Introduction to the Ionosphere (part 2)

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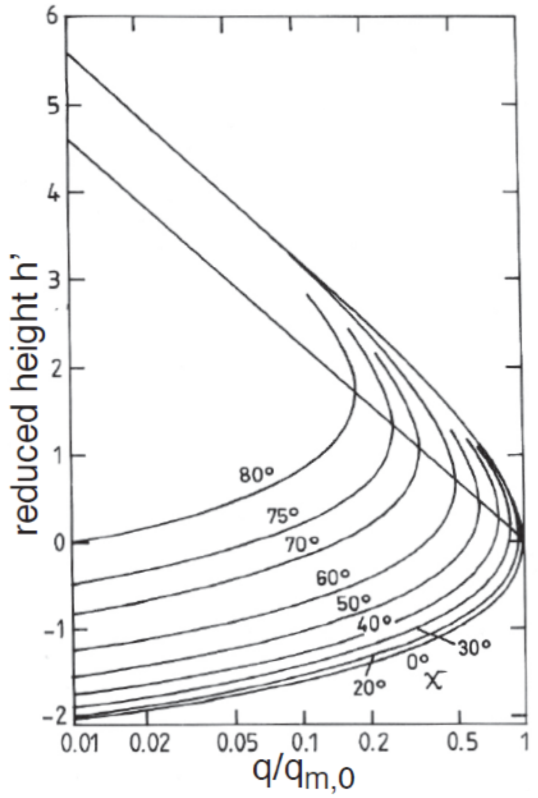
The ionosphere

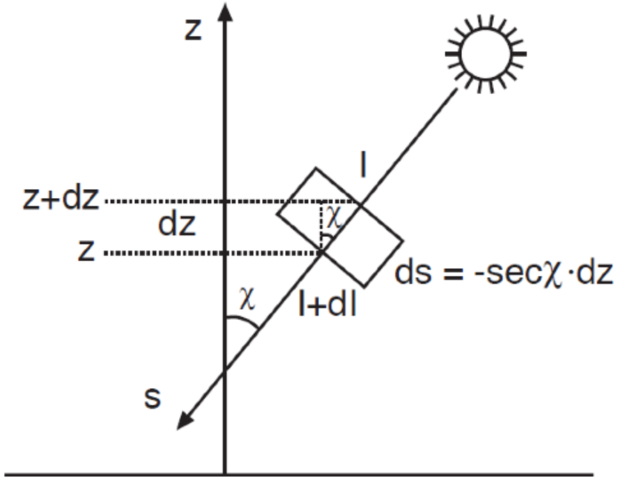
Ionization source: solar radiation

Chapman production function by using a height variable $h' = h - \ln \sec \chi$:

$$q(\chi, h') = q_{m,0} \cos \chi \cdot \exp\left[1 - h' - e^{-h'}\right] \quad ,$$

where χ is the solar zenith angle and $h = (z - z_{m,0})/H$, where H is the atmospheric scale height.





With larger zenith angle χ, the peak of ionization rate rises in altitude and decreases by a factor $\cos \chi$.

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Ionization source: particle precipitation (electrons)

High-energy electron deposit energy at lower altitudes.

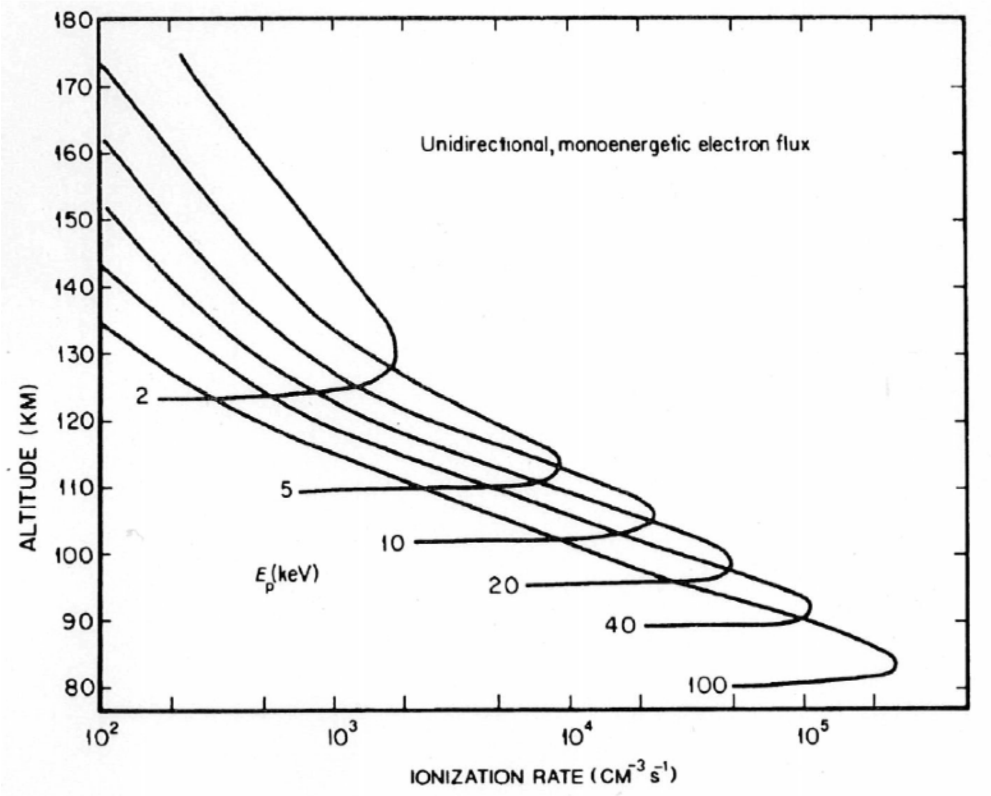

Figure: Ionization rate for monoenergetic electrons with energies 2-100 keV

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Ionization source: particle precipitation (protons)

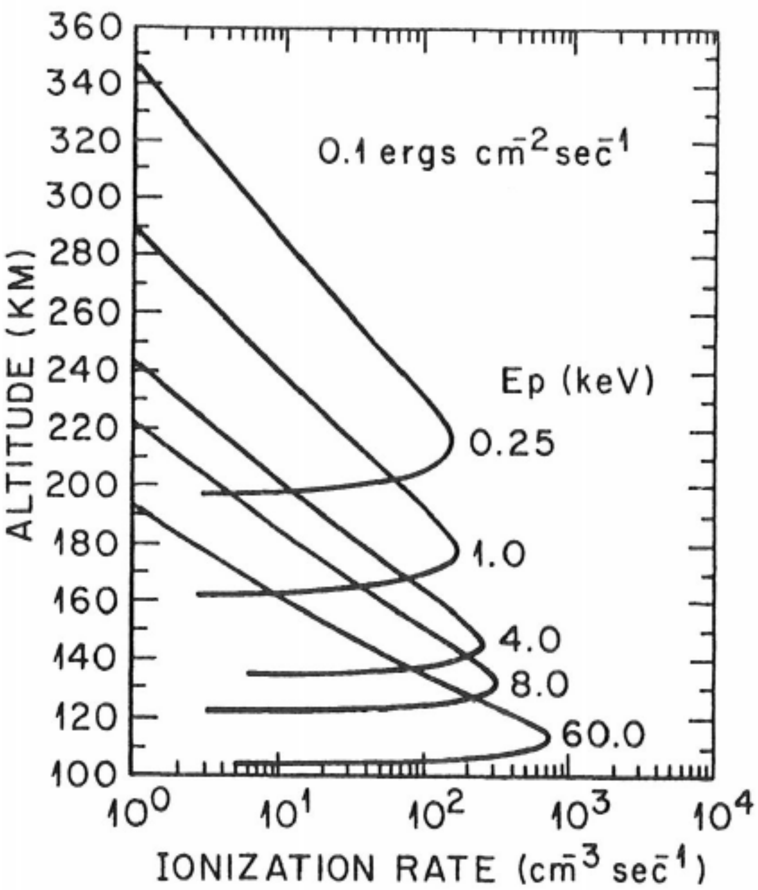

Figure: Ionization rate for monoenergetic protons with energies 0.25-60 keV

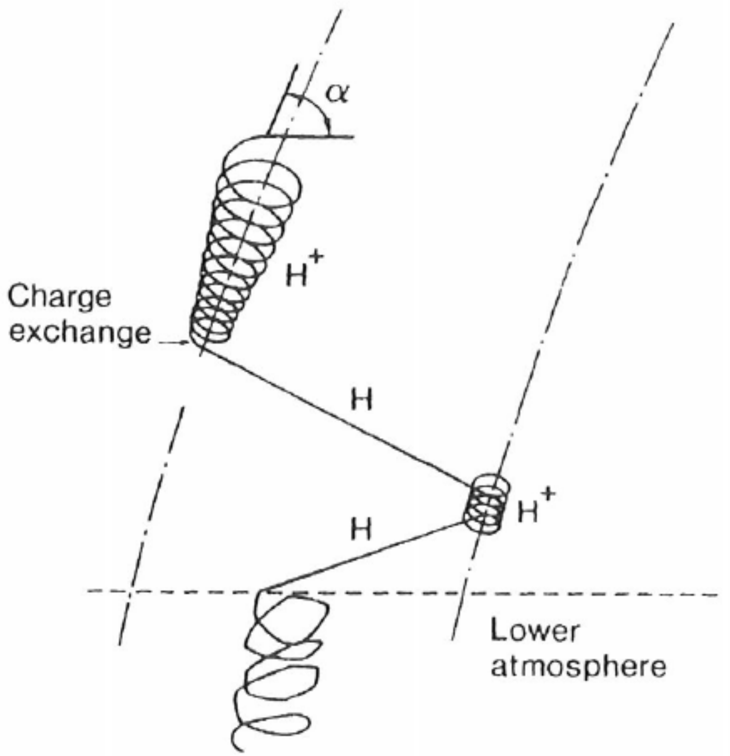

Figure: Protons may make charge exchange with neutral hydrogen.

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Loss mechanisms

We have now dealt with the production rate, but there are also loss terms to deal with:

$$\frac{\partial n_{i,e}}{\partial t} + \nabla \cdot (n_{i,e}\mathbf{v}_{i,e}) = q_{i,e} - l_{i,e},$$

1. Recombination
2. Transport/Diffusion

While chemical recombination is very important at lower altitudes (D, E, F1 regions), diffusion plays a larger role at higher altitudes (F2 region) where the densities are very low.

The ionosphere

Equations of motion

Conductivities matter because the ionosphere is a plasma with an embedded magnetic field.

$$\nabla \cdot [\sigma \cdot (\mathbf{E}(\mathbf{r}, t) + \mathbf{U}(\mathbf{r}, t) \times \mathbf{B})] = 0$$

Parallel equation of motion:

$$\mathrm{q\,E} = \mathrm{m_i} \nu_{\mathrm{in}} \mathrm{u_i} \qquad -\mathrm{eE} = \mathrm{m_e} \nu_{\mathrm{en}} \mathrm{u_e}$$

Perpendicular equation of motion:

$$\mathrm{q}\left(\mathbf{E}_{\perp} + \mathbf{u}_{i} \times \mathbf{B}\right) = \mathrm{m_i} \nu_{\mathrm{in}} \mathbf{u}_{\perp i}$$

$$-e\left(\mathbf{E}_{\perp} + \mathbf{u}_{e} \times \mathbf{B}\right) = \mathrm{m_e} \nu_{\mathrm{en}} \mathbf{u}_{\perp e}$$

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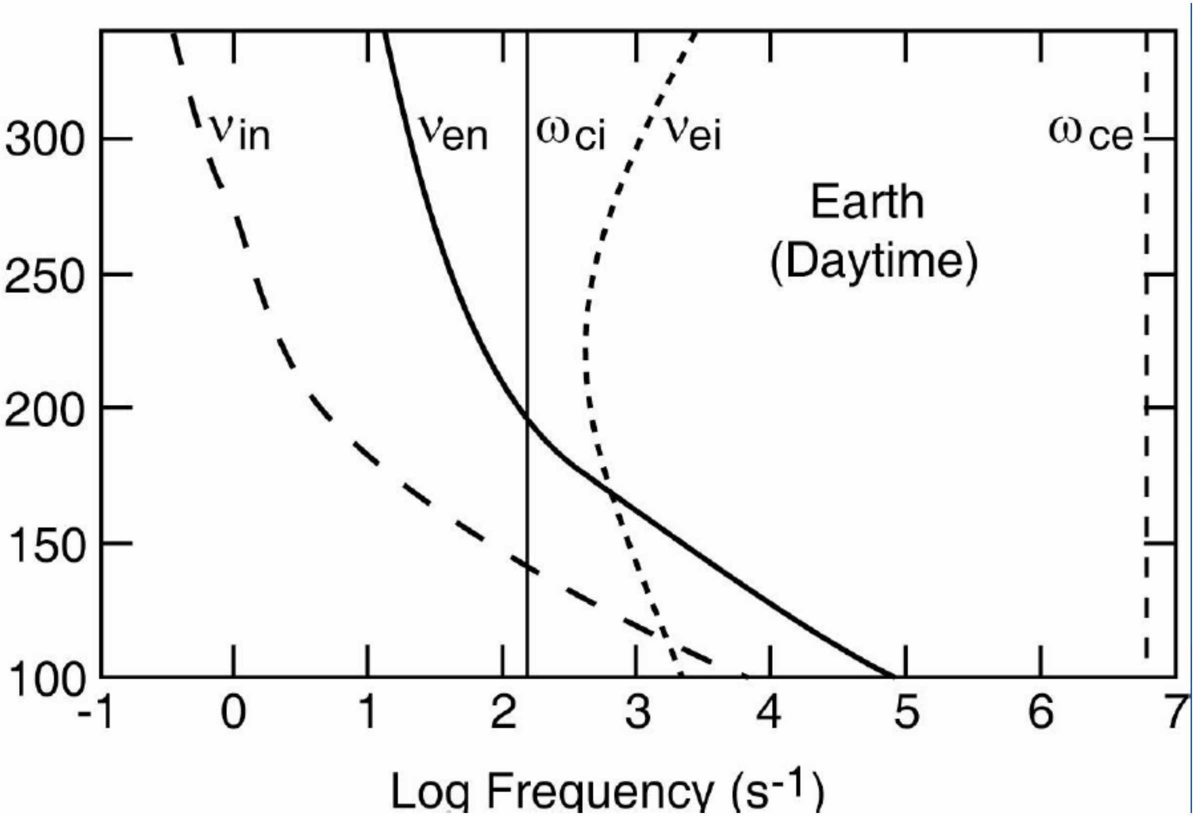
Collision frequencies

Ion and electrons collide with neutrals as they gyrate. How they move in response to imposed force fields depends very much on the collision frequency relative to the gyro-frequency.



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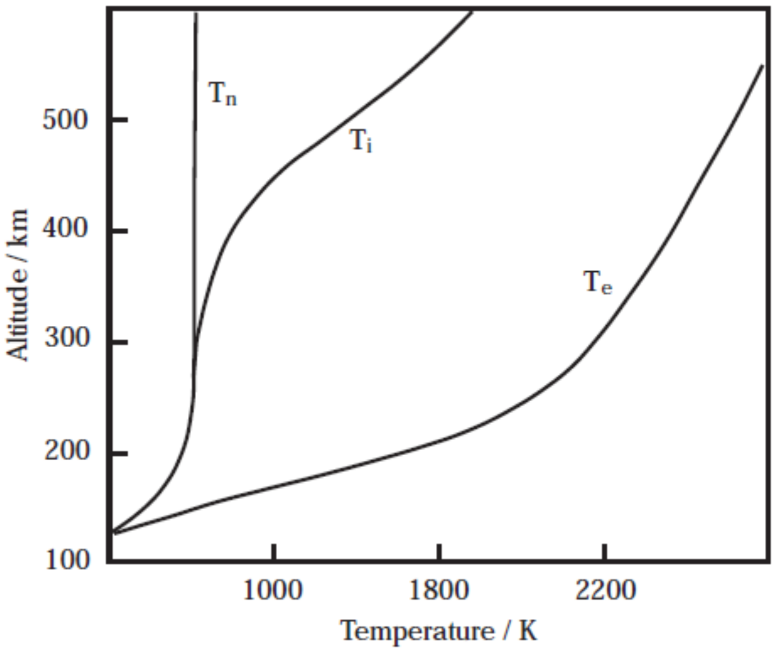

Question: Why are T_n and T_i identical at low altitudes? Why is T_e so much higher than either T_n or T_i?

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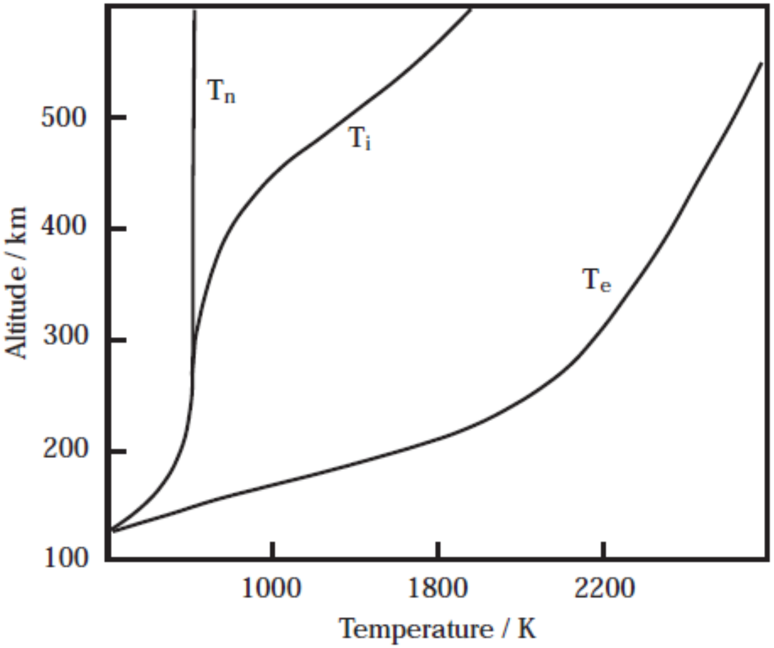

Answer: At lower altitudes, the ions and neutrals have the same temperature due to a high rate of collisions and the high mass of the ions. The electrons have a gyrofrequency much higher than the collision frequency. The electron temperature typically remains higher than the ion temperature due to its much lower mass.

The ionosphere

Conductivity

- Pedersen conductivity (parallel to E)

$$\sigma_1 = [\frac{1}{m_e \nu_{en}}(\frac{\nu_{en}^{\;2}}{\nu_{en}^2 + \Omega_e^2}) + \frac{1}{m_i \nu_{in}}(\frac{\nu_{in}^{\;2}}{\nu_{in}^2 + \Omega_i^2})] n_e e^2$$

- Hall conductivity (along EXB)

$$\sigma_2 = [\frac{1}{m_e \nu_{en}}(\frac{\Omega_e \nu_{en}}{\nu_{en}^2 + \Omega_e^2}) - \frac{1}{m_i \nu_{in}}(\frac{\Omega_i \nu_{in}}{\nu_{in}^2 + \Omega_i^2})] n_e e^2$$

- Parallel conductivity (parallel to B)

$$\sigma_0 = [\frac{1}{m_e \nu_{en}} + \frac{1}{m_i \nu_{in}}] n_e e^2$$

- Conductivity tensor

$$j = \begin{pmatrix} \sigma_1 & \sigma_2 & 0 \\ -\sigma_2 & \sigma_1 & 0 \\ 0 & 0 & \sigma_0 \end{pmatrix} \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix}$$

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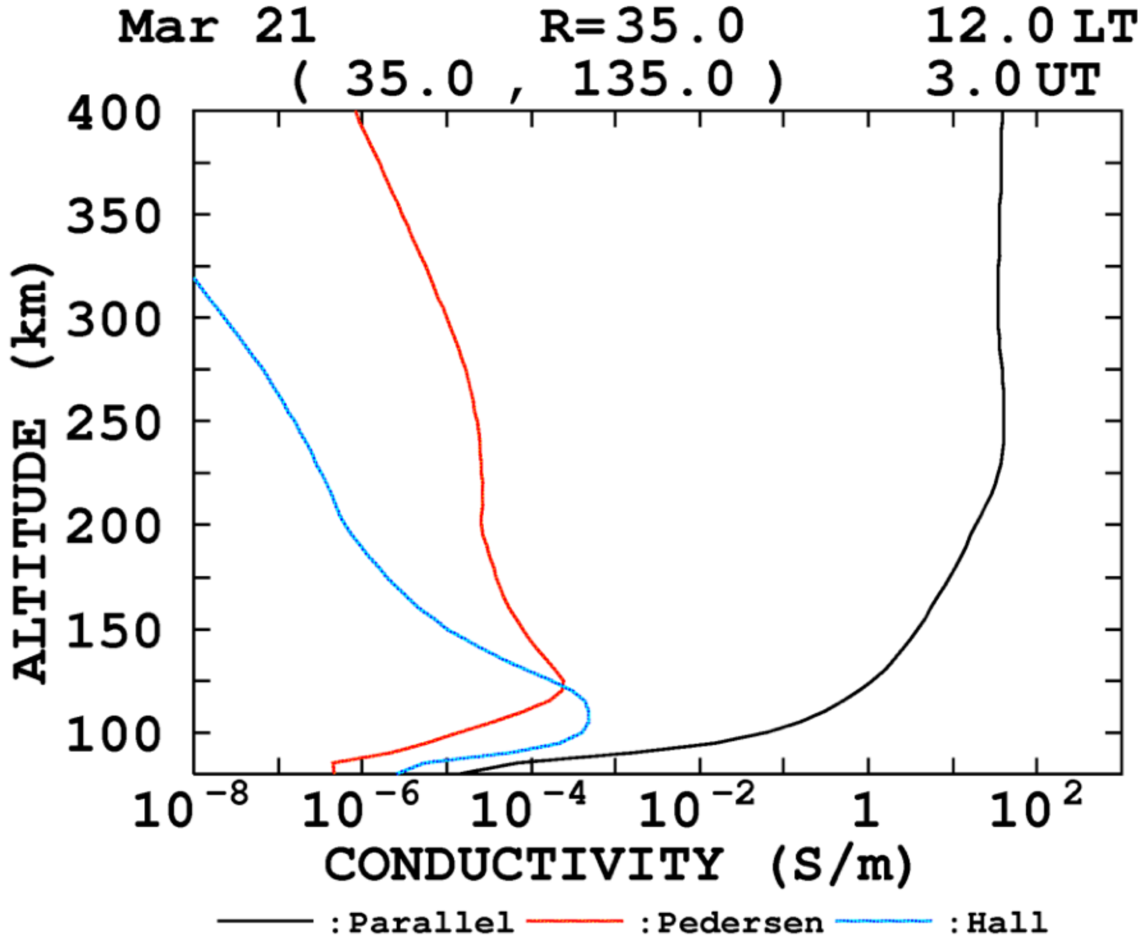
Conductivities



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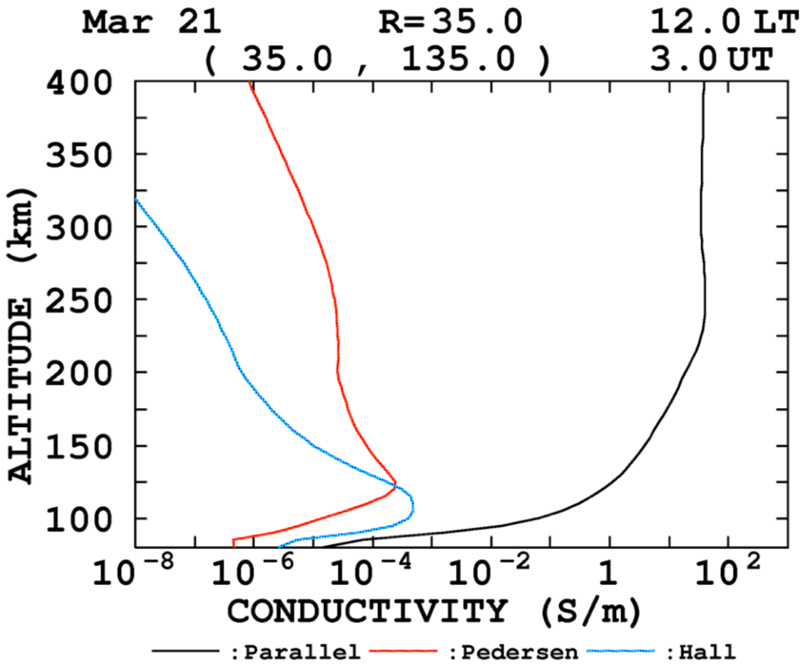
Conductivities



Question: There is a peak in the Hall and Pedersen conductivities in the E-region. What ionospheric phenomenon also peaks at this altitude?

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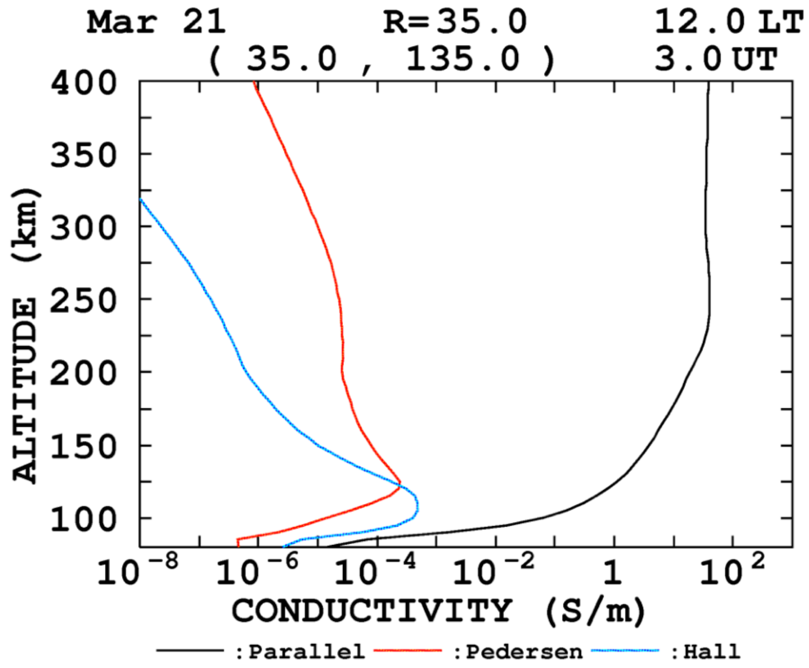
Conductivities



Answer: The auroral and equatorial electrojets

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Debye length

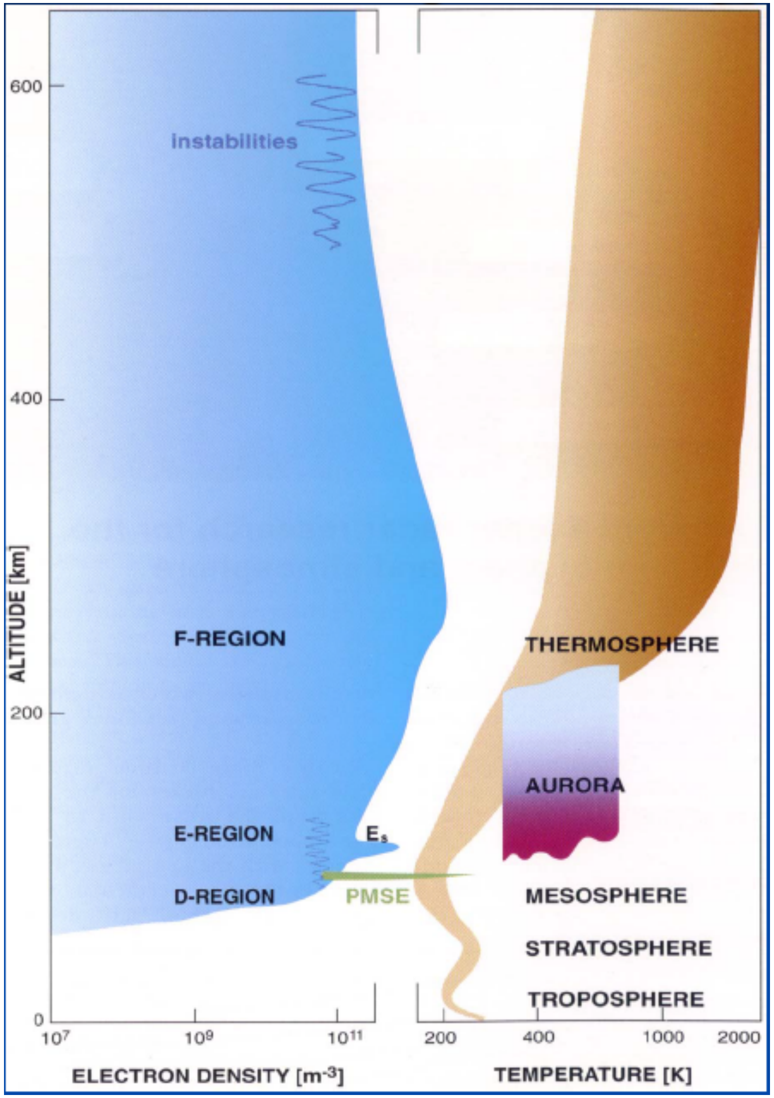
- The Debye length is a measure of the plasma’s ability to shield out electric potentials that are applied to it
- The Debye length marks the division between different regimes of plasma’s behavior; i.e. collective plasma motion versus that of individual particle motion.
- Plasma phenomenon that take place over distances greater than the Debye length must be described in terms of collective behavior of the plasma.
- Plasma will not support large potential variations (i.e. will seek to maintain charge neutrality) over distances larger than the Debye length.

The ionosphere

Debye length

- The Debye length increases with altitude – from a few millimeters in the F-region up to meters in the magnetosphere
- The Debye length in the E and F regions ranges from 0.1 – 1 cm

$$\lambda_D \simeq 69\sqrt{\mathrm{T}_e/\mathrm{n}_e}$$



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Question: If we want to measure bulk plasma parameters with an incoherent scatter radar, how will the Debye length affect our choice of radar frequency?

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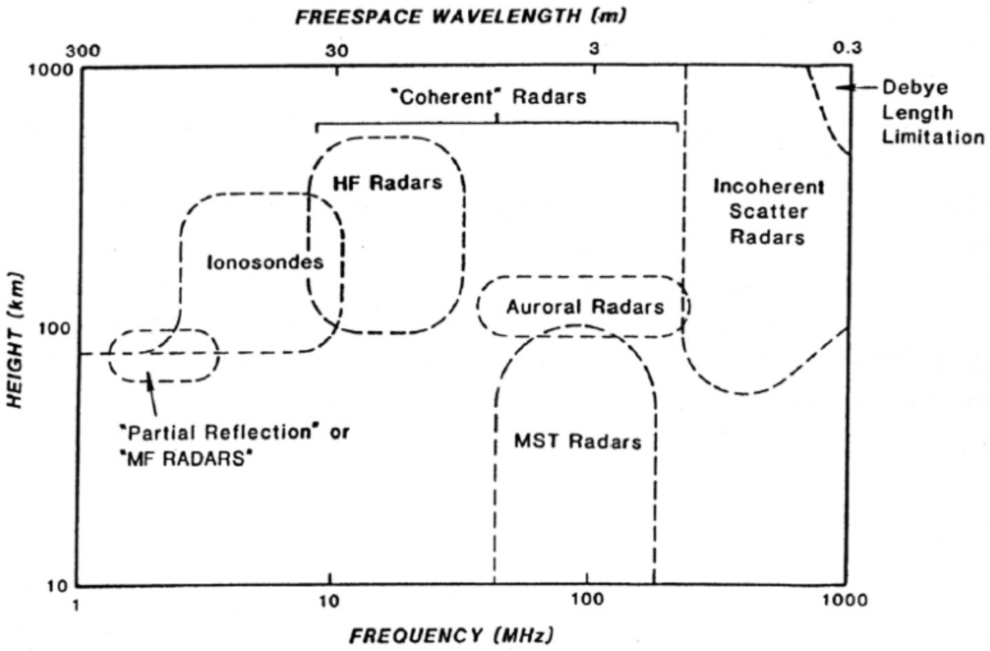

Answer: While the radar frequency needs to be higher than that of ionospheric plasma frequencies and irregularities, it should also be chosen with a wavelength greater than the Debye length. This becomes an issue at higher altitudes.

Literature

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