Nuclear Parity

- $\psi(r) \Rightarrow \psi(-r)$ Even.
- $\psi(r) \Rightarrow -\psi(-r)$ odd.
- For a <u>nucleon</u> ψ is either of even (π = +) or odd (π = -) parity.
- For the <u>nucleus</u> $\pi = \pi_1 \pi_2 \pi_3 \ldots \pi_{A.}$
- Individually not possible.
- Overall π can be determined experimentally.
- Overall I^{π} for a nucleus (nuclear state).
- Transitions and multipolarity of transitions (γ-emission).

Electromagnetic moments

- Electromagnetic interaction ▶ information about nuclear structure.
- Charge ▶ electric; current ▶ magnetic.
- Electromagnetic multipole moments.

Field $\propto 1/r^2$ (zeroth, L=0) electric monopole moment.

$1/r^3$ (first, L=1) electric dipole moment.

$1/r^4$ (second, L=2) quadrupole moment.

………

$1/r^2$ magnetic monopole (questionable….!).

Magnetic Dipole (familiar).

Higher order magnetic moments.

Electromagnetic moments

- Expectation value of the moment. $\int \psi^* \vartheta \psi dv$
- Each multipole moment has a parity, determined by the behavior of the multipole operator when r ➔ -r.
- Parity of ψ does not change the integrand.
- Electric moments: parity $(-1)^L$.
- Magnetic moments: parity $(-1)^{L+1}$.
- Odd parity ▶ vanish.

Vanishing moments

electric dipole.
magnetic quadrupole.
electric octupole.
…………

Electromagnetic moments

- Electric monopole: net charge *Ze*.
- Magnetic dipole:

$$\mu = iA$$

$$\mu = \frac{e}{T} A \; ; \quad \mu = \frac{e}{2\pi r / v} \pi r^2 \; ; \quad \mu = \frac{evr}{2}$$

$$\mu = \frac{emvr}{2m} \; ; \quad \mu = \frac{epr}{2m} \; ; \quad \mu = \frac{e}{2m} L$$

- g-factors.

Nuclear Magnetic Moment

Remember, for **electrons**

Revise: Torque on a current loop.

$$\mu_B = \frac{e\hbar}{2m_e} = 9.2740154x10^{-24} J/T = 5.7883826x10^{-5} eV/T$$

Bohr magneton

Orbital $\mu_L = -g_L \frac{e}{2m_e} L$ $\mu_{Lz} = -g_L \frac{e\hbar}{2m_e} m_\ell = -m_\ell \mu_B$

Gyromagnetic ratio (g-factor) $g_L = 1$

Spin $\mu_S = -g_S \frac{e}{2m_e} S$ $\mu_{Sz} = -g_S \frac{e\hbar}{2m_e} m_s = -2m_s\mu_B = \pm\mu_B$

$g_S = 2.0023 \approx 2$

Z component ?? Experiment, applied magnetic field.

Nuclear Magnetic Moment

For **Nuclei**

$$\mu = g\frac{e}{2m_p}I \qquad \mu_z = g\frac{e\hbar}{2m_p}m_I = g\mu_N m_I$$

Nuclear magneton $\mu_N = 5.05084x10^{-27} J/T = 3.15245x10^{-8}\ eV/T$

For **free protons and neutrons**

$$\mu_z = \frac{1}{2}g\mu_N$$

Proton: g = 5.5856912 ± 0.0000022 ~ 3.6 ↑
Neutron: g = -3.8260837 ± 0.0000018 ~ 3.8 ↓

The proton g-factor is far from the g_S = 2 for the electron, and even the uncharged neutron has a sizable magnetic moment!!!

▸ Internal structure (quarks).

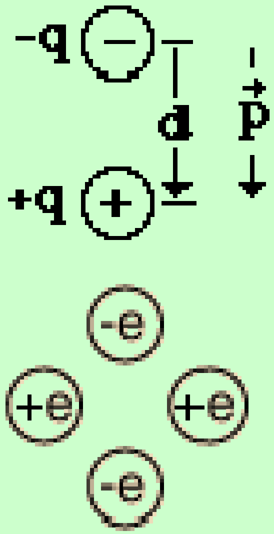
Nuclear Magnetic Moment

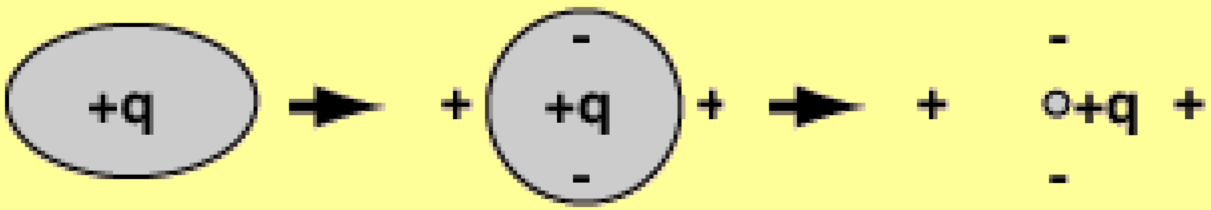
Nuclide	Nuclear spin	Magnetic moment μ (in μ_N)
n	1/2	-1.9130418
p	1/2	+2.7928456
^{2}H (D)	1	+0.8574376
^{17}O	5/2	-1.89279
^{57}Fe	1/2	+0.09062293
^{57}Co	7/2	+4.733
^{93}Nb	9/2	+6.1705

Electromagnetic moments

- The nucleus has charge (monopole moment).
- No dipole moment since it is all positive.
- But if the nucleus is not spherically symmetric, it will have a quadrupole moment.

Classical moments



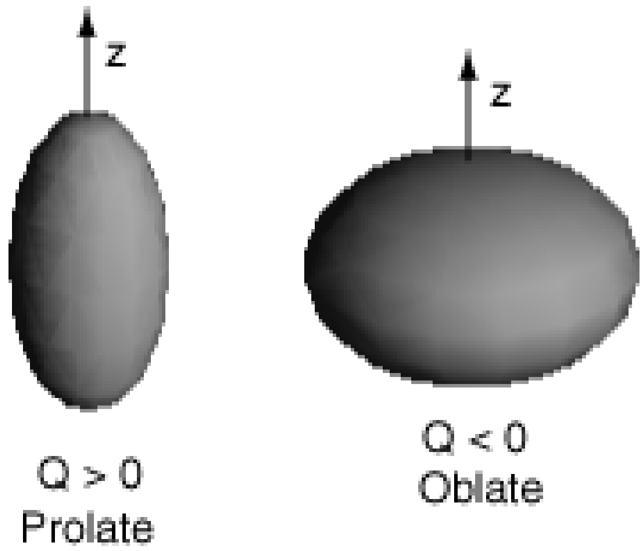


Electric Quadrupole Moment

- For a point charge *e*: $eQ = e(3z^2 - r^2)$.
- Spherical symmetry ▶ $x^2 = y^2 = z^2 = r^2/3$ ▶ $Q = 0$.
- For a proton:

$$eQ = e\int \psi^* (3z^2 - r^2)\psi dv$$

- In the xy-plane: $Q \sim - \langle r^2 \rangle$.
- $\langle r^2 \rangle$ is the mean square radius of the orbit.
- Along z: $Q \sim +2 \langle r^2 \rangle$.
- Expected maximum $\sim e r_0^2 A^{2/3}$.
- *Up to* 50×10^{-30} *em*^{2}.
- *Up to 0.5 eb.*



Electric Quadrupole Moment

Nuclide	Q (b)
^{2}H (D)	+0.00288
^{17}O	-0.02578
^{59}Co	+0.40
^{63}Cu	-0.209
^{133}Cs	-0.003
^{161}Dy	+2.4
^{176}Lu	+8.0
^{209}Bi	-0.37

- Closed shell ▶ Spherically symmetric core.
- Test for shell model
- Strongly deformed nuclei…..!