THE SOLAR ECLIPSE EFFECT ON DIFFUSION PROCESSES OF $O^+ + O_2 \rightarrow O_2^+ + O$ REACTION FOR THE UPPER IONOSPHERE OVER KHARKOV

by

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The Sun is the most effective factor in determining all processes in the ionosphere. For this reason, examining the effect of solar eclipses on the earth ionosphere provides a very important source of information about sudden and medium-scale changes in the ionosphere structure during a solar eclipse. In this study, the effect of solar eclipse on March 29, 2006 in Kharkov on self-diffusion of $O^+ + O_2 \rightarrow O_2^+ + O$ reaction was investigated depending on the altitude (202, 252, and 303 km). As a result of the investigation, the minimum value of self-diffusion coefficient was seen at three altitudes on March 29, 2006 at the time of full covering in the solar. Self-diffusion coefficients were found to increase with increasing altitude. The results of the experimental study conducted to examine the effect of the eclipse on the ionosphere using high frequency wave propagation in Turkey where it was seen total eclipse on March 29, 2006 and the result that we obtained in this research are consistent with each other.

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

Introduction

The ionosphere drastically affects the propagation of radio waves so the ionospheric variability is very important for ionospheric physics, chemistry and radio communications. The electron density distribution, which is a complex function of geomagnetic spatial and temporal variations and solar activity, has an important role in the formation of the ionosphere [1-5]. The solar activity is a very effective parameter in the stratification of the ionosphere, ionospheric electron, and ion density change. Several studies were indeed conducted to observe the effects of different ionospheric changes caused by solar eclipse [6]: induced gravity waves [7-12], and the progress of acoustic gravity waves [13-15], total electron content decrease [16-19], changes of the critical frequencies of the E, F_1, and F_2 regions, [20, 21, 6], using the incoherent scatter (IS) radar of Institute of Ionosphere, located near Kharkov city [22-26] have been extensively done [27].

Solar eclipse has a significant potential to the investigations of important events such as transport, photoionization and loss processes in the ionosphere due to sudden changes in solar radiation [28]. The ionization of atoms and gas molecules in the ionosphere by X-rays and the ultraviolet radiation from the Sun depends on solar cycle, solar intensity, seasons and

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geophysical variations. These factors affect ionization in the ionosphere simultaneously with the internal processes such as chemical reactions among the atoms and gas molecules. The ionosphere regions are equally disturbed, because solar eclipse gradually reduces the solar spectral flux. Eclipse has a dominant effect on the reduction of electron density, which is the most fundamental particle of the ionosphere. The two charge reactions in which O^+ ions, in the F_2 region, are controlled through neutral atmosphere new species produce such as NO^+ and O_2^+ which the dominant species in the F_1 region:

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

$$O^+ + O_2 \rightarrow O_2^+ + O$$

The stratification of the F layer into sublayers (as the F_1 and F_2) becomes more apparent due to solar eclipse. During the eclipse, the F region shows a large upward drift towards the upper heights. This upward drift may also cause slowing of the diffusion and hence reduce the ionization of the F_2 region, while increase the accumulation of ionization in the F_1 region, which the stratification become more prominent [29, 30].

The diffusion event has attracted the attention of many authors both theoretical and experimental in the all regions of ionospheric plasma [31]. In 1928, Hulburt suggested the issue of diffusion in the ionosphere but his equations were partially wrong. In 1960, a research on how production, loss, diffusion and electromagnetic drift for determine the equilibrium of the daytime F_2 layer was done by Rishbeth [32]. Pavlov and Pavlova [33] derived the general equations for thermal diffusion and diffusion correction factors in an ion by using Grad's 13-moment expression under partially ionized plasma conditions. In another study, Bohm-type diffusion coefficient was studied by Dominguez quantum mechanical methods for plasma [31]. Sagir *et al*. [5] suggested a new way that established a relationship between diffusion equation and the electrical conductivity and it applied to the mid-latitudes ionosphere plasma.

Unlike the aforementioned works, we calculated self-diffusion coefficients (SDC) of $O^+ + O_2 \rightarrow O_2^+ + O$ reaction, in which cross-section is calculated by classical method (plasma physical), for night (solar eclipse) and day time in the ionospheric F region. In these calculations, both the data obtained from Kharkov IS radar and the thermospheric NRLMSISE-00 model was used.

General informations

The March 29, 2006 solar eclipse

At March 29, 2006 the total solar eclipse was observed from within a narrow corridor which traverses half the Earth. The path of the total solar eclipse begins in Brazil and reaches across the Atlantic, Northern Africa, and central Asia where it ends at sunset in western of Mongolia. A partial eclipse was seen within a corridor, which includes the northern two thirds of Africa, Europe, and central Asia. Ukraine is one of the countries where the solar eclipse of March 29 is seen as a partial eclipse since the maximum coverage of the sun disk was 77.4%. The partial eclipse in Kharkov continued from 10.02 to 12.21 according to universal time (UT), and the maximum coverage of the Sun disk took place at 11.12 UT. The solar eclipse duration in Kharkov city is 2 hours 18 minutes in total.

Kharkov incohorent scatter radar

The Kharkov IS radar, located 90 km from the city of Kharkov, has a high informative source on the parameters and processes controlling the ionospheric plasma behavior at European midlatitudes. The geographic co-ordinates of the IS radar are: 49.6° N and 36.3° E. The

IS radar is a very important measurement tool for measure with acceptable height resolution (10-100 km) and accuracy the following ionospheric parameters: vertical component of the charge particle transport velocity, V_z, temperatures of electrons, T_e, and ions, T_i, electron density, N_e [24].

Material and method

Analysis of ionosphere chemistry with theoretical or experimental methods must be carried out due to a large number of factors, such as the great increases in the energy regime of the earth-ionosphere system, the change in density and temperature during the solar eclipse, collision and the abrupt disconnections. In this study, the transport processes of a reactive collision were investigated during the solar eclipse. The investigation of reactive collision processes is of great importance for the upper ionosphere [34]. The complexity of the reactive collisions is due to the difficulty in calculating of the reaction cross-section as both the quantum mechanics and plasma physical (classical) [35]. It is important to calculate an important transport process such as diffusion in a reactive collision.

The self-diffusion is a very simple example for molecular diffusion. Consider a system two kinds of particles whose molecular masses are similar to each other. The particle concentrations are denoted by n_0 and n_1 where n_0 is the concentration of the tidy molecules and $n_1 \ll n_0$ is the trace particle concentration. Assume that the concentration of n_1 is not uniform as a function of the z co-ordinate so that the gas will again be subdivided to many thin layers parallel to the (x, y) plane. The n_1 particles pass the interfaces between the gas layers from below and above. When $\mathrm{d}n_1/\mathrm{d}z > 0$, many molecules will pass the interface from above than from below. Thus, a net flow transition is provided from the higher density region the lower density region. The net particle flux in the z-direction is the difference between the numbers of upward and downward moving tracer molecules passing unit interface area per unit time. The net particle flux, j_z, is proportional to the density gradient of n_1 particles:

$$J_z = -D\frac{\mathrm{d}n_1}{\mathrm{d}z} \tag{1}$$

where the SDC of the gas is denoted by D.

In the case of self-diffusion the n_1 concentration is a slowly varying function of z, while the temperature remains constant in the container. The following equation is written:

$$J_{\mathrm{diff}}\left(z_0\right) = -\frac{1}{3}\lambda\overline{v}\frac{\partial n\left(z_0\right)}{\partial z} \tag{2}$$

This expression has to be compared to the empirical result for the concentration gradient generated self-diffusion used in fluid dynamics, eq. (1) gives this expression. If the SDC is written directly from here [36]:

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

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

Results and discussion

In the research, SDC of the reaction $O^+ + O_2 \rightarrow O_2^+ + O$ was calculated separately at the changing time periods from UT 09:00 to 12:30 for 202, 252, and 303 km on March 28, the day before the eclipse, March 29, the day of the eclipse, and March 30, the day after the eclipse, 2006. While reaction cross-sections have been calculated by classical methods like plasma physical, in these calculations, ion densities and ambient temperatures have been taken from Kharkov IS radar and neutral densities have been taken from NRLMSISE-OO atmosphere model. Figure 1 shows effect of the solar eclipse on March 29, on SDC of the reaction $O^+ + O_2 \longrightarrow O_2^+ + O$ which has significant effect on ionospheric ionization for three days (March 28, 29, and 30) and for three altitudes (202, 252, and 303 km).

On the day of the eclipse, the changes which were observed in SDC are nearly same at 202, 252, and 303 km. The clearest point of the similarity is in the time period in which the maximum coverage takes place in the sun disk. The SDC has been taken its minimum value around 11:12 when the time of the maximum coverage. It has been observed that whereupon the maximum coverage, SDC has increased and it has been continuing. In fig. 1, it is seen that the diffusion increases from 09:00 to 10:00 and then it decreases from 10:02, when the time partial solar eclipse starts, to total eclipse.

The day before the eclipse, on March 28, it has been determined that changes in SDC did not show remarkable similarities for all three elevations. While the minimum value of SDC was seen for 202 km at 09:00, for 252 km at 10:00, for 303 km about at 11:15, the maximum value was seen for 202 at 12:20, for 252 at 12:30 and for 303 about at 12:30.

In fig. 1, it can be seen that there is not significant temporal changes in increases and decreases in SDC for all altitudes on the day after eclipse, March 30. While SDC took its minimum value for 202 and 252 km at 09:00, it took its minimum value for 303 km at 11:15. It was recorded that while SDC reached its maximum value at 202 and 252 km at 15:25, the value was at 303 km at 12:00.

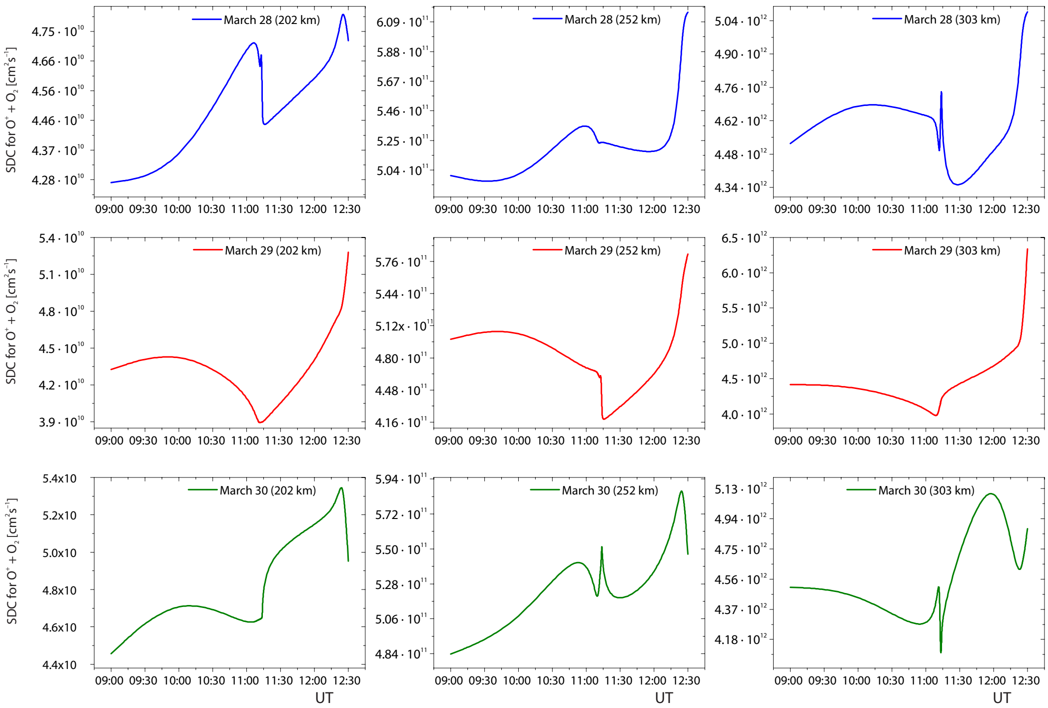

Figure 1. Variation of SDC with the different ionospheric height for days March 28, 29, and 30, 2006

The total eclipse which was passed almost half of the earth on March 29, 2006, includes Turkey. The eclipse began in Antalya at 12:37 and it ended in Trabzon at 15:25 according to Turkey's zone time. The use of high frequency (HF) radio wave propagation is one of the tools used to detect irregularities in the ionosphere [37, 38]. In order to observe the effects of the eclipse in the atmosphere, Turkish scientists carried out a measurement-based experiment using HF, HF wave propagation [39]. In fig. 2, it is shown that ionospheric signal strength data of the HF wave propagation experiment which is established receiving and transmitting stations broadcasting between Trabzon and Antalya with a wave propagation of 5.47 MHz for the dates March 28, 29, and 30, 2006.

On March 29, the signal strength tended to decrease from local time 11:00 to about 13:00 when the beginning of the partial eclipse and it started to increase with the transition the partial eclipse. The maximum value of the signal strength was seen between 13:54 and 13:57 which was the middle of the total eclipse. The signal strength which showed sharp decrease with the end of the total eclipse until the end of the partial eclipse, started to increase again from 14:30. Figure 2 shows that increases and decreases on March 30, the day after the eclipse, are softer than increases and decreases on March 28, the day before the eclipse. In other words, the strength of increase and the strength of decrease on March 28 are higher than the strength of increase and the strength of decrease on March 30.

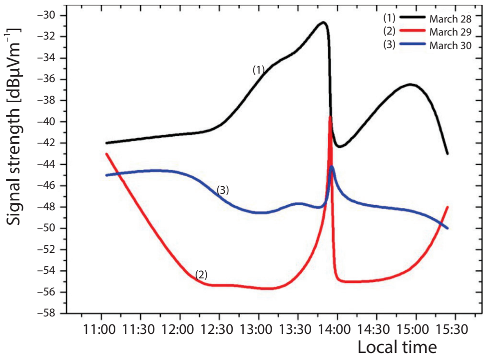

Figure 2. Variation of the signal strength during the total solar eclipse for days March 28, 29, and 30, 2006 [39]

Conclusions

The results of this study which was conducted to examine the effects of solar eclipse on SDC, one of the basic ionospheric transfer processes, showed that the maximum SDC value was obtained after the end of the eclipse on March 29, 2006. Compared to the days March 28 and 30 of when the daylight conditions were experienced, transition night conditions with the gradual covering of the sun disk on March 29 and sudden return to the daylight conditions after these conditions that lasted few minutes, can be explained as the reason that the maximum SDC was seen on the date and time periods. Also, the reason why the minimum SDC was calculated at 202 km on March 29 is that the molecular intensity of O_2 which is the neutral particle of the reaction decreases while altitude is increasing. As it can be understood from eq. (3), the reason for obtaining the minimum SDC is that increases and decreases in O_2 molecular density is higher compared to other parameters in the expression of $\lambda = 1/\sigma NO_2$ which is one of the two parameters required in the calculation of SDC. The reason for the increase in SDC for all three altitudes from UT 09:00 to 10:00 on the eclipse day is that the partial eclipse has not started and it has been at noon in Kharkov.

It has been determined that the SDC results calculated at all altitudes on the days before the eclipse and on the days after the eclipse, do not show similarity with each other and with the eclipse day changes. It was found that the SDC values on March 30 were generally greater than the values on March 28, and the increases and decreases in variations were more complex.

The results of the experimental study conducted to examine the effect of the eclipse on the ionosphere using HF wave propagation in Turkey where it was seen total eclipse on March 29, 2006 and the result that we obtained in the research are consistent with each other. The results of the research in which the HF signal strength was measured separately on March 28, 29, and 30 has shown that the signal strength reached its maximum value within a few minutes of the total eclipse period on March 29. It is consistent with minimizing diffusion which is seen in the result of the research in the eclipse time period. The changes in the signal strength on March 29, especially in the time period when the total eclipse occurred, and the trend of change on March 30 show similarity. It has been found that there are no similarities mentioned, looking at the changes in signal strength on March 28. Consequently, decreasing of SDC to its minimum value approximately between 11:00 and 11:30 which was the full covered time period on March 29 from the time of origin 09:00 to the time of the total eclipse is softer than the changes after the eclipse. Kharkov incohorent scatter radar measurements and measurement data which have been made using the HF wave propagation in Turkey are consistent with each other.

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