Einstein-de Haas Nuclear Analogous Experiment

By

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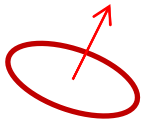
Polarized target group at COMPASS

Historic point #1:

- The paper “Experimenteller Nachweis der Ampèreshen Molekularströne” by A. Einstein and W. J. de Haas Verhandl. d. Deut. Physik. Ges. 17, 152) was publicised in 1915 year.

- The concept of the “Nuclear spin” was elaborated later on in 1925-1927 years.

Historic point #2:



The main goal of [E-de H] was: The natural ferromagnetism can be explained by the magnetic momentum of a simple closed Ampère current loop and without any radiation.

The idea of [E-de H] experiment in our understanding: Due to the absence of radiation in the natural magnets and according to the conservation of angular momentum in the process of magnetizing and demagnetizing of a sample

“this change of the inner angular momentum must correspond to the occurrence of compensating angular momentum of an another kind; the latter will be a crude mechanical angular momentum ”.

Historic point #3:

Looking backward, 25 years after [E-de H]- experiment:

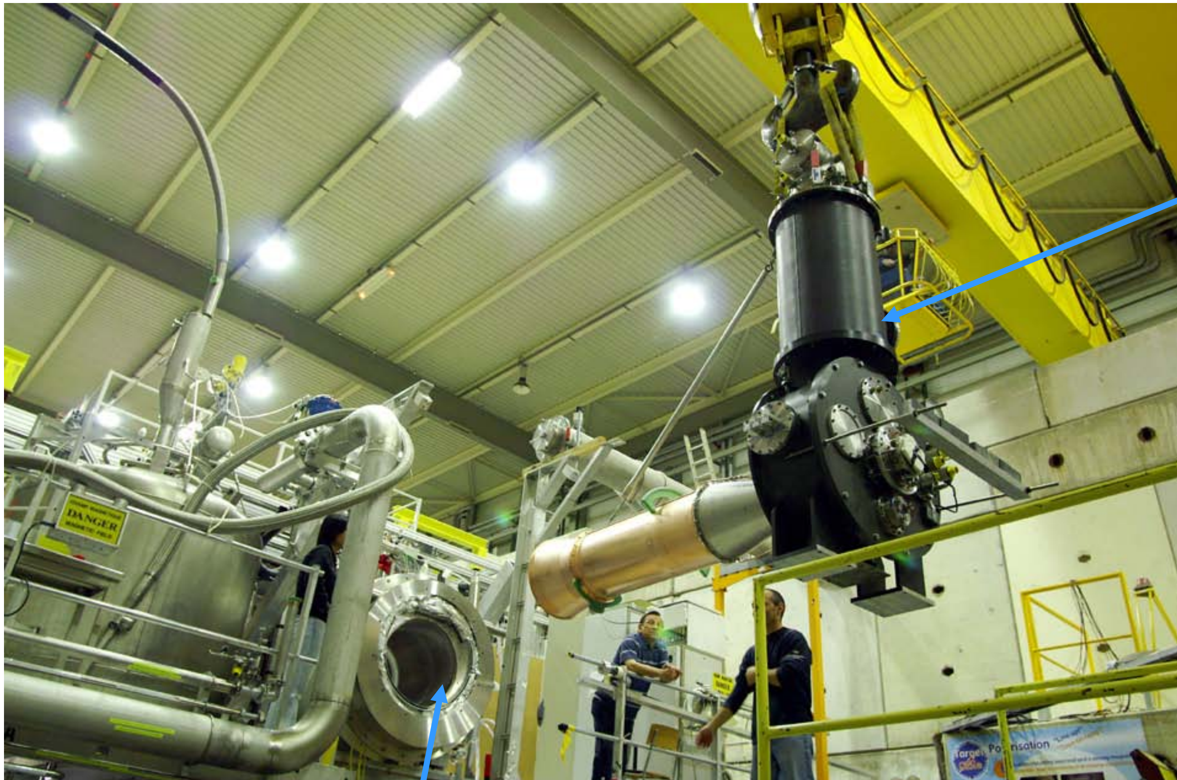
“The gyromagnetic effects ... in a very direct way demonstrate the difference between electric dipoles, which consist of two equal charges of opposite sign at a short distance and magnetic dipoles, which consists of circular Ampère molecular currents.”

C.J. Gorter and B. Kahn, Physica, VII, no 8, **1940**, p.753

This hint gave us the idea for our nuclear analogue experiment, namely:

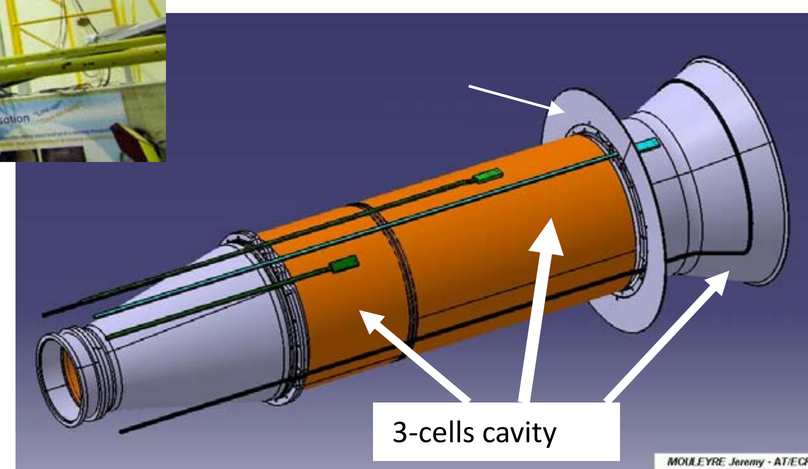
The demagnetization of the polarized target must induce another compensating mechanical angular momentum.

CERN’s 3-cells polarized target

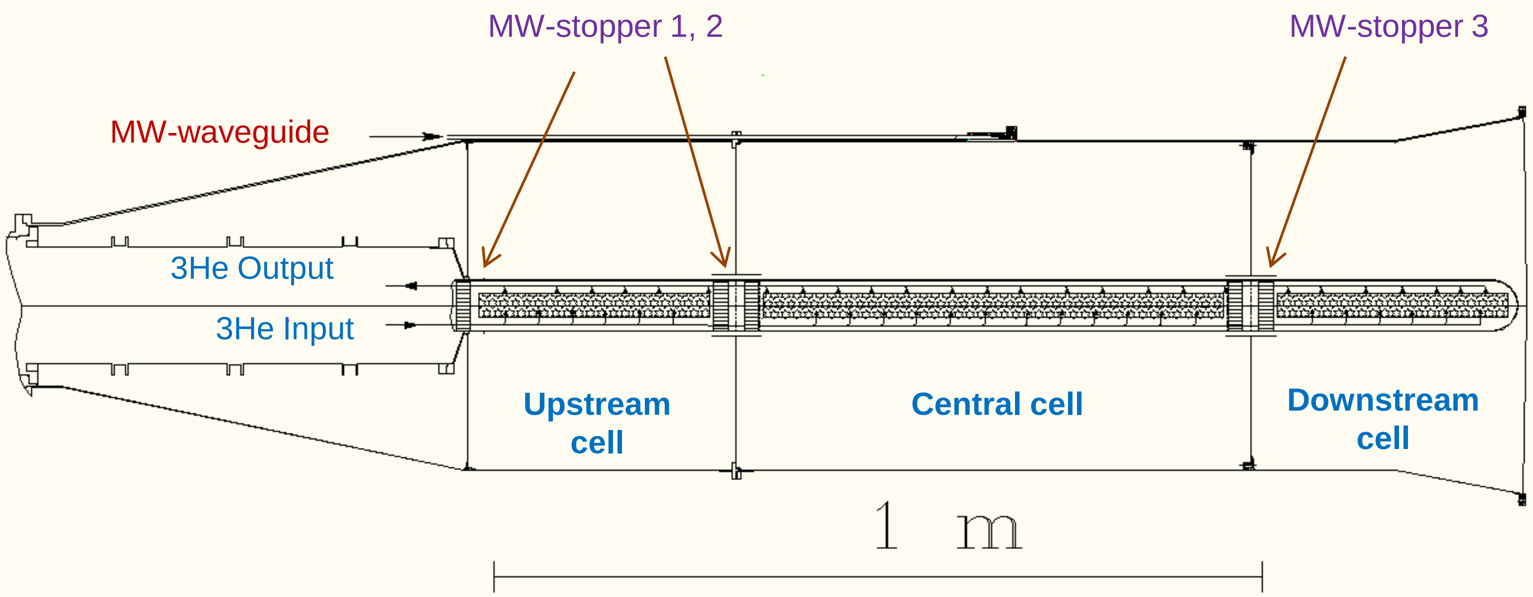


Dilution fridge

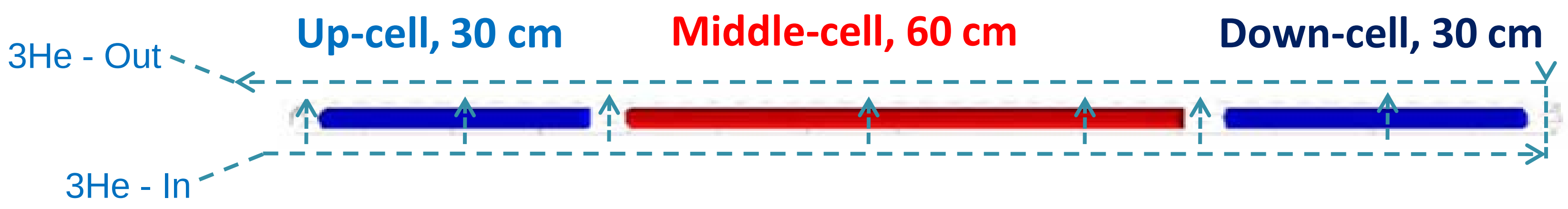
2.5 T Solenoid
& 0.6T dipole



3-cellsNH3- polarized target at CERN



1. Target **volume** of bout: 400+800+400 cm^3, **Surface** 1.5 m^2
2. **H (**solenoid) =2.5 T ±2·10^-5
3. **H (**dipole) 0.6 T ±5·10^-2
4. Microwave **frequency** 70 GHz
5. 3He-**inlet** and 3He-**Outlet**
6. MW-stoppers make the electrical isolation of cavities



The target consists of granulated crystalline ammonia (NH_3) loaded in three cylindrical cells .

The material is located in the mixing chamber of a 3He/4He dilution fridge and cools down at 100 mK.

3He atoms move under osmotic pressure inside the mixture. They go through the target material and are able to get contacts with polarized nuclei of ammonia.

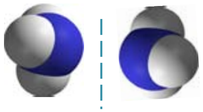
What are the ways and means for coupling between ammonia and

3He/4He mixture :

a. *Direct transport of angular moments from NH_3 to 3He nuclei

b. By excitation of lattice vibrations and excitation of 3He/4He mixture:

- **Translation  (from zero to some MHz),
- ***Torsion and Rotation degree of freedom (10^{13} Hz)
- *** Inversion degree of freedom ($3 \cdot 10^{13}$ Hz)



* Proposed by C.J. Gorter and B. Kahn

** F.P. Reding and D.F. Horning, J. Chem.. Phys. V 22, p.1926 (1954)

*** Ref: see C.H. Townes, A.L. Shawlow, Microvave Spectroscopy 1955.

We estimate the relaxation times for the average spin energy due to magnetic and quadrupolar interactions during cross-relaxation between proton and nitrogen spins.

Ed-d **- dipolar interaction energy between proton and nitrogen :**

$$E_{d-d} \approx \frac{\mu_P \mu_N}{\left\langle r_{PN}^3 \right\rangle_{d-d}} \approx \frac{1.4\cdot 10^{-23} * 2.0\cdot 10^{-24}}{\left\langle r_{PN}^3 \right\rangle_{d-d}} \approx \frac{3\cdot 10^{-47}}{\left\langle r_{PN}^3 \right\rangle_{d-d}}$$ (c.g.s)

Wq-q **- energy of quadrupolar interaction :**

$$W_{q-q} \approx \frac{e^2 Q \cdot \left\langle \left(3\cdot Cos^2\vartheta - 1\right)^2 \right\rangle_{\vartheta}}{4\cdot \left\langle r_N^3 \right\rangle} \approx \frac{\left(4.8\cdot 10^{-10}\right)^2 * 2.0\cdot 10^{-26}}{4\cdot \left\langle r_{PN}^3 \right\rangle_{d-d}} \frac{4}{5} \approx \frac{9\cdot 10^{-46}}{\left\langle r_{PN}^3 \right\rangle_{d-d}}$$

Assuming $\left\langle r_{PN}^3 \right\rangle_{d-d} \approx \left\langle r_N^3 \right\rangle_{q-q}$ we have :

$$\frac{T_{q-q}}{T_{d-d}} \approx \left(\frac{E_{d-d}}{W_{q-q}}\right)^2 \approx \left(\frac{3\cdot 10^{-47}}{9\cdot 10^{-46}}\right)^2 \approx 0.001$$

R.V. Pound, Phys. Rev. **79,** 685 (1950) ;
C.P. Slichter, Principles of Magnetic Resonance, Ch.5, Springer-Verlag Berlin Heidelberg New-York 1980.

So, if the relaxation time of magnetic energy is of about 1 hour, its relaxation over the quadrupolar interactions will lead to of about the

seconds!!!

At almost zero magnetic field the average quadrupole interaction energy <*Hq*> is proportional to the alignment *A(N)* of nitrogen spins:

$$\left\langle H_Q \right\rangle \approx h\nu_q \left\{3\cdot\cos^2\vartheta - 1\right\}\left\langle 3I_z^2 - I(I+1)\right\rangle = h\nu_q \left\{3\cdot\cos^2\vartheta - 1\right\} A(N)$$

$$A(N) = \left\langle 3I_z^2 - I(I+1)\right\rangle / I^2 = \left\langle 3m^2 - I(I+1)\right\rangle / I^2$$

Then, a change of alignment produces a transport of angular momentum from spin system to the lattice to conserve the total momentum.

This process could be realized in the proton-nitrogen cross-relaxation.

Let us go to the experiment!

At 0.2 K and 2.5 T homogeneous solenoid field the nuclear spins in ammonia were polarized by the DNP-method up to ±80 %.

Then our experiments were performed without use of external alternating fields.

At positive proton polarization:

Slowly sweeping up and down of the static field does not affect sensors

Observation:

At 0.03T the proton –nitrogen cross-relaxation takes place

As a result : Partial exchange of polarizations between Proton and Nitrogen spins

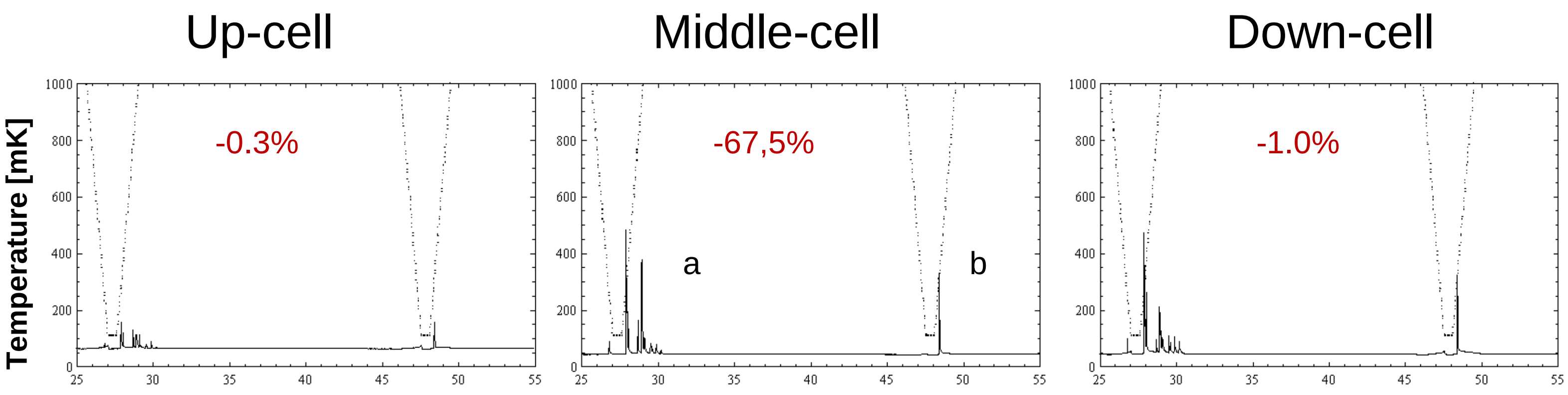
No any visible thermal effects coming from material !

See SMC experiments by B.Adeva et al. NIM in Phys. Res. A 419 (1998) 60-82;

Review by D.Edmonds, Phys. Rep. (Sec. C of Phys. Let. 29,N4 (1977) 233-290)

At positive polarization the cross-relaxation goes by adiabatic way without visible thermal effects coming from ammonia.

We wished to repeat the same tests at the negative nuclear polarizations.

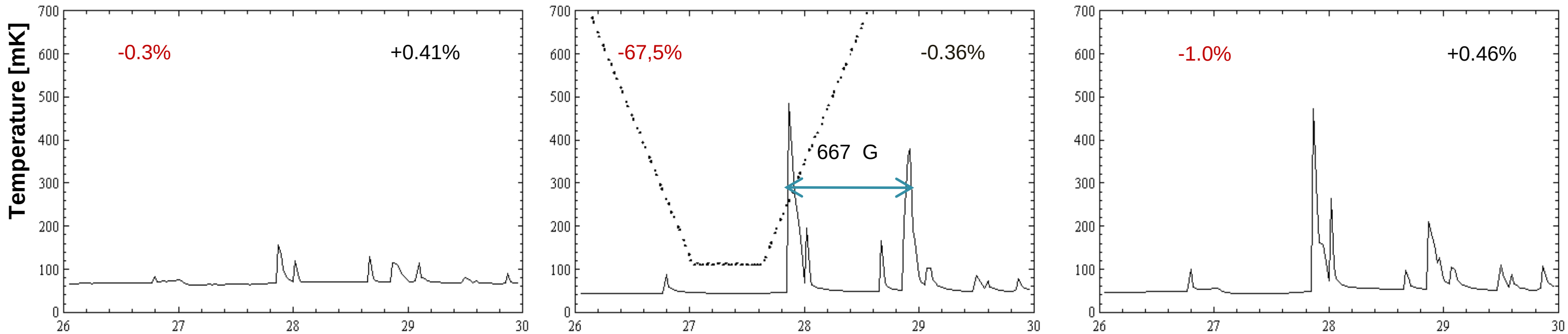


Time [Min] (bottom scale); Dotted lines: the dipole field in [G] (left scale)

1. The change of nitrogen alignment nearby 0.03 T field excites the lattice vibratory spectra. The plot shows an nondegenerating (a) and degenerated (b) magneto-mechanical spectra of 14N; the effect is absent at static field.

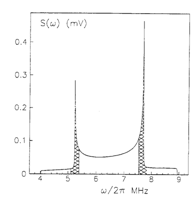
The vibratory spectra taken in the inhomogeneous field of dipole magnet

Up-cell | Middle-cell | Down-cell

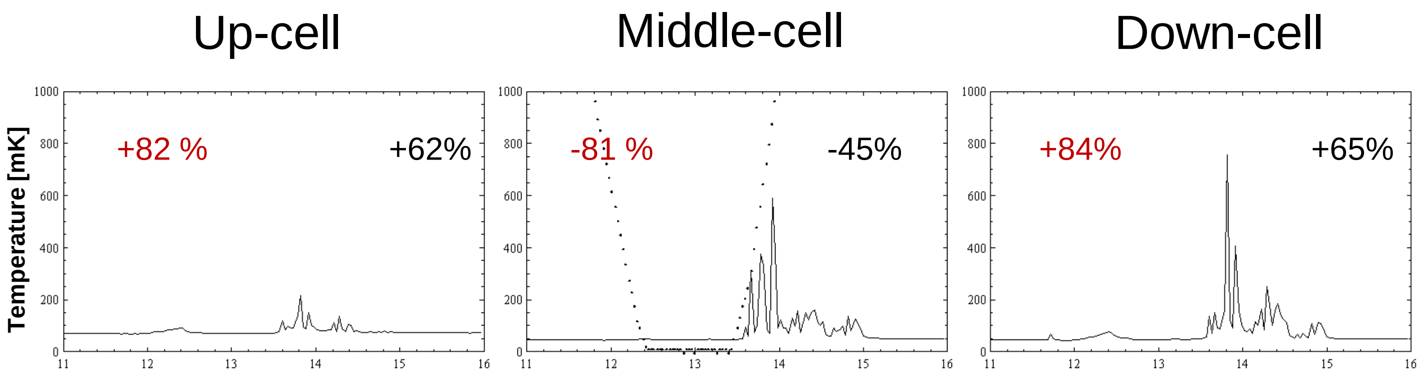


Time [Min] (bottom scale); Dotted line: the dipole field in [G] (left scale)

2. Vibratory excitations spread up and down from the middle sell arising the fast nuclear relaxation at the positively polarized Up and Down cells .



Estimation of the spectral resolution of the vibration spectra in the homogeneous solenoid field; **H (**solenoid) =0.03 T $\pm 2\cdot 10^{-5}$.



Time [Min] (bottom scale); Dotted line shows the solenoid field in [G] (left scale)

The spectral resolution of magneto-mechanical vibrations consists of about 0.1 MHz.

Summary

1. The nuclear magneto-mechanical effect was observed in the irradiated ammonia at superlow temperatures and at negative spin polarizations.
2. Nitrogen spins produce the lattice vibrations when their alignment is being varied at the proton-nitrogen cross-relaxation.
3. Lattice vibrations are transmitted by 3He/4He mixture; they are detected by thermometers and made faster the relaxation of positively polarized protons.
4. Evidence was produced, that a presence of quadruple nuclei in the polarized target materials makes shorter the relaxation time at negative polarization as compared with positive polarizations.
5. By the same reason, the negative polarization could be higher than the positive one due to its faster built-up at superlow temperature.

Thank you!