Spin Radiation: Properties and Suggested Experiments

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INTRODUCTION

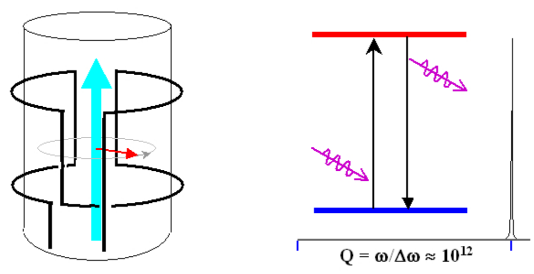
In normal MR practice, nuclei are excited and their spin states are detected by induction coils or cavities. Under these conditions, a theoretical physicist has to cope with the complex problem of the interaction of nuclear spins with the front-end device via non-radiative electromagnetic field. This raises conceptual doubts [1-2] which are still not completely settled [1], especially when it comes to reconciling in a single theoretical framework the evolution of macroscopic nuclear magnetization (Bloch equations and classical induction) with the quantum characteristics of NMR spectra with their complex Hamiltonians and sharp transitions.

Recent studies of *spin noise induction* [3-5] are throwing new light on these problems and raise new questions about the emission/absorption of electromagnetic quanta by spin systems and about their phase coherence. The topic has been brought up also by the author at a couple of Conferences in the context of long-range detection and/or stimulation of spin radiation which might pave a way for MR on scales ranging from sub-planetary to astronomical.

This poster discusses some properties of spin radiation such as its chirality and directionality, proposes experiments which might clarify whether they obey quantum rules, and speculates what those rules imply in terms of remote spin-radiation MR spectroscopy. The outcome of such experiments should lead to further elucidation of those aspects of spin induction & radiation which are still subject to discussions.

Various descriptions of the MR phenomenon

According to a specific context, we routinely switch between markedly different types of descriptions (explanations) of the MR phenomena:



- **Classical induction** is used to describe technical aspects of inductively detected nuclear magnetic resonance. This includes macroscopic Bloch equations and most technical descriptions of the front-end sensor coil assemblies (left drawing).
- **Quantum physics of single systems** is used to describe NMR and ESR spectra with their incredibly high "quality factors" which are completely out of reach of any classical device (right drawing). This category includes principally the simulations of spin system spectra.
- **Hybrid descriptions employing ensemble quantum mechanics** (density matrics) are used to describe some of the collective properties of spin systems such as relaxation and phase coherences which paly a crucial role in the design of complex pilse sequences.

Which of these descriptions is correct?

Or, rather, how can they be reconciled? This is still an open problem, even though serious progress has been done during the last decade and more can be expected from the study of now well established phenomenon of relatively easily detectable spin noise "radiation".

Spin Induction versus Spin Radiation

It has been pointed out repeatedly that standard NMR signal detection phenomena such as FID (Free Induction Decay) and spin noise, though quantum, are NOT of a radiative nature. In order to explain their undeniable quantum aspects it is therefore necessary to resort to the quantum electrodynamics with its concepts of virtual photons and describe the interaction between a spin system and the coil (or cavity) in terms of virtual photon creation and annihilation operators. This, though feasible, looks overly complicated and has been never really carried all the way through.

Be it as it is, it appears that a true non-local spin radiation over large distances (a non-local set-up) has never been detected or, apparently, not even looked for.

On the other hand, it is not clear why traditional, remote spin systems spectroscopy should be impossible, except perhaps for its prohibitively low absorption and emission intensites.

There arises a suspicion that perhaps some of its properties make its detection improbable or that it has not been looked for assiduously enough. The Author is convinced that true spin radiation detection is possible in both absorption and emission modes but that, in order to be successful, one must take into account some of its distinguishing properties.

Of course, since spin radiation is still hypothetical, so are its properties. Until successful experimental detection, we cannot but speculate and make conjectures about them.

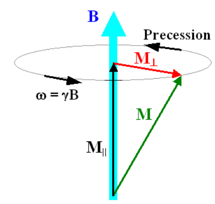
In what follows, I wish to make two conjectures about spin radiation, namely its **chirality** and its marked **directionality**, which, if confirmed, might be extremely helpful in its detection.

Chirality of spin radiation

Considering the nature of Larmor precession about an external magnetic field there is little doubt that any **emitted spin radiation must be circularly polarized**.

Since the "generator" of the radiation is a **rotating** magnetic dipole (which in turn generates a rotating electric component), the emitted photons will necessarily have a rotating magnetic component.

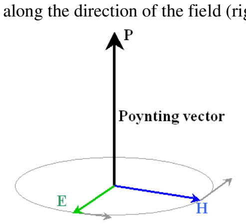
Absorbtion of radiation would appear to be subject to less stringent requirements in order to be effective. Like in the case of traditional excitation in a coil or cavity, it is sufficient that it contains a circularly polarized component compatible with the processing dipoles.



Since chiral RF and MW transmitters and receivers both exist and are commonly used, the chirality of spin radiation may serve as one of its distinctive features.

Directionality of spin radiation

Considering Maxwell equations and, in particular, the definition of the Poynting vector (left Figure), it is easy to see that a magnetic moment precessing about a magnetic field should irradiate energy along the direction of the field (right Figure).



$\nabla \times E = -\mu\, \partial H/ \partial t$

$\nabla \times H = +\varepsilon\, \partial E/ \partial t$

$\nabla . E = 0$

$\nabla . H = 0$

$P = E \times H$

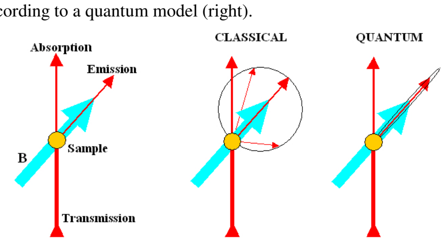
Elmag radiation:

$E \perp H$, $E \perp v$, $H \perp v$

$|v| = c$

$|E|/|H| = Z_0$ (377 Ω)

A doubt which can arise at this point regards how narrow will such a **spin radiation beam** be. In a stimulated spectroscopic arrangement like the one shown below left, assuming that the incident radiation is effective in stimulating spin radiation emission, the latter could behave either according to classical laws (rotating classical dipole) with its rather low directionality (center) or according to a quantum model (right).



The quantum description, clearly preferred in this case, follows from the fact that an emitted photon, having spin 1, carries away one complete quantum of magnetic momentum and this must match the $\Delta I_z = 1$ condition of allowed transitions within a spin system.

Hence the conjecture that the emitted beam, if detectable, will be extremely narrow (it can be shown that it will be broadened only by spin-lattice interactions – the same ones which give rise to longitudinal relaxation.

Is it possible to test these conjectures experimentally

Over typical laboratory distances it may be too difficult to dispose of transmitter and receier antennas with sufficiently narrow beams at NMR frequencies, but ESR experiment at microwave lengths are clearly possible. Sample and field arrangements like the one in the above Figure are also feasible, so there is hope ...

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This poster and additional information is permanently available in *Stan's Library* (www.ebyte.it/stan/Poster_SpinRadiation.html).

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