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EXPLICIT DEPENDENCE ON TEMPERATURE OF PARTICLES ENERGY LOSSES IN PLASTIC DETECTORS.

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ABSTRACT

A global description of collisional energy losses in atomic media is developed for the entire energy range of projectile particles . Explicit dependence on the temperature of the medium is derived by integration of this formulation in the space of velocities of the target molecules.The effect of temperature is noticeable in the domain of nuclear stopping, becoming practically negligible at the level of electronic stopping predominance.The implications are discussed as well as the present experimental restrictions for observation of temperature effects in plastic detectors.

KEYWORDS

Temperature; frequency distribution; velocity distribution; spring constant; interatomic potential.

INTRODUCTION

The effect of finite temperature on the energy transfer from particles to SSNTD has been evaluated.The importance of the temperature in the fundamental process of track formation has been emphasized by Benton(1970), in relation to the establishment of thermal and chemical equilibrium due to the absorbed energy and to the environmental effects.This work is concerned only with the stage of energy deposition from the incident particles to the electronic and atomic systems of the solid detector.Questions associated with this problem are: whether the temperature effects contribute to the understanding of track formation and how the evaluation of these effects is useful towards a better identification of track parameters; whether the presently available materials are sensitive enough to detect these effects or if it will be necessary to develop more sensitive materials for this task.

In a previous study (Pérez-Peraza and co-workers 1983), the polymer CR-39 was evaluated against an ideal material with respect to temperature effect sensitivity.The comparison was based on Debye's frequency distribution, although it was indicated that it should be verified by a more in depth analysis. It was also indicated at the time that the Lennard-Jones potential used was unrealistic.The work described here provides an argument for the goodness of Debye's frequency distribution approximation and shows the effects that a finite temperature has on particle energy losses within plastic detectors, under a more realistic potential.

INELASTIC LOSSES IN ATOMIC MEDIA OF FINITE TEMPERATURE

The assumption is made that in an atomic system, the velocity of 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 velocities between w and $w + dw$.In this range, the number of particles per unit time, that undergo an interaction with a projectile of velocity v, is $|v-w|\, f(w)dw$ where σ is the cross section for the interaction of fast particles with electrons (or nucleons). The average energy loss of a particle per unit time is obtained by multiplying the above expression by the average energy change of a particle, $\langle\Delta E\rangle$. Since $\langle\Delta E\rangle\sigma$ is the probability that a collision with energy change ΔE, takes place, then $\langle\Delta E\rangle\sigma=S_{tp}$ where S_{tp} is the stopping cross section per target particle and represents the energy loss per unit length divided by the number of target particles i.e. $S_{tp}=(de/dx)/N$. In these terms, the total energy loss due to all target particles is:

$$(dE/dt)_T=\int_0^{w_{max}} S_{tp}\,|v-w|\,f(w)\,dw \qquad (1)$$

where w_{max} is the velocity for which the target particle energy is equal to the projectile energy.

The Lindhard and Scharff(1961) expression and the Bethe-Block formula for velocities smaller and larger than $z^{0.66}v_0$ respectively are used in the case of electronic stopping. Here, z is the projectile's atomic number and v_0 is Bohr's velocity. Then;

$$S_e=\frac{2.62\times10^{-2}z_t q^{1.16}\beta}{A(z_t^{0.66}+q^{0.66})^{3/2}}\ (\mathrm{Ev/n\quad cm}) \qquad v<z^{2/3}v_0$$

$$\frac{2.29\times10^{2}z_t q^2}{A\,A_t\,\beta^2}\left(27.67-\mathrm{Ln}\,I_o^2+\frac{4\mathrm{Ln}\,1823A}{(1-\beta^2)^{1/2}}+2\mathrm{Ln}\beta^2-\delta-\frac{2C_z}{z_t}-2\beta^2\right)(\mathrm{eV/n}\times\mathrm{cm}) \qquad v>z^{2/3}v_0 \qquad (2)$$

where z_t is the target atomic number, A_t and A are the masses of target and projectile and q is the projectile charge. When enough matter is transversed, $q=q_{eff}$ (as in solids) and q=z when it is completely stripped of its electrons, β is the particle velocity with respect to the velocity of light, I_0 is the mean ionization (excitation) potential and δ and C_z are correction factors to account for density effects and deep electronic shells.Thus:

$$(dE/dx)_T=|(dE/dx)_i/(dE/dx)_{LS}+(dE/dx)_i| \qquad (3)$$

For nuclear stopping, the Lindhard and co-workers (1963) expression may be rewritten as:

$$S_n=\frac{8.2\times10^{-15}z_t q\varepsilon^{0.275}\exp\,(-\varepsilon^{0.55}+0.009)^{0.84}}{(A+A_t)\ (z_t^{0.66}+q^{0.66})^{1/2}}\ (\mathrm{eV/n}\times\mathrm{cm}) \qquad (4)$$

with $\varepsilon=|3.37\times10^{-2}\ A\,A_t/z_t q(A+A_t)|E$, where E(eV/n) is the particle kinetic energy. Then from (3) and (4) the composite equation for total energy loss is $(dE/dx)_T=(dE/dx)_{ns}+(dE/dx)_{es}$ and does not depend on having the temperature equivalent to zero (T 0). To introduce the temperature aepenaency, the last expression must be integrated over all target velocities as shown in (1) such that $(dE/dx)(eV/gcm^2\times n)=(1/\rho\,|v-w|)(dE/dt)$ under the premise that the particle velocity (v) appearing explicitly or implicitly in expressions (2) and (4) is replaced by $|v-w|$. As stated in the paper by Pérez-Peraza and co-workers(1983), the distribution f(w) was developed by resorting to solid state theory, which states that the vibrational energy of a crystal containing a linear chain of N atoms is equivalent to the energy of a system of 3N harmonic oscillators. This system is described by a definite frequency distribution spectrum $Z(\nu)d\nu=4\pi V(2/c_t^{\,3}+c_l^3)\nu^2 d\nu$,furnishing the possible modes of vibration of a contiuum in the frequency interval $\nu$and ν +d . Here c_t and c_l are the transverse and longitudinal components of the velocity of sound in the solid and V is the volume. This is the so called Debye's frequency distribution. Blackman(1937), following the atomic theory of lattice vibrations proposed by Born and von Karman(1912), showed that this distribution did not represent the real frequency spectrum of a diatomic cubical lattice[1]. Blackman's work shows that the frequency distribution of monoatomic species present two peaks instead of the soft parabola proposed by Debye.Extrapolating we expect that the frequency distribution of polyatomic species, as in polymers, should have many more peaks so that the soft distribution obtained from Debye's ap-

[1]See for examole Born and Huang (1954)

proximation will only be a smoothing of the peak distribution. This implies that polyatomic species are nearer than monoatomic species to the continuum resulting from Debye's approximation. The distribution developed under the preceeding conditions (Debye's approximation of the continuum) is given by:

$$f(w)=\left|2.4\times10^{-2}k_s^{3/2}\,h^3/D(KT)^{9/2}\right|\times\left|w^2/\exp(hw/2KT(3KT/k_s)^{1/2}-1\right|=C\left|w^2/\exp(w/w_c)-1 \quad (5)$$

where $w_c^{-2}=1.49\times10^{-9}(k_s/T^3)$ cm/s is a characteristic velocity such that the most probable velocity of the distribution is given by $w_{mp}=1.6w_c$ and $C=(3.32\ 10^{-27}/D)\times(k_s/T^3)^{3/2}$ where D is the result of integrating $x^2/(e^x-1)$ numerically from 0 to θ_D and θ_D is Debye's temperature. This distribution was normalized to a maximum velocity of the medium, which we call Debye's velocity, established by the 3N degrees of freedom of the harmonic oscillators, and is given by:

$$w_D=2(3N/4\pi V)^{1/3}(3KT/\rho)^{1/2}(Y/k_s)^{1/2}(\text{cm/s}) \quad (6)$$

where Y is the Young's modulus of the material and ρ its density.

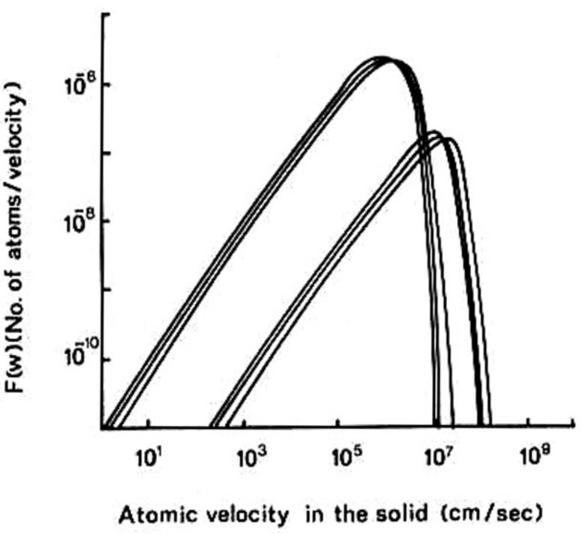

Fig. 1 Velocity distribution f(w). (See text).

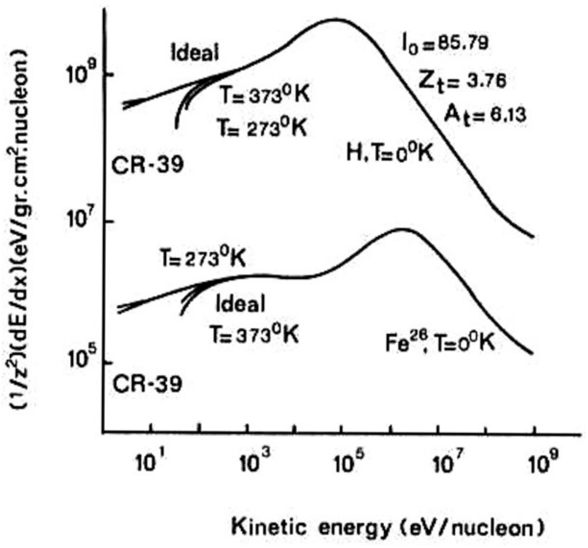

Fig. 2 Total energy losses for protons and Fe^{26}. (See text).

RESULTS AND DISCUSSION

Figure 1 shows the velocity distributions for CR-39 and for an ideal material. It is apparent that the ideal material is not far from being of unrealistic nature as compared to CR-39. The total energy loss for protons and Fe^{26} is shown in Fig. 2. It can be seen that CR-39 shows the dependency on temperature for values up to 100 eV/n while the ideal material shows the effects for values as high as 1Mev/n. Likewise it shows that for heavier projectiles at higher temperatures, the effect of finite temperature shifts to higher energies. For a fixed energy the importance of the effect on the losses is greater as the temperature increases while at a fixed temperature the effect is more noticeable for light ions than for heavy ions depending also on the energy of observation. Figures 3 and 4 allow a more detailed analysis of temperature effects and their dependency on the projectile charge. It may be seen that as the ion is stripped of more of its electrons, the difference between the curves corresponding to temperature and non-temperature dependent effects becomes less pronounced and the effect itself dissapears at a higher energy.

Qualitative analysis of other potentials show that k_s varies drastically. This is crucial because as seen from equation (5) and (6) and visual inspection of Fig. 2,3 and 4, k_s is an important parameter in the calculation of total energy losses with temperature dependence on the medium. Although it seems difficult to acquire experimental evidence on this matter as the events are in low energy range and almost undetectable by SSNTD, this information will prove valuable if the total energy losses have been overestimated as suggested here. The importance of the interatomic potential should be emphasized as well as the necessity to find a suitable realistic potential for the SSNTD.

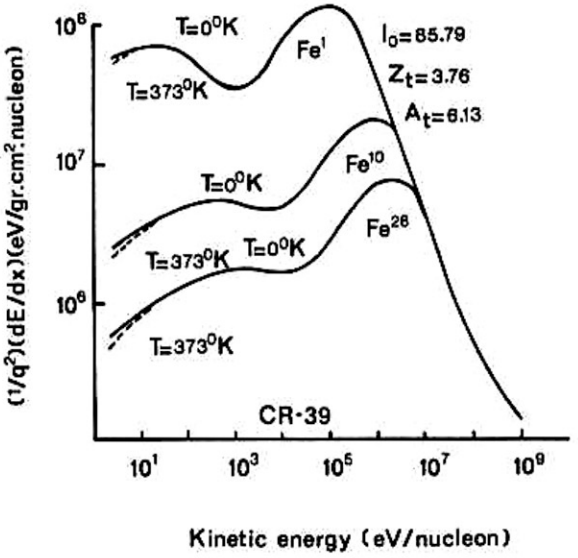

Fig. 3 Comparison of total energy losses for Fe^1, Fe^{10} and Fe^{26} in CR-39.

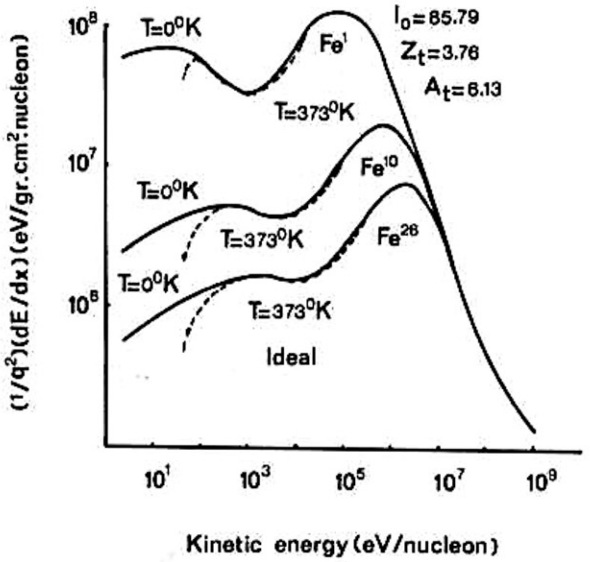

Fig. 4 Comparison of the total energy losses for Fe^1, Fe^{10} and Fe^{26} in the ideal material.

CONCLUSIONS

The results obtained by Blackman (1937) on the frequency spectrum of diatomic cubical lattices and the extrapolation to polyatomic species lead to the conclusion that polymers may be well represented by the continuum theory in Debye's approximation. An exact calculation shold be developed for comparison.

Upon applying a more realistic potential to the equations presented for total energy losses with temperature dependence, we find that the losses could have been overestimated even for CR-39.

The dependence of the velocity distribution on the spring constant, k_s, its dependence on the potential considered as well as the range of variation of this constant through a number of potentials, requires a more in depth study on the interatomic potentials of polymers.

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