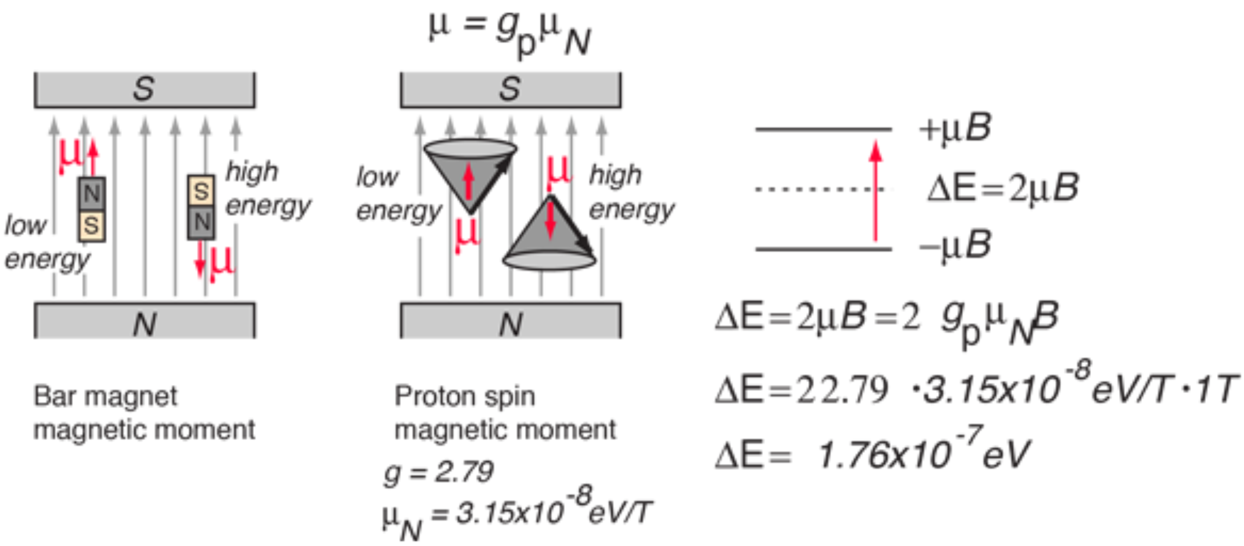
Nuclear Spin Polarization

In nuclear magnetic resonance (NMR) studies, a strong magnetic field is used to partially polarize the nuclear spins. Taking protons as the most common example, the excess of proton spin in the direction of the magnetic field constitutes a small net magnetization of the material. The proton spin tends to align with the magnetic field, that being the state of minimum magnetic potential energy. The proton can take only two spin states which are visualized as states of precession of the proton spin around the magnetic field direction (low energy) and around the direction opposite the field (high energy). The behavior of the proton magnetic moment in the magnetic field can be visualized like a tiny bar magnet between two magnetic poles. It will tend to align with the field and it takes positive work to turn it opposite the field. The difference in energy between the two proton spin states for a magnetic field of 1 Tesla (10,000 Gauss) is shown below.



Note that the energy difference between the spin states is very small in comparison with the average thermal energy of about 0.04 eV at 300K temperature. This implies that the degree of polarization that can be maintained at ordinary temperatures is very small indeed. The equilibrium difference between the lower and upper states is given by the Boltzmann factor, which in this case can be approximated by the first two terms of the exponential series.

$$e^{\frac{-\Delta E}{kT}} \cong 1 - \frac{\Delta E}{kT} = 1 - \frac{1.76x10^{-7}}{0.04} = 1 - 4.4x10^{-6}$$

The excess of protons in the aligned (lower) state is only about four out of a million. Fortunately, this tiny fractional excess is enough to allow sufficient signal strength for NMR to make it a major analytical tool in chemistry.

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References
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