IV.f. Effect of Core Excitation on *B*(E2) Values

P. G. BIZZETI

University of Florence, Florence, Italy

I shall try to summarize some experimental facts related to electric quadrupole moments in the ^{40}Ca region. I do not pretend to give a complete report, but I would like to start the circus discussion with some considerations on a very particular set of states in the even nuclei which have a single closed shell.

Figure 1 shows the low lying levels of $1f_{7/2}$ nuclei that have two identical particles or holes with respect to the magic numbers 20 and 28. One can observe that the excitation energies of the lowest 2^+, 4^+ and 6^+ states are quite similar in all the cases. One would, therefore, expect[1,2] that all these states and the ground states of $(f_{7/2})^{\pm 2}$ nuclei can be equally well described within the $(f_{7/2})^2$ configuration (with perhaps some small mixing of $f_{7/2}p_{3/2}$).

Until a couple of years ago, this conclusion was not contradicted by the actual knowledge of the transition strengths. The measured B(E2) values for the $2^+ \to 0^+$ transitions in ^{42}Ca,

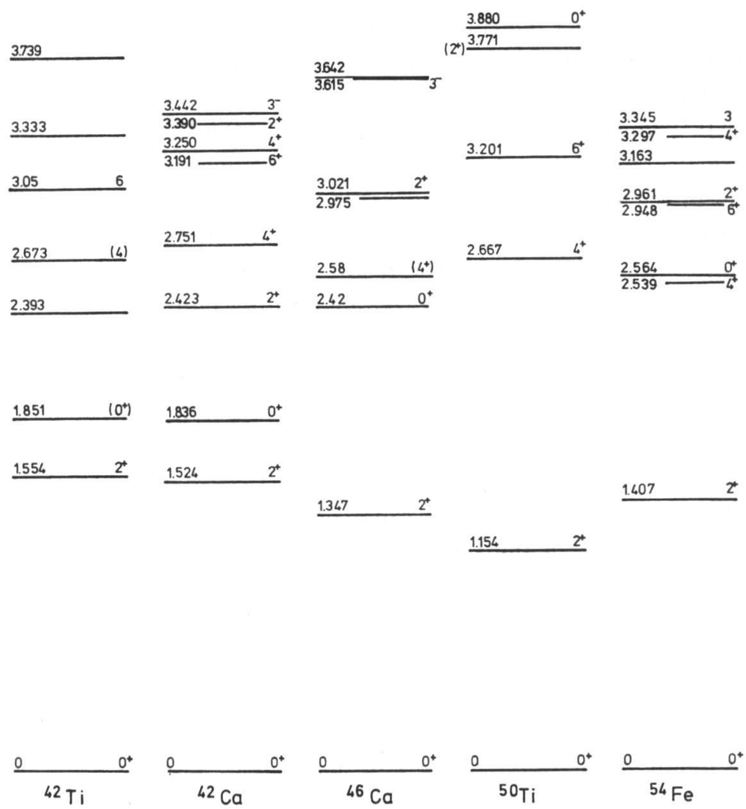

Fig. 1. Level scheme of the even $1f_{7/2}$ nuclei which have a single closed shell.

Table I. Values of B(E2) for the $6^+ \rightarrow 4^+$ transitions in $(1f_{7/2})^{\pm 2}$ nuclei.*

	B(E2)/e^2fm^4		e_{eff}
	exp.	$(f_{7/2})^n$	
^{42}Ca	6.30 ± 0.11	11.6	0.74 ± 0.01
^{50}Ti	33.6 ± 1.1	12.6	1.63 ± 0.03
^{54}Fe	39.9 ± 0.8	12.4	1.79 ± 0.02

* For experimental results see refs. 3, 4 and older papers quoted there. The values of $\langle r^2 \rangle$ are taken from ref. 4.

^{46}Ca, ^{50}Ti and ^{54}Fe, shown in the old tabulations,[1] were in fact almost equal. If an effective charge is defined as the square root of the ratio of experimental and calculated values of B(E2), the same value $e_{eff} \approx 1.7$ was, therefore, deduced for both protons and neutrons in the $f_{7/2}$ orbitals.

I shall now discuss the evidence against the above conclusions, that comes out of the recent experimental measurements. The experimental evidence concerns:

I. the E2 transitions between high-spin states ($6^+ \rightarrow 4^+$),
II. the E2 transitions between low-spin states ($2^+ \rightarrow 0^+$), and
III. the static electric-quadrupole moments.

The experimental B(E2) values for the $6^+ \rightarrow 4^+$ transitions in $(f_{7/2})^{\pm 2}$ nuclei are shown in Table I. They are the best averages of recent measurements[3,4] which are in good agreement with one another. The corresponding effective charge values are also shown in Table I. One

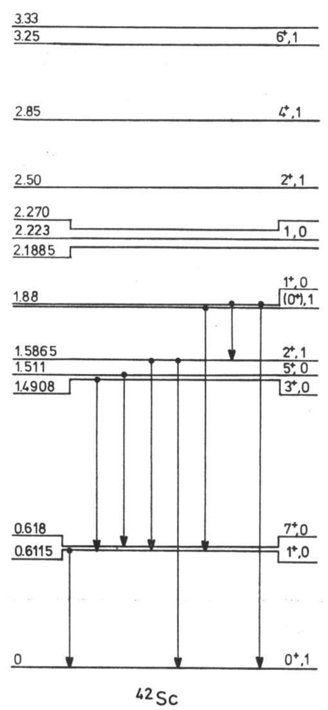

Fig. 2. Level scheme of ^{42}Sc (from ref. 5).

can observe that for ^{50}Ti and ^{54}Fe, the values of e_{eff} for the $6^+ \to 4^+$ transitions are still of the order of 1.7, while for ^{42}Ca the value is only 0.74. The corrections for configuration mixing would produce even smaller values for the effective charge. For instance, the first order correction for an $f_{7/2}p_{3/2}$ admixture to the 4^+ state (with Kuo and Brown residual interactions) would reduce the value of e_{eff} in ^{42}Ca by about 25% (see Fig. 3 of ref. 3).

Also, for the $2^+ \to 0^+$ transitions, the experimental situation has changed appreciably in recent times. More information is available for the $A = 42$ triplet and for the ^{46}Ca nucleus. The mean life and decay properties of the lowest 2^+ $T = 1$ state in ^{42}Sc have been determined by Grawe, Hartman and Kändler[5]. The 10% branch to the 0^+ $T = 1$ g.s. (Fig. 2) corresponds to a strength of 10.4 ± 5.7 w.u. For the corresponding transition in ^{42}Ti, three experimental results were available last year at the Legnaro Conference on $f_{7/2}$ nuclei. The agreement among them was not very good at that time, but, since then, one of them has been revised[6], the errors have been reduced, and now I think we have a rather reliable and accurate value also for ^{42}Ti. A cross check of the three transition strengths in ^{42}Ca, ^{42}Sc and ^{42}Ti is also possible, since the corresponding transition amplitudes should depend linearly on the third component of the isospin. This relation is, in fact, quite well verified (see Fig. 3).

Values of the effective charge, as defined above, can be deduced for proton and for neutron configurations. Results are shown in Table II. One can observe that the proton effective charges in ^{50}Ti and ^{54}Fe, as well as the neutron effective charge for the ^{42}Ca $2^+ \to 0^+$ transition, are significantly smaller than the value deduced for ^{42}Ti.

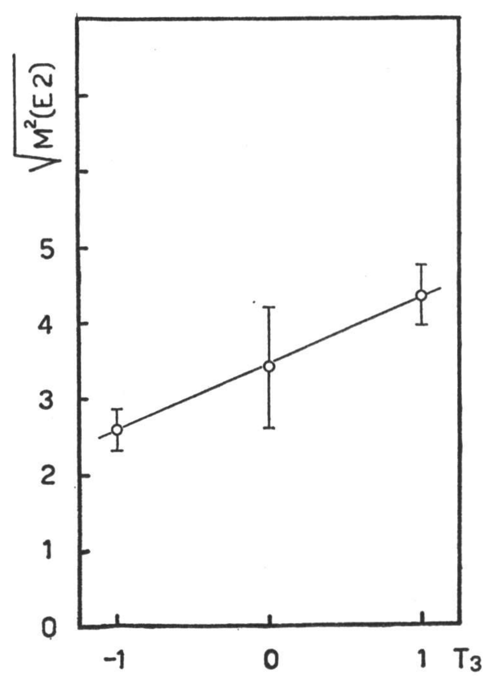

Fig. 3. Transition amplitudes for the $2^+ \to 0^+$ transition in the isospin triplet $A = 42$, plotted as a function of T_3 (here $T_3 = -1, 0, +1$ for ^{42}Ca, ^{42}Sc and ^{42}Ti, respectively). The expected relation $M(\mathrm{E2}) = a + bT_3$ is well verified.

Table II. Values of B(E2) for the lowest $2^+ \to 0^+$ transitions (from ref. 9).

	$B(\mathrm{E2})/e^2\mathrm{fm}^4$		e_{eff}
	exp.	$(f_{7/2})^n$	
^{42}Ca	75.3 ± 6.2	25.5	1.72 ± 0.07
^{46}Ca	32.5 ± 3.4	25.5	1.13 ± 0.06
^{42}Ti	137 ± 28	25.5	2.32 ± 0.23
^{50}Ti	66 ± 5.6	27.6	1.55 ± 0.07
^{54}Fe	102 ± 10	27.4	1.93 ± 0.09
^{46}Ca	98.0 ± 9.2	34.0	1.70 ± 0.08
^{52}Cr	134 ± 14	36.7	1.92 ± 0.10

Finally, a new measurement of the $2^+ \to 0^+$ transition strength in ^{46}Ca has been reported at this Conference.[8] The neutron effective charge deduced from it is significantly lower than the value found for the same transition in ^{42}Ca and closer to the effective charge for the $6^+ \to 4^+$ transition.

The experimental situation for the $2^+ \to 0^+$ transitions is summarized in Table II. From the simple comparison in Tables I and II, one can observe that $(f_{7/2})^2$ configurations with constant effective charge can perhaps describe the $N = 28$ isotones, but certainly not the $A = 42$ nuclei.

The key to the problem is the presence of additional 0^+ and 2^+ states, which in ^{42}Ca lie at only Ex = 1.838 MeV and 2.423 MeV, respectively, and which correspond to core excited (probably deformed[10,11]) states. Since the $(f_{7/2})^2$ states and the additional states are very close together, they are expected to mix appreciably one with another, and to share the electric quadrupole strength carried by the core-excited configurations. If that is so, it is easy to understand why the $(f_{7/2})^2$ scheme works rather well in ^{50}Ti, where the lowest excited 0^+ state is rather high, but so badly in ^{42}Ca. More generally, it is easy to see that the anomalous enhancement of the $2^+ \to 0^+$ transitions is strictly related to the low-lying additional states, not only in ^{42}Ca but also in the other single-closed-shell nuclei. In fact, let us plot the polarization charge as a function of the excitation energy, $E^*(0_1^+)$, of the lowest excited 0^+ state (Fig. 4). All experimental points cluster around a straight line which corresponds approximately to a power law with exponent -1. This fact is perhaps surprising, since the structure of the additional 0^+ and 2^+ states is probably quite different in the different cases, but it shows, in my opinion, that the enhancement of the $2^+ \to 0^+$ transitions is really well correlated with the presence of core excited states.

For the case of ^{42}Ca, this point of view is supported by the theoretical calculations of Gerace and Green[11] and Flowers and Skouras,[12] but, on experimental grounds, the most direct support comes from the values of the static quadrupole moments of the 2^+ states, which have been recently measured at Rochester.[13] I do not want to emphasize this point too much, since I think that Dr. Cline is going to discuss it at more length. But I would like to stress that the sign of the experimental value for ^{42}Ca, $Q(2^+) = -18.9 \pm 8.1\ \mathrm{e \cdot fm^2}$, is opposite to that of the value predicted for the $(f_{7/2})^2$ configuration. This fact strongly suggests a considerable mixing of the lowest 0^+ and 2^+ levels with low lying, intrinsically deformed states.

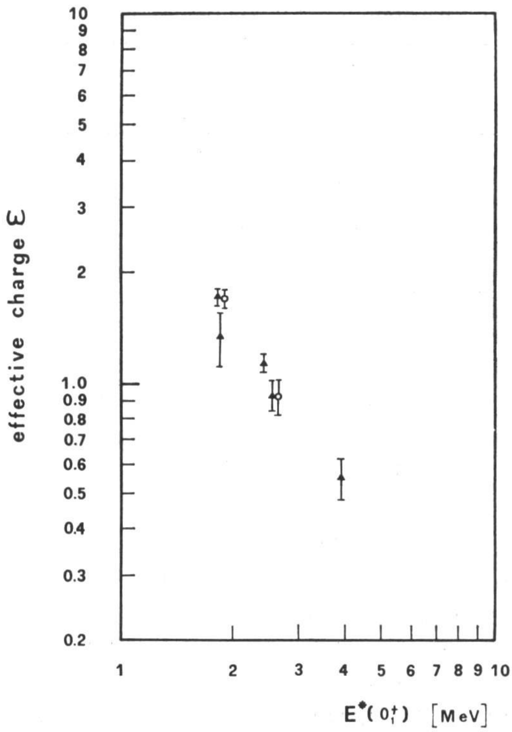

Fig. 4. Polarization effective charge ε plotted as a function of the excitation energy of the lowest excited 0^+ state ($\varepsilon = e^{p}_{eff} - 1$ or $\varepsilon = e^{n}_{eff}$, respectively, for proton or for neutron configurations). Experimental points (from the top): triangles–^{42}Ca, ^{42}Ti, ^{46}Ca, ^{54}Fe, ^{50}Ti; circles–^{44}Ca and ^{52}Cr. (from ref. 9).

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Discussion

A. ARIMA (Stony Brook): In order to extract effective charges, we have to take into account the neutron excitation from the $f_{7/2}$ shell to the $p_{3/2}$ shell in ^{50}Ti and ^{54}Fe. This is necessary to keep isospin good. If we include this effect, the extracted value of effective charge for the proton will be changed.

BIZZETI: What I did was much simpler than you thought. That is, the number I gave was only the ratio of experimental pure $(f_{7/2})^2$ values, so I did not take into account any mixing with more complicated states for $N = 28$ isotone. If one wants to take this mixing into account, I think that there is a calculation by Dr. Osnes which has been referred to in the $f_{7/2}$ Conference.

L. ZAMICK (Rutgers Univ.): I agree with Prof. Arima about keeping isospin good. However, I still think, in a first order perturbation theory of ^{54}Fe, only the proton will contribute to the effective charge in the configuration mixing. However, when one goes beyond first order perturbation theory, certainly the neutron will contribute.

ARIMA: But, Since the core-polarization mechanism causes the effective charge, additional charge is associated with the neutron. Once you excite a neutron from $f_{7/2}$ to $p_{3/2}$, you have to add this contribution.

T. YAMAZAKI (Univ. of Tokyo): In a published paper, in which we used the Kuo-Brown wave functions, we showed that the polarization charges for proton and neutron turn out to be nearly the same. However, some time ago, Prof. Arima told me that the polarization charges become appreciably different if one uses isospin-conserved wave functions.