Introduction to the Ionosphere

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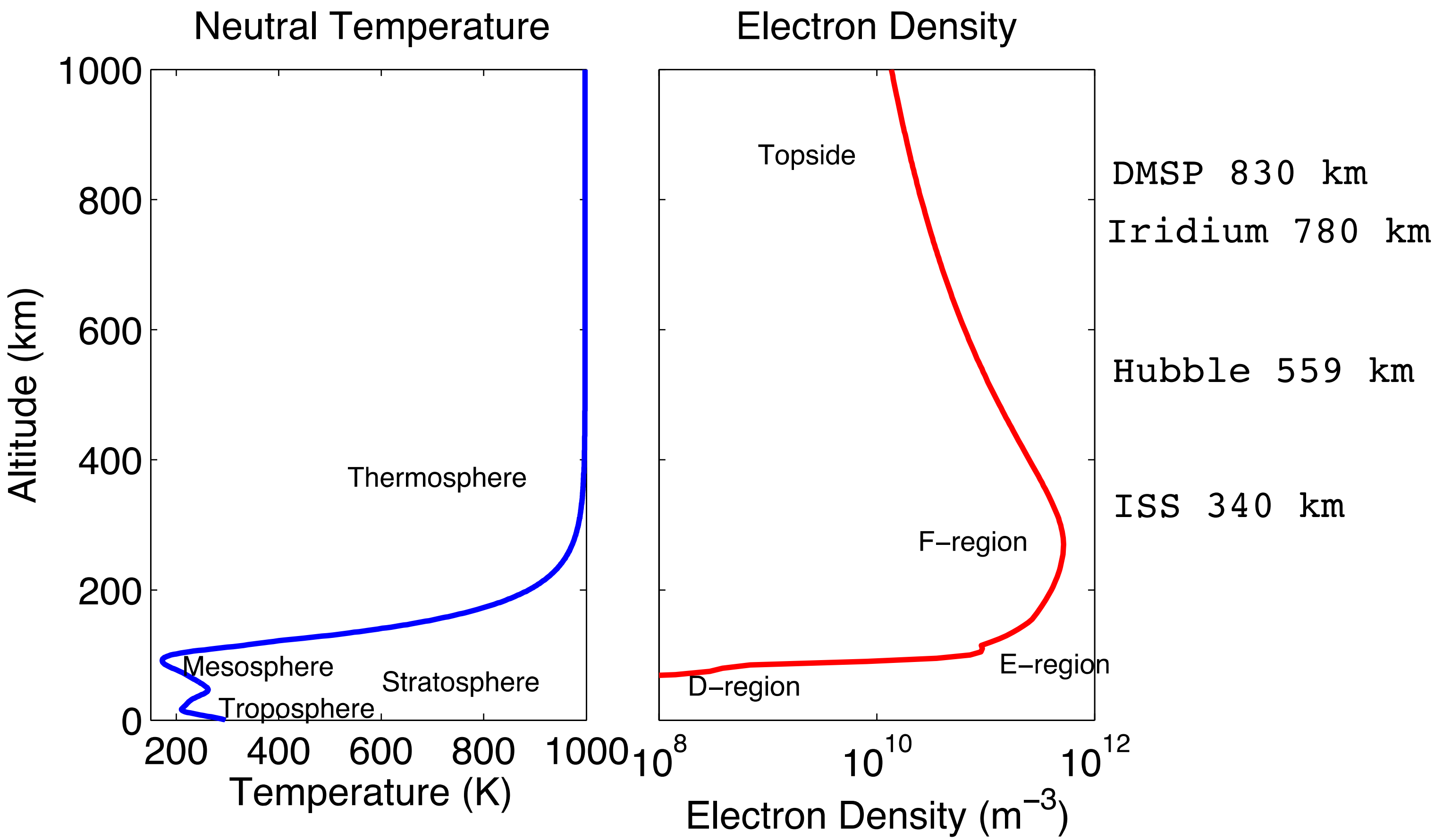
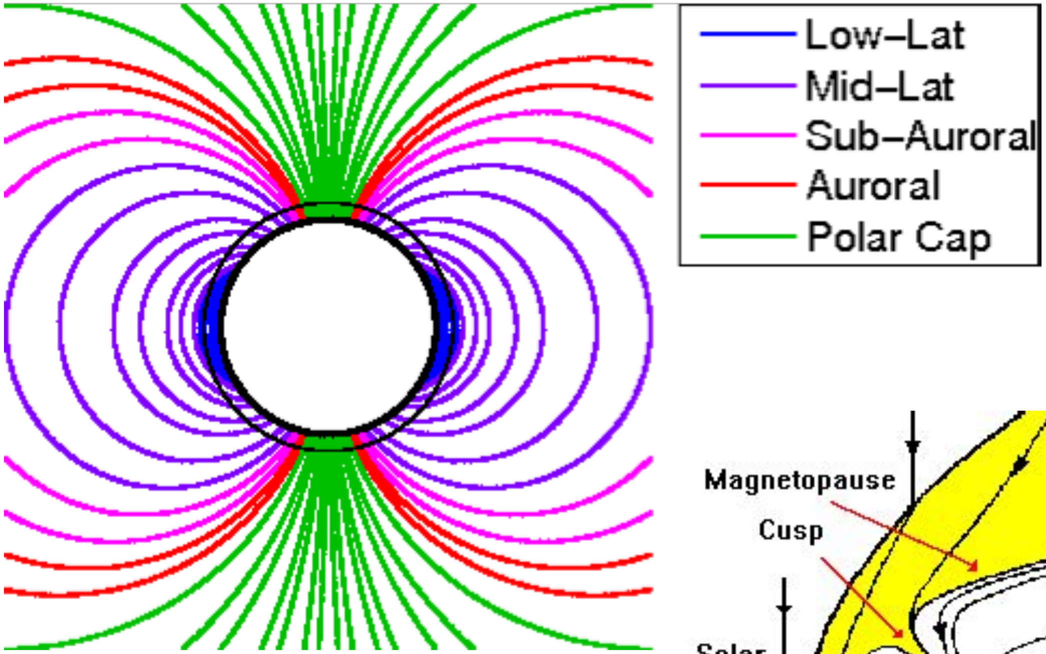
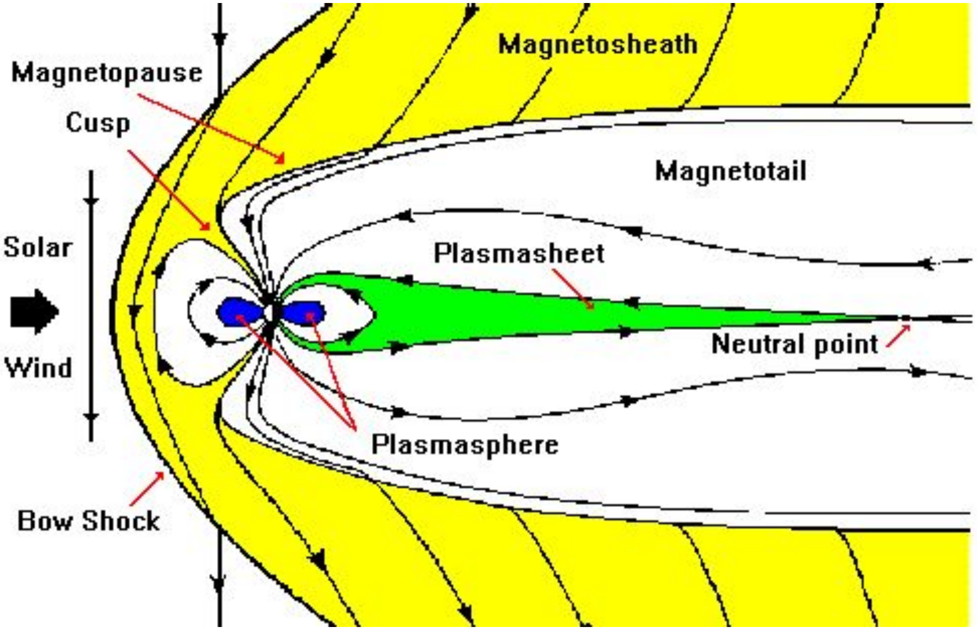
The Upper Atmosphere



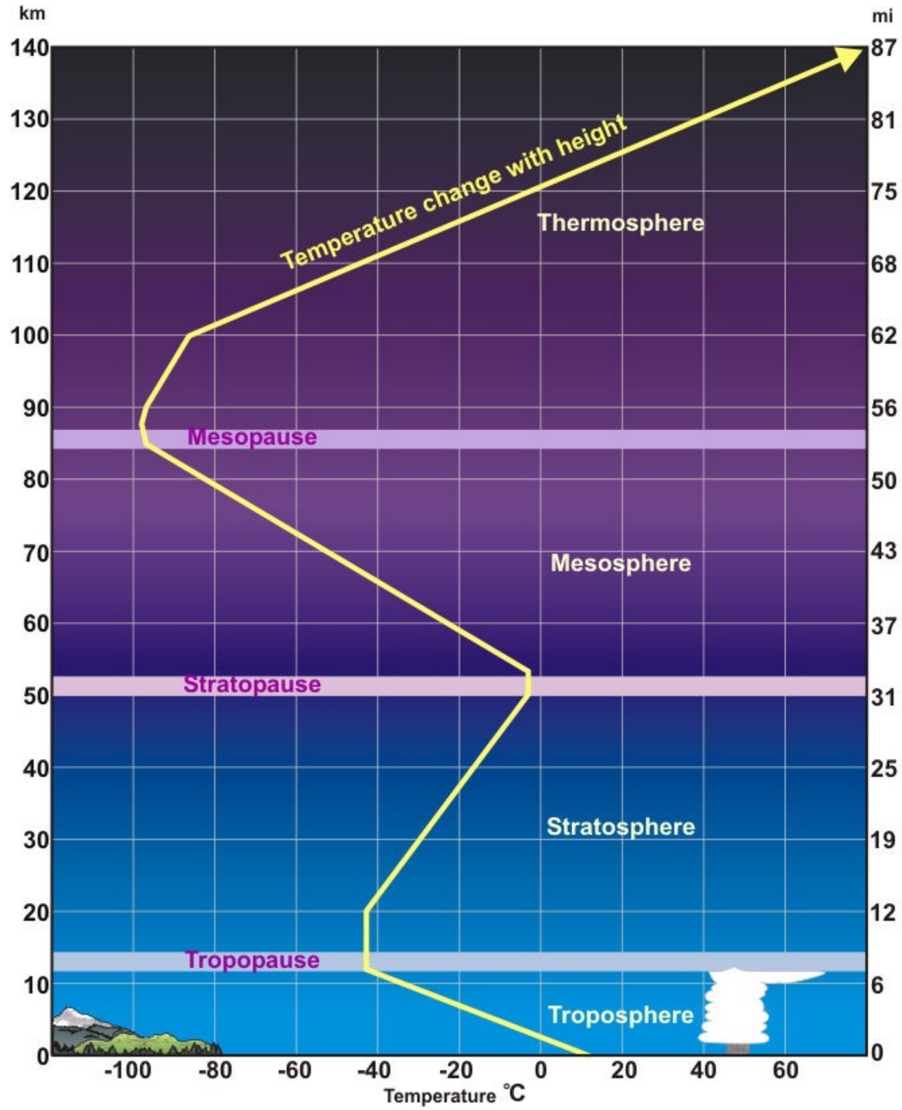
The Magnetic Field





The neutral atmosphere

- The **troposphere** is heated by the warm ground and infrared radiation is emitted radially. T decreases with height. The **tropopause** is at 12-15 km, T_{min} ~ -53C.
- In the **stratosphere**, the ozone (O_3) layer at 15-40 km absorbs solar radiation. The **stratopause** is at 50 km with T_{max}~7C.
- In the **mesosphere**, heat is removed by the radiation of infrared and visible airglow as well as by eddy transport. The **mesopause** is close to 85 km with T_{min} ~ -100C.
- In the **thermosphere**, UV radiation is absorbed and it produces dissociation of molecules and ionization of atoms and molecules.



The neutral atmosphere

Atmospheric gas in a stationary state

Above the surface of the Earth, the atmospheric pressure *p* and density *n* are given

$$p = p_0 \exp\left[-\int_{z_0}^{z} \frac{mg}{k_B T(z)} dz\right] = p_0 \exp\left[-\int_{z_0}^{z} \frac{dz}{H(z)}\right]$$

and

$$n = n_0 \frac{T_0}{T(z)} \exp\left[-\int_{z_0}^{z} \frac{dz}{H(z)}\right]$$

Where p_0 and n_0 are values at a reference height z_0. If the atmosphere is isothermal (T=constant), the **scale height** H

$$H = \frac{k_B T}{mg}$$

Is independent of altitude and then the hydrostatic equations are

$$p = p_0 \exp\left(-\frac{z - z_0}{H}\right), \quad n = n_0 \exp\left(-\frac{z - z_0}{H}\right)$$

The neutral atmosphere

Atmospheric gas in a stationary state

Since the scale height is in fact dependent on temperature and we now know that temperature increases with altitude in the thermosphere,

$$H = \frac{k_B T}{mg}$$

we will see in upcoming lectures that it is possible to take ISR measurements with lower range resolution in the F-region as compared to the lower E-region.

The neutral atmosphere

Atmospheric regions by composition

- The **homosphere** is the region below about 100 km altitude, where all gas constituents are fully mixed; i.e. the relative concentrations of different molecular species are independent of height. This is caused by turbulent mixing of the air.
- The **turbopause** is the upper boundary of the homosphere at an altitude of about 100 km.
- The **heterosphere** is the region above the homosphere. In the absence of atmospheric turbulence, each molecular species distributes with height independently of the other species (according to its own scale height). At great altitudes light molecular species dominate.

The neutral atmosphere

Composition in the heterosphere

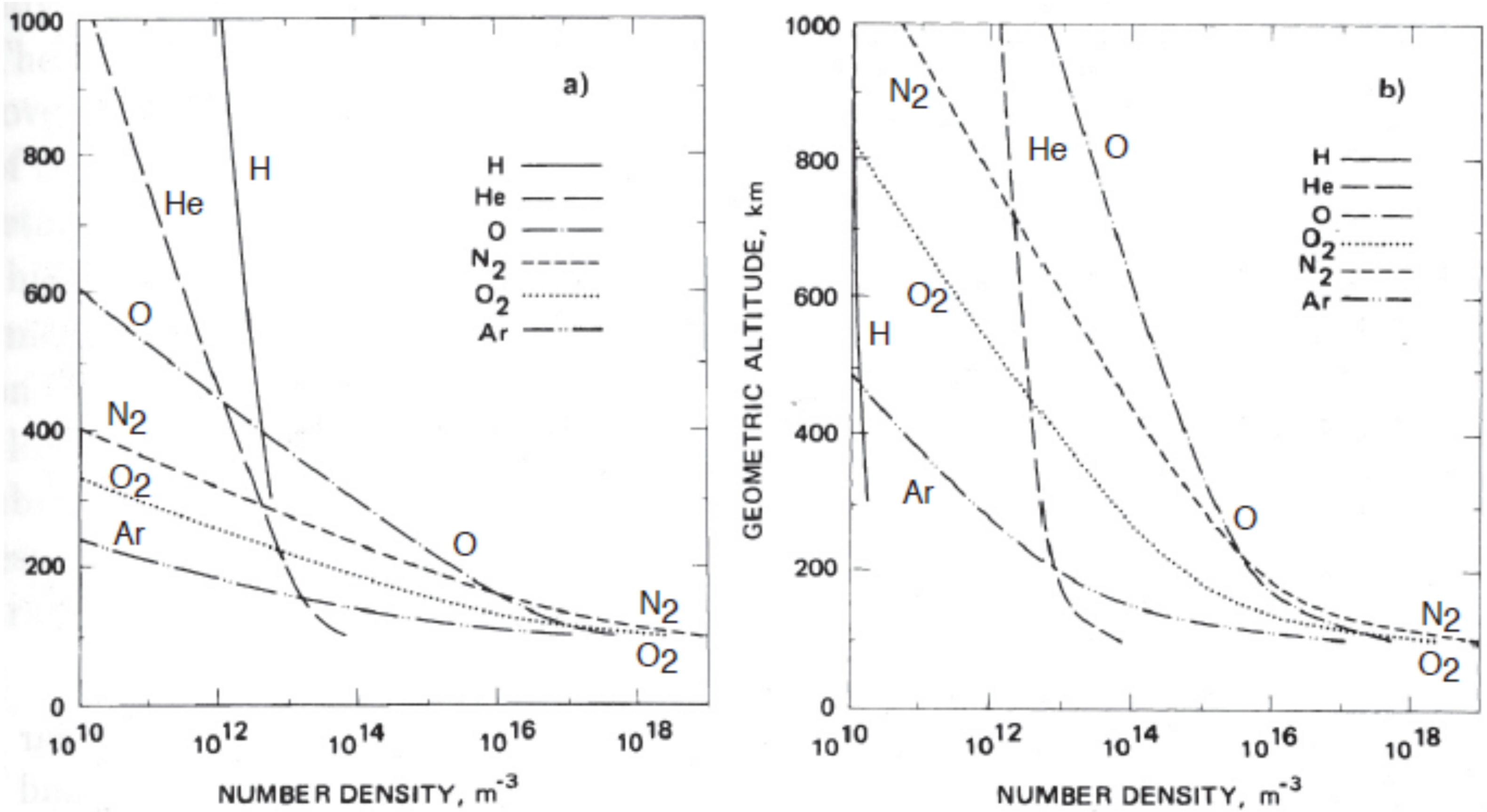


Figure: Atmospheric composition during (a) solar minimum and (b) solar maximum (U. S. Standard atmosphere, 1976).

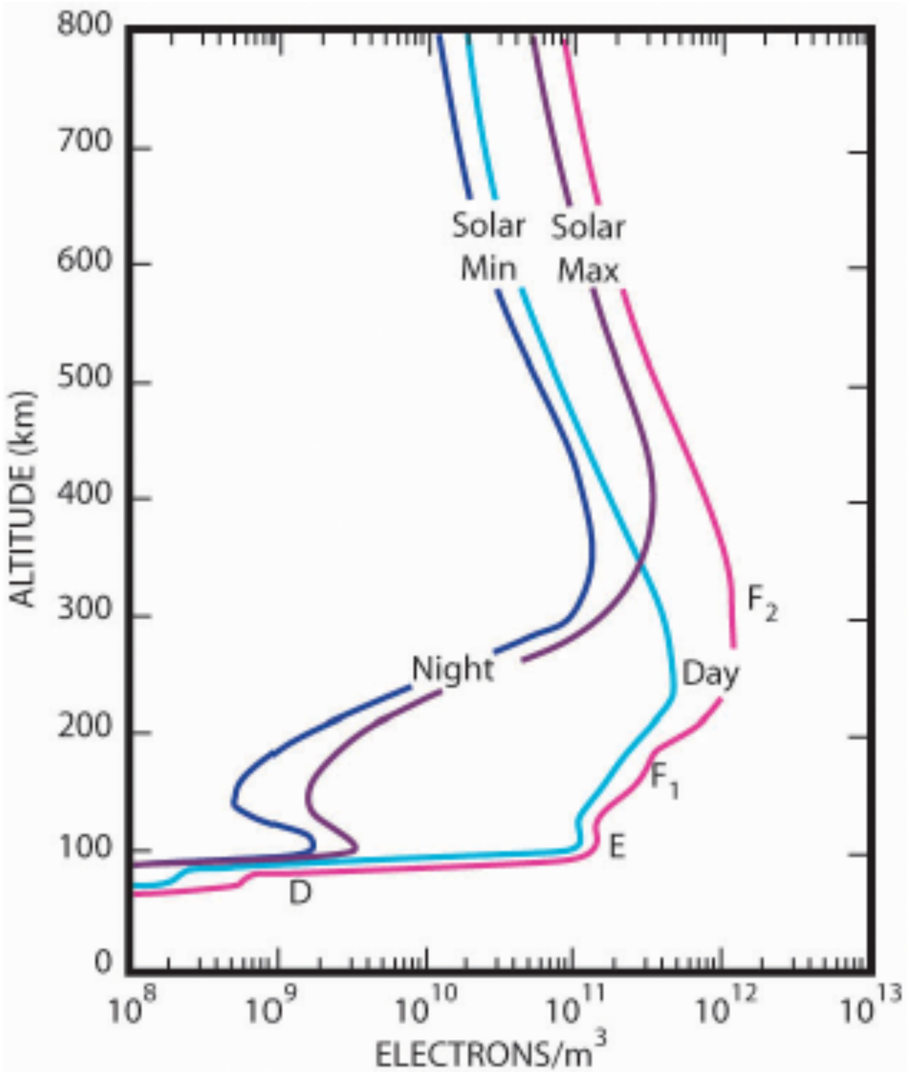
The ionosphere

Ionospheric regions and typical daytime electron densities:

- **D region**: 60-90 km, n_e = 10^8-10^9 m^{-3}
- **E region**: 90-150 km, n_e = 10^{10}-10^{11} m-3
- **F region**: 150-1000 km, n_e=10^{11}-10^{12} m^{-3}

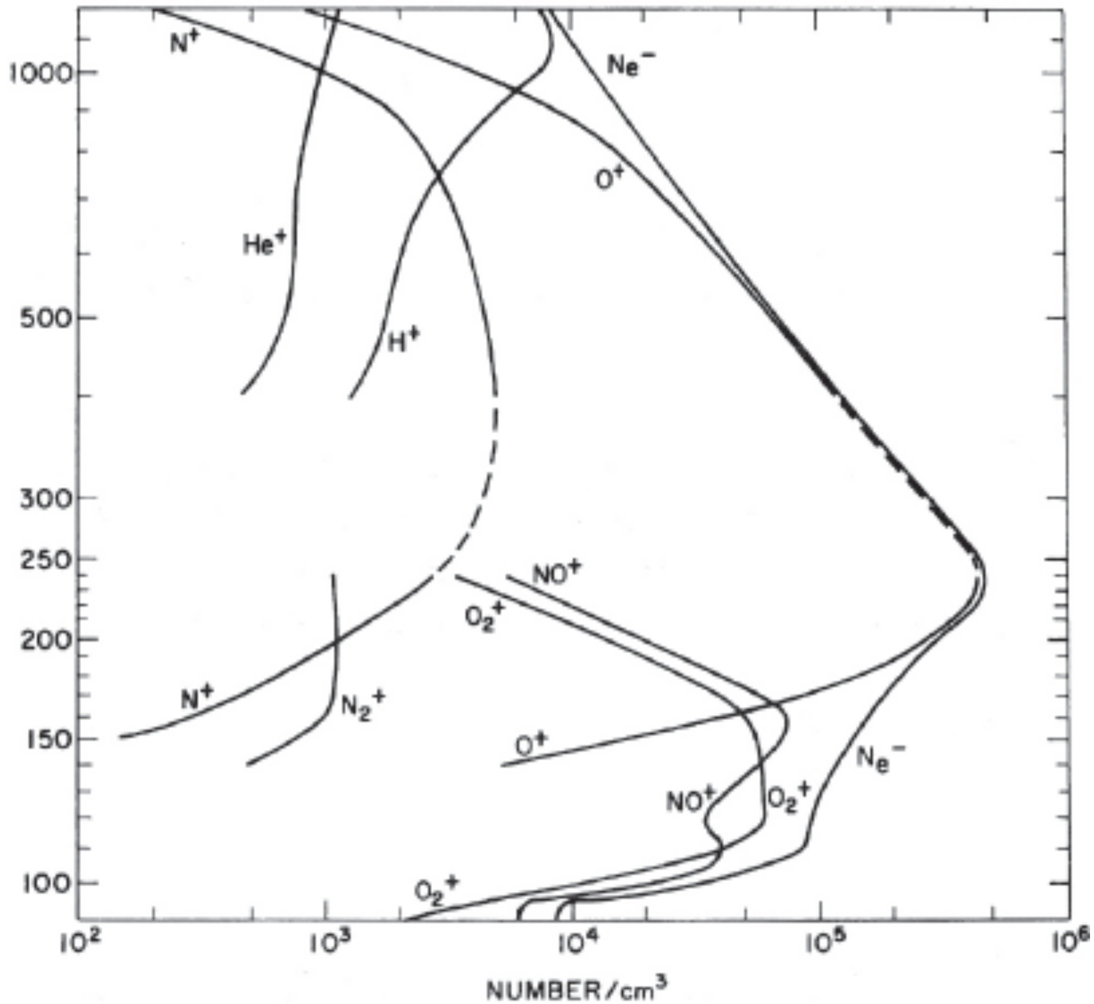
The ionosphere has great variability:

- Solar cycle variations (in the upper F region)
- Day-night variations in lower F, E, and D regions
- Space weather effects based on short-term solar variability (lower F, E, and D regions)



The ionosphere
Composition in the heterosphere

- O^+ dominates around the F region peak and H^+ starts to increase rapidly above 300 km.
- NO^+ and O_2^+ are the dominant ions in E and upper D regions (Ion chemistry: e.g. $N_2^+ + O \rightarrow NO^+ + N$).
- The D-region (not shown) contains positive and negative ions (e.g. O_2^-) and ion clusters (e.g. $H^+(H_2O)_n$, $(NO)^+(H_2O)_n$)



The ionosphere
Ion temperatures

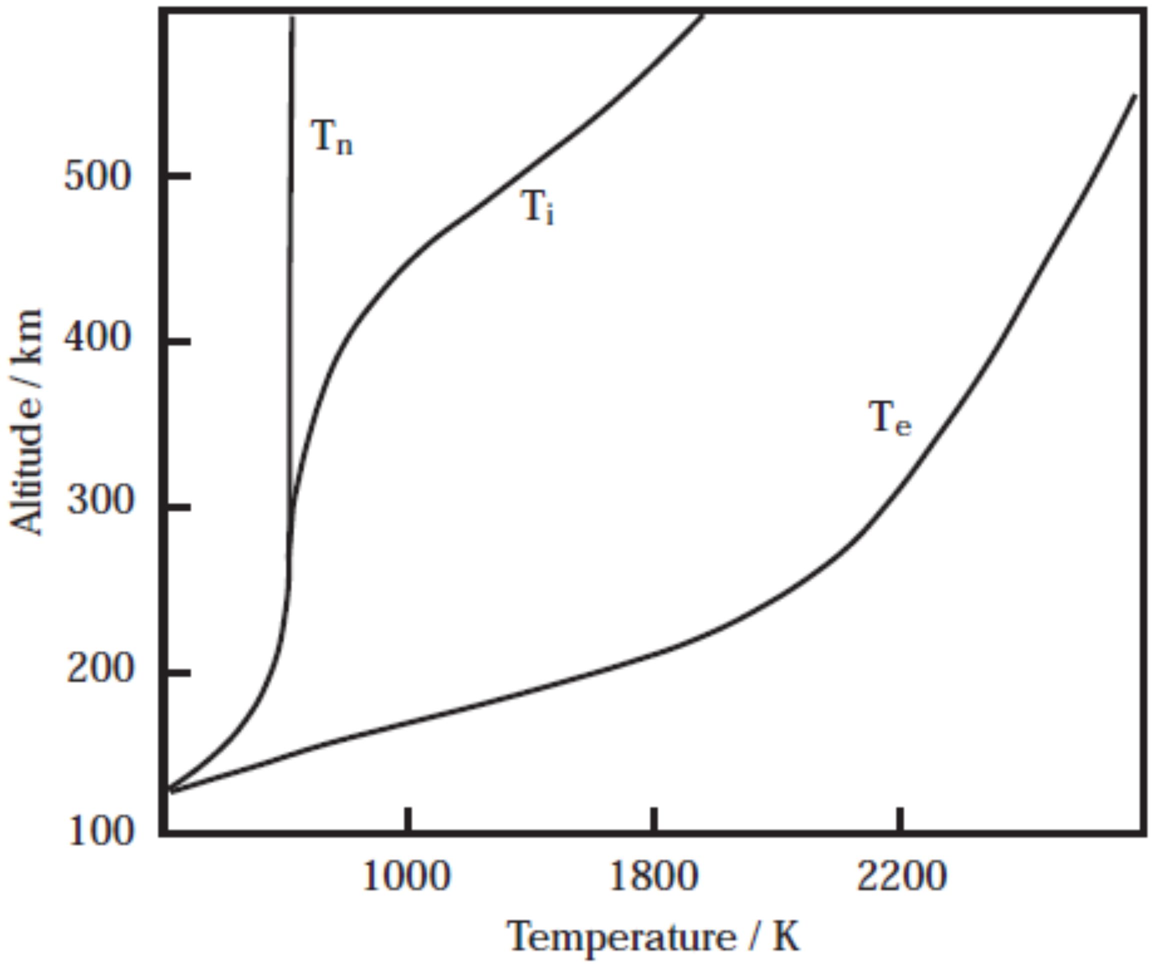


Figure: An example of neutral, ion, and electron temperature profiles

The ionosphere

Dynamics of the ionosphere

The important equations for ions (number density n_i) and electrons (number density n_e) in the ionosphere are the continuity equations:

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

where q is the production rate per unit volume and l is the loss rate per unit volume; and the momentum equations:

$$n_i m_i \left(\frac{\partial}{\partial t} + \mathbf{v}_i \cdot \nabla\right)\mathbf{v}_i = n_i m_i \mathbf{g} + e n_i(\mathbf{E} + \mathbf{v}_i \times \mathbf{B}) - \nabla p_i - n_i m_i \nu_i(\mathbf{v}_i - \mathbf{u})$$

$$n_e m_e \left(\frac{\partial}{\partial t} + \mathbf{v}_e \cdot \nabla\right)\mathbf{v}_e = n_e m_e \mathbf{g} - e n_e(\mathbf{E} + \mathbf{v}_e \times \mathbf{B}) - \nabla p_e - n_e m_e \nu_e(\mathbf{v}_e - \mathbf{u})$$

Where **E** is the electric field, **B** is magnetic induction, p_i and p_e are the pressures of the ion and electron gas, and the ion-neutral and electron-neutral collision frequencies are denoted by ν_i and ν_e respectively

Literature

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