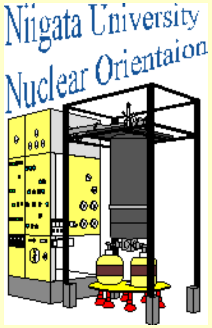

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NMR-ON study of ^{197}Pt*Ni*

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NMR-ON study

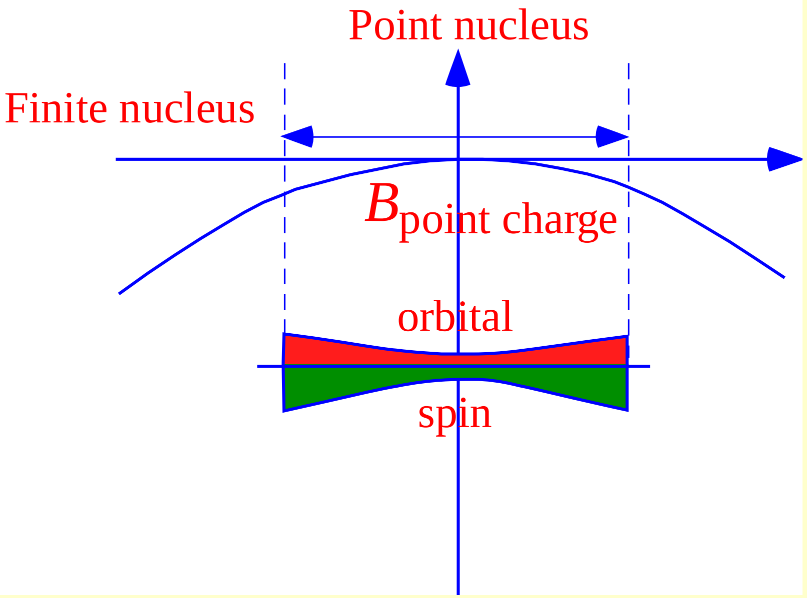
- Low-temperature nuclear orientation is useful to get a polarized unstable nuclei system.
- Nuclear magnetic resonance of oriented nuclei (NMR-ON) has been widely applied in the study of the electromagnetic properties of unstable nuclei and hyperfine interactions of dilute impurities in ferromagnetic metals.

Hyperfine anomaly

Magnetic Hyperfine interaction of a nuclear state with magnetic moment distribution $\mu(r)$ in a magnetic hyperfine field with radial distribution $B_{\mathrm{hf}}(\mathrm{r})$

$$-\mu B_{\mathrm{hf}} = -\int \mu(r)\, B_{\mathrm{hf}}(r)\mathrm{d}r = -\mu B_{\mathrm{hf}}(0)(1+\varepsilon)$$

single-level anomaly(ε): deviation from the point-dipole interaction (Bohr-Weisskopf effect)



Hyperfine anomaly $^{1}\Delta^{2}$

$$\frac{-\mu_1 B_{\mathrm{hf}\,1}}{-\mu_2 B_{\mathrm{hf}\,2}} = \frac{\nu_1}{\nu_2} = \frac{g_1}{g_2}\left(1 + {}^{1}\Delta^{2}\right)$$

$${}^{1}\Delta^{2} = \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} \sim \varepsilon_1 - \varepsilon_2$$

Bohr Weisskopf effect

$$\frac{\nu^{(1)}}{\nu^{(2)}}\frac{\mathrm{g}^{(2)}}{\mathrm{g}^{(1)}}=1+{}^{1}\Delta^{2}=\frac{1+\varepsilon^{(1)}}{1+\varepsilon^{(2)}}\approx 1+\varepsilon^{(1)}-\varepsilon^{(2)}$$

Anomaly factor (single particle model)

$$\varepsilon_{\text{s.p.}}=-\left[\alpha_S\left\{b_2\left(1+\tfrac{2}{5}\zeta\right)\left\langle\left(\frac{R}{R_N}\right)^2\right\rangle_{\text{s.p.}}+b_4\left(1+\tfrac{4}{7}\zeta\right)\left\langle\left(\frac{R}{R_N}\right)^4\right\rangle_{\text{s.p.}}\right\}\right.$$

$$\left.+\alpha_L\left\{\tfrac{3}{5}b_2\left\langle\left(\frac{R}{R_N}\right)^2\right\rangle_{\text{s.p.}}+\tfrac{3}{7}b_4\left\langle\left(\frac{R}{R_N}\right)^4\right\rangle_{\text{s.p.}}\right\}\right]$$

Anomaly factor including core polarization and mesonic current effects (Fujita Arima)

$$\varepsilon=-0.62b_S\left\langle\left(\frac{R}{R_N}\right)^2\right\rangle_{VN}-0.38b_S\left\langle\left(\frac{R}{R_N}\right)^2\right\rangle_{VN}$$

$$\times\frac{1}{\mu}\left\{\pm g_s{}^{\mathrm{VN}}\frac{3\left(I+\frac{1}{2}\right)}{4\left(I+1\right)}+\frac{3}{4}\frac{g_s{}^{\mathrm{VN}}}{\left(g_s-g_l\right)^{\mathrm{VN}}}\left(\mu-\mu_{\text{s.p.}}-\delta\mu_{\text{mes}}\right)\right\}$$

***b_s*:** **electron coefficients**

***R/R_N*:** **radial integrals of nucleus**

(H.H.Stroke and R.J.Blin-Style, PR123(61)1326

NMR in ferromagnetic metal (Fe, Ni,..)

Resonance frequency (magnetic interaction)

$$\nu = \frac{g\mu_N}{h}\left(B_{hf} + (1+K)B_0\right)$$

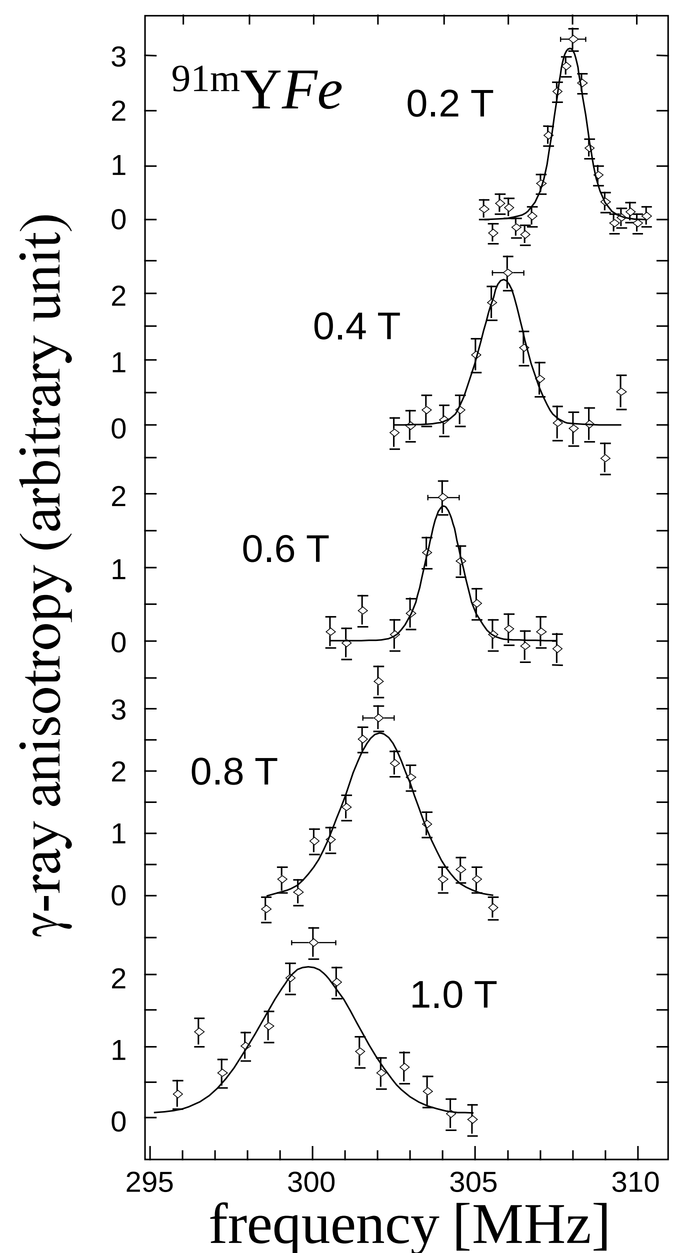
$$= \nu_0 + \frac{d\nu}{dB_0} \cdot B_0$$

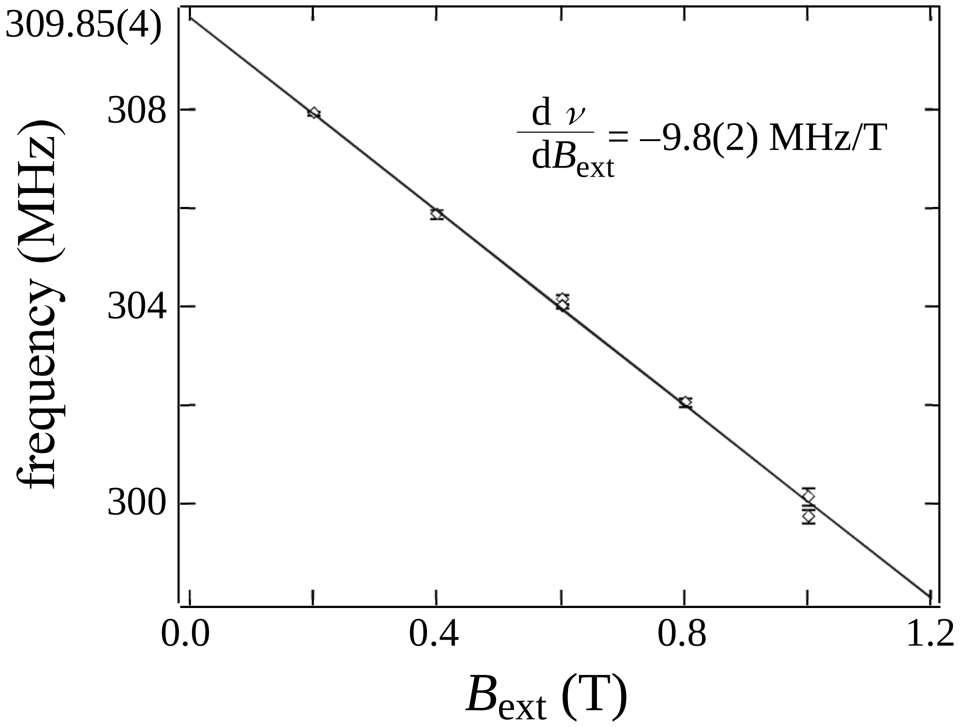
HFA

no or very small deference between isotopes

$${}^{1}\Delta^{2} = \frac{\nu_0^1}{\nu_0^2} \frac{d\nu_2 / dB_0}{d\nu_1 / dB_0} - 1$$

Hyperfine anomaly of Yttrium isotopes





^{91}Y(1/2$^-$), ^{91m}Y(9/2$^+$)

$$\frac{g_1}{g_2}=\frac{d\nu_1/dB}{d\nu_2/dB}$$

$^{91}\Delta^{91m}$ = –4.2(8) %

Platinum isotope

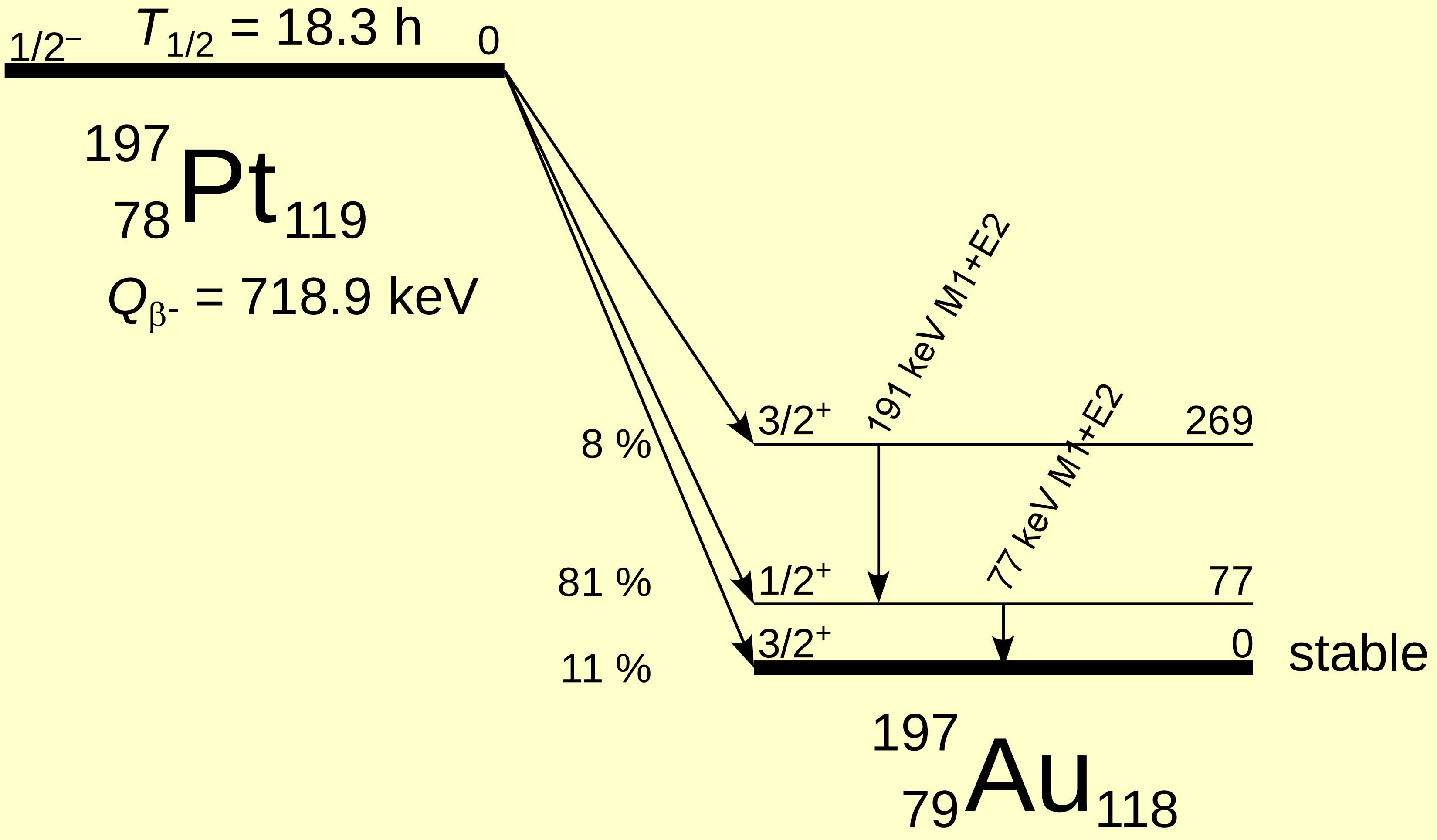
Nucleus	I^{π}	$T_{1/2}$	μ (μ_N)
^{191}Pt	$3/2^-$	2.9d	–0.494(8)
^{195}Pt	$1/2^-$	stable	+0.60952(6)
^{197}Pt	$1/2^-$	18.3h	0.51(2)

^{191}Pt*Ni*: $\nu_0 = 84.349(4)$ MHz

$d\nu/dB = -2.449(8)$ MHz/T

G. Seewald et al.: Phys. Rev. B66, 174401, (2002)

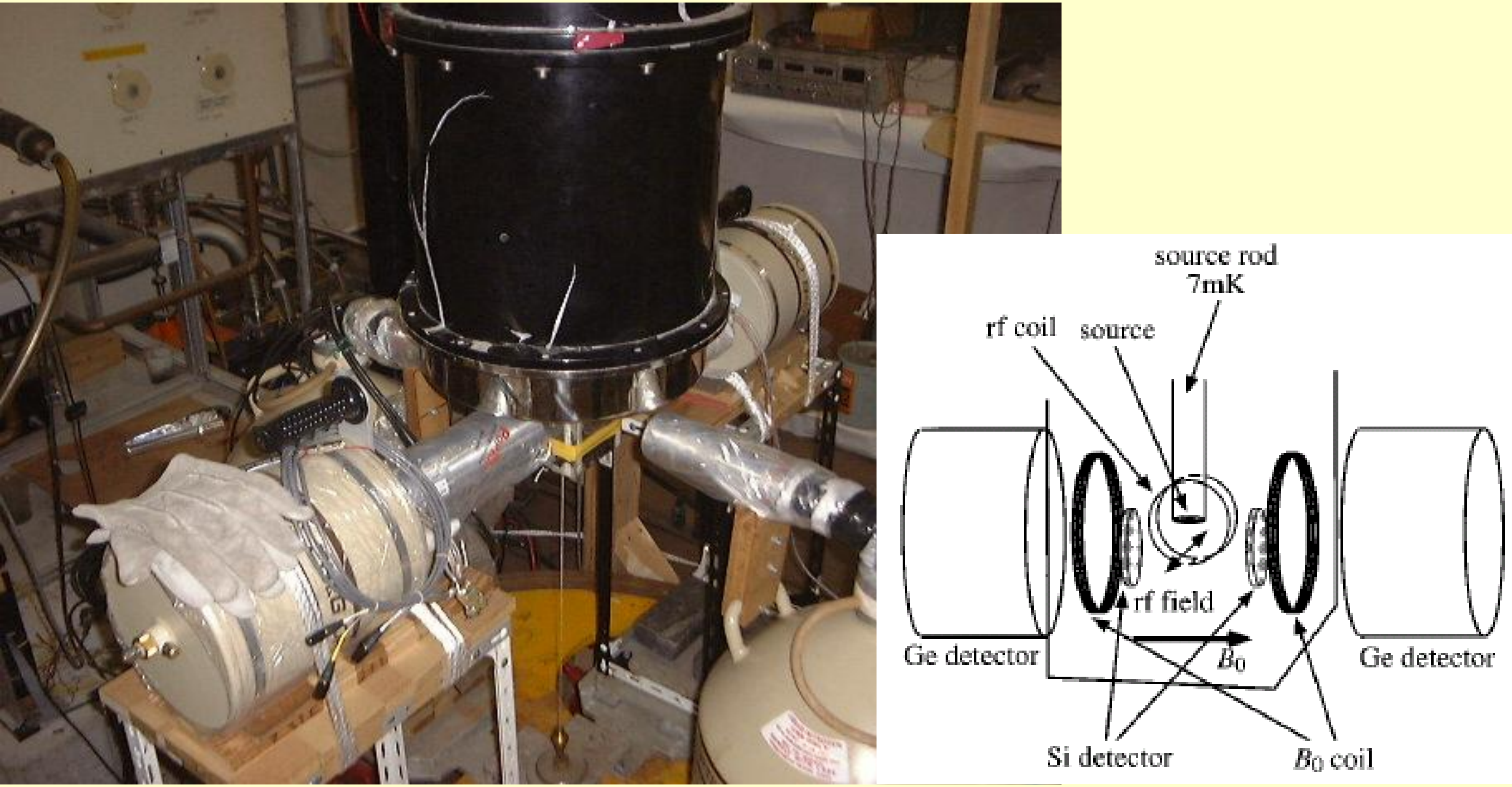
Decay scheme of ^{197}Pt



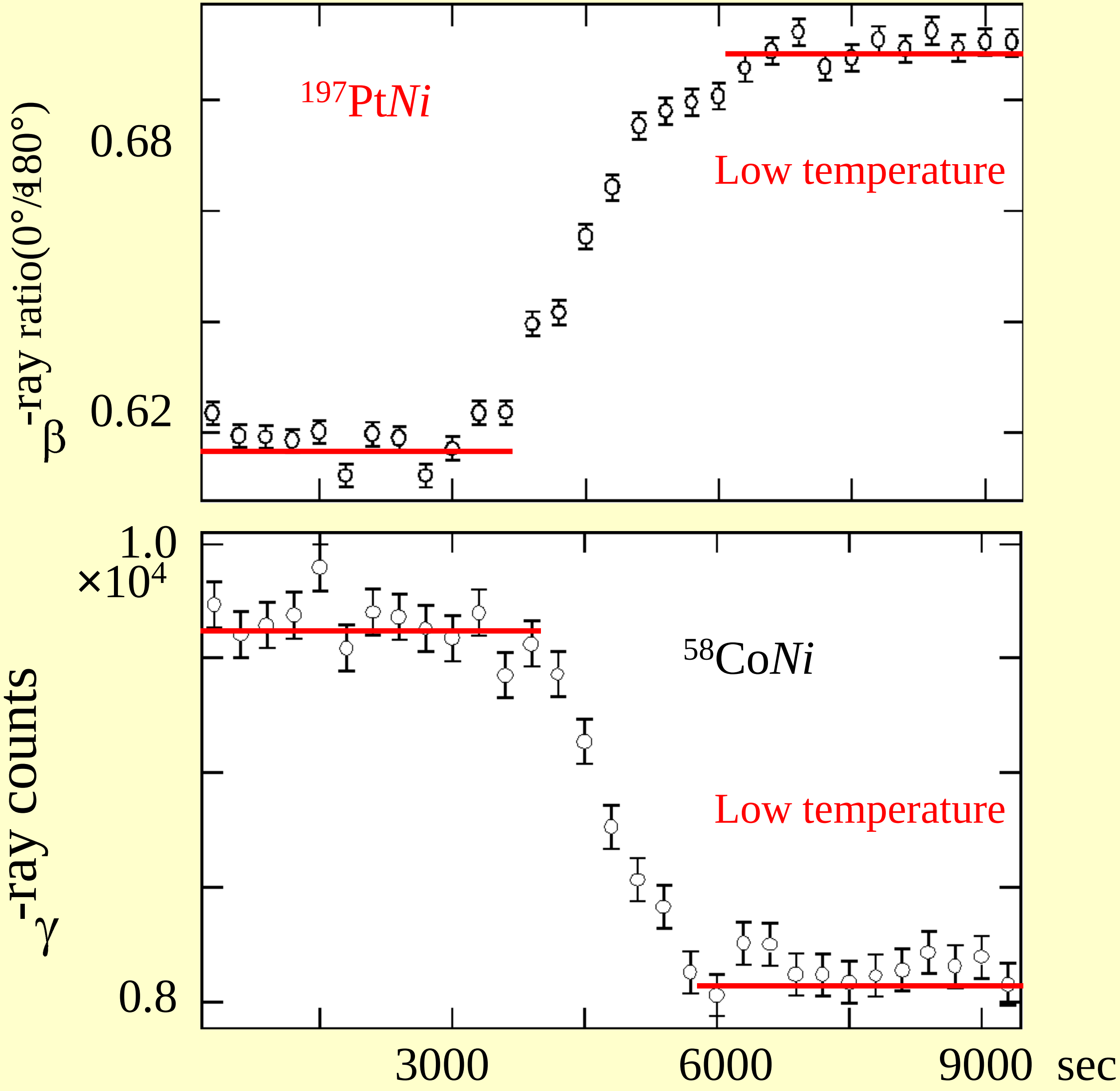
Sample preparation

- The samples of ^{197}Pt*Ni* were prepared by the thermal neutron irradiation method.
- Thin alloy foils of Pt*Ni* (0.1 at. % of the 96 % enriched ^{196}Pt, 2.6μm thickness) were irradiated in a reactor at the Japan Atomic Energy Research Institute.
- After irradiation, the sample was annealed in vacuum for 30min. at 800°C.

$^{3}He/^{4}He$ dilution refrigerator



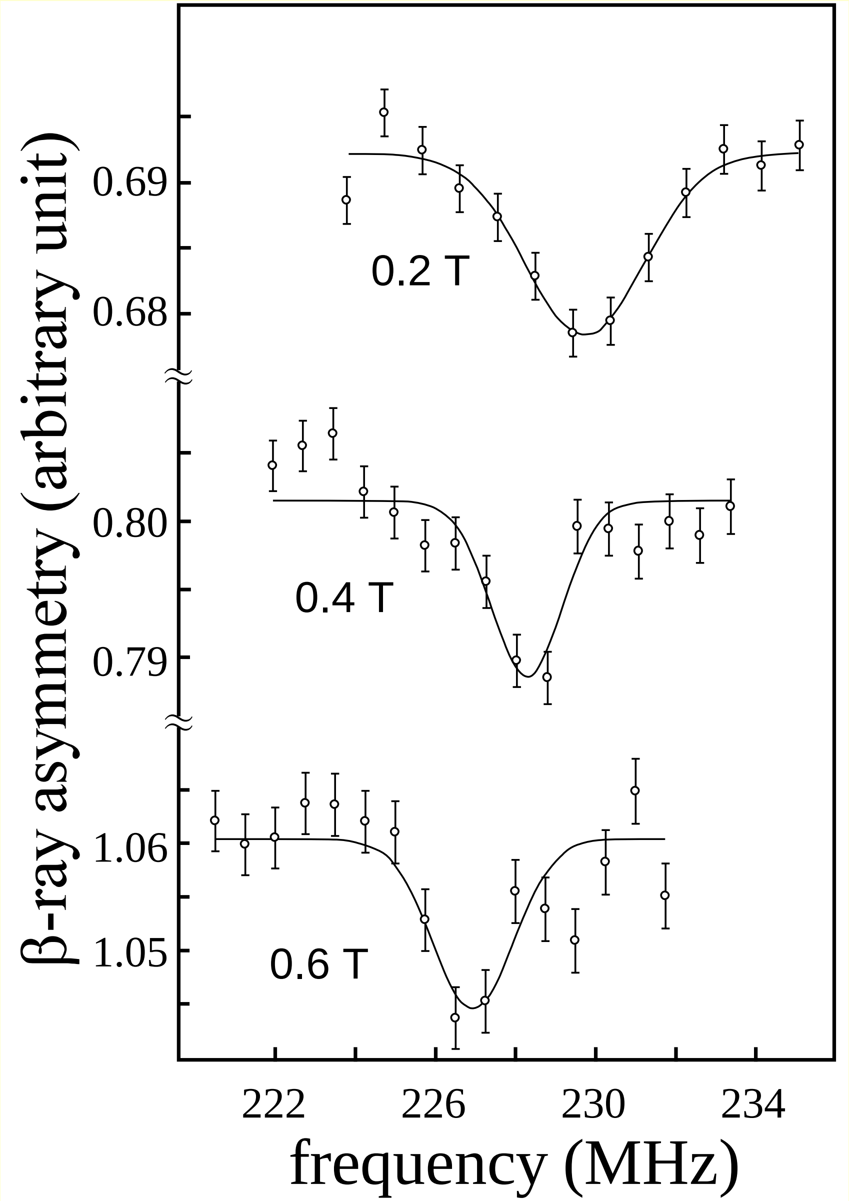
Cool down to 7 mK

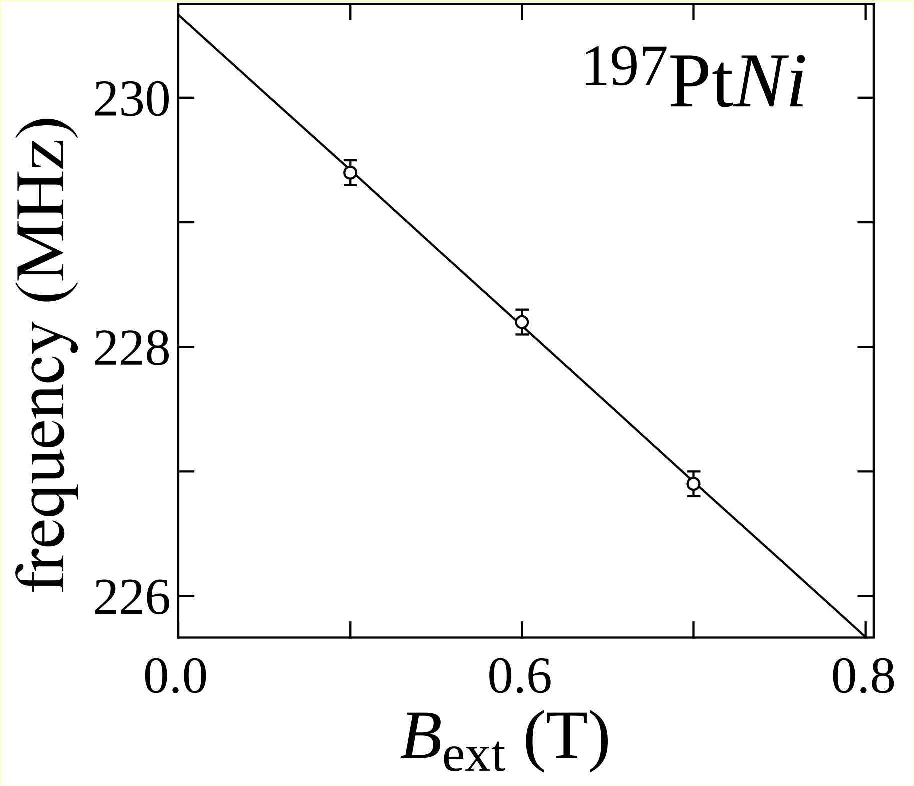


asymmetry
1.12(1)

anisotropy
0.844(3)
↓
7 mK

NMR-ON $^{197}\mathrm{Pt}\mathit{Ni}$



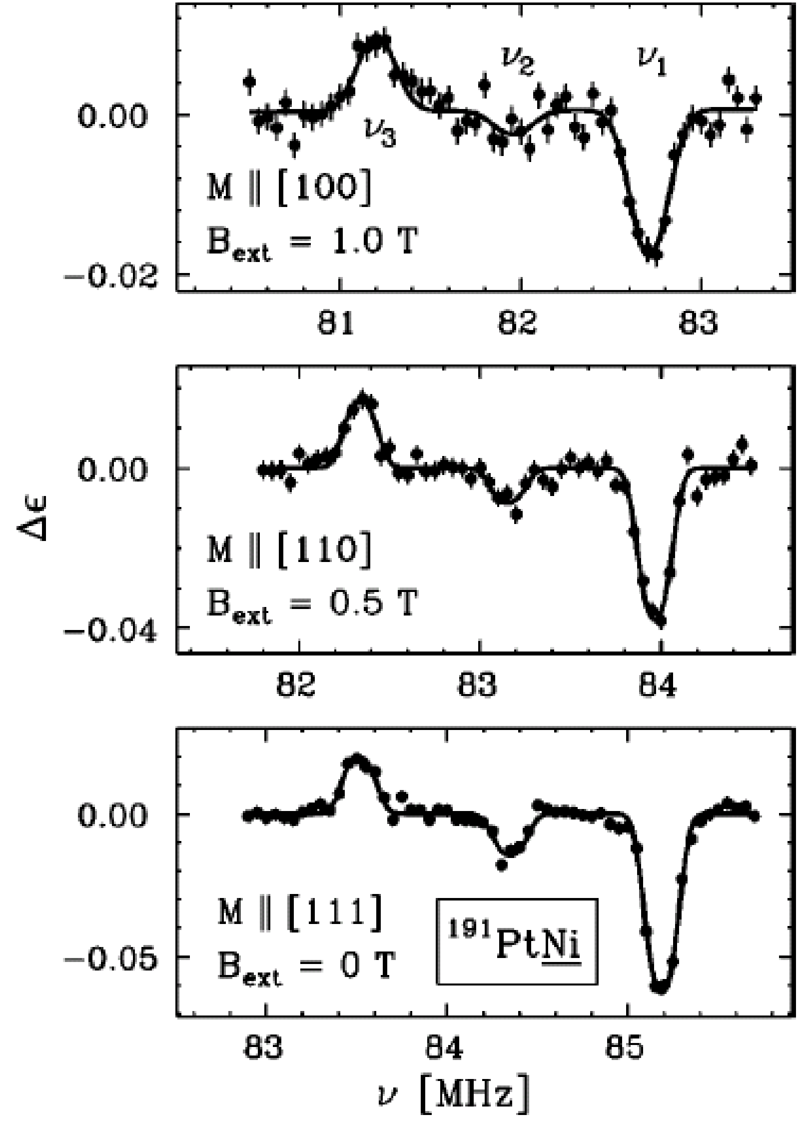


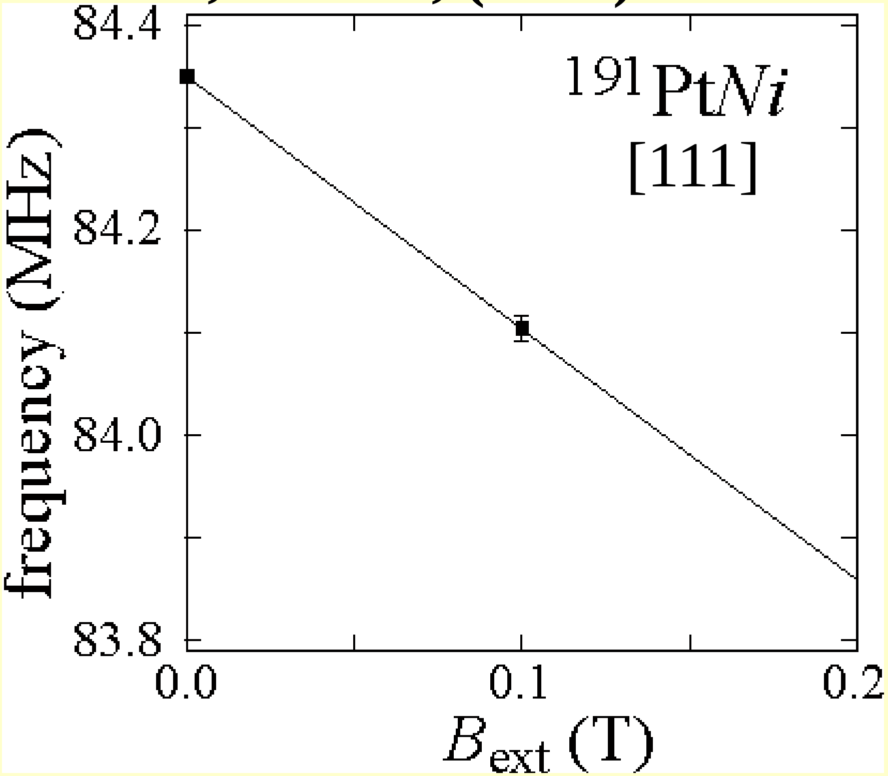
$\nu_0 = 230.7(2)$ MHz

$\mathrm{d}\nu/\mathrm{d}B = -6.2(5)$ MHz/T

NMR-ON study for ^{191}Pt*Ni* (Munich Univ.)

G. Seewald et al.: Phys. Rev. B66, 174401, (2002)





$\nu_0 = 84.349(4)$ MHz

$d\nu/dB = -2.449(8)$ MHz/T

Hyperfine anomaly ${}^{191}\Delta^{197}$ method 1

	I^{π}	ν_0(MHz)	g-factor
${}^{197}\mathrm{Pt}\mathit{Ni}$	$1/2^{-}$	230.7(2)	1.02(4)
${}^{191}\mathrm{Pt}\mathit{Ni}$	$3/2^{-}$	84.349(4)	0.329(3)

$$ {}^{191}\Delta^{197} = \frac{\nu_0^{191}}{\nu_0^{197}} \frac{g({}^{197}Pt)}{g({}^{191}Pt)} - 1 = \underline{+13(2)\%} $$

single particle	+0.2%	Phys. Rev. 123, 1316 (1961)
core polarization	-0.6%	Nucl. Phys. A254, 513 (1975)

Hyperfine anomaly ${}^{191}\Delta^{197}$ method 2

	I^{π}	ν_0(MHz)	dν/dB(MHz/T)
${}^{197}\mathrm{Pt}Ni$	$1/2^-$	230.7(2)	–6.2(5)
${}^{191}\mathrm{Pt}Ni$	$3/2^-$	84.349(4)	–2.449(8)

$$ {}^{191}\Delta^{197} = \frac{\nu_0^{191}}{\nu_0^{197}} \frac{{}^{d\nu}\!/_{dB}\left({}^{197}\mathrm{Pt}Ni\right)}{{}^{d\nu}\!/_{dB}\left({}^{191}\mathrm{Pt}Ni\right)} - 1 = \underline{-7(7)\%} $$

single particle	+0.2%	Phys. Rev. 123, 1316 (1961)
core polarization	-0.6%	Nucl. Phys. A254, 513 (1975)

Even though a large error, but consistent with theoretical calculations

Hyperfine anomaly $^{195}\Delta^{197}$ (same I^{π})

	I^{π}	ν_0(MHz)	g-factor
^{197}Pt*Ni*	$1/2^{-}$	230.7(2)	1.02(4)
^{195}Pt*Ni*	$1/2^{-}$	316.0(65)*	+1.2190(1)

*M. Kontani and J. Itoh: J. Phys. Soc. Japan 22 345, (1967)

$$^{195}\Delta^{197} = \frac{\nu_0^{195}}{\nu_0^{197}} \frac{g(^{197}Pt)}{g(^{195}Pt)} - 1 = \underline{+15(5)\%}$$

If we use the known magnetic moment of ^{197}Pt, the hyperfine anomaly between ^{195}Pt and ^{197}Pt is very large, even though they have same spin-parity. The known magnetic moment of ^{197}Pt should be wrong.

Magnetic moment of ^{197}Pt

- The known value of ^{197}Pt (0.51(2) μ_N) was measured by the atomic beam method. It was reported by Y.W. Chan, *et al*. in Bulletin of the American Physical Society 13, No.6, 895 CE14(1968), but it was not published.
- Using the known hyperfine field of ^{195}Pt*Ni* (–34(7) T) and the present result, the magnetic moment of ^{197}Pt can be deduced as:

$$\mu(^{197}\mathrm{Pt}\text{: } 1/2^{-}) = 0.45(1)\ \mu_N.$$

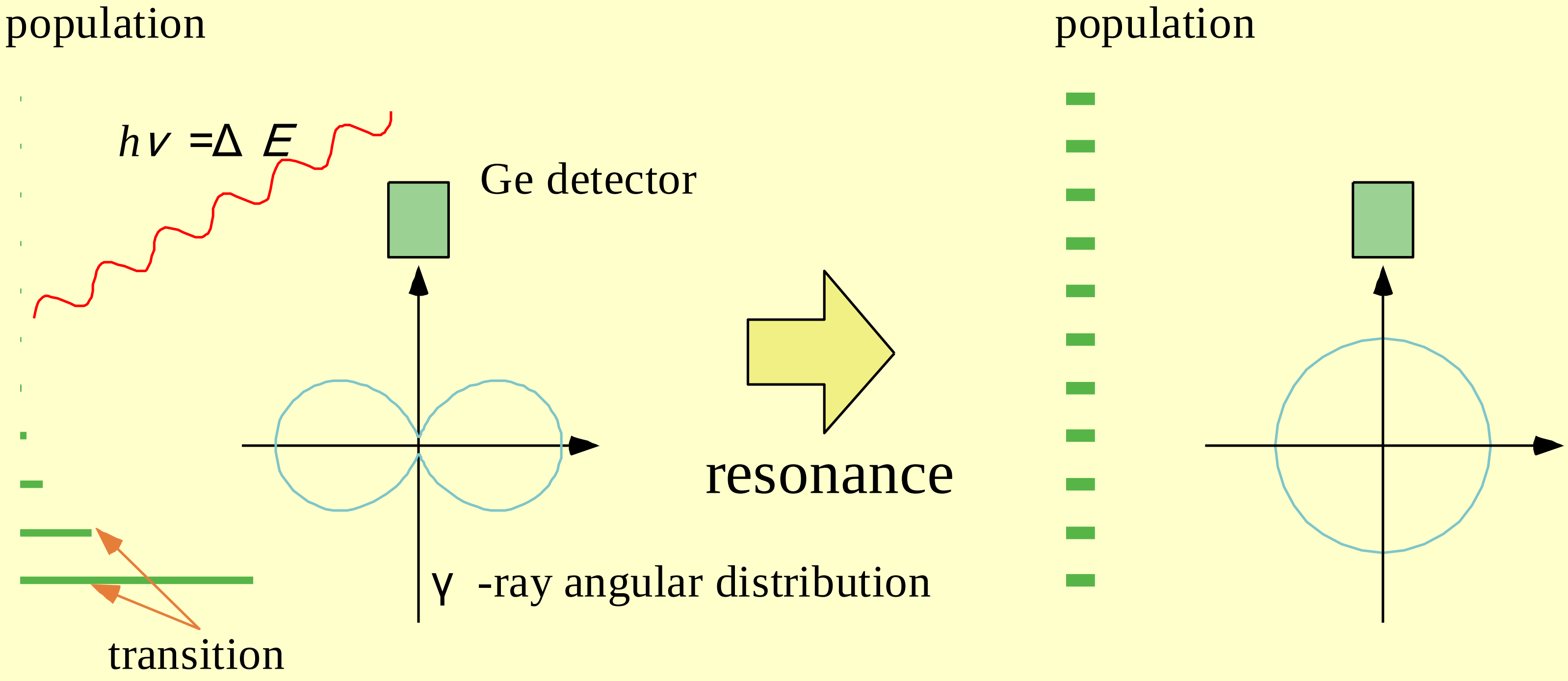
where we ignore the hyperfine anomaly $^{195}\Delta^{197}$ because they have same spin-parity. Using this value, the hyperfine anomaly $^{191}\Delta^{197}$ can be deduced:

$$^{191}\Delta^{197} = 0(2)\ \%.$$

Summary

- We observed the NMR-ON spectra of $^{197}\mathrm{Pt}Ni$.
- Comparing with the result of $^{191}\mathrm{Pt}Ni$, we deduce the hyperfine anomaly $^{191}\Delta^{197} = +13(2)\%$. This value is too large. The known magnetic moment of $^{197}\mathrm{Pt}$ should be wrong.
- Using the known $B_{\mathrm{hf}}(^{195}\mathrm{Pt}Ni)$, the magnetic moment of $^{197}\mathrm{Pt}$ is deduced as: $\mu(^{197}\mathrm{Pt}) = 0.45(1)\ \mu_{\mathrm{N}}$.
- Using this new value, the hyperfine anomaly is $^{191}\Delta^{197} = 0(2)\ \%$.

Low temperature nuclear orientation
(NMP–ON)



population

$h\nu = \Delta E$

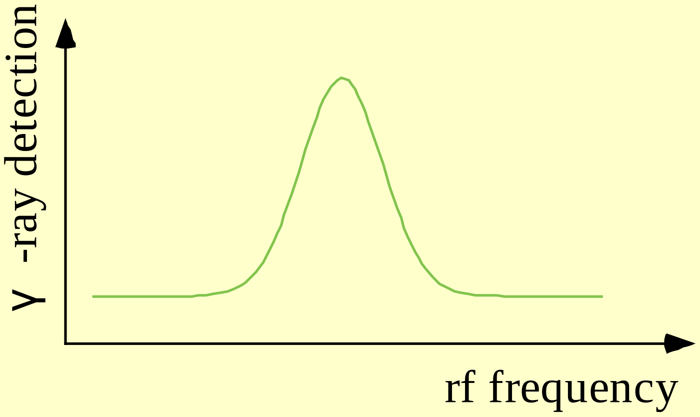
Ge detector

transition

γ -ray angular distribution

resonance

population

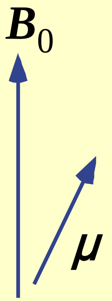


γ -ray detection

rf frequency

Low temperature nuclear orientation
(NMP–ON)

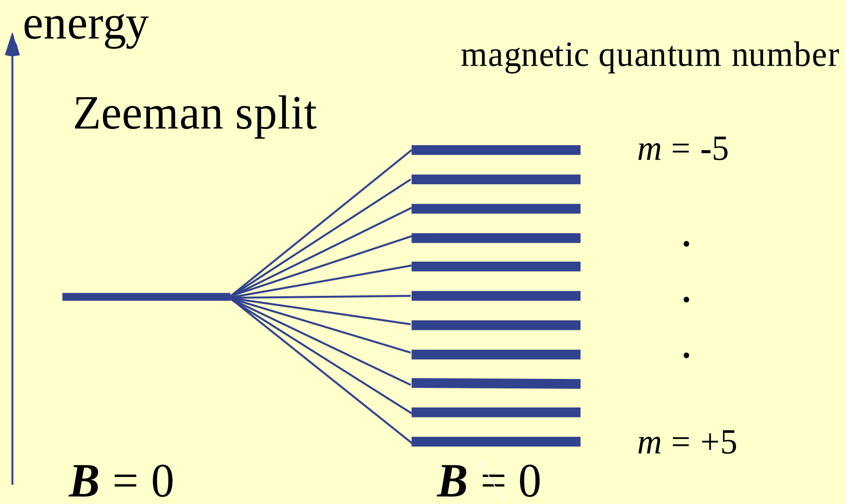
Magnetic Interaction

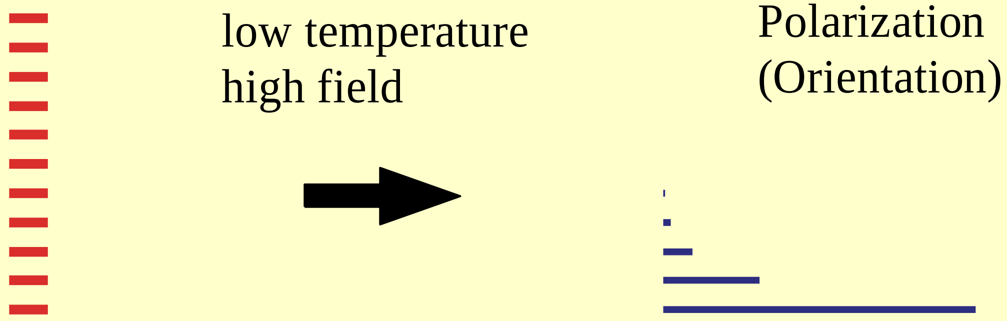


$$\mathcal{H} = -\boldsymbol{\mu} \cdot \boldsymbol{B}$$
$$= -g\mu_N \boldsymbol{I}\cdot \boldsymbol{B}$$
$$= -g\mu_N \boldsymbol{B}_0\boldsymbol{I}_z$$

$$E_m = \langle m|\mathcal{H}|m\rangle$$
$$= -g\mu_N \boldsymbol{B}_0 m$$

$I = 5$ case





low temperature
high field

Polarization
(Orientation)

Population $a_m \propto e^{-E_m/kT}$ Boltzmann ditribution

External field dependence of $^{91}\mathrm{Y}Fe$ and $^{91\mathrm{m}}\mathrm{Y}Fe$