Chapter 1
Introduction

1.1 Introduction

Cosmic rays, i.e., radiation from the cosmos, are energetic particles or gamma rays originating outside the Earth. They were discovered by V. Hess in 1912, and since then scientists have tried to understand the origin of cosmic rays. The first step to a successful acceleration mechanism came in 1949, when E. Fermi proposed what is now known as the theory of stochastic acceleration or second-order Fermi acceleration. This was the first theory explaining how ordinary charged particles can gain energy to become energetic particles in space plasmas, although this theory could not completely explain the energy spectrum of galactic cosmic rays. In 1954, Fermi proposed another acceleration mechanism with greater efficiency, now called first-order Fermi acceleration. This theory was successful in explaining the power-law momentum distribution of galactic cosmic rays, corresponding with observations. Nowadays, scientists still believe that first-order Fermi acceleration is the main mechanism producing cosmic ray particles. Since this acceleration process is likely to take place at shocks in space plasmas, it can also be called shock acceleration.

After the appearance of the acceleration ideas proposed by Fermi, many works on shock acceleration have been published. Most of the theories were based on the diffusion approximation. The approximation allowed scientists to solve many problems with analytic methods; however, it is an approximation that is not always correct. Actually, there is a pitch angle transport equation that can be used to model the shock acceleration with greater accuracy, but solving this is much more complicated than using the diffusion approximation. In general, it cannot be solved analytically. Recently, there were some works on shock acceleration solving the pitch angle transport equation by numerical methods. These works showed some interesting results that were never seen before when using the diffusion approximation or previous analytic solutions of the pitch angle transport equation for special cases. Ruffolo (1999) was the first work providing solutions of the pitch angle transport equation in the situations of oblique, nonrelativistic shocks for non-ultrarelativistic particles. This work discovered a peak in the spatial distribution near the shock that was not predicted by previous work using the diffusion approximation. This result was soon confirmed by Gieseler et al. (1999). After that, Klappong et al. (2001) and K. Klappong (M.Sc. thesis), who used a pitch angle transport to study particle acceleration at shocks and compression regions with various compression widths, provided evidence that the peak arises due to the magnetic mirroring effect, which is neglected in the diffusion approximation. Thus, the peak can be called the "mirroring peak."

In this work, we would like to understand more about effects of magnetic mirroring on shock acceleration with varying magnetic mirroring strength by varying the angle between the magnetic field lines and the shock or compression normal vector. We study these situations by simulating the transport of particles at shocks and compression regions. We simulate the situation by numerically solving both the pitch angle transport equation and a diffusion-convection equation obtained by using the diffusion approximation. The differences between those results should indicate how magnetic mirroring affects our situations of interest.

1.2 Objectives

• Develop the computer programs and methodology for finding solutions of the pitch angle transport equations and diffusion-convection equations which are used to treat particle transport at shocks and compression regions.

• Study the effects of magnetic mirroring on particle acceleration at shocks and compressions with various angles between magnetic field lines and shock/compression normal vectors by comparing the spatial distributions and spectral indices obtained by solving the pitch angle transport equation with those from the diffusion-convection equation.

1.3 Thesis Outline

A rough outline of this thesis is as follows: Chapter 1 provides an introduction to and objectives of this work. All unfamiliar technical terms will be described in detail in later chapters. Chapter 2 will provide some background information about cosmic rays, the motion of charged particles in a space plasma, and the concept of shock acceleration. In Chapter 3, there are explanations on how we model shocks and compression regions. Furthermore, this chapter provides some knowledge about the transport equations we use, an explanation on how to derive the diffusion-convection equation by using the diffusion approximation on the pitch-angle transport equation, and an explanation on how to modify the equations to be suitable for our situations of interest. Chapter 4 will talk about the main numerical methods and methodology that we use to find our solutions. Chapter 5 will show our results and discussion. Chapter 6 will provide the summary of this work. Appendix A provides the relation between the energy spectral index and momentum spectral index. Appendix B supplies some evidence pointing out that supernova remnant shocks are the origin of galactic cosmic rays. Appendix C shows the tables of simulation parameters. Finally, Appendix D provides all results obtained from this work.