Comparison of deformation of α- and non α-cluster systems

S. Kundu*, C. Bhattacharya, S. Bhattacharya
Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata - 700064
** email: skundu@vecc.gov.in*

Introduction

In recent years several experiments have been done to study the deformation of an excited composite using light charged particle spectroscopy [1-7]. The shape of a composite nucleus produced in a nuclear reaction should normally be explained by rotating liquid drop model (RLDM) [8]. But it was observed large deformation in α-cluster system ^{28}Si*[1], ^{32}S*[7], ^{40}Ca*[6], from the study of light charged particle (LCP) spectra. For all these α-cluster systems, deep inelastic orbiting had already been conjectured from the fragment emission studies [9-11]. In the present study, our aim is to see whether α-clustering is the only reason for large deformation in such systems. For this purpose the deformations of several α-cluster and non-α-cluster systems have been recalculated from LCP spectra using statistical model calculation.

Extraction of deformation

Standard statistical model calculation is quite successful to explain the energy spectra of LCP emitted from a compound nucleus where it is assumed as rotating liquid drop. But there are many cases of heavy ion induced reactions where experimental spectra do not match with the predicted spectra [1, 3, 5-7]. Therefore, in order to explain the LCP energy spectra, one may require extra deformation of the CN in statistical model calculation. This may be incorporated by increasing the radius parameter of optical model potential which basically affects the lower energy part of the spectra. Higher energy part may be reproduced by changing the effective moment of inertia which affects the level density. The effective moment of inertia is written as, $I_{eff} = I_0(1 + \delta_1 \ell^2 + \delta_2 \ell^4)$ where δ_1 and δ_2 are 'deformability' parameters. But it is not always possible to explain the LCP spectra by introducing only a deformation. As the magnitude level density parameter a also affects the slope of the energy spectra, one has to consider the proper value of a and its dependence on excitation energy. To explain the energy spectra of p and α emitted from different reactions W. E. Parker et al [2] have varied effective critical angular momentum, ℓ_{cr}, the mean initial excitation energy, and the effective particle evaporation barrier in the statistical model code GANES[12].

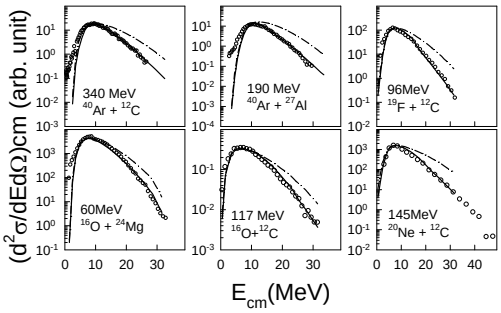

Fig.1 Typical α-particle spectra of a few systems mentioned in Table I. For details see the text.

In the present study we have taken a constant value of the level density parameter as $A/8$ and radius parameter $r_0 = 1.29$ fm as used in [1]. Here we have basically recalculated the theoretical prediction to reproduce the experimental result by changing δ_1 and δ_2 only. All other parameters are kept same as in Ref. [1]. To compare the deformation of the composite produced in the different reactions we can extract the standard quadrupole deformation parameter, β, using the procedure given in Ref. [1]. It is assumed that the non-deformed and the deformed nuclei are spherical and symmetric ellipsoid in shape with volume $\frac{4}{3}\pi R_0^3$ and $\frac{4}{3}\pi abc$, respectively, where R_0 is the radius for non-deformed nucleus and a, b, c are the three semi-axes of the ellipsoid with sharp surfaces. Using Hill-Wheeler parameterization one obtains the expression of $\beta = 1.057\ln(b/a)$ [1]. The values of b/a and β are extracted for two

TABLE I: The values the of β obtained from, (A) 'deformability parameter' using RLDM, and, (B) optimized 'deformability parameter' to fit with experimental spectra.

System	E_{lab}	ℓ_{cr}	ℓ_{av}	$\delta_1^A \times 10^{-5}$	$\delta_2^A \times 10^{-8}$	$\delta_1^B \times 10^{-5}$	$\delta_2^B \times 10^{-8}$	$\beta^A_{\ell_{av}}$	$\beta^B_{\ell_{av}}$
^{40}Ar+^{12}C[2]	340	34	23	6.8	6.8	90.0	6.8	0.14	0.67
^{40}Ar+^{27}Al[2]	190	48	32	3.1	2.7	33.0	2.7	0.15	0.56
^{56}Fe+^{12}C[2]	476	38	25	2.8	2.7	20.0	2.7	0.08	0.29
^{86}Kr+^{12}C[2]	730	44	29	0.8	0.7	0.8	0.7	**0.04**	**0.04**
^{7}Li+^{24}Mg[3]	47	15	10	28.0	66.0	100.0	66.0	0.10	0.24
^{19}F + ^{12}C[3]	96	18	12	28.0	66.0	150.0	600.0	0.14	0.54
^{16}O + ^{93}Nb[4]	75	34	23	0.2	0.8	0.2	0.8	**0.01**	**0.01**
^{12}C + ^{58}Ni[4]	50	23	15	2.3	2.7	2.3	2.3	**0.02**	**0.02**
^{30}Si + ^{30}Si[5]	120	36	24	4.9	6.1	140.0	2.0	0.13	0.89
^{32}S + ^{27}Al[6]	100	29	19	4.3	4.9	80.0	2.0	0.06	0.49
^{32}S + ^{58}Ni[6]	135	48	32	0.1	1.6	9.0	2.0	0.05	0.25
^{32}S + ^{64}Ni[6]	135	53	36	0.4	1.0	4.0	2.0	0.06	0.20
^{20}Ne + ^{27}Al[7]	158	40	27	8.6	11.0	35.0	2.0	0.26	0.46
^{16}O+^{24}Mg[6]	60	22	15	14.0	22.0	90.0	2.0	0.11	0.38
^{16}O+^{12}C[1]	116	20	13	37.0	110.0	190.0	2.0	0.22	0.52
^{20}Ne+^{12}C[7]	145	22	15	25.0	59.0	250.0	2.0	0.20	0.72

different sets of 'deformability' parameters (those obtained from RLDM and from fitting CASCADE calculations with the present data) have been given in Table I.

Result, discussion and conclusion

We have reanalyzed the experimental α-particle spectra for various reactions, a few of which are shown in Fig.1 by open circles. The dash-dot-dashed and solid lines represent CASCADE calculations with RLDM and optimized values of spin dependent 'deformability' parameters, respectively (see Table I). The values of quadrupole deformations for different systems under the present study are given in Table I. It is seen that all α-cluster systems, i.e., ^{16}O+^{24}Mg, ^{16}O + ^{12}C, ^{20}Ne + ^{12}C need extra deformation than the predicted value of RLDM. On the other hand, some non-α-cluster systems, ^{86}Kr + ^{12}C, ^{16}O + ^{93}Nb, ^{12}C + ^{58}Ni do not require any extra deformation other than RLDM predicted values. But the rest of the non-α-cluster systems require extra deformation over the prediction by RLDM. As energy spectra of the α-particles for both α-cluster systems as well as a few non-α-cluster systems cannot be explained by RLDM, it cannot be concluded that α-clustering is the only reason for large deformation seen all these α-cluster systems. But extra deformation in all the α-cluster systems indicates possibility of cluster effect; however, the present study indicates that dynamics of the α-clustering should be investigated to understand large deformation in the light, non-α-like nuclear system, in particular.

References

[1] S. Kundu *et al.*, Phys. Rev. C **87**, 024602 (2013), Pramana **82**, 727 (2014).
[2] W. E. Parker *et al.*, Phys. Rev. C **44**, 774 (1991).
[3] D. Bandyopadhyay *et al.*, Eur. Phys. J. A **14**, 53 (2002).
[4] E. Mirgule *et al.*, Pramana **67**, 369 (2006).
[5] G. La Rana *et al.*, Phys. Rev. C **35**, 373 (1987).
[6] B. Fornal *et al.*, Phys. Rev. C **37**, 2624 (1988), Phys. Rev. C **41**, 127 (1990), Phys. Rev. C **44**, 2588 (1991).
[7] A. Dey *et al.*, Phys. Rev. C **74**, 044605 (2006).
[8] S. Cohen *et al.*, Ann. Phys. **82**, 557 (1974).
[9] C. Bhattacharya, Phys. Rev. C **72**, 021601 (2005).
[10] S. Kundu *et al.*, Phys. Rev. C **78**, 044601 (2008).
[11] D. Shapira *et al.*, Phys. Rev. Lett. **53**, 1634 (1984).
[12] N. Ajitanand *et al,.* Nucl. Instr. and Methods A **243**, 111 (1986).