



Fig. 1.6. Synopsis of magnetospheric currents.

A number of current systems exist in the conducting layers of the Earth's ionosphere, at altitudes of 100–150 km. Most notable are the *auroral electrojets* inside the auroral oval, the *Sq currents* in the dayside mid-latitude ionosphere, and the *equatorial electrojet* near the magnetic equator.

In addition to these perpendicular currents, currents also flow along magnetic field lines. As shown in Fig. 1.6, the *field-aligned currents* connect the magnetospheric current systems in the magnetosphere to those flowing in the polar ionosphere. The field-aligned currents are mainly carried by electrons and are essential for the exchange of energy and momentum between these regions.

## 1.4. Theoretical Approaches

The dynamics of a plasma is governed by the interaction of the charge carriers with the electric and magnetic fields. If all the fields were of external origin, the physics would be relatively simple. However, as the particles move around, they may create local space charge concentrations and thus electric fields. Moreover, their motion can also generate electric currents and thus magnetic fields. These internal fields and their feedback onto the motion of the plasma particles make plasma physics difficult.

In general the dynamics of a plasma can be described by solving the equation of motion for each individual particle. Since the electric and magnetic fields appearing in each equation include the internal fields generated by every other moving particle, all equations are coupled and have to be solved simultaneously. Such a full solution is not only too difficult to obtain, but also of no practical use, since one is interested in knowing average quantities like density and temperature rather than the individual velocity of each particle. Therefore, one usually makes certain approximations suitable to the problem studied. It has turned out that four different approaches are most useful.

The simplest approach is the *single particle motion* description. It describes the motion of a particle under the influence of external electric and magnetic fields. This approach neglects the collective behavior of a plasma, but is useful when studying a very low density plasma, like found in the ring current.

The *magnetohydrodynamic* approach is the other extreme and neglects all single particle aspects. The plasma is treated as a single conducting fluid with macroscopic variables, like average density, velocity, and temperature. The approach assumes that the plasma is able to maintain local equilibria and is suitable to study low-frequency wave phenomena in highly conducting fluids immersed in magnetic fields.

The *multi-fluid* approach is similar to the magnetohydrodynamic approach, but accounts for different particle species (electrons, protons, and possibly heavier ions) and assumes that each species behaves like a separate fluid. It has the advantage that differences in the fluid behavior of the light electrons and the heavier ions can be taken into account. This can lead to charge separation fields and high-frequency wave propagation.

The *kinetic theory* is the most developed plasma theory. It adopts a statistical approach. Instead of solving the equation of motion for each individual particle, it looks at the development of the distribution function for the system of particles under consideration in phase space. Yet even in kinetic theory certain simplifying assumptions have to be made and there are different flavors of kinetic theory, depending on the kind of simplification made.

In the present book we will describe all these approaches and apply them to suitable geophysical plasma phenomena. We will start with the single particle approach. Subsequently, we will derive the basic equations of the kinetic theory, but then first turn to the fluid theories and their applications, before we finally go into the details of the kinetic approach.