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Optimum Target Orientation in Nuclear Reactions Experiments

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In a recent paper[1] the effects of target thickness upon the energy resolution of analyzing systems are discussed. This is done in terms of a certain quantity, the total energy loss in the target, which is made to be independent of the depth at which the reaction takes place by suitable orientation of the target. But one actually measures the energy of the emitted particle, and then one should try to compensate two combined effects: (1) its energy loss in the target and (2) the way in which the energy loss of the incident particle is transmitted to the outgoing one. As we shall presently show these two losses cannot be simply added.

We shall use the same notation as reference 1: An (a,b) reaction proceeds in a target of thickness t whose normal forms an angle α with the direction of the projectile (a); α is positive when it lies on the same half-plane as θ, angle of the emitted particle (b), and negative otherwise. Consider the reaction taking place at depth y inside the target. Then, to a first approximation, the energy E_b will be *reduced* with respect to that resulting from an ideally thin target in the amount

$$\Delta E_b=\frac{dE_b}{dx}\frac{t-y}{\cos(\theta-\alpha)}+\left(\frac{\partial E_b}{\partial E_a}\right)_\theta \frac{dE_a}{dx}\frac{y}{\cos\alpha}, \tag{1}$$

where dE/dx is the energy loss rate. The first term in the right-hand member of Eq. (1) represents the energy loss of the outgoing particle in the target, while the second stands for the effect on its energy due to energy loss of the projectile. The only difference with Eq. (1) of reference 1 appears in the factor $(\partial E_b/\partial E_a)_\theta$, the variation of energy of particle b detected at angle θ/unit variation of energy of particle a.

If we now write

$$\Delta E_b=\frac{dE_b}{dx}\frac{t}{\cos(\theta-\alpha)}+y\left[\left(\frac{\partial E_b}{\partial E_a}\right)_\theta \frac{dE_a}{dx}\frac{1}{\cos\alpha}-\frac{dE_b}{dx}\frac{1}{\cos(\theta-\alpha)}\right], \tag{2}$$

we see that the first term in the right-hand member does not produce any effect on energy resolution if straggling is neglected; it only accounts for a constant correction easily computable from the known values t, θ, and α. The second term is responsible for the energy spread

$$\Delta E_b]_{y=t}-\Delta E_a]_{y=0}=t\left[\left(\frac{\partial E_b}{\partial E_a}\right)_\theta \frac{dE_a}{dx}\frac{1}{\cos\alpha}-\frac{dE_b}{dx}\frac{1}{\cos(\theta-\alpha)}\right], \tag{3}$$

which can be made zero if

$$f=\frac{\cos(\theta-\alpha)}{\cos\alpha}=\frac{1}{(\partial E_b/\partial E_a)_\theta}\frac{dE_b/dx}{dE_a/dx}. \tag{4}$$

The first equation defining f is the same as the corresponding one in reference 1, but the second is different because of the factor $(\partial E_b/\partial E_a)_\theta^{-1}$. This means that Fig. 3 of the aforementioned paper, giving the optimum angle α as a function of θ for different values of f, is still valid, but the determination of f from E_b as given by Fig. 4 for 15-Mev deuterons is not, at least for light target nuclei. When the masses of the target nuclei are much greater than those of incident and detected particles $E_b\simeq E_a+Q$ (Q being the reaction energy) and $(\partial E_b/\partial E_a)_\theta\simeq 1$. In such a case no correction is needed.

In the general case, however, a correction factor must affect the values of f obtained from B. L. Cohen's paper.[1] It can be calculated from the general scattering relations as

$$\left(\frac{\partial E_b}{\partial E_a}\right)_\theta^{-1}=\frac{E_a}{E_b}\frac{(m_c+m_b)E_b+(m_c-m_a)E_a+m_cQ}{(m_c+m_b)E_b+(m_c-m_a)E_a-m_cQ}, \tag{5}$$

where m_c is the mass of the residual nucleus.

In elastic scattering $(Q=0)$, for instance, the ordinates of d curves should be multiplied by E_a/E_b.

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[1] B. L. Cohen, Rev. Sci. Instr. 30, 415 (1959).