11. Planetary Ionospheres and Magnetospheres

11.1 Earth: Ionospheric Layers

Sunlight interacts with planetary atmospheres to produce excited atoms and ions, and the ions interact with each other and with neutral atoms to produce unique, altitude-dependent populations. As with other aspects of the terrestrial planets, we know the ionosphere of the Earth best, so we start with it. Figure 11.1 shows the electron density and ionospheric layers in the Earth’s ionosphere. During the daytime, the D layer forms and the F layer separates into two parts, F₁ and F₂; at night the D layer disappears, and the F layers merge into a single layer.

11.1.1 The F Layer

The F layer is created primarily by solar EUV radiation in the wavelength range 10 nm < λ < 80 nm.

11.1.1.1 Atoms and Ions in the F Layer The dominant neutral atoms are O and N₂. Atomic oxygen is much more abundant than O₂ in the F region.

Fig. 11.1. Electron density vs. altitude in the Earth’s ionosphere. Typical curves and ionospheric layers are shown for night and day. The curves vary considerably with solar activity, sunspot number, and time of year. From Iribarne and Cho 1980, Figure I-7, p. 10
because most of the $O_2$ has undergone photodissociation (or photolysis):

$$O_2 + h\nu \rightarrow O + O \quad \text{photodissociation} \quad (11.1)$$

where, as an aid, we list the mechanism after the reaction. The dominant ions are primarily $O^+$ with smaller amounts of $O$, $NO^+$, $N^+$.

11.1.1.2 Production Mechanisms The production of the ions is due to several reactions. The dominant (source) reactions are as follows:

A. The primary\(^1\) reactions, the process, and the wavelength range are

$$O + h\nu \rightarrow O^+ + e^- \quad \text{photoionization} \quad \lambda < 91.0 \ \text{nm} \quad (11.2a)$$

$$N + h\nu \rightarrow N^+ + e^- \quad \text{photoionization} \quad \lambda < 85.2 \ \text{nm} \quad (11.2b)$$

$$N_2 + h\nu \rightarrow N_2^+ + e^- \quad \text{photoionization} \quad \lambda < 79.6 \ \text{nm} \quad (11.2c)$$

B. The secondary reactions are

$$N_2^+ + O_2 \rightarrow N_2 + O_2^+ \quad \text{charge transfer} \quad (11.3a)$$

$$N_2^+ + O \rightarrow N + NO^+ \quad \text{ion exchange} \quad (11.3b)$$

Most of the $N_2^+$ produced in the primary reactions is thus removed by the secondary reactions.

11.1.1.3 Loss Mechanisms The loss mechanisms (sinks) of the ions are as follows:

A. Molecular ions

The most common process is dissociative recombination, where the electron recombines with a molecule, dissociating it into two neutral atoms in the process:

$$O_2^+ + e^- \rightarrow O + O \quad \text{dissociative recombination} \quad (11.4a)$$

$$NO^+ + e^- \rightarrow N + O \quad \text{dissociative recombination} \quad (11.4b)$$

$$N_2^+ + e^- \rightarrow N + N \quad \text{dissociative recombination} \quad (11.4c)$$

\(^1\) The words “primary” and “secondary” refer to the sequence of events, not to relative importance, i.e., the primary reactions have to occur first, in order for the secondary reactions to occur.