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THE CHEMISTRY OF THE IONOSPHERE

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ABSTRACT

The most important of long-term changes in the structure of the ionosphere corresponds to the solar sunspot cycle. The changes not only affect the reflection of radio waves but also alter the concentrations of various species in the upper atmosphere. As well as a small meteor can affect the chemistry of the ionosphere, the effects of human activities are also detectable.

Keywords: *Ionosphere – Electron densities – solar sunspot – radio waves.*

INTRODUCTION

The success of early radio transmissions across the Atlantic Ocean convinced a number of physicists that the atmosphere of the Earth had a conducting layer at an altitude of some 80 km. This layer became known as the ionosphere and was probed with radio waves from below. Later, studies were extended through the use of radio-sounders carried aloft by rockets or the direct measurements of the gaseous components for chemical components. The early work established the fairly well- developed layered structure that is shown in Fig. (1) The layers originally detected by radio reflection also proved to be quite useful in describing chemical structure but it should be remembered that in reality there is a single ionosphere layer and the boundaries represent changes in the gradient of electron density which refracts the impinging radio waves. The ionosphere is electrically neutral so the presence of positive ions was inferred from the earliest observations. In fact positive ion chemistry is probably more distinctive for the various layers of the ionosphere than is the electron density.

The first studies showed pronounced diurnal and long-term changes in the structure of the ionosphere. The most important of these long- term changes corresponds to the solar sunspot cycle. The changes not only affect the reflection of radio waves but also alter the concentrations of various species in the upper atmosphere. The electrons in the ionosphere are produced by photo-ionization. Above 100 km the photo-ionization is largely brought about by extreme ultraviolet radiation while below this altitude Lyman-A radiation is important. There are also small contributions from cosmic ray bombardment at somewhat lower altitudes where the atmosphere becomes less tenuous. However, magnetic shielding of the Earth means that cosmic radiation is only important at fairly high latitudes. The production of electrons at night presents a problem because cosmic rays do not appear to be an adequate source for this. Night-time ionization has often been attributed to a downward flux of protons and ultraviolet night glow (radiation from excited species in the upper atmosphere).

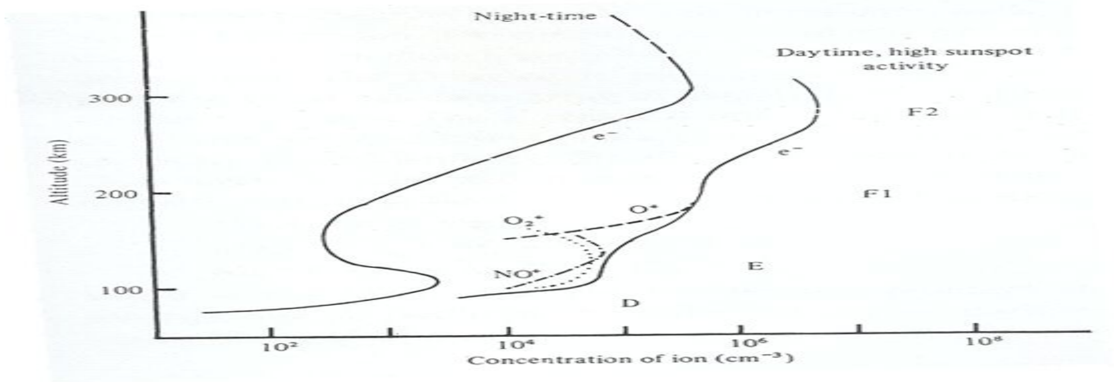

Fig. (1) electron densities and some positive ion concentrations in the ionosphere. The letters indicate the D, E, F1 and F2 regions of the ionosphere.

The principal reaction that leads to the production of electrons in the D region of the ionosphere is the photo-ionization of nitrous oxide. This is because it has the lowest ionization potential of the dominant species in the atmosphere. However, despite this we can see from Fig. (1) that NO+ is not the most abundant positively charged species in the upper atmosphere. In fact at about 80 km altitude the principal ion is a water cluster or hydrated proton H+ (H2O)2. The charge initially carried by the NO+ ion is transferred to the water cluster via an O2+ intermediate.

The production of electrons and ions is balanced by loss processes in a quasi-steady-state ionosphere. The loss processes usually involve reduction of the photo-electron to thermal energies followed by ion-electron recombination or electron attachment. Typical processes might be represented as follows:

NO + e- N + O (dissociative recombination) (1)
O + + e- O + hv (radiative recombination) (2)
O2 + O2 + e- O2- + O2 (three-body attachment) (3)

The physics of the electron in the upper atmosphere is very important when considering radio transmissions. However, with the advent of sampling opportunities provided by rocket soundings atmospheric chemists have become increasingly interested in the chemistry of the upper atmosphere. Fig. (1) Shows that the positive charge in the F-layer of the ionosphere is largely carried by O+ while at lower levels it is more likely to be present on NO+, O2+ and, lower down in the atmosphere, the hydrated proton. The complete picture of positive ion chemistry is a long way off even though many hundreds of reactions are often used in descriptions.

The D-region is particularly complex because of the presence of an extensive array of negatively charged poly-molecular hydrates of water. The E-region is interesting because it sometimes shows thin sporadic layers that appear to be derived from metal ion chemistry in mid-latitudes. Significant increases in the intensities of these layers are observed in response to meteor showers so an extra-terrestrial origin for the metal ions is very likely.

Typical reactions are:
Mg + hv Mg+ + e- (4)
Mg+ + O2 + M MgO2+ + M (5)
Mg+ + O3 MgO+ + O2 (6)

Where M is a third body. The first reaction produces electrons but subsequently the positively charged metal and metal oxide species can react with the electrons.

If small meteor can affect the chemistry of the ionosphere it is not surprising that the effects of human activities are also detectable. When Skylab was launched it was the first time a large booster operated in the upper portion of the ionosphere (190 km). Electron densities were lowered over a radius of 1000 km around the flight path of the rocket.

This electron-hole may be understood by considering the fact that some 1.2 X 1031 molecules of water and hydrogen were released during the ionosphere portion of the flight. Oxygen ions (O+) are normally removed from the ionosphere through reaction with oxygen and nitrogen:
O+ + O2 O2 + O (7)
O+ + N2 N2 + O (8)

But the reactions involving hydrogen or water are known to be about a thousand times faster. This can lead to a considerable reduction in the concentration of electrons through the reactions:

O+ + H2 O H2O+ + O (9)
O+ + H2 OH+ + H (10)

Followed by:
e- + H2O+ H2 + O (11)
e- + H2O+ OH + H (12)
e- + OH+ O + H (13)

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