WELCOME

THE PHYSICS OF IONOSPHERE

Talk By

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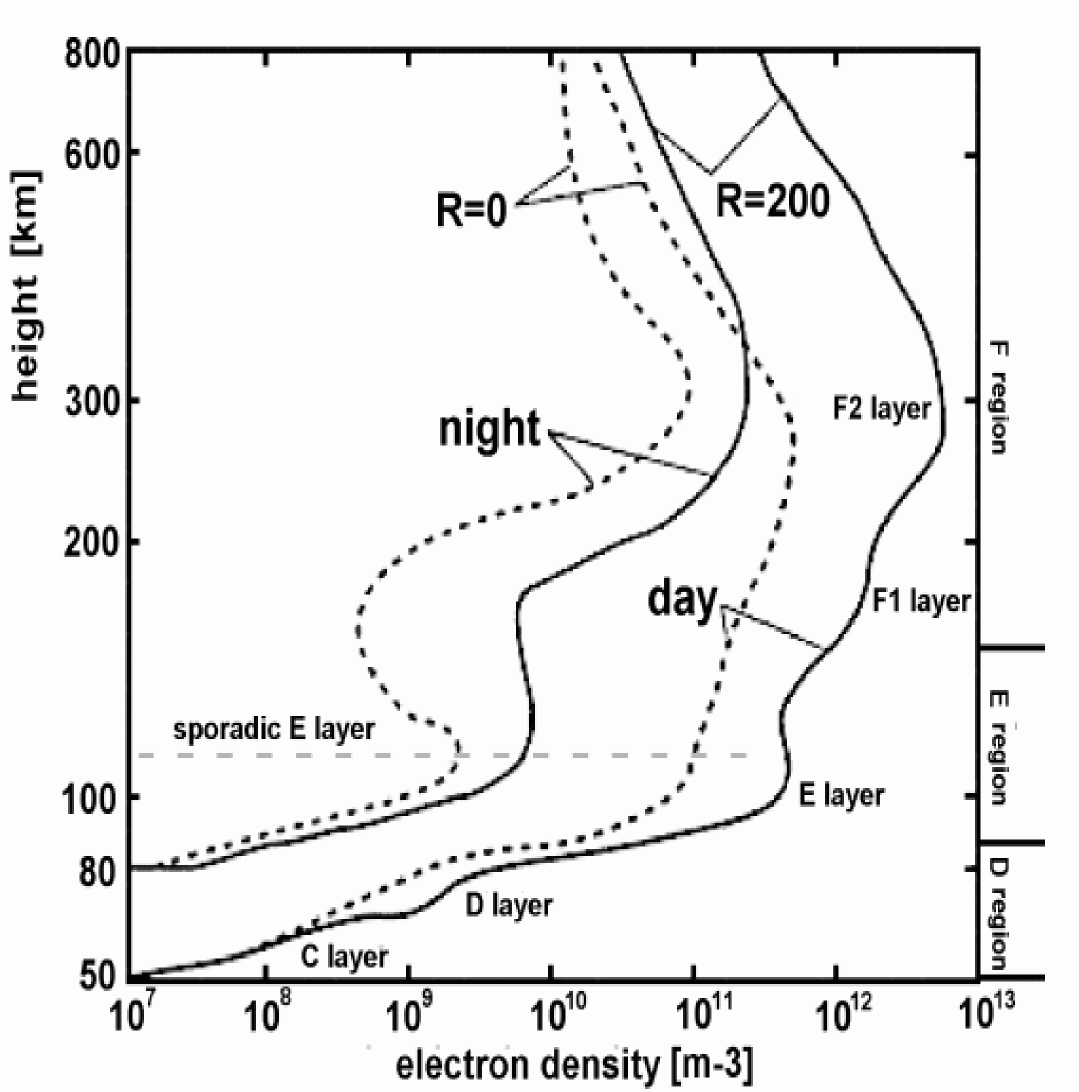
Outline

1. Ionosphere - Introduction
2. Major Physical Processes
   - Photochemical Processes
     - Production of Ionospheric Layers
   - Transport Processes
3. Electrodynamic
   - Conductivity of Ionosphere

Ionosphere – Introduction

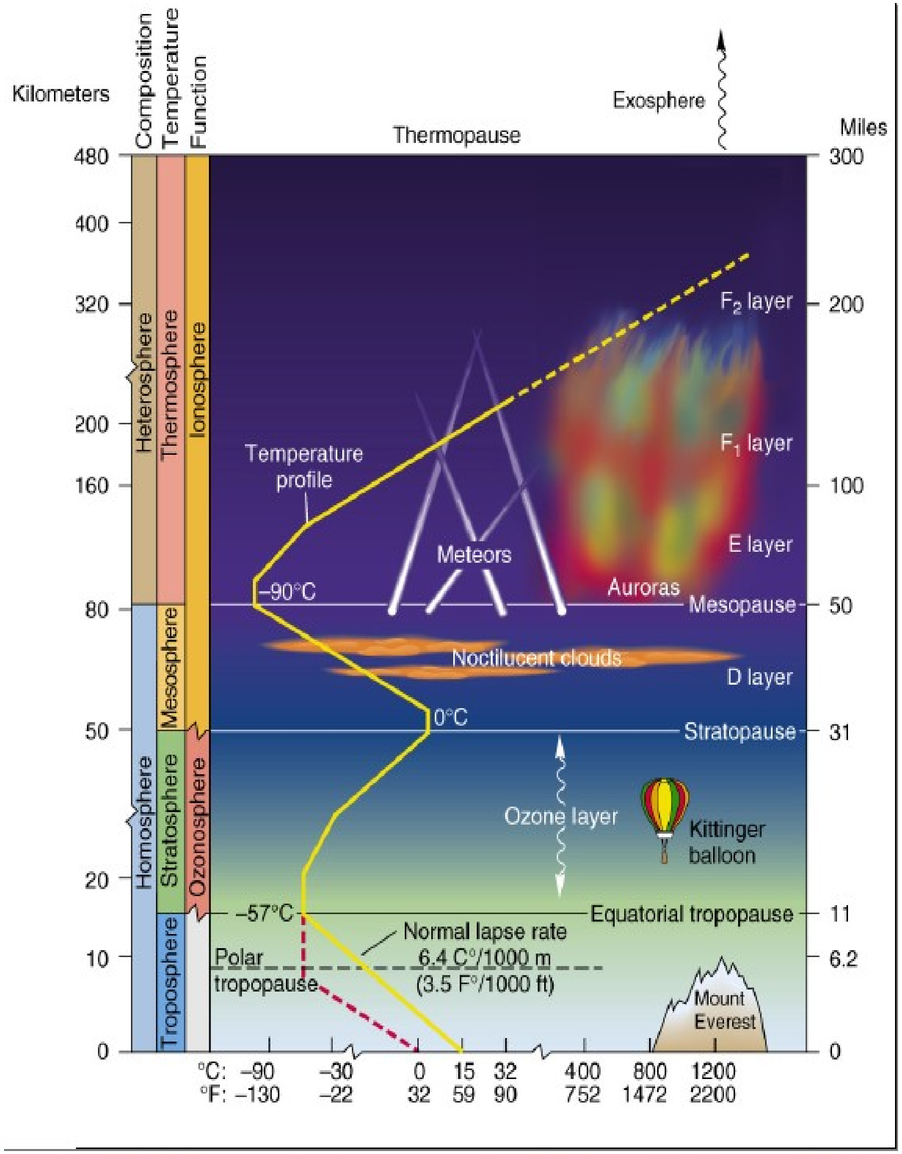
- A region in the atmosphere that contains a plasma of free ions and electrons which make ionosphere electrically conducting.
- Hence ionosphere can be considered as a conductor.
- When this 'conductor' moves in the geomagnetic field, an emf is induced in it which drive ionospheric currents.
- This current generating system is called "*Ionospheric Wind Dynamo*".

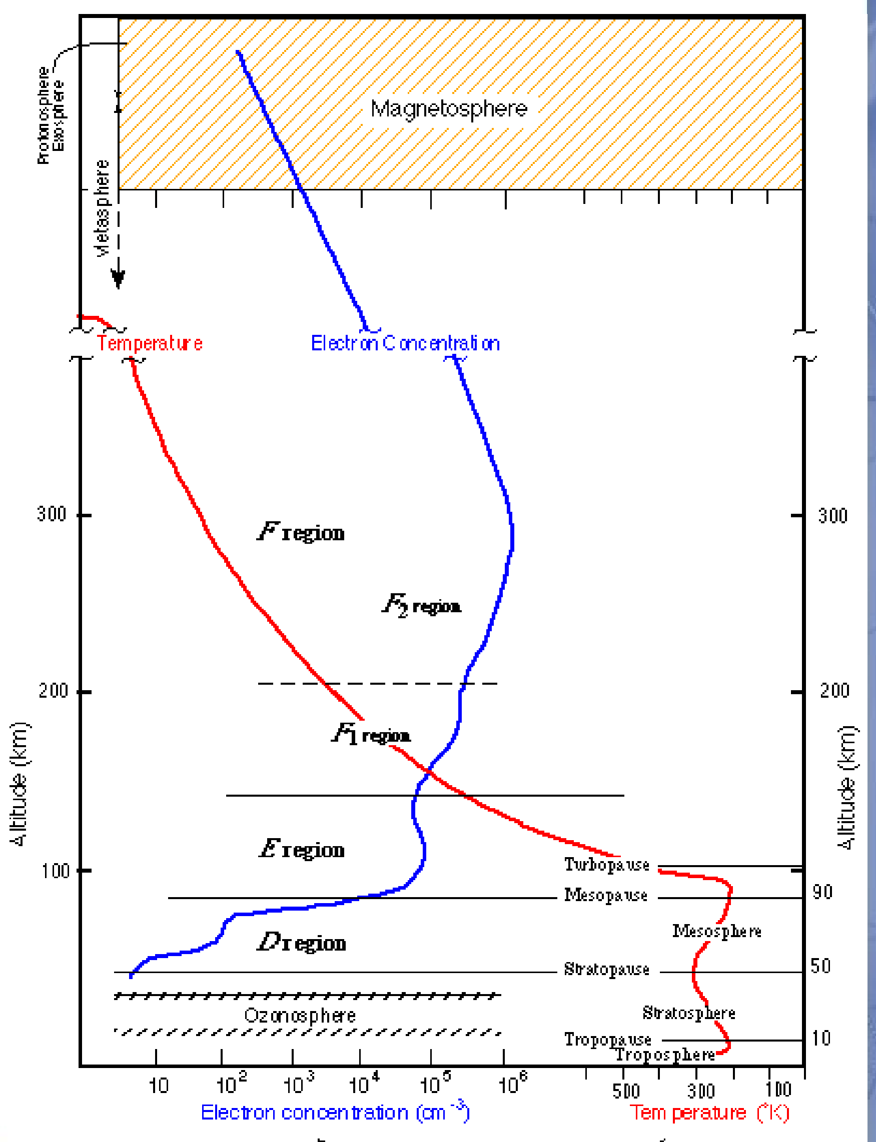
Ionosphere - Introduction



- Ionosphere is spread in meso - thermospheres.
- As far as the electrodynamic studies are concerned, the most important physical quantity of this region is its electron concentration.
- Electron concentration varies appreciably during day and night and during solar cycle.

Ionosphere - Introduction





Ionospheric Plasma

- The collective oscillations of electron gas in the ionospheric plasma give rise to several interesting phenomena. For any given plasma with a number concentration n for electrons of mass m, there exist a characteristic plasma oscillation frequency given by:

$$\omega_p^2 = \frac{ne^2}{\varepsilon_0 m}$$

  where ε_0 is the permittivity of free space.
- From the basic equations of motions, we can find a relation connecting plasma frequency with the relative permitivity of the medium:

$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2}$$

  where ω is the frquency of the electromagnetic radiation.

Ionospheric Plasma

- The relation tells us a great deal:
  - If ε is positive, a transverse electromagnetic wave propagates with a phase velocity $c/\sqrt{\varepsilon}$.
  - If ε is negative,the wave is reflected back.
  - If ε is equal to zero, the the wave get absorbed inside.
- From these, it is clear that in a plasma, frequencies below certain frequencies are reflected.
- This property of plasmas is exploited in communications and researches using satellites and radars.
- We can calculate the electron density in ionosphere apllying this concept.

Major Physical Processes

- Two major physical processes control the ionosphere:
  - **Photochemical Processes**:
  - Processes that result in the production or destruction of ionization.
  - Dominant in the lower ionosphere D and E region
  - **Tranport Processes:**
  - Processes that result in the *movement* of ionization.
  - Dominant in the upper ionosphere.
  - F2 layer lies at the level of transition between these two regions.

Physical Processes

These two effects (Photochemical Processes and Tranport Processes) can be summarized in an equation of continuity:

Within a cell of unit volume in the ionosphere;

$$\frac{\partial N}{\partial t} = q - l(N) - \nabla.(NV)$$

Where,

V: net drift velocity vector
Q: production
L: loss
N: electron concentration

PhotoChemical Processes

- In the Photochemical regime, which is approxiamtely below 200km, we consider transport processes unimportant. Hence the equation of continuity reduces to:

$$\frac{\partial N}{\partial t} = q - l(N)$$

But, since the time constant associated with loss reaction is very less, we can see to a good approximation that there is no much local change in the concentration with respect to time.

Hence $q = l(N)$

in this regime.

PhotoChemical Processes

- Theory of Ionization: Considering the attenuation of solar radiation travelling through atmosphere, we could derive an expressionfor the rate of production of *q* as a function of height *h* and zenith angle χ as:

$$q(z,\chi)=\frac{\eta I_{\infty}}{eH(z)}e^{1-z-e^{-z}\sec\chi}$$

where,

η : ionizing efficiency

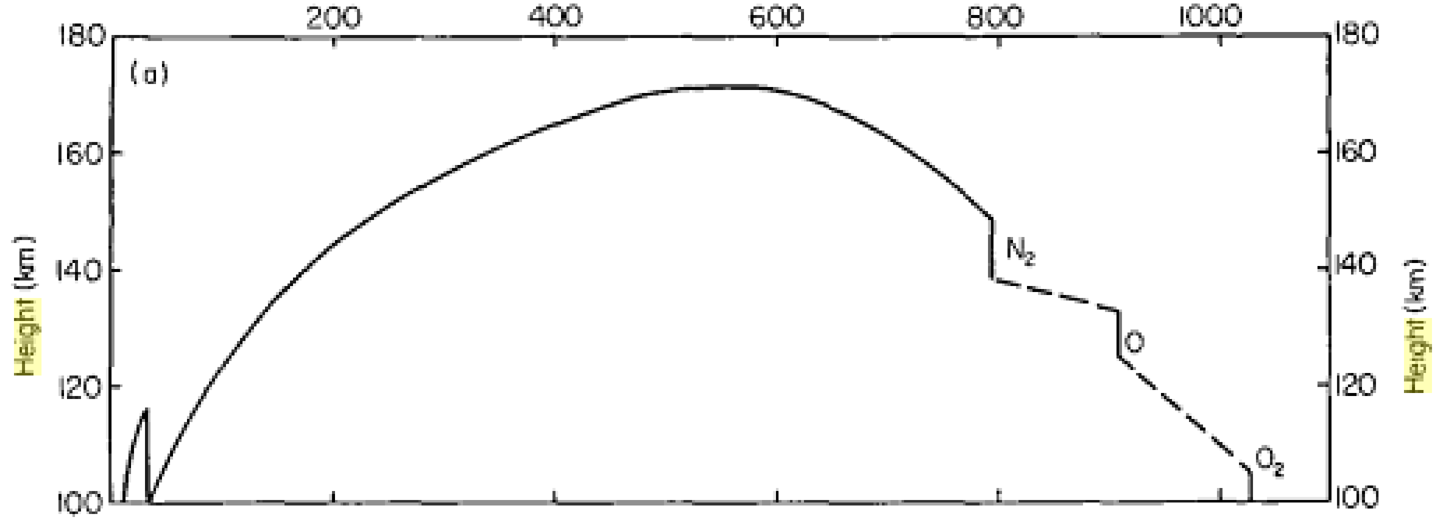
I_{∞}: unattenuated solar flux at the top of the atmosphere

PhotoChemical Processes

Production of Ionospheric Layers:

Height of Unit Optical Depth for vertically incident radiation, as a function of wavelength:

The breaks at 31, 796,911 and 1027 (Angstrom) corresponds to the K-absorption limit of N-2 and ionization limits of N-2,O and O-2 respectively.



Transport Processes

- In the transport regime, the horizontal gradients of electron concentration and the drift velocity are very small compared with the vertical gradients. Thus as a good approximation, only the vertical contributions need to be retained in the transport term in the equation of continuity.
- Thus we have,

$$\nabla . (NV) = \frac{\partial}{\partial h}(VW)$$

  where W is the upward drift velocity.
- In the transport regime, negative ions are scarce, except in the night time E region.Hence we can ignore thier presence to a good approximation.

Transport Processes

- Then the number of positive and negative ions is the same.
- The rate of change of this charge also is insignificant. Thus if any electric current pass flows, it must be non-divergent.
- Then,

$$\nabla . \vec{j} = e \nabla . (N_i \vec{V}_i - N_e \vec{V}_e) = 0$$

If concentrations of electron and positive ions are the same, it makes no difference if we use N in common for both the species in the continuity equation.

Electrodynamics

- The electrical phenomena and their interacting dynamical effects together is called ionospheric electrodynamics.
- Electrodynamic features are strongly organized with respect to the geomagnetic field. Hence the observations can also be beautifully organized interms of magnetic co-ordinates.
- Ionospheric electrodynamics depends mainly on the conductivity of the ionosphere and the strength of the thermospheric winds, both of which further depends on the flux of solar UV absorbed in the upper atmosphere.
- Further, the amount of solar UV flux aborbed heavily on the solar activity.

Conductivity

- The main generator of Ionospheric current is the wind dynamo. It operates when upper atmospheric winds move electrically conducting medium through the geomagnetic field. This motion creates an emf that drives currents and causes electric polarization charges and electric fields to develop.
- Two other minor current generating systems also exist:
  - Solar wind – Magnetosphere interation: If the current associated with this is weak, it is called a magnetically quiet period. The opposite one is magnetically disturbed period.
  - Electrical Storm Activities

Conductivity

- For explaining conductivity, we use multifluid theory, in which the neutrals and the different charged species are treated as separate fluids that interact through collisions.
- Above 90km, nearly all ions are positively charged. Hence all ion species could be considered to be a single fluid.
- The charged constituents are assumed to be in force balance.
- Pressure gradient and gravitational forces are neglected for calculating conductivities.
- The relevant forces are Lorentz force and the friction between fluids in different velocities.
- Number densities of electrons and ions are equal.

Conductivity

- At equilibrium, we get two equations

$$N_e e(\vec{E}+\vec{v}_i\times\vec{B})=N_e m_i \nu_{in}(\vec{v}_i-\vec{v}_n)+N_e m_i \nu_{ie}(\vec{v}_i-\vec{v}_e)$$

for ions.

$$-N_e e(\vec{E}+\vec{v}_e\times\vec{B})=N_e m_e \nu_{en}(\vec{v}_e-\vec{v}_n)+N_e m_e \nu_{ei}(\vec{v}_i-\vec{v}_e)$$

for electrons.

- Solving these, we get expressions for conductivities:
  - Parallel Conductivity:

$$\sigma_{ll}=N_e\frac{e^2}{m_e(\nu_{en_{ll}}+\nu_{ei_{ll}})}$$

ν isthe collision frequency

Conductivity

- Perpendicular Conductivity:
- It has two different tributories viz, Hall conductivity and Pederson conductivity.
  - Pedersen conductivity:

$$\sigma_P = \frac{N_e e}{B}\left(\nu_{in}\frac{\Omega_i}{\nu_{in}^2+\Omega_i^2}+\nu_{en_{per}}\frac{\Omega_i}{\nu_{en_{per}}^2+\Omega_e^2}\right)$$

  - Hall Conductivity:

$$\sigma_H = \frac{N_e e}{B}\left(\frac{\Omega_e{}^2}{\nu_{en_{per}}^2+\Omega_e^2}-\frac{\Omega_i{}^2}{\nu_{in}^2+\Omega_i^2}\right)$$

Conductivity

- Where $\Omega_i = eB/m_i$ is the angular gyrofrequenccy for the ions who gyrate in hte geomagnetic field.
- The total current density in the ionosphere is the sum of all these two components:

$$\vec{J} = \vec{J}_{ll} + \vec{J}_{per}$$

where

$$J_{ll} = \sigma_{ll} E_{ll} \vec{b}$$

and

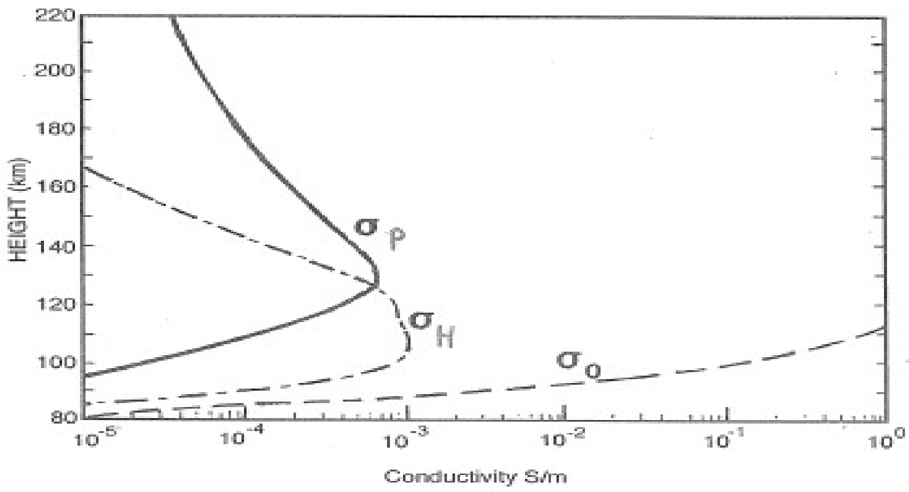
$$J_{per} = \sigma_P \left(\vec{E}_{per} + \vec{v}_n \times \vec{B} \right) + \sigma_H \vec{b} \times \left(\vec{E}_{per} + \vec{v}_n \times \vec{B} \right)$$

Conductivity

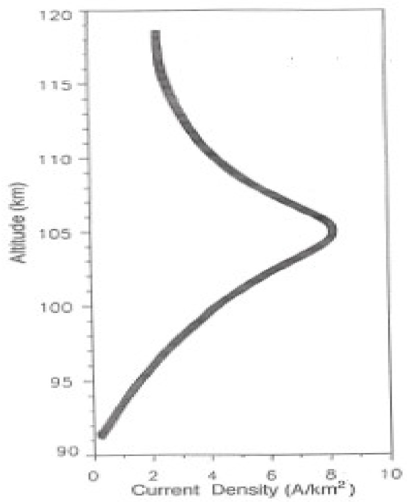
- The quantity $\vec{v}_n \times \vec{B}$ is called the *dynamo electric field*.
- Pedersenconductivity gives the component in the direction of the electric field for currents perpendicular to the magnetic field.
- Hall conductivity gives the component perpendicular to both the electric field and the magnetic field.
- The expression for conductivities is based on the assumption that the collision frequencies are independent of the fluid velocities. This is a reasonable assumption as long as the relative velocities are small with respect to the thermal velocities (of the order of 300 m/s to 1000 m/s, for ions and neutrals) depending on the temperature and composition.

Conductivity

- When the relative velocities of the ions and neutrals are comparable with thermal velocities (like those in the auroral regions where strong electric fields associated with magnetosphere processes can exist) these expressions are *inaccurate*.



- *Figure at the top shows the day time conductivity ofnosphere.*
- *Bottom figure shows the vertical profile of current density in the equatorial electrojet.*



Conductivity

- It can be seen that, above 80km, the *parallel conductivity* is much larger than the Pedersen and Hall conductivities.Its value depends on the electron temperature at an order of 3/2 where as it is independent of the electron density.
- Pedersen peaks at 125km and Hall at 105-110km. At a given altitude both of these are proportional to the electron density.
- The ratio of Hall to Perdersen is greater than 1 between 70km and 125km. It is maximum (~36) around 100km.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