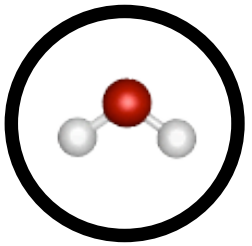
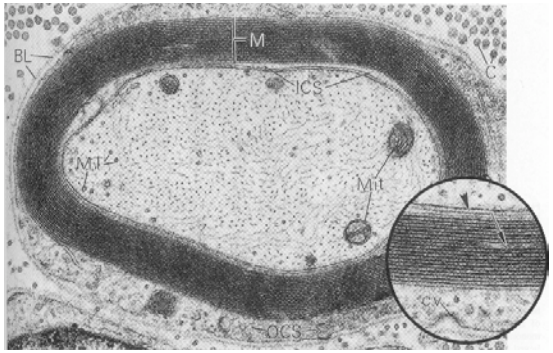
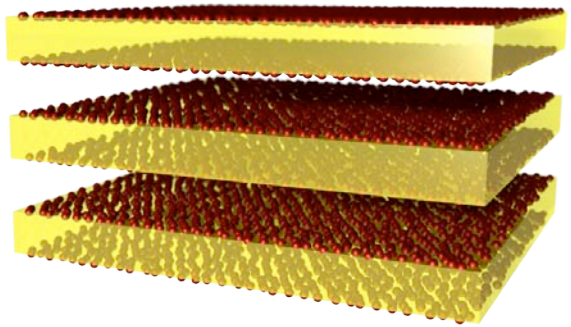
Cell membranes and cell water diffusion



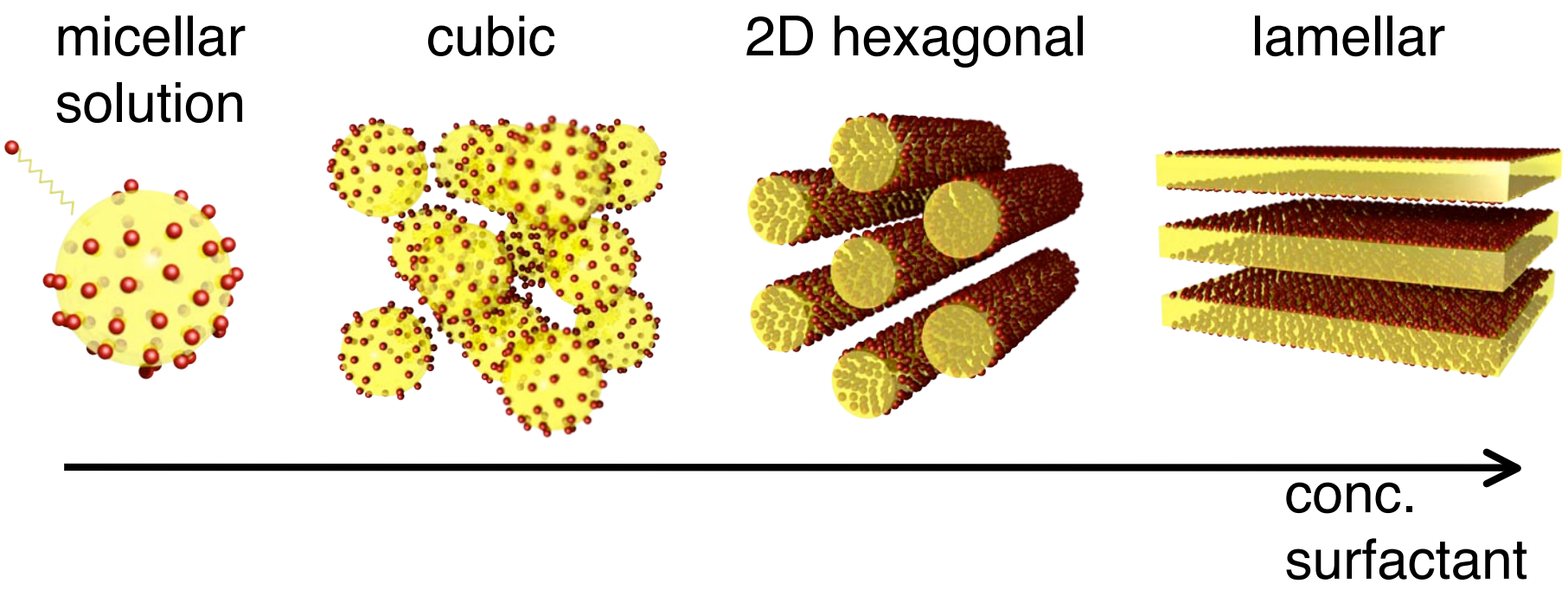
- Membranes
  - Anisotropic motion
  - Effect on ^{31}P MRS
- Basics of diffusion MRI
- Water diffusion in cells





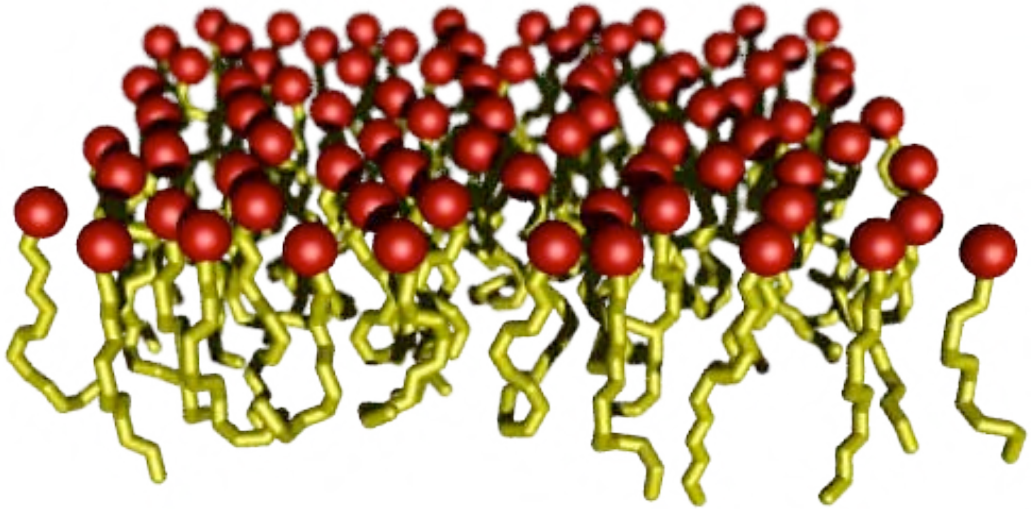
Surfactants and liquid crystals

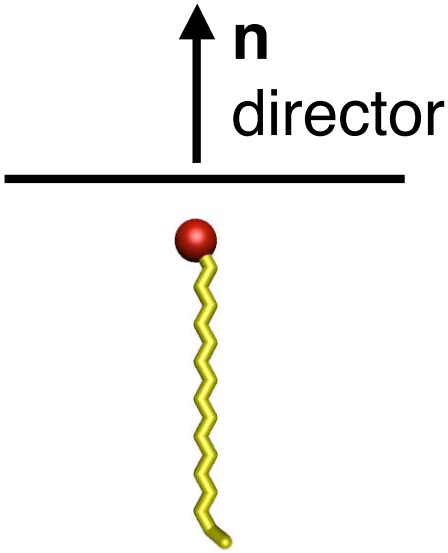
Self-assembly in water solution



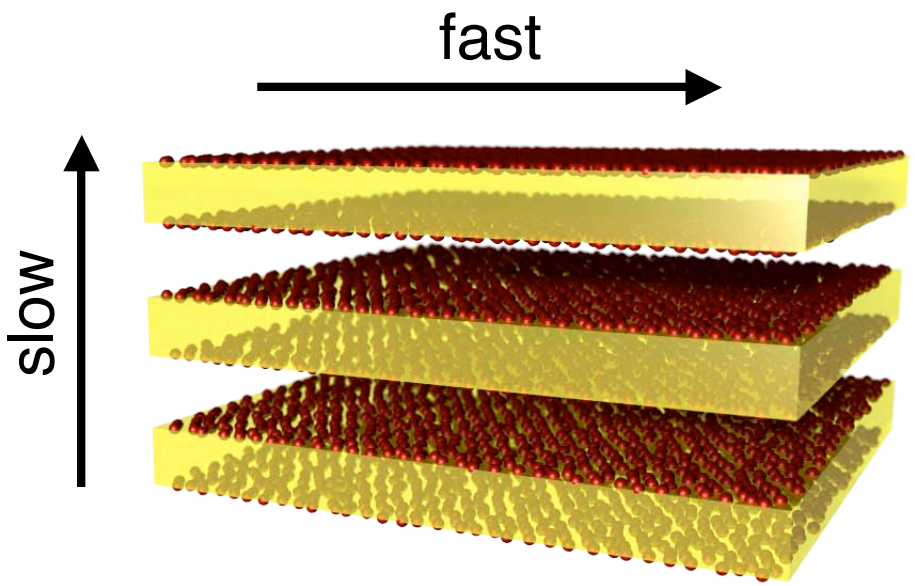
Motion in a lamellar phase

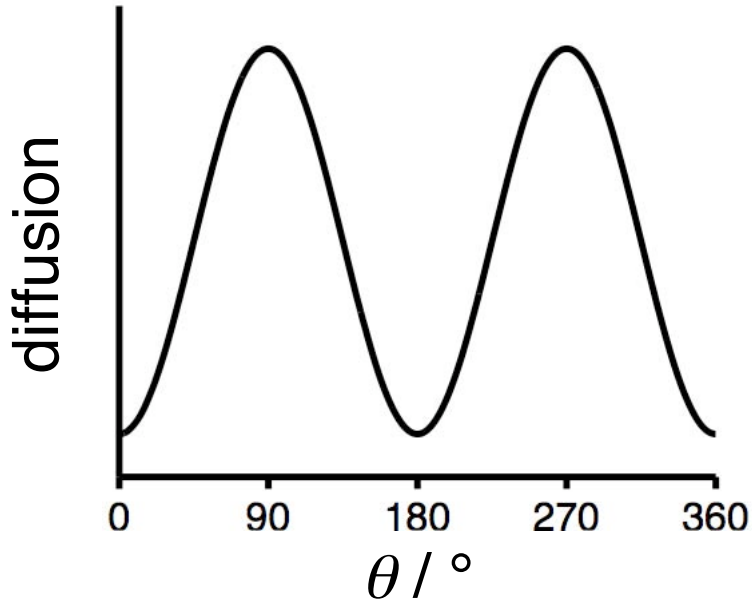
- Rotation, translation, change of conformation
- Fast, but anisotropic!

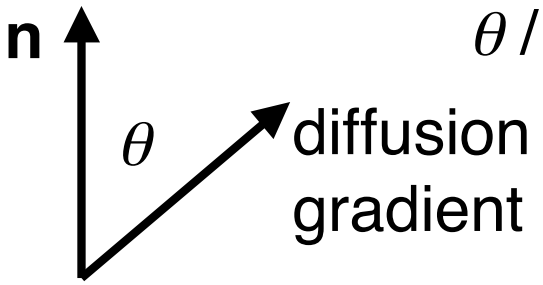




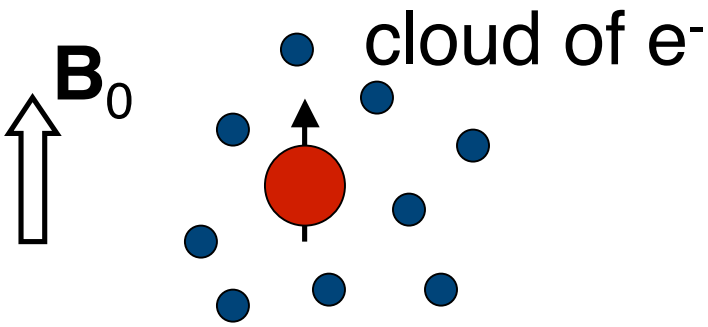
Anisotropic self-diffusion





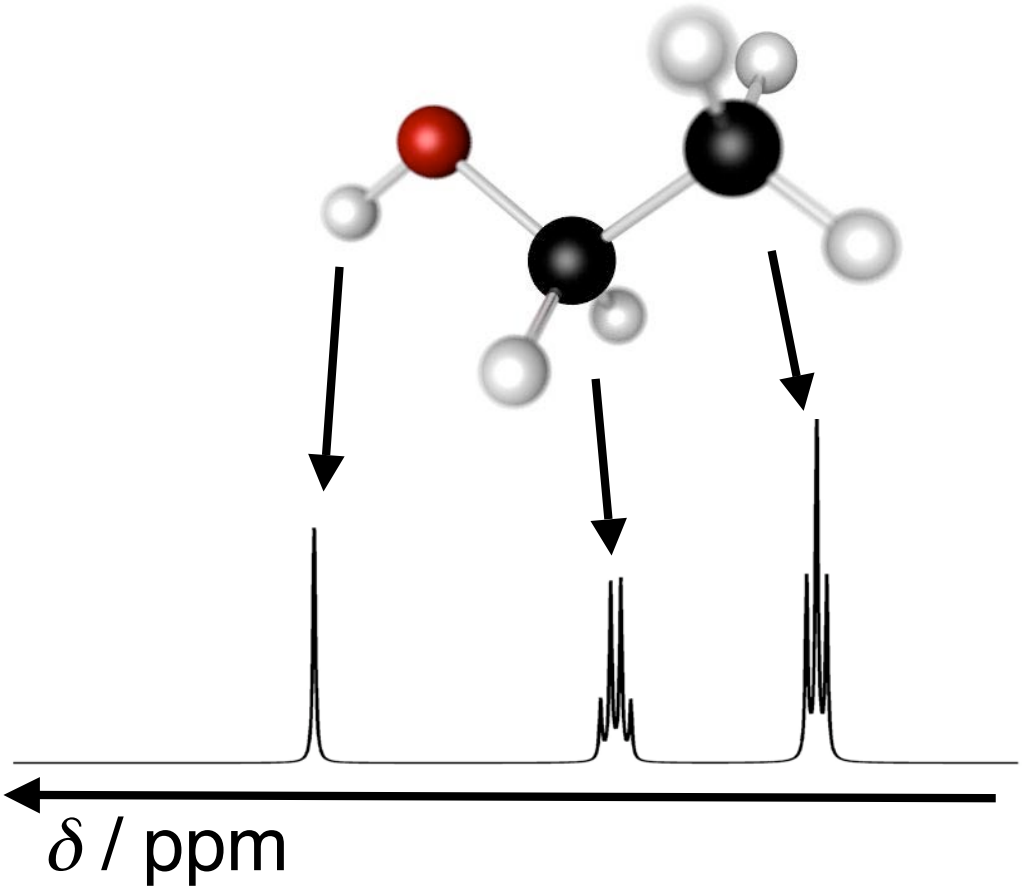


Chemical shift, δ



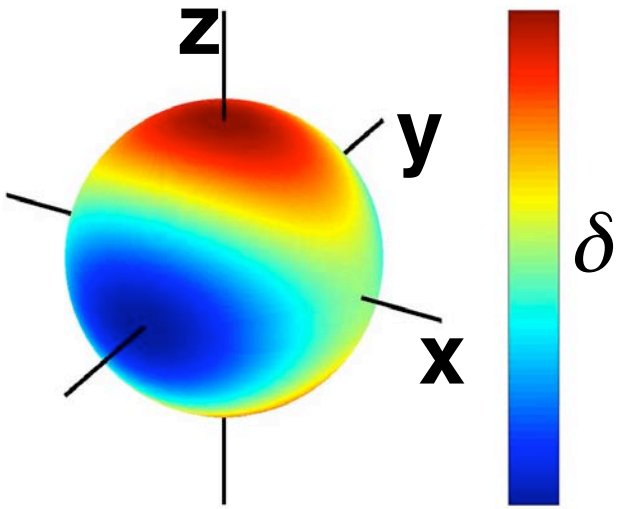
$$\omega_0 = \gamma B_0 (1 - \sigma)$$

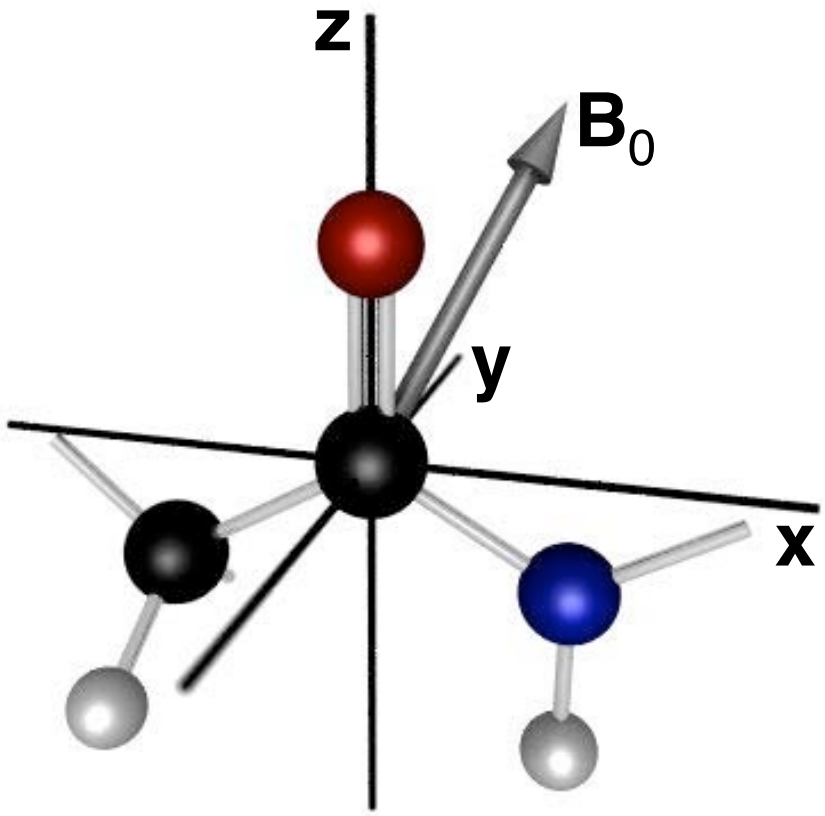
chemical shielding



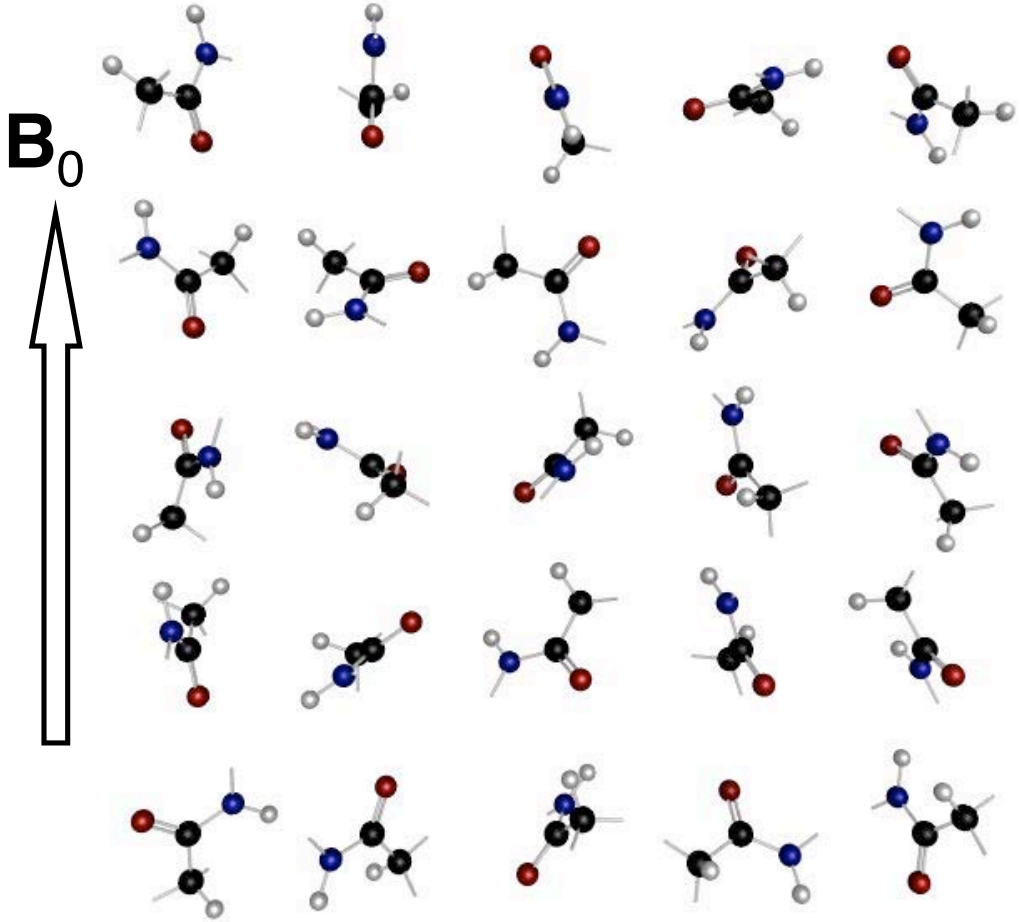
Chemical shift anisotropy (CSA)

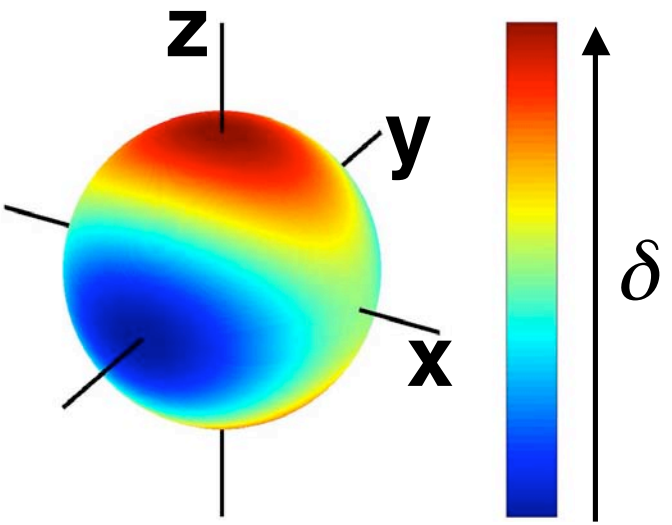
Shift depends on relative orientation $\mathbf{B}_0$ - molecular frame

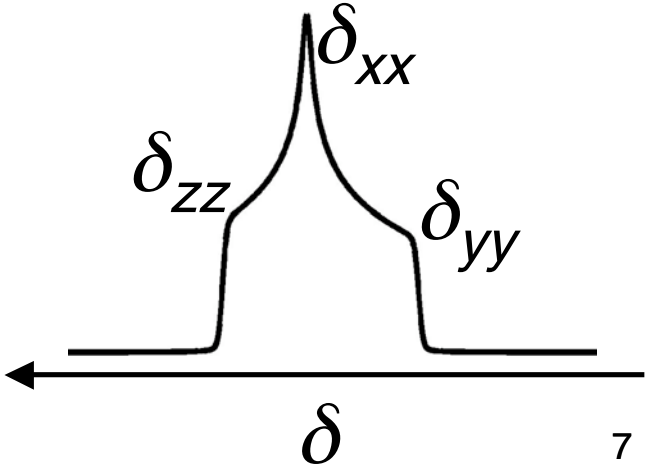




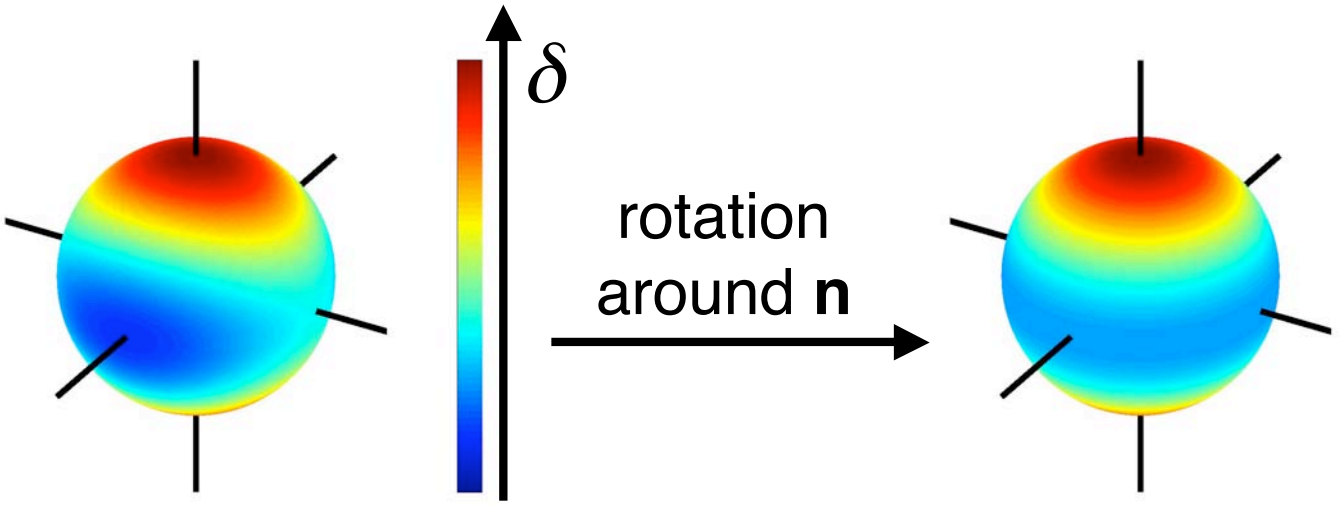
Powder pattern

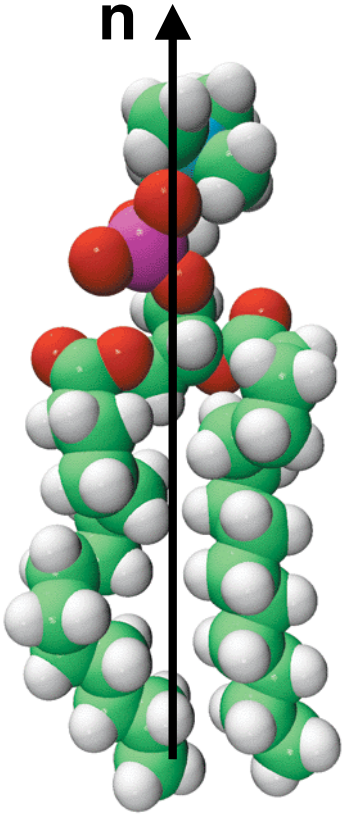






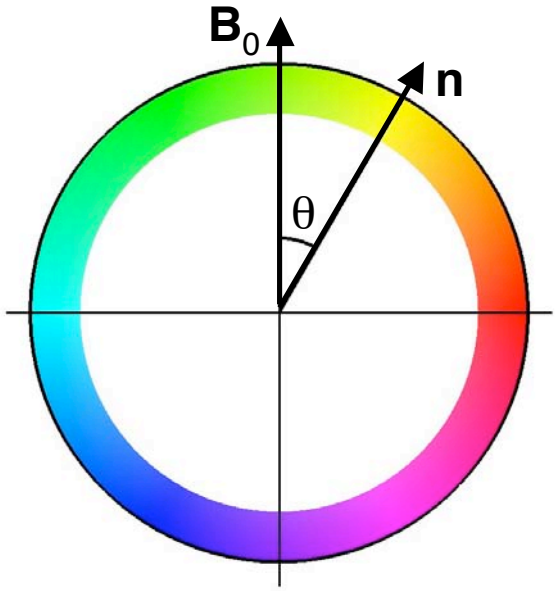
Rotation around molecular axis

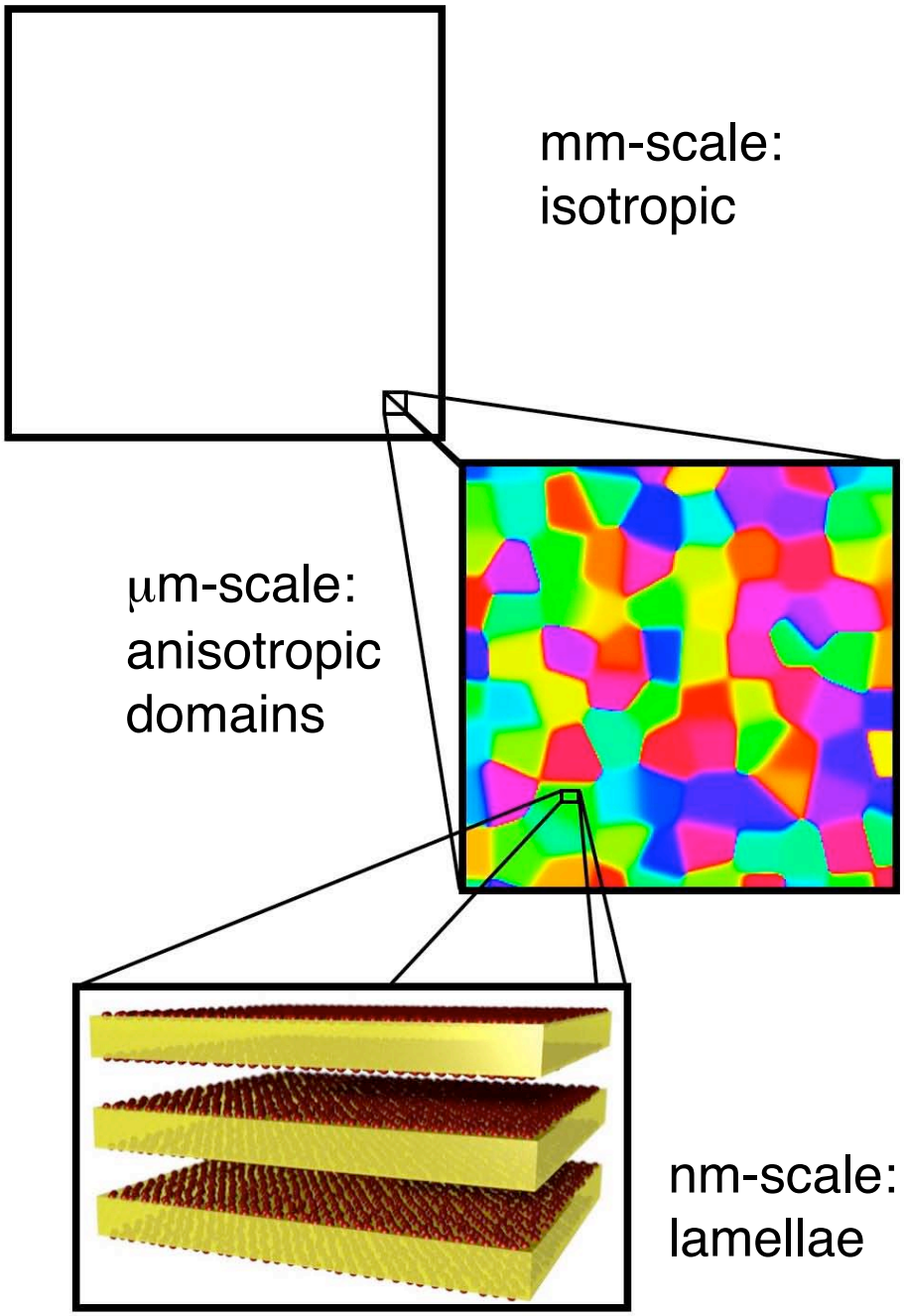




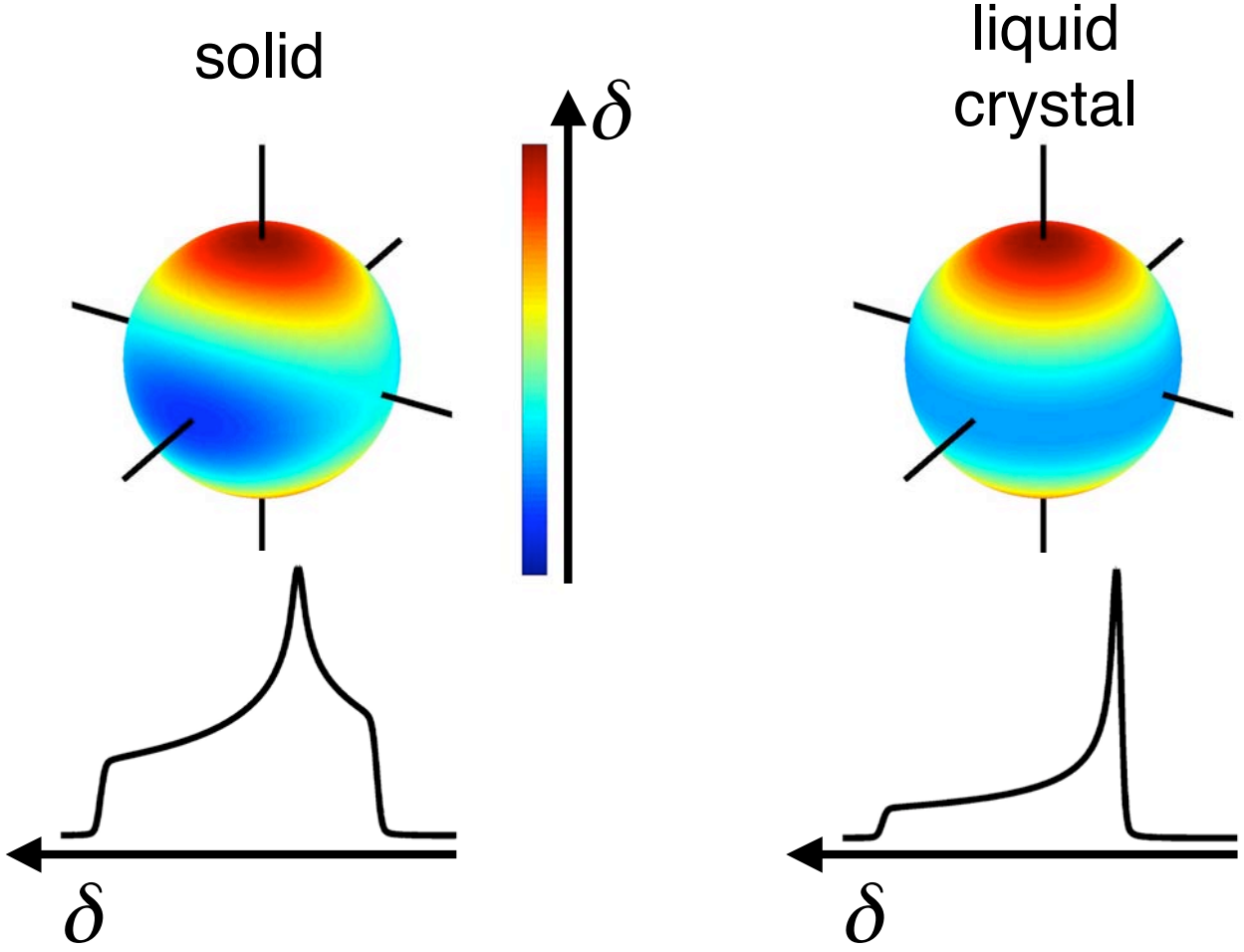
DMPC from
Avanti website

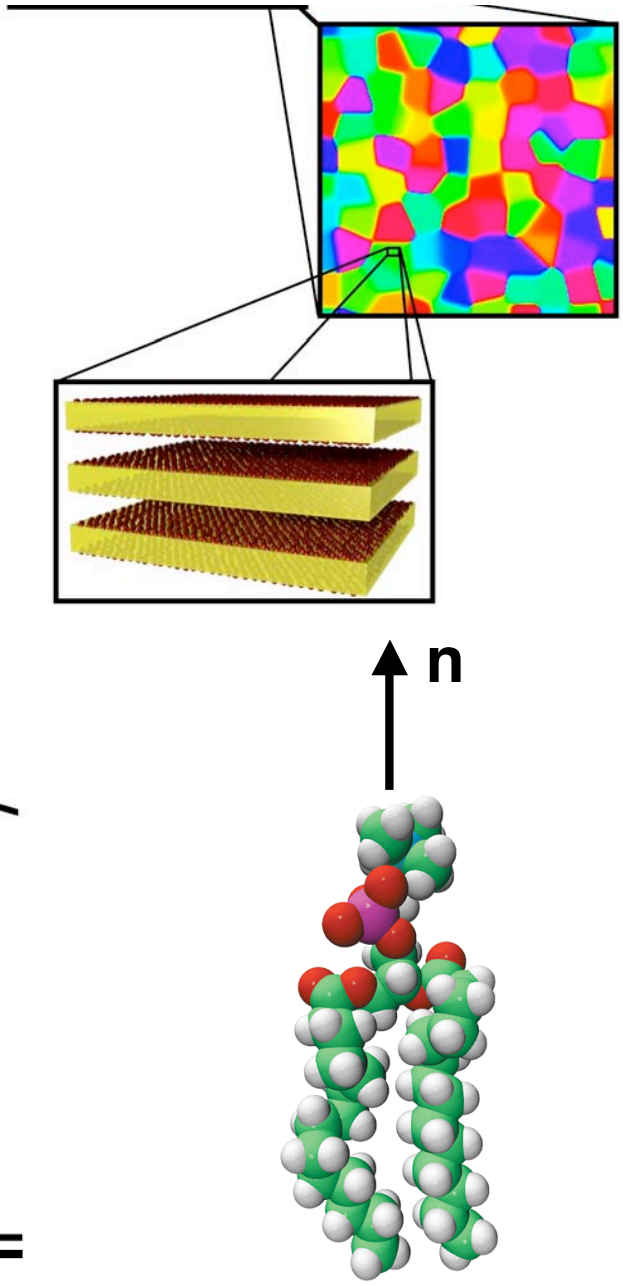
Powder of crystallites



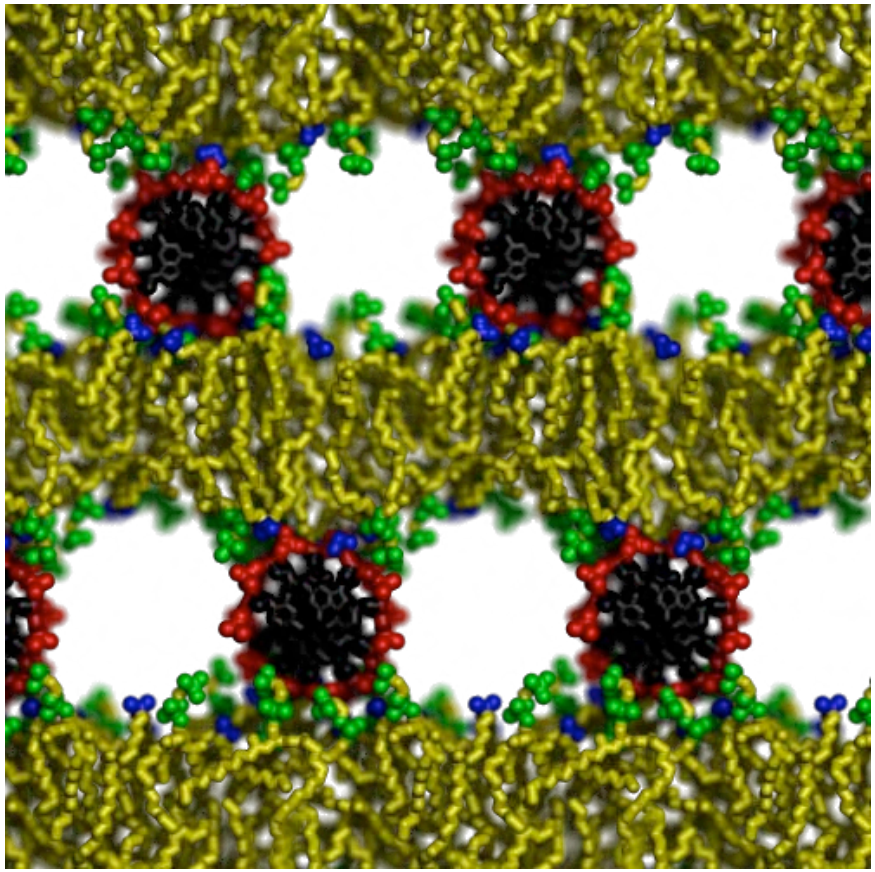


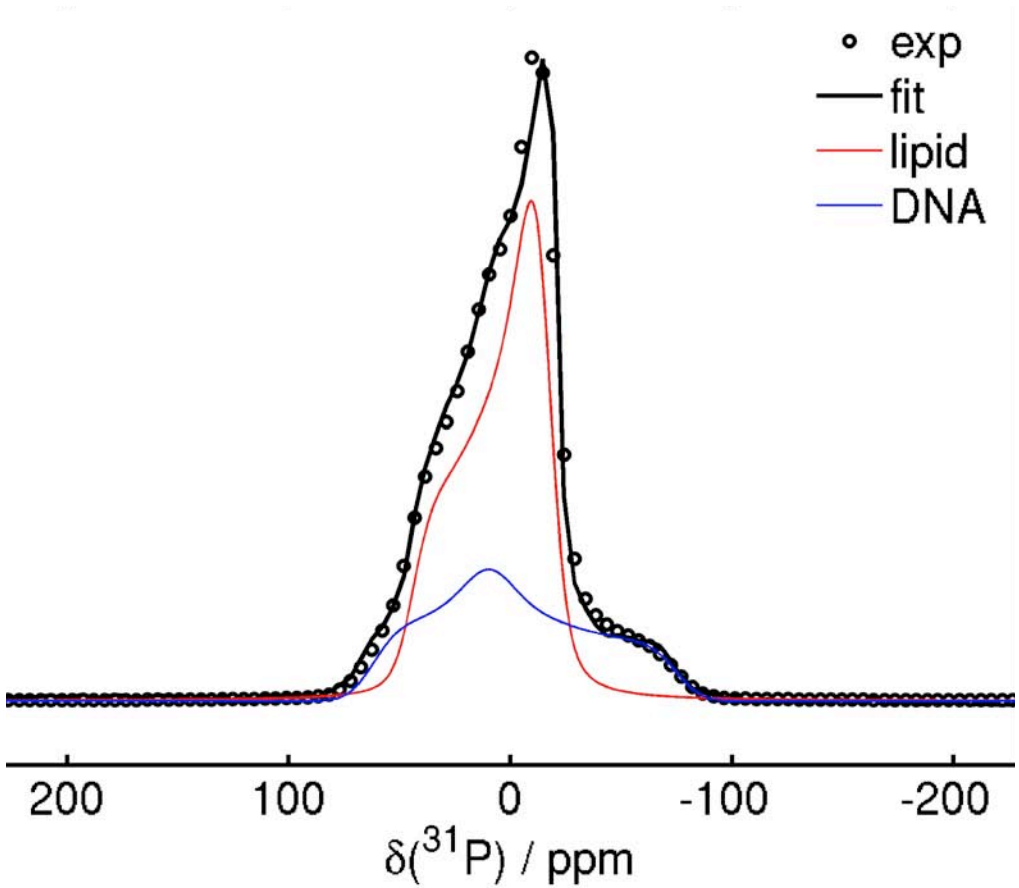
^{31}P lineshapes





DNA and phospholipid



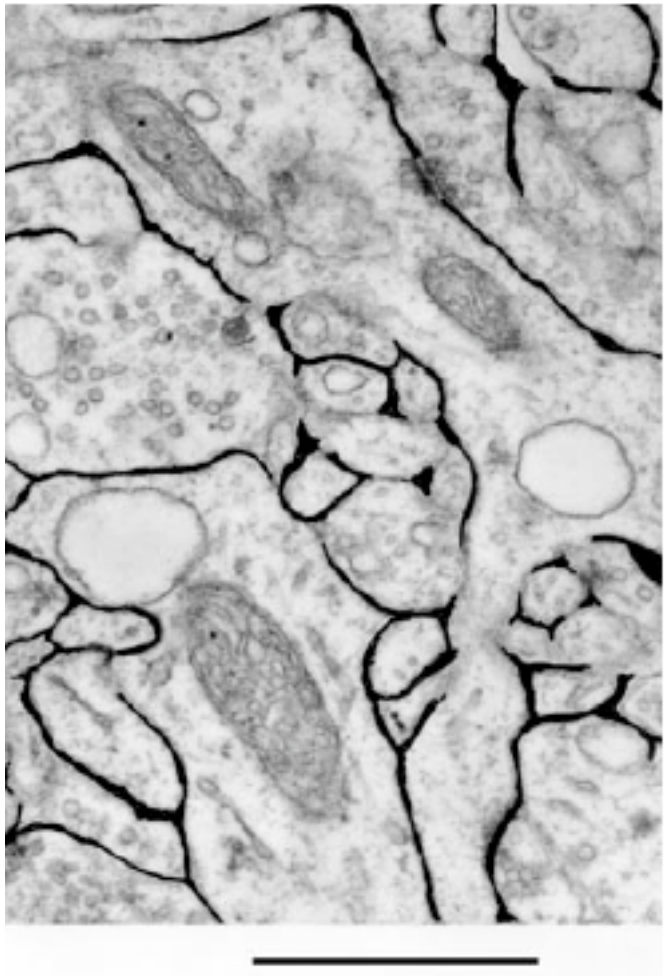


Leal, Sandström, Nevsten, Topgaard, Biochim. Biophys. Acta (2008)

Water in biological tissues

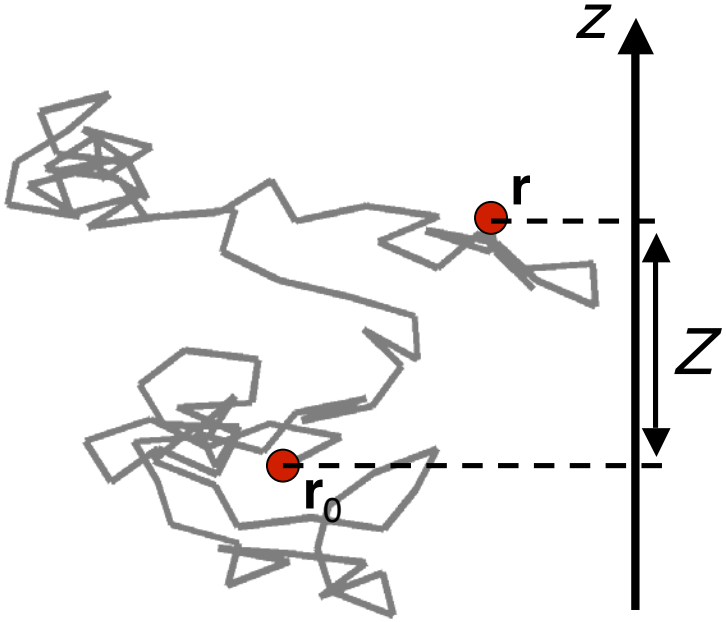
- Extracellular space
- Cytoplasm
- Vacuoles
- Mitochondria
- …

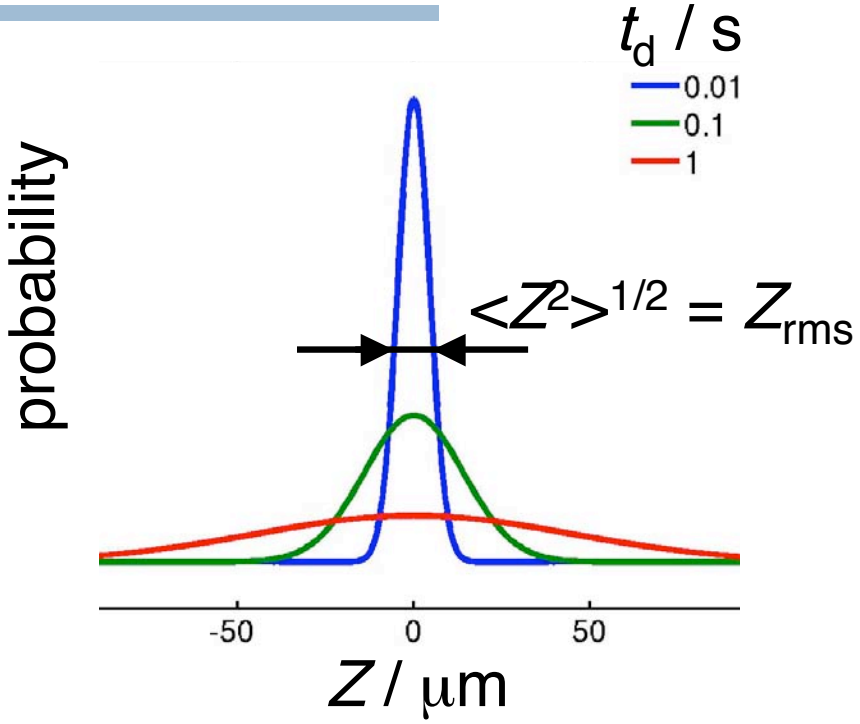
Separated by membranes of varying shape and permeability



Nicholson, Rep Prog Phys (2001)

Self-diffusion

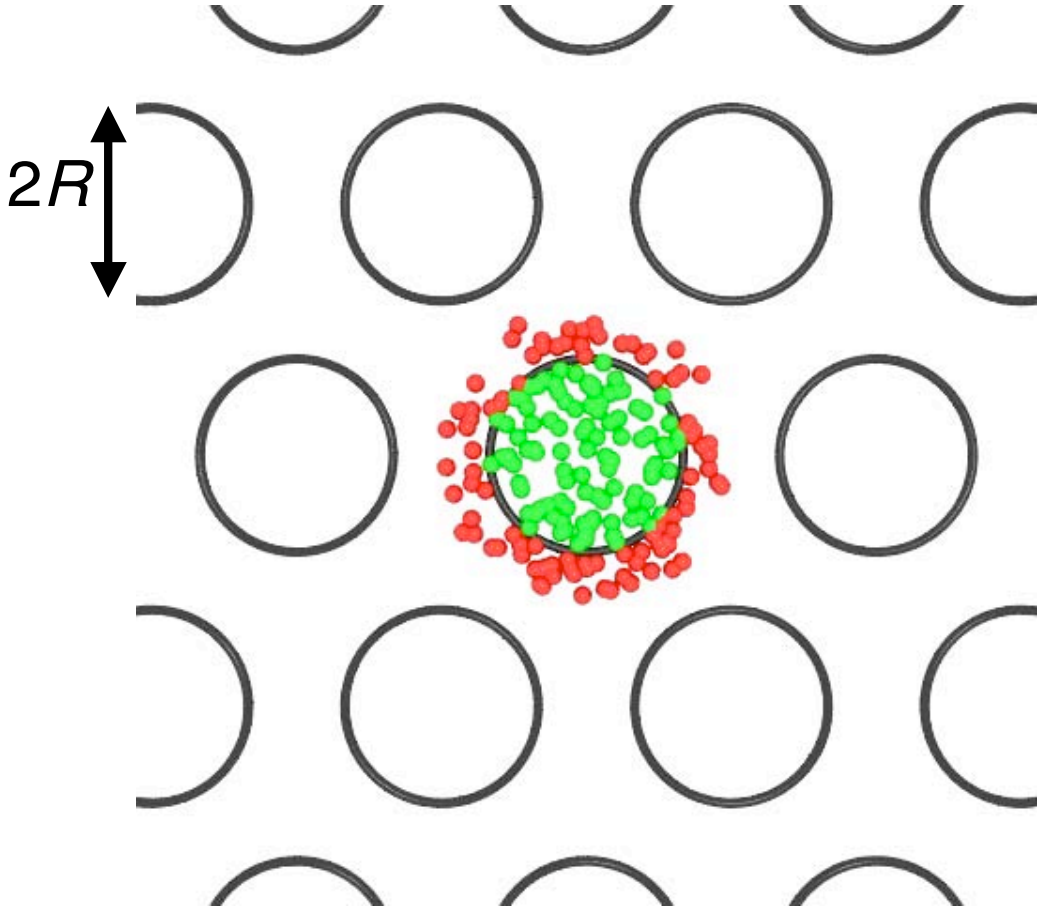


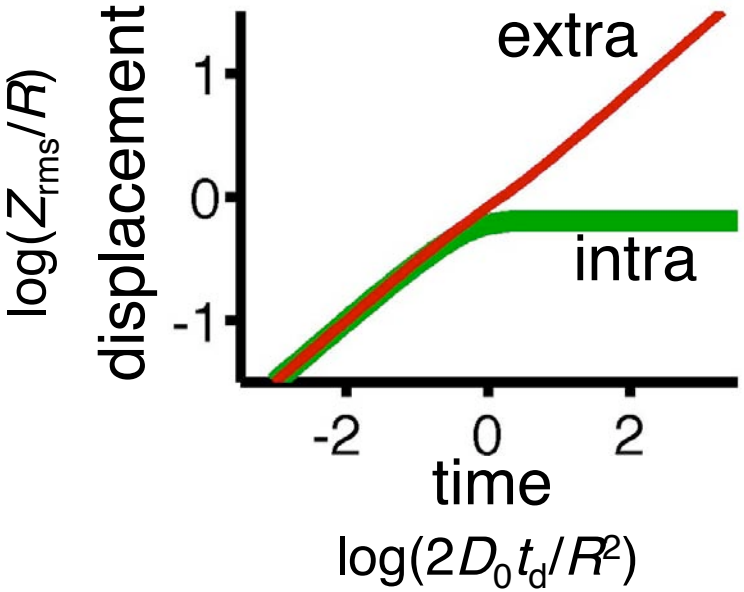


$$\left\langle Z^2 \right\rangle = 2Dt_{\mathrm{d}}$$

mean-square displacement, $\langle Z^2 \rangle$
diffusion coefficient, D
diffusion time, t_{d}

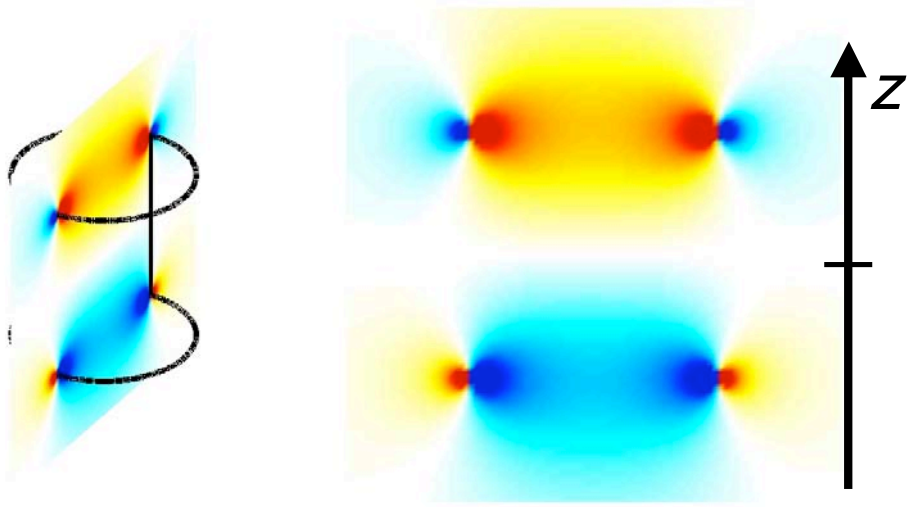
Free and restricted diffusion

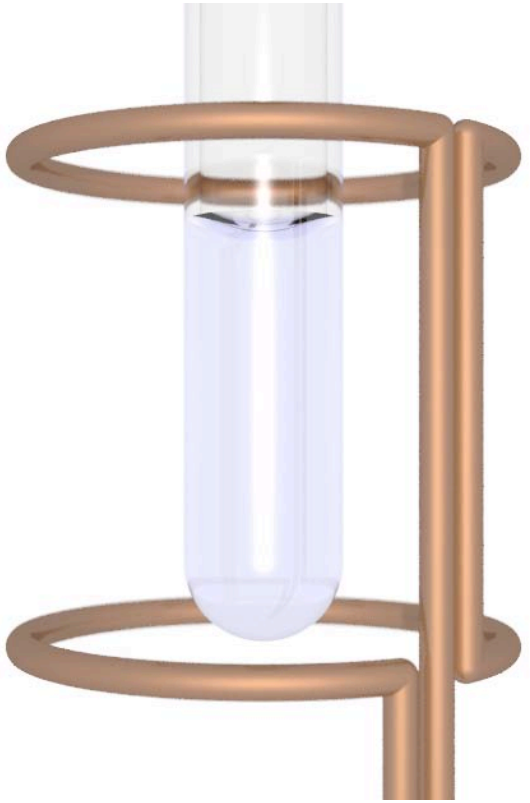




Magnetic field gradient, *G*

Electromagnet





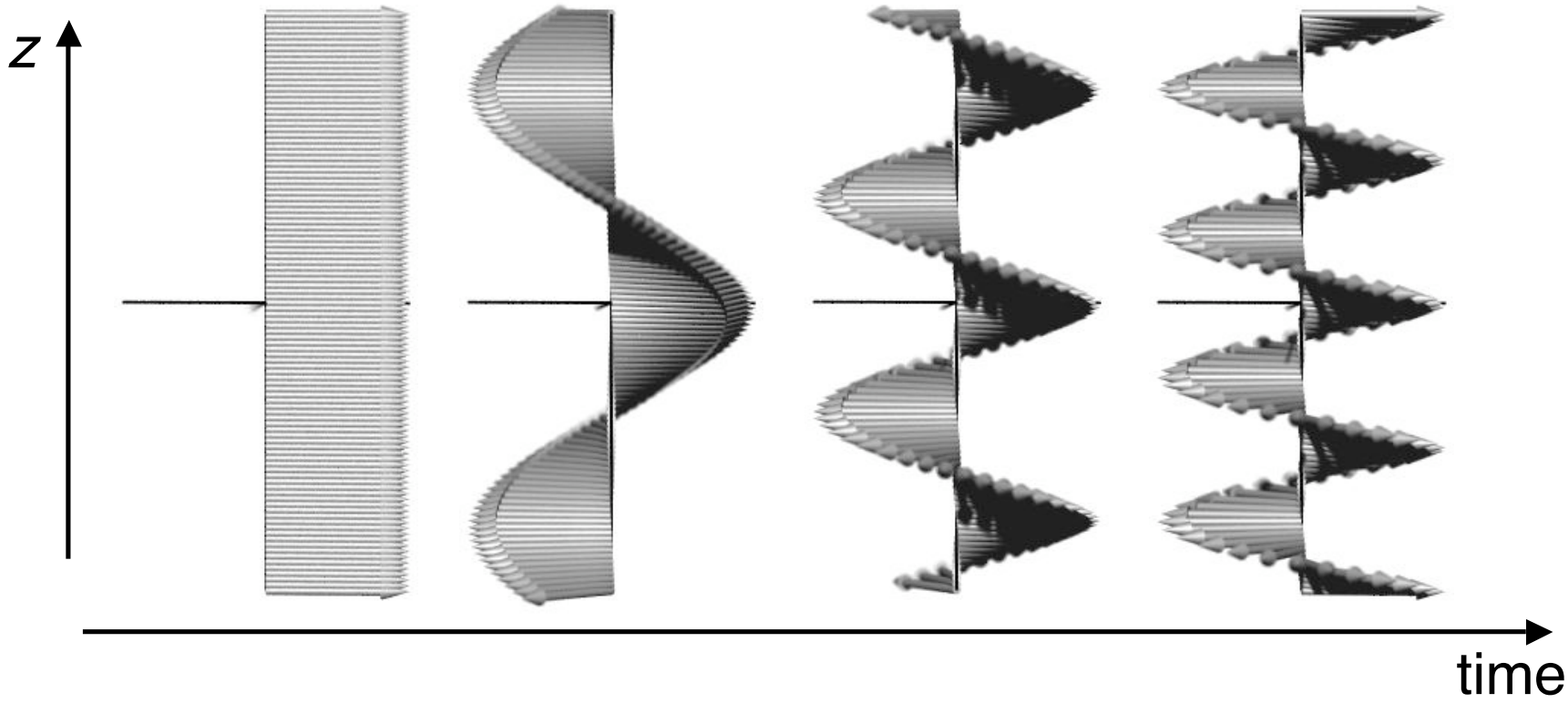
resonance frequency

$$\omega_0(z) = \gamma(B_0' + Gz)$$

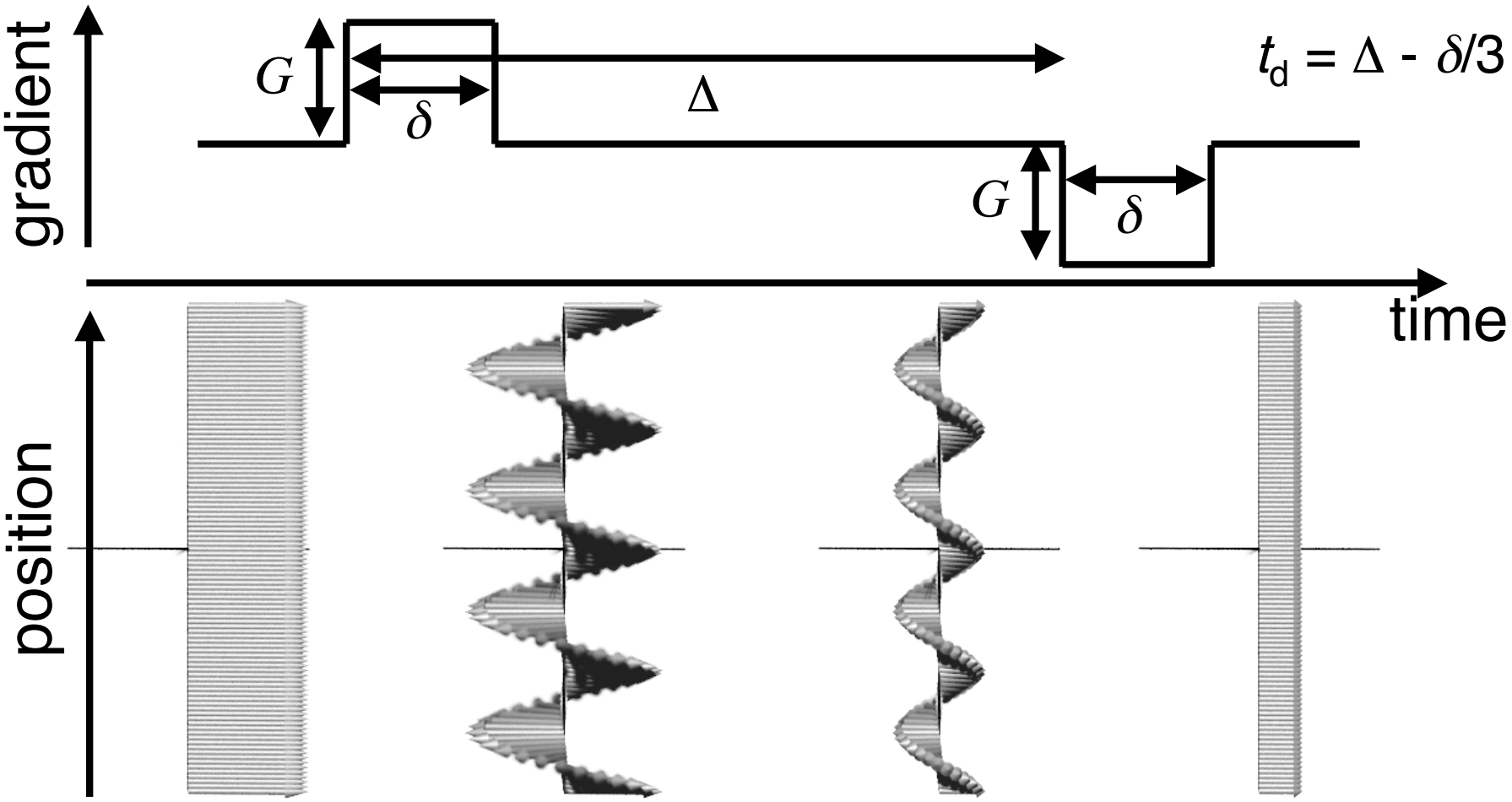
position

homogeneous field from supercon

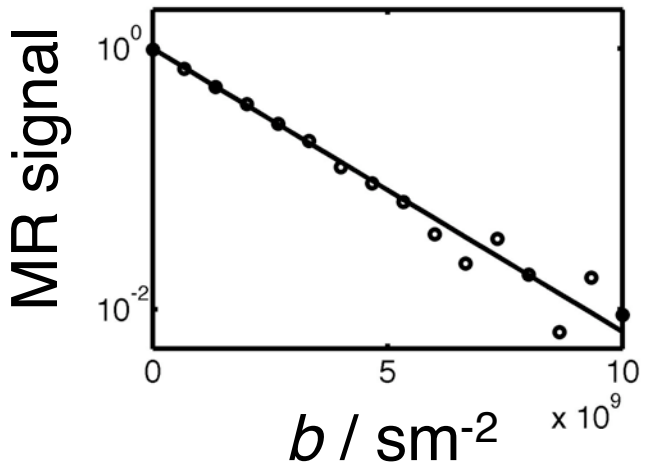
Spin evolution in a gradient



Diffusion NMR/MRI



D from exponential fit



Diffusion weighting (DW)

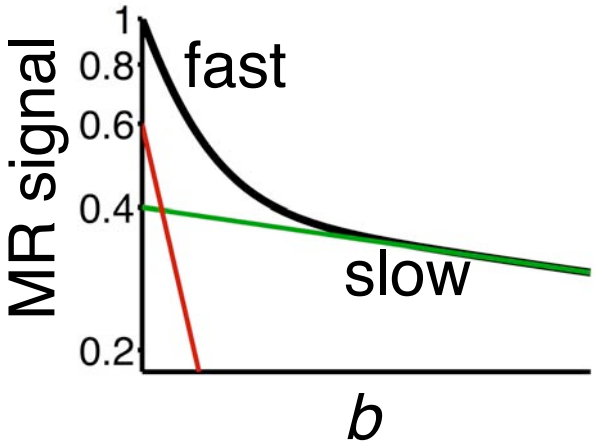
$$b = (\gamma G \delta)^2 (\Delta - \delta/3)$$

varied

$$E = e^{-bD}$$

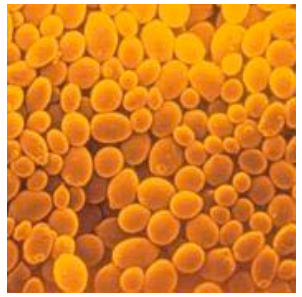
MR signal, *E*

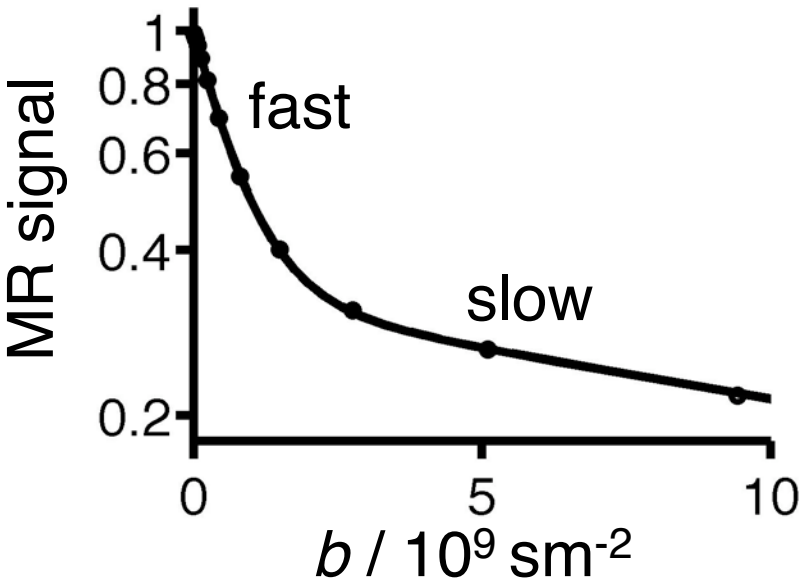
Two components



Simple cell system

Baker's yeast



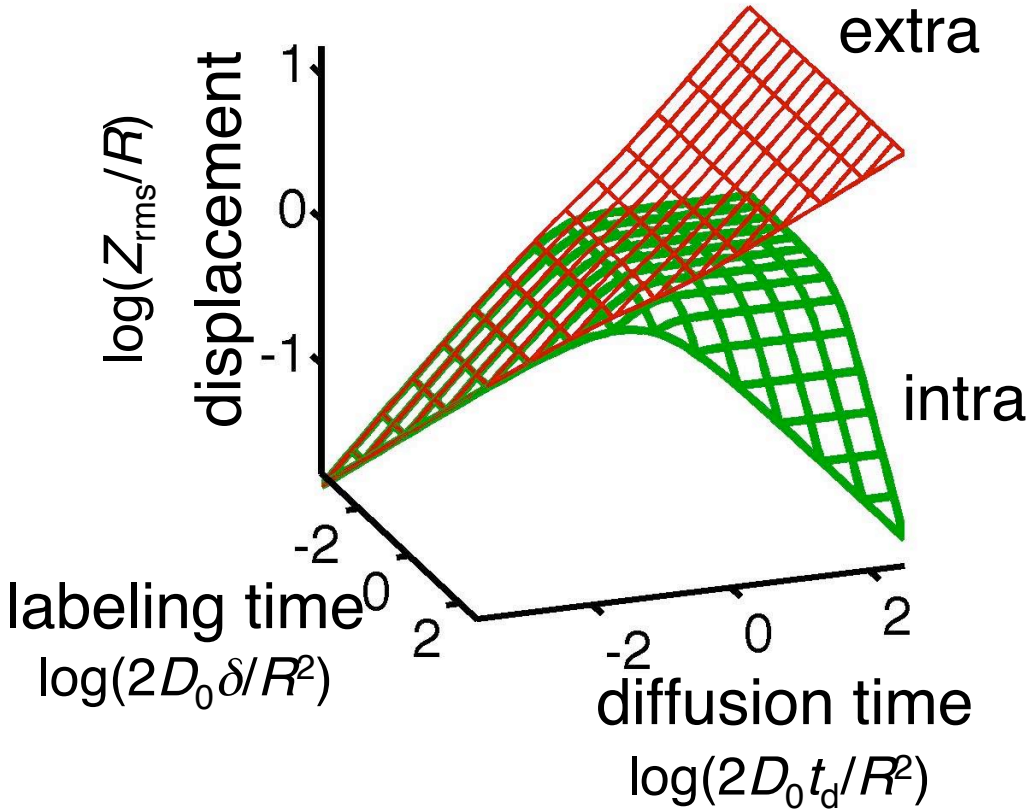


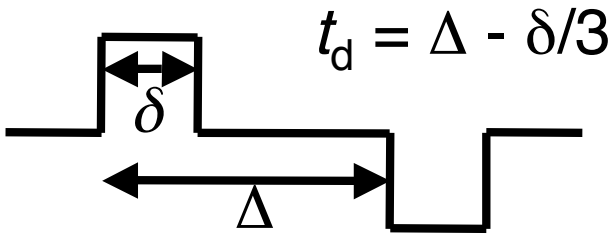
Fast: extra

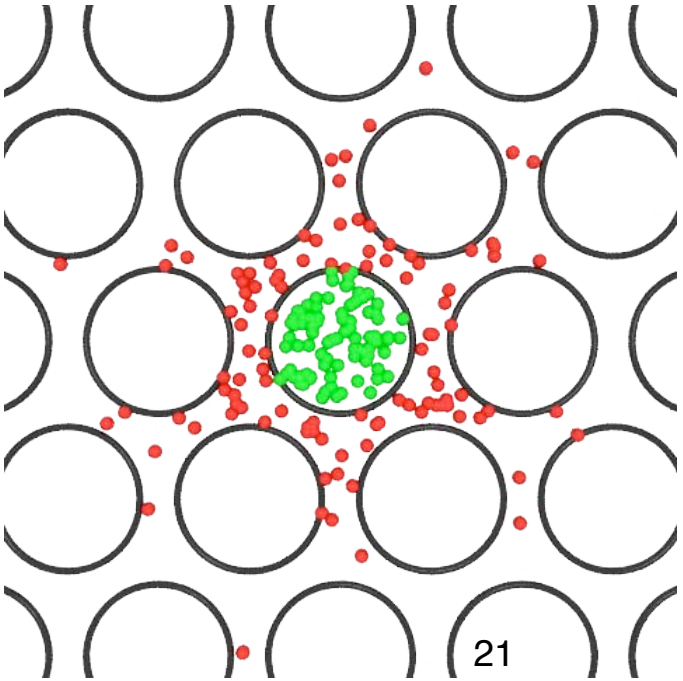
Slow: intra

Malmborg et al., J. Magn. Reson. 180 (2006)

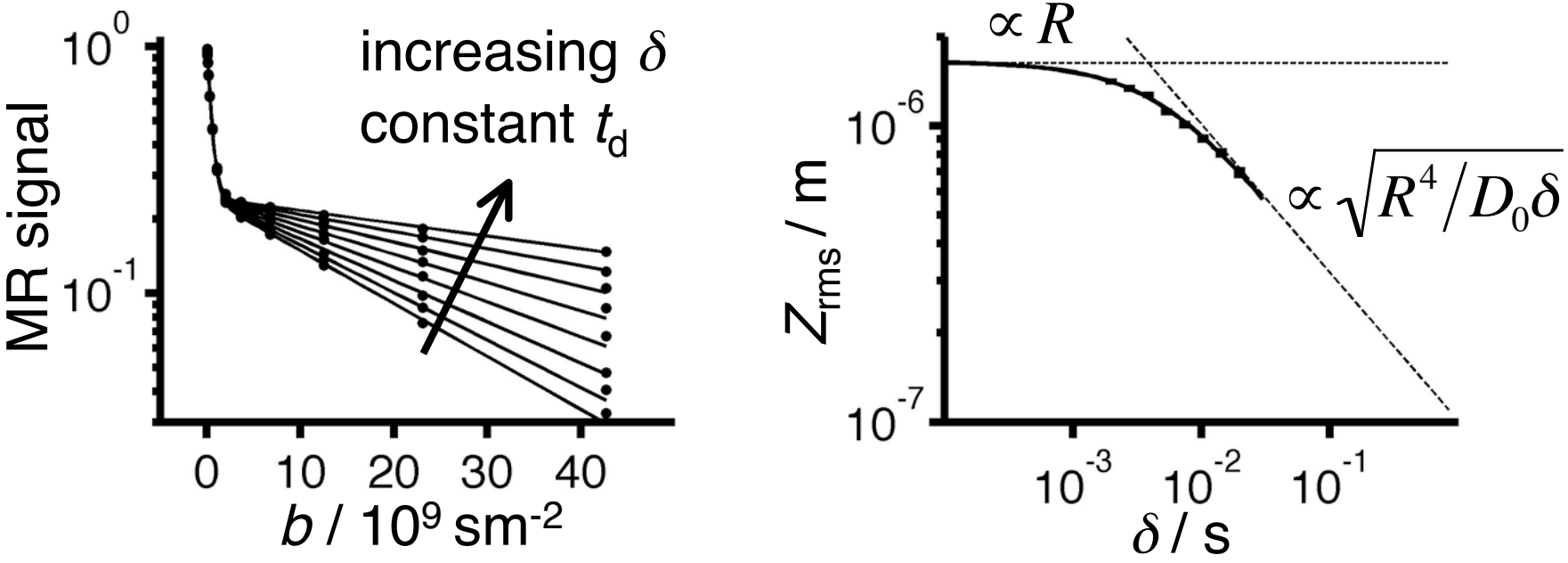
Time scales t_d and δ







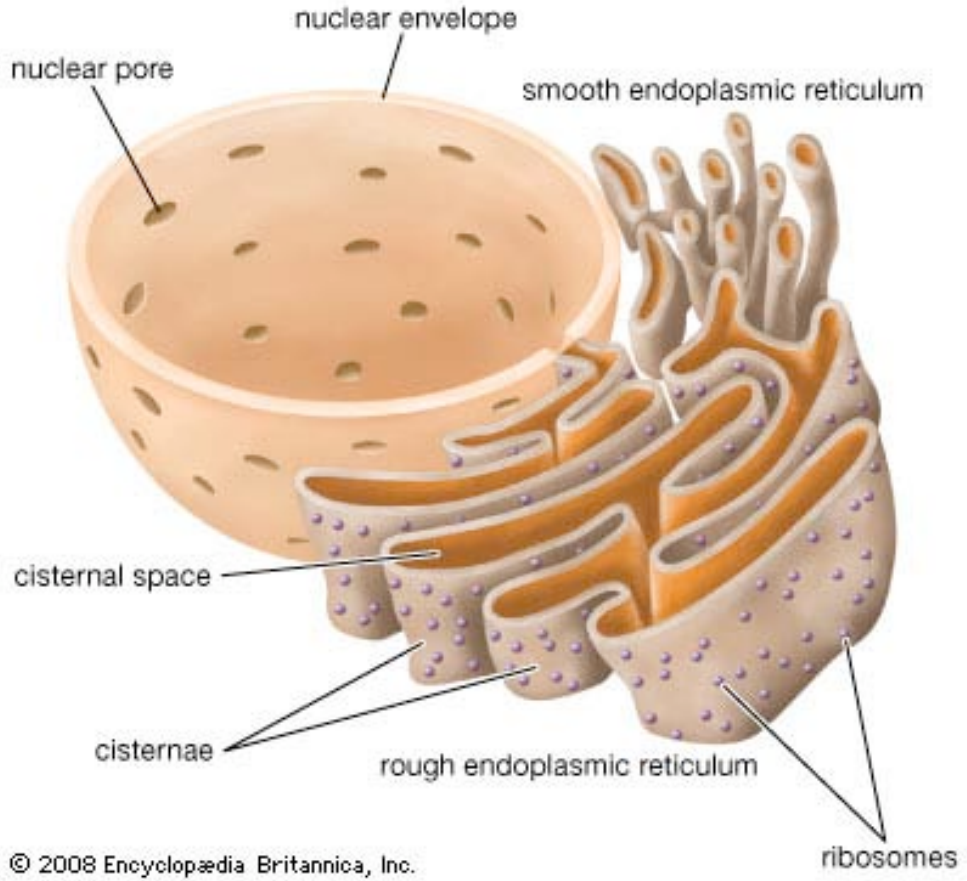
Intracellular diffusion, D_0



model fit => R, D_0

The intracellular labyrinth

70 vol% water



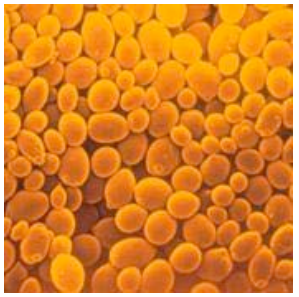
http://bugs.bio.usyd.edu.au

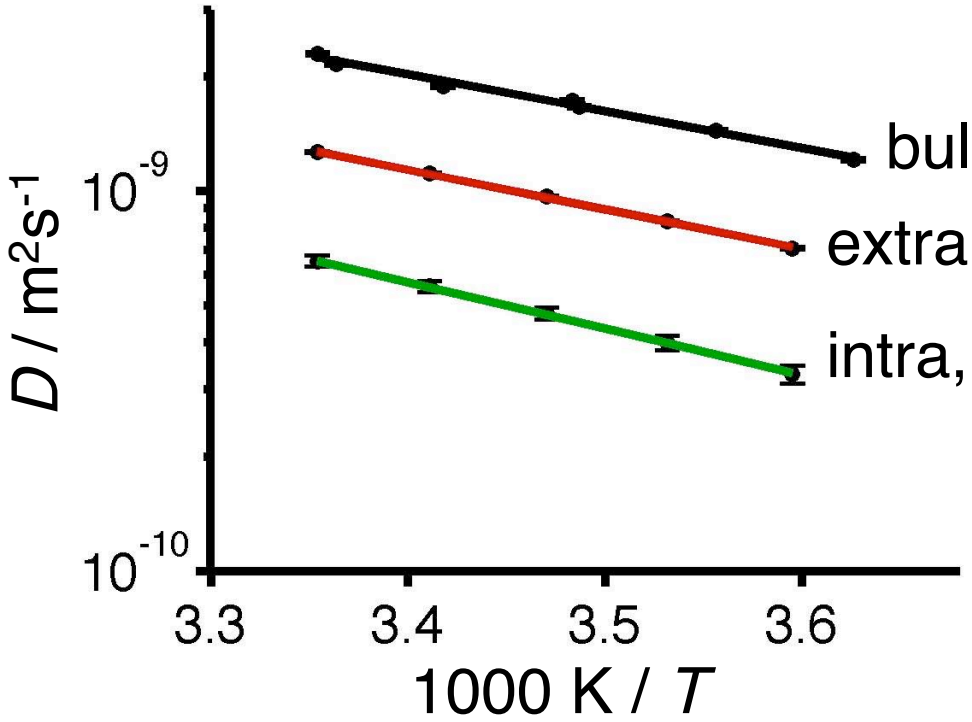
$2R \approx 5\ \mu m$

www.brio.se

D_0 – infinite labyrinth

Activation energies





bulk, 18.5±0.4 kJ/mol

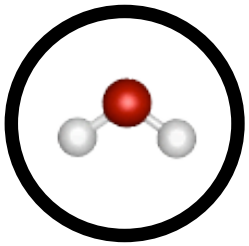
extra, 19.9±0.3 kJ/mol, ~0.6D_{bulk}

intra, 23±2 kJ/mol, ~0.3D_{bulk}

- Tortuosity
- (Hydration)
- (Exchangeable H)

Åslund, Topgaard. J. Magn. Reson. 201 (2009)

Cell membranes and cell water diffusion



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  - Effect on ^{31}P MRS
- Basics of diffusion MRI
- Water diffusion in cells