Title: Special Guest Talk - 'The serendipitous road to a Nobel prize'

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THE SERENDIPITOUS ROAD TO A NOBEL PRIZE

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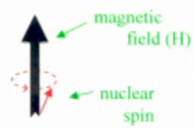
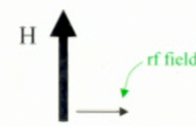
NUCLEAR MAGNETIC RESONANCE

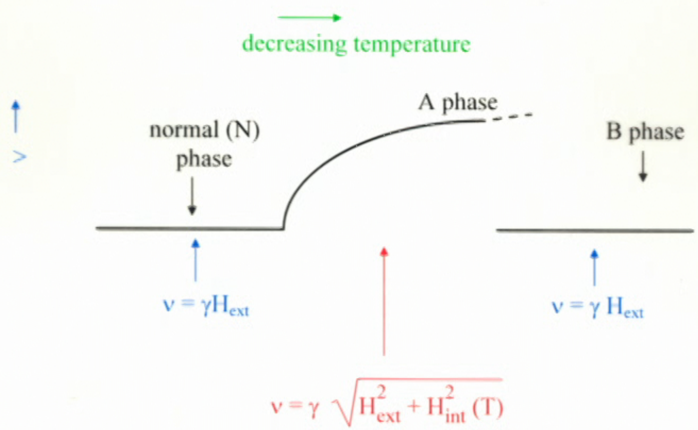


Rate of "precession"
$\nu = \gamma H$
"gyromagnetic ratio"

γ is known, (in ^{3}He, ~ 3 kHz/gauss)
so, rate of precession (ν) measures magn. field (H)
To measure ν, apply
oscillating (r.f.) field $\perp$ H:
field is strongly absorbed when its frequency is ν.



NMR IN LIQUID ^{3}He BELOW 3mK:



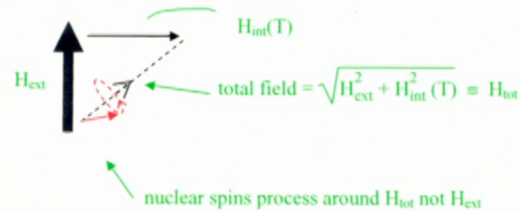
What is going on? (in context of possible Cooper pairing, no-one had thought about NMR at all…)

THE ^{3}HE NMR PUZZLE (cont.)

In A phase, precession freq. ν is larger than value (γH_{ext}) in N phase, and given be expression of form

$$\nu = \gamma \sqrt{H_{ext}^2 + H_{int}^2(T)}$$

Simplest interpretation:



Problem:

Only possible origin of H_{int} (T) is other nuclear spins

Max. value of field of one nuclear spin on another (at distance of closest approach of atoms) < 1 gauss.

But, experimental value of $H_{int}(T)$ is ~ 30 gauss!

FIRST EVIDENCE FOR BREAKDOWN OF QUANTUM MECHANICS?

RESULT OF MORE SOPHISTICATED APPROACH:

A. Simple classical argument too naive.

(no "transverse" internal field)

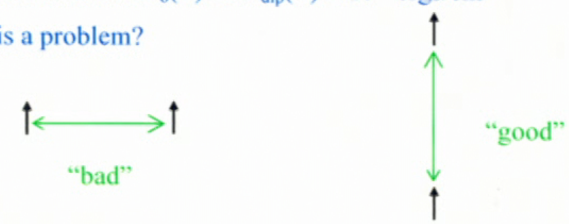
B. Nevertheless, indeed predict formula

$$\nu = \gamma \sqrt{H_{ext}^2 + H_o^2(T)}$$

where $H_o^2(T)$ is proportional to average value of nuclear dipole interaction energy $E_{dip}(T)$.

Experimental value of $H_o(T) \rightarrow E_{dip}(T) \sim 10^{-3}$ ergs/cm^3

Why is this a problem?



— energy difference (ΔE) between "good" and "bad" orientations $< 10^{-7}$ K per pair.

— thermal energy (E_{th}) ($= k_B T$) $\sim 10^{-3}$ K.

$\Rightarrow$ preference for "good" orientation over "bad" only $\sim \Delta E/E_{th} < 10^{-4}$

$\Rightarrow$ resulting value of $E_{dip}(T)$ much too small to fit experiment.

Need preference for "good" over "bad" ~ 1 not $\sim \Delta E/E_{th}$!

$\Rightarrow$ many sleepless nights in late June 1972...

SPONTANEOUSLY BROKEN SPIN-ORBIT SYMMETRY:

the analogy with ferromagnetism

FERROMAGNET

H_{ext} ↑ ↑ good ↓ bad

difference in energy per spin = ΔE (small)

Above Curie temp. ("paramagnetic" phase), spins behave independently ⇒ thermal energy E_{th} competes with ΔE ⇒ polarization only ~ $\Delta E/E_{eth} \ll 1$

Below T_c ("ferromagnetic" phase): strong (exchange) forces constrain all spins to lie parallel:

↑↑↑↑↑... or ↓↓↓↓↓...

"good" "bad"

$E_{good} - E_{bad} \sim N\Delta E \gg E_{th}$

⇒ polarization ~ 1

LIQUID ^{3}HE

good ↑↑ bad ↑↑

difference in energy per pair ≡ $\Delta E < 10^{-7}$ K

In normal phase, pairs behave independently ⇒ E_{th} competes with ΔE ⇒ "polarization" (pref. for good orientation over bad) only ~ $\Delta E/E_{th} \ll 1$.

In A phase, assume: strong (kinetic-energy, VDW) forces constrain all pairs to behave in same way ⇒ either all "good" or all "bad"

$E_{good} - E_{bad} \sim N\ \Delta E \gg E_{th}$ (N ~10^{23}!)

⇒ polarization can be ~ 1

But… what would make all pairs of nuclear spins behave in the same way?

A possible answer: Cooper pairs form and undergo Bose condensation! (then must all behave in exactly the same way, including internal (relative) configuration)

Spring of 1973: 1-month visit to Cornell U. (thanks to Bob Richardson)

serendipity no. 4: Kyoto work on 2-band superconductors plays vital role!

⇒ detailed microscopic theory explained existing data and predicted inter alia: behavior in longitudinal NMR experiment

No such experiments existed, but done in summer of 1974 by Doug Osheroff, confirms theoretical prediction.

Another crucial theoretical development in spring 1973: Anderson-Brinkman theory of stability of A phase (difficult to understand in "naïve" BCS theory).