On the importance of interstellar Helium for the propagation of heavy Cosmic Rays

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The influence of interstellar He on the fragmentation of heavy cosmic rays in the interstellar medium (ISM) has long been a controversial subject. While H-induced cross section data are now available over broad mass and energy ranges, little data for He-induced fragmentation exists (see /1/,/2/ and references therein). With the recent reports of accurate measurements of the secondary/primary ratios in cosmic rays /3/ and of H-induced cross sections /4/,/5/ the problem of including interstellar He in propagation calculations becomes even more critical. As is argued in /6/ the escape lengthes λe deduced from the B/C+O and Sc-Cr/Fe ratios cannot be reconciled within the frame of a simple leaky box model assuming the ISM composed of pure H. It is quite remarkable that the discrepancy is especially large in the GeV region where (i) secondary/primary ratios measured by several groups agree fairly well (see /6/) and (ii) fragmentation cross sections have been recently measured with good accuracy /4/,/5/.

At this stage one may wonder if this is an effect of having neglected the interstellar He in the propagation calculations. Indeed a hint that the ISM He could play a role in the GeV region is indicated in Table 1 which displays the ratios of He-induced and C-induced to H-induced fragmentation and total inelastic cross sections. It is seen that the fragmentation cross sections for Fe secondaries in He-induced reactions do not scale as the total cross section while the effect is much attenuated for C secondaries. The same trend for C-induced cross sections is also indicated in Table 1. It is therefore expected that the escape length calculated from Fe secondaries, which is very sensitive to variations of nuclear cross sections, will be strongly affected while the effect for C+O secondaries will be much less important.

In order to check for the magnitude of the effect concerning the propagation of galactic cosmic rays, a calculation of the escape length λe at 1 GeV/n was performed with the ISM composed of 10% He and 90% H. More specifically the λe(C+O) and λe(Fe) were computed from the B/C+O and Sc-Cr/Fe ratios as measured in the HEAO3-C2 experiment /3/. According to Table 1 the fragmentation cross sections in He were scaled to proton cross sections with factors of 1.8 and 1.0 for C+O and Fe secondaries respectively. The total inelastic cross section in He is computed from $C*(A_t^{1/3}+A_p^{1/3} - 1.25)^2$ mb with C=78 mb up to A =8 /7/ and C=69 mb in the Fe region /10/. The calculations were performed using a new matrix program inspired from /8/ which incorporates a self-consistent treatment of ionization energy losses. It was checked that the λe's computed for a pure H ISM agree with /6/ within a few percent.

The escape length from C+O and Fe secondaries at 1 GeV/n, averaged over 3 energy bins between 0.8 and 1.3 GeV/n are given in Table 2 for both cases of a pure H and a mixed He+H ISM composition. The errors quoted in Table 2 reflect the statistical errors on the measurements of the secondary/primary ratios only. The escape length deduced from Fe secondaries is larger than that from C+O secondaries by 3 sigma's and 4 sigma's for pure H and He+H ISM respectively. These results strongly indicate that the discrepancy at 1 GeV/n between the λe deduced from the C and Fe secondaries in a simple leaky box model could be even more serious when interstellar He is taken into account. The present analysis reinforces the conclusion drawn in /11/ that the leaky box model with a pure exponential path length distribution is no more able to explain the cosmic ray data as they become more precise. We emphasize that the most important parameters used in the present analysis are measured ones, which increases the reliability of the results. It is also clear that the lack of He-induced fragmentation data becomes more critical as more H-induced cross sections are measured, calling for an effort to perform such measurements.

References

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Table 1 - Ratio of He-induced and C-induced to H-induced cross sections for fragmentation and total inelastic reactions at 1 GeV/n.

Reaction	He-induced	C-induced
C -> Be	1.9 /2/	2.6* /9/
Total	2.0 /7/	3.3 /7/
Fe -> Sc-Cr	1.0 /2/	1.2 /4/
Total	1.6 /10/	2.3 /4/

* at 0.42 GeV/n

Table 2 - The escape length deduced from C+O and Fe secondaries for pure H and He+H ISM composition. The last column gives the ratio $\lambda e(Fe)/\lambda e(C+O)$ with the statistical errors on the secondary/primary measured ratios only.

ISM	$\lambda e(C+O)$ (g/cm^2)	$\lambda e(Fe)$ (g/cm^2)	ratio
pure H	7.25 ± 0.13	10.39 ± 0.80	1.43 ± 0.15
He(0.1)+H(0.9)	8.94 ± 0.16	20.43 ± 2.50	2.28 ± 0.33