Quantitative description of uncertainties in the safe minimum value of impact parameter in Coulomb excitation experiments

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The electromagnetic interaction has been contributing more than any other phenomenon to the understanding of nuclear structure, theoretically as well as experimentally, since from the beginning of nuclear physics. The obvious reason being among the known fundamental interactions it is the best understood. The idea of exciting atomic nuclei by using the time-dependent electromagnetic field of the impinging charged particles was conceived in 1930's and was named as the electromagnetic or Coulomb excitation [1, 2]. Since then the nuclear physicists are using it enthusiastically as a highly prolific tool to unravel various nuclear structural properties of normal as well as exotic nuclei. Experimentally, for the reliable extraction of nuclear structural observables the dominance of Coulomb excitation process is to be ascertained. At below Coulomb barrier incident beam energies one is not concerned for the dominance of Coulomb excitation process as the condition is automatically fulfilled. But it is not the case with the most common above barrier intermediate beam energies available to the exotic beams being produced in various laboratories worldwide. The experiments performed at these energies are undoubtedly prone to nuclear contributions (also termed as absorption effects). Therefore, the purity of Coulomb excitation process is ensured by taking the measurements below some definite value of small forward scattering angle in laboratory frame of reference (θ_{lab}^{max}). The forward measurement is the sole criterion to practically eliminate the involvement of absorption effects. The θ_{lab}^{max} which eliminates the absorption effects is itself decided from the safe minimum value of impact parameter b_{min}. The value of b_{min} must be large enough such that it can ensure the physical separation of colliding nuclei which in turn switches off the absorption effects. A scheme for the determination of b_{min} has been proposed recently which is given by the following expression [3]

$$b_{\min} = 1.185\,(R_P + R_T)\left(1 + \frac{16310}{\exp\left(\frac{\gamma}{0.0887}\right)}\right) \quad (1)$$

with γ as relativistic Lorentz factor and $R_{P(T)} = 1.2\,A_{P(T)}^{1/3}$, $A_{P(T)}$ being the mass number of projectile (target). However, it is not the only value of b_{min} proposed for the determination of θ_{lab}^{max}, the other values of b_{min} commonly used are $R_P + R_T$+Δ where values of Δ extend from 2-5 fm. To name a few, $R_P + R_T$+2 fm [4-8], $R_P + R_T$+4 fm [9] and $R_P + R_T$+5 fm [10-12]. Unfortunately, there exists a lack of unanimity on any method to determine b_{min} and hence θ_{lab}^{max}. Because the value of b_{min} is very crucial in Coulomb excitation process, therefore, the spread of 2-5 fm in the value of Δ is significantly large. But the choice of Δ is just based on qualitative intuitive ideas and have no quantitative theoretical or phenomenological background. In the present work the problem regarding the choice of Δ has been investigated for several projectile target systems over incident intermediate beam energies.

To begin with it is better to use the recently proposed formula b_{min} as reference and find the difference between b_{min} and $R_P + R_T$ i.e Δ. In table 1 the values of Δ are mentioned for several projectile-target systems viz ^{26}Ne+^{197}Au to ^{208}Pb+^{208}Pb over incident beam energies ranging from 30 MeV/A-300MeV/A.

Table 1 Different values of Δ for a number of projectile and target systems at incident beam energies ranging from 30MeV/A to 300MeV/A.

Projectile-Target System	$\Delta\ (= b_{min} - R_P + R_T) fm$ at various beam energies				
	30 (MeV/A)	50 (MeV/A)	100 (MeV/A)	200 (MeV/A)	300 (MeV/A)
^{26}Ne+^{197}Au	3.7	3.3	2.7	2.1	2.01
^{32}Mg+^{197}Au	3.8	3.4	2.78	2.2	2.06
^{44}S+^{197}Au	4.0	3.6	2.9	2.3	2.14
^{56}Ti+^{197}Au	4.1	3.7	3.0	2.4	2.21
^{78}K+^{197}Au	4.3	3.8	3.1	2.5	2.31
^{96}Mo+^{197}Au	4.4	4.0	3.2	2.6	2.38
^{110}Sn+^{197}Au	4.5	4.1	3.28	2.6	2.43
^{197}Au+^{197}Au	4.96	4.45	3.6	2.86	2.67
^{208}Pb+^{208}Pb	5.0	4.53	3.67	2.94	2.72

It is clear from the table that value of Δ for ^{26}Ne+^{197}Au system decreases from 3.7 fm to 2.0 fm corresponding to increase in incident beam energy from 30 MeV/A to 300 MeV/A. Similar trend prevails for all other systems but have different values of Δ which is found to be decreasing with increasing beam energy for a projectile-target system. On the other hand the values of Δ are found to be increasing with mass number of projectile as one moves downwards for a particular beam energy. The minimum value of Δ is found to be 2 fm for ^{26}Ne+^{197}Au system at 300 MeV/A while its maximum value is found to be ~5 fm for ^{197}Au+^{197}Au *and* ^{208}Pb+^{208}Pb systems at 30 MeV/A. In other words the value of Δ varies from 2 fm to 5 fm for projectile-target systems ^{26}Ne+^{197}Au to ^{208}Pb+^{208}Pb at intermediate incident beam energies. From above discussion the reason for taking the values of Δ equal to 2-5 fm for intermediate energy Coulomb excitation experiments becomes clear quantitatively i.e the reason for the generally quoted values of b_{min} as $R_P + R_T + \Delta$, with Δ (= 2 - 5fm) becomes clear.

In conclusion, the different values of b_{min} ($R_P + R_T + \Delta$ with Δ = 2 - 5fm) used to decide the θ_{lab}^{max}, which were supposed to be based on the qualitative intuitive ideas are found to be based on quantitative background with reference to the recently proposed formula for b_{min} given by eqn (1).

References

[1] E. Rutherford et al, Reactions from Radioactive Substances, Cambridge University Press, Cambridge, England (1930).
[2] V. F. Weisskopf, Phys. Rev. **53**, 1018 (1938) 1018.
[3] Rajiv Kumar et al, Phys. Rev. C **81,** 037602 (2010).
[4] J A Church et al Phys. Rev. C **72**, 054320 (2005).
[5] Andrew Ratkiewicz, Ph.D Thesis (2011).
[6] T Baugher et al, Phys. Rev. C **86**, 011305 (2012).
[7] H L Crawford et al, Phys. Rev. Lett **110**, 242701 (2013).
[8] V M Bader et al, Phys. Rev. C **88**, 051301 (R) (2013).
[9] R W Ibbotson et al, Phys. Rev. Lett. **80**, 2081 (1998).
[10] D Cline Ann. Rev. Nucl. Part. Sci. **36**, 683 (1986).
[11] H Scheit et al, Phys. Rev. Lett. **77**, 3967 (1996).
[12] M Zielinska et al Acta Phys. Pol. B **39**, 519 (2008).