed over Kharkov from 10:02 to 12:21 according to universal time (UT), and the maximum coverage of the solar disk took place at 11:12 UT. The partial eclipse duration is 2 hours 18 minutes in total.

We used the Kharkov ISR data to investigate the effect of solar eclipse in the ionospheric regions. The Kharkov ISR has a very important source about processes characterizing the ionospheric plasma behavior around the region where it is located. The geographic co-ordinates of the radar are: 49.6° N and 36.3° E. The ISR is a unique measurement tool for measuring the basic ionospheric parameters such as vertical component of the charge particle transport velocity, V_z, temperatures of electrons, T_e, and ions, T_i, electron density, N_e [12].

Data and methods

Analysis of ionosphere/thermosphere chemistry with both theoretical and experimental works must be carried out due to numerous factors, such as the great increases in the energy system of the earth-ionosphere system, short and medium-scale changes in density and temperature during the solar eclipse, collision and the abrupt interruptions in electromagnetic wave propagation. In this study, the diffusion processes for $O^+ + N_2$ reactive collision were investigated during the March 2006 solar eclipse. The reactive collisions are of great importance in understanding the upper ionosphere [20]. The difficulty in calculating of the reaction cross-section complicate the analysis of the reactive collisions processes [21]. For this reason, it is important to calculate an important transport process such as self-diffusion for a reactive collision.

Transport processes

Diffusion

The dynamical and chemical processes are effective on a significant part of particle distribution in the ionosphere/atmosphere system. Transport event begins to play an important role in determining the particle distribution, when the rates of destruction and formation of a chemical constituent are comparable to the rate of compounds affected by dynamical mechanism. The varieties of temporal and spatial scales produce transport. In atmospheric works, it is usual to distinguish between activities that can be resolved on the large-scale advection and molecular diffusion that are often parameterized by diffusion coefficients. Molecular diffusion primarily controls vertical transport of chemical compounds in the ionosphere [22]. One of the simple examples for molecular diffusion is self-diffusion concept. Random motion of medium particles without any changes in medium chemical constituent is called as self-diffusion which is characterized by self-diffusion coefficient (SDC). All components of the structure and mutual diffusion coefficients are clearly related to SDC [23].

In the case of self-diffusion the concentration is a slowly varying function of direction, while the temperature remains constant in the container. If the SDC is written directly:

$$D = \frac{1}{3}\lambda\overline{v} \tag{1}$$

where λ is the mean free path and $\overline{v}$ – the mean particle velocity.

The SDC can be obtained with a different expression terms λ and $\overline{v}$. The diffusion coefficient can be re-written in relation basic molecular properties:

$$D = \left(\frac{2}{3}\frac{1}{\sigma}\sqrt{\frac{k}{\pi m}}\right)\frac{\sqrt{T}}{n} \tag{2}$$

where σ is reaction cross-section for ion-neutral collision [24].

Results and discussion

In this research, reaction dynamics and SDC of $O^+ + N_2'$ reactive collision are calculated for the date of March 28, 29, and 30, 2006. The main purpose of the research is to examine changing SDC which is an important transfer process in while-eclipse, pre-eclipse and post-eclipse as consisting of the day before (on March 28, 2006) and the day after (on March 30, 2006) of the solar eclipse on March 29, 2006. The SDC were calculated from UT 09:00 to 13:00 for 202, 252, and 303 km on March 28, 29, and 30. Temporal change of SDC is shown in fig. 1 for three altitudes.

Changes of SDC are nearly same in each three altitudes from the time starting at UT 10:02 to the time ending at 12:21 on March 29, when the solar eclipse occurred. The SDC fall down minimum in each evaluation at UT 11:12 which is the time of maximum occultation. Whereupon maximum coverage, it is detected that SDC increases. In the day of eclipse, SDC values are higher than SDC values which belong before the eclipse in each three altitudes.

The day before the eclipse, on March 28, it is seen that changes of SDC values are different in all altitudes. Minimum value of SDC is found approximately at 11:15 for 202 km, at 12:05 for 252 km and approximately at 11:30 for 303 km and also maximum values is found at different time periods.

On March 30, the day after the eclipse, it is encountered that there are similarities in increase and decrease in terms of the time in three altitudes of SDC. Both minimum value and maximum value are found in similar time periods. For three altitudes, it is reached that the minimum value is between 11:00 and 11:30 and the maximum value is between 12:00 and 12:30.

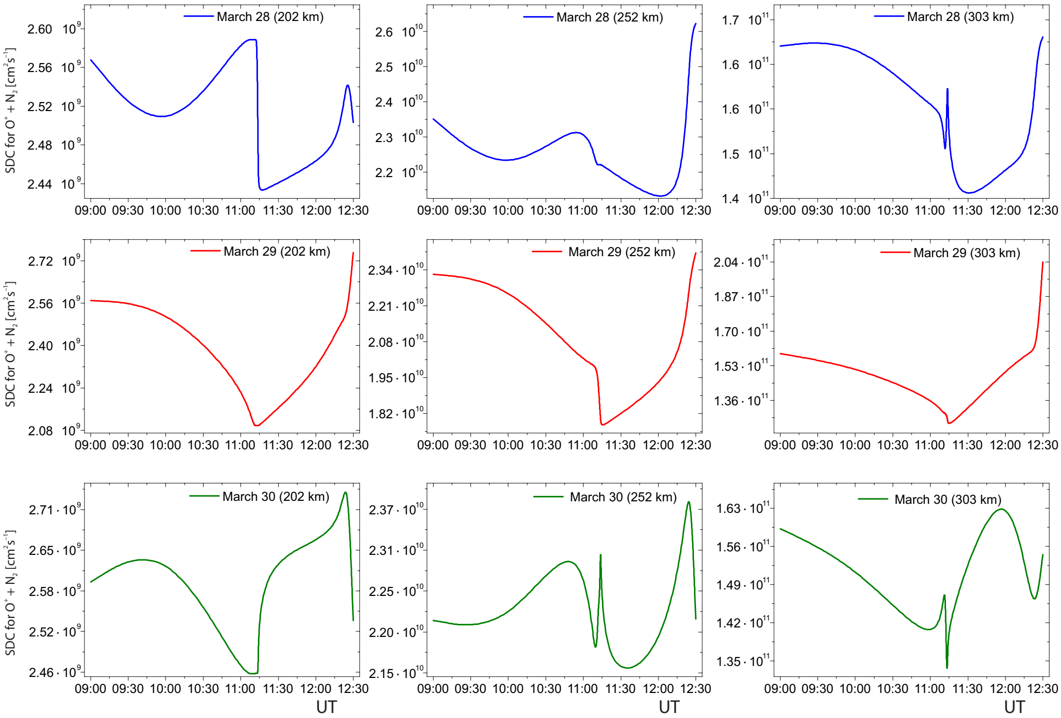

Figure 1. Change of self diffusion coefficient with the ionospheric height for days March 28, 29, and 30, 2006

Total eclipse which was passed almost half of the earth on March 29, 2006, includes Turkey. In order to examine the effect of the eclipse on the date, Turkish scientists do an experiment as using high frequency (HF) wave propagation [25]. They used the HF system to detect disturbances in the ionosphere in previous studies [26, 27]. The eclipse started in Antalya at 12:37:33 and it finished in Trabzon at 15:25:21, including daylight saving time in Turkey's zone time. Figure 2 shows that ionospheric noise measurement data belonging HF wave system in which broadcast transmitting and receiving stations, are established between Trabzon and Antalya.

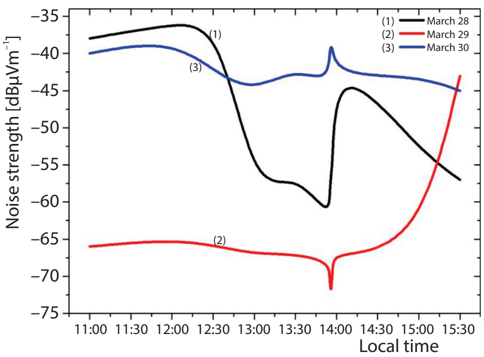

Figure 2. Variation of the noise strength during the total solar eclipse [25]

The noise power has showed decreasing gradually from local time at 12:00 to approximately at 14:00 on March 29. The noise strength fell down its minimum value approximately at 13:55. As soon as the total eclipse ended, the noise strength decreased. Changes on March 28 and March 30 do not show similarity both each other and in the day of the eclipse. On the one hand, changes are complex and rigid in the noise strength on March 28. On the other hand, changes are more linear and soft on March 30.

Conclusions

It has been determined that SDC increases with the increase of ionospheric altitude in each three days and the maximum diffusion value is reached at 303 km on March 29. It is thought to cause that compared to normal sunny days without eclipse with the day of the eclipse, obtaining maximum value of SDC, whereupon the eclipse, suddenly night conditions ends and switch day time conditions thus the Sun effect is strongly felt in the ionosphere. In addition, the reason why minimum SDC was seen at 202 km on March 29 is that altitude decreases because obtaining SDC, the efficiency of N_2 molecular density is more than the density of O^+ and the efficiency of the reaction cross-section.

The fact that the diffusion took the lowest value between 11:10 and 11:15 when the full coverage occurred in the date of the eclipse on March 29 shows the consistency of Kharkov ISR measurement data and it corresponds to expected results.

It has been determined that the diffusion values on March 28 and March 30 do not have any similarities both each other and the data on March 29. However, it has been observed that the perturbations of SDC on March 30 are more than the perturbations on March 28. It shows that the perturbations which continues after the eclipse is more than before. In other words, the effects of the sun, in the ionosphere, are also affective on the day after the eclipse.

It can be said that results of effects of solar eclipse in Turkey on ionosphere, results of the study of the experimental measurement and obtaining results of our study are consistent with one another. The minimum noise value has been reached on March 29 and the time period when full coverage occurred, in the experiment which atmospheric noise has been measured with the help of HF wave propagation for the dates March 28, 29, and 30. While the data on March 28 show similarity to decrease in the time period when the eclipse occurred, the data on March 30 differ. It supports the finding that the post-eclipse period is more perturbations than before.

The obtaining results exhibit the effect of the solar eclipse on an important transfer process as diffusion, how important and effective measurement-based data are.

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