

Is Quantum Mechanics Necessary for Understanding Magnetic Resonance?

by

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Aim of the paper

1. MR is often presented as a phenomenon that necessitates a quantum mechanical explanation whereas it really is a classical effect
2. Few attempts to challenge common misleading explanations
3. It is the purpose of this article to:
 - a) challenge some of the myths and misleading explanations appearing in MR tutorials.
 - b) to suggest alternative, yet correct explanations and graphs based on classical mechanics only.

The theory section provides examples of common misconceptions, prove them wrong or misleading, and gives alternative explanations.

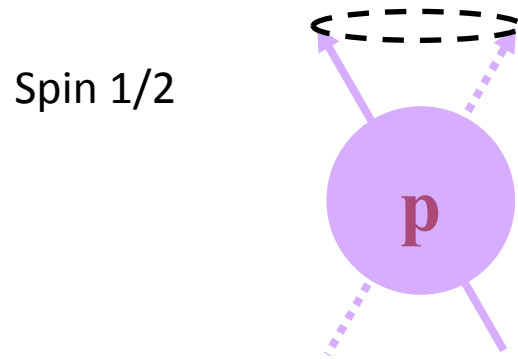
Myth 2: **MR Is a Quantum Effect**

- Proton spin is a quantum effect but MR is not
 - MR deals with manipulation of magnetization which is the net sum of all the spins in the system (ensemble of spins) and can therefore accurately be described by classical mechanics => correspondence principle
- MR is not a QM measurement, but a classical one
 - Measuring the precession of magnetization does not collapse the system into one of its eigenstates

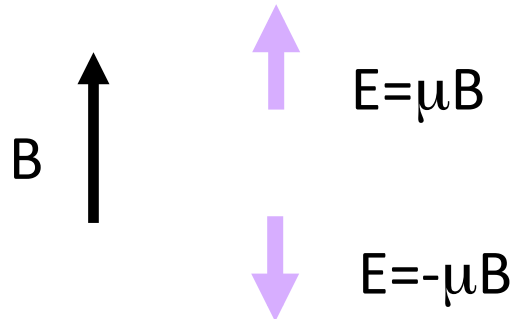
Example of Bad Explanation?

Spin Angular Momentum

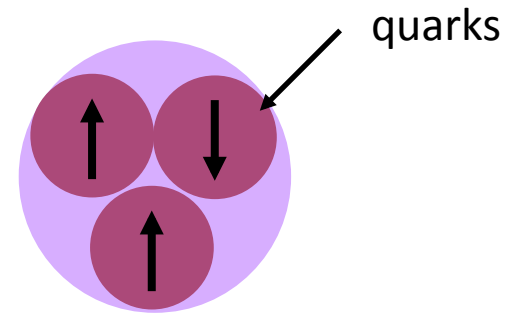
Classical View



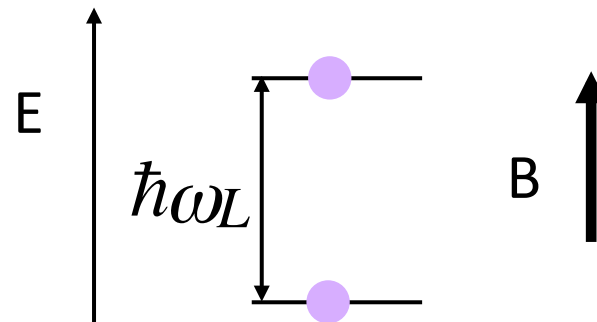
Precessing top



Quantum View

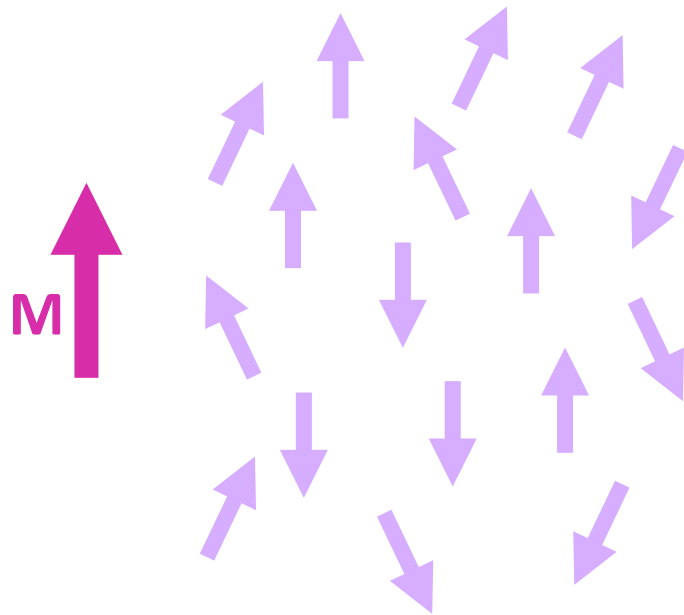


Property of quarks



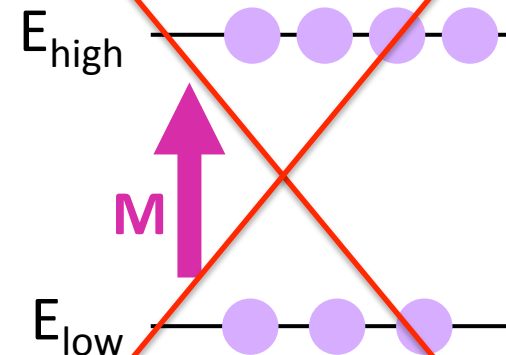
Spin Ensemble \rightarrow Magnetization

Classical View



$M =$ Vector sum of all
the spins

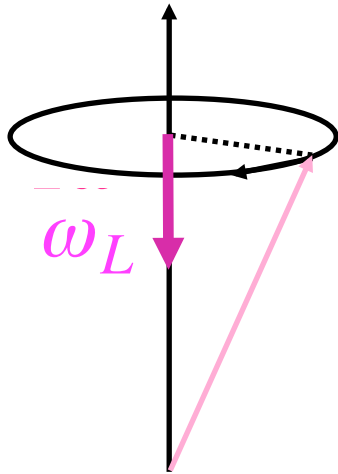
Quantum View



$M =$ Population
difference between the
two energy levels

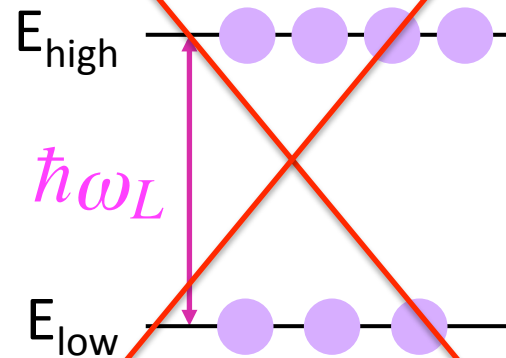
Larmor Frequency

Classical View



ω_L = Frequency of precession of M

Quantum View

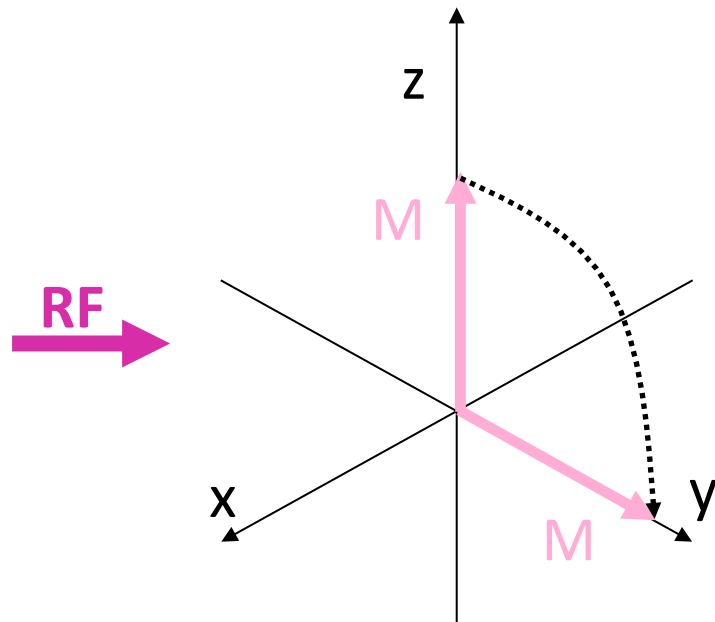


ω_L = Frequency defining the separation of energy levels

$$\omega_L = \gamma B$$

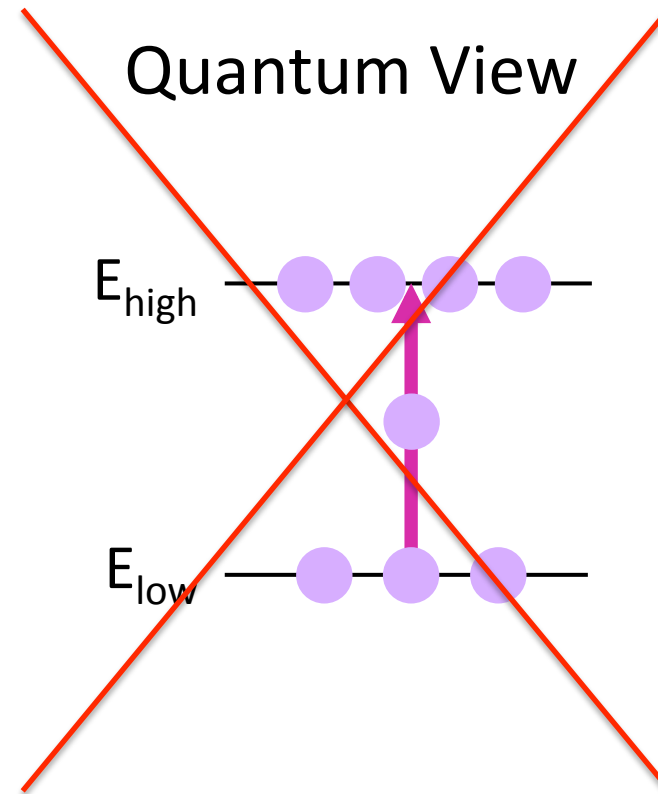
RF Excitation

Classical View



RF pulse tips magnetization away from z -axis

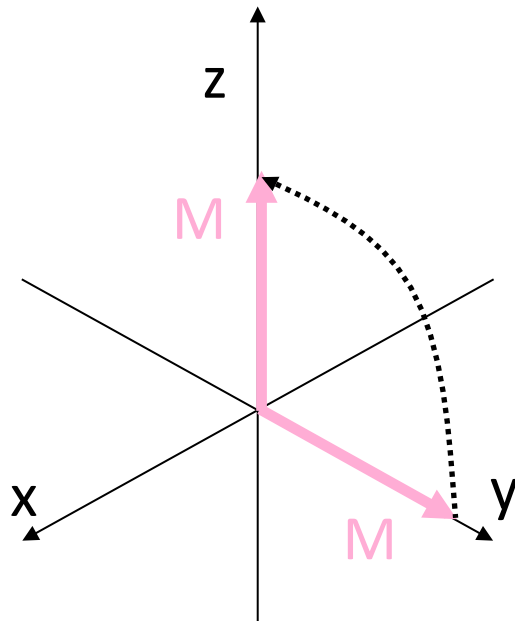
Quantum View



RF pulse excites transitions of atoms from low to high energy level

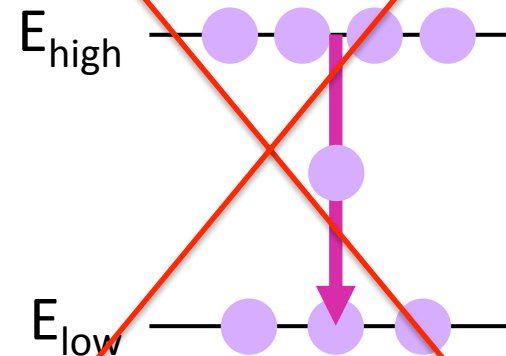
RF Relaxation

Classical View



Relaxation of
Magnetization towards its
thermal equilibrium

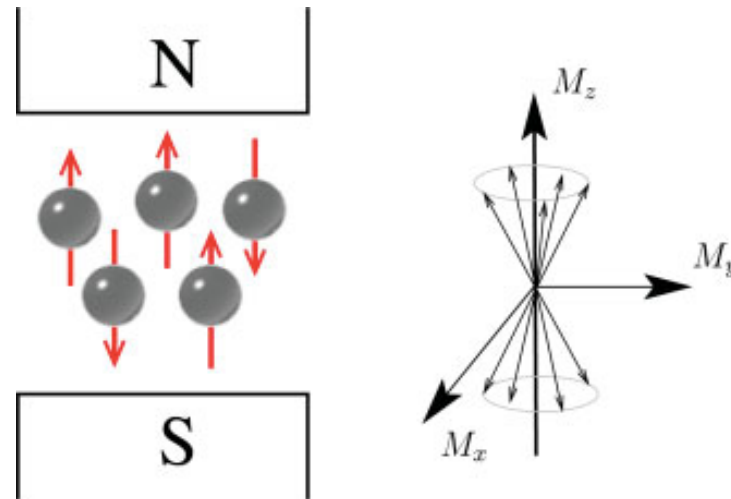
Quantum View



Relaxation of atoms back to
the ground state

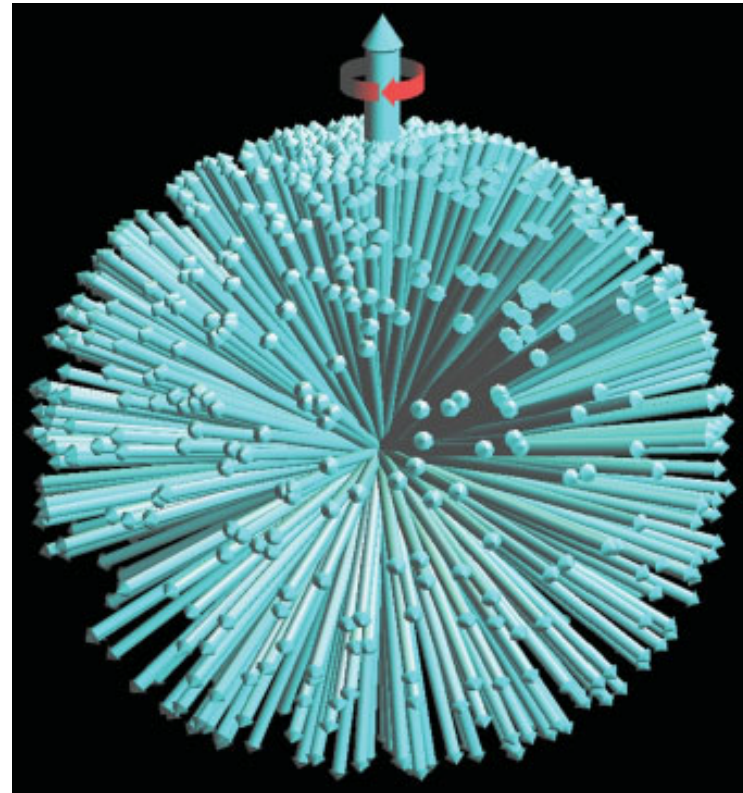
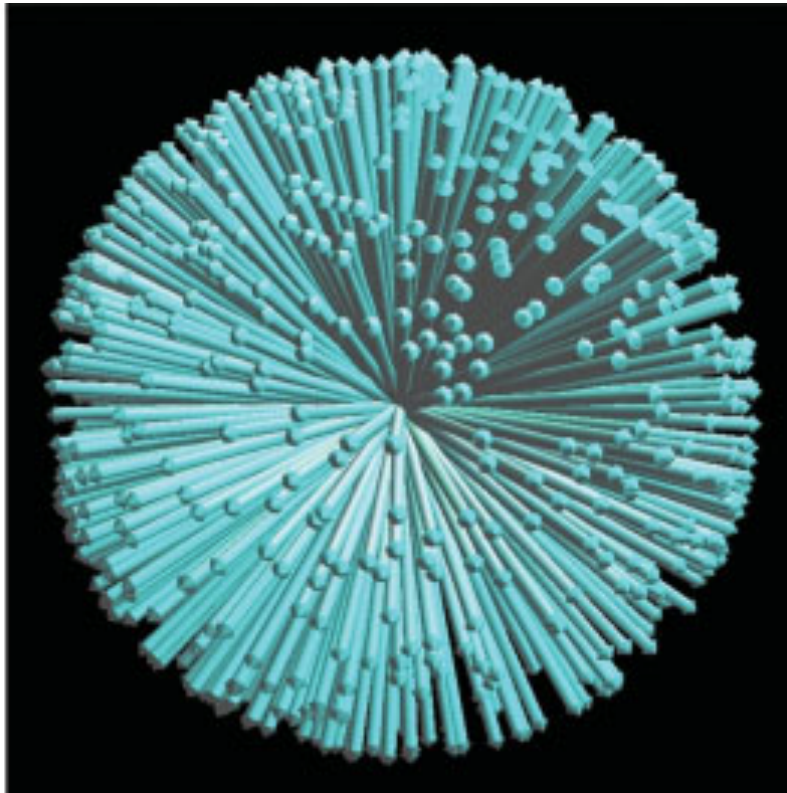
Myth 1:

According to QM, Protons Align Either Parallel or Anti-parallel to the Magnetic Field

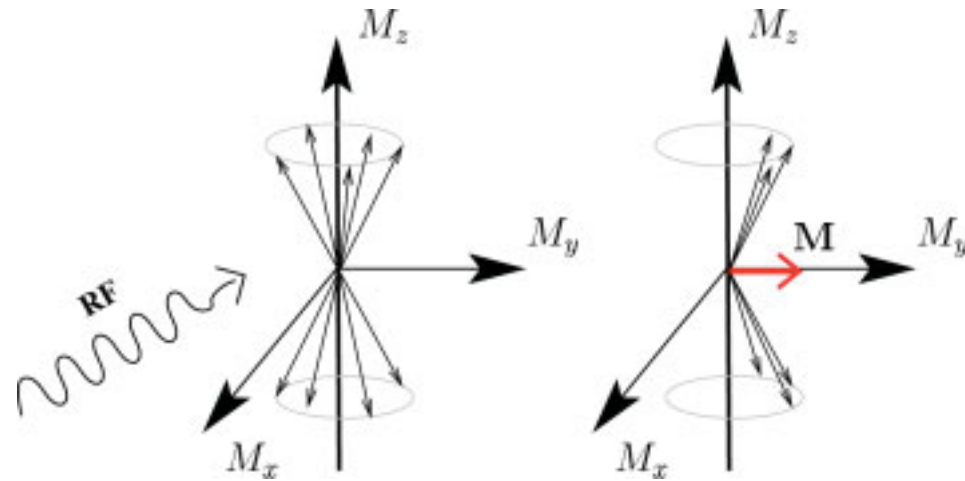


- Fact: spins (before and after MR measurement) are in the superposition of eigenstates
- A measurement of the net magnetization causes a perturbation of the system that is insufficient to affect the individual protons significantly. In particular, they are not brought into their eigenstates by the measurement process.

Myth 1:
Alternative representation

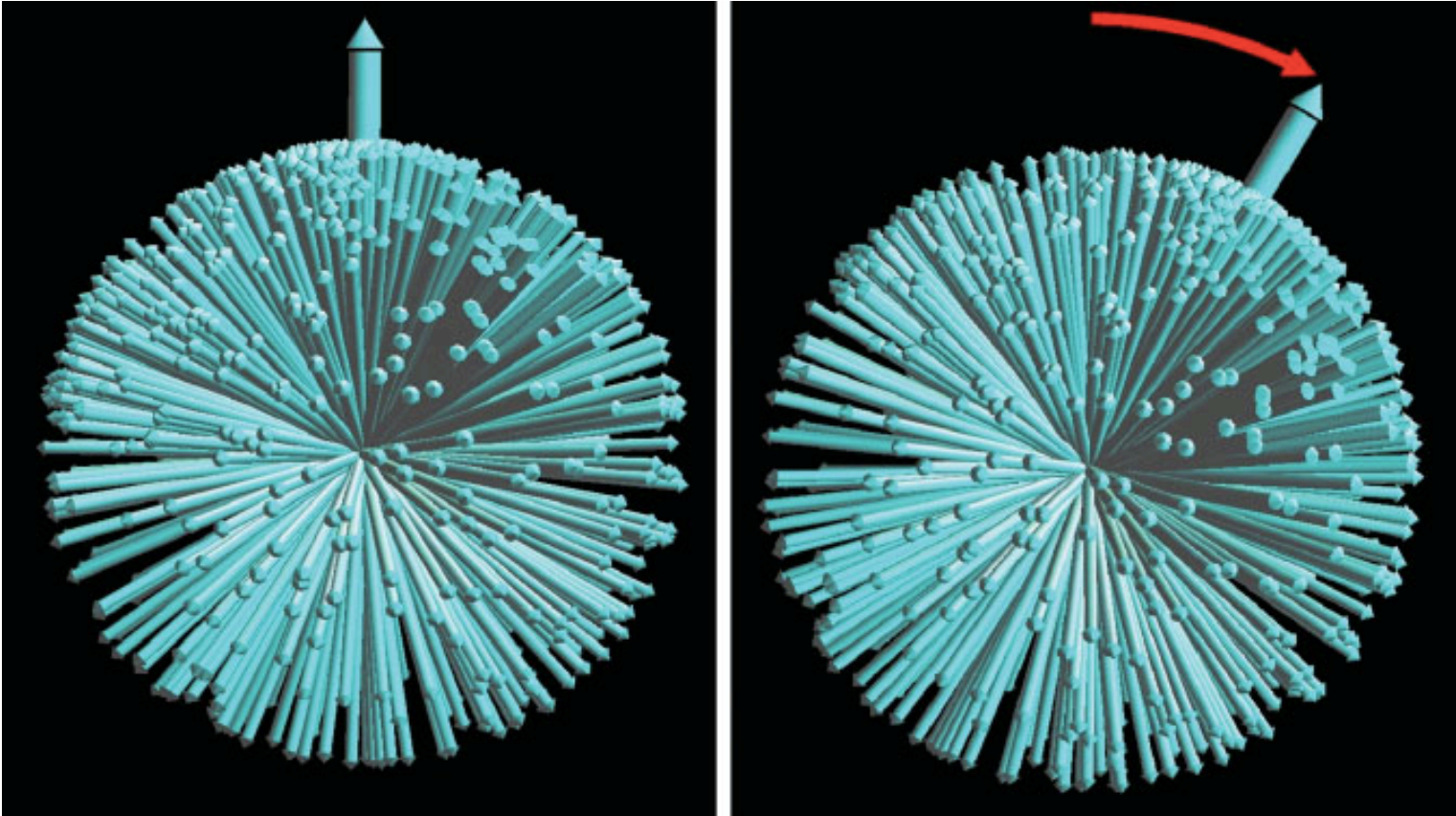


Myth 3: RF Pulses Brings the Precessing Spins into Phase



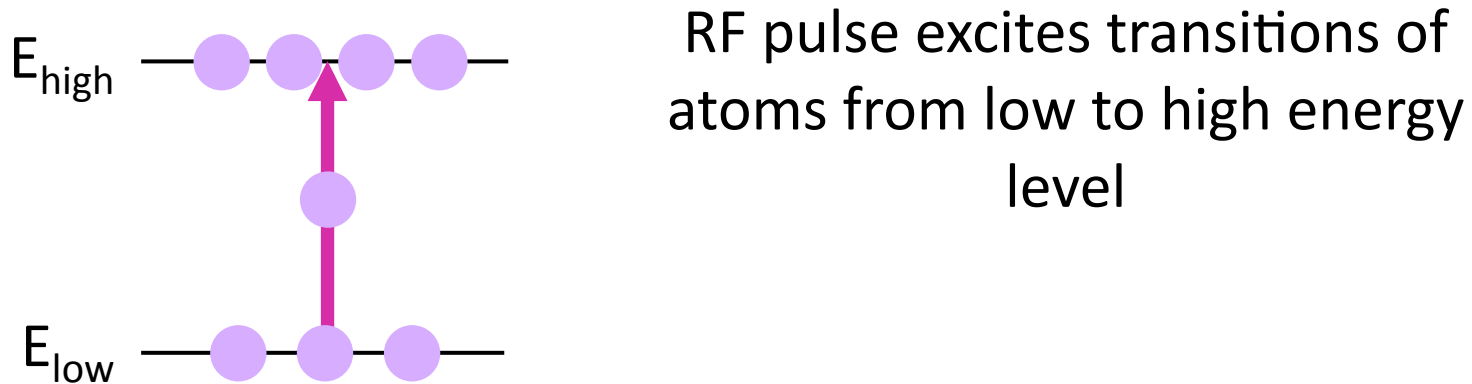
- This results from the attempt to explain transverse magnetization
- RF fields cannot change relative orientation between non-interacting spins

Myth 3:
Alternative representation



Myth 4:

MR is described by absorption and emission of RF radiation and therefore photons



- Dipole generates 2 fields, near- and far-field (EM theory)
 - Emission/absorption of RF field (photons) is a far field phenomena
 - MR detection/reception is a near-field phenomena (because RF wavelength is bigger than the object dimension)
- => MR is very different from other types of spectroscopy (Raman and IR, where real photon transitions occur)

Myth 4: **Alternative representation**

1. Hoult introduces about virtual photons
 - “misunderstanding of the process of nuclear magnetic resonance NMR signal generation and reception, and even in accepted texts, it is frequently described in terms of absorption and emission of radio waves, or radiation, by a two-level quantum system”.
2. Need to conceptualize interacting dipoles => relaxation

Conclusion

- Using a scanner, it is extremely difficult to do experiment that reveal the quantum aspects of MR. Hence, the natural consequence is to acknowledge that MR is accurately described as a classical phenomenon
- The consequence in the context of MR is that a classical description is adequate, and overwhelmingly so in tutorials for nonphysicists