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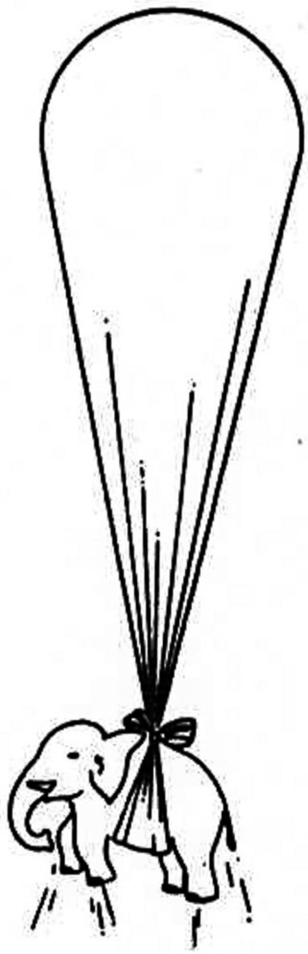

THE EFFECT OF FINITE TEMPERATURE ON PARTICLE ENERGY LOSSES AND IMPLICATIONS FOR TRACK FORMATION IN SSNTD

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I. Introduction

In this work we search to evaluate the effect of finite temperature during the phase of energy transfer of particles to SSNTD which are commonly used in experimental cosmic ray physics. First we develop a composite equation for inelastic losses in atomic media, valid for all particle velocities, and after, introduce the temperature of the material by integrating that expression in the space of velocities, of the target particles.

II. Inelastic Losses in Atomic Media of Finite Temperature

Let assume that in an atomic system, the velocity of the atoms and their bounded electrons may be described by a unique velocity distribution f(w)dw which determines the number of target particles per unit volume with velocity between w and w+ dw. The number of particles in the velocity range that undergo an interaction with a projectil of velocity v, per unit time, is $|v-w| \sigma f(w)dw$, where σ = cross section of interaction of the fast particle with electrons (or atoms), such that multiplying by $\langle\Delta E\rangle$, the average change in energy(loss), we obtain the average energy loss of a particle per unit time $\langle\Delta E\rangle \sigma |v-w| f(w)dw$, where $S_{tp}=\sigma\langle\Delta E\rangle$ is the probability that a collision with energy change ΔE takes place. S_{tp} is the so called stopping cross section per target particle $S_{tp}=1/N(dE/dX)$. So the total energy loss due to all target particles with distribution f(w) is obtained by the integration of $S_{tp}\ |v-w|f(w)dw$. For electronic stopping we use the well known Lindhard and Scharf (1961) and the Bethe-Block formula, for velocities lower and higher than $Z^{0.66}v_o$ respectively, where Z is the projectil atomic number and v_o is the Bohr velocity; for nuclear stopping we used the expression of Lindhard et al.,(1963). Concerning the distribution f(w), we recured to solid state theory by means of the approximation of Debye(1912), which considers that as long as the wavelength of an elastic wave traversing a solid is large compared with the interatomic distances, the material looks like a continuum from the point of view of the wave: the corresponding frequency spectrum is cut-off at the Debye's frequency(ν_d). In our case the velocity of the normal vibration modes associated with the velocity of particles is the group velocity of the wave, and this is twice the phase velocity, so we have $\nu = w/2\lambda$. Since λ is the wavelength of the phase wave, thus it corresponds to the maximum elongation of the single harmonic oscillators in such a way that $\lambda = (3KT/k_s)^{1/2}$, where k_s is the spring constant of

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the considered oscillators. Therefore the frequency distribution may be converted into a velocity distribution, but in order that this distribution be only valid in the velocity range between O and w_d (where w_d is the cutoff in w corresponding to the cutoff frequency ν_d), we need to normalize it in that range. The Debye velocity in terms of the Young's modulus, Y, the material density, ρ, and the volume, V, may be expressed as

$$w_d = 2(3N/4\pi V)^{1/3}(3KT/\rho)^{1/2}(Y/k_s)^{1/2} \text{ (cm/sec)} \qquad (1)$$

where K is the Boltzman constant and T the temperature, so the normalized distribution is

$$f(w)=(2.4x10^{-2}k_s^{3/2}h^3/D(KT)^{9/2})(w^2/\exp(hw/2KT)(3KT/k_s)^{1/2}-1)$$

where D is a temperature-dependent-constant. Concerning the velocity distribution it can be seen that for a given N and T, the distribution only depends on the parameters Y and k_s, so we have proceeded to analyse two cases in relation with the target material: first, the CR-39 that according to some manufacturers has a value $Y=1.25x10^{22}$eV/cm, and which k_s value has been estimated under the assumption that the interatomic forces may be described by a Lenard-Jones (LJ) type potential,and on the other hand an 'ideal' material where $(Y/k_s)^{1/2}$ in(1) is $2.16x10^4$ times the value of the former material, considering that k_s is the interatomic force per unit length.we obtain k_s=72(E_d/r^2), where E_d is the dissociation energy and r the interatomic distance. So k_s=2.93x10^{18} eV/cm.

III. Results and Conclusions

In Fig.1 it is shown the obtained distribution of atomic velocities in solids. Two cases are illustrated, the polymer CR-39 and the 'ideal' material. The Debye cutoff velocities are indicated with dashed lines. In particular, T=293°K corresponds to the temperature of CR-39 as furnished by most of manufacturers. Inelastic losses for projectil protons and Fe^{26} are shown in Fig.2, for the 'ideal' material. In the case of the CR-39, the effect of temperature on the energy losses is shifted to very low energies. On Figs.(2 and 3) we have plotted the energy loss curves for different temperatures, in comparison to that of the independent temperature formulation. Therefore, for a material with the Y and k_s characteristics that we are suggesting here, losses of low energy ions would be overestimated. Since in this case the stopping power becomes lower at low velocities, the range of particles increases with respect to the range evaluated without temperature effects. This is illustrated in Fig.(4) for protons and Fe^{26}. For the implications on track formation in SSNTD we should remain that several track registration criteria have been developed to predict latent damage (Benton,1970): these are based on adjustable parameters in order to define a unique threshold registration value,whatever the energy of ions. This value, defined in the total energy loss criterion, does not fit correctly at all velocities, the experimental track registration data. This may perhaps be corrected if energy losses are evaluated with temperature: in fact, as can be seen in Fig.(1 or 2), for a given energy loss rate the corresponding particle energy in the domain (10^{-3}-1) MeV/n is not the same in the conventional loss curve (T=0) than in the temperature dependent curves, but it has been shifted to higher energies. With regard to the Restricted Energy Loss (REL) criterion, the adjustable parameter w_o, which upto now has been considered as an arbitrary parameter, will necessary be modified and would become eventually a definite value, if a unique threshold value for the total energy loss criterion is found. Also, in agreement with experiments, it is predicted that the Range Deficit Value will increase as the material sensitivity decreases, since the Range is indicrectly proportional to ks, and so to the E_d value. Our results are highly dependent on the ratio of the Young's modulus to the atomic spring constant of the material. So, it seems worth to perform experimental work at low energies to test the theoretical predictions. It should be noted that if experimental work evidences those temperature effects in common detectors, a substantial misinterpretation of cosmic ray parameters may have been occuring.

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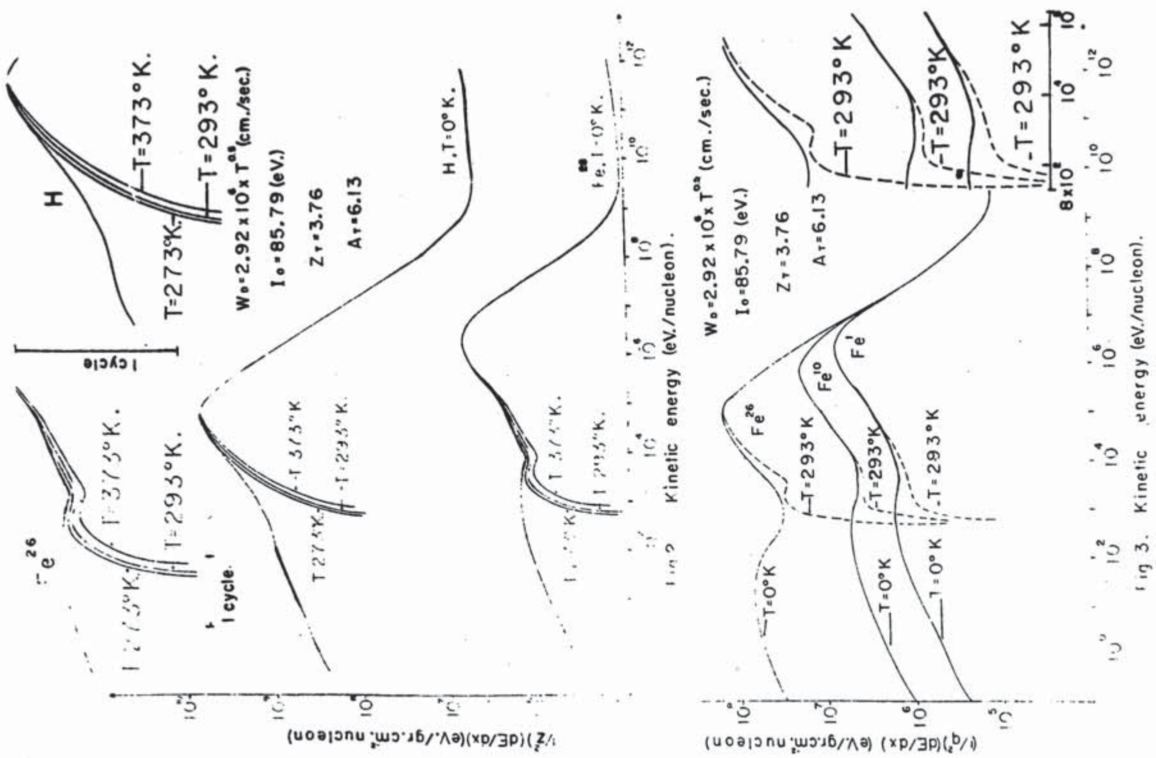
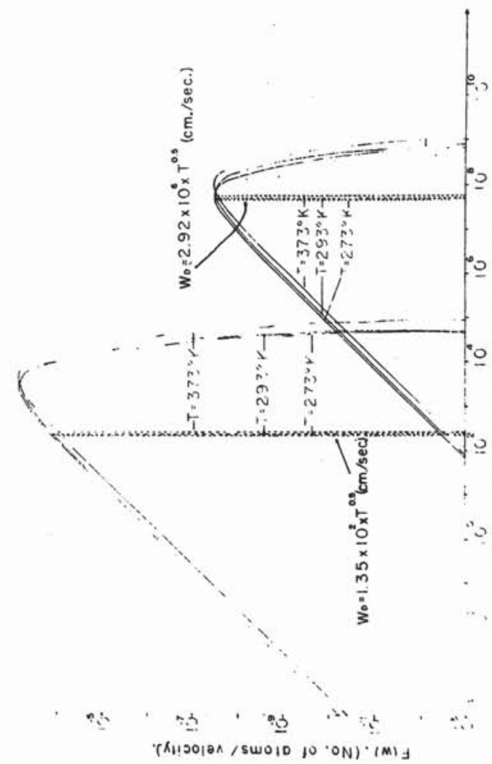
Errata : Fe^{26} and Fe^{1} are inversed on Fig. 3.





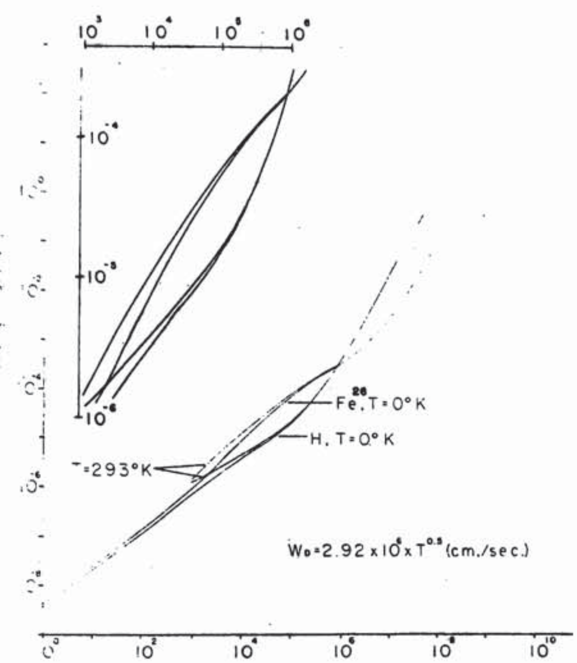


Fig 4 Kinetic energy (eV/nuelon)