THE ROLE OF ANTIPROTONS IN COSMIC-RAY PHYSICS

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Abstract. Though success eluded experimentalists from detecting cosmic-ray antiprotons over a long period of time, the study of cosmic-ray antiprotons has now become a fascinating field of research. In this review, we have attempted to elucidate the excitement in this area of research since the discovery of antiprotons in the laboratory. We have described the experiments carried out so far to measure the energy spectrum of antiprotons, from about 200 MeV to about 15 GeV, and summarised the results. The observed spectrum, with the limited data, appears to be very hard and is different from other components of cosmic radiation. Upper limits to the fraction of antiprotons in cosmic-rays have also been derived at higher energies, using the observed spectra of cosmic-ray primary and secondary particles at different depths in the atmosphere. We have described various physical processes by which antiprotons could be produced, such as high-energy interactions, neutron oscillations, evaporation of Mini Black Holes, decay of super symmetric particles, etc. The energy spectrum of antiprotons, which are produced through the above processes, undergoes modifications during propagation in the Galaxy. We have examined in detail the propagation models which have been employed to explain the observed data. It is shown that no single model could predict correctly the observed energy spectrum of antiprotons over the entire energy region. However, many models are able to explain the data at relativistic energies. It is difficult at this stage to make a choice among these models. The implications of these models for other components of cosmic-rays, such as positrons, deuterium, and He, have been discussed. We have examined the production of gamma rays in the Galaxy from sources, which produce the observed antiprotons through high-energy interactions. We have also briefly indicated the effect of possible re-acceleration during their confinement in the Galaxy. We finally emphasized the need for more detailed measurements of the spectral shape of cosmic-ray antiprotons to further refine speculations of their origin. Similarly, we have shown that detailed observation of the energy spectra of positrons, deuterium, and He at relativistic energies are crucial to test various propagation models.

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1. Introduction

Cosmic rays we sample in the neighbourhood of the Earth reach us after having undergone a chain of transformations beginning with what occurs in their source region. This includes interactions with matter, magnetic fields, and radiations, resulting in the destruction of primary particles, production of secondary particles and radiations, energy losses, and acceleration. An understanding of the observed cosmic-ray composition and spectra provides a consistent picture of the origin and propagation of cosmic rays, namely: (1) the sources of primary particles, (2) parameters relating to the injection and acceleration processes, (3) confinement regions of cosmic rays, and (4) propagation enroute to the solar system and in the interplanetary space. This picture continues to evolve as the observations improve with time.

It stands to reason that elements and isotopes known to be absent in astrophysical objects are assumed to be absent in the primary cosmic radiations also. Thus astrophysically rare particles observed in cosmic rays are considered to be secondary in origin. Some of the secondary particles such as D, ^{3}He, Li, Be, B, etc., observed in cosmic rays are due to the spallation of heavier nuclei with matter during their propagation. Other secondary particles such as antiprotons, positrons, and neutrinos are created as a result