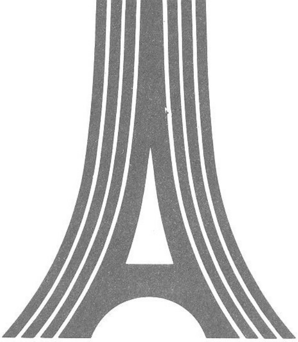

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COSMIC RAY COMPOSITION FROM ACCELERATION OF THERMAL MATTER

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It is proposed that the source composition of Cosmic Rays is controlled by Coulombian interactions during the acceleration of thermal matter. A given element is representative of the source or depleted depending on whether the predominant ionic state at the temperature of the source is lower or not to a threshold imposed by Coulombian losses. Coupling this restriction to the theory of ionization equilibrium, we calculate the source abundances. The results support sources of relatively low temperature.

1. INTRODUCTION.- The deviations of elemental abundances of Cosmic Rays at their Sources (GCRS) relative to Solar System (SS) or Local Galactic - (GL) abundances follow the same trend than those of Solar Flare Particles averaged over several flare events <SP> relative to Solar Atmospheric abundances (SA). Normalization to Si shows that, within statistical uncertainties, the ratios GCRS/SS(GL) and <SP>/SA for elements in the range $11 \leqslant Z \leqslant 30$ are normals with the exception of S, A_r and Z_n that together with elements of $Z \leqslant 10$ are subabundant. Slight differences between solar and galactic sets appear in the degree of subabundance of H_e,C and N. We claim that there exist at the sites of acceleration, selectivity effects that at global scale are common to the sources of Cosmic Rays and Solar particles, and that at local scale account for the variation of elemental abundances from one solar particle event to another. We identify these selectivity effects with the constraints imposed by Coulombian interactions of the -- accelerated ions with the matter of the sources, during the stage in which these ions are energizated from thermal to suprathermal energies. We discuss here the conditions of acceleration efficiency and temperature able to reproduce the elemental Cosmic Ray Abundances at the level of their sources, and we will report elsewhere the conditions to reproduce the different elemental abundances of Solar Particles displayed in different flare events.

2. SELECTIVITY EFFECTS ON COSMIC RAY COMPOSITION.- The role of energy losses on the determination of particle composition has been previously discussed (Pérez-Peraza and Lara, 1979): it has been pointed out that when the amount of matter and the acceleration efficiency are such that the energy loss rate is not negligeable with respect to the acceleration rate, particles that are drawn from the thermal matter of the source by the acceleration process are braked by the Coulombian interaction with the background ions and electrons of the medium. Electronic stopping in the high energy range (ionization losses) may eventually become important after acceleration, while particles traverse the dense environment of the source, or, -- when high energy particles enter within an acceleration process, proceeding from a preliminar acceleration stage. Since the energy loss rate per nucleon depends on the ratio q^2/A, (where q and A are the charge and mass of ions respectively), losses at the beginning of the acceleration are highly sensible (through q) to the temperature of the medium: different elements and even different ions of a same element are braked in a different manner.

Ions for which their deceleration rate is systematically lower than the -- operating acceleration rate $(dE/dt)_a=\alpha_a f(E)$, (where α_a is the acceleration efficiency and $f(E)$ is a function of energy/nucleon) are "free accelerated". If the major ion of a given element, at the temperature of the Source, is "free accelerated" the abundance of that element is representative of local abundances. However, if the acceleration rate is not systematically higher than the deceleration rate, there exist two threshold values of energy, E_s and E_s', defined by $(dE/dt)_a=(dE/dt)_d$ such that $(dE/dt)_a>(dE/dt)_d$ only for $E<E_s$ and $E>E_s'$: these particles can only reach energies up to the bound E_s (with the exception of the negligeable fraction of the Maxwell distribution, which thermal energy at the temperature of source is higher than E_s'). If the predominant ion of a given element at the temperature of the acceleration region is under these conditions, this element appears subabundant relative to local abundances, because only ions of charge lower than the predominant one are accelerated to observational energies. Therefore, it is possible to define, for each ion, a critical value of the acceleration efficiency, above which this ion is "free accelerated", and below which it is depressed. This critical value is defined at an energy, E_c, where both the acceleration and deceleration rates are tangentially equated: $\alpha_c(A,Z)=\text{Cte.}\times(q^2/A)\, f(E_c,T,N)$ where $f(E_c,T,N)$ is a factor evaluated at E_c for the temperature and density of the source. This may be rewritten in terms of the critical value of protons as $\alpha_c(Z,A)=(q^2/A)\alpha_c(p)$. It can be realized that if the efficiency of the acceleration process were higher than the critical values α_c of all the existing ions of all elements, at the temperature of the source, the composition of the radiation should be typical of local abundances, which is not the case in Cosmic Rays, neither, in general, for Solar flare particles. It follows that if preferential acceleration of protons were to be produced, $\alpha_a>\alpha_c(p)$, that is $\alpha_a=\delta\alpha_c(p)$ (with $\delta>1$), and for preferential acceleration of heavier ions, it is needed $\alpha_a>(q^2/A)\alpha_c(p)$, what entails that

$$(q^2/A)<\delta \tag{1}$$

according to this relation for a given value of δ, there is an upper limit of the charge, q_s, below which the ions are "free accelerated". Obviously, a given element is representative of local abundances or subabundant, depending on whether the predominant charge state at the temperature of the source is lower or not to q_s. We have plotted the constraint (1) for a wide range of δ values, up to the Z_n. We have tabulated on Table 1 some arbitrary examples: a given element may be free accelerated from q=1 and even q=z (z= atomic number) depending on the acceleration efficiency (δ). It can be seen that if δ is relatively small, quite independently of the state of the major ionic component,

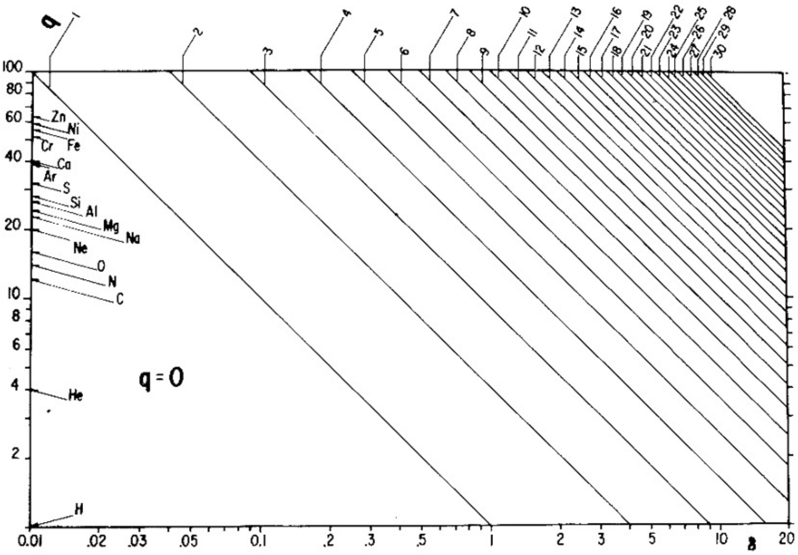

Fig. I. According to $(q^2/A<\delta)$ it may be found in this scheme the q_s values, such that thermal ions with $q\leq q_s$ are free accelerated.

the Cosmic Ray flux will appear correlated with the first ionization potential, provided that the temperature is not enough high **that** the state q=1 does not exist anymore. As illustration of how does the selectivity works, suppose for instance, that $T= (3.2-8)x10^{4}\,^{\circ}K$, so the major component of H_e is q=1, in which case one should have $\delta>0.\mathbf{25}$, otherwise we should not expect H_e at observational energies, whereas if $T>8x10^{4}\,^{\circ}K$, the major state is q=2, such that if $\delta<1$, the H_e will appear depressed relative to local abundances. To quantify this selectivity, restriction (1) must be coupled to the theory of ionization equilibrium: according to this, ionic fractions are expressed as $\xi_q(A,T)=n_q(A,T)/N_t(A,T)$, where $n_q(A,T)$ is the number of ions of the element A, which are in the state q in a medium of temperature T, and $N_t(A,T)=\sum_{q=o} n_q(A,T)$ is the total number of those particles, including atoms. Therefore, designing Q= GCRS/LA (or <SP>/SA) (where LA=GL or SS) we have $Q = N_{ions}(A)/N(A) = \left(\sum_{q=1} n_q\right)/N_t = \xi_A$ in such a way that introducing preferential acceleration leads to

$$Q(A)=\xi_A(A,T)=\left[\sum_{q=1}^{q_s} n_q(A,T)\right]/N_t(A,T) \quad (2)$$

Calculations relative to Si have been displayed in Table 2 for arbitrary values of Temperature and δ.

TABLE 1

Examples from Fig. 1 of the upper bounds q_s ($q^2/A<\delta$): ions of charge $q\leq q_s$ are free accelerated.

Element	H	He	C	N	O	Ne	Na	Mg	Al	Si	S	Ar	Ca	Fe	Ni	Zn
δ<0.015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
=0.044	-	-	-	-	-	-	1	1	1	1	1	1	1	1	1	1
=0.050	-	-	-	-	-	1	1	1	1	1	1	1	1	1	1	1
=0.063	-	-	-	-	1	1	1	1	1	1	1	1	1	1	1	2
=0.072	-	-	-	1	1	1	1	1	1	1	1	1	1	2	2	2
=0.25	-	1	1	1	2	2	2	2	2	2	2	2	3	3	3	4
=0.40	-	1	2	2	2	2	3	3	3	3	3	3	4	4	4	5
=0.60	-	1	2	2	3	3	3	3	4	4	4	4	4	5	5	6
=0.70	-	1	2	3	3	3	4	4	4	4	4	5	5	6	6	6
=1.00	1	2	3	3	3	4	4	4	5	5	5	6	6	7	7	8
=1.10	1	2	3	3	4	4	5	5	5	5	5	6	6	7	8	8
>13.76	1	2	6	7	8	10	11	12	13	14	16	18	20	26	28	30

3. DISCUSSION.- This procedure is highly sensitive to the results of ionization equilibrium, which in turn are highly variable depending on the approach employed for calculations, i.e., whether the plasma density is -- enough high or not for the photonic radiation field to be considered, etc. For the work used here our calculations seem to be slightly more consistent with <SP>/Photosphere than with GCRS/LA. Due that losses depend on q^2/A, a cold source (low ionization states) turns to be more convenient to deplet light elements relative to heavy elements; however, not so cold ($>10^{4}\,^{\circ}K$) because the ionic fractions of H_e, N, O and N_e become extremely low, such that even if δ is high the predicted abundances are quite below the observational ones. In addition to this constraint of temperature, δ must be relatively high in order to avoid a severe depletion of light elements. This is, of course, only a preliminar analysis, and a more realistic one should consider the effects of charge interchange and magnetic rigidity within the source; in fact, depending on the relationship between the mean free paths for Coulombian charge interchange and the characteristic step for acceleration, ions may or not undergo charge transfer within the source. Suppose that the major ionic state of a given element at the source is $q_m=1$, electron capture at low energies would depress by neutralization the flux of the accelerated ions of this element. On the other hand, if the highest charge state allowed for free acceleration coincides with the major state ($q_s=q_m$), electron loss at relatively higher energies would deplet the flux by ionization from q_m to (q_m+1). We have arbitrarily considered here that conditions are such that the charge of ions remain unchanged during acceleration, and they reach the stripped state during propagation outside the source. It should be emphasized that for acceleration we mean what is conventionally called injection; we do not favour necessarily a 2nd step of acceleration, but rather a very efficient step of injection: in fact, in or

TABLF 2.- Arbitrary Examples of the Predicted Particle Source Abundances (Relative to Silicon) from "Free Acceleration" with Respect to Collisional Losses: Ionic Fractions are from JAIN and NARAIN (1978). Conventional Values of Solar Particles and Galactic Cosmic Rays at the Sources are Quoted as Frame of Comparison.

	Element	H	He	C	N	O	Ne	Na	Mg	Al	S	Ar	Ca	Fe	Ni
log T=5.1	$\delta=0.6$	-	0.035	$\boxed{0.002}$	$\boxed{0.0008}$	0.25	0.75	0.79	0.92	1.0	0.18	0.17	0.38	0.86	0.92
	$\delta=0.7$	-	0.035	$\boxed{0.002}$	0.296	0.25	0.75	1.0	1.0	1.0	0.18	0.78	0.96	1.0	1.0
	$\delta=1.0$	0.99^{i}	0.035	0.184	0.296	0.25	0.99	1.0	1.0	1.0	0.91	1.0	0.99	1.0	1.0
log T=4.0	$0.25\leq\delta<1.0$	-	$\boxed{\sim^{i}10^{-7}}$	0.26	$\boxed{0.025}$	$\boxed{0.0009}$	$\boxed{1.8\times10^{-6}}$	0.99	0.99	0.98	0.49	0.003	1.0	0.99	0.93
	$\delta>1.0$	0.11^{i}	$\boxed{\sim^{i}10^{-7}}$	0.26	$\boxed{0.025}$	$\boxed{0.0009}$	$\boxed{1.8\times10^{-6}}$	0.99	0.99	0.98	0.49	0.003	1.0	0.99	0.93
	$\frac{\langle SP\rangle^{a}}{\text{Photosphere}^{b}}$	$\sim0.35(1.9)^{e}$	$\sim0.15^{f}$ 0.78 ± 0.33^{h}	0.21 ± 0.04	0.27 ± 0.12	0.25 ± 0.09	0.64 ± 0.34^{g} 0.97 ± 0.41^{h}	1.25 ± 0.67	1.06 ± 0.15	1.38 ± 0.55	0.46 ± 0.06 0.66 ± 0.53^{g}	0.17 ± 0.15^{g} 1.25 ± 0.45^{h}	1.66 ± 0.6	1.22 ± 0.27	1.15 ± 0.65
	$\left(\frac{GCRS}{SS}\right)^{c}$	0.04 ± 0.01	0.04 ± 0.01	0.48 ± 0.01	0.19 ± 0.10	0.32 ± 0.09	0.15 ± 0.05	1.25 ± 0.8 0.25^{d}	1.07 ± 0.40 0.80^{d}	1.84 ± 0.64 1.8^{d}	0.30 ± 0.10 0.55^{d}	$<2.1^{j}$ 0.85^{d}	2.0 ± 0.62 1.7^{d}	1.49 ± 0.37 1.09^{d}	1.25 ± 0.35
	$\left(\frac{GCRS}{GL}\right)^{b}$	0.30 ± 0.004	0.046 ± 0.012	0.38 ± 0.13	0.13 ± 0.06	0.22 ± 0.06	0.24 ± 0.1	1.34 ± 1.12	1.0 ± 0.12	1.64 ± 0.80	0.28 ± 0.11	0.33 ± 0.10	1.0 ± 0.31	1.16 ± 0.21	1.07 ± 0.40

(a) Cook, W. R., Stone, G. C. and Vogt, R. E.; Ap. J. letters, 238, L97, 1980.
(b) Meyer, J. P.; Private Communication; Int. School of Cosmic Rays, Erice, 1980.
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(e) From the Value of He Particles Quoted in (a), and with $\langle P/\alpha\rangle \simeq 22$.
(f) The Value of He Quoted in (b) as "other media" has been considered for the photosphere.
(g) Particle data over coronal values, as quoted in (a).
(h) Particle data over solar wind values, as quoted in (a).
(i) The ionic fractions of H and He were taken from House, L.L., 1964, Ap.J. Suppl. 8, 307.
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der that charge equilibrium to be established when particles of $Z\leqslant30$ traverse a medium, without the action of an acceleration process, it is enough that the amount of traversed matter through circumstellar envelopes to be $X\geqslant10^{-2}$ gr/cm^2. Therefore, particles leaving the injection volume will rapidly reach the nuclear charge, such that if they needed to enter another acceleration process, heavy nuclei would be depressed relative to light nuclei, because their stronger constriction (in Z^2/A) imposed by ionization losses to participate in the process (at least that this 2nd stage is quasi-continuous and contiguous to the injection stage, like in Solar Flares, in order that particles do not undergo much charge interchange). Ionization losses during propagation through the dense environment of sources may perhaps modulate the energy spectrum but not the composition: the composition would be rather altered by restrictions to participate in another acceleration stage. On the other hand, selectivity effects associated to magnetic rigidity must take place during the escape from the injection volume but not during injection into a presumed 2nd acceleration step: again, because between both stages q would tend rapidly to Z, not noticeable -- effects (in A/Z) would exist among elements of $Z\geqslant2$, whereas escape from the injection region introduces effects in A/q (or A/q* if the charge equilibrium is established; where q* is the effective charge). It must be pointed out that we do not discard a 2nd acceleration step up to ultra-relativistic energies, associated for instance with supernova remnants, stellar winds and OB associations (Montmerle, 1979) but the efficiency must be very high and/or the medium very dilute to completely ignore ionization losses and do not alter the composition determined during the injection process. Finally, the results displayed here support an origin for the bulk of Cosmic Radiation related with injection by stellar flare-like-processes up to relativistic energies, from objects of a near solar composition and moderate temperature.

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