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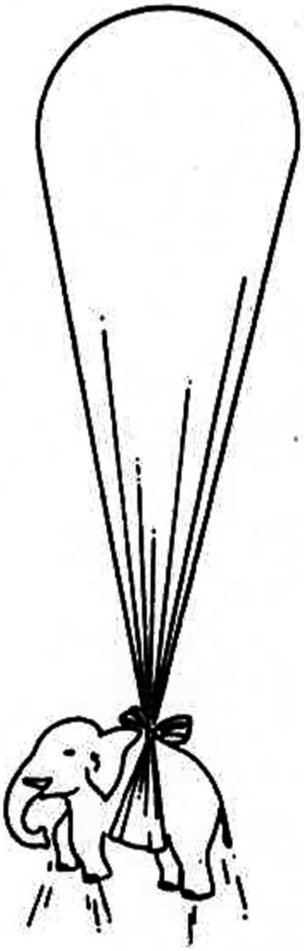

PARTICLE CHARGE EVOLUTION DURING ACCELERATION AND IMPLICATIONS ON MASS AND CHARGE SPECTRA

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1. Introduction

Perez-Peraza et al.,(1983) gave theoretical arguments supporting the establishment of charge transfer between the accelerated ions and source matter at least during the injection process. Among the arguments given, was the fact that the effective charge of ions is much higher at low velocities, that it is predicted at laboratory scale by the well known semi empirical expression of effective charge. As a matter of fact, if instead of assuming that the target particles are at rest($\xi=1$) we consider that the target medium has a finite temperature things which are different. It must be taken into account that nuclei begin to accelerate with their local charge states(Q_L), according to the source temperature, so the effective charge must be normalized to match Q_L at the level of the ion thermal velocity. In Fig.1 we illustrate the evolution of charge equilibrium for ions of iron in atomic and ionized hydrogen. It is shown how the assumption $\xi=1$ is much lower at low velocities than either with $\xi=\xi_{AH}$, or with $\xi=\xi_{IH}$, and how these two last are in turn lower than when they are normalized to their corresponding $Q_L(T)$. It can be seen that the difference in charge at low velocities is quite drastic such that at E>7MeV/n, iron is completely stripped. Because the 'similitudes' between galactic cosmic ray source abundances and solar particles abundances averaged over several events(Perez-Peraza, 1981), it must be expected that similar phenomena determine the charged spectrum of energetic particles, whatever the kind of source involved. So it is worth to investigate whether the accelerated ions undergo charge transfer or not in astrophysical source. This may be translated in the evaluation of the relative importance between the mean free path for charge-changing processes and the characteristic length of the acceleration step.

2. Particle Charge Transfer During Their Acceleration

Following Perez-Peraza et al.,(1983) the conditions for the establishment of electron loss and capture respectively, when an acceleration process is modulating the velocity v of particles in the source are

$$\alpha < 2(v^{3-2n}-v_c^{3-2n})N\sigma/(3-2n)(\mu/2)^{n-1} = \mathcal{E} \qquad (1)$$

$$\alpha < 2(v_c^{3-2n}-v^{3-2n})N\sigma/(3-2n)(\mu/2)^{n-1} = \mathcal{E}' \qquad (2)$$

where α is the acceleration efficiency of the Fermi(n=0.5) or the Betetron(n=1) processes, μ=atomic mass unit, V_c =

cross velocity where the cross sections for electron catpure and loss are equated and σ is the corresponding cross section. Introducing the threshold value α_c for the acceleration efficiency be able to overcome the Couloumb barrier, the criteria described in the previous expressions are hence translated to the restrictions $E/\alpha_c>1$ and $E'/\alpha_c>1$; therefore for a given acceleration process and a fixed density N, these criteria reduce to the correct evaluation of the cross section $\sigma(v)$ (and so of v_c) and to the evaluation of α_c through the adequate energy loss rate. With regard to σ of low charge and highly charged nuclei, we employed those given in the literature (Nikolaev,1965). So, in sources of atomic matter if we have hydrogenic ions, $q \gg (Z-1)$, then the cross velocity for protons is the Bohr velocity, v_o, whereas for heavier ions $(Z>1)$, $v_c = 1.27\ Z^{0.43} v_o$. On the other hand when $q <(Z=1)$ as it is expected in sources of atomic hydrogen $v_c=1.53\ q^{0.43} v_o$. For a source of plasma we used for hydrogenic ions $q \geq (Z-1)$(high T), the cross-section of Bethe and Salpeter (1957) for radiative capture, and obtained $v_c=0.039\ Z^{0.9} v_o$ When the source is a plasma of relatively low T, $q<(Z-1)$ we obtained $v_c=0.039\ q^{1.24} Z^{-1/3} v_o$. Concerning the evaluation of α_c, the rates of Coulomb losses with explicit temperature dependence, have been previously discussed by Pérez-Peraza and Lara (1979); for the Fermi and Betatron mechanisms in a source of atomic hydrogen $\alpha_c = 3.38\times10^{-13} N\ q^{0.52}/A$ and $\alpha_c = 4.5\times10^{-9} N q^{0.16}/T^{0.27} A^{0.78}$ respectively, whereas in a source of ionized hydrogen we obtained respectively $\alpha_c = 3.89\times10^{-7}\ N^{0.98}\ q^{1.92}/T^{0.96}\ A^{0.88}$ and $\alpha_c = 0.28\ N^{0.97}\ q^{1.87}/T^{1.45}\ A^{0.67}$. Introduction of the adequate σ and v_c in our criteria for $v>v_c$ and $v<v_c$ respectively, allows us to determine whether the accelerated ions undergo electron loss or not, and whether they undergo electron capture or not. It is worth to point out that the establishment of one charge-transfer process during acceleration does not necessarily entail charge equilibrium: the acceleration efficiency may be relatively low to allow for electron loss at $v>v_c$, but enough high to inhibit electron pick-up, and conversely in the range $v<v_c$.

3. Results and Conclusions

Nuclei up to F_e were analysed for typical parameters of astrophysical sources, $T = (5\times10^3-2.5\times10^8)^oK$ and $N=(1-10^{15})\ cm^{-3}$. The establishment of charge equilibrium is shown in Fig.2 with point-dashed lines. In the range $v>v_c$ electron capture and loss are also systematically established up to a certain energy for which electron capture is not allowed any more. This restricted range of charge equilibrium is illustrated in Fig.2 with dashed lines. Establishment of electron loss alone, with no capture allowed is shown with solid lines in Fig.2. Electron capture in the domain $v<v_c$ is established at $T>10^6\ ^oK$. So, this means that light elements do not capture in the domain $(v<v_c)$, since at those temperatures their thermal velocities are higher than their

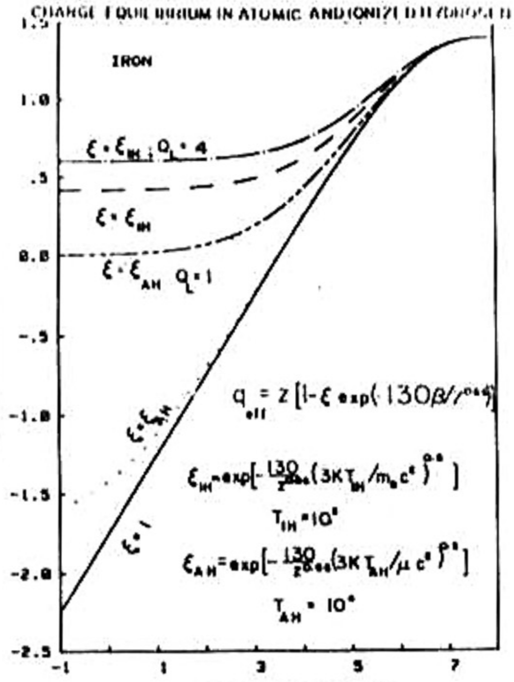

Fig. 1

respectives v_c, and thus they begin to capture in the range of electron loss predominance. Pure electron capture in the domain $v<v_c$ and electron loss $v>v_c$ are shown in Figs.3 and 4 with solid lines. The domain of charge equilibrium is illustrated with dashed lines in Figs.3 and 4. The first implication of our results is the fact that the well known semi-empirical expressions of effective charge, to describe the charge equilibrium do not apply in astrophysical sources when acceleration only allows for the establishment of one charge-changing process. In the evaluation of energy losses during acceleration (solid line in Fig.5), we arbitrarily used $q_f^* = Z[1 - \xi\exp(-\alpha\beta^{0.33})]$, normalized to Q_L at the level of the ion thermal velocity, in the range where only electron loss is established and $q_f^* = Q_L \exp[-\alpha(\beta-\beta_{th})^{0.33}]$ in the low energy domain when only electron capture is established: where $\beta_{th} = (3\ KT/\mu A)^{1/2}$. With regard to the mass spectrum of the accelerated particles it must be emphasized that, the fact that the heavier the element the wider the temperature and energy domain and the higher the probability for establishment of electron capture, favourizes the enrichment of heavy elements, because the decrease of effective charge entails a decrease of Coulomb losses, (q_f^{*2}/A) at low energies. In Fig. 5 it is illustrated the comparison between the energy loss curve with realistic charge-changing processes during acceleration, in contrast with the assumptions of establishment of charge-equilibrium, and that of preservation of local charge through all the energy domain. The fact that at $v>v_c$ electron loss is established for all elements argues against the determination of the mass spectrum in a secondary acceleration state where they enter with relatively high energies, since q approaches Z and Coulomb barriers are thus more restrictive for heavy ions. Our results rule out the direct measure of solar particle charge states to diagnose the source temperature.

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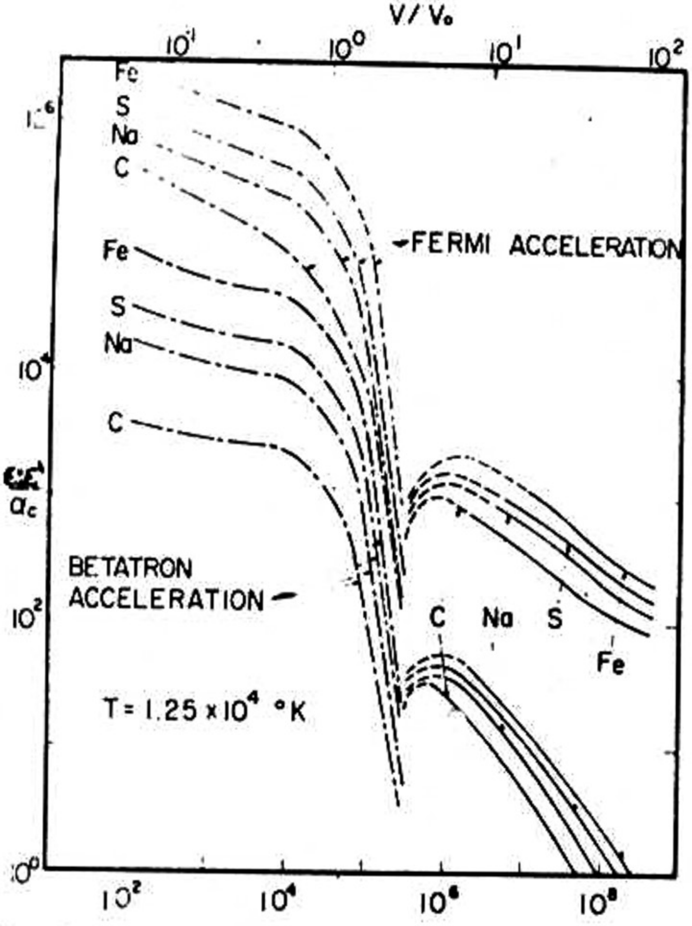

Fig.2

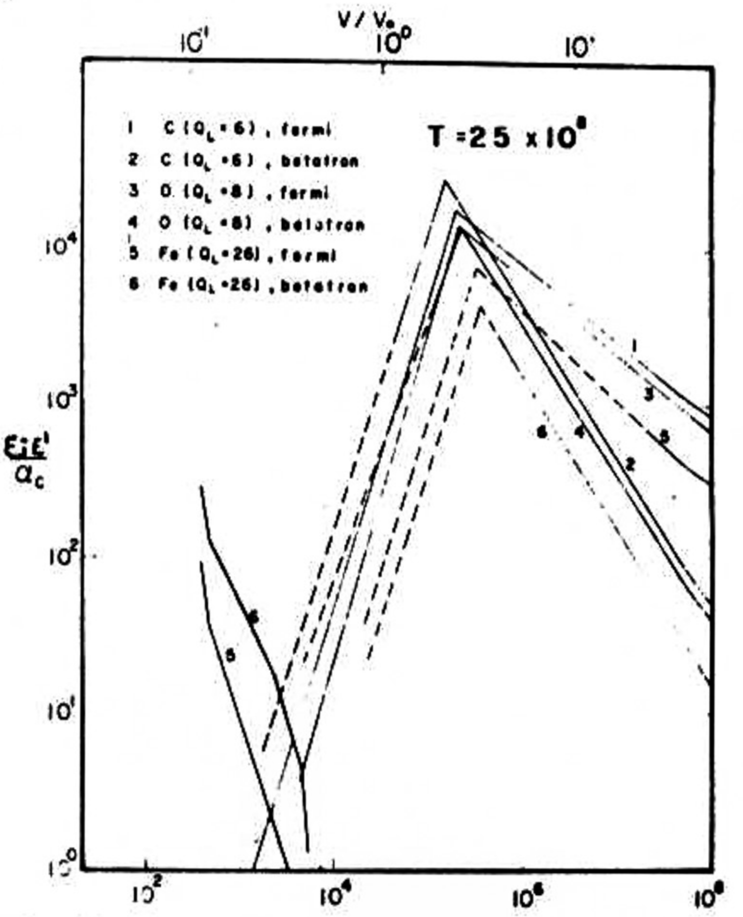

Fig.3

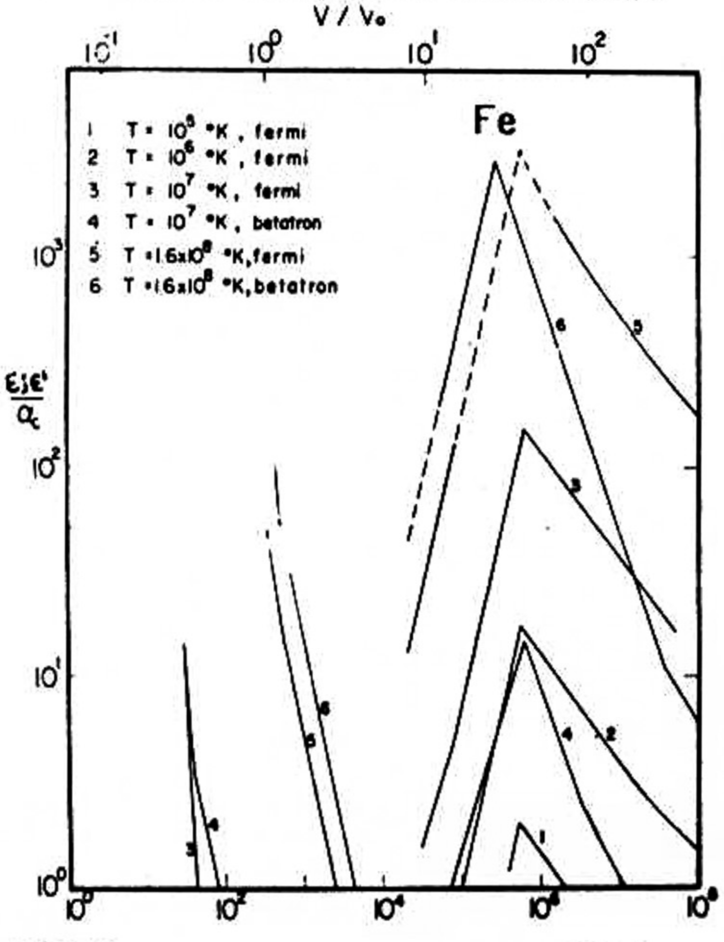

Fig.4

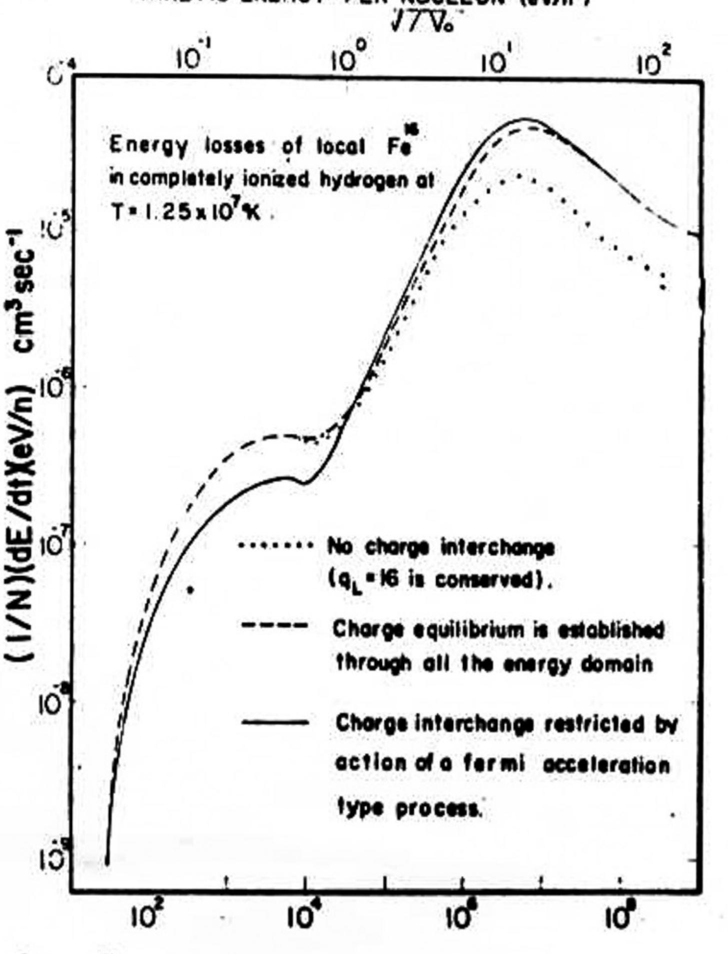

Fig. 5