COSMIC-RAY INJECTION INTO SHOCK-WAVES

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When corrected for the effects of propagation in the interstellar medium (i.s.m.), the observed composition of galactic cosmic rays can give us some clues as to the origin of these particles. It is noteworthy that the main pecularities of the cosmic ray source composition (CRS), as compared to normal i.s.m. abundances (Meyer 1979), bear some resemblance to that of i.s. grains, as inferred from i.s. absorption line measurements (e.g. York 1976) : (1) the refractory elements Al, Si, Mg, Ni, Fe and Ca, which in i.s. clouds are almost completely locked into grains, are present with normal abundance ratios in the CRS. (2) normalized to Si, the volatile and reactive elements C, N, O, S and Zn are underabundant in CRS by factors of 2.5 to 6 ; these elements are only partially depleted in the i.s.m. (3) at a given rigidity the ratios H/Si and He/Si are lower than in the i.s.m. by a factor of ~ 25 ; while H and He atoms are virtually absent in i.s. grains. (1) implies that cosmic rays originate in astrophysical sites where the grains have either not condensated as yet, or where they have been (at least partially) destroyed. Then , to account for (2) and (3), one might consider that an unspecified mechanism selects the particles to be accelerated, possibly according to their first ionization potential (Cassé 1979 and references there-in).

We present here an alternative point of view : we propose that cosmic rays are accelerated out of grain material freshly released in the i.s.m., and of ambient particles which have interacted with the grains. A more specific model, which can account for (1), (2) and (3), is based on the dynamical and physical behaviour of i.s. grains embedded in clouds swept by fast ($v_s \gtrsim 100$ Km s^{-1}) i.s. shock waves.

a) Gas-grain dynamics

The interaction of a shock wave of velocity v_c with a gas cloud is radiative if the gas behind the shock cools down in a time shorter or comparable to that of passage of the shock [i.e. if the gas column $N > v_s\ (n\ t_c)$, where n is the density and t_c the cooling time ; e.g. if $N \gtrsim 10^{18}$ cm^{-2} for $v_s = 100$ Km s^{-1}] . Behind the shock, the gas cools rapidly and gets compressed ; the grains, whose interaction length with the gas is much longer than the mean free path of thermal particles, do not "see" the shock, so that they have a velocity of order v_s with respect to shocked gas. If the magnetic field has a component parallel to the shock front, the grains can be accelerated by a

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betatron mechanism, which offsets the braking effect of ambient particles. Consequently, gas-grain interactions lead to chemical and physical implantation effects, including sputtering ; this is probably why refractory elements are less depleted in fast interstellar clouds (Spitzer 1976).

b) Sputter-induced suprathermal composition

Particles with energy < 600 ev/n, corresponding to relative velocities <350 Km/s, are implanted into the grains at depths < 300 A°. If the grain diameter exceeds ∿ 500 A°, no transmission sputtering occurs ; then, for the dominant sputtering species, He, the net sputtering yield at relevant energies is ∿1-2 x 10^{-1} at/at for most refractory materials. If the grain temperature is high enough, most of the implanted H and He atoms diffuse out. Thus, sputtering in the cooling layers of shocked gas creates a population of particles with grain-like velocities ($v_g \simeq v_s$ >>thermal velocity), which is a mixture of ambient particles (mostly H and He) and of heavier atoms detached from the grains. The number ratio of H to (Z > 2) is consistent with the CRS value of 57 (CRS from Meyer 1980, private communication).

c) The Ne problem

In this framework, Ne atoms would be implanted together with H and He, and subsequently thermally released. One would then get a ratio Ne/H ≃ cosmic value (10^{-4}), which is 8 times smaller than the CRS value. On the other hand, it is possible that i.s. grains, prior to the passage of the shock, have suffered adsorption and/or irradiation sequences that have loaded them with gaseous species, which are locked in the lattice or adsorbed on active sites at the surface. The very top atomic monolayers would then be saturated with C, N, O, Ne and Ar atoms mainly (this picture is consistent with the depletion of Ar derived from Copernicus results, York 1971). Thus, in the most vulnerable part of ordinary silicate grains, the Ne/Mg ratio can be , like in CRS, of order 1.

d) Shock induced injection mechanism

Shock waves have been invoked by many authors as a possible site of cosmic ray acceleration ; this hypothesis is based on theoretical and on energetical arguments, and is supported by interplanetary observations. However, as in most theories of statistical acceleration, the injection problem remains open (e.g. Blandford 1979). We have shown that a suprathermal population of a composition akin to that of CRS is generated behind radiative shock waves. The particles released by the grains will be somewhat boosted by betatron acceleration in the layers which are undergoing compression ; however, in most cases, this mechanism cannot compensate for the ionization losses. Nevertheless, if we postulate the existence of magnetic turbulence in the troubled, recently shocked gas, the suprathermal particles preserve or increase their velocity, so that some of them can overtake the shock front and be injected in a shock acceleration mechanism.

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