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Educational simulator app and web page for exploring Nuclear and Compass Magnetic Resonance

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Introduction

A graphical app and browser-based simulator, **CompassMR**, was developed for initial Magnetic Resonance (MR) education. It is available at *http://drcmr.dk/CompassMR/* and executes directly in most browsers with no further need for software. Easy access and a simple user interface invite student experimentation that improves understanding of basic MR phenomena.

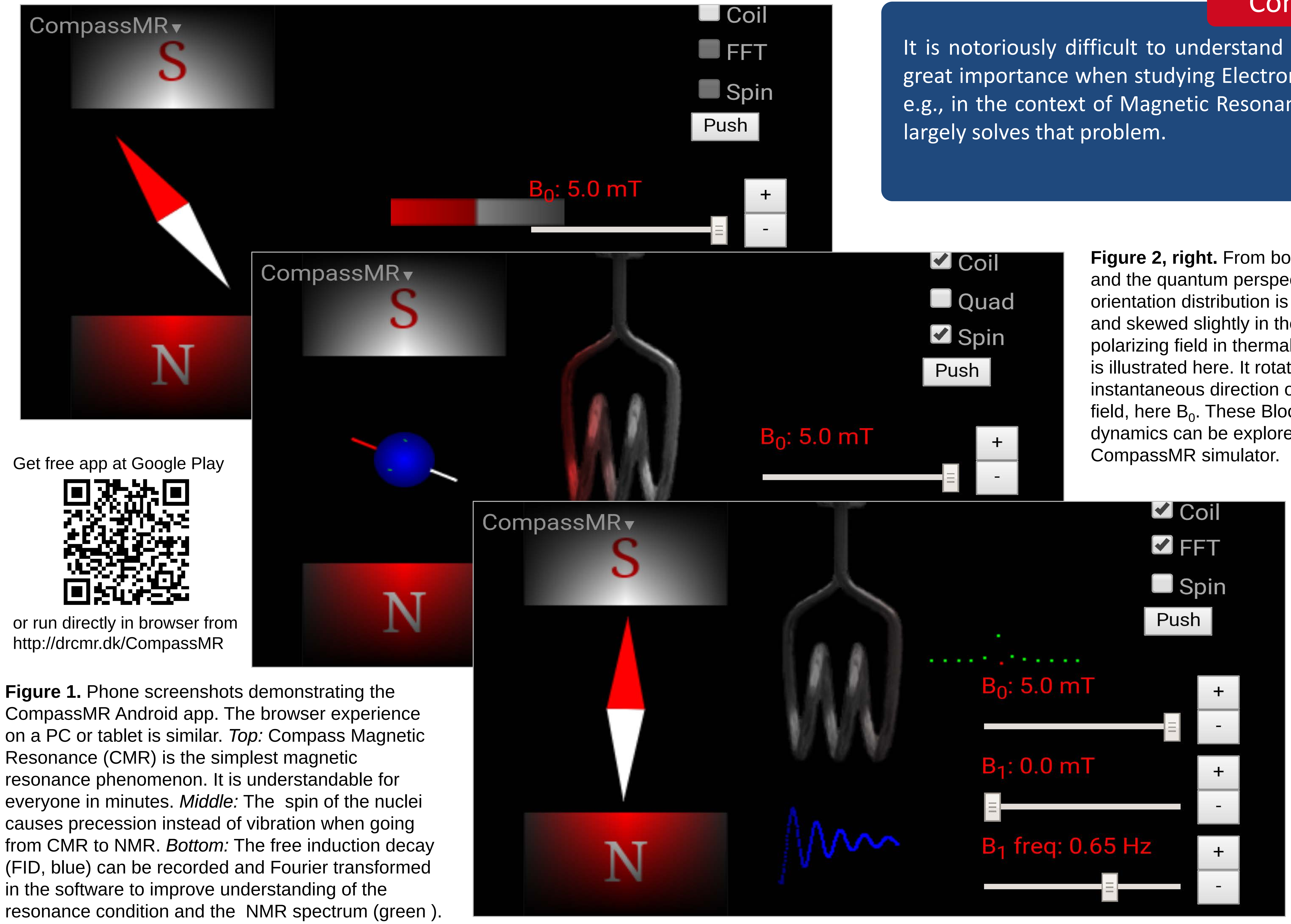
The simulator is used to introduce and explore electromagnetism, magnetic dipoles, static and radiofrequency fields, Compass MR, the free induction decay (FID), relaxation, the Fourier transform (FFT), the resonance condition, spin, precession, the Larmor equation, Nuclear MR, resonant excitation (linear and quadrature), and off-resonance effects.

Methods

The simulator is a complete HTML5/JavaScript[1,2] rewrite of the JavaCompass[3] so it now executes in modern browsers with no additional software needed. Spin dynamics and enhanced responsiveness was added. Android App conversion was accomplished using Adobe PhoneGap[4].

The basis for the graphical spin simulation is the semi-classical Bloch vector equation[5] for a proton in combined stationary and oscillating magnetic fields, B_0 and B_1. For providing intuitive insight, the corresponding classical equation of motion for a compass needle in similar fields is used to simulate Compass Magnetic Resonance (CMR) that is similar to NMR except for needle vibration substituting nuclear precession. The nuclear Bloch vector moves like the magnetic moment of a classical rotating charge distribution [6] as shown in the simulator.

Spin is a consequence of Quantum Mechanics (QM) and not all aspects of spin and nuclei are represented in this naive picture. Beyond spin, the consequences of QM for proton MR are largely not observable, however, and the QM Bloch vector moves as shown in the simulator. Hence, it demonstrates nuclear dynamics more accurately than typical QM-inspired "cone" pictorial representations aimed at giving better representations of MR than classical mechanics, while often doing the opposite. This justification of the classical perspective is discussed in detail in [7].



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or run directly in browser from http://drcmr.dk/CompassMR

Figure 1. Phone screenshots demonstrating the CompassMR Android app. The browser experience on a PC or tablet is similar. *Top:* Compass Magnetic Resonance (CMR) is the simplest magnetic resonance phenomenon. It is understandable for everyone in minutes. *Middle:* The spin of the nuclei causes precession instead of vibration when going from CMR to NMR. *Bottom:* The free induction decay (FID, blue) can be recorded and Fourier transformed in the software to improve understanding of the resonance condition and the NMR spectrum (green).

Conclusion

It is notoriously difficult to understand the demonstrated concepts , but they are of great importance when studying Electron or Nuclear Magnetic Resonance (ESR, NMR), e.g., in the context of Magnetic Resonance Imaging (MRI). The CompassMR simulator largely solves that problem.

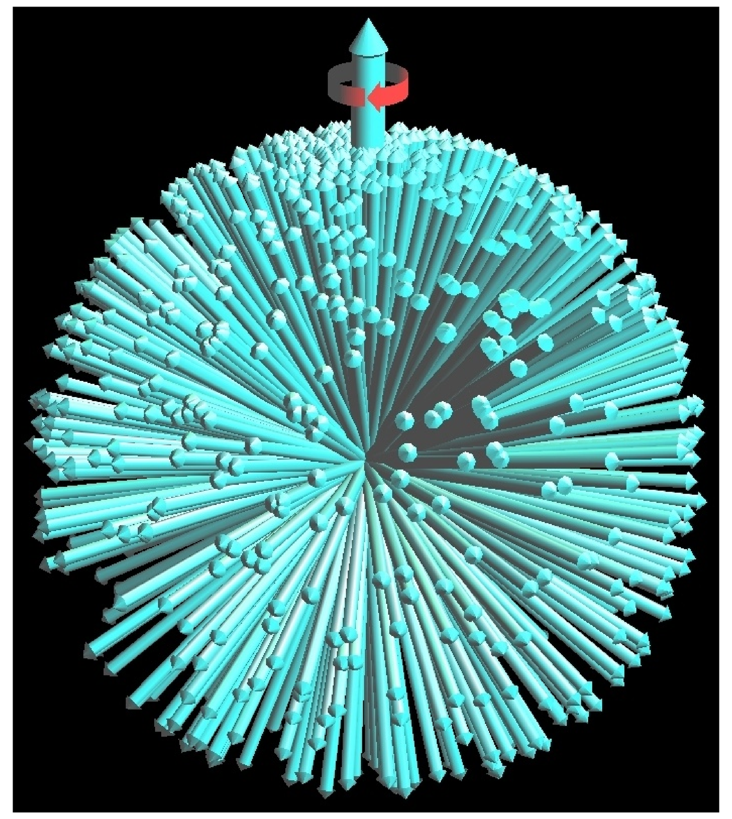

Figure 2, right. From both the classical and the quantum perspective, the spin orientation distribution is near isotropic, and skewed slightly in the direction of the polarizing field in thermal equilibrium. This is illustrated here. It rotates around the instantaneous direction of the magnetic field, here B_0. These Bloch vector dynamics can be explored using the CompassMR simulator.

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