How is the ionosphere formed?

How is the ionosphere formed? a. Photoionization

Ionization Rate =
(radiation intensity) x (ionization cross section) x (density)

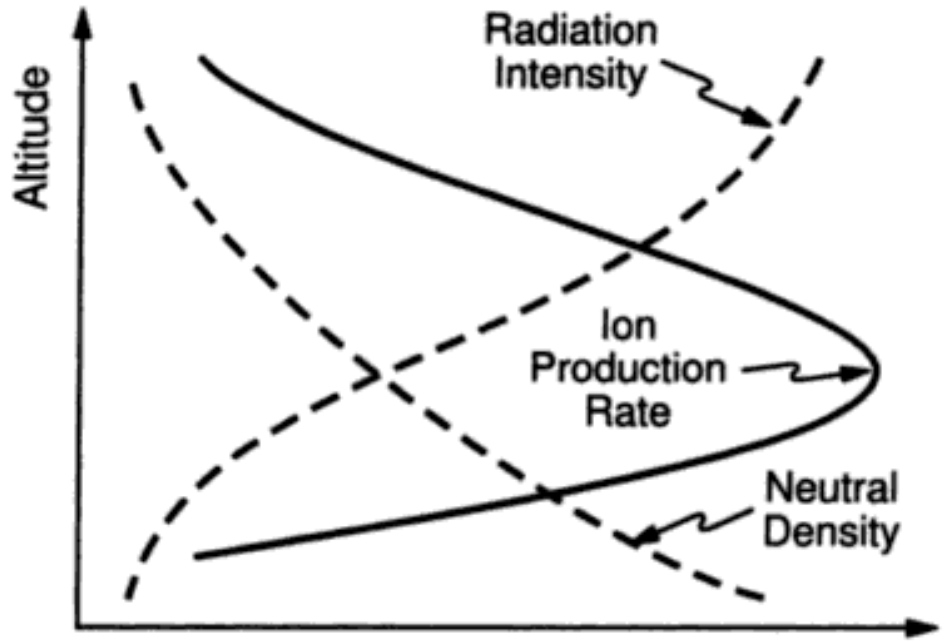
$$q_z = I_z \sigma_i n_z$$

$$q_z = I_\infty \sigma_i n_o \exp\left[-\frac{z - z_o}{H} - \frac{\sigma n_o H}{\mu} \exp\left[-\frac{z - z_o}{H} \right] \right]$$

Note: σ_i is ionization cross section and σ is absorption cross section. There is much wavelength and species dependent chemistry detail buried in σ_i

How is the ionosphere formed?

Formation of an ionized layer:



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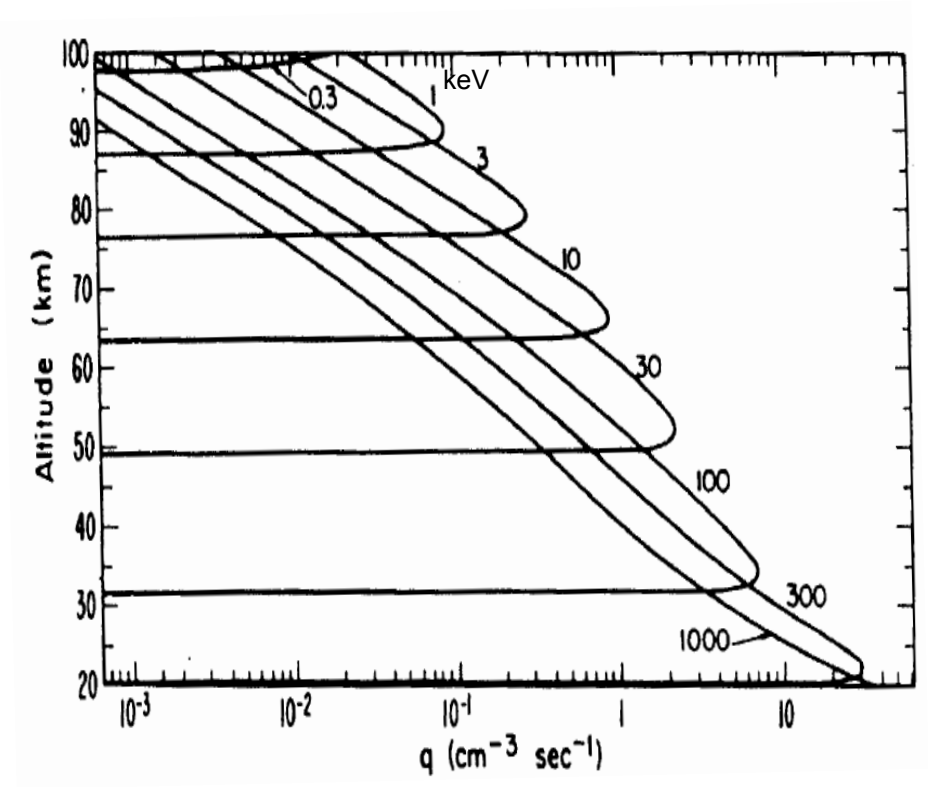
How is the ionosphere formed?

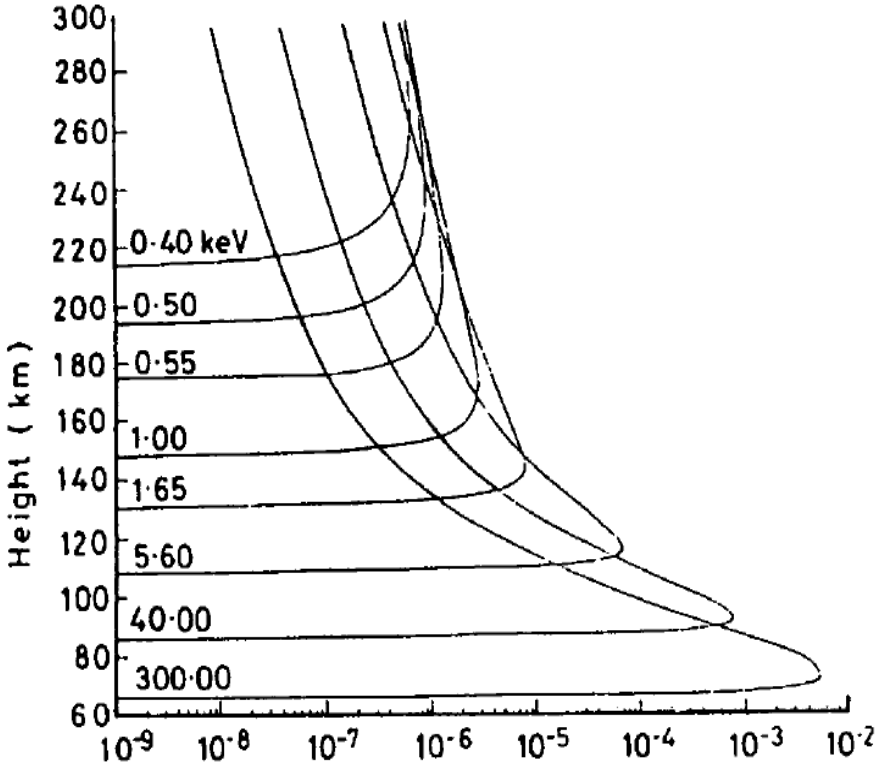
How is the ionosphere formed? b. Impact ionization

Ionization Rate - Energy Dependant:

Due to proton precipitation



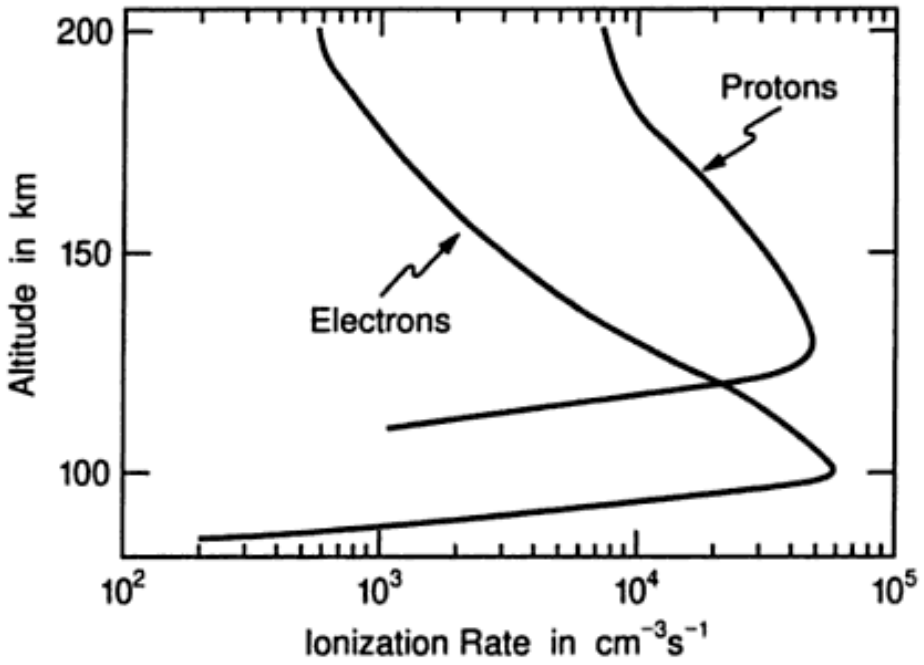
Due to electron precipitation



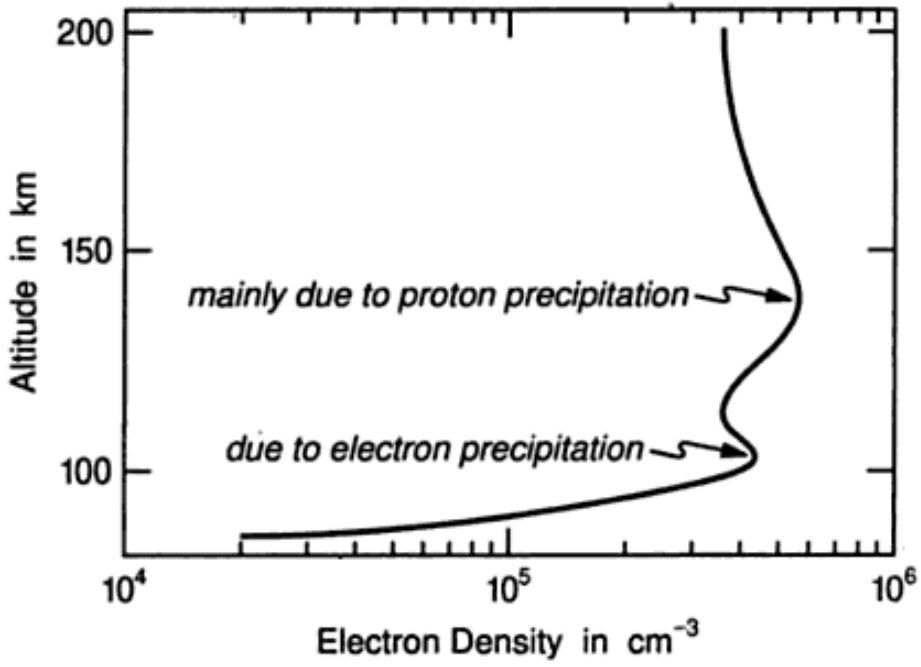
How is the ionosphere formed?

How is the ionosphere formed? b. Impact ionization

Ionization Rate Integrated over all precipitation energies:



Total ionization due to precipitation over diffuse aurora:



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Note: These processes are most important at high latitudes (due to magnetic morphology), and at night when photoionization does not contribute!

Structure of the Ionosphere

Summing up:

Production of electrons from ionization of the neutral atmosphere from solar radiation and impacts from precipitating electrons and ions is counteracted by the processes of recombination and attachment.

$$\frac{dn_e}{dt} = q_{v,e} - \alpha_r n_e^{\,2} - \beta_r n_e$$

Considering a system in equilibrium, i.e. $dn_e/dt = 0$
We find two simple proportionalities that determine the electron number density

Structure of the Ionosphere

Lower Ionosphere

In the lower ionosphere, recombination is the dominant loss process for electrons. Hence:

$$\frac{dn_e}{dt} = 0 \quad , \quad q_{v,e} - \alpha_r n_e^{\,2} - \cancelto{0}{\beta_r n_e} = 0$$

$$n_e = \left(\frac{q_{v,e}}{\alpha_r} \right)^{1/2}$$

At lower altitudes the electron density is proportional to the square root of the ionization rate.

Structure of the Ionosphere

Upper Ionosphere

In the upper ionosphere, attachment is the dominant loss process for electrons. Hence:

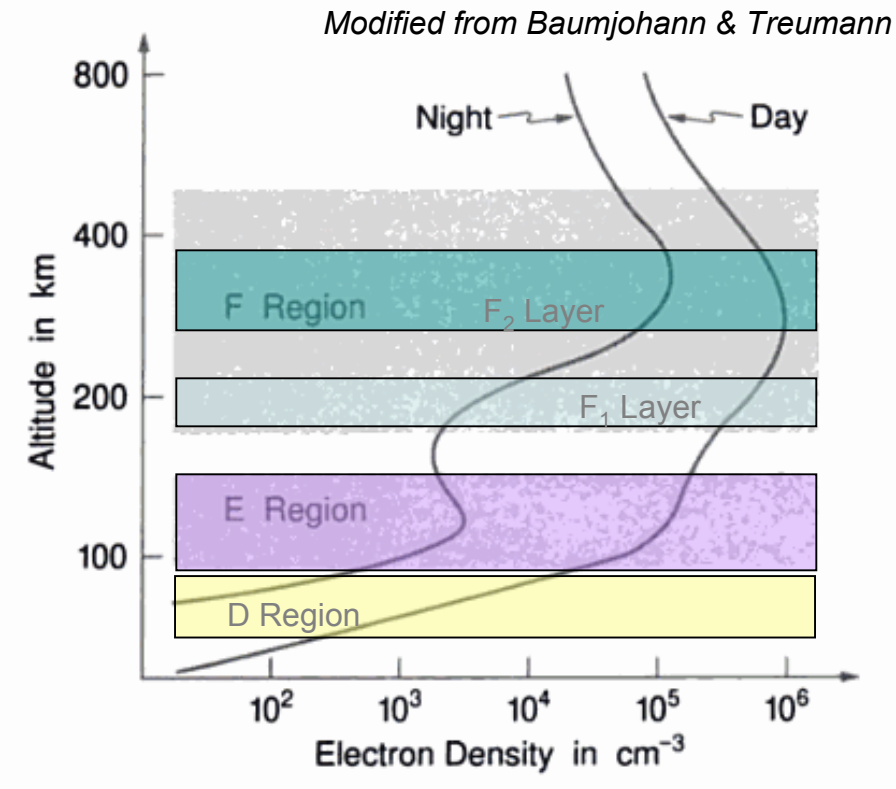
$$\frac{dn_e}{dt} = 0 \quad , \quad q_{v,e} - \alpha_r \overset{0}{\cancel{n_e^2}} - \beta_r n_e = 0$$

$$n_e = \frac{q_{v,e}}{\beta_r}$$

At higher altitudes the electron density is proportional to the ionization rate.

Structure of the Ionosphere

Layers of the Ionosphere:



D-region: Below 90 km, very weakly ionized and dominated by neutral gas dynamics (not a plasma)

E-region: Peaks at 110 km. Mainly produced by long wavelength UV (90nm) ionizing molecular Oxygen. At high latitudes impact ionization also plays important role. Electron density greatly reduced at night.

F-region: F_1 peaks at ~200 km, and is formed by shorter λ UV due to composition. Like the E-region, it has a strong diurnal signature. F_2 peaks at ~300 km, at high altitudes only attachment counteracts ionization (which is limited by neutral density).