Charge dependence of nuclear force

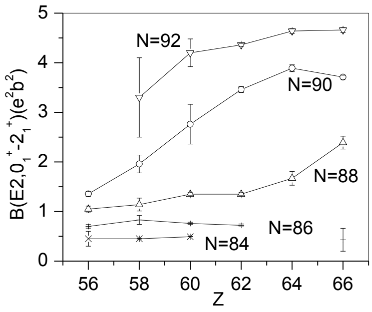
J B Gupta
Ramjas College, University of Delhi, Delhi 110007

Introduction

Both neutrons and protons are associated with a common isospin quantum number τ = 1/2. In the iso-spin space they represent the projections $\tau_0 = \pm 1/2$. The charge independence of nuclear force is a widely accepted property, i.e. the p-p, n-n and T=1 n-p pairs have equal interaction strength. It is reflected in many nuclear properties. It is also known that the T = 0, n-p force is slightly greater than the T = 1 n-p force. The excess of neutrons over protons compensates for the coulomb interaction between protons and determines the β-stability line. The symmetry energy depends on the neutron excess (N-Z)/A factor. With the shape transition with varying Z or N, the nature of the I^{π} =2+ (and of others) changes in its rotational content with I(I+1) spin dependence.

$$E(I) = a\, I(I+1) + bI + c\, I^2(I+1). \qquad (1)$$

The second term represents the vibraional energy and the last one the RV interaction. With increasing rotational content, E_2 decreases and the B(E2, $0\rightarrow2$) strength increases. Long ago Grodzins [1] observed that the product $E_2 \times B(E2)\uparrow$ is constant for large part of the nuclear chart. This involves the charge independence of the nuclear force. However, we illustrated its breakdown for the N=88 isotones of Nd-Dy [2]. The energy E_2 increases with increasing Z at N=88 (and in N=86) isotones. But the values of B(E2) also increases (Fig. 1). That gives an increasing value of the product in N=88 isotones of Nd-Dy. Hence the breakdown of the Grodzins product constancy rule occurs.



Fg.1. Variation of $B(E2)\uparrow$ versus Z for Ba to Dy at N = 84-92.

The rising E_2 with increasing Z was ascribed to the Z=64 subshell effect by Casten *et al.* [3]. If Z=64 is a subshell, then the proton boson numbers N_p have to be counted from Z=64, rather than from Z=50. The decreasing N_p explains the decreasing nuclear deformation. But B(E2) ignores the sub shell effect and rises with Z. Why a decreasing deformation has increasing B(E2) strength?

The $E_{12/2}$ versus $R_{4/2}$ plot (Fig. 2) clearly shows the falling values for Nd, Sm and Gd. That is the rotational content is falling with increasing Z. So normal view of increasing B(E2) with increasing rotation content does not apply here. Next, we look at the beta softness. The energy level plot for N=88 shows that when E_2 is rising (falling MoI) with increasing Z, the value of $E(0_2)$ is also falling, that is the nucleus is becoming more vibrational (Fig.3). But this also signifies the softness to β-vibration. The energy $E(0_2)$ may be related to the RV interaction term in (1), which is increasing here.

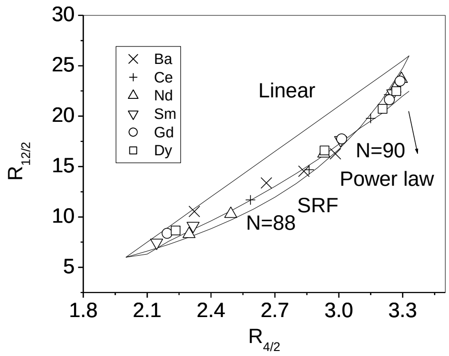


Fig. 2. Plot of energy ratio $R_{12/2}$ versus $R_{4/2}$. Linear curve is from Eq. 1, 'SRF' from Eq. 2, ($E_I = AI(I+1)/(1+\sigma I)$) and 'power law' from Eq. $E_I = aI^b$.

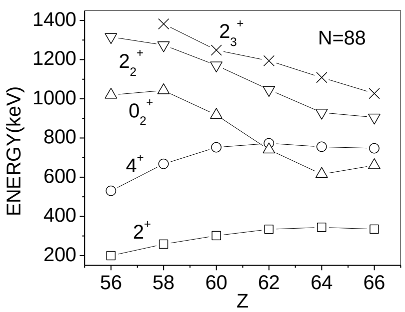


Fig. 3 Energy levels of Ba-Dy at *N*=88. Here $I^\pi = 2_1^+, 4_1^+$ are rising with *Z*, and 0_2^+ is falling with *Z* along with 2_2^+, 2_3^+.

The charge independence of nuclear force is reflected in the potential well $V(\beta,\gamma=0°)$. The position of the V_{min}, its depth, width and wall slopes are determined by combined effect of neutrons and protons. That determines the eigenvalues E_n. It also determines the β-softness of the nucleus.

The E2 matrix element $(\psi|M(E2)|\psi>$ and B(E2) strength is dependent not only on the wave functions ψ involved, but also on the M(E2) operator, *which is charge dependent*. here. This dependence on the operator is evident here when the wave functions correspond to more vibrational status and thus act in opposition.

Thus while the shape of the nucleus and its deformability is determined by the charge independent nuclear force, the electromagnetic *E2 transition strength is dependent on the proton numbers, not on the effective valence proton numbers N_p*. The B(E2) ratio R=B(E2,4-2)/B(E2, 2-0) is almost constant, on account of cancellation effect. At N=90, the increase in B(E2) due to increasing deformation is in phase with charge dependent effects, hence not visible. For Z ≥ 66, the proton pair bosons act like holes, and Er, Yb with lesser proton holes exhibit decreasing deformation as well as decreasing B(E2)↑. Here the charge independence of nucleons is exhibited.

The magnetic moment μ (2+) reflects the charge dependence of the nuclear force, Here it exhibits the increase with Z at N=88. To sum up, the charge dependence is especially exhibited when the effect of protons are different on the intrinsic shape of the nucleus and the E2 transition strength.

[1] L. Grodzins, Phys. Lett.**2**, 88 (1962)
[2] J .B. Gupta, Phys. Rev.**C89**, 034321 (2014)
[3] R F Casten et al Phys. Rev. Lett. **47**, 1433 (1981)