Treatment of Coulomb Interaction Contribution in Direct Nuclear Reactions.

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With the rising interest in the heavy ion nuclear reactions in the recent years [1] there is a need to incorporate the contribution of Coulomb interaction in the direct nuclear reactions [2]. As the direct reactions are supposed to be taking place in a relatively short span of time it is expected that there contribution should be a small (in comparison to the nuclear) but short range component of the long range Coulomb interaction. It is also well known that except for the inelastic scattering type of reactions there are essentially 3-bodies involved in the direct reaction process. For such direct nuclear reactions there exist finite range formalism which involves the short range nuclear interactions, either in total or in residual interaction forms to provide the required mechanism for the direct reactions. However, when heavy ions are involved, for example in reactions such as $^{24}Mg(^{12}C,^{16}O)^{20}Ne$, $^{16}O(^{6}Li,d)^{20}Ne$, $^{16}O(^{12}C,2^{12}C)^{4}He$, [3] $^{24}Mg(^{12}C,2^{12}C)^{12}C$ etc. the Coulomb interaction part is usually neglected particularly in that part which leads to the transition. In a reaction $A(a,\widehat{a+b})B$ (where $A=\widehat{b+B}$ and $\widehat{a+b}$ could be a bound state as in the case of pickup reactions or could be a free scattering state as in the case with Knockout Reactions) the Coulomb part of the a-b interaction will however be a long range part. However, because of the bound state nature of $\widehat{b+B}$ in the initial state the longer range part of a-b and b-B Coulomb interaction can not lead to the breakup of A into b+B. The breakup can occur due to short range but stronger residual part of the Coulomb interaction $V_{bB}(r_{ab},r_{bB})$.

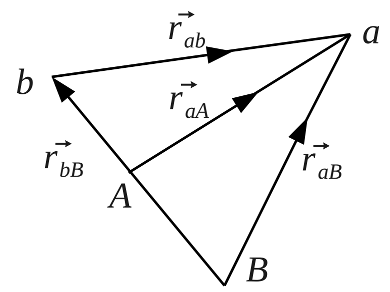

FIG. 1: Vector diagram used in equations.

$$V_{bB}(r_{aA},r_{bB})=\frac{Z_bZ_ae^2}{r_{ab}}+\frac{Z_aZ_Be^2}{r_{aB}}-\frac{Z_aZ_Ae^2}{r_{aA}} \quad (1)$$

for any value of r_{aA} the $\vec{r_{bB}}$ can have any orientation, but the most probable angle averaged orientation (as far as Eq.(1) is concerned) can be found to be perpendicular to $\vec{r_{aA}}$. If the r.m.s. distance of r_{bB} is R then for any $r_{aA}\sim r$ we have for large r's,

$$r_{ab}=\left(r_{aA}^2+\frac{B^2}{A^2}R^2\right)^{1/2}\sim r_{aA}\left(1+\frac{B^2}{2A^2}\frac{R^2}{r_{aA}^2}\right)$$

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therefore for large r's we have,

$$V_{bB}(r,R)\sim\frac{Z_ae^2}{r}(Z_b(1-\frac{B^2}{2A^2}\frac{R^2}{r^2})+Z_B(1-\frac{b^2}{2A^2}\frac{R^2}{r_{aA}^2}) -(Z_b+Z_B))$$

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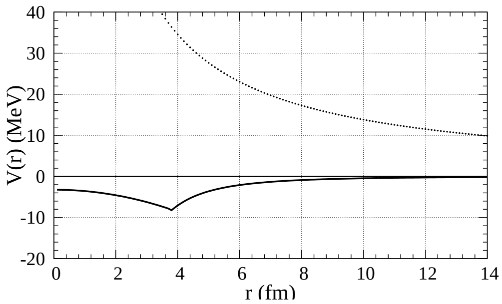

FIG. 2: Effective residual (Solid line) and Free Coulomb interaction (Dotted line) for $^{24}Mg(^{16}O, 2^{16}O)^8Be$ reaction.

$$= -\frac{Z_a e^2}{2r}\left(Z_b \frac{B^2}{A^2}\frac{R^2}{r_{aA}^2} + Z_B \frac{b^2}{A^2}\frac{R^2}{r_{aA}^2}\right)$$

Normally for light medium mass nuclei $B = 2Z_B$, $b = 2Z_b$, $a = 2Z_a$ thus,

$$V_{bB}(r,R) = -\frac{Z_a R^2 e^2}{2r^3 A^2}\left(\frac{b}{2}B^2 + \frac{B}{2}b^2\right)$$

$$= -\frac{abBR^2e^2}{8Ar^3}$$

Which decays as r^{-3} and hence the long range component of the Coulomb interaction reduces to a short range interaction as a function of $r_{aA}(\sim r)$. In the case of nuclei the shorter range part of the Coulomb interaction is usually taken as that due to a uniformly charged sphere.

$$V_{ab}(r_{ab},R) = \frac{Z_a Z_b e^2}{2R^C_{ab}}\left(3 - \left(\frac{r}{R^C_{ab}}\right)^2\right)$$

$$= V_{ab}(r,R) = \frac{Z_a Z_b e^2}{2R^C_{ab}}\left(3 - \frac{r^2 + \frac{B^2R^2}{A^2}}{(R^C_{ab})^2}\right)$$

$$V_{aB}(r_{aB}) = \frac{Z_a Z_B e^2}{2R^C_{aB}}\left(3 - (\frac{r_{aB}}{R^C_{aB}})^2\right)$$

$$= V_{aB}(r,R) = \frac{Z_a Z_B e^2}{2R^C_{aB}}\left(3 - \frac{r^2 + \frac{b^2}{A^2}R^2}{(R^C_{aB})^2}\right)$$

$$V_{aA}(r,R) = \frac{Z_a Z_A e^2}{2R^C_{aA}}\left(3 - \left(\frac{r}{R^C_{aA}}\right)^2\right)$$

$$= V_{aA}(r,R) = \frac{Z_a Z_A e^2}{2R^C_{aA}}\left(3 - \frac{r^2}{(R^C_{aA})^2}\right)$$

V_{bB} can be easily evaluated numerically but will be a short range component in r and R.

Thus in this contribution we have shown that only a short range component of the long range Coulomb interaction takes part in the direct pickup or knockout reactions.

This effective radial Coulomb transition interaction for $^{24}Mg(^{16}O, 2^{16}O)^8Be$ reaction is compared with the free Coulomb interaction in Fig. 2. It is seen that the repulsive longer ($\frac{1}{r}$) range part is converted to a feeble ($\frac{1}{r^3}$) attractive form which in the ^{16}O-^{16}O density overlap region this turns repulsive but still mild.

References

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