Магнитный резонанс

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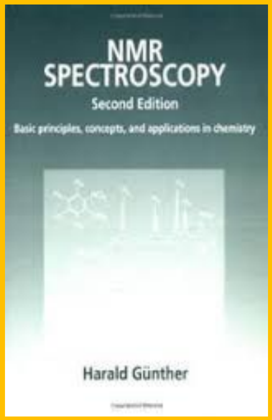
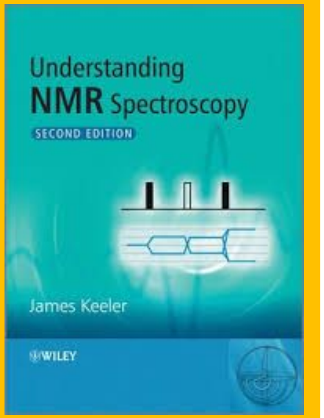
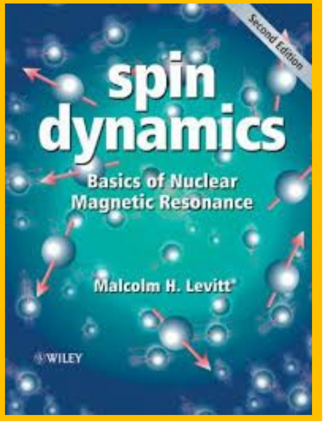
Books



Harald Günther
NMR Spectroscopy: Basic Principles, Concepts, and Applications in Chemistry



James Keeler
Understanding NMR Spectroscopy
http://www-keeler.ch.cam.ac.uk/lectures/Irvine/



Malcolm H. Levitt
Spin Dynamics

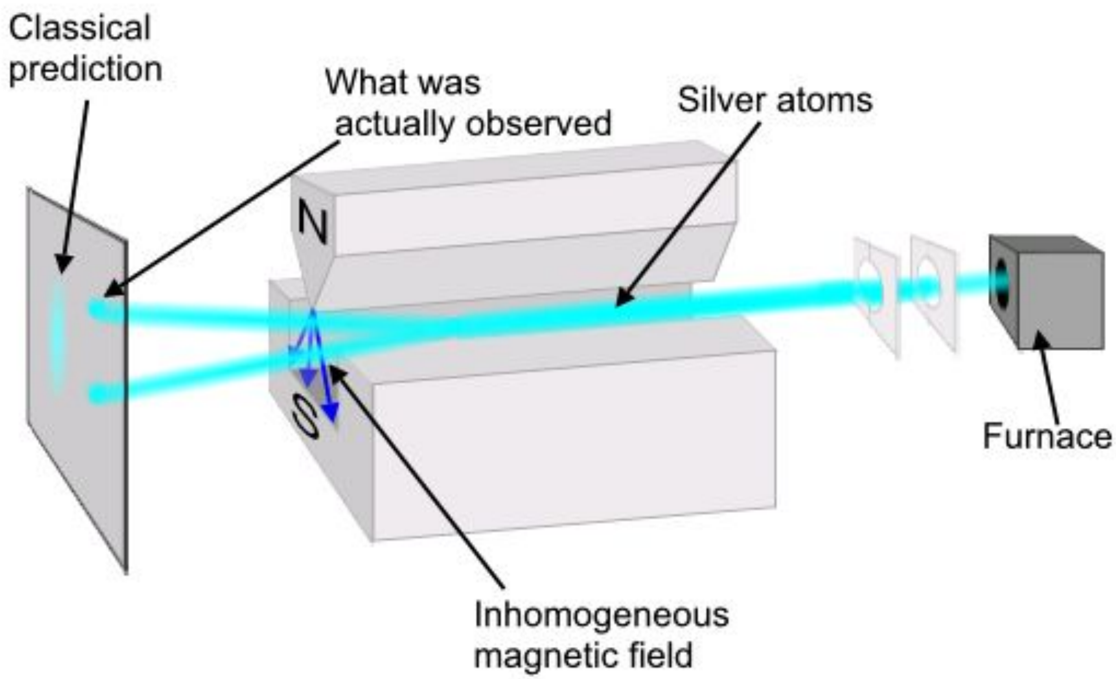
Discovery of spin and magnetic resonance effect

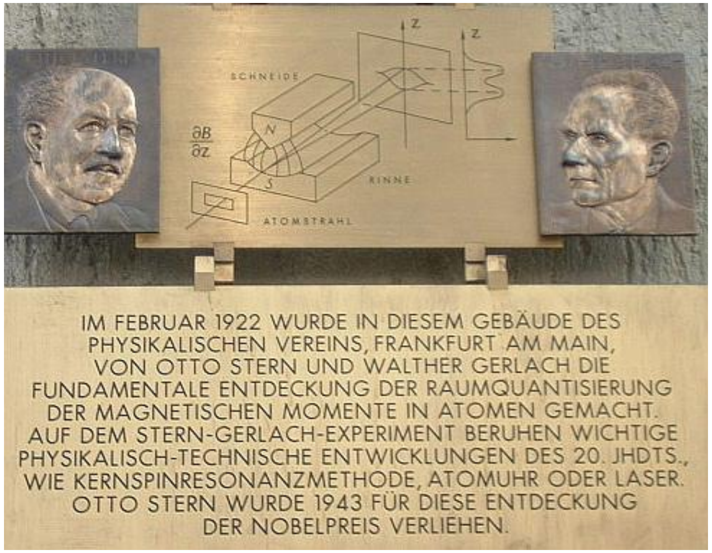
Stern-Gerlach experiment

electrons move on orbits,
producing angular momentum and magnetic dipole moment

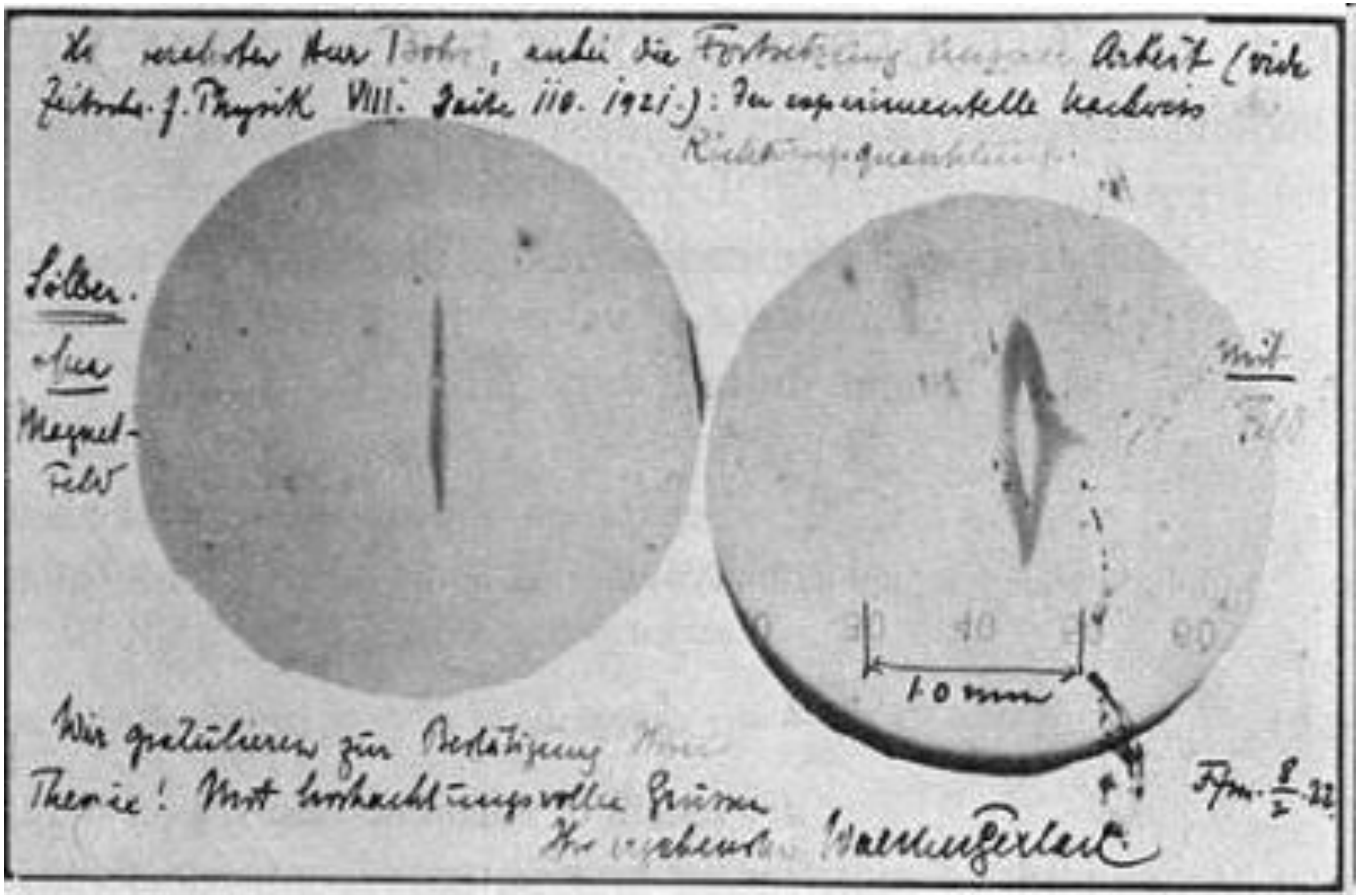
Lorenz and Zeeman theory:
all orientations of magnetic dipoles are allowed

Bohr and Sommerfeld theory:
only few orientations of magnetic dipoles are allowed





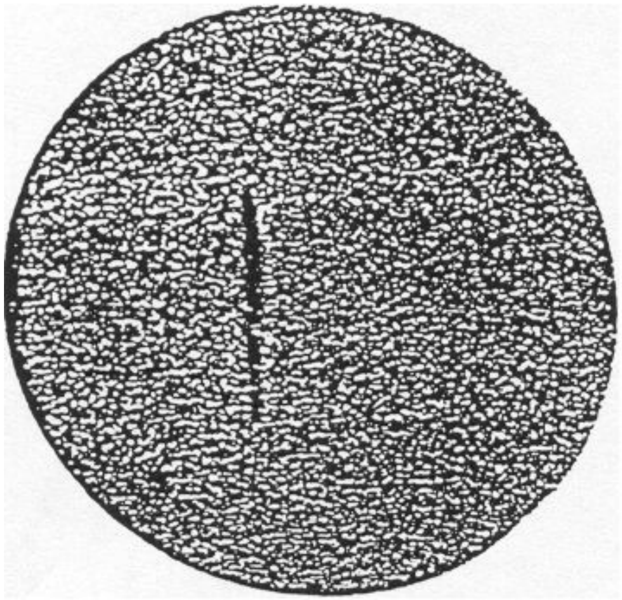
Stern-Gerlach experiment

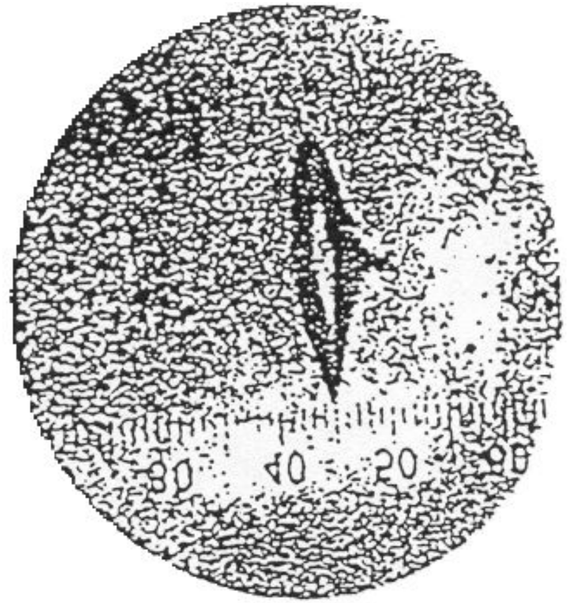


“Attached the continuation of our work (Zeitschrift für Physik 8 (1921) 110): The experimental proof of directional quantisation. Silver without magnetic field / with magnetic field. We congratulate on the confirmation of your theory.”

the postcard from Gerlach to Bohr, 8.02.1922

Stern-Gerlach experiment





Gerlach, W. and O. Stern, "Der experimentelle Nachweis der Richtungsquantelung". *Zeitschrift fur Physik* 1922, 9, 349-352.

"Hopefully now even the incredulous Stern will be convinced about directional quantization"

a letter from Pauli to Gerlach, 17.02.1922

Concept of spin (first proposed in 1925)

Wolfgang Pauli
1900-1958

Ralph Kronig
1904-1995

George Uhlenbeck
1900-1988

Samuel Abraham Goudsmit
1902-1978

Tried to explain spin as rotation of the particle, was critisized by Pauli and never published this idea ↑

↑ Did not speak with Pauli before publishing ↑

Spin (of electron) is two-valued quantum degree of freedom

Wolfgang Pauli

Probably nobody really understands spin on a level above the technical mathematical rules

Malcolm Levitt in „Spin Dynamics“

Spin and magnetic dipole moment

To have magnetic dipole moment particle needs 1) mass
2) charge
3) spin

Particle	**Mass**	**Charge**	**Spin**	**Magnetic dipole moment**
Electron	√	√	√	√
Proton	√	√	√	√
Neutron	√	×	√	√
Neutrino	√	×	√	×
Photon	×	×	√	×
Graviton (?)	×	×	√	×
Carbon-12	√	√	×	×
Carbon-13	√	√	√	√

Which elementary particles have no spin?

Higgs bosons (explain mass of particles)

Squarks (quark partners in the Standard Model) **existence not confirmed**

Graviscalars (excitation of the gravitational field) **existence not confirmed**

Axions (introduced to solve the CP-problem) **existence not confirmed**

Nuclear spin and nuclear magnetic dipole moment

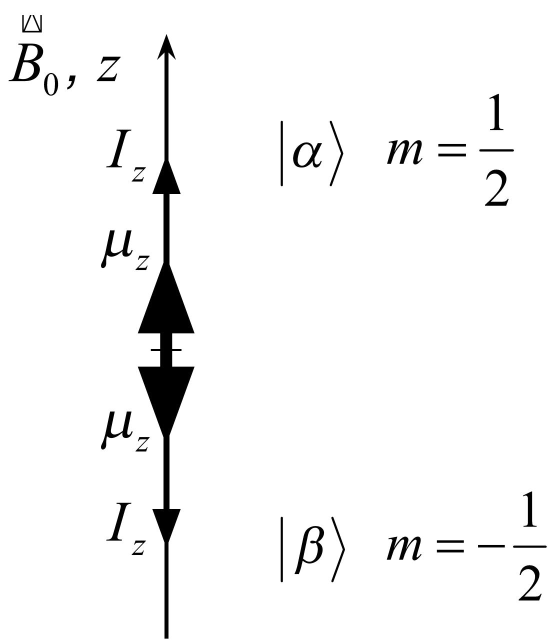
Total spin angular momentum $$I = \sqrt{S(S+1)}\hbar \qquad S = \left(0, \frac{1}{2}, 1, \frac{3}{2}, 2, \ldots\right)$$

Projection on *z*-axis $$I_z = m\hbar \qquad m = -S, -S+1, \ldots, S-1, S$$

Every nucleus with non-zero spin has magnetic moment $$\vec{\mu} = \gamma \vec{I}$$

Projection on *z*-axis $$\mu_z = m\gamma\hbar \qquad m = -S, -S+1, \ldots, S-1, S$$

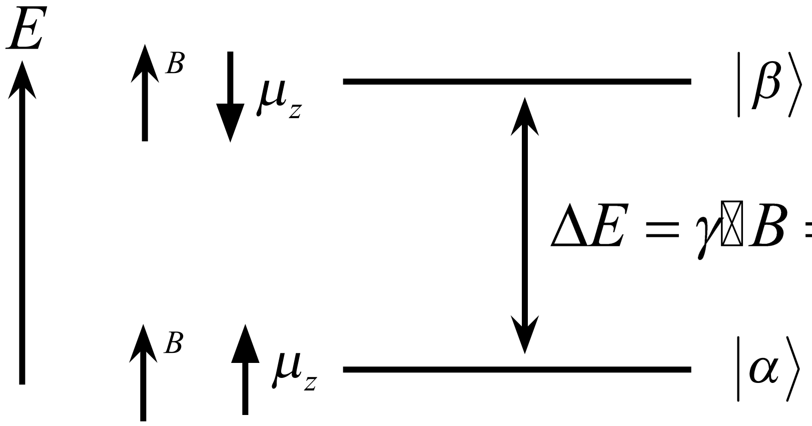
Example for spin ½ particle



Nucleus	Abundance	Spin *S*	γ /$10^6 \cdot$ rad $\cdot$ $T^{-1}s^{-1}$
^{1}H	99.985%	1/2	267.5
^{2}H	0.015%	1	41.1
^{12}C	98.89	0	-
^{13}C	1.11	1/2	67.3
^{14}N	99.63	1	19.3
^{15}N	0.37	1/2	-27.1
^{16}O	99.759	0	-
^{17}O	0.037	5/2	-36.3

Nuclear spin 1/2 in magnetic field

$$E_m = -m\gamma\hbar B$$

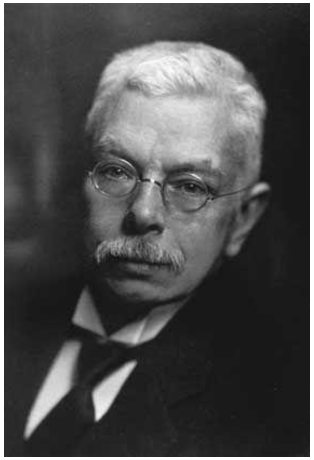


$$|\beta\rangle \quad m = -\frac{1}{2} \quad E_{-\frac{1}{2}} = \frac{1}{2}\gamma\hbar B$$

$$\Delta E = \gamma\hbar B = \omega\hbar = h\nu$$

$$|\alpha\rangle \quad m = \frac{1}{2} \quad E_{\frac{1}{2}} = -\frac{1}{2}\gamma\hbar B$$

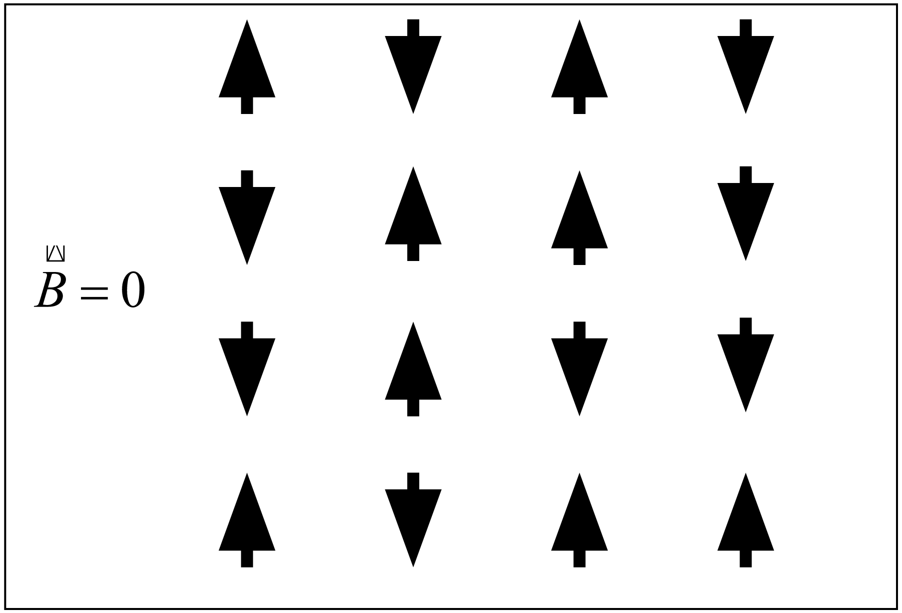
Zeeman effect discovered in 1896, Nobel Prize in 1902

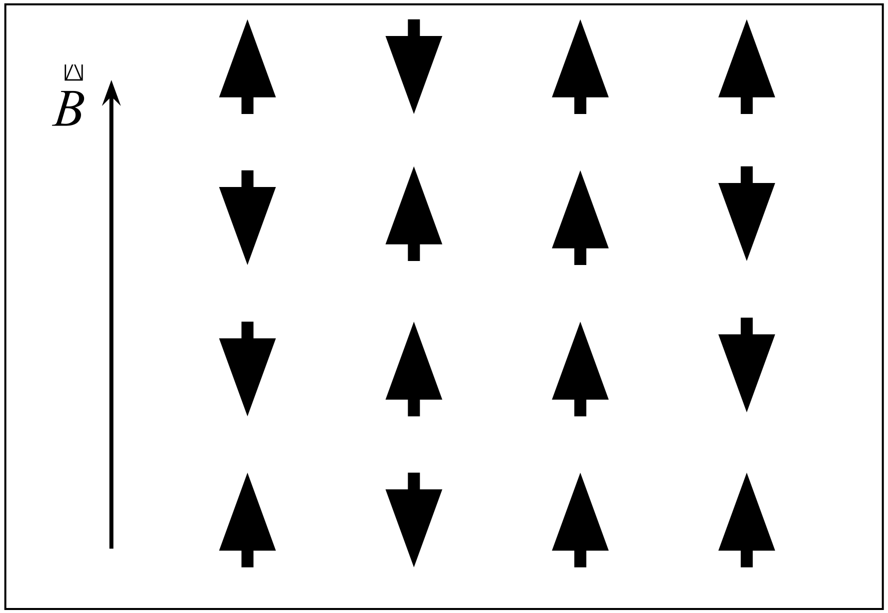


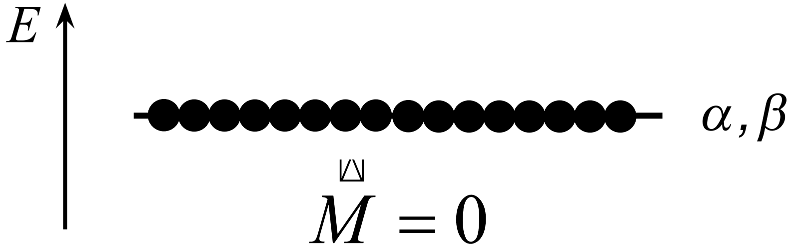
Pieter Zeeman
1865-1943

Hendrik Antoon Lorentz
1853-1928

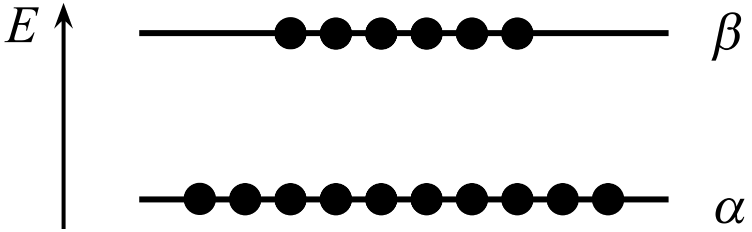
Ensemble of nuclear spins 1/2 in magnetic field







$$\vec{M} = 0$$



$$\vec{M} = const \cdot \left(x_\alpha - x_\beta \right)$$

Nobel Prizes in physics for the discovery of NMR

1944	1952	1952
		
Isidor Isaac Rabi 1898-1988 Columbia U., NY, USA	Felix Bloch 1905-1983 Stanford U., CA, USA	Edward Mills Purcell 1912-1997 Harvard U., MA, USA

work of 1938
NMR in beam

work of 1945-46
NMR in bulk

A winter of our first experiments… looking on snow with new eyes. There the snow lay around my doorstep – great heaps of protons quietly precessing in the Earth's magnetic field. To see the world for a moment as something rich and strange is the private reward of many a discovery…

from the Nobel Prize address of Purcell

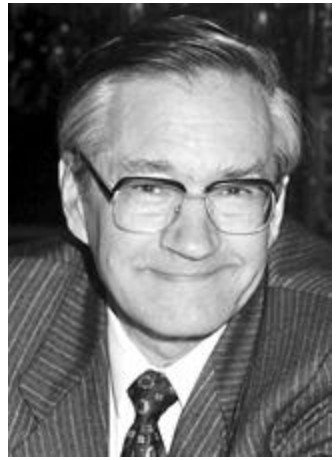
Nobel Prizes for the applications of NMR

1991	2002	2003	2003
			
Richard R. Ernst b. 1933 ETH, Switzerland	Kurt Würthrich b. 1938 ETH, Switzerland	Paul C. Lauterbur 1929-2007 U. Of Illinois, IL, US	Peter Mansfield b. 1933 U. Of Nottingham

Multidimensional NMR

MRI

3D structure of biomolecules



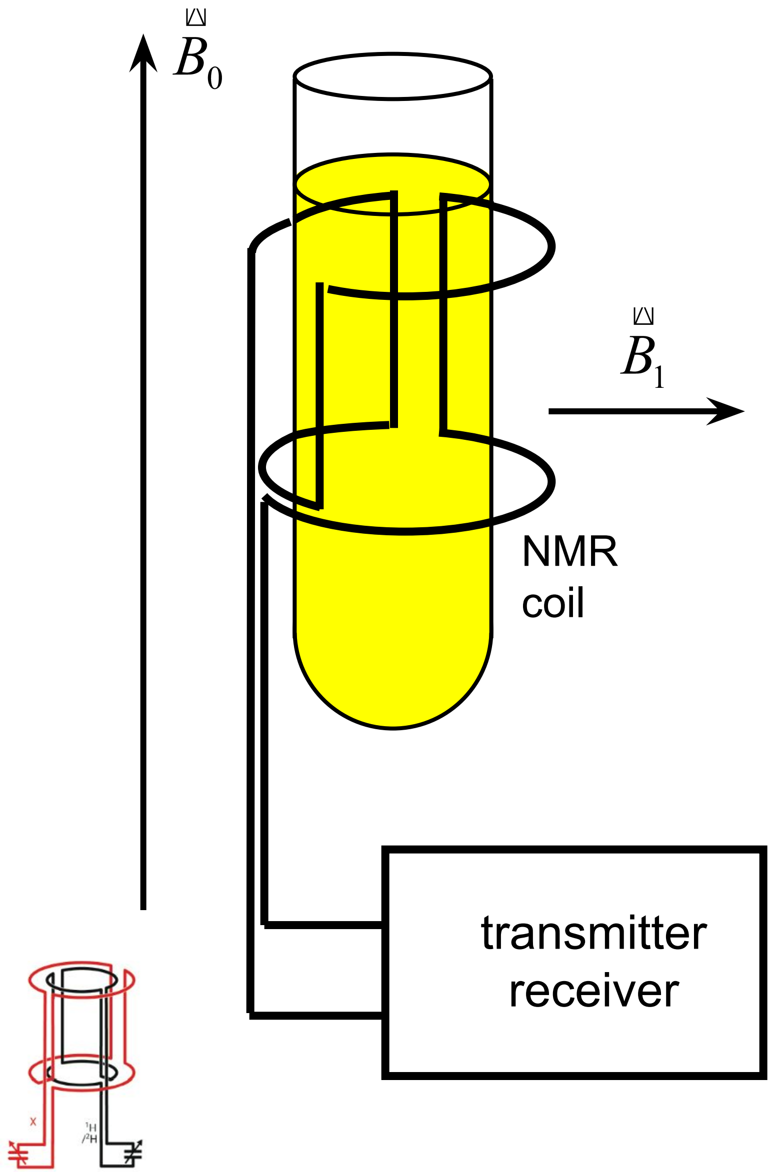
Richard R. Ernst

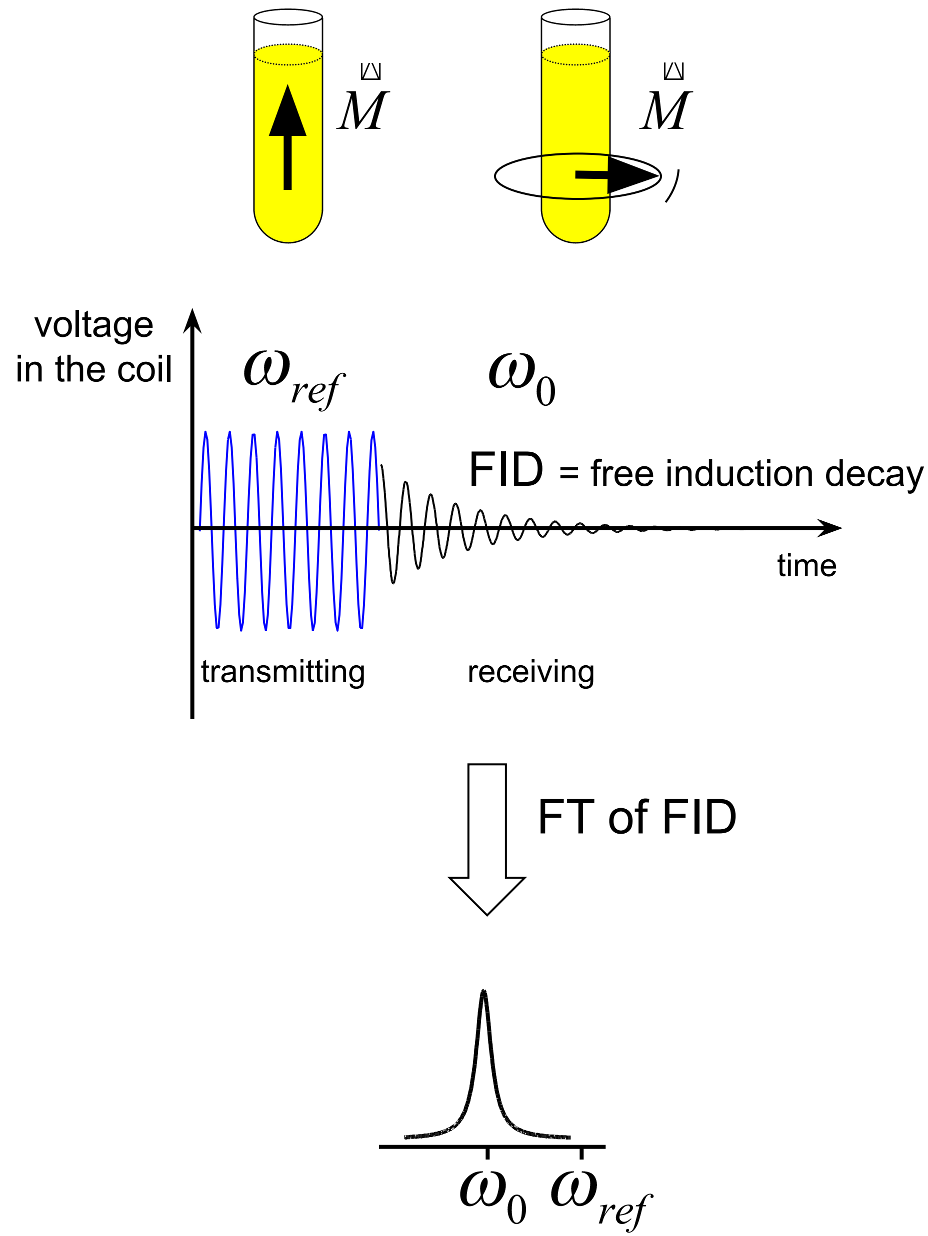
What are the reasons behind NMR's success?... nature has generously provided us with three basic physical properties:

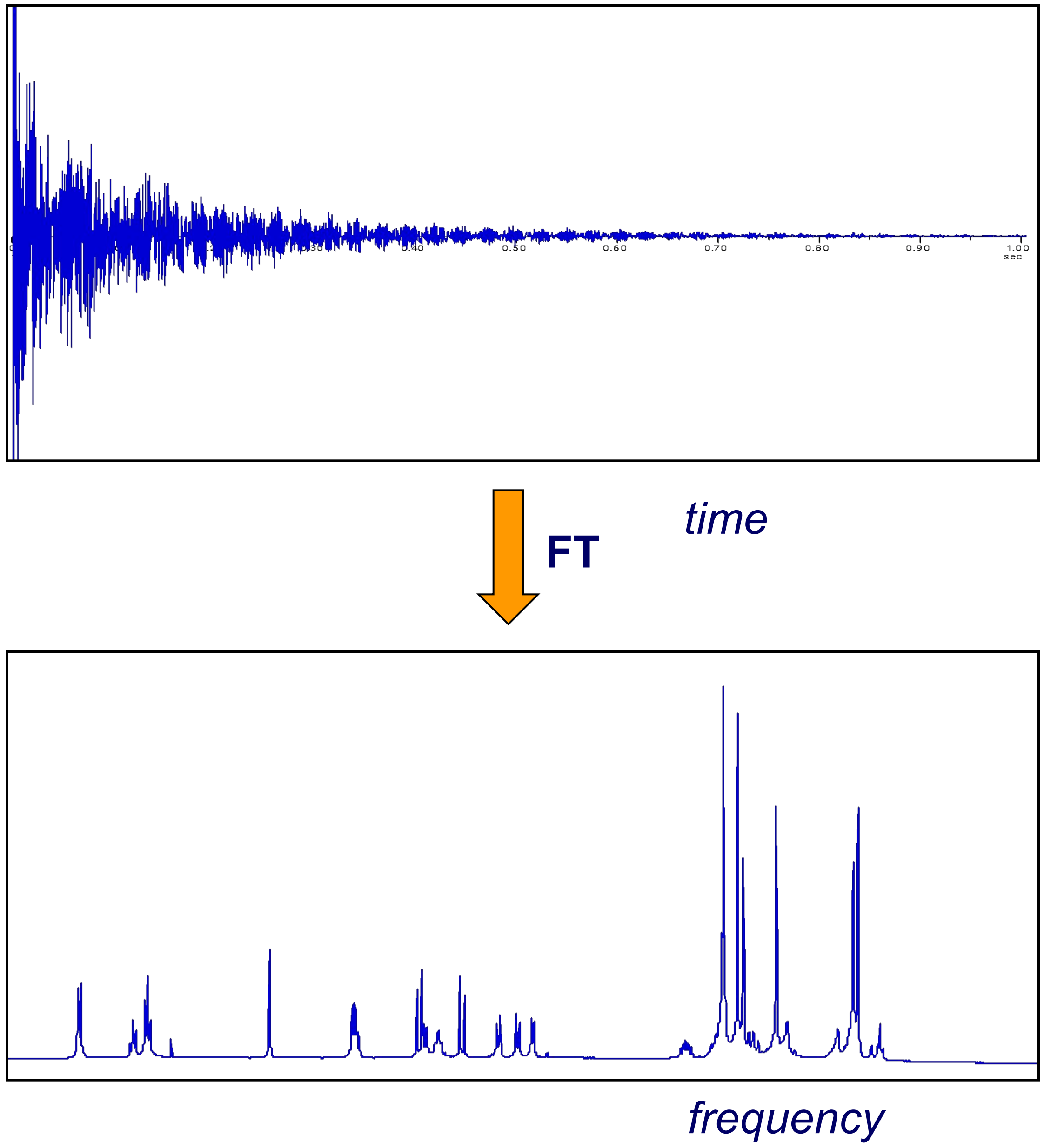
(1) The nuclear sensors ... are as localized as ever needed, with a diameter as small as 2 fm, allowing for almost unlimited spatial resolution.
(2) Interactions with the environment at less than 0.2 J/mol are extremely weak, permitting virtually perturbation-free sensing of the surroundings. Nevertheless, the interactions are highly sensitive to the environmental conditions.
(3) Internuclear pair interactions provide accurate distance information and information on bond angles.

Overview of an NMR experiment and design of NMR instruments

Brief overview of the NMR experiment






0.40
0.50
0.60
0.70
0.80
0.90
1.00
sec
FT
time
frequency