Az NMR és a bizonytalansági elv rejtélyes találkozása

ifj. Szántay Csaba

MTA
Kémiai Tudományok Osztálya

A Simple, Geometrical Approach to the Steady-State Solution of the Bloch Equations

INTRODUCTION

Because of the enormous and universal success of Fourier transform (FT) NMR methods, the continuous-wave (CW) instrument has become nearly extinct. This has brought about a somewhat conflicting situation in teaching the basics of NMR spectroscopy. Clearly, the emphasis is on the FT method with all its intriguing implications. However, certain fundamental principles are strongly related to CW theory, and therefore it is equally true that in order to achieve a healthy perspective on NMR, the CW concept simply cannot be brushed aside altogether. From a practical viewpoint, it should also be noted that the CW method is still important in other areas of magnetic resonance (e.g., ESR), and it has been resurrected to an extent on some high-tech FT NMR instruments for special applications. The method is also important for the operation of spectrometer lock-systems. Furthermore, at a basic level, the CW concept is more complicated and involves more mathematics than the FT method, and so a reasonably elaborate treatment of the CW theory inevitably tends to blow the issue out of proportion. Indeed, this may be one of the reasons that in modern NMR textbooks and courses, the topic is discussed only in a very sweeping manner, if at all. Yet we cannot escape the feeling that this deprives the novice of a more profound understanding of magnetic resonance, which seems to create a subtle conceptual problem in the teaching of basic NMR.

It is interesting to examine how the magnitude of $B_1$ influences this picture. When $B_1$ is increased, saturation becomes more significant. (In the vector model, the degree of saturation corresponds with the shortening of the $M$ vector with respect to its original length, $M_0$.) Figure 6 shows computer simulated resonance circles that were calculated by implementing the corresponding solutions of the Bloch equations for three different, increasingly higher $B_1$ values, with all other parameters being unchanged. For simplicity, $T_1$ was taken to be equal to $T_2$. Each circle is positioned on the surface of the same sphere, which possesses the characteristic parameters depicted in Fig. 6a (it is a sphere only if $T_1 = T_2$). The projections of these circles onto the $y'$ and $x'$ axes, represented as a function of $\omega_0$, afford the familiar absorption and dispersion resonance signals, respectively. The surface of this sphere represents the equilibrium of the absorption and relaxation rates, but now also as a function of the amplitude of $B_1$. As $B_1$ is increased, the plane of the circles tilts downward, and the net magnetization tends to disappear while moving on the surface of the sphere. The reason for this becomes clear from the following argument: Let us be exactly on resonance, with $M$ lying within the $yz'$ plane. The definition of the $R_1$ and $R_2$ vectors tells us that if $T_1 = T_2$, then $\Sigma \epsilon R$ always points toward the tip of the $M$ vector. If, for simplicity, we take both $T_1$ and $T_2$ to be unity (e.g., 1 s), then $\Sigma \epsilon R = M_0 - M$ (Fig. 7). Since $T$ is necessarily perpendicular to $M$, the $T + \Sigma \epsilon R = 0$ equation ensures that $\Sigma \epsilon R$ is also perpendicular to $M$. Thus, when we force $M$ to take up greater $\theta$ values by slowly increasing $B_1$ (and thus $T_1$), $M$ necessarily has to move along a Thales circle, and therefore its length decreases monotonically, as shown in Fig. 7. Evidently, $M$ can never reach the $y'$ axis, because at this point, $T_1$ would have no $T_2$ component to counterbalance the influence of transverse relaxation, and the macroscopic net magnetization would be completely eliminated.
ABSTRACT: With the trend of designing superconducting probes and very high-frequency NMR spectroscopic tools increasingly being perceived as critical steps in the direction of dissipation, it is shown that the recovery of the NMR signal is accomplished in a non-linear way by the resistive losses in the conductors. Following the pioneering work of T. P. Little and R. S. Berry, the phenomenon of radiation damping is investigated. The current flowing through the sample is shown to be a source of radiation damping. The effect of radiation damping is to reduce the amplitude of the NMR signal. This damping is the result of the radiation losses in the sample and the surrounding conductors. The radiation damping is an important factor in the design and operation of superconducting NMR systems. The radiation damping effect is described by the damping factor, which is the ratio of the radiation damping to the decay rate of the NMR signal. The radiation damping is an important factor in the design and operation of superconducting NMR systems.
A “REJTETT CSEREPARTNER” JELENSÉGE, KINETIKÁJA, ÉS ALKALMAZOTT NMR SPEKTROSZKÓPIÁI HATÁSAI
Analysis and Implications of Transition-Band Signals in High-Resolution NMR

Czaba Szántay, Jr.
Spectroscopic Research Division, Gedeon Richter Ltd., POB 37, H-1413 Budapest, Hungary

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The problem of signal generation in and received from regions outside the active coil area is overcome in the context of using standard measurement techniques. Some of the conceptual and practical consequences of the existence of such transition-band signals are highlighted. Examples include radiation damping, pulse width calibration and the presence of radiofrequency homogeneity

independent, improper saturation, and exchange and relaxation-rate determinations. One interesting implication is that apparent sample-to-sample variations in the calibrated 600 pulse width values are a function not only of pulse timing and field inhomogeneity, but also of the following: (1) the level of field inhomogeneity, (2) the sample treatment, (3) the presence of a phenomenon known as "spin-diffusion," and (4) the presence of a phenomenon known as "spin-lattice relaxation.

Key Words: high-resolution NMR; spin-diffusion; Bloch simulation; implications.

In high-resolution NMR, the so-called "spin-diffusion" effect (or "spin-lattice relaxation") can be ignored because of the short separation times in the time evolution of the sample. The signal is generated in the active coil area, and the received signal is only weakly affected by the field inhomogeneity. However, it is important to note that the spin-diffusion and spin-lattice relaxation effects can be important in the time evolution of the sample if the separation times are long. The signal is generated in the active coil area, and the received signal is only weakly affected by the field inhomogeneity. However, it is important to note that the spin-diffusion and spin-lattice relaxation effects can be important in the time evolution of the sample if the separation times are long.

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Evolution of Magnetization in a $B_1$ Field. I. The Impact of $B_0/B_1$ Inhomogeneity and Fast Chemical Exchange in High-Resolution NMR

CSABA SZÁNTAY, Jr.

Golden Richter Ltd. Spectrometric Research Group, ELTE, 1111 Budapest, Hungary. E-mail: cszanta@richter.hu

ABSTRACT: Since the magnetization evolves relatively little and rapidly in high-resolution NMR, the focus is on the behavior of the net magnetization, and the effects of inhomogeneities in the $B_0$ and $B_1$ fields, which are caused by chemical exchange. Discussion is divided into two distinct regions: (i) the case of $B_0$ field inhomogeneities and moderately fast chemical exchange, and (ii) the case of $B_1$ field inhomogeneities and slow chemical exchange. The results of these studies are compared and contrasted with the case of a $B_0$ field that is static and a $B_1$ field that is stationary.

KEYWORDS: High-resolution NMR; $B_0$ inhomogeneity; nutation; underdamping; overdamping; phase randomization of the first and second kind; transition-band signals; Bloch simulations.

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positive absorption-mode resonance, while if

$$M^{+\alpha} = -M_\alpha, M^{-\alpha} = 0,$$

we obtain a pure negative absorption-mode signal. In this system, the time dependence of $M$ is governed by the Bloch equations (9), which in this case take the following simple vectorial form:

$$\frac{dM}{dt} = \gamma [M \otimes B_0] - \lambda_1 M_\alpha + \lambda_2 (M^0 - M_\alpha).$$

The term $\gamma M \otimes B_0$ represents the torque $K = dM/dt - \gamma M \otimes B_0$, which causes the net moment vector $M$ to circulate (nutation) in the $yz$ plane with an angular frequency $\gamma B_0$. To construct the equations for the $\alpha$th component, using the comparison of the $M_{\alpha}$ with the $M_{\alpha}^0$ for all $\alpha, \alpha' = 1, \ldots, N$, the terms $\lambda_1 M_\alpha$ and $\lambda_2 (M^0 - M_\alpha)$ (or $\lambda_3$, $\lambda_4$, $\lambda_5$, $\lambda_6$).

From hereon it will prove useful to refer to the four quadrants (Q) of the $yz$ plane as Q1-Q4 (cf. Fig. 2). It can be shown (10) that when $\gamma B_0$ is increased from a small value to a high-power irradiation, the steady-state point given by $M^0$ moves clockwise, with an increasing steady-state angle $\theta^\alpha$, along a Thales semicircle in Q1 (cf. Fig. 2).

Figure 1. The steady-state condition, represented for the special case when $\lambda_1 = \lambda_2 = \gamma B_0 = 1$ and the inhomogeneity $B_0$ field is aligned along the $+x$ axis of the rotating frame. The equilibrium point is characterized by the condition $R + K = 0$, i.e., the net relaxation vector $R$ balances the torque $K = \gamma M \otimes B_0$ (see text).

By varying the $\gamma B_0$ value, $M^0$ moves along the depicted Thales circle but always remains in quadrant I (cf. Fig. 2).
NMR and the Uncertainty Principle: How to and How Not to Interpret Homogeneous Line Broadening and Pulse Nonselectivity. I. The Fundamentals

CSABA SZÁNTAY Jr.
Spectroscopic Research Division, Gedeon Richter Plc., H-1475 Budapest, 10, POB 27, Hungary

ABSTRACT: Both the essence of homogeneous NMR line broadening as well as the theoretical framework for measuring its width and in consequence often rationalized in field of chemistry, are in many cases often rationalized in field of chemistry. "The problem is that even for the basic concepts that are the uncertainty principle is the most thoroughly discussed problem, there is no way to discuss the uncertainties in the context of our scientific background."

KEY WORDS: uncertainty principle, Fourier transforms, RF pulse, NMR echoes

INTRODUCTION

In Parts I and II of [1-3], I presented an overview of the essential principles of Fourier analysis and the Fourier transform by using an unconventional formalism and approach, as motivated by the "Two NMR Problems" (namely: both the essence

NMR and the Uncertainty Principle: How to and How Not to Interpret Homogeneous Line Broadening and Pulse Nonselectivity. II. The Fourier Connections

CSABA SZÁNTAY Jr.
Gedeon Richter Plc., Spectroscopic Research Division, 10, POB 27, Budapest H-1475, Hungary

ABSTRACT: Following the treatments presented in Parts I and III of [1], here I would like to address the popular notion that the frequency of a monochromatic RF pulse as well as that of a monochromatic RF pulse is "in effect" uncertain due to the Bloch-Ehrenfest Uncertainty Principle, which also manifests itself in that the FT-spectrum of this temporal function is spread over a certain frequency band. I will show that the frequency spread should not be interpreted as "in effect" meaning a range of physical drifts of the RF field in the frequency, and "spatial frequencies" in the latter case. The fact that a shorter pulse is a more slowly decaying echo has a wider FT-spectrum in a field weakly due to the Fourier Uncertainty Principle, which is a well known, and easily misunderstood concept. A proper understanding of the Fourier Uncertainty Principle tells us that the root-spectrum of a monochromatic pulse is not "in effect" because of any "uncertainty" in the RF frequency, but because the spectrometer profiles cut off the pulse's spatial frequency, phase, amplitude, length, temporal location inside the complex amplitudes of the FT-spectrum's constituent internal spatial harmonic waves. A monochromatic RF pulse is capable of exciting nonmonochromatic magnetizations in a last purely classical or quantum effect that has nothing to do with "uncertainty". Analogously, "Lorentzian echoes" receive exactly the same thing physically as "exponential decay", and all inferences as to the physical reasons for that decay must be based on independent experimental observations.

KEY WORDS: uncertainty principle, Fourier transform, RF pulse, NMR echoes
matematyka
filozofia
filozofia
psychologia
a magspínek pulzus-gerjesztésének értelmezési paradigmája

GLOBÁLISAN ELTERJEDT MAGYARÁZAT:

PFT NMR

Heisenberg B. E.

\[ \Delta t \cdot \Delta \omega \geq \text{konst.} \]

\[ \Delta \omega_0 \]

Larmor frekvencia rezonancia tartomány

\[ \cos(\omega_1 t) \]

alakú rádió-frekvenciás elektromágneses pulzus

\[ \omega_1 \]

\[ \Delta t \]
a magspínek pulzus-gerjesztésének értelmezési paradigmája
GLOBÁLISAN ELTERJEDT MAGYARÁZAT:

\[ \cos(\omega_1 \cdot t) \] alakú
rádió-frekvenciás
elektromágneses
pulzus

\[ \Delta t \]

\[ \omega_1 \]

\[ t \]

Főként tükröződik a pulzus
széles Fourier
spektrumában is

PFT NMR

\[ \text{“SINC”} \]

ez tükröződik a pulzus
széles Fourier
spektrumában is
a magspínek pulzus-gerjesztésének értelmezési paradigmája

GLOBÁLISAN ELTERJEDT MAGYARÁZAT:

\[
\cos(\omega_1 t) \text{ alakú rádió-frekvenciás elektromágneses pulzus}
\]

\[
\Delta t
\]

\[
\omega_1 \quad t
\]

\[
\text{Heisenberg B. E. } \Delta t \cdot \Delta \omega \geq \text{ konst.}
\]

\[
\Delta \omega_0 \quad \text{Larmor frekvencia rezonancia tartomány}
\]

\[
\text{NOMINÁLISAN MONOKROMATIKUS (}\omega_1\text{)} \quad \text{RF PULZUS}
\]

\[
\text{EFFEKTÍVE POLIKROMATIKUS (}\Delta \omega_1\text{)}
\]

\[
\downarrow \quad \text{ezért a Larmor frekvenciák széles tartományát képes gerjeszteni}
\]
“As the Uncertainty Principle indicates, a pulse of carrier frequency $\omega_1$ will contain, in effect, a range of frequencies centred on $\omega_1$. The distribution of RF magnetic field amplitudes takes the form $\sin(x)/x$ which is the frequency-domain equivalent of a short pulse in the time domain. The two domains are connected by the Fourier transform.”

“Although the applied excitation may be precisely centred at a frequency $\omega_1$, our act of turning the excitation power on at time zero and off at time $\Delta t$ effectively broadens the spectral range of the excitation to a bandwidth of $\sim 1/\Delta t$.”

“… the RF source is monochromatic, so we have to work out a way of using a single frequency to excite multiple frequencies. If the irradiation is applied for a time $\Delta t$, then, due to the Uncertainty Principle, the nominally monochromatic irradiation is uncertain in frequency by about $1/\Delta t$.”

“…if the pulse is made shorter, we will no longer have a truly monochromatic frequency spectrum even though the source is still monochromatic”.

“A pulse of monochromatic RF can be described in the frequency domain as a band of frequencies. The Heisenberg principle states that there is a minimum uncertainty in the simultaneous specification of the frequency and the duration of the measurement. This means that, as the pulse length decreases, irradiation is spread over a wider frequency band. The sinc Fourier spectrum of a rectangular RF pulse shows that a shorter pulse gives a wider sinc band.”
MILYEN (PRE)KONCEPCIÓK VEZETNEK EHHEZ A MAGYARÁZATHOZ?
NMR = kvantummechanikai jelenség

Heisenberg B.E. alkalmazható

Energia

$pulszus = kvantummechanikai \text{ "entitás"}$
Fourier transzformáció = időbeli jel felbontása frekvencia komponenseire

$$f(t) \xrightarrow{\text{FT}} \tilde{F}(\omega)$$

$$\cos(\omega_1 t) |_{\Delta t} \text{ spektruma } = \cos(\omega_1 t) |_{\Delta t} \text{ “frekvencia komponensei”}$$
a kvantummechanikai és klasszikus leírás korrelációja: a Heisenberg B.E. a FT területén is érvényesül:

\[ \Delta t \cdot \Delta \omega \geq \text{konst.} \]
a magyarázat helyesnek tűnik

Heisenberg

Fourier

mi ezzel a probléma?
A mágneses rezonancia *NEM* rádió hullámok (fotonok) abszorpciója / emissziója!
Valójában:
(makroszkópikus) mágneses rezonancia = klasszikus, determinisztikus jelenség (mágneses terek klasszikusan leírható kölcsönhatása)!

az RF hullám mágneses komponense  a minta mágnesezettsége
The Magnetic Resonance Myth of Radio Waves

D. I. Hoult
Biomedical Engineering and Instrumentation Branch
Division of Research Services, Building 13, Room 3173
National Institutes of Health, Bethesda, MD 20892
Received March 30, 1989

An inaccurate description of magnetic resonance is current among those employing it in medicine and biology. The technique is purported to use radio waves for both stimulation of the sample and for reception of the ensuing signal. Arguments are presented which counter this myth, and using only magnetic fields, an accurate classical description of transmission and reception is given.

INTRODUCTION

A strange notion exists that nuclear magnetic resonance (NMR) uses radio waves for both excitation of a sample and for the reception of signal. Where this idea originated is difficult to say, for it cannot be found in any of the basic, long-established texts. However, its acceptance within, at least, the medical imaging community is now nearly universal, and attempting to combat the weight of several books that contain this error is a depressing matter, for one is often greeted with ill-mannered skepticism.

Why then should one bother? On the one hand, there is the academic's annoyance at the perpetuation of a falsehood, and with it, the intimated belief that a faulty building block can eventually cause the learned tower to tumble. On the other hand, there is the knowledge that the NMR frequency range is sandwiched between those of electric power lines and microwaves, both of which have been accused of being health hazards. Guilt by association with electric fields thus links in the wings.

Part of the problem perhaps lies in trying to use elementary quantum mechanics to explain the NMR phenomenon. The picture of two levels separated by energy &Delta;v, where &Delta;v is Planck's constant and v0 is the Larmor frequency, is appealing in its simplicity: Transmission involves the absorption of photons which cause transitions from the low energy state to the high energy state (see Figure 1). Of course, photons are usually portrayed in undergraduate texts as quantum of light, which is simply electromagnetic radiation, but with NMR the frequency of 'radiation' is much lower, so the photon must be a radio wave! Conversely, after transmission, relaxation occurs as nuclei drop back into the lower energy state. In the process, they emit photons (radio waves again), and an antenna picks up the signal and passes it to the radio receiver that is the NMR system. The whole scenario is attractive: It appeals to the familiar in its use of radio waves and carries authority with its invocation of quantum mechanics. Unfortunately, it is also erroneous and misleading.

Is Quantum Mechanics Necessary for Understanding Magnetic Resonance?

LARS G. HANSEN
Danish Research Centre for Magnetic Resonance, Copenhagen University Hospital, Hvidovre, Denmark

ABSTRACT: Educational material introducing magnetic resonance (MR) typically contains sections on the underlying principles. Unfortunately the examinations given are often unnecessarily complicated or even wrong. MR is often presented as a phenomenon that necessitates a quantum mechanical explanation whereas it really is a classical effect, i.e., a consequence of the common sense expression in classical mechanics. This insight is not new, but there have been few attempts to challenge common misleading explanations, so authors and educators are inadvertently keeping myths alive. As a result, new students' first encounter with MR are often base on the explanations that make the subject difficult to understand. Typical problems are addressed and alternative intuitive explanations are provided. © 2008 Wiley Periodicals, Inc. Concepts Magn Reson Part A 17A: 325–340, 2008.

KEY WORDS: magnetic resonance imaging; education; quantum mechanics; classical mechanics; tutorial; spin; myths

INTRODUCTION

Since the beginning of the twentieth century it has been known that classical physics as expressed in Newton's and Maxwell's equations do not form a complete description of known physical phenomena. If, for example, classical mechanics described the interactions between electrons and nuclei, atoms would not exist as they would collapse in fractions of a second because orbiting electrons radiate energy and hence loose speed according to classical mechanics. The phenomena not explicable by classical mechanics inspired the formulation of the fundamental laws of quantum mechanics (QM). They have been tested very extensively for almost a century and no contradictions between experiments and the predictions of QM are known.

The QM theory is probabilistic in nature, i.e., it only provides the probabilities for specific observations to be made. This is not a surprising aspect of a physical law as a system cannot generally be prepared in a state precisely enough to ensure a specific future outcome (the uncertainty of the initial condi-
Mi köze van tehát mindehhez Heisenbergnek?

\[ \Delta t \cdot \Delta \omega \geq \text{konst.} \]

kvantummechanikai + valószínűségi állítás!

RF pulzus = oszcilláló mágneses tér
\( \omega_1 \) az idő-dimenzióban pontosan definiált a frekvencia dimenzióban pedig NEM?

"NOMINÁLISAN" monokromatikus = "EFFEKTÍVE" polikromatikus???
A MEGOLDÁS
and

\[ \mathcal{L}(\psi) = \int \mathcal{L}^{(1)}(\psi) \, d\tau \quad \text{(II-30)} \]

with (II-29) and (II-30) now being formally symmetric. Referring to Eqs. (II-26b) and (II-27b), it must therefore be understood that their asymmetry does not affect the principle that the FT is one-to-one; the fundamental point is that \( f(\omega) \) can be recovered exactly from \( \mathcal{L}(\psi) \) but the factor \( 1/2\pi \) must be taken into account. It is in this implied sense of ensuring the symmetry between the operations \( \mathcal{F} \) and \( \mathcal{F}^{-1} \) that one must interpret the meaning of the symbol \( \mathcal{F}^{-1} \) in (I-47), which reflects the invertible nature of the FT. With this understanding, the Fourier inversion theorem can formally be written as:

\[ \mathcal{F}^{-1} \mathcal{F}[f(\omega)] = f(\tau) \quad \text{(II-31a)} \]

**Spectral:**

\[ \mathcal{E}(\omega) = \mathcal{E}^{(2)}(\omega) + i \cdot \mathcal{E}^{(3)}(\omega) \quad \text{(II-32b)} \]

- It is important to remember that the function value at a given frequency of an FT spectrum has the following meaning: \( \mathcal{E}^{(2)}(\omega) \) is associated with a complex cosine wave \( e^{-i\omega t} \cdot \cos(\omega t) \) and \( \mathcal{E}^{(3)}(\omega) \) is associated with a complex sine wave \( e^{-i\omega t} \cdot \sin(\omega t) \).

In analogy to our discussion of FA in section II.2, further insights and a gain into the FT by noting again that the right-hand side of Eq. (II-26b) represents an infinite collection of real, "principle phasors" on the phase-frequency scale. Thus, in analogy to (171)-(176) and (181)-(186), we can formulate the following scheme:

\[ \mathcal{F}^{-1} \mathcal{F}[f(\omega)] = \mathcal{F}^{-1} \mathcal{F}[\mathcal{E}(\omega)] \quad \text{(II-33a)} \]

\[ \mathcal{E}(\omega) = \mathcal{E}^{(2)}(\omega) + i \cdot \mathcal{E}^{(3)}(\omega) \quad \text{(II-34a)} \]

\[ \mathcal{F}^{-1} \mathcal{F}[f(\omega)] = \mathcal{F}^{-1} \mathcal{F}[\mathcal{E}(\omega)] \quad \text{(II-35a)} \]

\[ \mathcal{E}(\omega) = \mathcal{E}^{(2)}(\omega) + i \cdot \mathcal{E}^{(3)}(\omega) \quad \text{(II-36a)} \]

\[ \mathcal{F}^{-1} \mathcal{F}[f(\omega)] = \mathcal{F}^{-1} \mathcal{F}[\mathcal{E}(\omega)] \quad \text{(II-37a)} \]
Heisenbergnek SEMMI köze az ÜGYHÖZ!
Két fajta Bizonytalansági Elv létezik!

Heisenberg
B. E.:
\[ \Delta t \cdot \Delta \omega \geq \text{konst.} \]
valószínűségi állítás

Fourier
B. E.:
\[ \Delta t \cdot \Delta \omega \geq \text{konst.} \]
determinisztikus állítás

VALÓJÁBAN EZZEL VAN DOLGUNK!

A név a formális alaki hasonlóságból ered!

Formális (matematikai) hasonlóság, de különböző fizikai jelentés!
A Fourier “Bizonytalansági” Elv állítása:

\[ f(t) \text{ “keskeny” } \rightarrow F(\omega) \text{ “széles”} \]
\[ f(t) \text{ “széles” } \rightarrow F(\omega) \text{ “keskeny”} \]

(SEMMI “BIZONYTALANSÁG”!)
Mindkét dimenzióhoz azonos fizikai értelmezést kell rendelnünk!

A "KONJUGÁLT FIZIKAI EKVIVALENCIA" TÖRVÉNYE

natív dimenzió

$\tilde{F}(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt$

$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{F}(\omega) e^{i\omega t} d\omega$

transzformált dimenzió
...mit “csinál” a Fourier transzformáció...

...mi a “spektrum” jelentése...?

\[
\tilde{F}(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-i\omega t} \cdot dt
\]
A FT lényege:

\[ f(t) \text{ dekompozíciója } A \cdot e^{i\omega t} \text{ alakú,} \]

végben idejű BÁZIS ELEMEK

végben frekvenciatarományú

sorává

\[ f(t) = \frac{1}{2\pi} \cdot \int_{-\infty}^{\infty} F(\omega) \cdot e^{i\omega t} \cdot d\omega \]

Bázis elem = matematikai absztrakció, aminek NINCS inherens fizikai jelentése!

A fizikai jelentést MI (emberek) rendeljük hozzá, nem pedig belőle fakad!
Az információ csomag van átkódolva! A "spektrum" a kódok összessége!
(a fizikai értelmezést MI adjuk, az NEM a "kódok" sajátja!)
Az RF pulzus széles off-rezonancia hatásának magyarázata:

“kényszererő amplitúdó”!

lineáris határeset: pulzus FT spektruma ~
~ NMR gerjesztési profil (Szuperpozíció Elv)
A MEGOLDÁS
antrópikusan árnyalt tudományos gondolkodás
Az "igazság" nem létezhet az emberi értelemtől függetlenül: a világról nem, csak a világ általunk alkotott LEÍRÁSÁRÓL állíthatjuk, hogy igaz, vagy hamis. Tudományos igazság alatt valójában nem "abszolút igazságot" kell értenünk, hanem a világnak egy olyan leírását, amely a megerősítésére és cáfolatára tett kísérletek egész sorát kiállta, ezért helyesnek tekinthető. (Richard Rorty, John Webb)
“átlagember”  “képzett tudós”
#3

szemléleti koncepcionális intuitív leírás / megértés / értelmezés

matematikai alapú leírás / megértés / értelmezés

fizikai alapú leírás / megértés / értelmezés
"reflekszerű de-absztrahálás"
"ismeretlen ismerős"

\[ F(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-i\omega t} \cdot dt \]
“(matematikai) fa vs. (fizikai) erdő”

“Pontosan mit is akartunk itt mondani?”
“enjoy your flight”
“elveszett jelentés”

Nyelvem határai ismereteim határait jelentik. Csak azt tudom, amit (PONTOSAN*) meg tudok nevezni.

- Ludwig Wittgenstein (*SZ.CS.)
JELENTŐSÉG + MERRE VEZET MINDEZ?
Ó! PARADIGMAVÁLTÁS!
Honnan tudná az ember, hogy melyik a saját útja, ha csak járt utakon jár?

– Reinhold Messner