Time Dependent Recoil In Vacuum measurements on radioactive ions

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Nuclear moments – Why?

• Nuclei with non-zero spin have magnetic dipole moment
  \[ \mu = g I \left[ \mu_N \right] \]

- Sources of nuclear magnetism:
  - orbital movement of charged particles;
  - intrinsic spin of the nucleons.

- Magnetic moment of a nucleus:
  \[ \vec{\mu} = \sum_{k=1}^{A} g^{(k)}_{\ell} \vec{\ell}^{(k)} + \sum_{k=1}^{A} g^{(k)}_{s} \vec{s}^{(k)} \] - the contribution of every nucleon

- \( \pi/\nu \) g factors:
  - free – nucleon
    \[ g^\pi_s = 5.585 \quad g^\pi_\ell = 1 \]
    \[ g^\nu_s = -3.286 \quad g^\nu_\ell = 0 \]
  - effective
    \[ g^\pi_s = 0.7 \times g^\pi_s \quad g^\pi_\ell = 1 \times \]
    \[ g^\nu_s = 0.7 \times g^\nu_s \quad g^\nu_\ell = 0.7 \times \]
Nuclear moments around the “Island of Inversion”

- Mg’s and the “Island of Inversion”
  - \(^{32}\text{Mg}\) – first identified with high B(E2) and low \(E_x\) (2\(^+\))

- Ground-state’s moments of the Mg isotopes:
  - s.p. states, not sensitive to configuration mixing but to the odd-nucleon orbit
  - e.g. \(^{31}\text{Mg}\) – magnetic moment of 1/2\(^+\) state well reproduced even if its energy (\(sd\) model space) is > 1 MeV off
Even-even Mg isotopes (2\(^+\) states)

- \(^{26}\text{Mg}\) – new results from a TF measurement (B.P. McCormick et al., PLB 779, 445 (2018))
- \(^{24}\text{Mg}\) (N=Z) and \(^{26}\text{Mg}\) (\(v_{d_{5/2}}\) subshell) – rather “simple” theory cases
- \(^{28}\text{Mg} – ^{32}\text{Mg}\) – real tests for the interactions

- \(^{28}\text{Mg}\) – the important (or not?) role of the N=16 sub-shell gap at Z=12?
- New estimations for the borders of the “Island of Inversion”
  T. Otsuka et al., INPC 2016 presentation.
  → it is necessary to include \(pf\) admixtures in order to reproduce the structure of the excited states already in \(^{30}\text{Mg}\)
Experimental approach

• Important ingredients:
  o Obtain nuclear spin-oriented ensemble
  o Apply an external (magnetic) perturbation → ω_L = - \frac{g\mu_NB}{\hbar}
    • Have sufficient time for the interaction
    • Know with a sufficient precision the perturbing field
  o Measure the level of perturbation

• Time Differential measurements: E. Recknagel in Pure and Applied Physics, 40C
  • observe several rotations of the nuclear spin ensemble within its lifetime
    → for a state with g ~ 0.4 – 0.5
      lifetime          magnetic field
      150 ns            1 Tesla
      1.5 ps           100 kTesla
TDRIV – basic principles and RIB geometry

$$D = \nu T$$

$$F = I + J$$

$J$ electron spin

$G$ nuclear spin

$$\bar{G}_k(T) = \int_0^T G_k(t) \lambda e^{-\lambda t} dt$$

$$G_k(\infty) = \int G_k(t) \lambda e^{-\lambda t} dt$$


24Mg @ ALTO

$$|g(2^+)| = 0.538 (13)$$

A. Kasoglu et al., PRL 114, 062501 (2015)
TDRIV @ HIE-ISOLDE – the setup

- 8 Miniball triple cluster detectors @ (close to) 90° angles

DSSD for particle detection
- 3.9 mg/cm² Nb target
- 1.1 mg/cm² Ta degrader

- angular coverage
  \( \theta = 21° – 50° \)
  14 sectors
  \( \varphi = 0° – 360° \)
  4 quadrants, 12 sectors each

- first use of the Miniball plunger
- ~ 20 distances

- ~7% efficiency at 1.4 MeV
**22Ne – a “test” measurement**

- $^{22}\text{Ne}$ (5.5 Mev/u, 1.5 ppA) – from EBIS rest gas
- Beam intensity ($10^7$ pps) - limited by the scattering rate in the CD detector
- 5 days stable beam run

| our preliminary value: $|g| = 0.445(25)$ |
| vs. |
| previous measurements: |
| $|g| = 0.326(12)$ |
| and |
| $|g| = 0.36(3)$ |

R.E. Horstman *et al.*, NP A 275 (1977), 237

How reliable is the previous value of $g(2^+)$ of $^{22}$Ne?

- Could there be something *not quite correct* with the *previous most accurate $g(2^+)$ value* of R.E. Horstman *et al.* (adopted by N.J. Stone in “Table of nuclear moments” INDC(NDS)-0658)???

- Comparison of previously known $g(2^+)$ in
  - $^{20}$Ne: $|g| = 0.54(4)$ (R.E. Horstman *et al.*, NP A 248, (1975), 291)
  - $^{22}$Ne: $|g| = 0.326(12)$ (R.E. Horstman *et al.*, NP A 275 (1977), 237)

  gives a discrepancy (a factor of ~ 2!) for the *transient field strength* of the two isotopes of the same element – *unphysical*!!!
The “real RIB” experiment

- $^{28}\text{Mg} \left( t_{1/2} = 20.9 \text{ h} \right)$ – the bright side
  - expected beam intensity: $1 \times 10^6 - 5 \times 10^5$ pps
  - available: $+ 5 \times 10^6$ pps!!
  - well pronounced particle – $\gamma$ angular correlations observed
  - 10 plunger distances measured

- and the difficulties …
  - count rates in the Ge detectors - $+ 5k / \text{Ge core}$ (and increasing!) with half of the available proton beam intensity. Running for 7 days @ 10k/det.
  - scattered beam deposited in the vacuum chamber
    – beta-decay $^{28}\text{Mg} \rightarrow ^{28}\text{Al} \rightarrow ^{28}\text{Si}$ (stable): 100% 1779 keV + more than 60% of higher than 1342 keV – impossible to be shielded …

- Present status
  - data under analysis in progress
Conclusions and outlook

• Magnetic moments of single particle (odd-mass ground or isomeric states) vs. collective (short-lived excited states) – probing different components and admixtures in the nuclear wave function

• Studies with high intensities post-accelerated RIB are very promising but require some special attention. The radioactive ion beam are radioactive. RIB of $10^6$ pps is high intensity! Where is the compromise between high-efficiency vs. large opening for RIB’s?

• Relying on old, “well established” results one may run into surprises. Revisiting experimental results from few decades ago (pushing the limits at their time) might be a necessary step before reaching for new exciting radioactive beam challenges.

• Stay tuned for exciting results to follow
The collaboration

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