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APPROXIMATE MATERIAL TEMPERATURE AND BOUNDARY MOTION CORRECTIONS FOR LOCAL
ENERGY DEPOSITION DUE TO ELASTIC SCATTERING

S. T. Perkins

August 1, 1977

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Abstract

An approximate correction for finite material temperature and boundary motion is presented for elastic scattering energy depositions.

Introduction

The TART¹ elastic scattering energy depositions assume the medium is at zero degrees Kelvin. An approximate correction will be developed for these energy depositions which takes into account the finite material temperature. This correction will then be expanded to take into account boundary motion. The results are applicable to charged particle scattering reactions as well.

Results

It will be assumed that the material temperature distribution can be described by the single speed model,² and that the scattering is isotropic in the center of mass system. The average final neutron energy is then described by a simple average over two angles. As pointed out by Canfield,³ this is only an approximation to the correct sampling distribution.

We make the following definitions:

m - mass of the neutron

M - mass of the target nucleus

subscript 1 - incident neutron

subscript 2 - emergent neutron

subscript A - incident target nucleus

subscript R - emergent target nucleus

subscript r - relative

subscript m - center of mass

μ - cosine of angle between $\vec{v}_1$ and $\vec{v}_A$

η - cosine of angle between $\vec{v}_2^*$ and $\vec{v}_m$

Quantities superscripted with an * are in the center of mass system.

Quantities not superscripted are in the lab system.

It can be shown⁴ that the final neutron speed in the lab system is given by

$$v_2^2 = v_m^2 + v_2^{*2} + 2v_m v_2^* \eta \quad (1)$$

Averaging over η leads to

$$\overline{v_2^2} = v_m^2 + v_2^{*2} \quad (2)$$

However, both v_m and v_2^* may be expressed in terms of μ ;

$$v_m^2 = \frac{1}{(m + M)^2} [(mv_1)^2 + (Mv_A)^2 + 2mv_1 Mv_A \mu] \quad , \quad (3)$$

and

$$v_2^{*2} = \left(\frac{M}{m + M} \right)^2 v_r^2 \quad (4)$$

where

$$v_r^2 = v_1^2 + v_A^2 - 2v_1 v_A \mu \quad (5)$$

Averaging Eq.(5) over μ leads to

$$\overline{v_r^2} = v_1^2 + v_A^2 \quad , \quad (6)$$

or the average relative energy is

$$\overline{E_r} = \left(\frac{m_A}{m_1 + m_A} \right) E_1 + \left(\frac{m_1}{m_1 + m_A} \right) E_A \quad . \quad (7)$$

Substituting Eq.(6) into Eq.(4) and averaging Eq.(3) over μ then leads to, after changing from speed to energy,

$$\overline{E_2} = \frac{A^2 + 1}{(A + 1)^2} E_1 + \frac{2A}{(A + 1)^2} E_A \quad , \quad (8)$$

where $A = M/m$. Defining $\alpha = [(A - 1)/(A + 1)]^2$, Eq.(8) may be written as

$$\overline{E_2} = \left(\frac{1 + \alpha}{2} \right) E_1 + \left(\frac{1 - \alpha}{2} \right) E_A \quad . \quad (9)$$

When $E_A = 0$, this result reduces to isotropic center of mass elastic scattering from a stationary nucleus.⁵

Our conservation of energy equation is

$$E_1 + E_A = \overline{E_2} + E_R \quad . \quad (10)$$

The difference in recoil energy before and after collision, ΔE_R , is the local energy deposition due to elastic scattering. From Eq.(10), this is equal to

$$\Delta E_R = E_R - E_A = E_1 - \overline{E_2} \quad . \quad (11)$$

Note that when $\overline{E}_2$ is given by Eq.(9), we can show that if

$$E_1 > E_A \quad , \quad \text{then } \Delta E_R > 0 \quad ;$$

and

$$E_1 < E_A \quad , \quad \text{then } \Delta E_R < 0 \quad .$$

Substituting Eq.(9) into Eq.(11), we obtain

$$\Delta E_R = \left(\frac{1 - \alpha}{2} \right) E_1 - \left(\frac{1 - \alpha}{2} \right) E_A \quad . \quad (12)$$

Equation (12) will now be approximately corrected for anisotropic center of mass elastic scattering. The first term on the rhs of Eq. (12) will be replaced by the elastic scattering local energy deposition currently in the TART file, $\Delta E_R(\text{TART})$. Furthermore, the single speed model energy of the incident target nucleus, E_A , is given by

$$E_A = \frac{3}{2} kT \quad , \quad (13)$$

where kT is the temperature of the medium (MeV). Equation (12) is thus equal to, in multigroup notation

$$\Delta E_{R_g} = \Delta E_R(\text{TART})_g - \left(\frac{1 - \alpha}{2} \right) E_A \quad . \quad (14)$$

It should be noted that Eq. (12) is in agreement with a Maxwellian distribution of target velocities if the relative cross section has a $1/v_r$ behavior.⁶

Let us now assume that the medium as a whole is moving with the velocity, $\vec{v}_B$. The velocities relative to an external observer, denoted by primed quantities, are obtained by adding on $\vec{v}_B$, e.g., $\vec{v}'_1 = \vec{v}_1 + \vec{v}_B$.

It will be further assumed that $\vec{v}_B$ (or $\vec{v}_A$ or $\vec{v}_1$) is isotropically distributed. One can then average over the cosine between v_B and, for example v_1 , to obtain

$$\overline{v_1'^2} = v_1^2 + v_B^2, \quad (15)$$

etc., for v_2' and v_A' . Again, we have only utilized an approximation to the correct sampling distribution for boundary motion.⁷ Defining E_B as

$$E_B = \frac{1}{2} m v_B^2 = 5.227 \times 10^{-3} v_B^2, \quad (16)$$

E_B in MeV, v_B in cm/sh, the speeds in the external observer reference frame, as per Eq. (15) may be converted to energies⁸;

$$E_1' = E_1 + E_B, \quad (17)$$

$$\overline{E_2'} = \overline{E_2} + E_B, \quad (18)$$

$$E_A' = E_A + A E_B. \quad (19)$$

Substituting Eq.(17) - (19) into Eq. (9) and solving for $\overline{E_2'}$ yields

$$\overline{E_2'} = \left(\frac{1 + \alpha}{2} \right) E_1' + \left(\frac{1 - \alpha}{2} \right) E_A' - \left(\frac{1 - \alpha}{2} \right) (A - 1) E_B. \quad (20)$$

Analogous to Eq. (11), the local energy deposition, $\Delta E_R'$, is equal to $E_1' - \overline{E_2'}$; thus Eq. (20) becomes

$$\Delta E_R' = \left(\frac{1 - \alpha}{2} \right) E_1' - \left(\frac{1 - \alpha}{2} \right) E_A' + \left(\frac{1 - \alpha}{2} \right) (A - 1) E_B. \quad (21)$$

Substituting in E'_A from Eq. (19),

$$\Delta E'_R = \left(\frac{1 - \alpha}{2} \right) E'_1 - \left(\frac{1 - \alpha}{2} \right) (E_A + E_B) \quad . \quad (22)$$

Our final result, analagous to Eq. (14) is then

$$\Delta E'_{R_g} = \Delta E_R(\text{TART})_g - \left(\frac{1 - \alpha}{2} \right) (E_A + E_B) \quad , \quad (23)$$

with E_A and E_B from Eq. (13) and (16), respectively. In the case that $E_A = 0$, i.e., kT , and $v_B = 0$, the energy deposition equals the first term in Eq. (23), as it should.

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8. 1 sh = 1 shake = 10^{-8} sec.

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