Chapter 1
Introduction

1.1 The Panorama of the Thesis

The thesis is about studying the transport of cosmic rays across the interplanetary-medium shock generated by solar flares. For this we have made up a physical model to simulate the transport and the model is cast in a mathematical form, a partial differential equation, which from now on will be called the transport equation. The transport equation is in a very complex form, see for example in Ruffolo (1995), and it is very hard, or even worse impossible, to find the analytic solution which has ever been solutions to mathematical physics equations traditionally. Then we turn to a numerical method to find the numerical solution instead. The solution to the transport equation is the distribution function, the number of particles inside a given flux tube per unit of the arc length along interplanetary magnetic field, the cosine of pitch angle, and the momentum of a particle. In this work we consider only the effects of streaming, convection, and pitch-angle scattering for simplicity in the transport equation, then the equation looks more simple in form than that of Ruffolo mentioned above. But the complexity in finding the solution is compensated by including influence of a solar-flare shock into the initial distribution. Now behaviors of the cosmic ray particles are investigated while the particles cross the shock, including the influence that the shock has on the transport of cosmic ray particle (propagation and acceleration). The propagation effect is about reflection at the shock front, taking place when the particles in the upstream region move in appropriate range of directions in de Hoffmann-Teller frame toward the shock. The reflection of the particle in the de Hoffmann-Teller frame keeps the magnitude of momentum unchanged but its direction is opposite to the incident one. This makes a sharp peak, more particles are here, near the shock at positive direction or along magnetic field. On the opposite way, the acceleration influence is about transport of particles across the shock and the shock accelerates them to higher momentum states. The acceleration of the particle by the shock takes place in both directions oppositely, i.e., from the downstream to the upstream region and from the upstream to the downstream region. Normally, few particles are in high momentum than low momentum state. When accelerated by the shock, the particles try to increase their number at high momentum states near the shock front. Thus the increase of particles near the shock both downstream and upstream regions can be observed sensibly. Because they have high momenta, the particles try to go quickly away from the shock in the same direction as they first incident it. By this way we find that the farther they go away from the shock, the lesser their number are. Because the intensity of this effect depends on both magnitudes and directions of cosine of pitch angles, anisotropies can be found in that negative anisotropy in the downstream region and positive anisotropy in the upstream region. The anisotropies occurring in the simulation come to agree qualitatively with the observations from spacecraft ISEE-3.

In addition to the work mentioned above we have studied a numerical method called PLIM, acronym of Piecewise Linear Interpolation Method, developed by Rajamäki and Saarinen (1994) for finding a numerical solution to a one-dimensional frontal phenomena equation. We used it to compute a numerical solution to simple problems which can be solved easily by using analytic methods. We found that the solution from PLIM agreed well with the analytic one for a problem with an initial function in a stepwise form while for a problem with an initial function in a peak form the PLIM solution deteriorated along time when compared with the analytic one.

1.2 Objectives

- To study changes in the flux and anisotropy of cosmic rays before and after crossing the shock.
- To study the acceleration of cosmic rays by the shock.
- To compare the result of simulation with observations from the ISEE-3 spacecraft.

1.3 Outline of the thesis

- The first chapter describes the panorama, objectives, outline, and usefulness of the thesis.
- We begin to go into details in chapter 2 with introduction to physical study of cosmic rays. We explain what cosmic rays are. Physical quantities related to transport of cosmic rays are defined and explained here.
- Chapter 3 does not really depend on the others. It is self-contained about the numerical method for solving a one-dimensional frontal phenomena.
- The content of Chapter 4 is the core of this work. Relations of physical quantities in one frame to another frame are derived. The conservation and transformation principles are worked out. The transport equation is set up and a numerical treatment follows. The chapter is closed with numerical results and data analysis.
- The last chapter is the conclusion of the work done in the previous chapter.

1.4 Usefulness of the research

We expect that we will understand better about the transport of cosmic particles especially when they cross the solar-flare shock and the influence of the shock to accelerate particles. An anisotropy can be explained by the result of the simulation. Then the computer codes developed in this work can be applied to further works that are more complicated than this one.