A mechanical analog of Nuclear Magnetic Resonance

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Wishful thinking
A long time ago, in a galaxy far far away, nuclei were invented. At some point between then and now, a technique called NMR spectroscopy was developed, and at present, most college students in chemistry are able to successfully “turn the crank” and use the device; however, the models generally presented for the functioning of NMR are really confusing!

Laboratory Structure
Our Modern Physics Laboratory is structured such that students can build physical understanding of the investigations. In the case of NMR, the students examine a number of different resonance investigations: Mechanical driven oscillator, RLC circuit, Mechanical model of NMR, and then onto NMR.

Deciphering NMR through basic theory
There are different “styles” of NMR spectroscopy: the external field can be swept; the frequency of a driving RF wave can be swept; or the driving RF wave can be pulsed pulsed. Either method causes certain particles to resonate at characteristic fields / frequencies, allowing for characterization of materials.

The complexities of NMR can be understood by first understanding precession of a magnetic moment under a magnetic field. The field provides a torque $\tau$ on the magnetic moment $\mu$ in order to line the particle’s angular momentum $L$ up with $B_{\text{ext}}$.

$$\tau = \mu \times B = \gamma L \times B$$

The torque is equal to a change in angular momentum over change in time, and the change in angular momentum can be rewritten to give the following:

$$|\tau| = \frac{\Delta L}{\Delta t} = \frac{L \sin \theta \Delta \phi}{\Delta t} = \frac{I \omega \sin \theta \Delta \phi}{\Delta t} = \frac{\mu B \sin(\theta)}{I \omega}$$

Finally, we get the Larmor frequency.

$$\frac{\Delta \phi}{\Delta t} = \frac{\mu B}{I \omega}$$

This frequency is the frequency at which the particle’s angular momentum precesses about the external field and is the resonant frequency.

Conclusion
Like many things in life, NMR Spectroscopy is presented to most students on a silver platter, and the actuality of what is happening is usually an afterthought; however, our relatively simple model was able to give a clear, macroscopic picture of what is happening in the mysterious technique known as NMR spectroscopy. It’s really not all that complicated! The usefulness of this model does not stop here. Further research is being planned to make use of this setup in understanding Magnetic Resonance Imaging (MRI) as well as resonance in different atomic environments (with other structures). Future research will give students a more in depth vision of these chemical and medical (but inherently physical) techniques.