Physics of aurora

1 Introduction

What is aurora?
At first we need a source of particles. It should emit charged particles more or less continuously.
Second we need an accelerator to accelerate the charged particles.
Third a magnetic field is needed to guide the particles to a target.
Fourth a geseous target wil be partly excited and the excited gas particles will finally emit some light.
Fifth a scientist will look at the generated light and he/she tries to solve how this has happened.

1.1 The Solar wind

Aurorae are the end product of a long chain.
- It starts from the **Sun**. Sun emits electromagnetic radiation (e.g. light) but also charged particles. The particle flux is called **solar wind** and it blows to space.
- The solar wind particles are mainly electrons and protons. A small fraction is α particles (nuclei of He atoms). The solar wind is electrically neutral.
- The solar wind spread to every direction. A tiny fraction is also coming to the Earth.
- Its speed is typically 400 km/s varying from 200 to over 1000 km/s.
- The density of the solar wind is typically 5 ions/cm^{3}and it varies from 0.4 to 100 ions/cm^3. - From time to time there are bursts in the solar wind.

1.2 The Earth magnetosphere

- Our Earth is a huge magnet. Its magnetic field originates from 10^9 A East-West current about 3000 km deep inside the Earth.
- This basic magnetic field varies very slowly. This variation is called secular variation. - On the magnetic poles the field is 0.64 G or 64 000 nT.
- Around Kiruna the vertical component of the magnetic field is about 51 500 nT and horizontal component about 10 800 nT. This means that the inclination of magnetic field is about 78°.
- The magnetic field if tilted from the rotational axis by 11.5°. - Magnetic

North Pole is close to the NW edge of Greenland.

1.3 The Earth atmosphere

- The Earth atmosphere is densest at the surface of the Earth.
- The density decreases when going upward.
- Several layers in the atmosphere have their own name: troposphere, stratosphere, mesosphere and termosphere.
- Below 100 km the atmosphere is homogenous and this region is called homosphere.
- In the homosphere the N_2 density is 78.1 % and O_2 density 20.9 %

- The atmospheric temperature varies with altitude. The coldest part is in mesopause at local summer, even below 130 K.
- Above 100 km the temperature rises quickly to several hundreds of K.
- Above $200-300$ km the temperature is close to Exospheric temperature
- The exospheric temperature depends on solar activity and magnetic activity. At highest may be 2500 K.

1.4 The Earth ionosphere

- The atmospheric layer, which affect the propagation of radio waves is called **Ionosphere**
- It covers the altitude region from 60-70 km up to 1000-2000 km
- There are different layers, D-, E-, ja F-layers
- There the ionization is relatively high, maximum is in F-layer, about 0.001
- In the ionosphere the atmosphere is no more homogenous. We call that part of the atmosphere heterosphere
- N_2 is no longer the most common constituent. Above $200-300$ km the atomic oxygen O starts to be the most common constituent, higher up even H and He.

There is a need to predict the conditions of the thermosphere where

- the energy input is dominated by solar UV photons, auroral energetic par-

ticles, electric fields and electric currents
- the major neutral constituents are O, N_2 and O_2 and the minor constituents are NO, N, H, He, Ar and CO_2
- neutral atmosphere dynamics are strongly influenced by plasma motions

1.5 The optical emissions in the ionosphere

- In the thermosphere most radiations from the atmospheric atoms and molecules which originate in the visible spectral range comes from **airglow** and **aurora**.
- Airglow is emission of chemically excited constituents, aurora is emission of particle collision excited atoms, molecules or ions. Dayglow and nightglow are both airglow.

- **nightglow** is generally too faint and structureless to be seen naked eye from the ground. It can be easily measured with sensitive photometers

- **dayglow** is overwhelmed by scattered sunlight in the lower atmosphere.

- **aurora** is the magnificent phenomenon of processes which we will be looked in more detail.

- Different techniques have been used to measure such radiation from the upper atmosphere.
- Analysis of various emission features has yielded insight into chemical processes, energy balance and the dynamic behaviour of the upper atmosphere.
- They are remote sensing: radar, TV, photometer and in situ measurements: balloons, rockets, satellites

1.6 Energetics

- Unlike lower levels of the atmosphere, the constituents of the thermosphere are not fully mixed.
- It becomes necessary, therefore, to describe the behaviour of each species by its continuity, momentun and energy equations.
- Each species has its own production and loss rates, transport properties and thermal characteristics, and is subject to different forces.

- The concentration of the j^{th} constituent, n_j, is given by the continuity equation,

$$\frac{\partial n_j}{\partial t} = P_j - L_j + \nabla \cdot (n_j \mathbf{v}_j) \tag{1}$$

where P_j and L_j are the production and loss rates and $\mathbf{v}_j$ is the velocity vector. Each term in the continuity equation represents a rate of change of the concentration of species j per unit volume with time t. The last term on the right side of Equation 1 represents the flux divergence.

- Motion of the j^{th} constituent is given by momentum equation.

$$\rho_j D_j \mathbf{v}_j / Dt + \nabla \cdot \overline{\mathbf{P}}_j = \sum_j n_j \mathbf{F}_j \tag{2}$$

The inertial term and the generalized pressure tensor term on the left hand side of the equation are balanced by the external forces, F_j, on the right side. The ρ_j is the mass density and $\overline{\mathbf{P}}$ is the pressure tensor and the external forces are gravitational and electromagnetic. (The convective derivative is $Dj/Dt = \partial/\partial t + v_j \nabla$). Each term in the momentum equation represents a force per unit volume.

The thermal properties are specified by the energy equation

$$n_j k D_j T_j / Dt = Q_j - L_j^T - n_j k T_j \nabla \cdot \mathbf{v}_j - \nabla \cdot \mathbf{q}_j + \sum_j n_j \mathbf{F}_j \cdot \mathbf{v}_j \tag{3}$$

Each term represents a time rate of change of energy per unit volume. The net rate of change (left side of the equation) is equal to the sum of the local heating rate, Q_j, heat loss rate,L_j, compressional heating (or cooling), divergence of the heat flow, q_j, and the work done on species j.

The equation of state

$$P_j = n_j k T_j \tag{4}$$

relates parameters that appear in the three conservation equations and defines the partial pressure of the jth species, k is Boltzmann's constant.

- The same laws of physics apply throughout the atmosphere, of course, but the relative importance of various processes varies widely between regions, accounting for the different behaviour of the characteristic parameters as a function of altitude.