NMR spectroscopy

basics and applications

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NMR spectroscopy and applications

Recommended literature

Hornak: http://www.cis.rit.edu/htbooks/nmr/bnmr.htm
P. J. Hore: NMR spectroscopy
Atkins: Physical Chemistry
M. Levitt: Spin Dynamics
Keeler: Understanding NMR spectroscopy

?

What is NMR spectroscopy?
What do we measure?
How do we measure?
How do we choose optimal conditions for the given purpose?
Sample preparation
Basic NMR knowledge/parameters
Applications: analytical chemistry (pharma, food industry)

I. The basics in nutshell

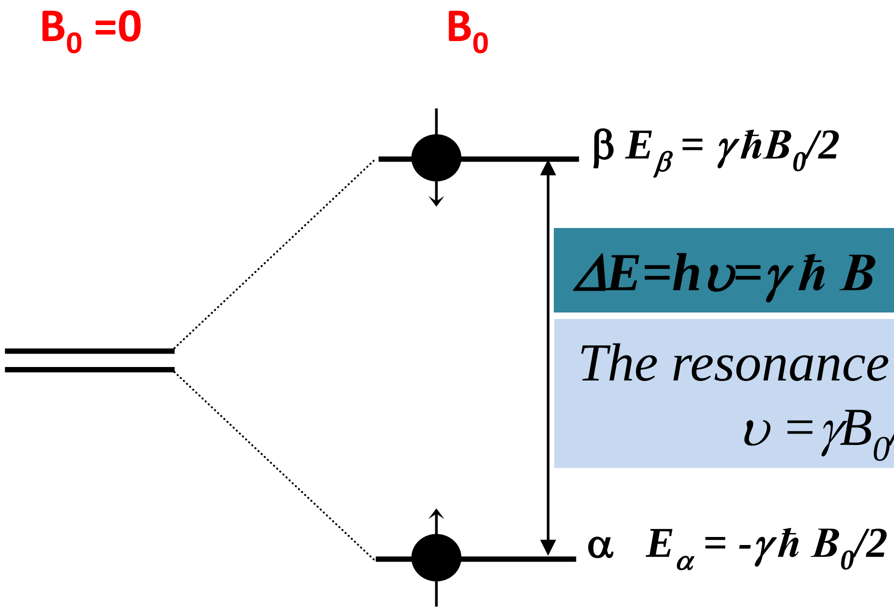
In the presence of the $\mathbf{B_0}$ magnetic field the *z* component of the magnetic moment will be:

$$\mu_z = \gamma I_z = \gamma m\hbar$$

The energy:

$$E = -\mu_z B_0 = -\gamma m\hbar B_0$$

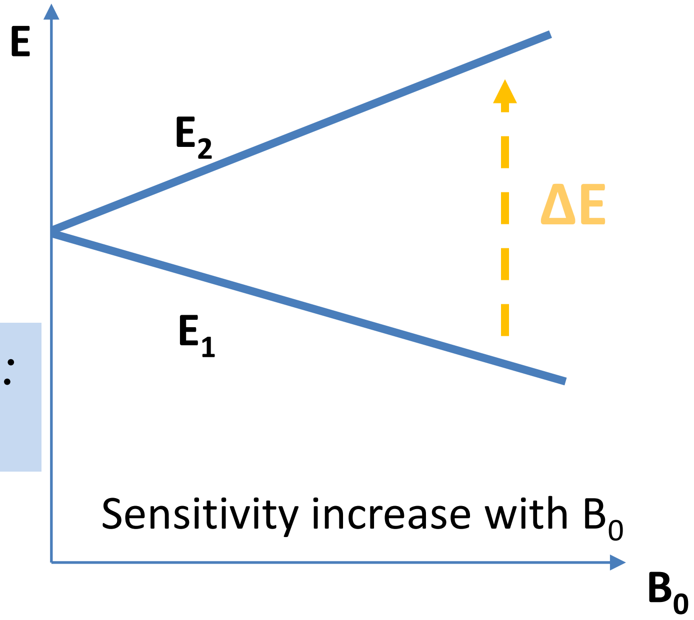
For a spin ½ nucleus there are two orientations (1/2; -1/2) and therefore two energy levels (E_α,E_β) .



$$\Delta E = h\upsilon = \gamma\hbar B$$

The resonance condition:

$$\upsilon = \gamma B_0/2\pi$$



Sensitivity increase with B_0

How easy is to measure a given nuclei?

Influencing factors: magnitude of the magnetic field, the natural abundance of the isotope, the giromagnetic ratio, the spin quantum number

$$\upsilon = \gamma B_0 / 2\pi$$

Nucleus	I	γ 10^7 rad $T^{-1}s^{-1}$	υ (B_0 =11,74 T) MHz	Natural abundance, %
^{1}H	½	26,7	500,00	99,98
^{13}C	½	6,73	125,72	1,108
^{14}N	1	1,93	36,118	99,63
^{15}N	½	-2,71	50,66	0,37
^{17}O	5/2	-3,63	67,78	$3{,}7 \cdot 10^{-7}$
^{23}Na	3/2	7,07	132,25	100
^{27}Al	5/2	6,97	130,28	100
^{29}Si	1/2	-5,32	99,32	4,7
^{31}P	½	10,84	202,40	100
^{43}Ca	7/2	-1,78	33,64	0,145
^{51}V	7/2	7,05	131,44	99,76
^{59}Co	7/2	6,30	44,68	100
^{103}Rh	½	-0,84	15,73	100
^{113}Cd	½	-5,96	110,91	12,26
^{195}Pt	½	5,83	85,99	33,8
^{205}Tl	½	15,69	230,83	70,5
^{19}F	½	25,18	470,3	100

II. The spectrometer

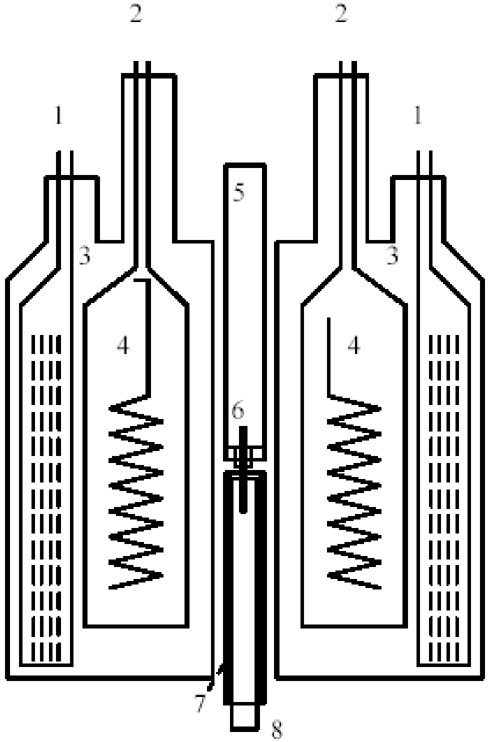
Superconducting magnet: B0

Probe-head: transmitter to generate B1 and receiver to detect the NMR signal

Preamplifier: magnifies the weak NMR signal

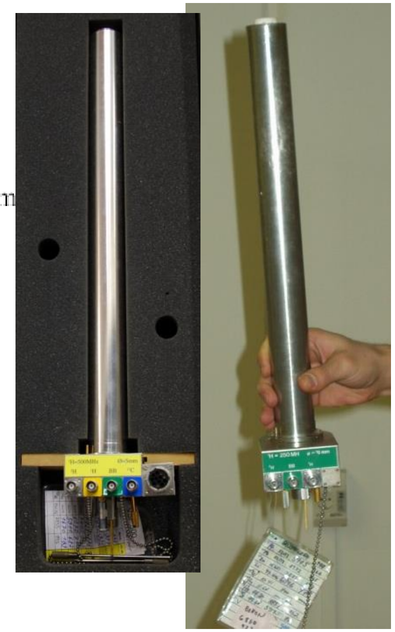
Shim-coil; Temperature controller

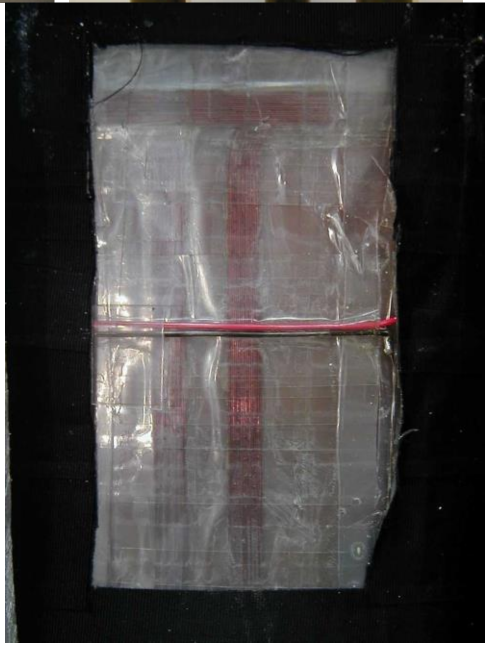
Analog-to-digital controller



1 Ports for liquid N_2
2 Ports for liquid He
3 Superinsulation and high vacuum
4 Main magnet coils + liquid helium
5 Sample lift and spinner assembly
6 NMR tube
7 Shim assembly
8 Probe-head

Fig. 1.1 Principles of a superconducting magnet





Magnets and magnetic field strength

500 MHz (11,7T), ELTE

700 MHz (16,4T), Prodigy , ELTE

Our newest investment: the industrial standard

400 MHz (9,3T), with sample changer, automated, ELTE

Probe-heads

´broadband´ : 1H, 19F and X nuclei

BBI (broadband inverse) inner coil 1H, outer coil X

BBO inner coil X (typically covering the 31P-15N frequency domain

dual probe-heads

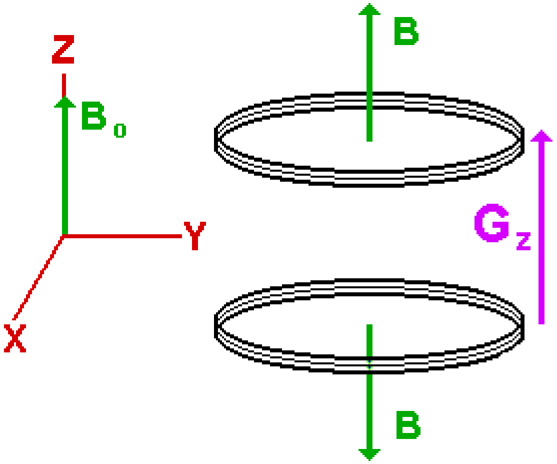
QNP: 1H, and 13C/19F/31P

Cryogenic probe-heads: the coil and the electronics are cooled

N2 cooling open system(Prodigy)

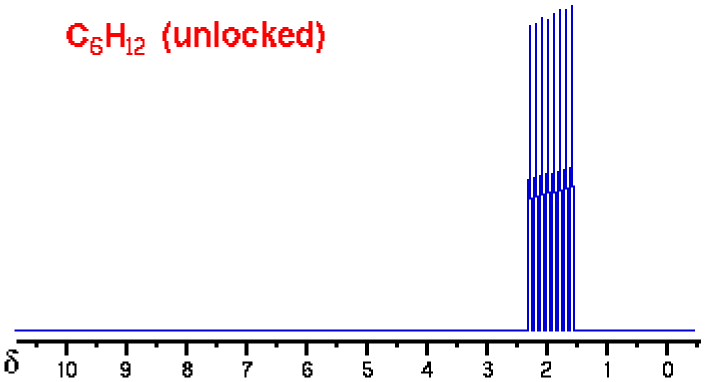
He cooling closed system (cryo)

Gradients: most common the z-gradient coil



The lock channel (^2H)

Sample contains deuterated solvent

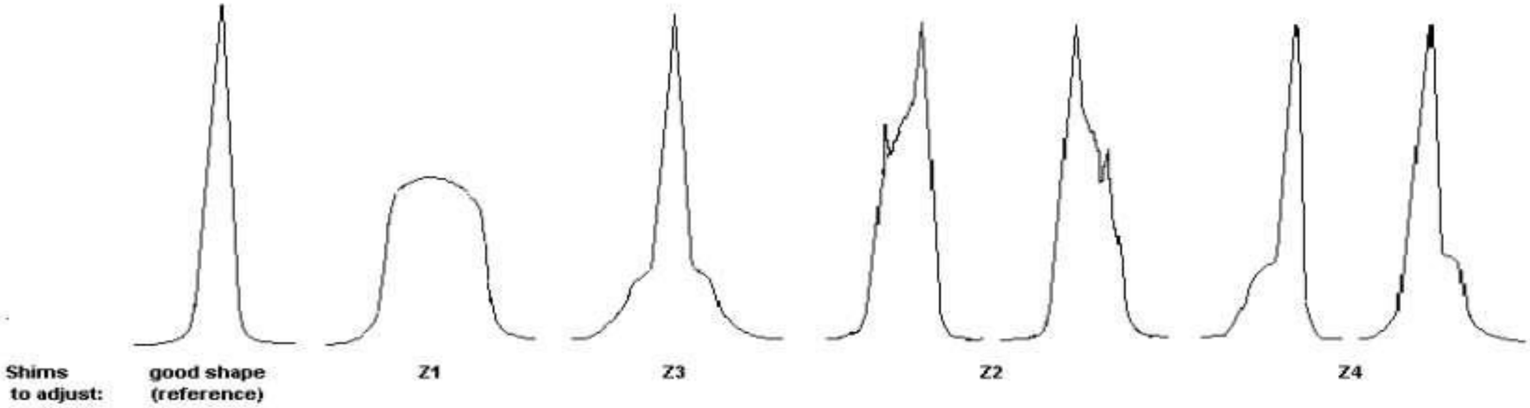


The shim coils

Arranged in various geometries

Variable current in the coils, that allow fine tuning the homogenity of the field around the sample: Z1-Z8, X, Y, XY..., X2-Y2, XY2...

Shim distorsion appears on ALL peaks of the spectrum!



Sample tubes

Most common:

5mm tube (OD)

normal tube: 500-600 µl

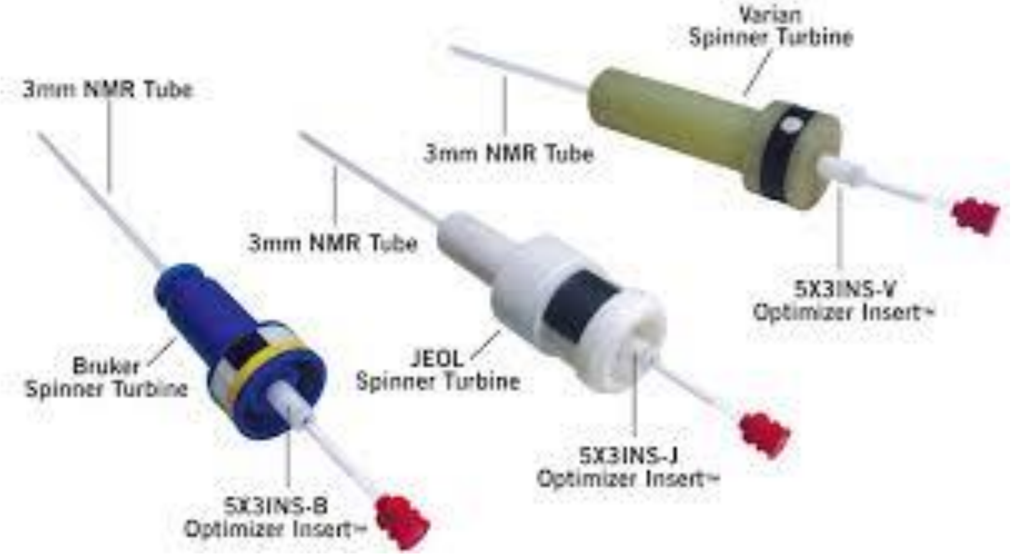
Shigemi tube: 280 µl

(special for each solvent

10 mm tube: cca 2 ml sample

3mm tube: 150 µl

2mm tube: max 50 µl



Field availability

1.2GHz 700MHz 500MHz 250MHz 10MHz

400MHz 80MHz 20MHz

?

Low field instrumentation

Permanent magnets

Compact instruments: little or no maintenance is needed

Small! No need for special room, huge space.

10, 20, 40, 60, 80 MHz

Relaxometers:

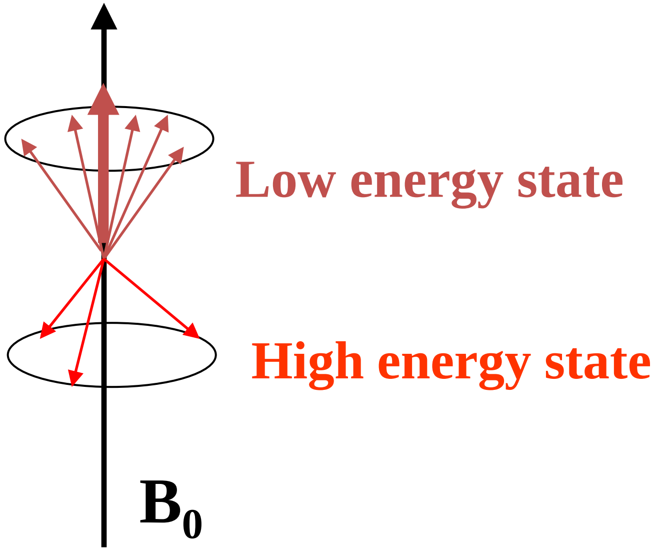
T2 relaxation measurements

1D/2D measurements

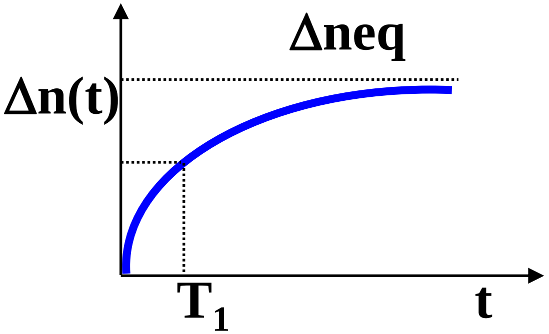
^{1}H, ^{19}F
^{31}P
^{13}C

NMR-MOUSE (Mobile Universal Surface Explorer)
inhomogeneous field
portable

III. Basics: The longitudinal relaxation time (T_1)



Real *thermodynamical equilibrium*.

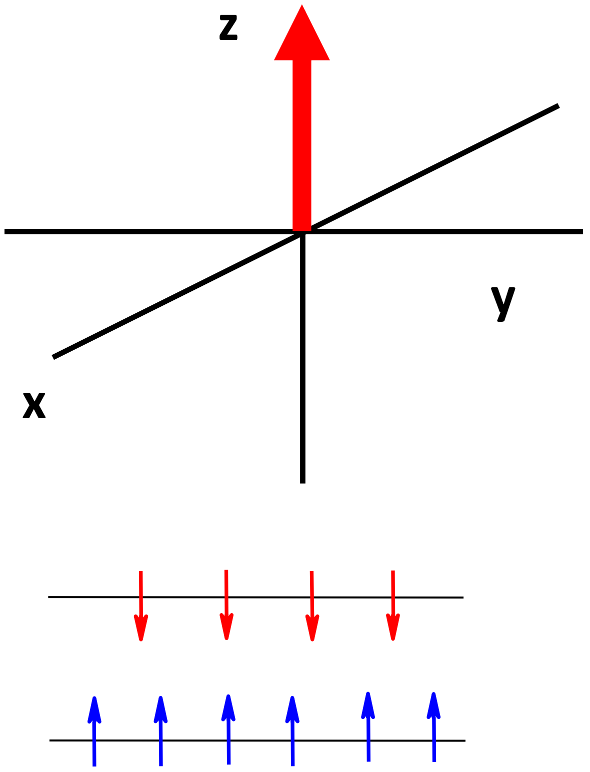


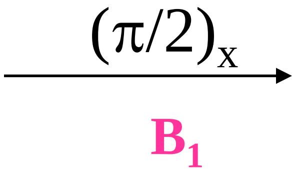
Reaching the equilibrium population difference Δn_{eq} is not instantaneous !!!
For a spin ½ nucleus:

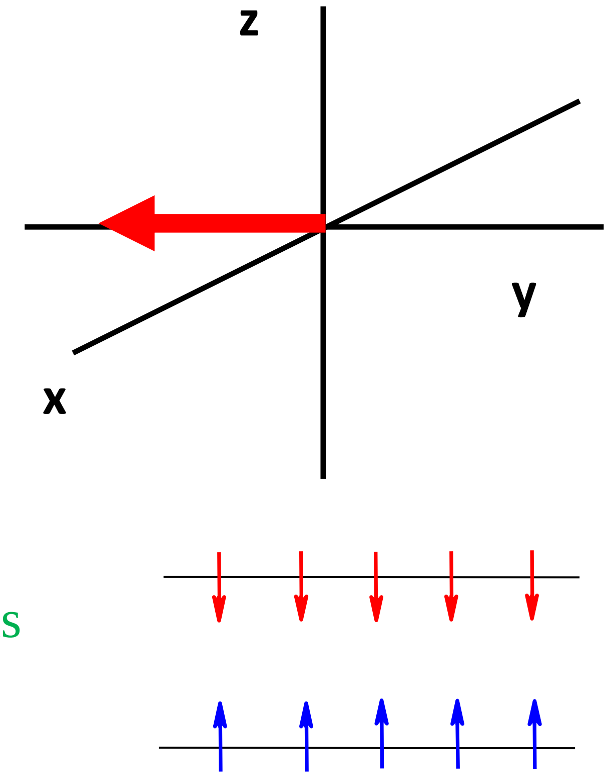
$$\Delta n(t) = \Delta n_{eq}[1-\exp(-t/T_1)]$$

☞ T_1 ms-s order. Depends on the nuclei, the solution composition, the viscosity, measurement temperature, etc.
☞ Longitudinal, or spin-lattice relaxation time

Excitation with the B_1 field







Flip angle: β

$\beta = \gamma B_1 t_p$

t_p time of the pulse (s)

Typical 90° pulse lengths

8-10μs

equilibrium

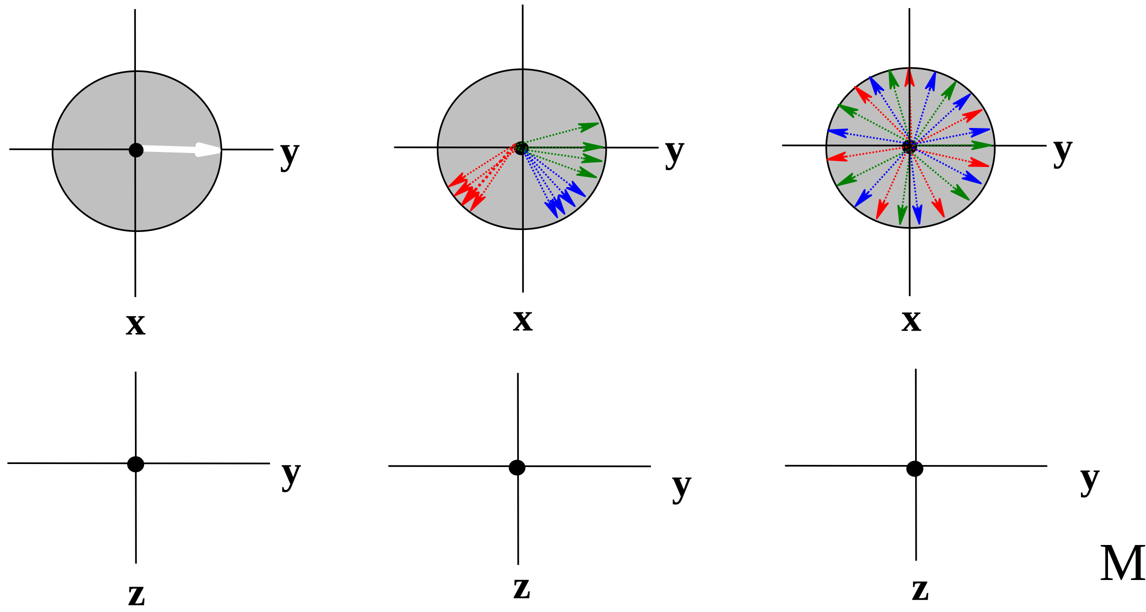
$M_0=M_z$

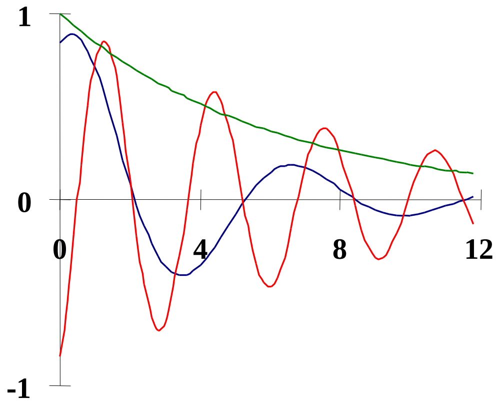
excited state

$M_0=M_y$

Transverse relaxation time (T_2)

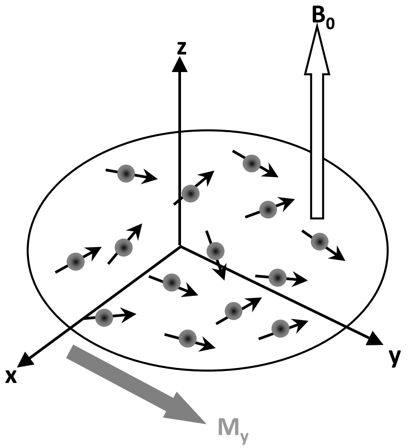
What happens to the M_y magnetisation?



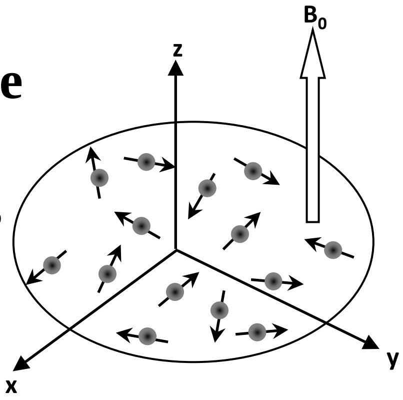


$$M_x = -M_0 \sin(\omega_0 t) \exp(-t/T_2)$$

$$M_y = -M_0 \cos(\omega_0 t) \exp(-t/T_2)$$

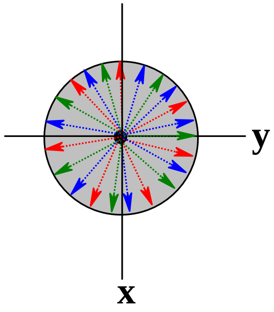


The *phase coherence* in the *xy* plane is lost
Analogy: clocks

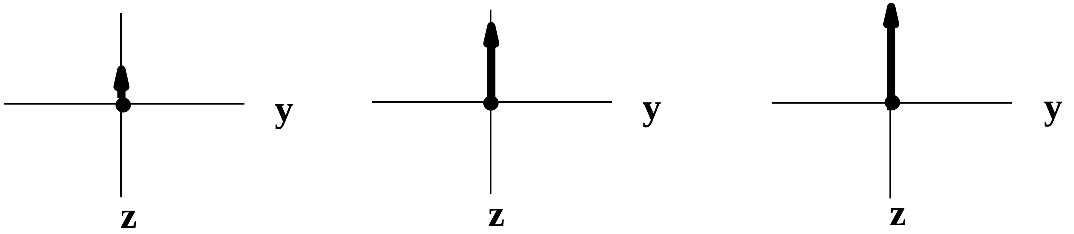


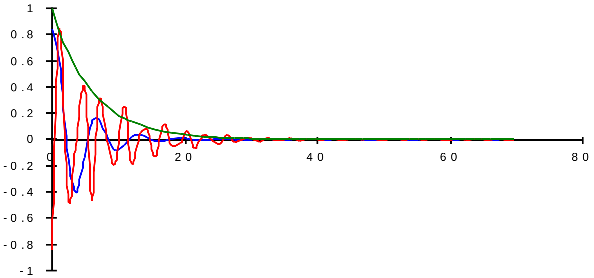
Spin-spin relaxation time, small molecules
$T_2 \leq T_1$,
proteins $T_2 \approx$ ms

The longitudinal relaxation time (T_1)



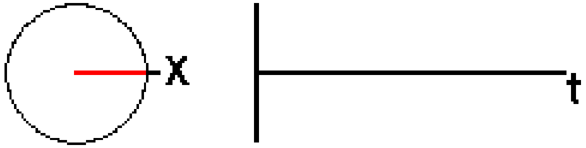
- The magnetization is built-up in the *z* dimension
- Slower than the transverse relaxation
- It is a highly important feature of quantitative NMR



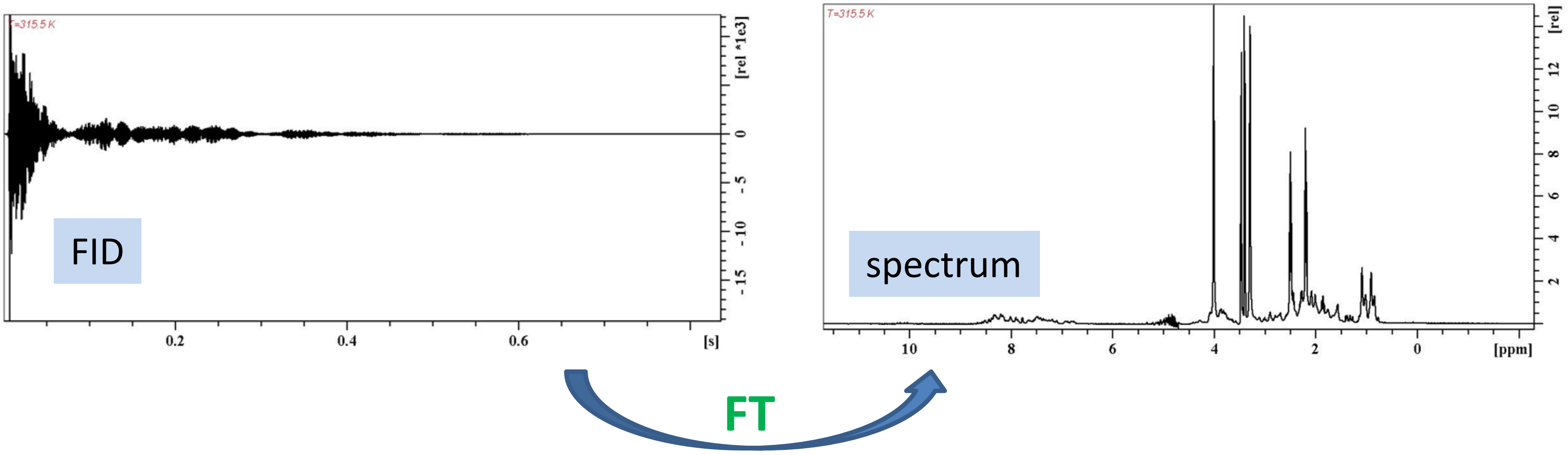


Fourier transformation, the NMR signal!

If a receiver coil is placed near the sample in the *xy* plane then the receiver detects the signal during the acquisition time

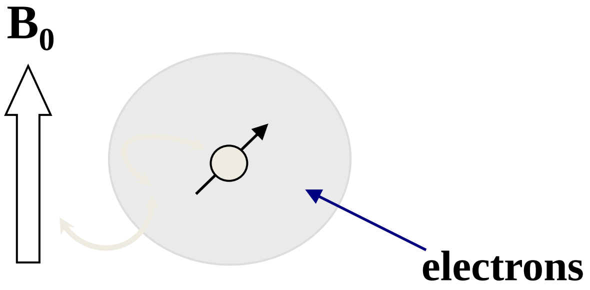


This signal is the FID (*F*ree *I*nduction *D*ecay)
The Fourier transform of this siggnal-time curve
is a signal-frequency variation called *spectrum*.



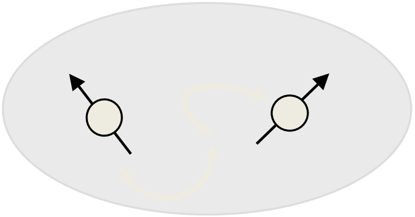
IV. Interactions between spins

1. The chemical shift



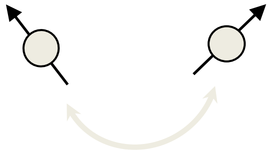
Indirect magnetic interaction between the B0 field and the spins via the electron cloud.

2. J coupling



Indirect magnetic interaction between the spins via their electron clouds. Spin-spin coupling via chemical bonds.

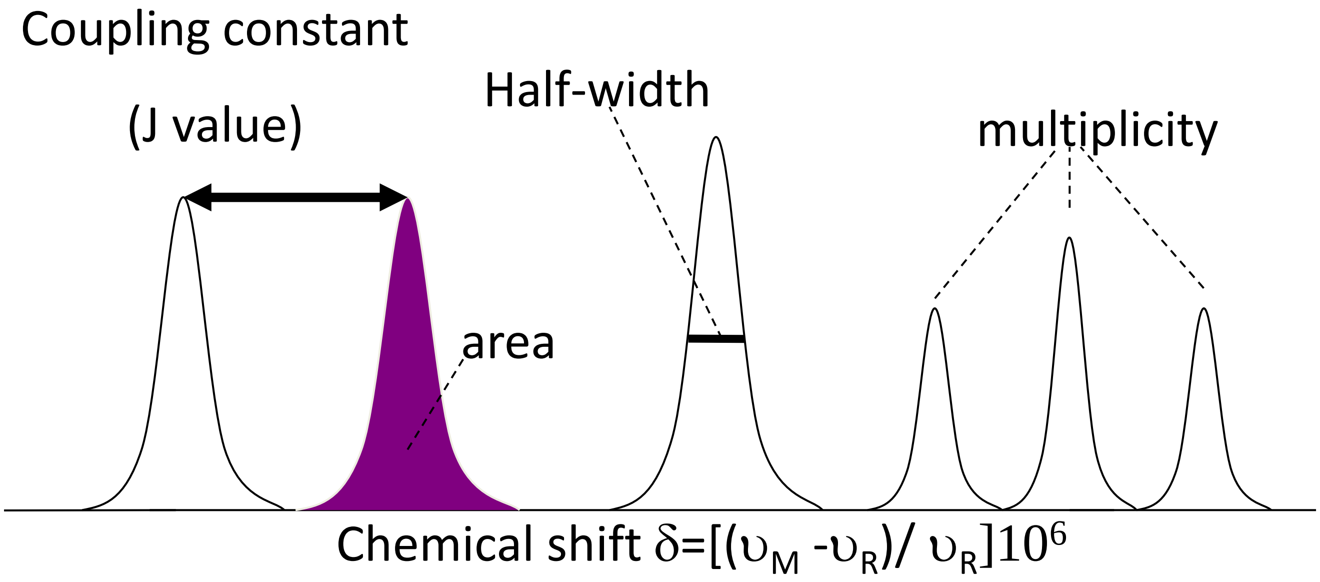
3. Direct dipole-dipole coupling



Direct magnetic interaction between the spins. Spatial proximity.

Informations from the spectrum

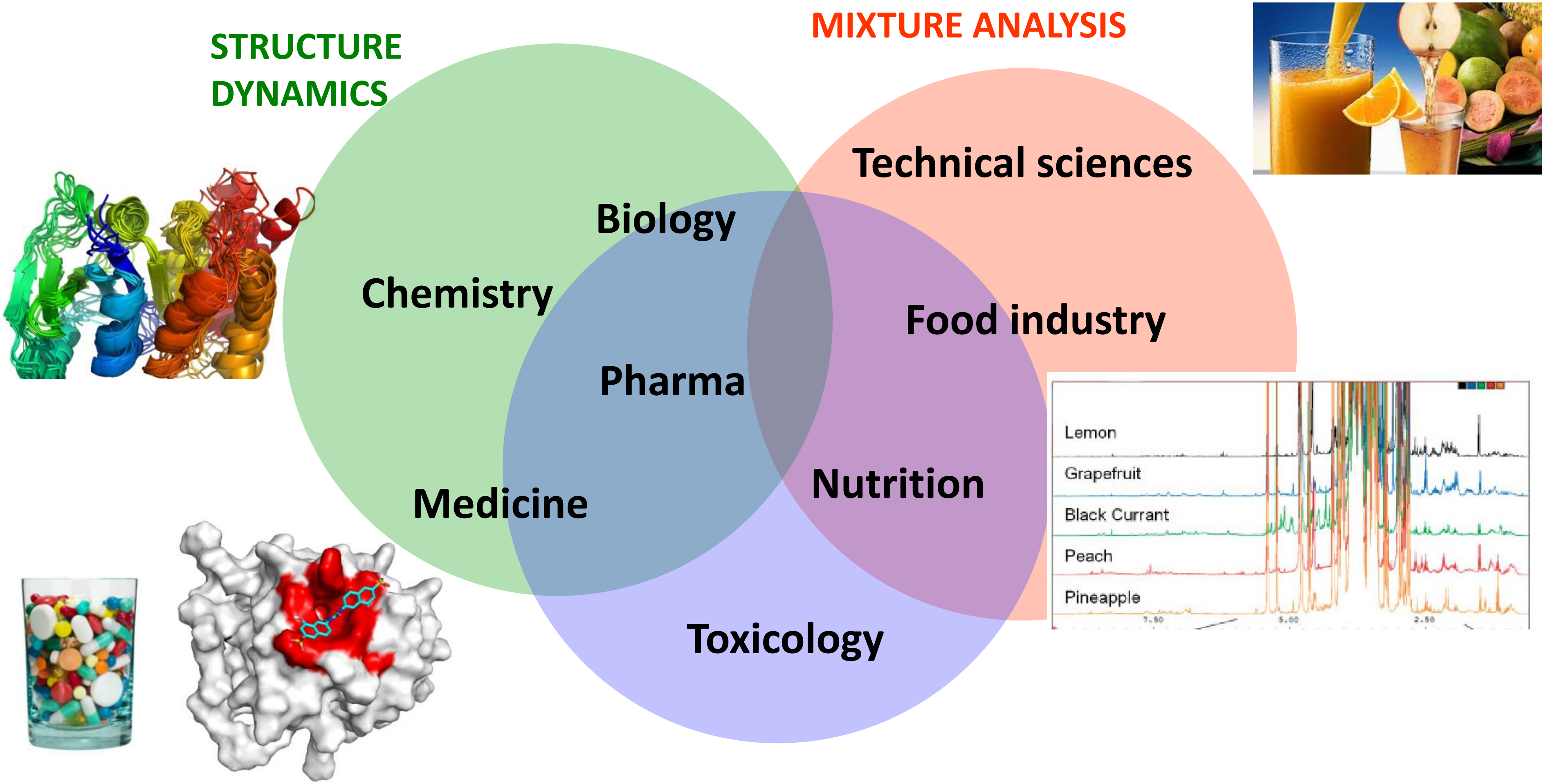
1. **The chemical shift value**
2. **The coupling constant**
3. **nOe**
4. **Exchange processes**



Where do we use this information? ☞ power of the technique
How do we get this information? ☞ personal skills

APPLICATION OF NMR SPECTROSCOPY

ATOMIC LEVEL INFORMATION IN SOLUTION!



STRUCTURE
DYNAMICS

MIXTURE ANALYSIS

Technical sciences

Biology

Chemistry

Food industry

Pharma

Nutrition

Medicine

Toxicology

MOLECULAR INTERACTIONS

ADDITIONAL TECHNIQUES

GC

MS

ICP

NMR

HPLC

TERMO GRAVIMETRY

IR

+ DLS, SEC, SAXS….