NMR of phospholipids and membrane-bound systems

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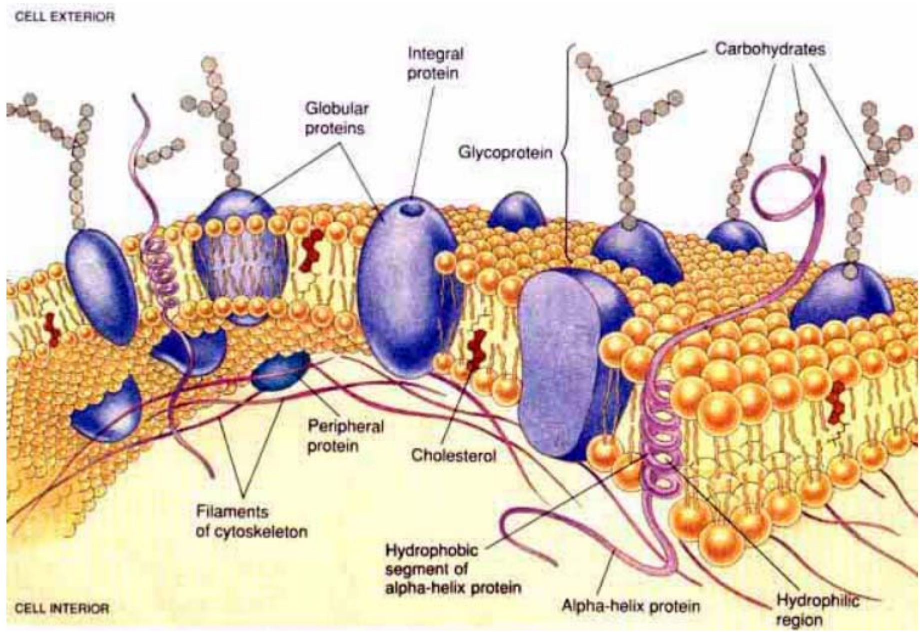
Plasma membrane

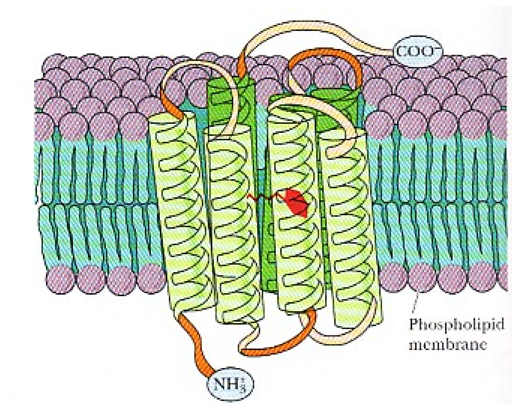


- Site of important biological processes
- Fluid mosaic model
- More recently: "dynamic, yet structured" cell membrane model

Singer and Nicolson (1972) Science, 175, 720.
Vereb et al. (2003) PNAS, 100, 8053.

Structure of membrane proteins

- 30% of all proteins are membrane proteins



- Important functions
  - Signal transduction
  - Stabilisation of membrane potential
  - Etc...

- Less than 0.2% of resolved protein structures are membrane proteins

- Important targets for drug development

Strategy

- Strategy for the determination of protein structure by solid-state NMR under MAS conditions

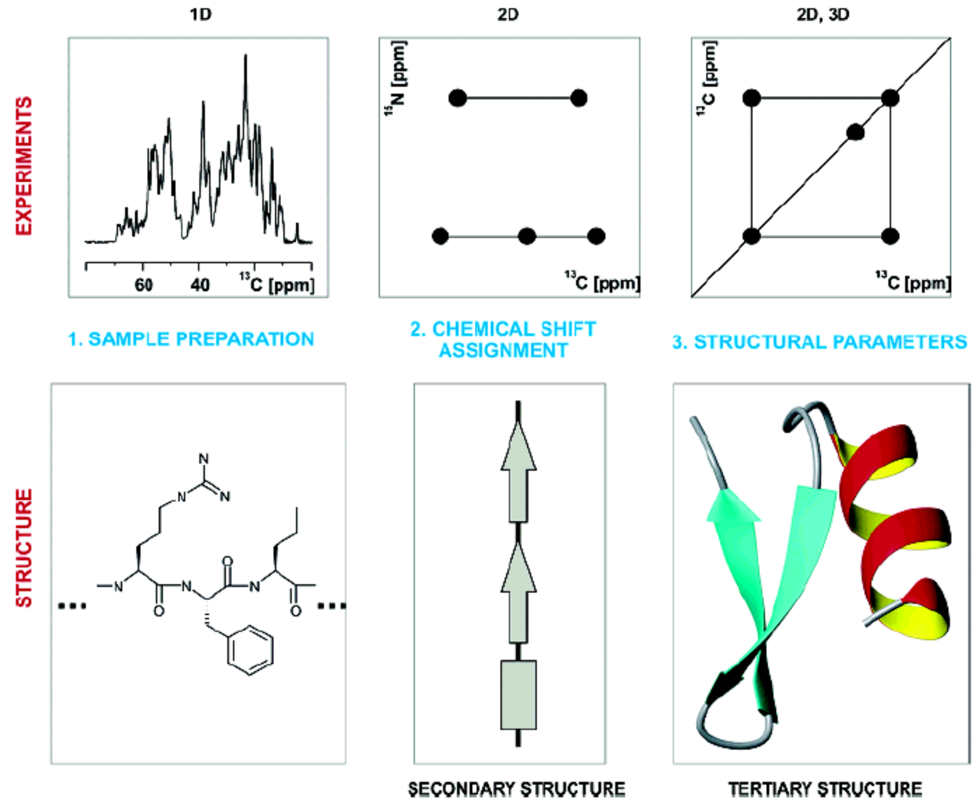
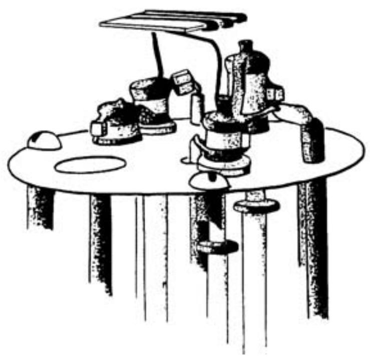


FIGURE 8. General approach for determining the structure of multiply labeled proteins in solid-state NMR under MAS conditions.

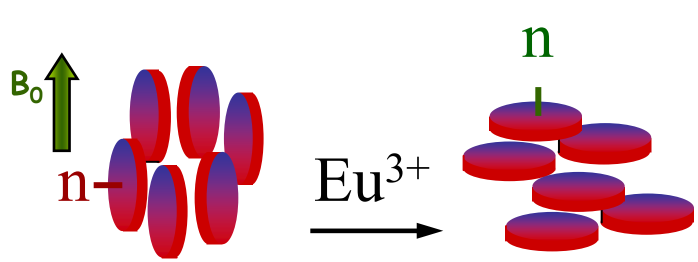
Luca et al. (2003) Acc. Chem. Res. 36, 858.

Oriented membranes

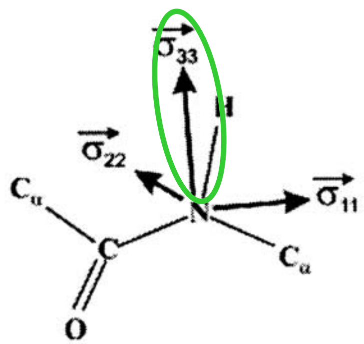
- Lipids mechanically oriented between glass plates

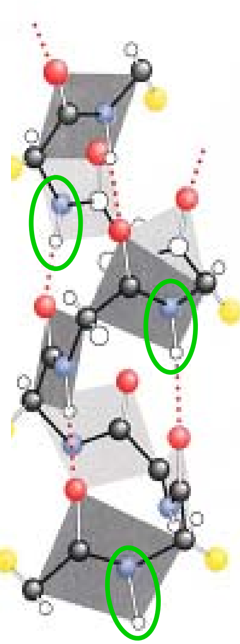


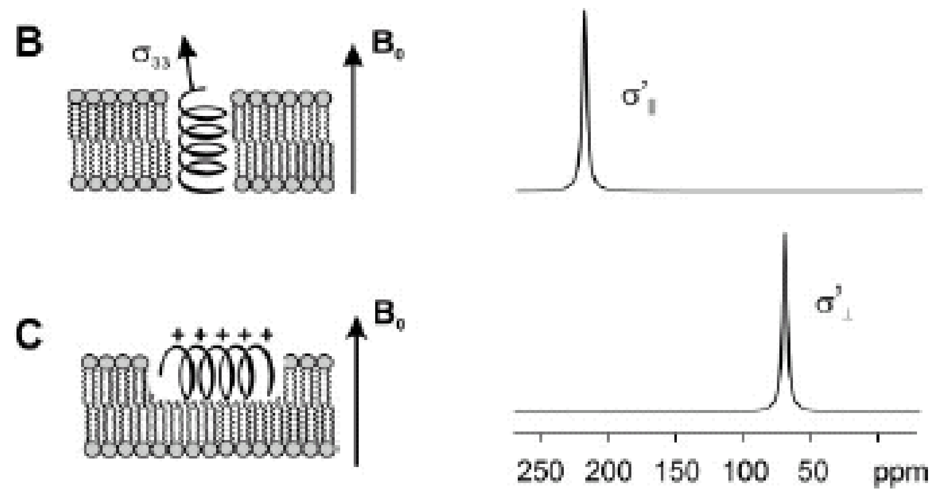
- Bicelle structures oriented in the magnetic field



Helix orientation by ^{15}N NMR



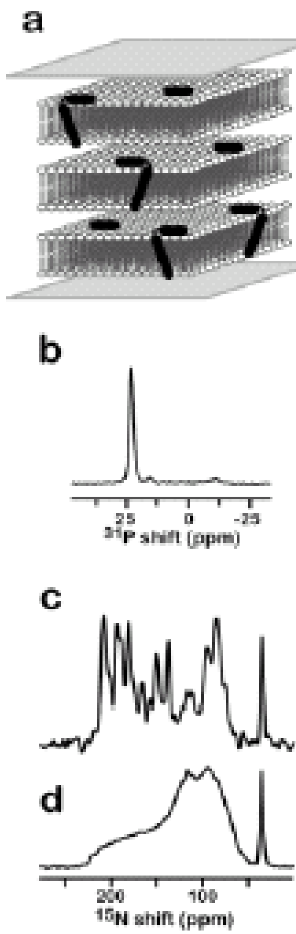




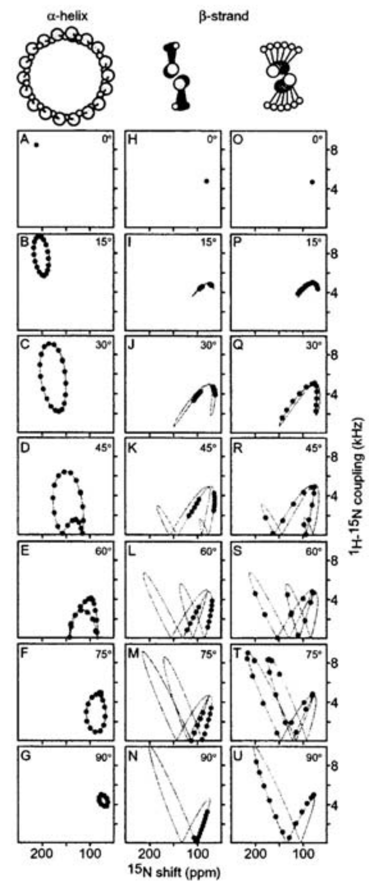
Correlation between δ_{ppm} and orientation

Bechinger et al. (2003) Concepts Magn. Reson. 18A, 130.

Uniformly labeled samples



PISEMA spectra



Marassi (2002) Concepts Mag. Reson. 14, 212.
Marassi (2001) Biophys. J. 80, 994.

Outline

- **Introduction**
  - The plasma membrane
  - Overview of methods to determine the structure of membrane proteins and peptides
  - Overview, NMR of lipid molecules
  - Phospholipids and lipid phases

- **MAS spectra of lipid bilayers**
  - ^{31}P, ^{1}H and ^{13}C MAS spectra

- **Static ^{2}H and ^{31}P NMR**
  - ^{2}H NMR
    - The quadrupolar interaction
    - Effects of axially symmetric motions
    - Lipid phases
    - Molecular voltmeter
  - ^{31}P NMR
    - Effect of dynamics
    - Vesicle morphology
    - Order parameters
    - Lipid phases
  - Application to the study of peptide-lipid interactions
  - Lipid dynamics
    - Overview of motional time scales
    - Study of lipid domains by 2D exchange ^{31}P NMR

Outline

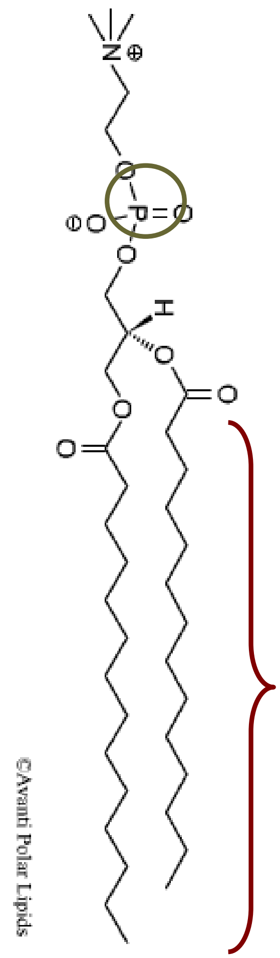
- **Oriented membranes**
  - Lipids oriented between glass plates
    - Typical ^{31}P NMR spectra
    - Effect of peptides on ^{31}P and ^{2}H spectra
  - Bicelles
    - Morphologies
    - Characteristic spectra
    - Order parameters
    - Effect of peptides on bicelle orientation
    - Fast-tumbling bicelles
- **Conclusions**

NMR of lipid molecules

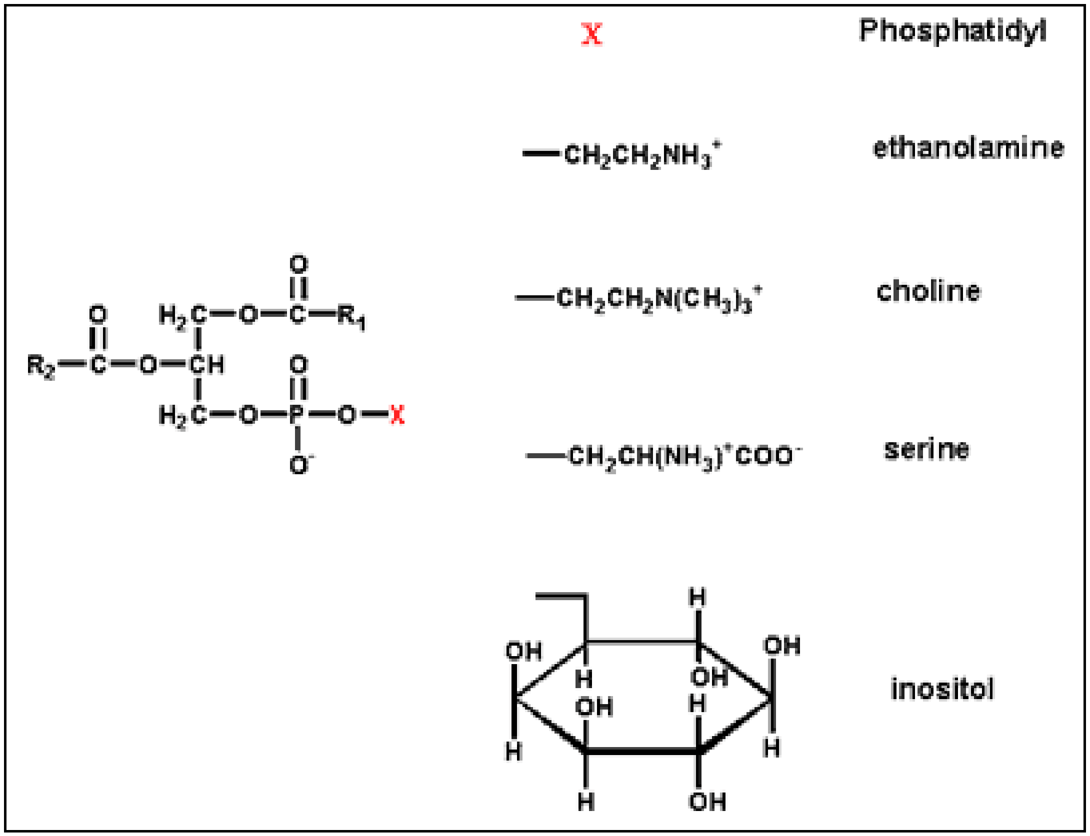
- MAS spectra
  - ^{31}P, ^{1}H, ^{13}C

- Static powder spectra
  - **Polar head group: ^{31}P NMR**
  - **Acyl chains: ^{2}H NMR**
  - Dynamics

- Oriented spectra
  - Lipids oriented between glass plates
  - Bicelles



Phospholipid head groups

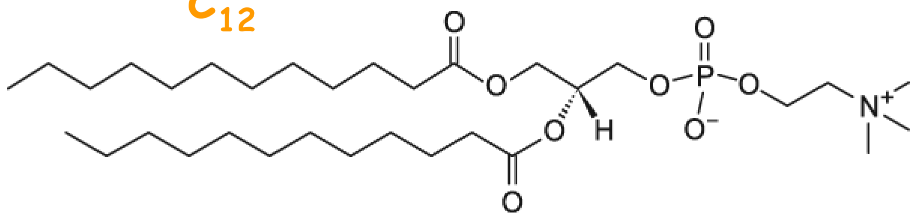


Phospholipid acyl chains

T_m

DLPC

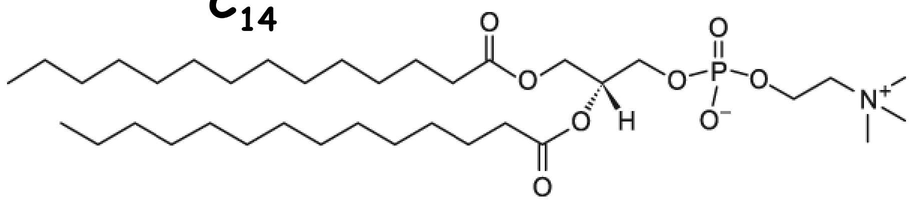
C_{12}



-1°C

DMPC

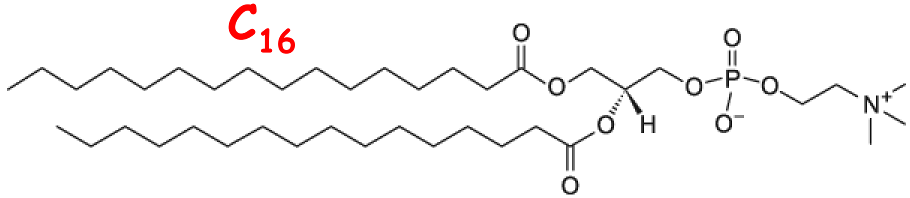
C_{14}



23°C

DPPC

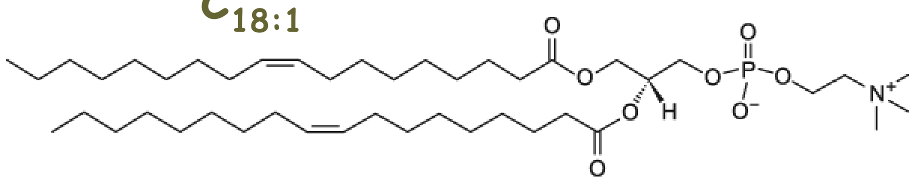
C_{16}



41°C

DOPC

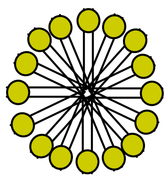
$C_{18:1}$



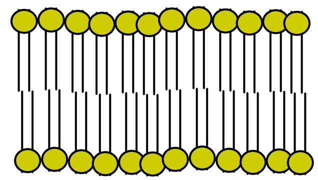
-20°C

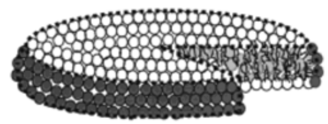
Lipid phases

Micelles



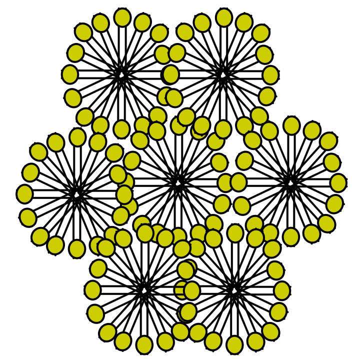
Bilayers

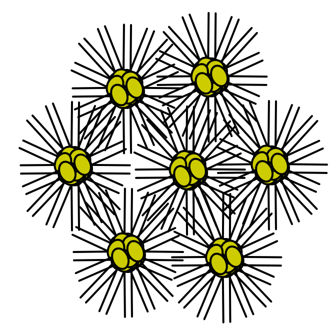




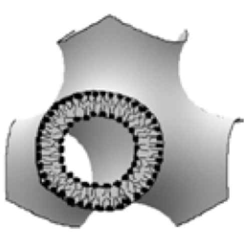
Bicelle

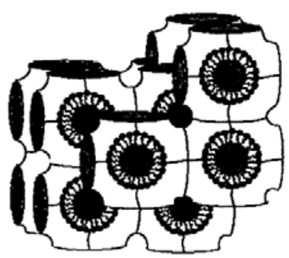
Normal or inverted hexagonal phases

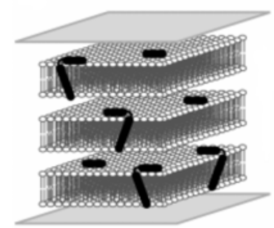




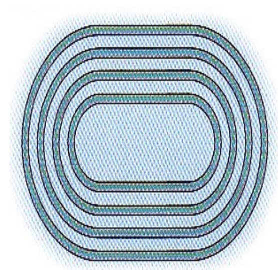
Cubic phase





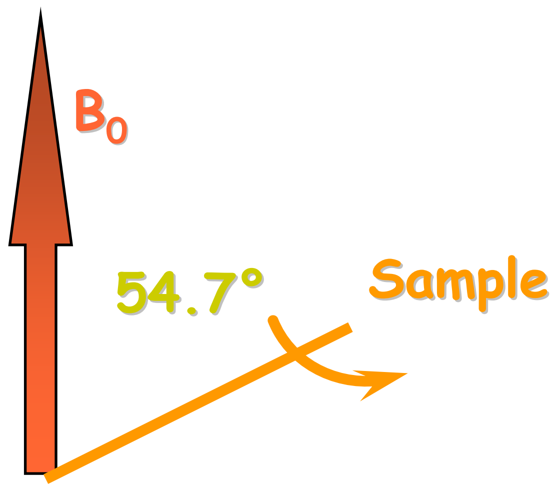


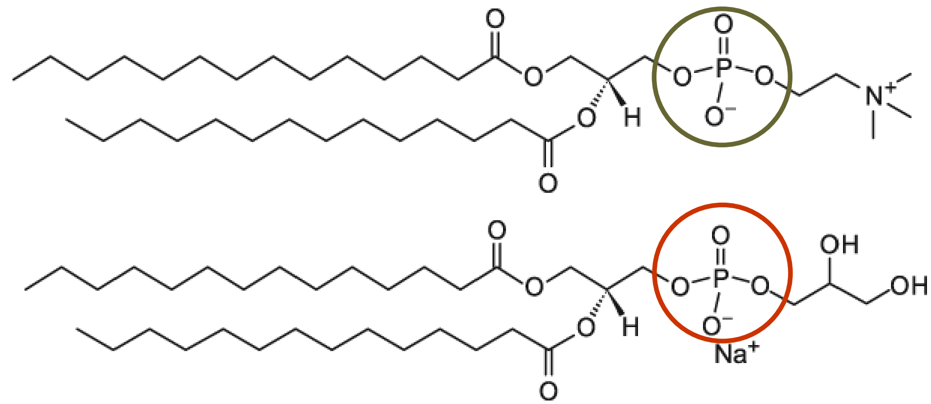
Oriented bilayers



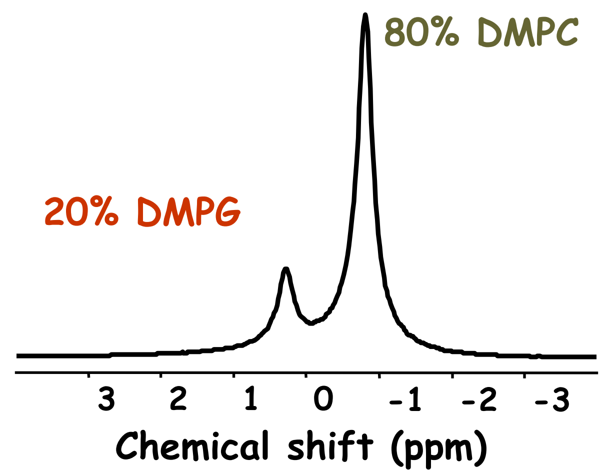
Multilamellar vesicle

^{31}P MAS NMR

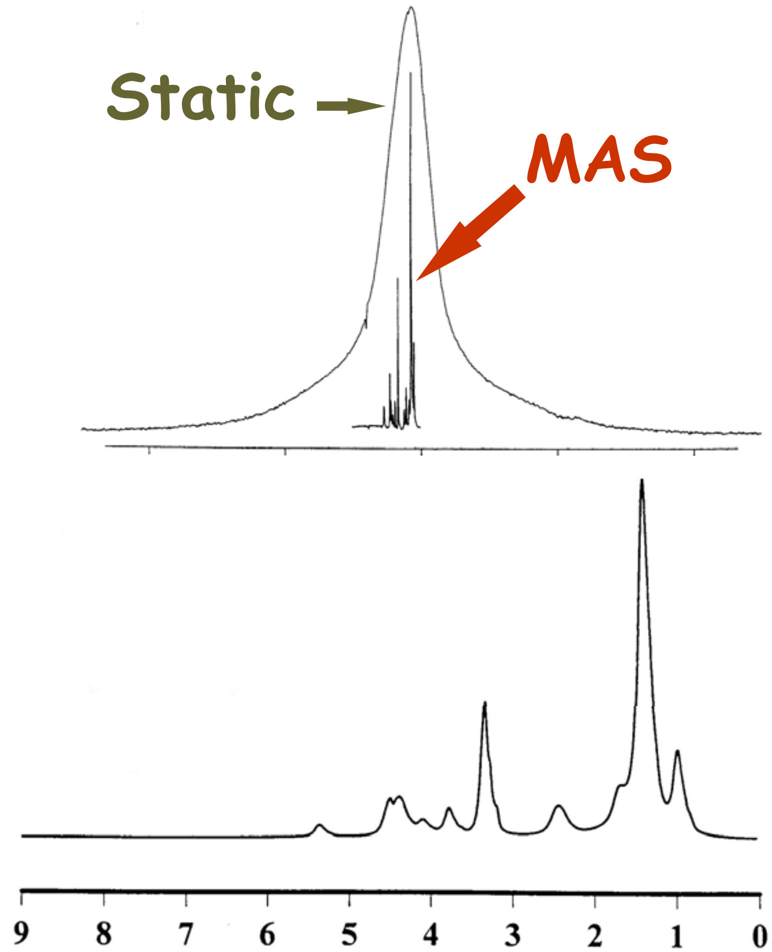




- Shielding, deshielding effects
- Dynamics, FWHM



^1H MAS NMR spectra of lipid bilayers



Davis et al. (1995) Biophys. J. 69, 1917.

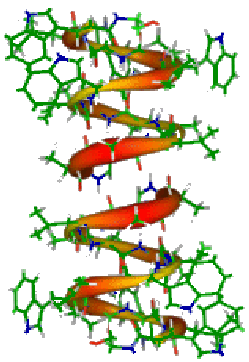
Effect of intermediate time scale motions

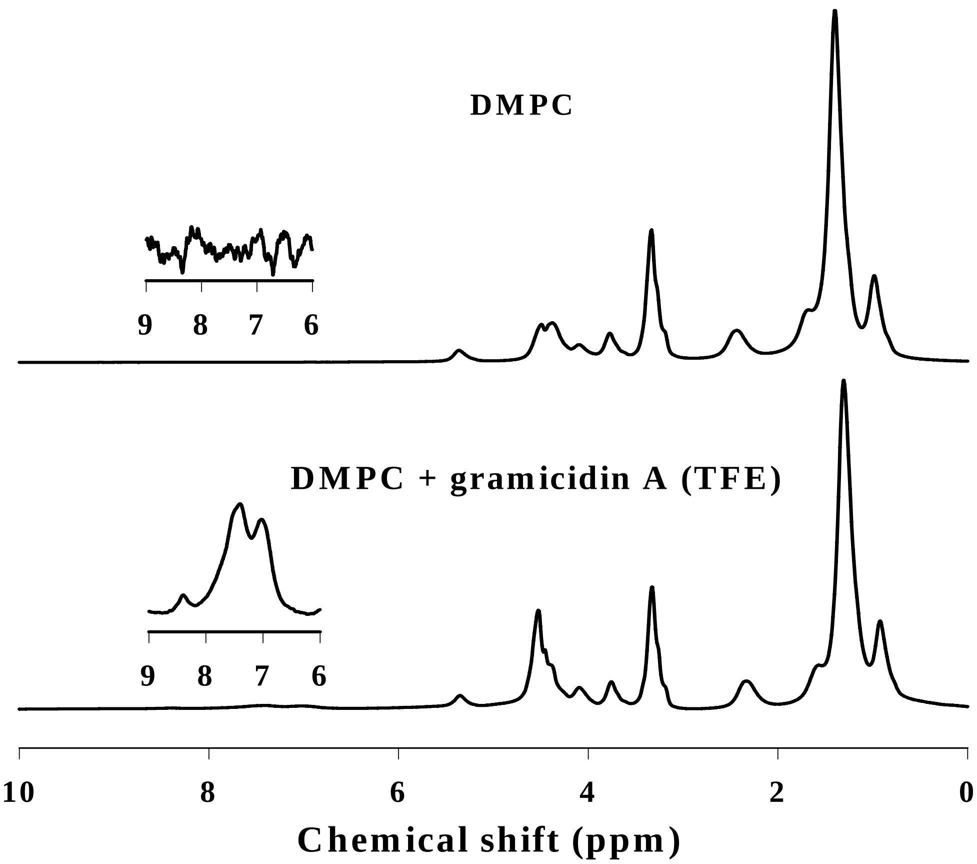
- Possible to obtain well-resolved ^1H spectra from multilamellar lipid dispersions at spinning speeds of 3 to 4 kHz
  - Rapid axial diffusion of the phospholipid about its long axis

- No identifiable peptide signals at spinning speeds of 3 to 4 kHz
  - Peptide reorientation fast enough?
  - Yes, $\tau_c = 7 \times 10^{-9}$ s for gramidicin A at 34°C

- Additional intermediate time scale motions
  - Wobble of the diffusion axis with respect to the local bilayer normal
  - $\tau_c = 6 \times 10^{-6}$ s for gramidicin A
  - Higher spinning speeds required

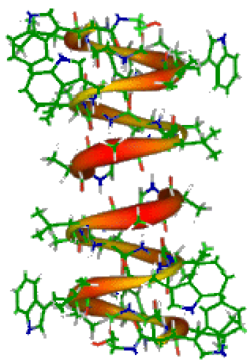
Solid-state ^{1}H NMR spectra

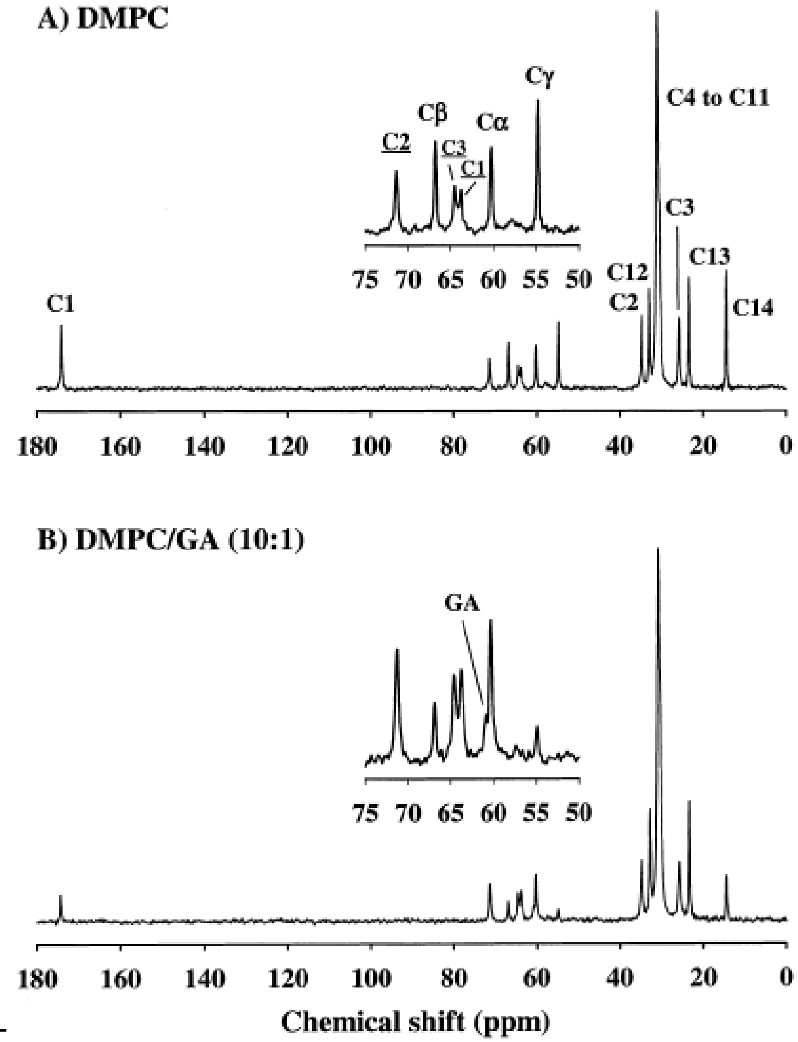




Bouchard et al. (1995) Biophys. J. 69, 1933.

^{13}C MAS NMR

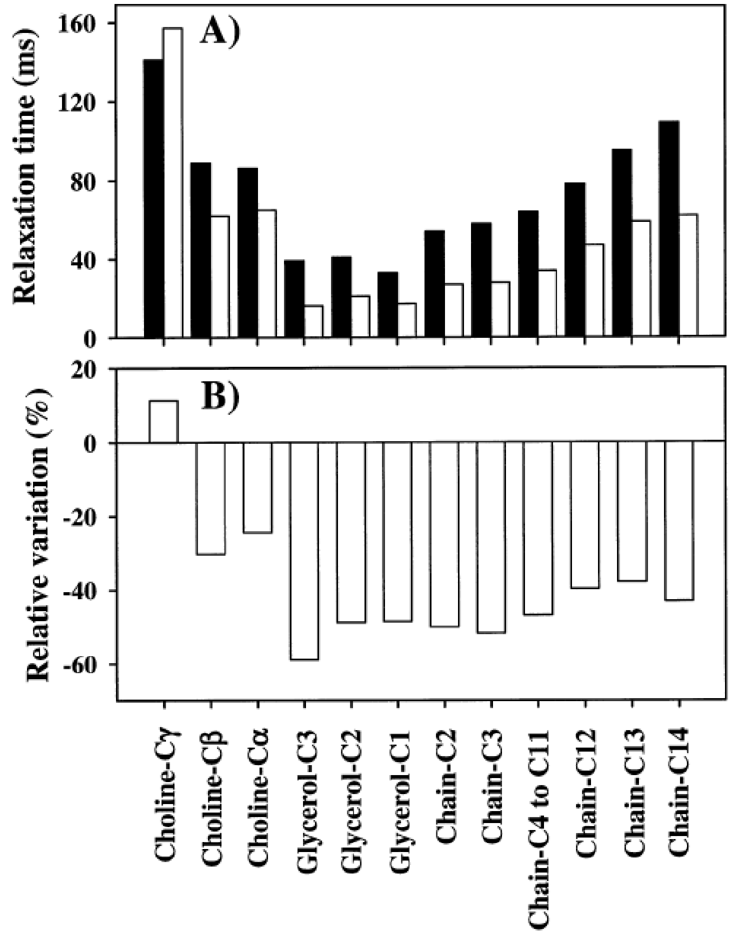


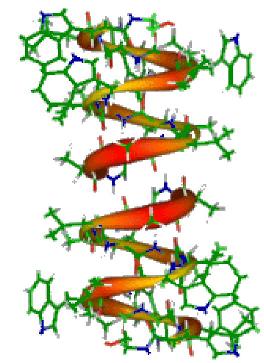


Bouchard al.. (1998) Biochim. Biophys. Acta 1415, 181.

^{13}C MAS NMR

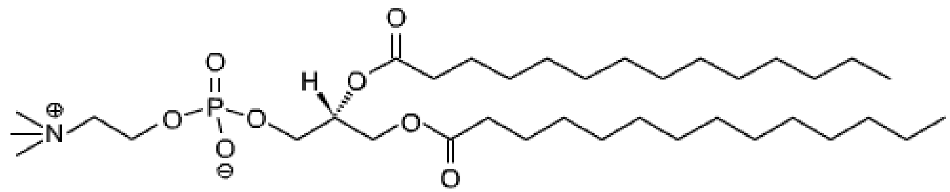
- Effect of gramicidin on DMPC dynamics, $^{1}H\ T_{1\rho}$





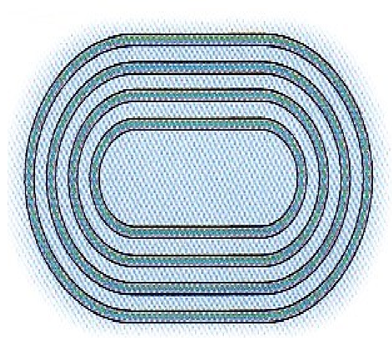
Bouchard al.. (1998) Biochim. Biophys. Acta 1415, 181.

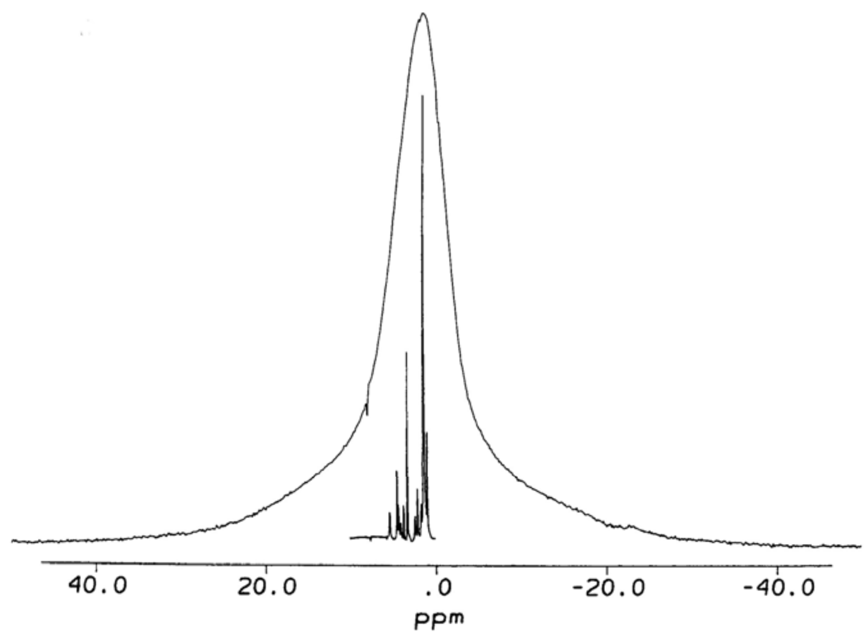
Why static deuterium NMR?



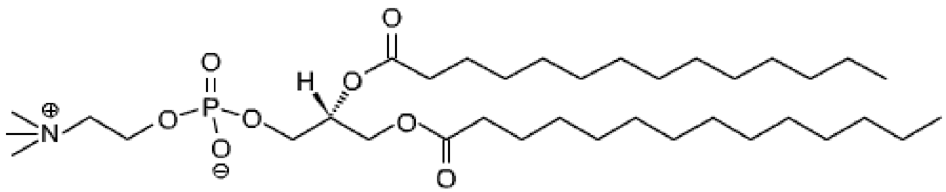
©Avanti Polar Lipids

Static ^{1}H spectrum
Multilamellar vesicles

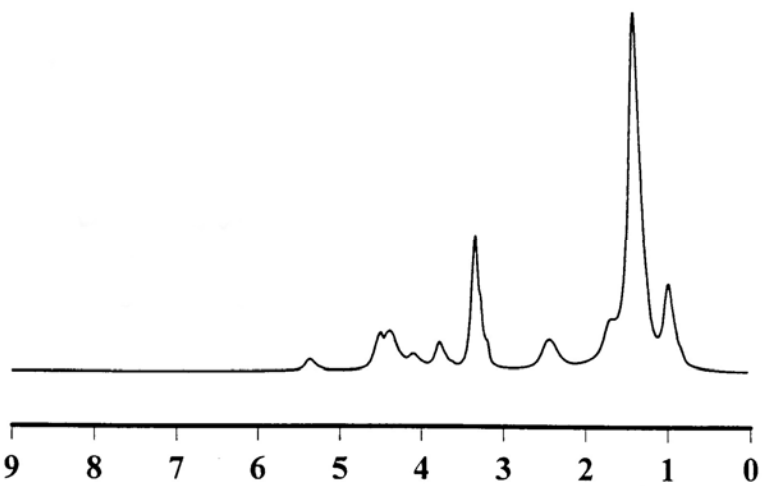




Why static deuterium NMR?

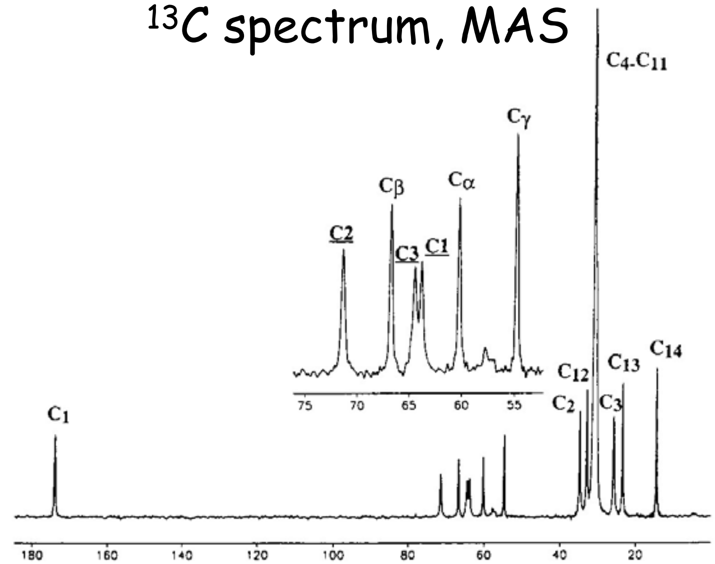


^{1}H spectrum, MAS



Chemical shift (ppm)

^{13}C spectrum, MAS

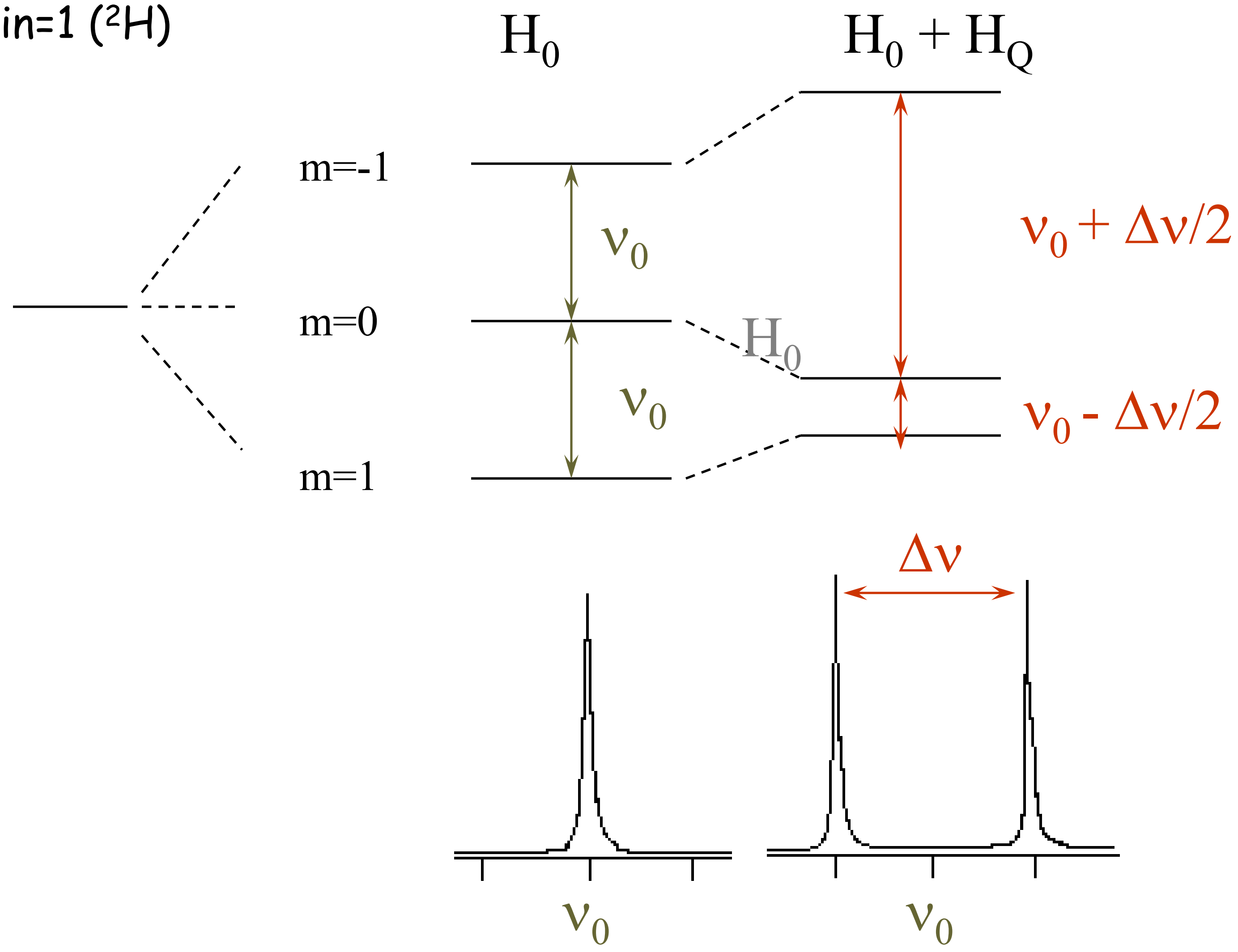


Chemical shift (ppm)

Little information on the order of CH_2 groups

Quadrupolar nuclei

Spin=1 (^2H)



Quadrupolar coupling

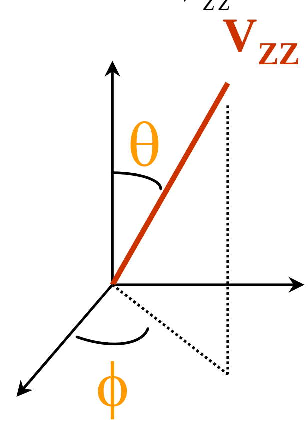
- Nuclei with spins greater than 1/2
- Interaction between the quadrupolar moment (eQ) and the electric field gradient at the center of the nucleus

$$\nu_Q = \frac{3}{2}\frac{e^2qQ}{h}\frac{1}{2}\left[\left(3\cos^2\theta - 1\right) + \left(\eta\sin^2\theta\cos 2\phi\right)\right]$$

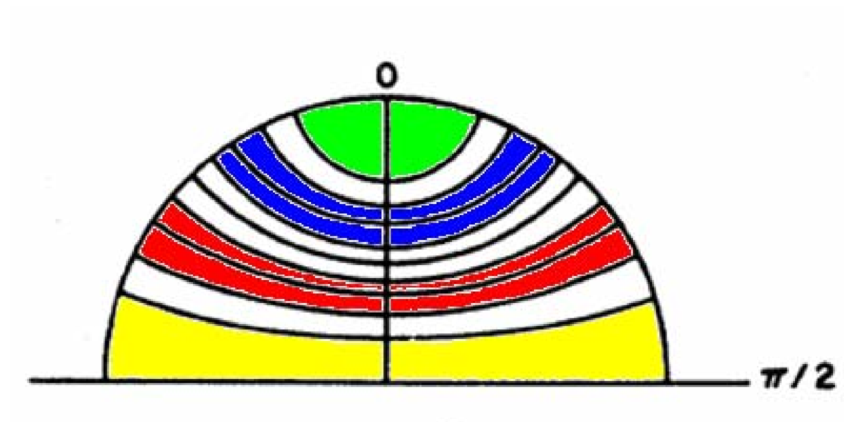
- e^2qQ/h= quadrupolar coupling constant = ~ 167 kHz (~ 3700 ppm at 7 T)
- V_{ZZ}, V_{yy} and V_{XX}= principal components of electric field gradient tensor
- If $V_{yy} = V_{xx}$

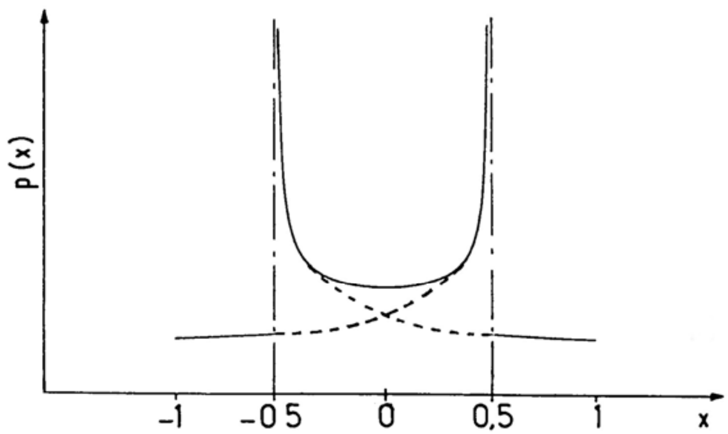
$$\nu_Q = \frac{3}{2}\frac{e^2qQ}{h}\frac{1}{2}\left(3\cos^2\theta - 1\right)$$

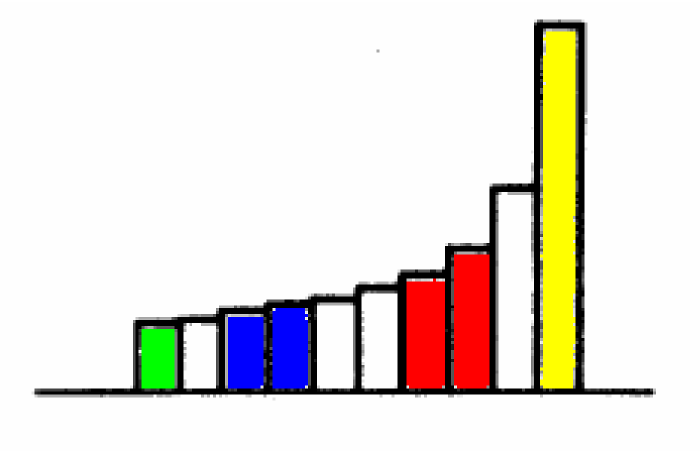
$$\eta = \frac{\left(V_{xx} - V_{yy}\right)}{V_{ZZ}}$$

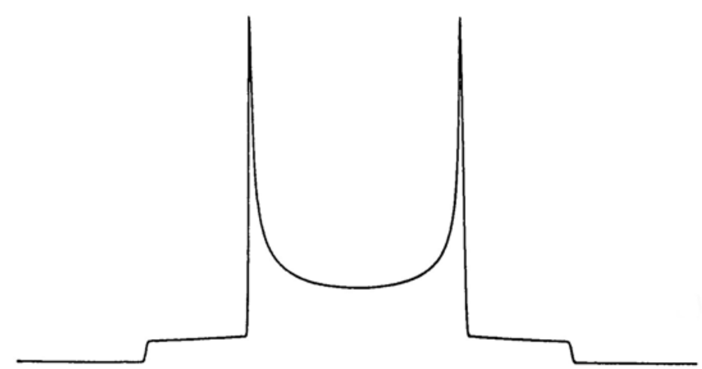


Shape of the spectra

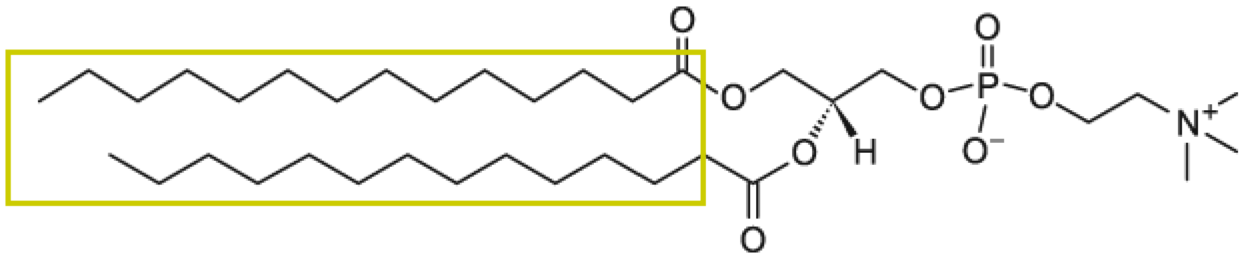








Acyl chains labeled with ^2H

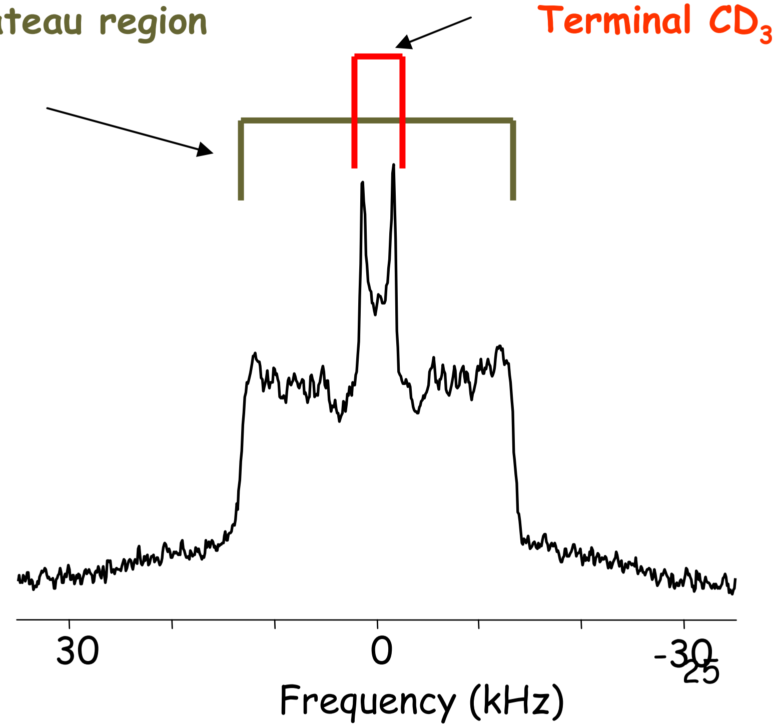


Quadrupolar splitting:

$$\Delta \nu_Q = \frac{3e^2qQ}{2h}\left(\frac{3\cos^2\theta - 1}{2}\right)\left\langle\frac{3\cos^2\beta - 1}{2}\right\rangle\left\langle\frac{3\cos^2\alpha - 1}{2}\right\rangle$$

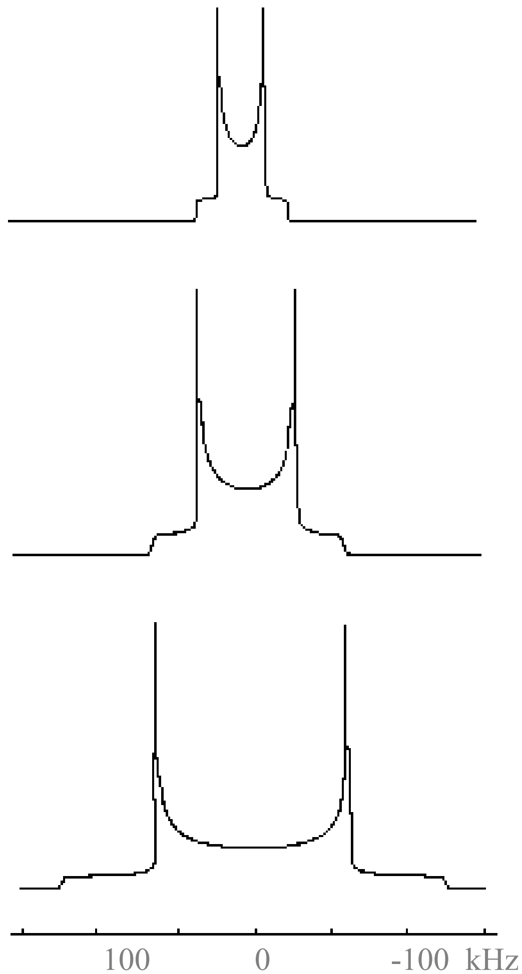
$\uparrow \Delta\nu_Q$ = order

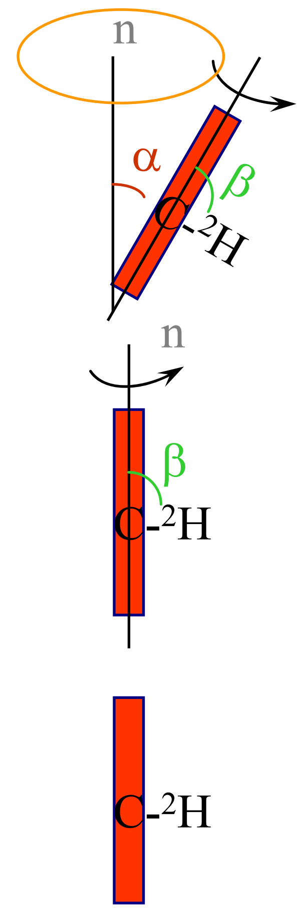
$\downarrow \Delta\nu_Q$ = disorder



Davis (1983) Biochim. Biophys. Acta 737, 117.

Effect of axially symetric motions





Rotation and oscillation

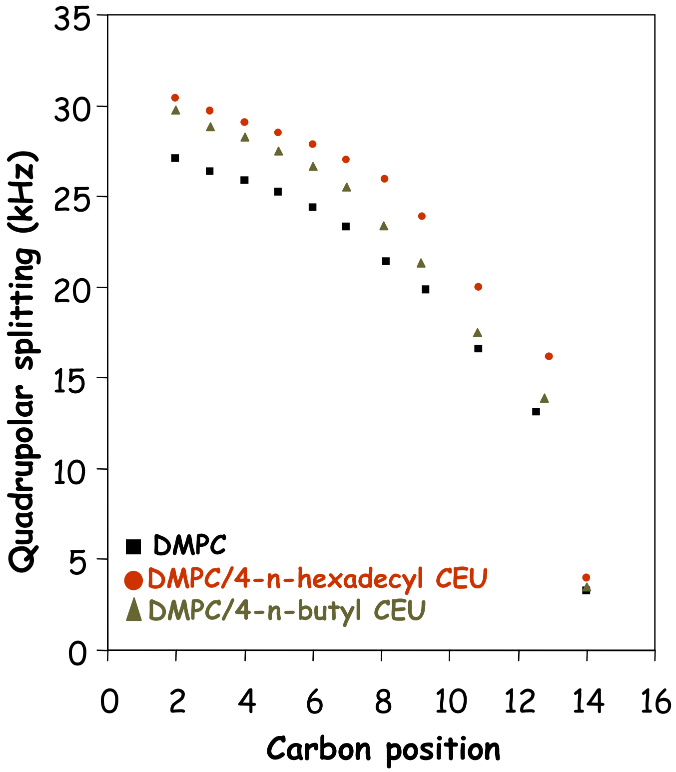
Fast axial rotation

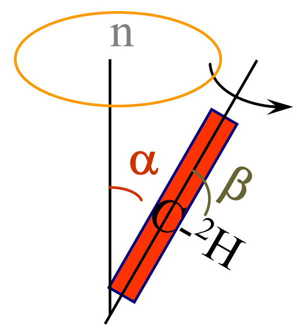
No motion

$$\Delta\nu_Q = \frac{3e^2qQ}{2h}\left(\frac{3\cos^2\theta - 1}{2}\right)\left\langle\frac{3\cos^2\beta - 1}{2}\right\rangle\left\langle\frac{3\cos^2\alpha - 1}{2}\right\rangle$$

Angular brackets:
Time average

Typical order profile



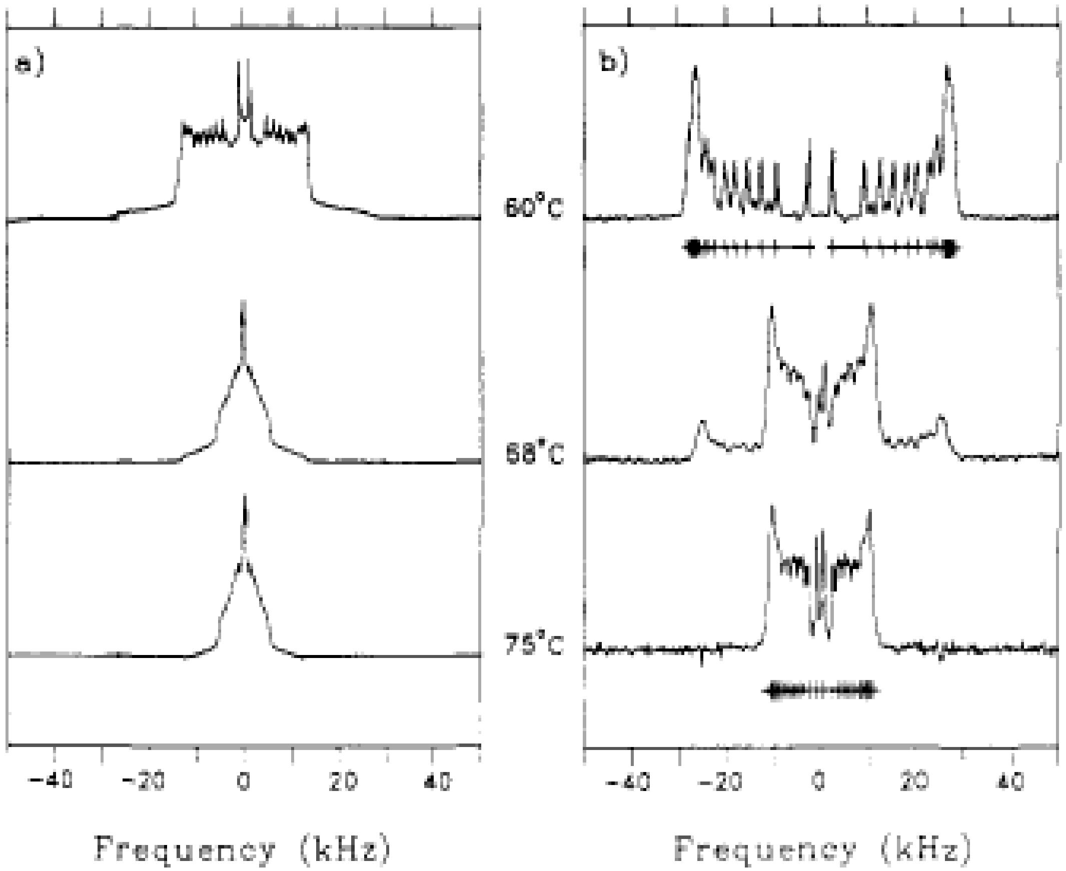


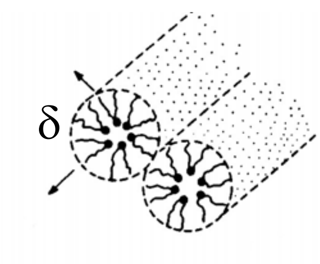
$$\Delta \nu_Q = \frac{3}{4}\left(\frac{e^2 qQ}{h}\right) \times S_{CD}$$

$$S_{CD} = \left\langle \frac{3\cos^2\beta - 1}{2} \right\rangle \left\langle \frac{3\cos^2\alpha - 1}{2} \right\rangle$$

conformational orientational

Hexagonal phase





$$\Delta \nu_Q = \frac{3e^2qQ}{2h}\left(\frac{3\cos^2\theta-1}{2}\right)\left\langle\frac{3\cos^2\beta-1}{2}\right\rangle\left\langle\frac{3\cos^2\alpha-1}{2}\right\rangle\left(\frac{3\cos^2\delta-1}{2}\right)$$

Hexagonal phase

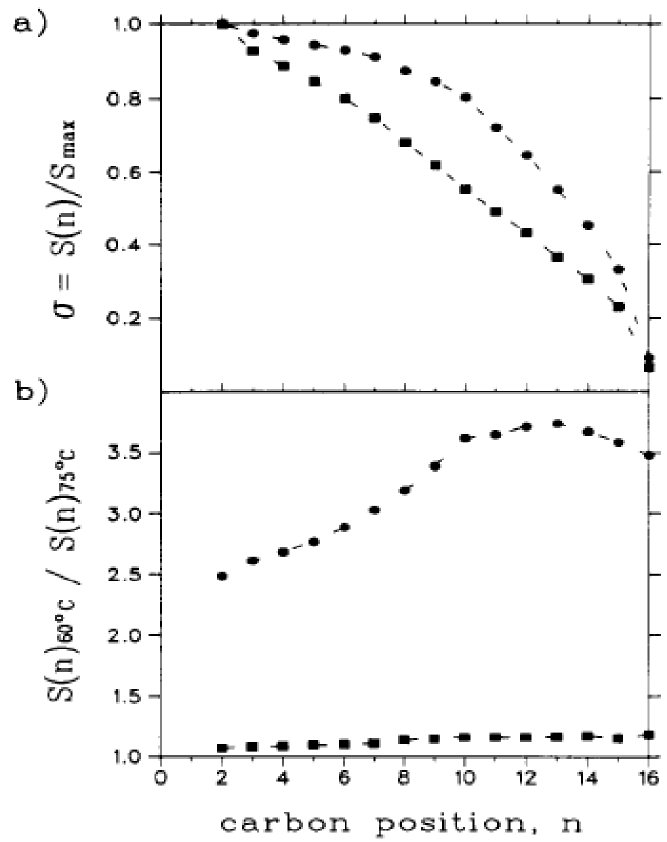
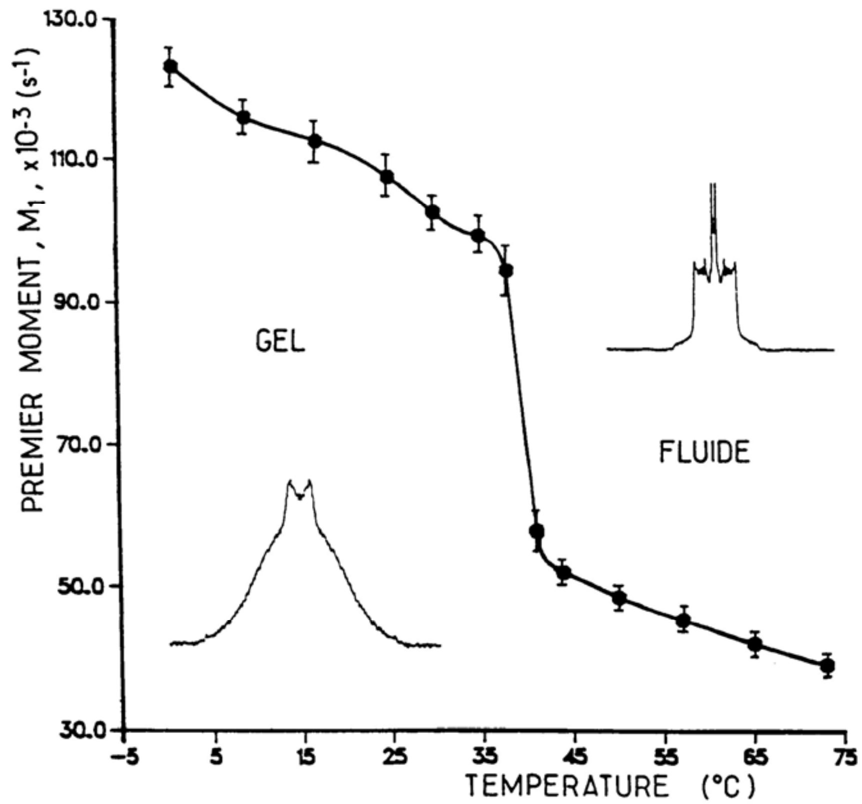


FIGURE 2: Influence of the lipid phase symmetry on the order profile. (a) Normalized orientational order profile of POPE-d_{31} in the L_α phase at 60 °C (●) and in the H_{II} phase at 75 °C (■). (b) Ratio of the order parameters $S(n)$ in the L_α phase (60 °C) to those in the H_{II} phase (75 °C) for POPE-d_{31} (●). The ratio for the same temperatures is plotted for POPC-d_{31} (■) which forms an L_α phase over the whole range of temperature.

Lafleur et al. (1990) Biochemistry 29, 8325.

Gel phase



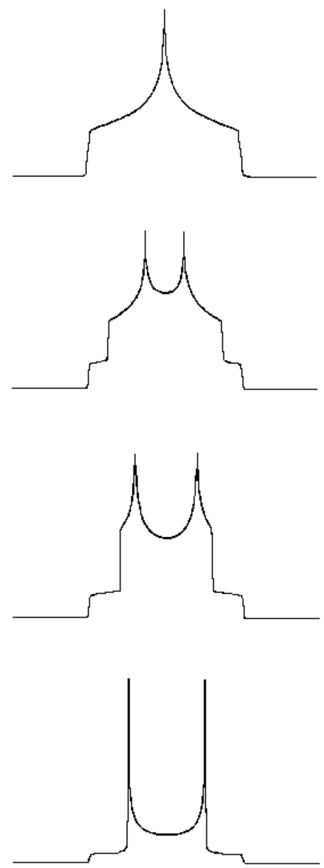
$$M_1 = \frac{\int_0^\infty \omega\, f(\omega)\, d\omega}{\int_0^\infty f(\omega)\, d\omega},$$

$$M_1 = -\frac{\pi}{\sqrt{3}} \frac{e^2 qQ}{h} \overline{S_{CD}},$$

Asymmetry parameter

- Effect of the asymmetry parameter on the ^{2}H NMR spectral lineshape

$$\eta = \frac{\left(V_{xx} - V_{yy}\right)}{V_{ZZ}}$$



$\eta = 1.0$

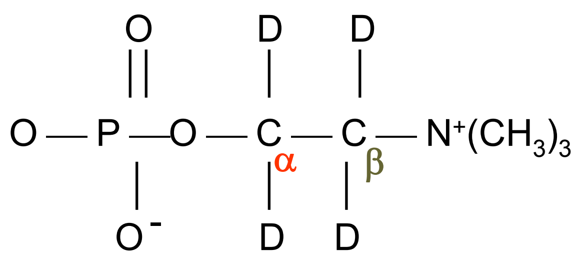
$\eta = 0.5$

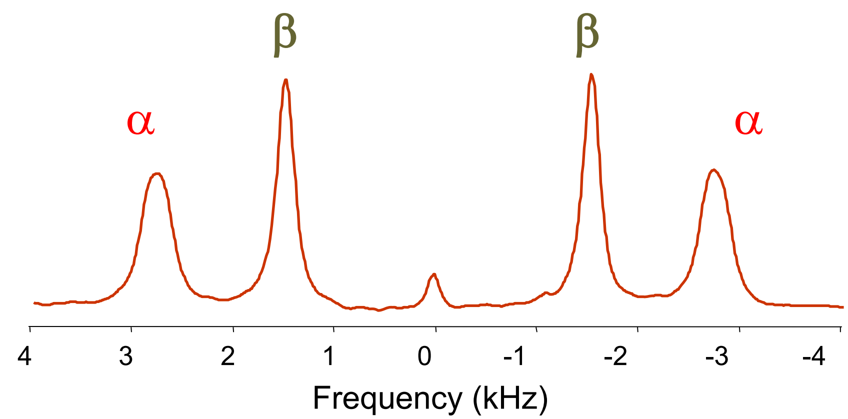
$\eta = 0.2$

$\eta = 0.0$

Molecular voltmeter

- Information on the conformational order of polar head groups
  - Bicellar system made with DMPC-d_4





- PC head group sensitive to the surface charge: molecular voltmeter

+ charge (+)	$\Rightarrow \downarrow \Delta\nu_{\alpha}$
	$\Rightarrow \uparrow \Delta\nu_{\beta}$

+ charge (-)	$\Rightarrow \uparrow \Delta\nu_{\alpha}$
	$\Rightarrow \downarrow \Delta\nu_{\beta}$

Seelig et al. (1987) Biochemistry, **26**, 7535.

Molecular voltmeter

+ charge (+)
⇒ ↓ $\Delta\nu_{\alpha}$
⇒ ↑ $\Delta\nu_{\beta}$

+ charge (-)
⇒ ↑ $\Delta\nu_{\alpha}$
⇒ ↓ $\Delta\nu_{\beta}$

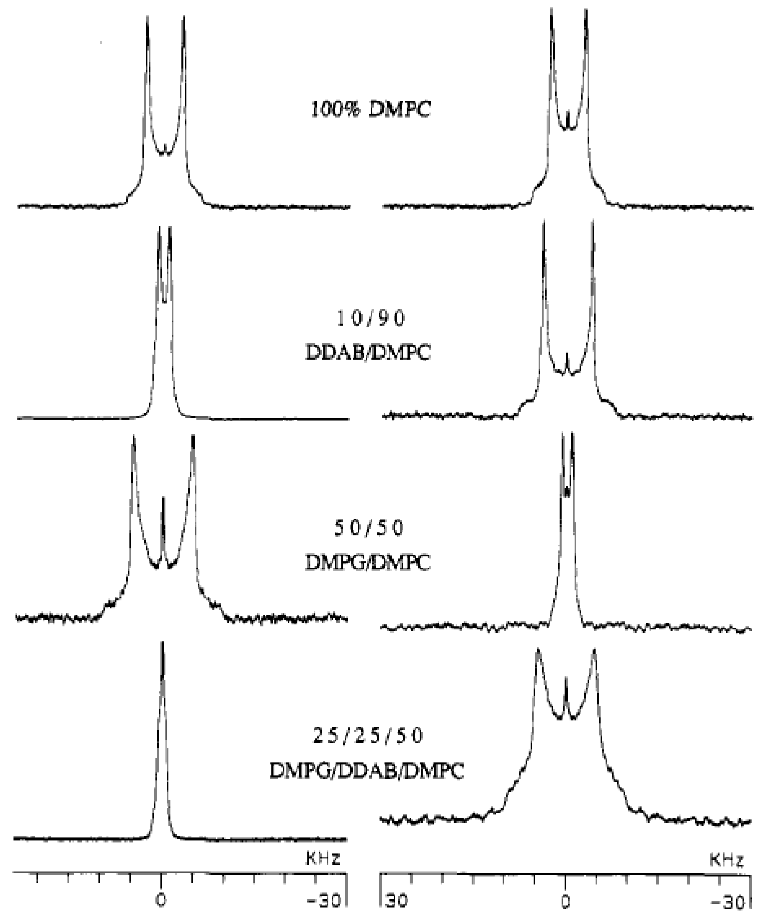


FIGURE 1: ^{2}H NMR spectra at 35 °C from DMPC-α-d_2 (left) and DMPC-β-d_2 (right) in membranes containing lipid mixtures with the molar compositions, from top to bottom, of 100% DMPC, 10/90 DDAB/DMPC, 50/50 DMPG/DMPC, and 25/25/50 DDAB/DMPG/DMPC. All spectra have been symmetrized.

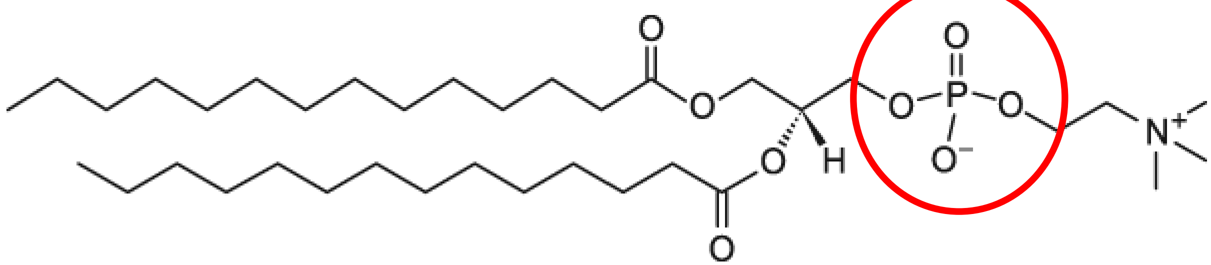
Marassi and Macdonald (1992) Biochemistry 31, 10031.

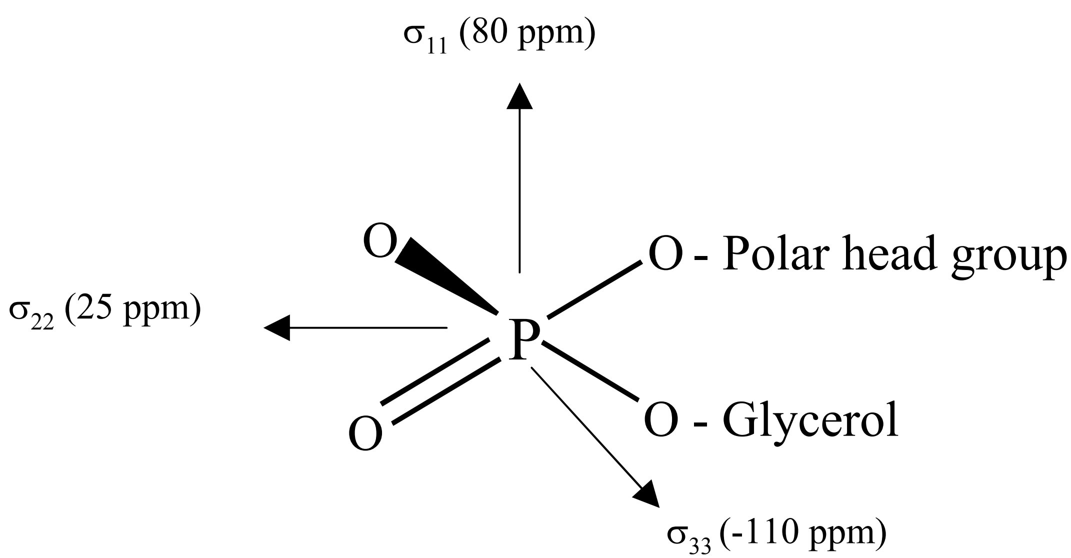
Phospholipids and ^{31}P NMR

Natural abundance, ^{31}P: 100%

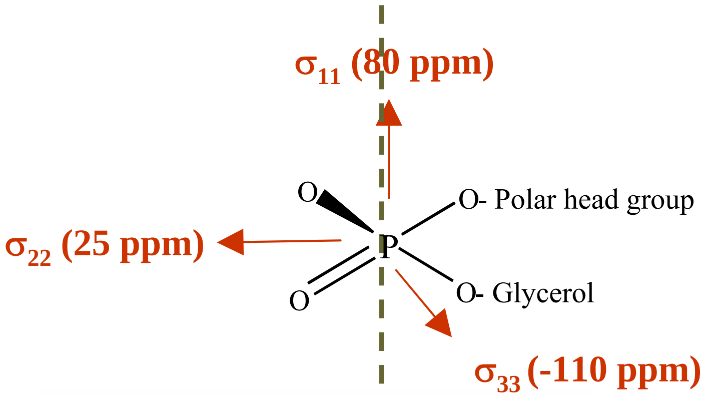
Spin: ½

DMPC



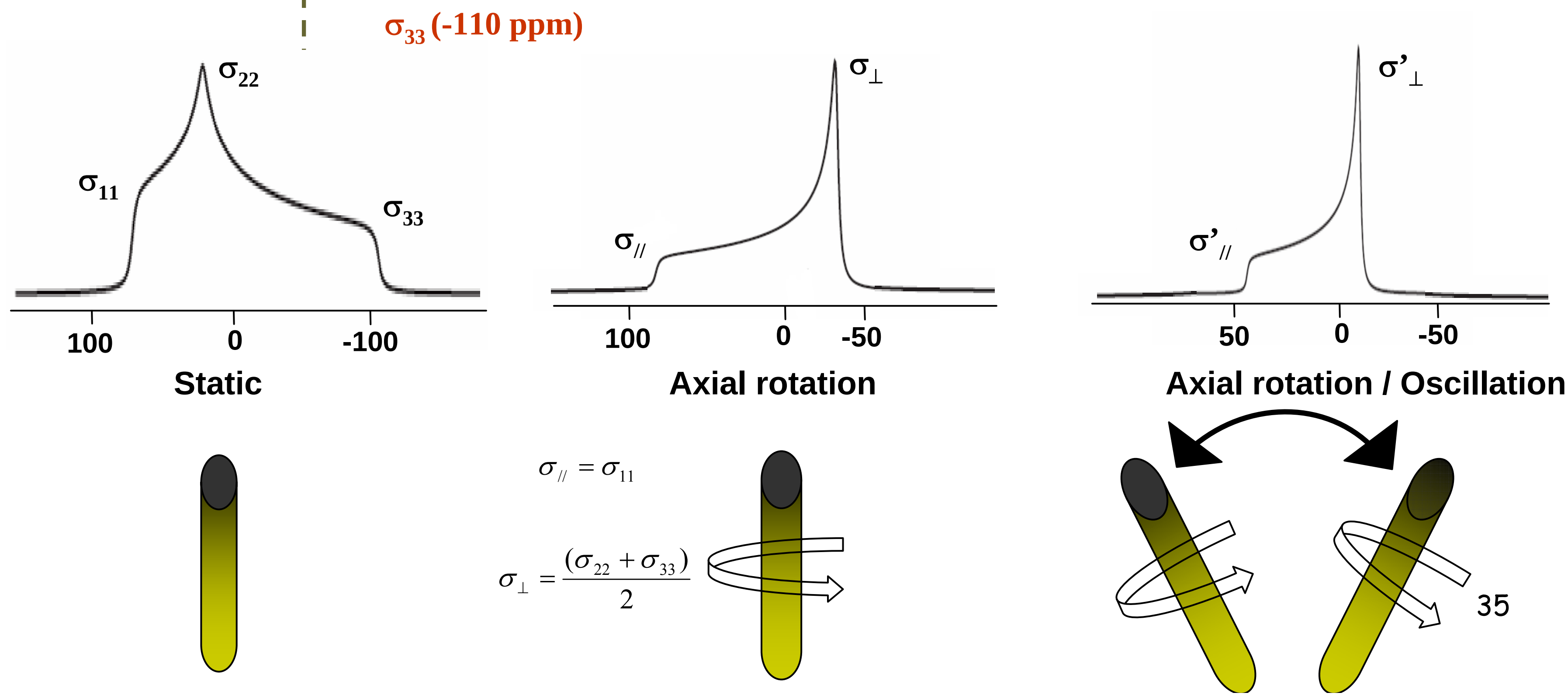


^{31}P NMR

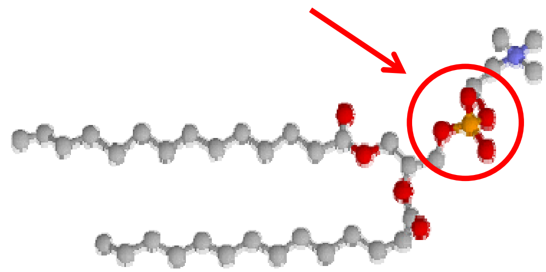


$$\sigma = \frac{1}{3}(\sigma_{11} + \sigma_{22} + \sigma_{33}) + \frac{1}{3}\sum_{j=1}^{3}(3\cos^2\theta_j - 1)\sigma_{jj}$$

Isotropic **Anisotropic**



^{31}P NMR order parameters



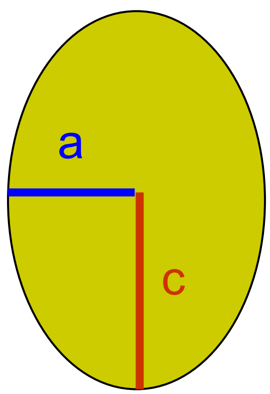
- Spectral width: **dynamics** / **orientation** of the polar head group

$$S_2 = \frac{\delta}{\delta_{ref}}$$

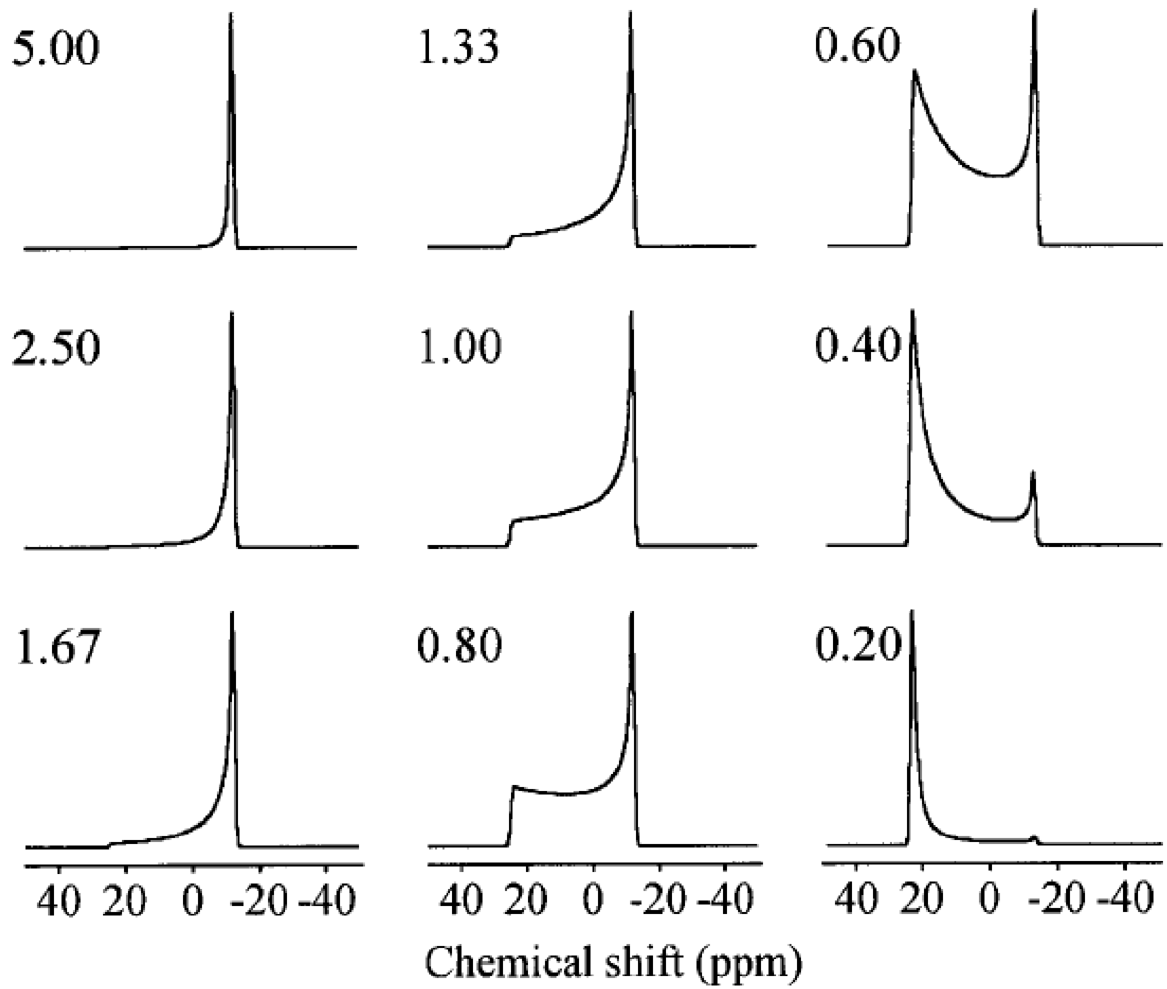
$S_2 = 1 \rightarrow$ No change
$S_2 = 0 \rightarrow$ Isotropic system

Picard et al. (1999) Biophys. J. 77, 888.
Picard et al. (2000) Can. J. Anal. Sci. Spectrosc. 45, 72.

^{31}P NMR, vesicle morphology

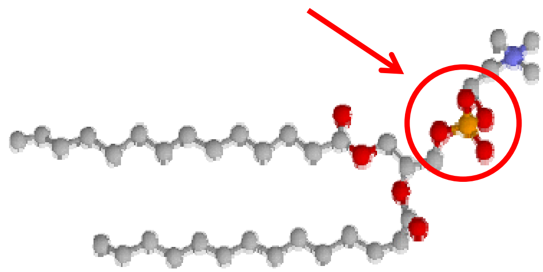


$$r = \frac{c}{a}$$



Picard et al. (1999) Biophys. J. 77, 888.

^{31}P NMR order parameters



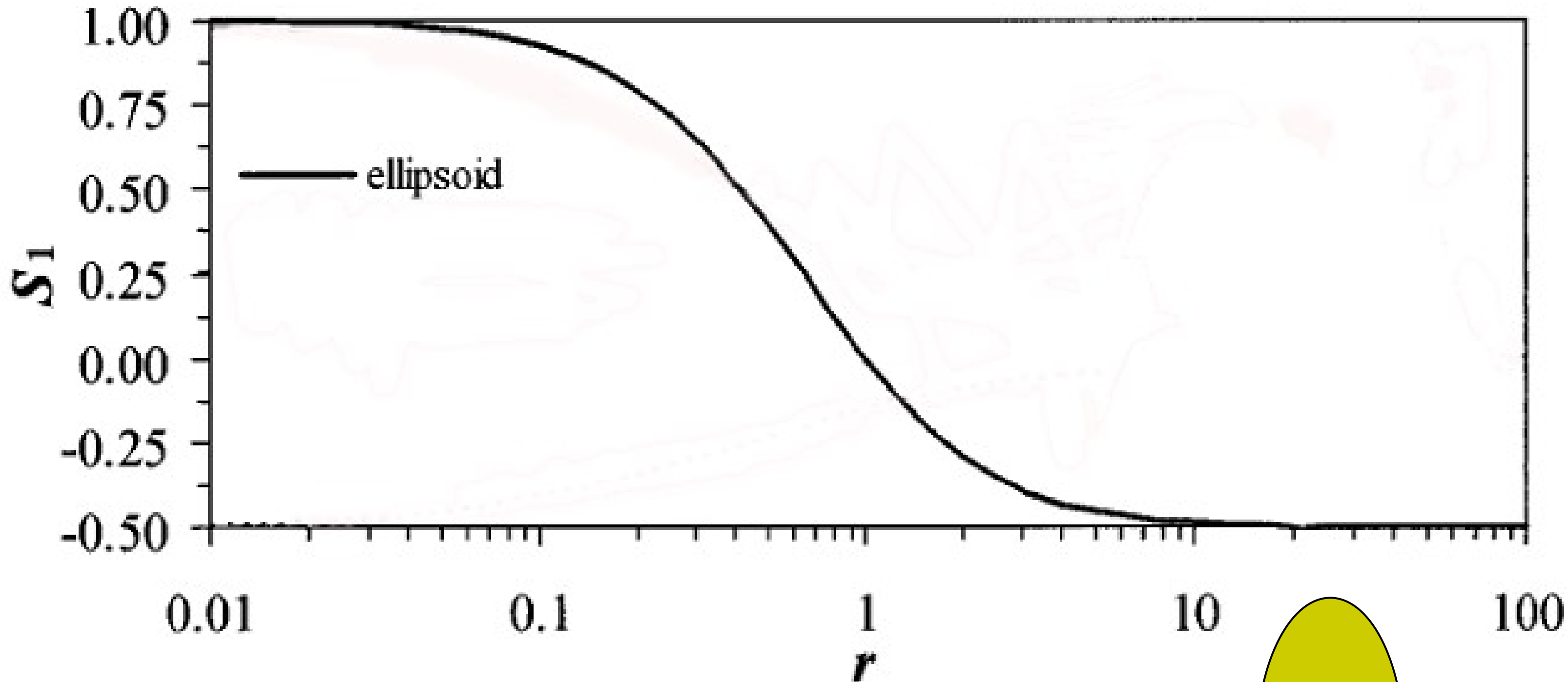
- Morphology: degree of **orientation** of the system

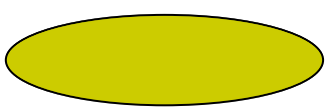
$$S_1 = \frac{M_1 - \delta_{iso}}{\delta}$$

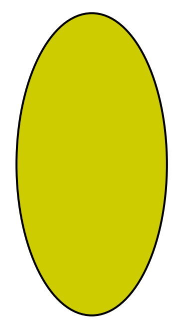
$S_1 = 1 \rightarrow$ Lipid main axis // B_0
$S_1 = -0.5 \rightarrow$ Lipid main axis $\perp$ B_0

Picard et al. (1999) Biophys. J. 77, 888.
Picard et al. (2000) Can. J. Anal. Sci. Spectrosc. 45, 72.

S_1 as a function of r



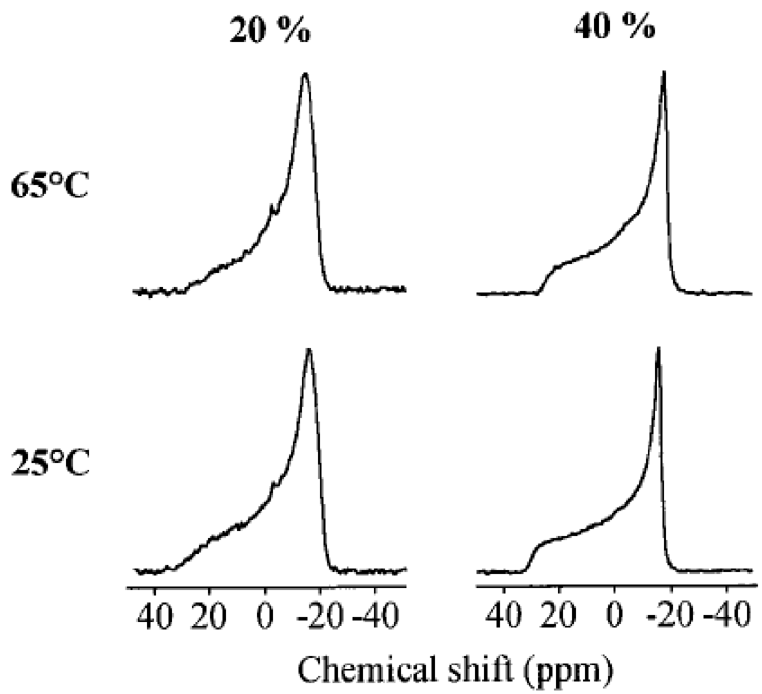


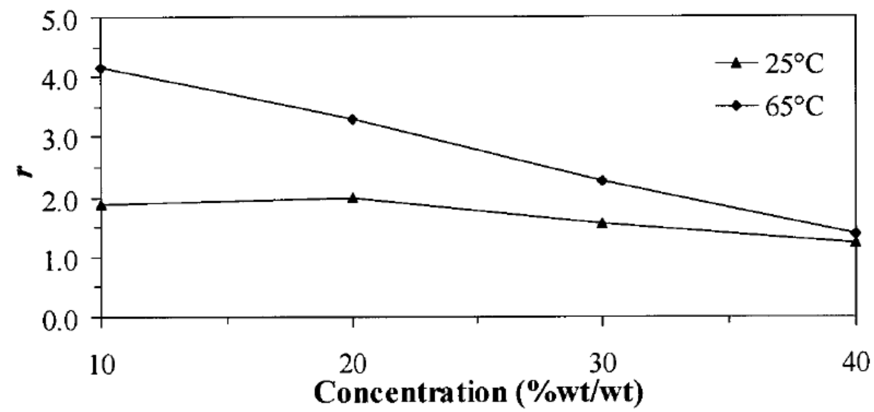


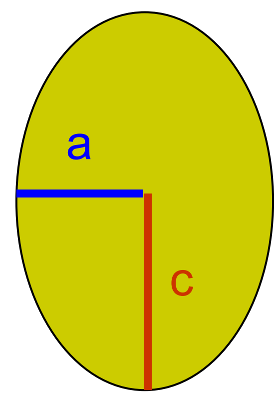
Picard et al. (1999) Biophys. J. 77, 888.

^{31}P NMR, vesicle morphology

- DMPC spectra



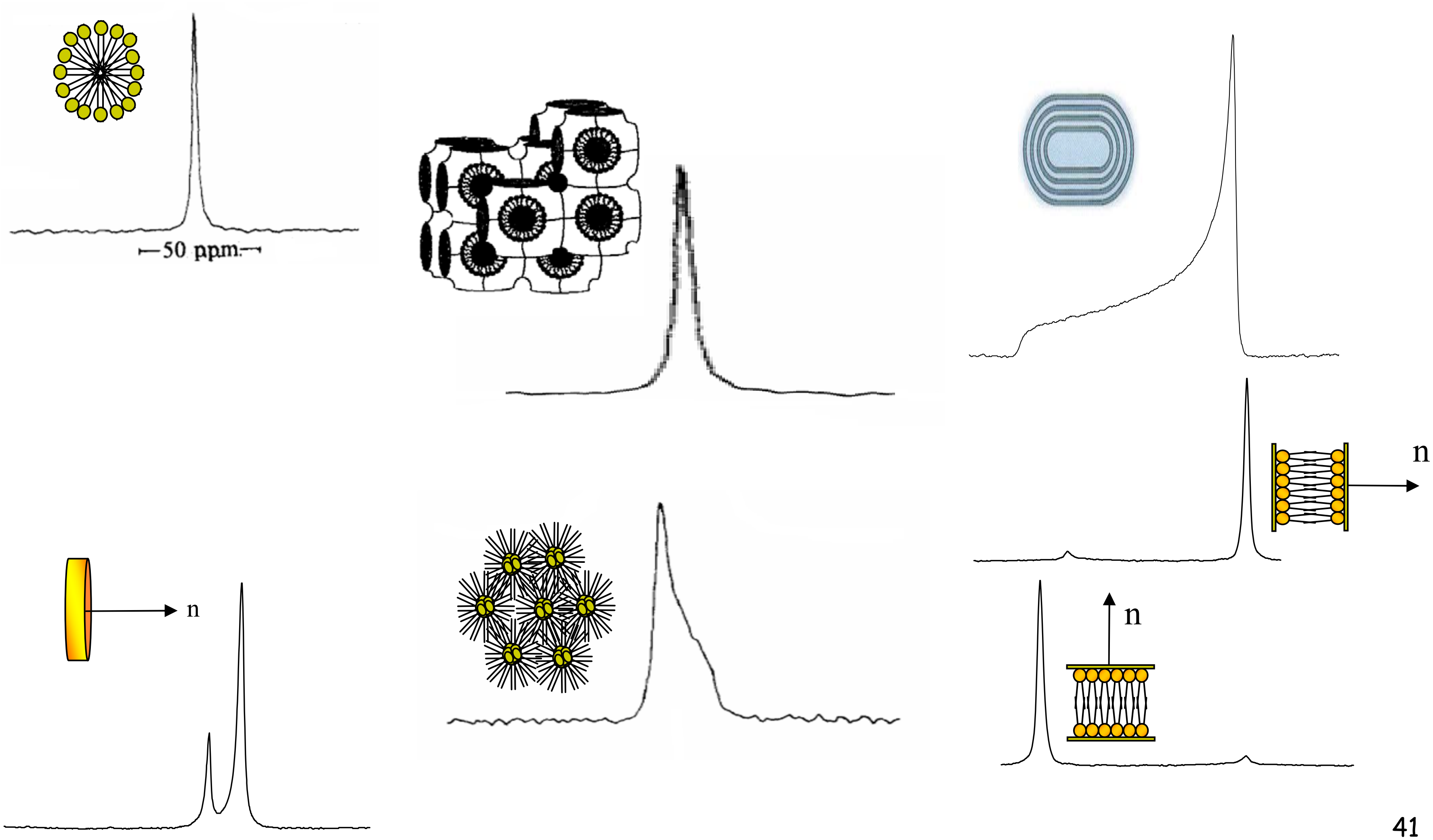




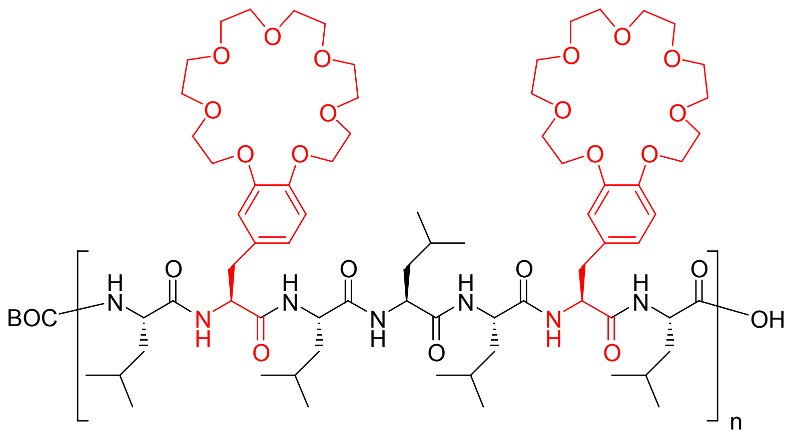
$$r = \frac{c}{a}$$

Picard et al. (1999) Biophys. J. 77, 888.

^{31}P NMR, lipid phases

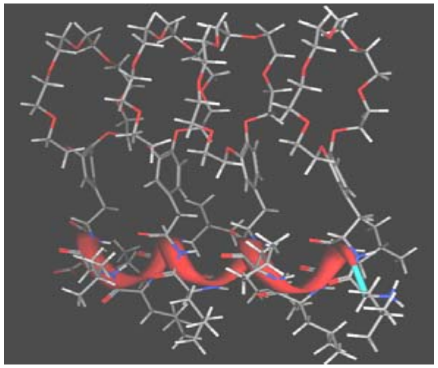


Novel peptides

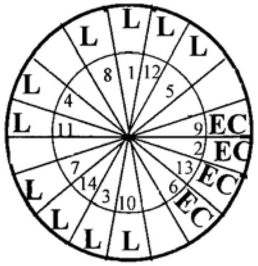


Boc-(L-EC$_{21-7}$-LLL-EC$_{21-7}$-L)$_n$-COOH

- Helicoidal structure
- Amphiphilic
- **Neutral**

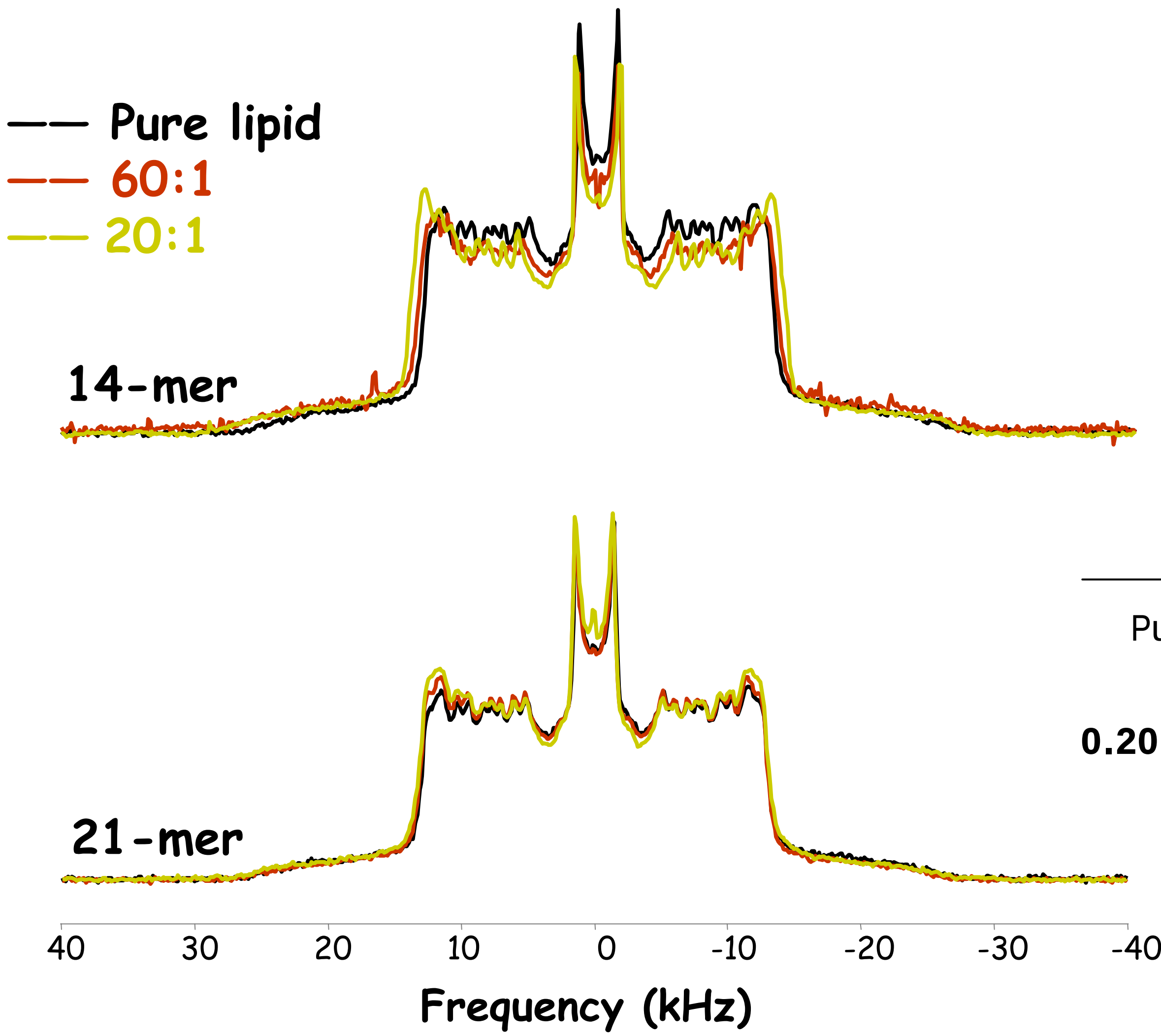


14-mer peptide	21-mer peptide
• ↑ vesicle permeability • Monoprotected peptide (Boc, COOH) slightly more active • Erythrocyte lysis • Length: 21 Å	• Monomolecular ion channel • No effect on vesicle permeability • Length: 31.5 Å



Biron et al. (2004) Bioorg. Med. Chem. 12, 1279.
Vandenburg et al. (2002) Chem. Comm. 16,1694.
Meillon et al. (1997) Angew. Chem. Int. Ed. Engl. 36, 967.
Biron et al. (2001) Biopolymers 55, 364.

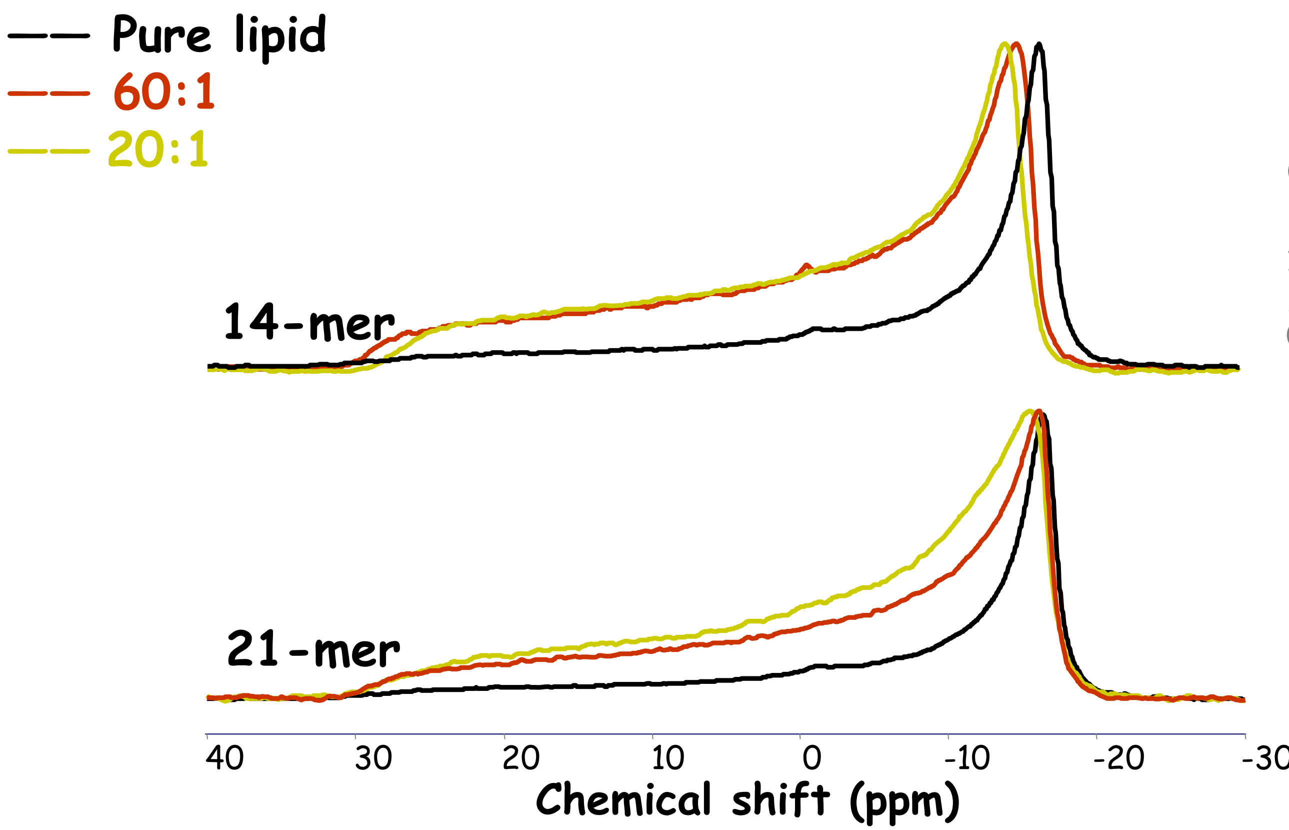
^{2}H NMR results

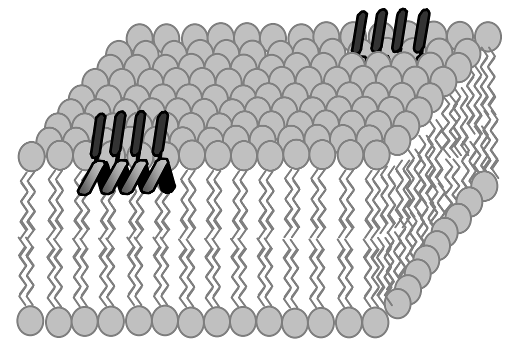


$S_{CD(P)}$ ($S_{CD(M)}$)		
Pure	+14-mer +21-mer	+14-mer +21-mer
0.20 (0.03)	**0.20 (0.03)** **0.20 (0.03)**	**0.21 (0.03)** **0.20 (0.03)**

Ouellet et al. (2006) Biophys. J. 90, 4071.

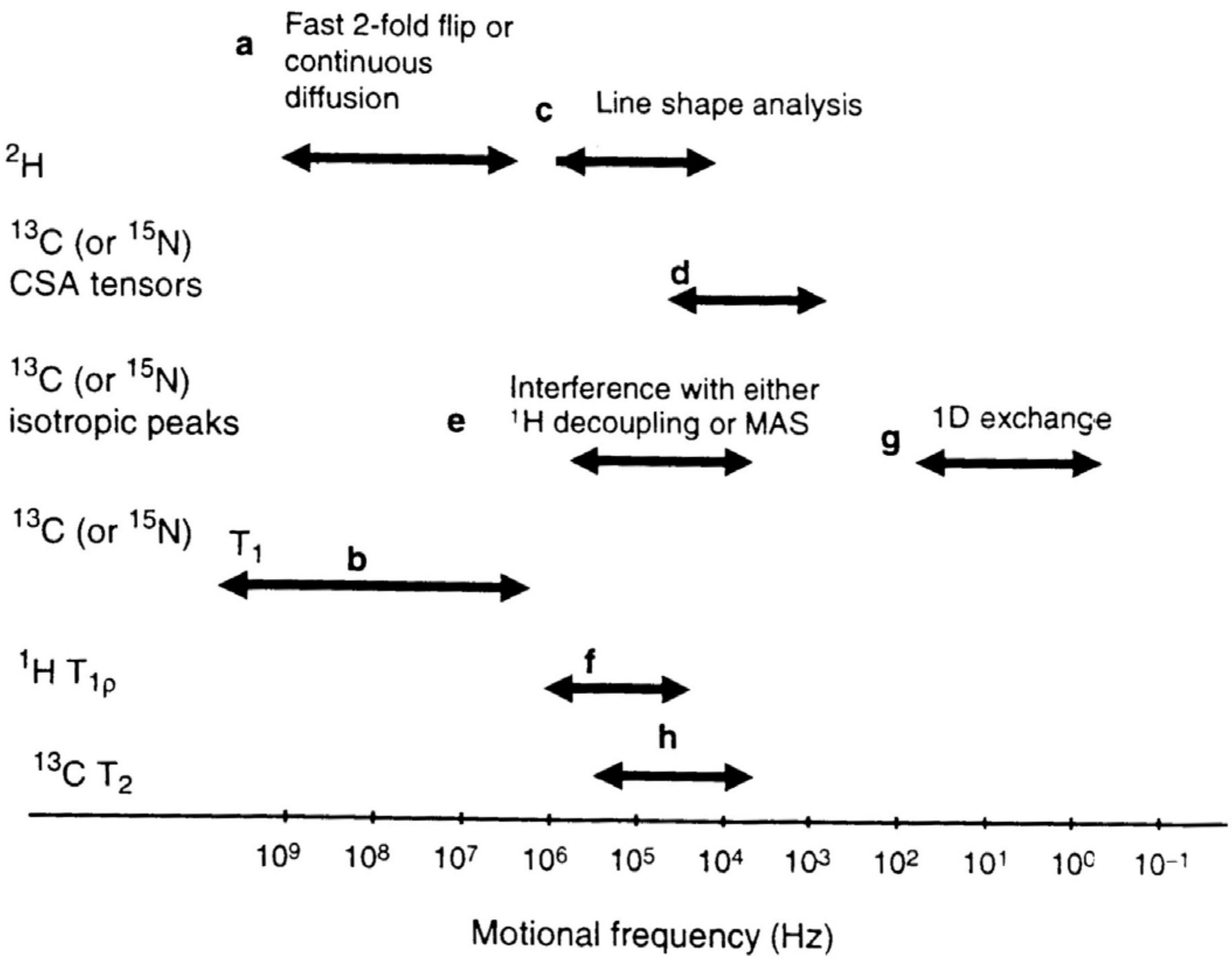
^{31}P NMR results



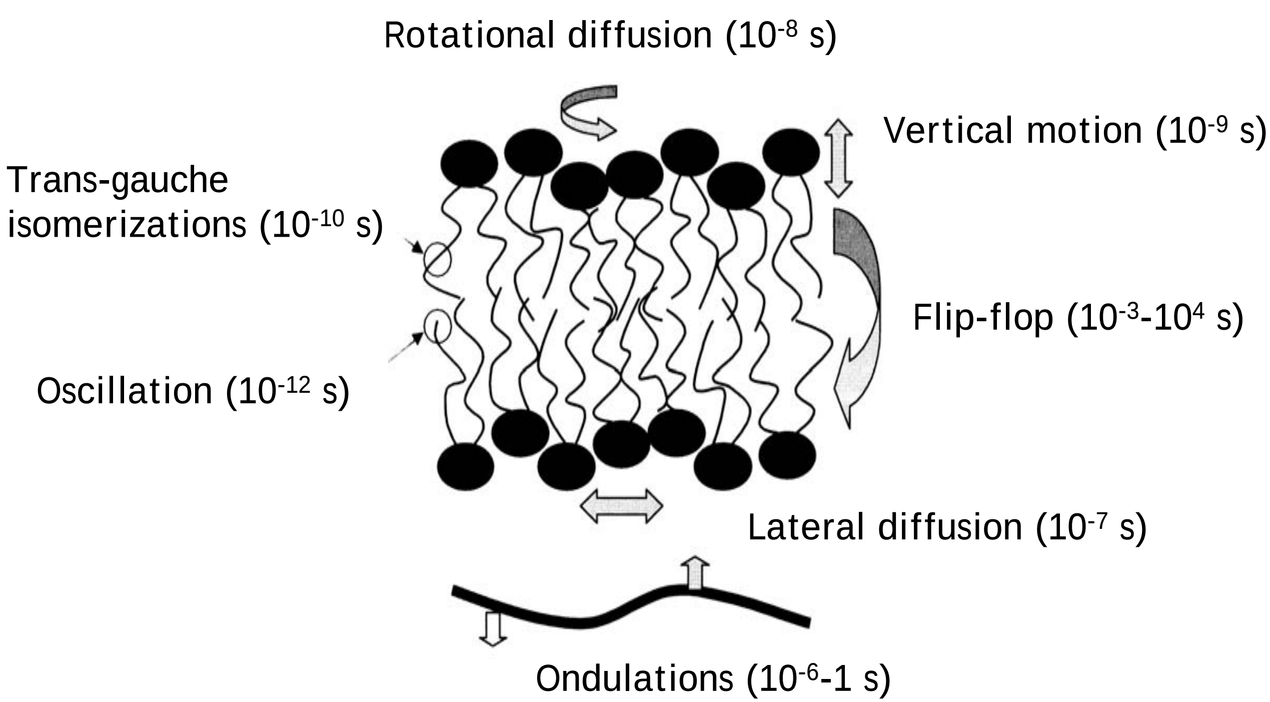


	S_1		S_2	
Pure	+14-mer +21-mer		+14-mer +21-mer	
-0.17	-0.02 -0.06	-0.01 -0.05	0.91 0.98	0.86 0.94

NMR and dynamics



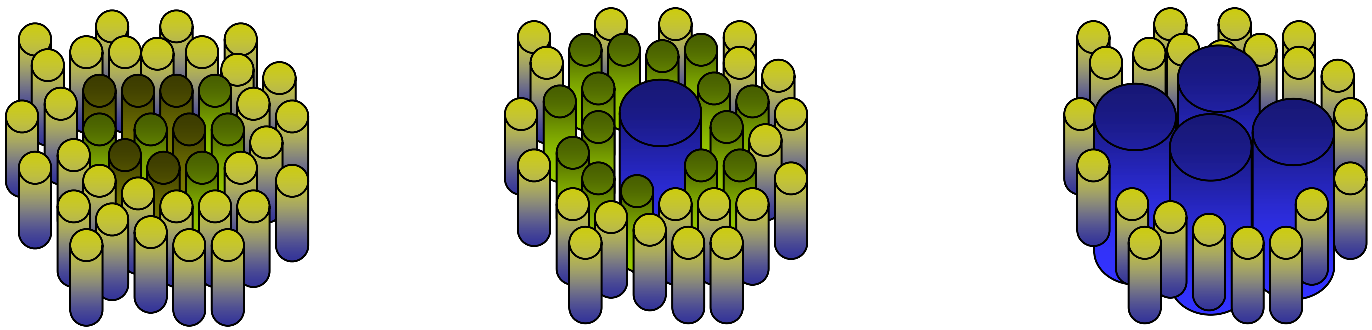
NMR and dynamics



Gawrisch (2005) in The Structure of Biological Membranes, CRC Press LLC, pp.147-171

Lateral heterogeneities or domains

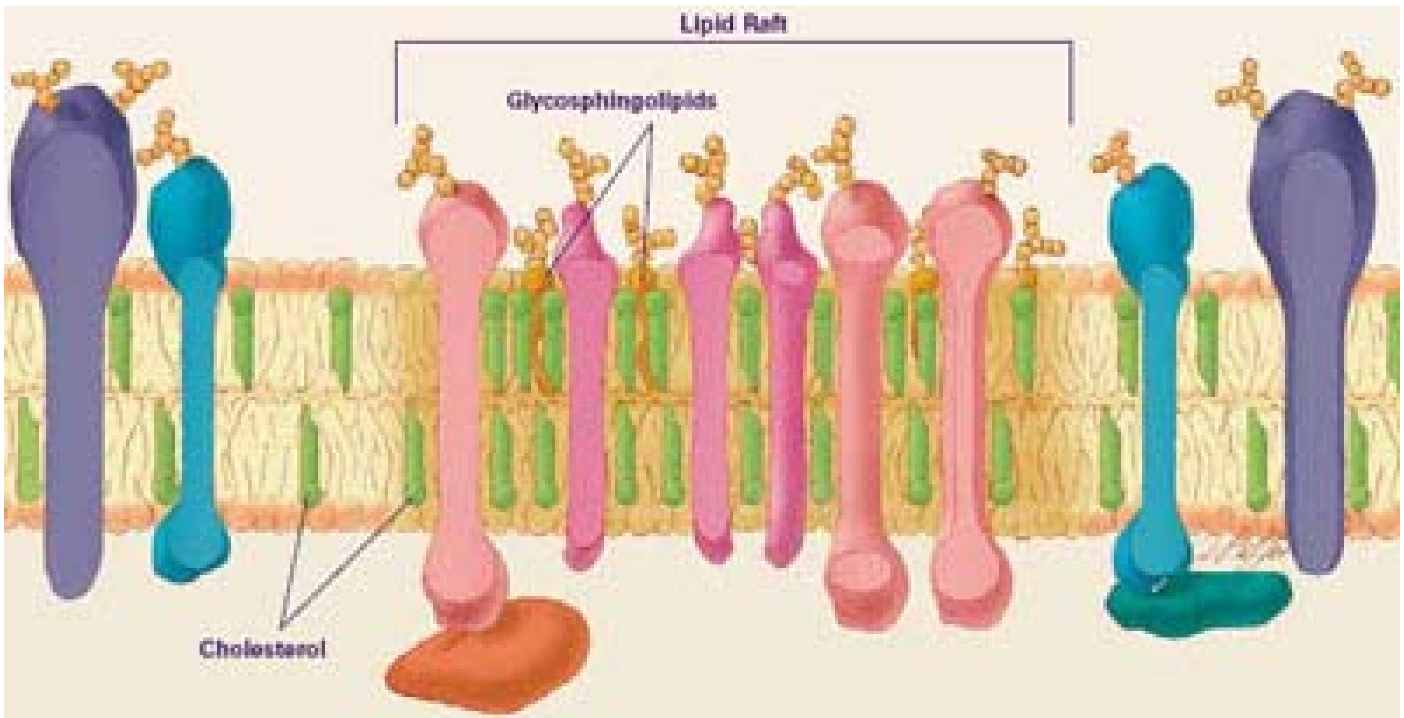
Lipid-lipid interactions **Lipid-protein interactions** **Protein-protein interactions**



- Biological roles
  - Passive transport of small molecules across the membrane
  - Modulation of the activity of certain membrane proteins
  - Vesicle fusion

Kleinfeld (1987) Current Topics in Membranes and Transport, 29, 1.
Mouristen and Jorgensen (1995) Mol. Membr. Biol., 12, 15.

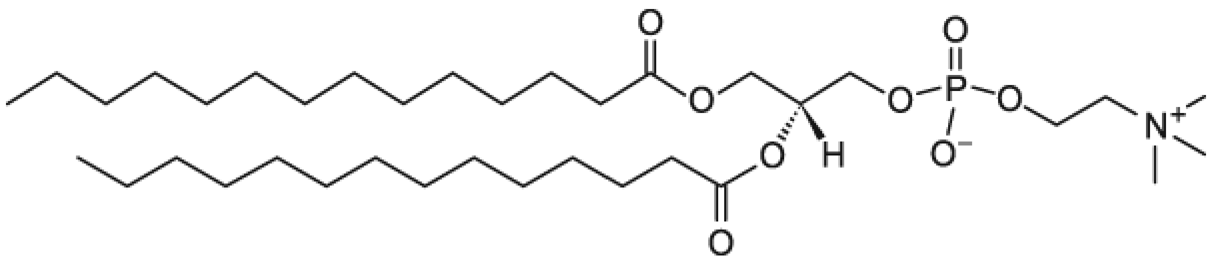
Lipid rafts



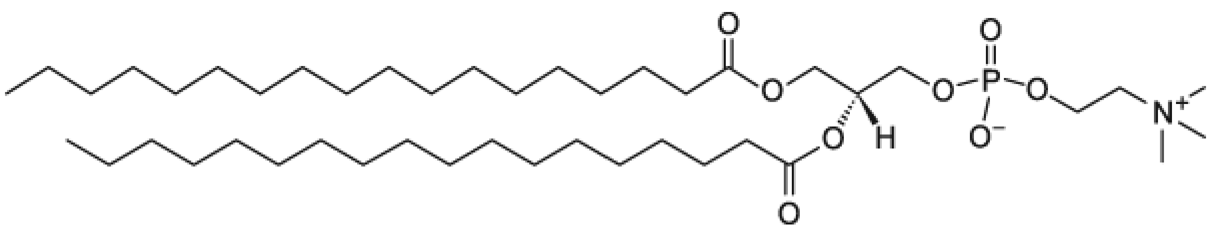
http://publications.nigms.nih.gov/insidethecell/images/ch2_lipidraft.jpg

Lateral heterogeneities or domains

- Mixture of two phospholipids: DMPC/DSPC



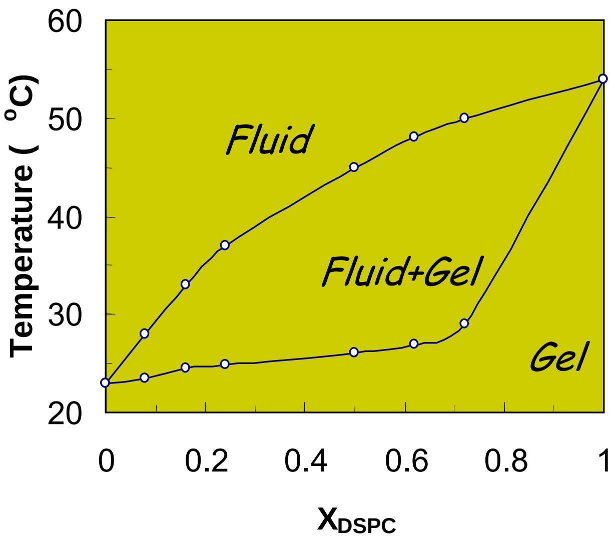
DMPC
n=14
T_m=23°C



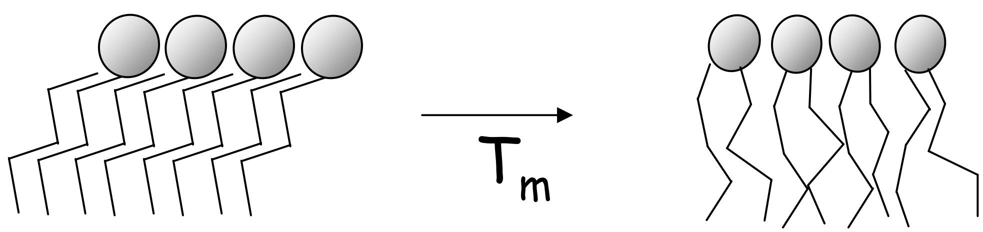
DSPC
n=18
T_m=55°C

Phase diagram

- Phase diagram of the DMPC/DSPC mixture



→ Partially miscible: coexistence of gel and fluid phases

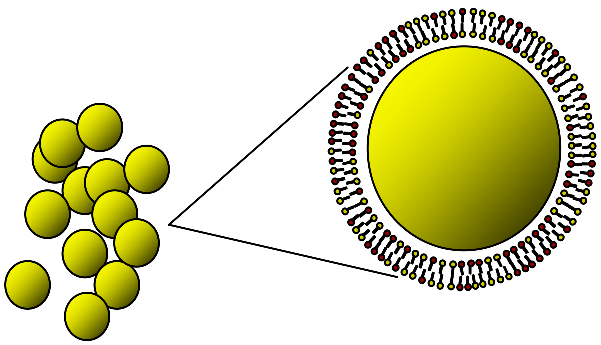


Slow lateral diffusion **Fast lateral diffusion**

Shimshick and McConnell (1973) Biochemistry, 12, 2351.

Adsorbed bilayer

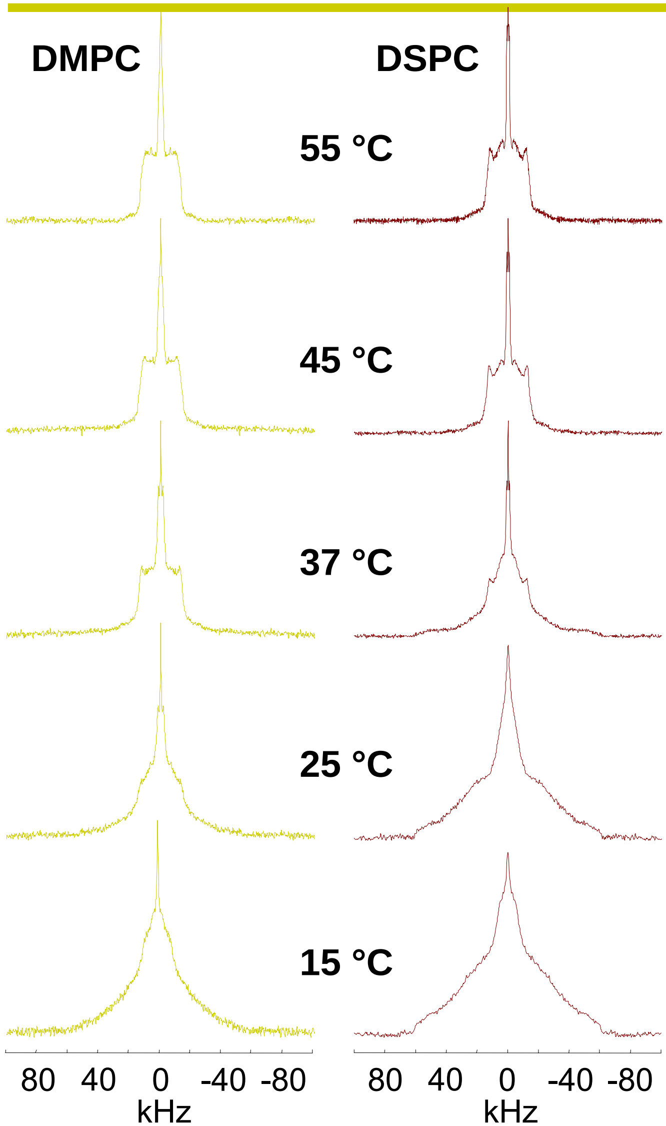
- DMPC/DSPC (1:1) bilayer adsorbed on silica beads of well defined radius (320 nm)

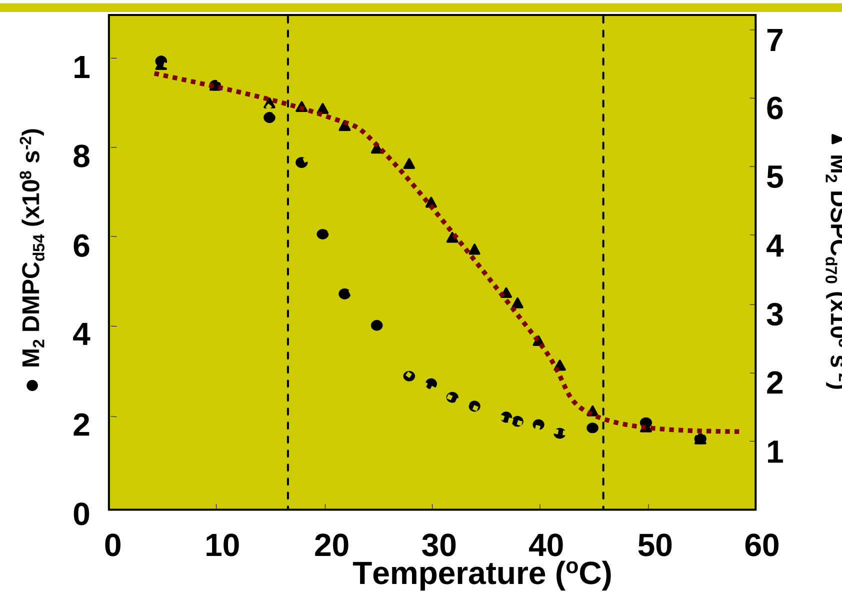


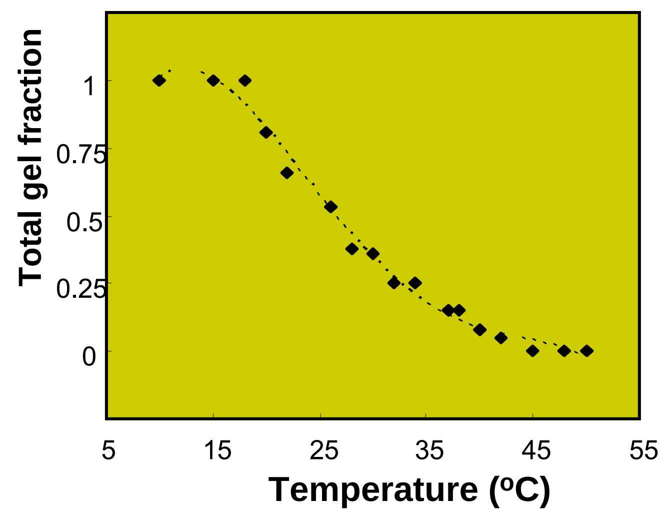
→ Well defined radius
→ Reduced membrane deformations
→ No tumbling

Arnold et al. (2004) Biophys. J., 87, 2456.

^2H NMR spectra

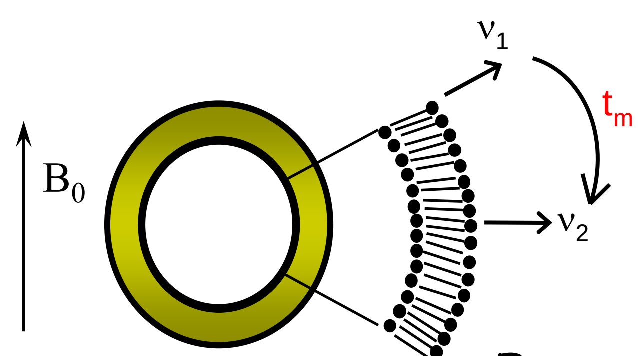






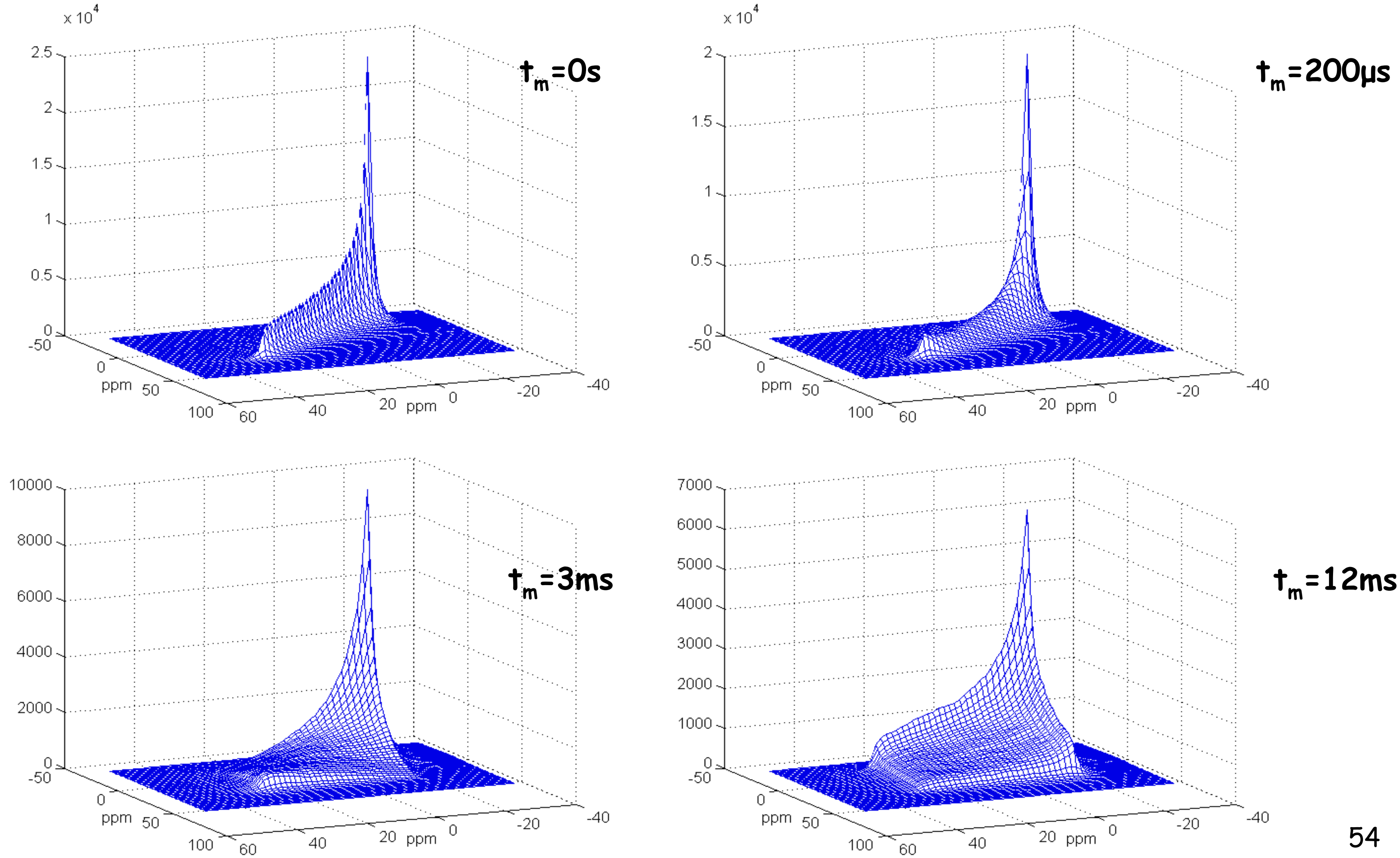
Exchange experiments

- 2D experiments to correlate the resonance frequency of one lipid at the beginning and at the end of a delay



Orientation change ↔ Frequency change

Exchange experiments



Autocorrelation function

- "Memory function" of the system

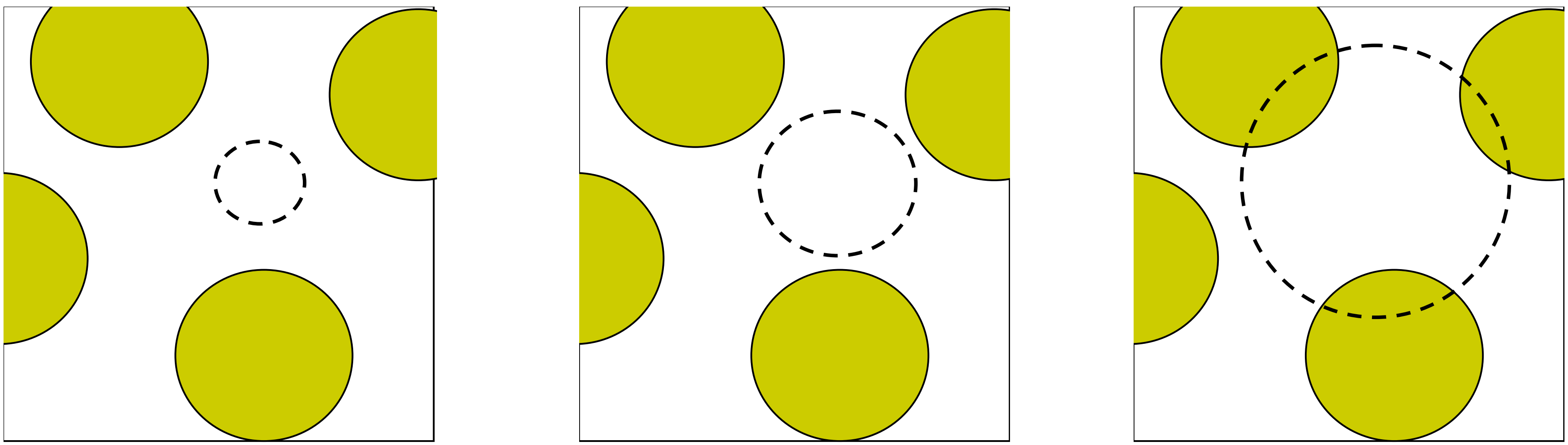
$$C_2(t_m) = \frac{5}{\delta^2} \frac{\iint \nu_1 \nu_2 S(\nu_1, \nu_2; t_m) d\nu_1 d\nu_2}{\iint S(\nu_1, \nu_2; t_m) d\nu_1 d\nu_2}$$

- Evolution in the presence of diffusion

$$C_2(t_m) = \exp\left(-\frac{t_m}{t_d}\right) \qquad t_d = \frac{R^2}{6D}$$

Schmidt-Rohr and Spiess (1994) Multidimensional Solid State NMR and Polymers, Academic Press, London.
Picard et al. (1998) Biophys. J., 74, 857.

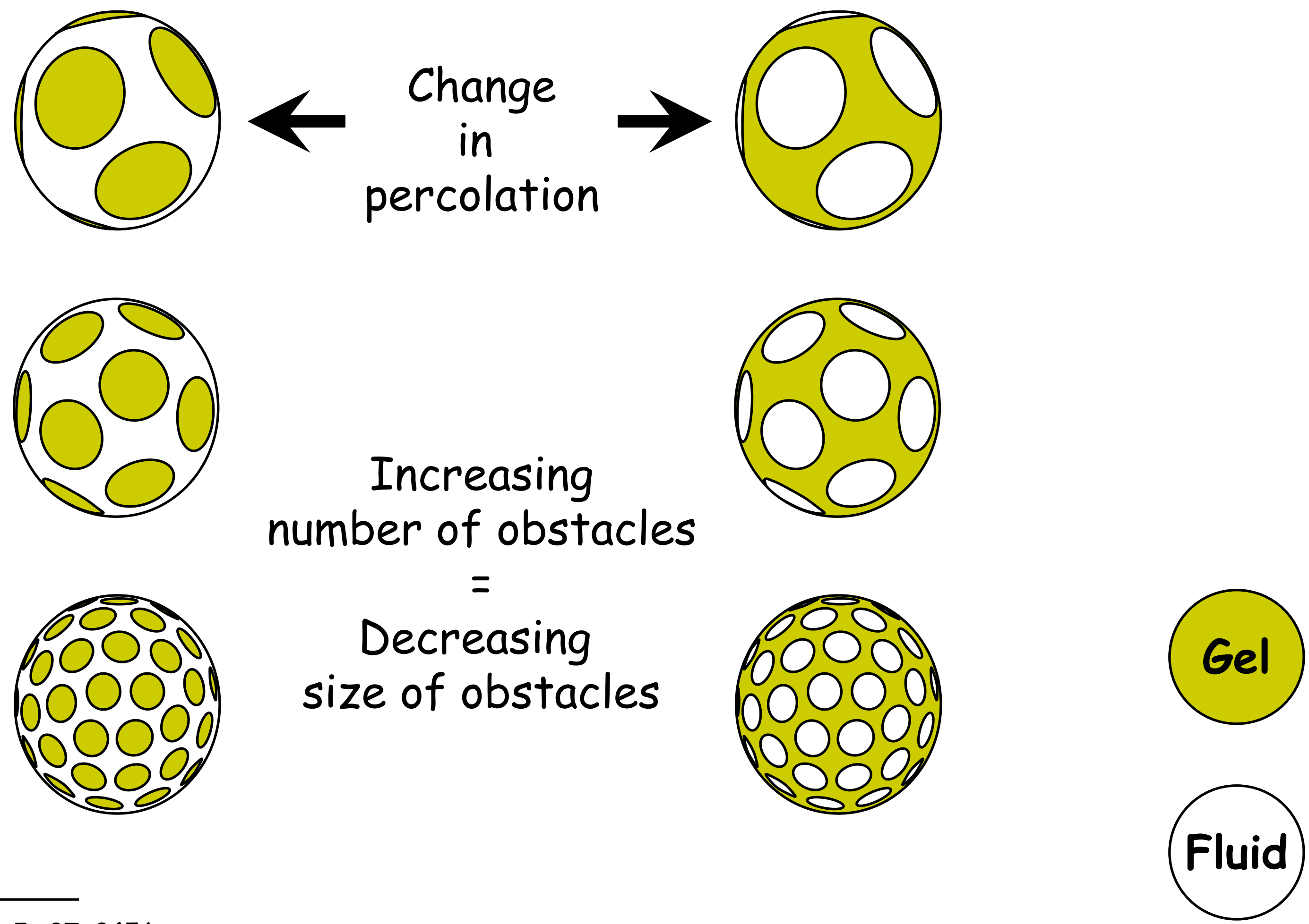
Lateral diffusion in the presence of obstacles



→ When t_m increases, the number of obstacles increases and the apparent diffusion coefficient decreases

→ **Numerical simulations to quantify this effect**

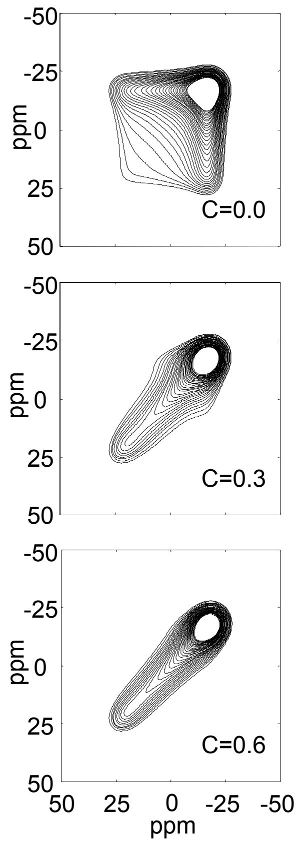
Random walk on a sphere in the presence of obstacles



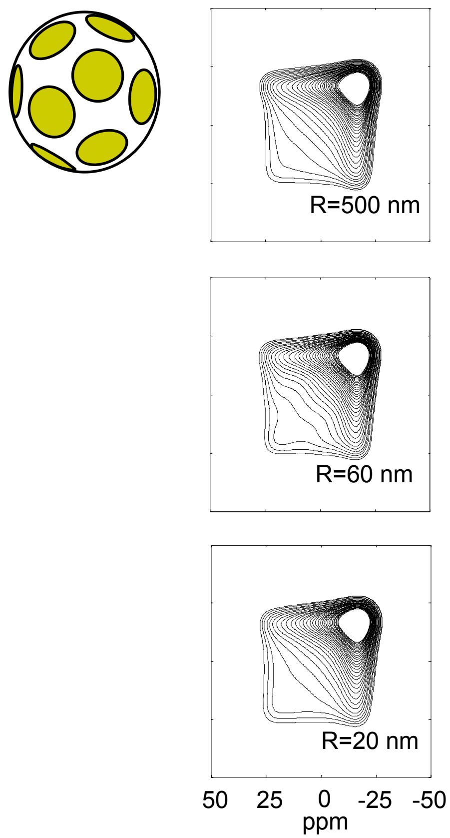
Arnold et al. (2004) Biophys. J., 87, 2456.

Spectral simulations

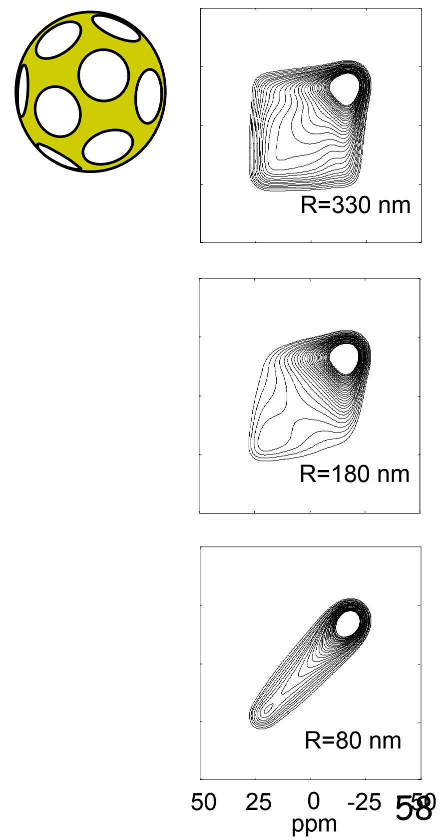
Concentration of point obstacles



Number (size) of discoidal immobile domains



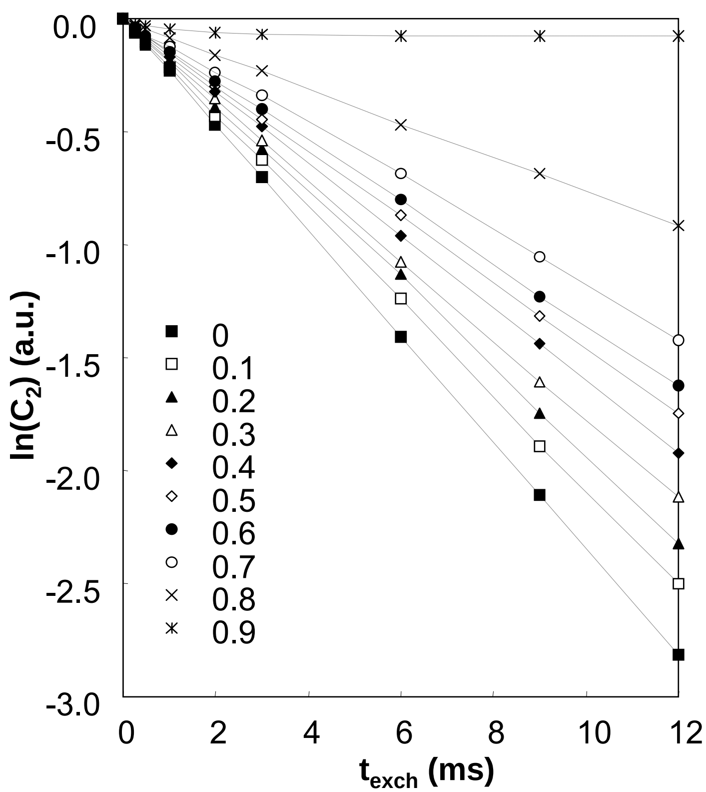
Number (size) of fluid discoidal domains



Constant obstacle area fraction of 0.5

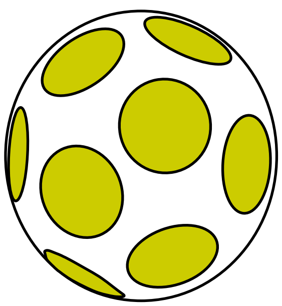
Simulations

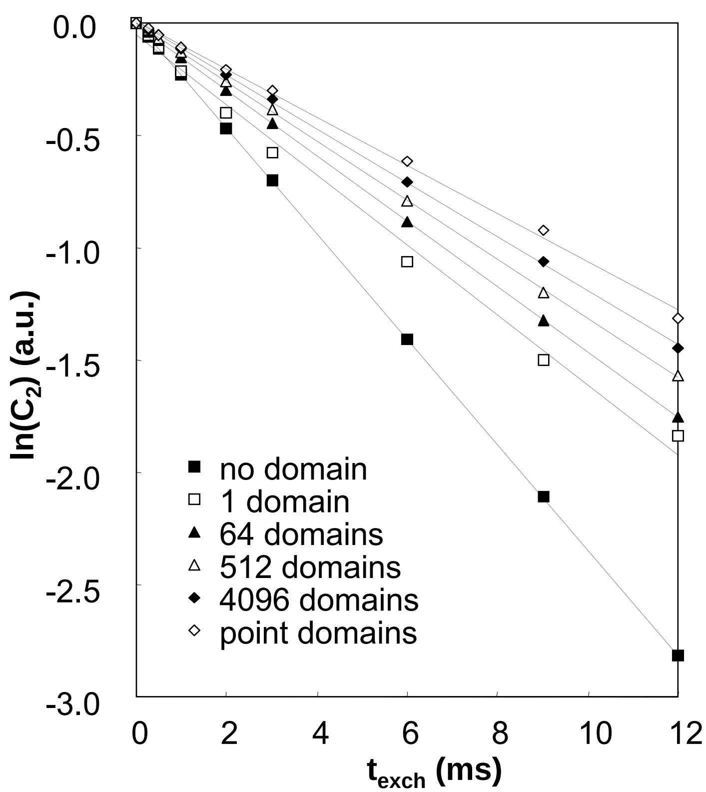
- 32 discoidal domains
- Different total obstacle areas



Simulations

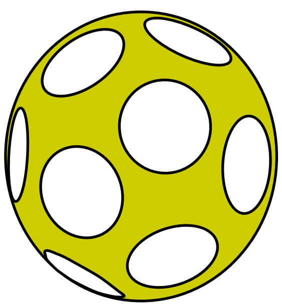
- Different numbers of discoidal **immobile** domains
- Constant obstacle fraction (0.5)

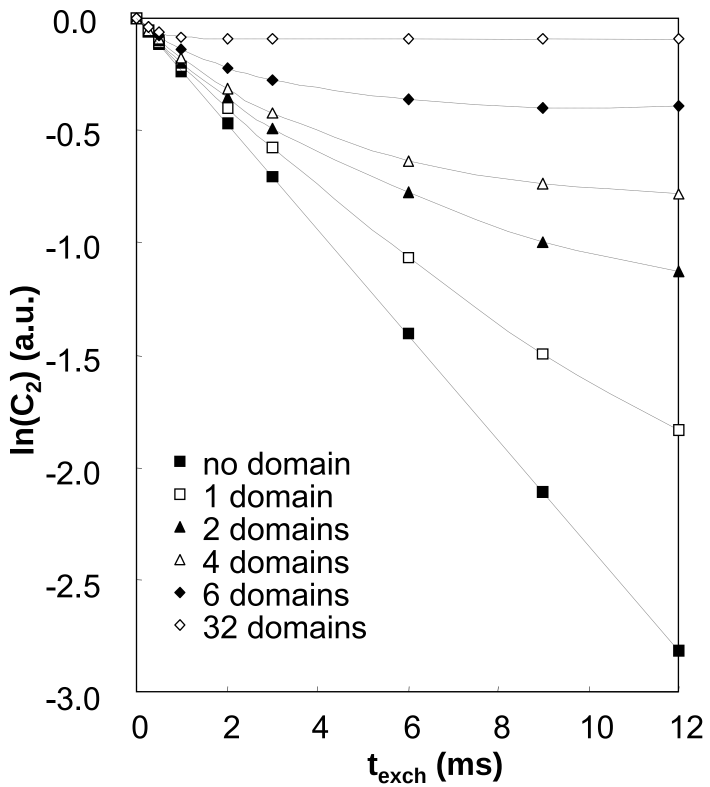




Simulations

- Different numbers of **fluid** discoidal domains
- Constant obstacle fraction (0.5)

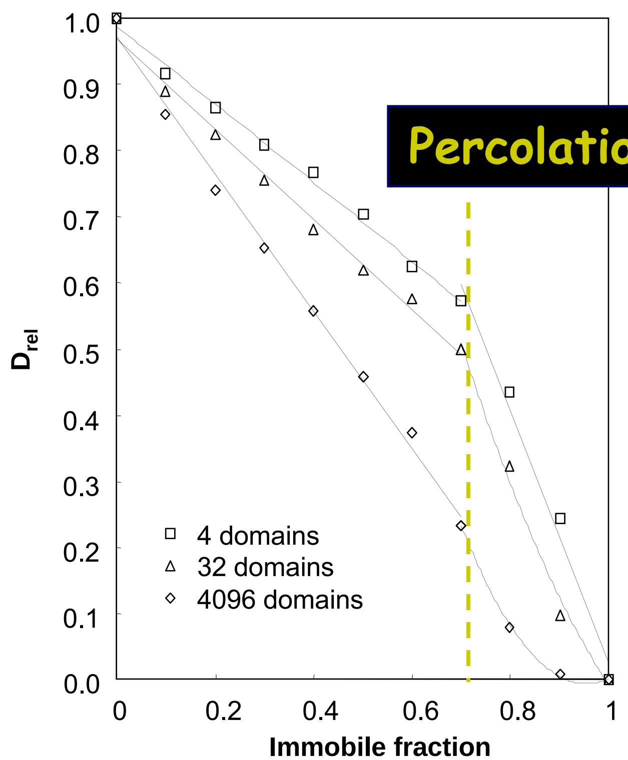




Simulations

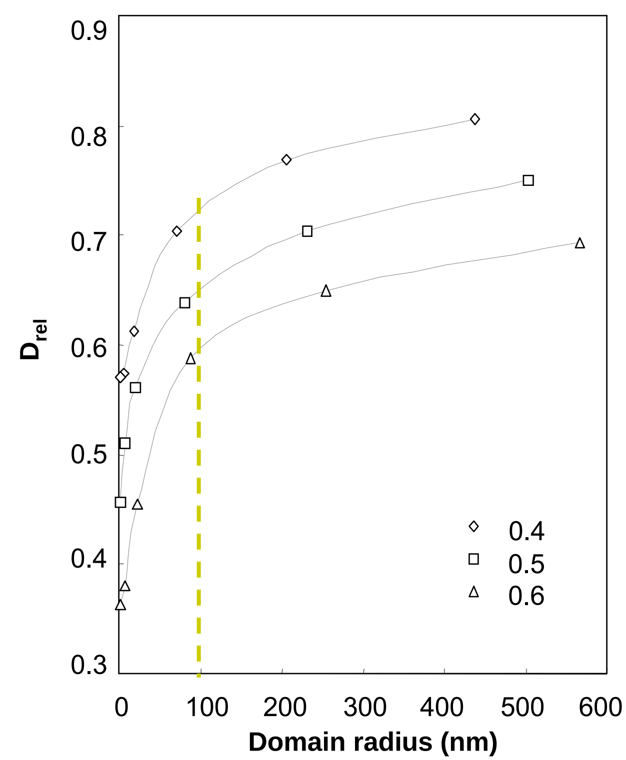
- Evolution of D_{rel} as a function of:

Total immobile fraction
Different numbers of domains



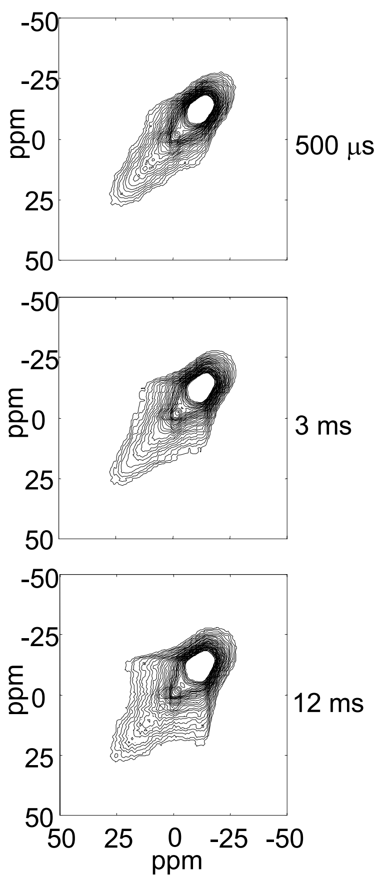
Percolation properties

Domain radius
Different immobile fractions

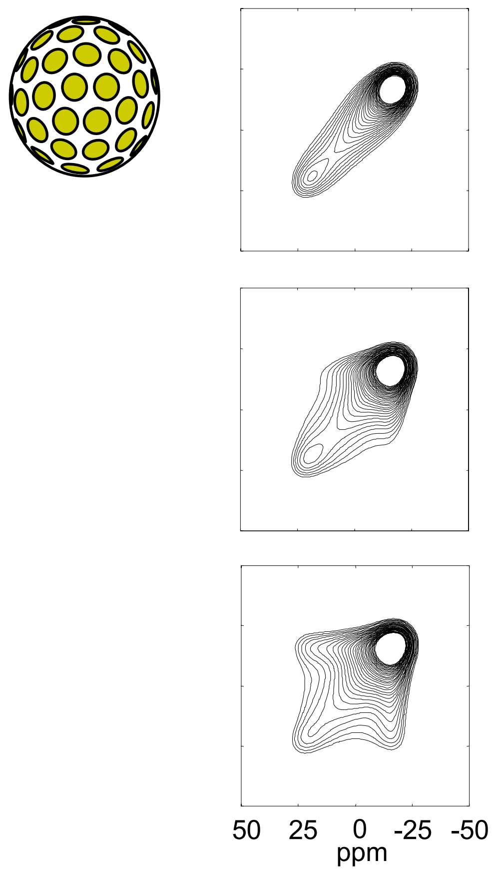


Fit of the experimental spectra (30°C)

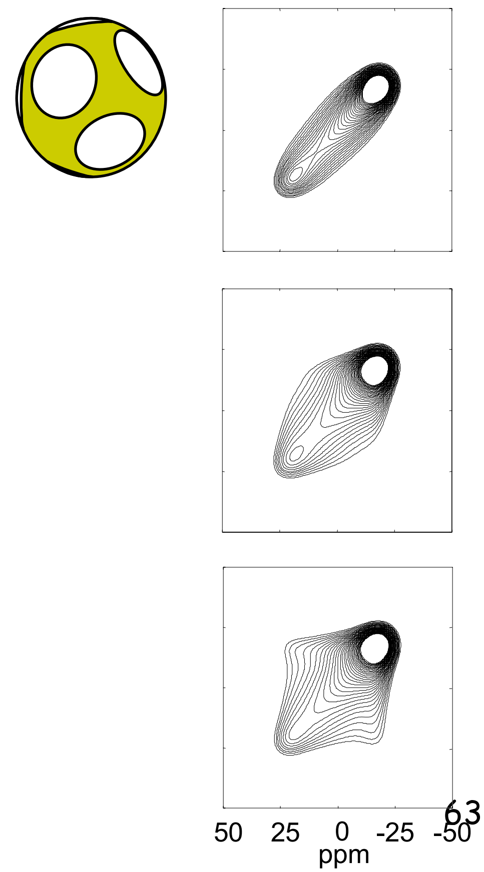
Experimental spectra



32 discoidal obstacles
Diameter: 140 nm



2 confined fluid areas
Diameter: 760 nm

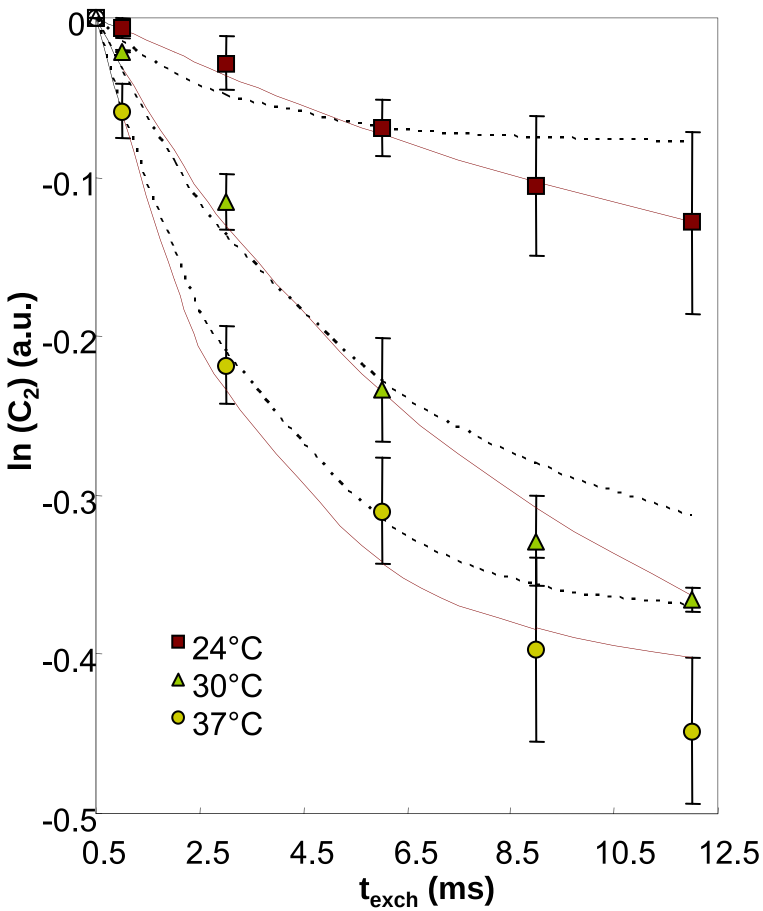


Comparison with other techniques

Technique	Domain phase	Diameter
EPR[1]	fluid	20 nm
NMR (^2H)[2]	gel	>200 nm
Neutron[3]	gel	10 nm
Monte Carlo[4]	Gel	>200 nm
FRAP[5]	Fluid	80 nm
NMR (^{31}P)	Gel	140 nm

1. Sankaram et al. (1992) Biophys. J., 63, 340.
2. Dolainsky et al. (1997) Phys. Rev. E, 55, 4512.
3. Gliss et al. (1998) Biophys. J., 74, 2443.
4. Jorgensen et al. (1995) Biophys. J., 95, 942.
5. Almeida et al. (1992) Biochemistry, 31, 7198.

Fit of the autocorrelation functions



Disk obstacles

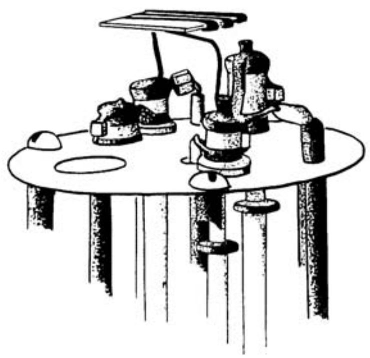
Disconnected fluid domains

Each curve fitted with a fast and a slow diffusing components

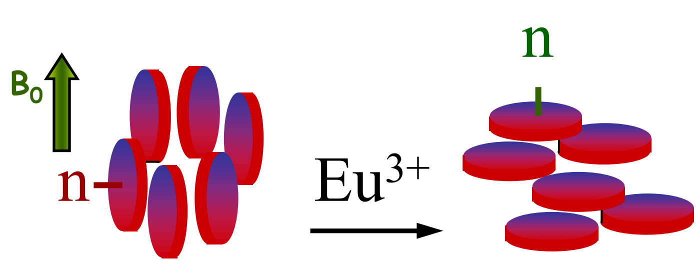
Arnold et al. (2004) Biophys. J., 87, 2456.

Oriented membranes

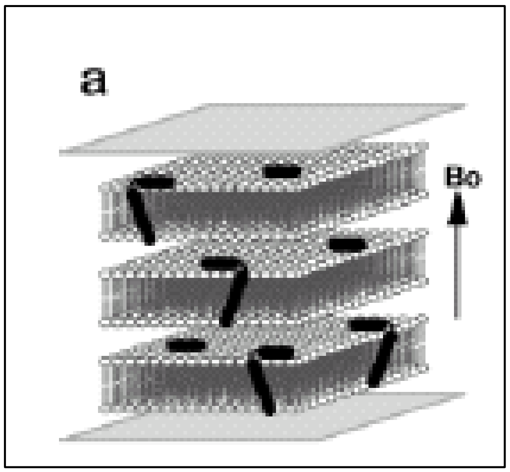
- Lipids mechanically oriented between glass plates

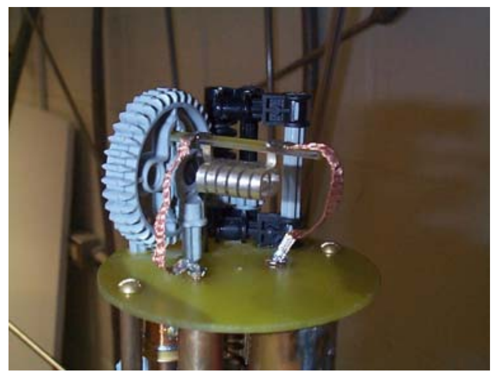


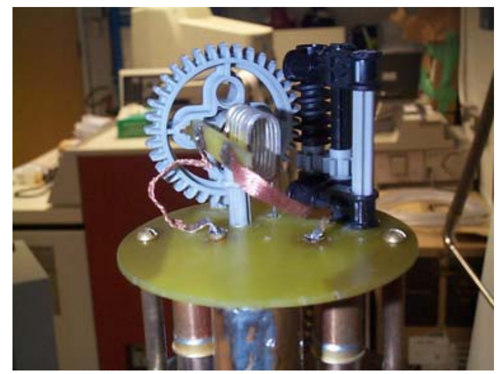
- Bicelle structures oriented in the magnetic field



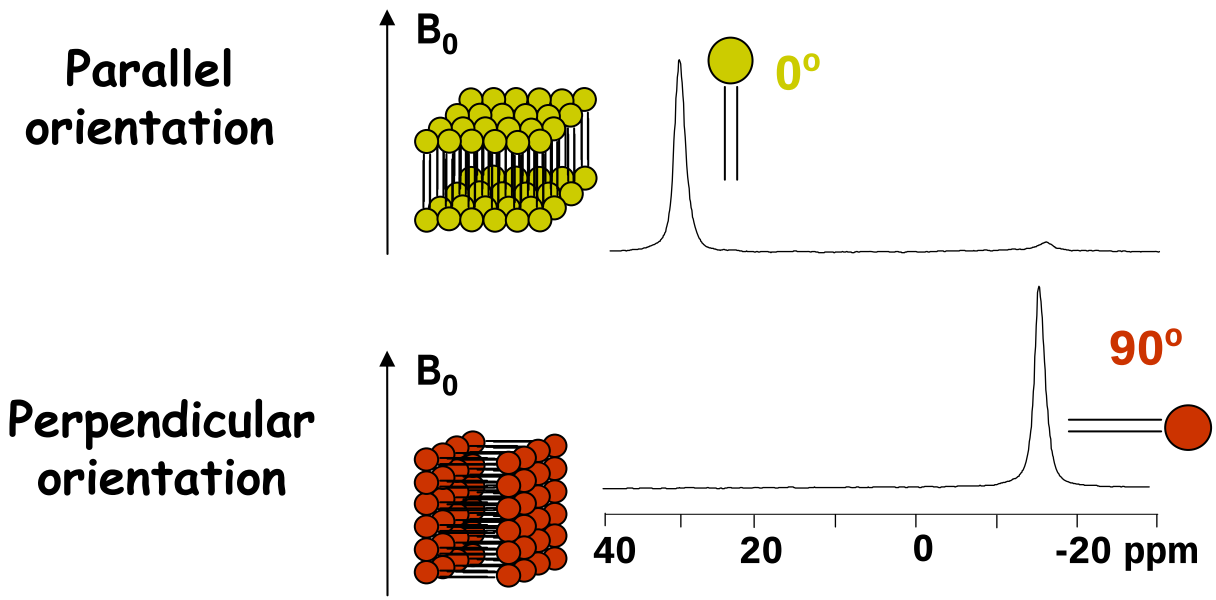
Bilayers oriented between glass plates







Bilayers oriented between glass plates

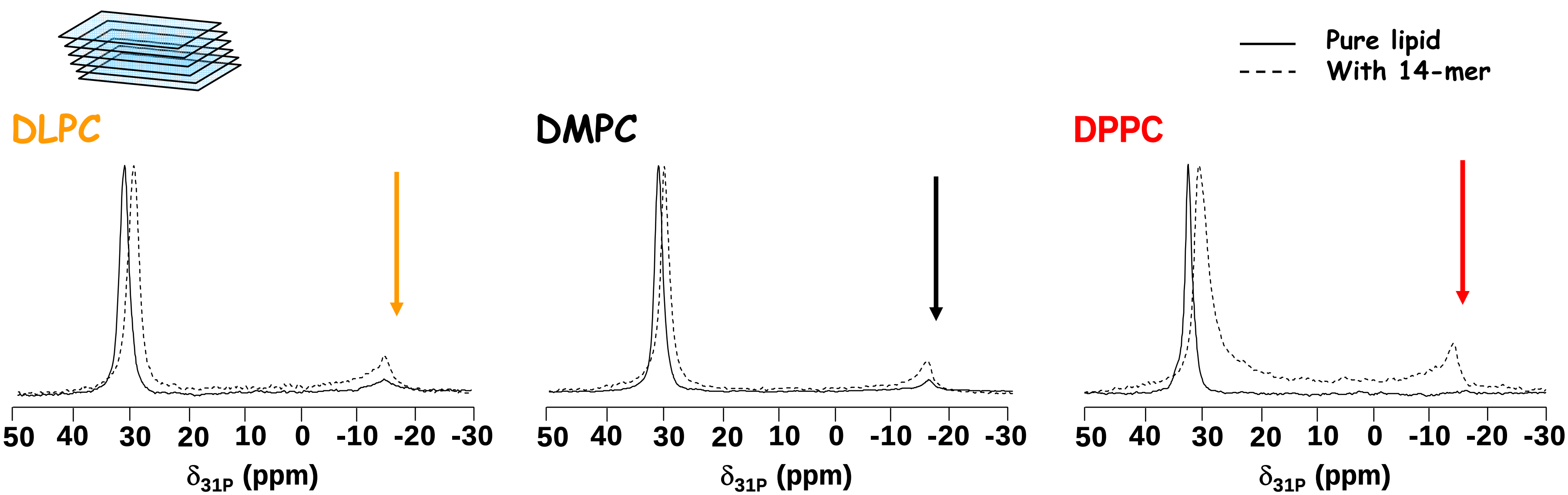


$\delta_{ppm} = f$ (Lipid orientation)

- Chemical shift (δ_{ppm})
- Full width half maximum ($FWHM_{ppm}$)
- Powder spectra

1° Head group conformation
2° Bilayer alignment

Effect on membrane alignment

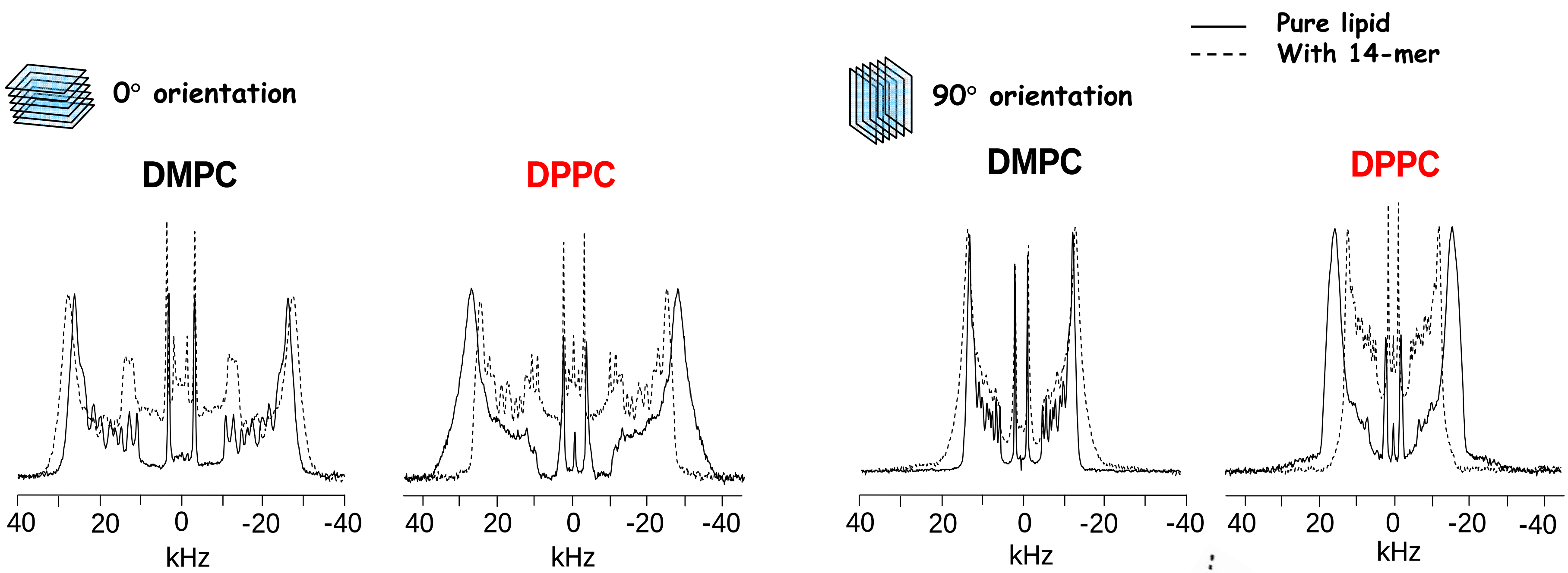


	δ (ppm)		FWHM (ppm)		% Loss of alignment
	Pure	14-mer	Pure	14-mer	
DLPC	31.2	29.7	1.9	2.3	-15 %
DMPC	31.1	30.1	1.7	1.9	-17 %
DPPC	32.0	30.1	1.5	3.6	-36 %

⇒ Orientation distribution → Effect more pronounced for DPPC

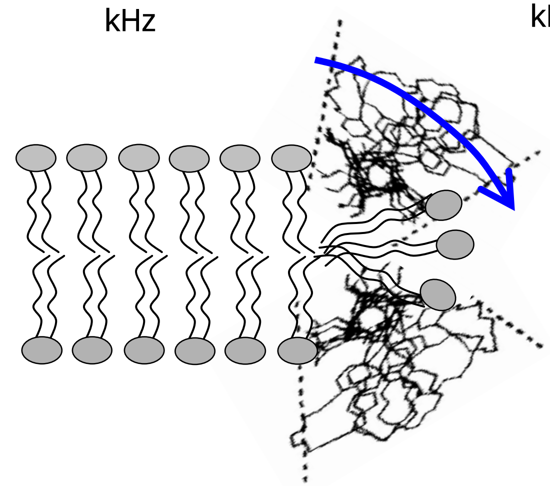
Ouellet et al. (2007) Biochemistry, 46, 6597.

^2H NMR spectra



↑ $\Delta\nu_Q$: **Order**

↓ $\Delta\nu_Q$: **Disorder**

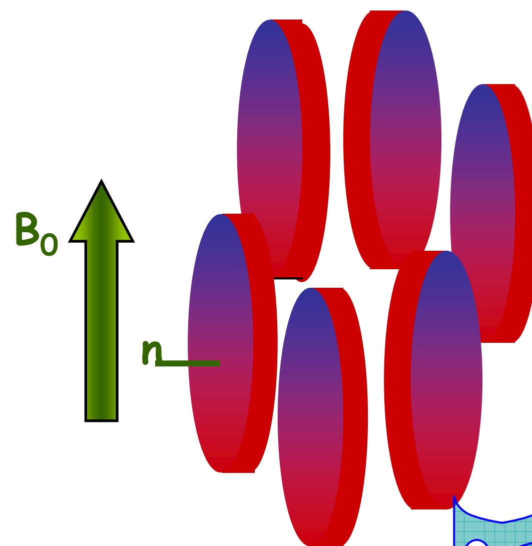


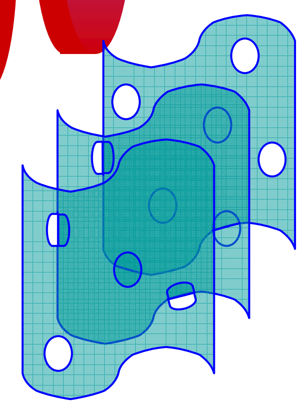
Ouellet et al. (2007) Biochemistry, 46, 6597.
Mani et al. (2004) Biochemistry 43, 13839.

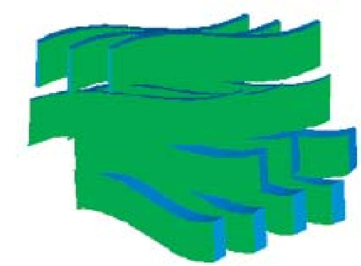
Bicelles

- Mixture of long chain (DMPC) and short chain (DHPC) lipids:
  - Discoidal vesicles
  - Perforated lamellae
  - Ribbons
- Spontaneous orientation between 30 and 45°C
  - Study of proteins at physiological temperatures
- Planar section mimics the surface of the cells
  - Vs curved surface of micelles
  - Preservation of enzymatic activity
- Variable size
  - Change in the molar ratio q

$$q = \frac{[\text{long chain lipids}]}{[\text{short chain lipids}]}$$



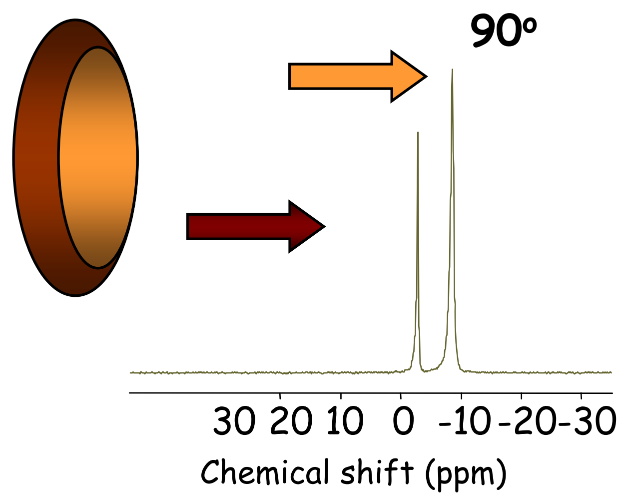




Sanders and Landis (1995) Biochemistry, 34, 4030.
Czerski and Sanders (2000) Anal. Biochem., 284, 327.
Raffard et al. (2000) Langmuir, 16, 7655.

Characteristic spectra, oriented bicelles

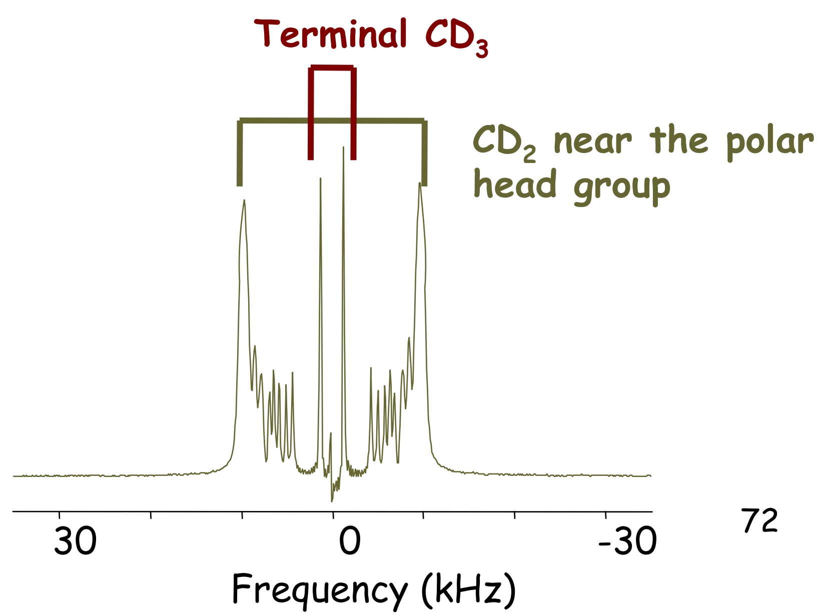
- ^{31}P NMR
  - Phospholipid head group



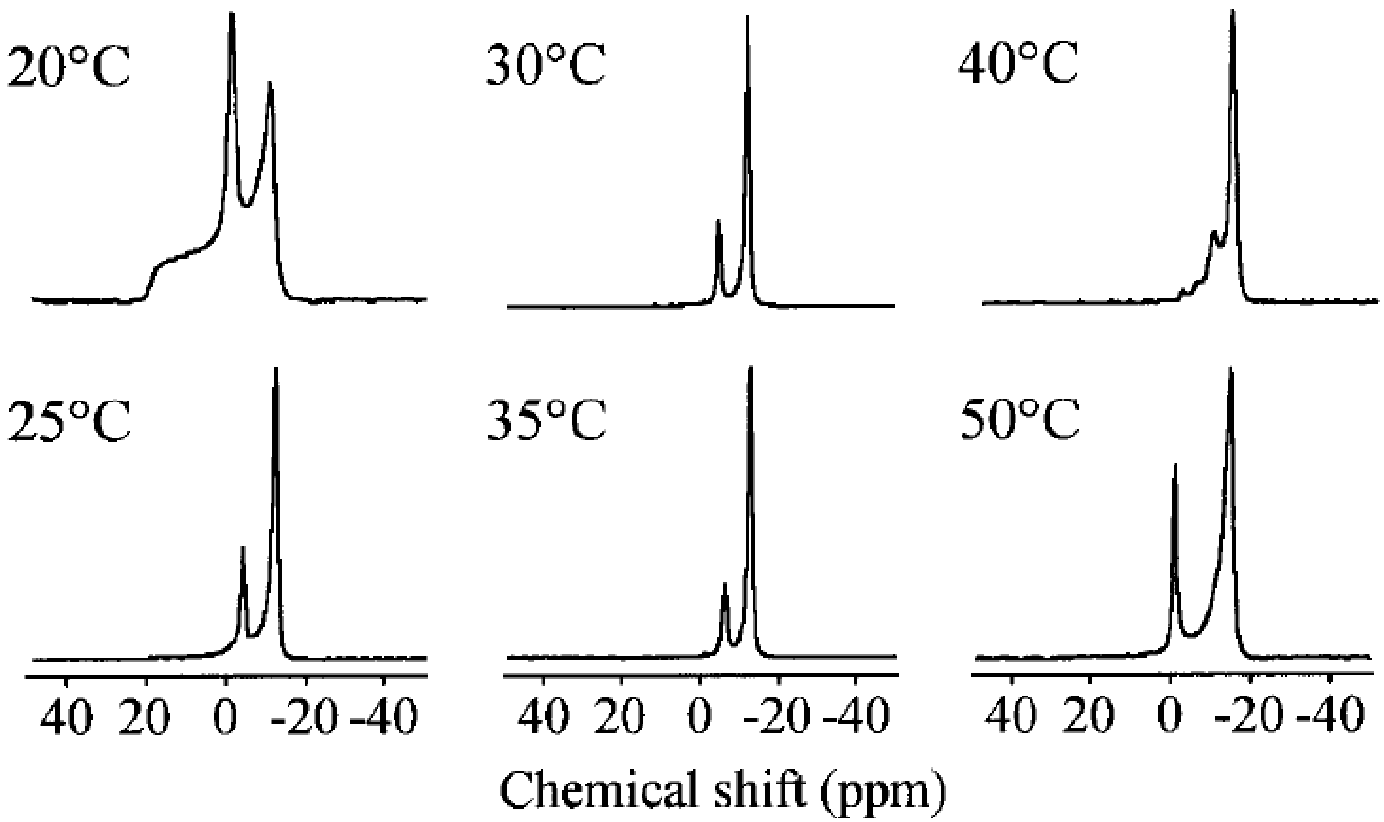
- ^{2}H NMR
  - Deuterated acyl chains

$\downarrow \Delta\nu_Q$ = disorder

$\uparrow \Delta\nu_Q$ = order

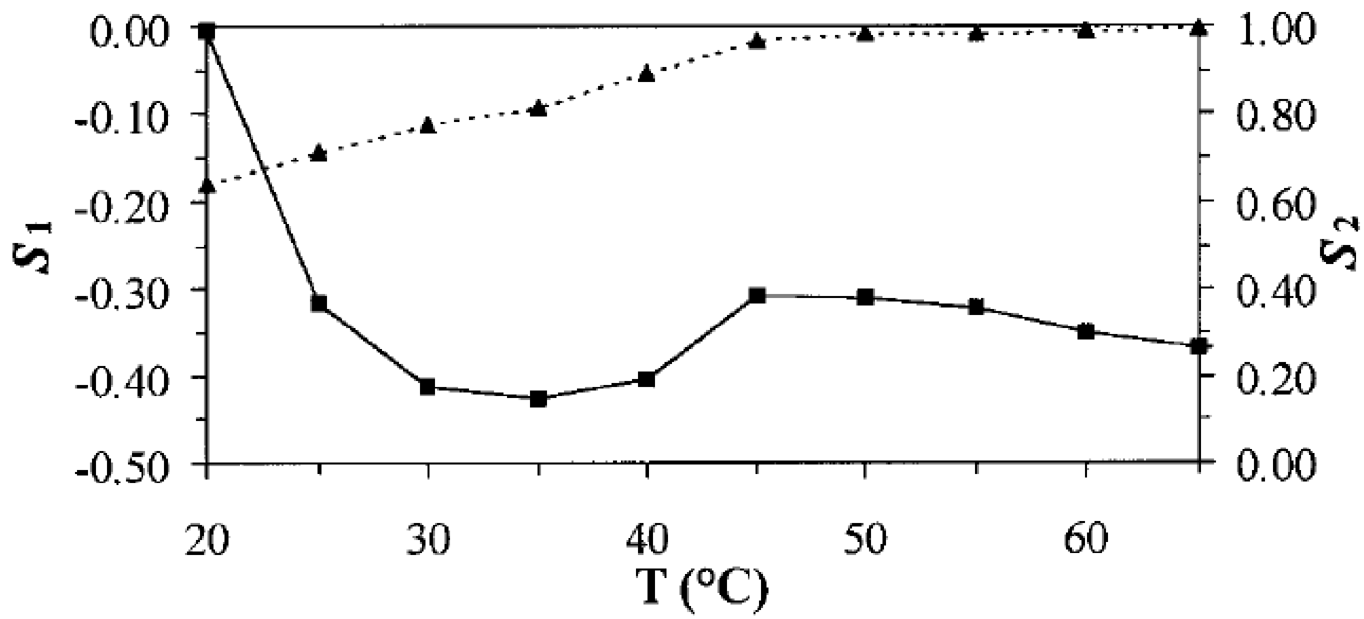


Bicelle spectra as a function of temperature



Picard et al. (1999) Biophys. J. 77, 888.

Order parameters

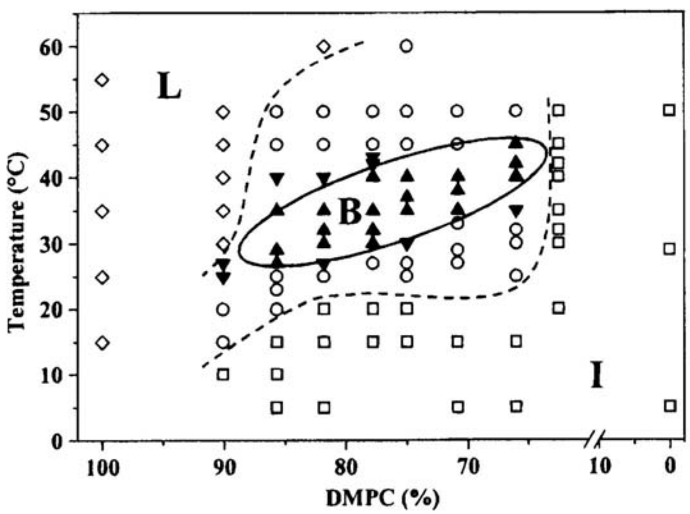


Picard et al. (1999) Biophys. J. 77, 888.

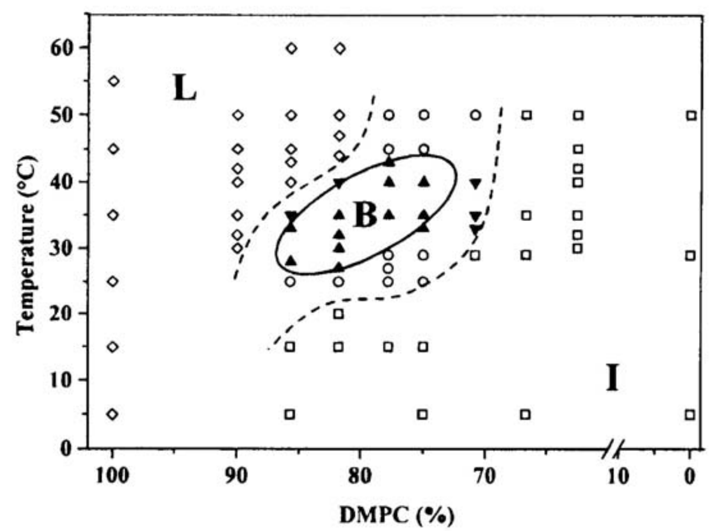
Bicelle phase diagrams

- Temperature-composition diagrams of DMPC/DHPC

80% (w/w) D_2O 100 mM KCl

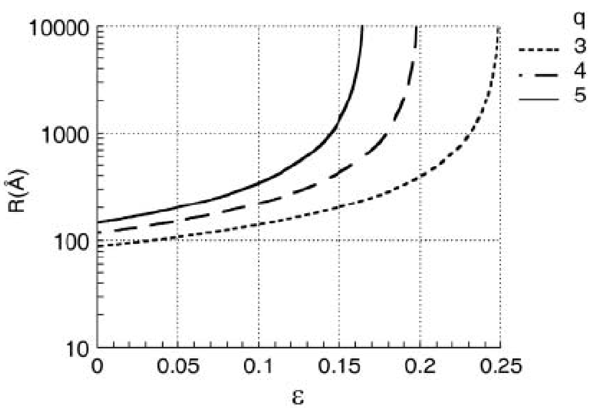


80% (w/w) D_2O

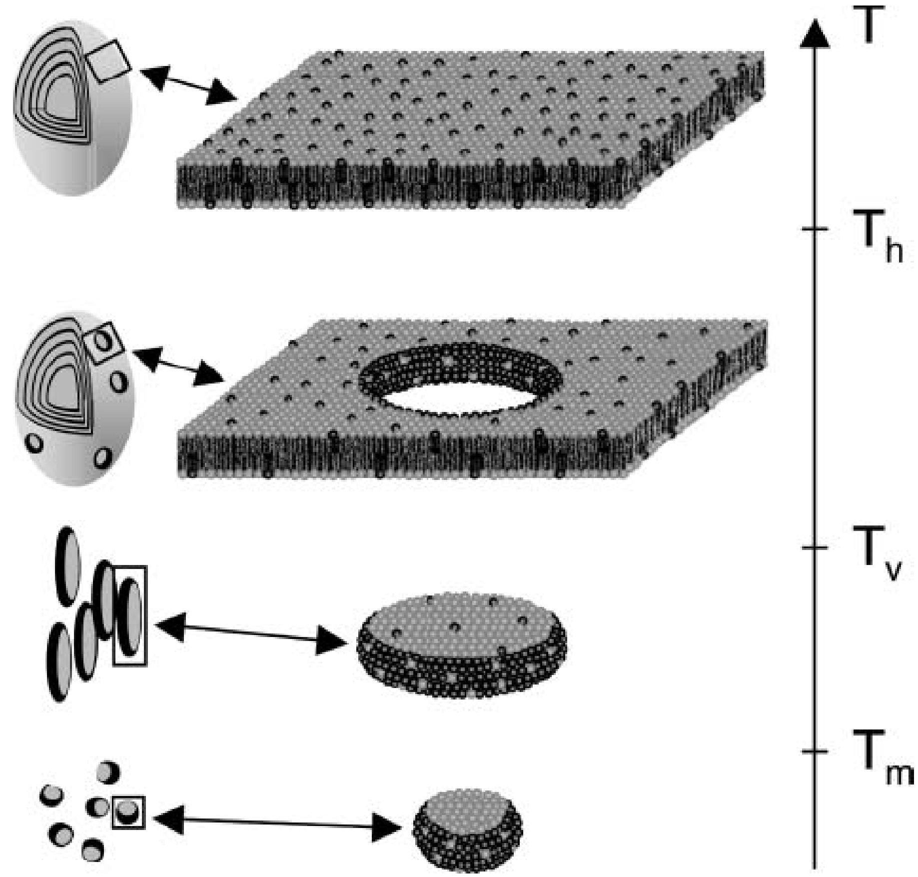


Raffard et al. (2000) Langmuir, 16, 7655.

Mixed bicelles

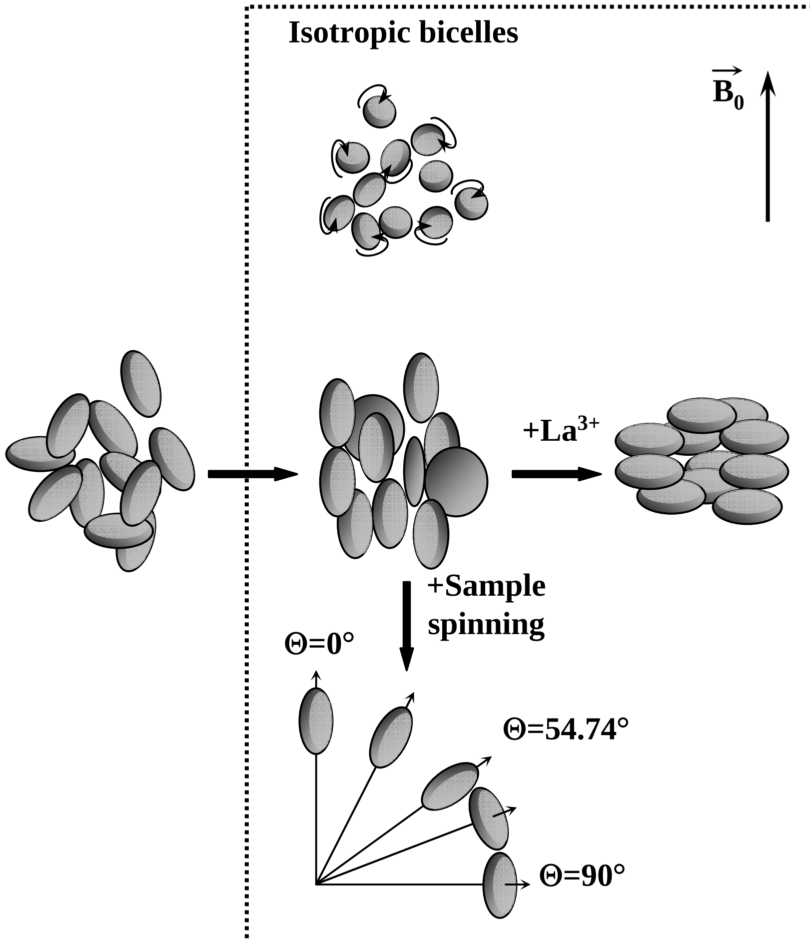


ε = mole fraction of DHPC
in the bilayer section



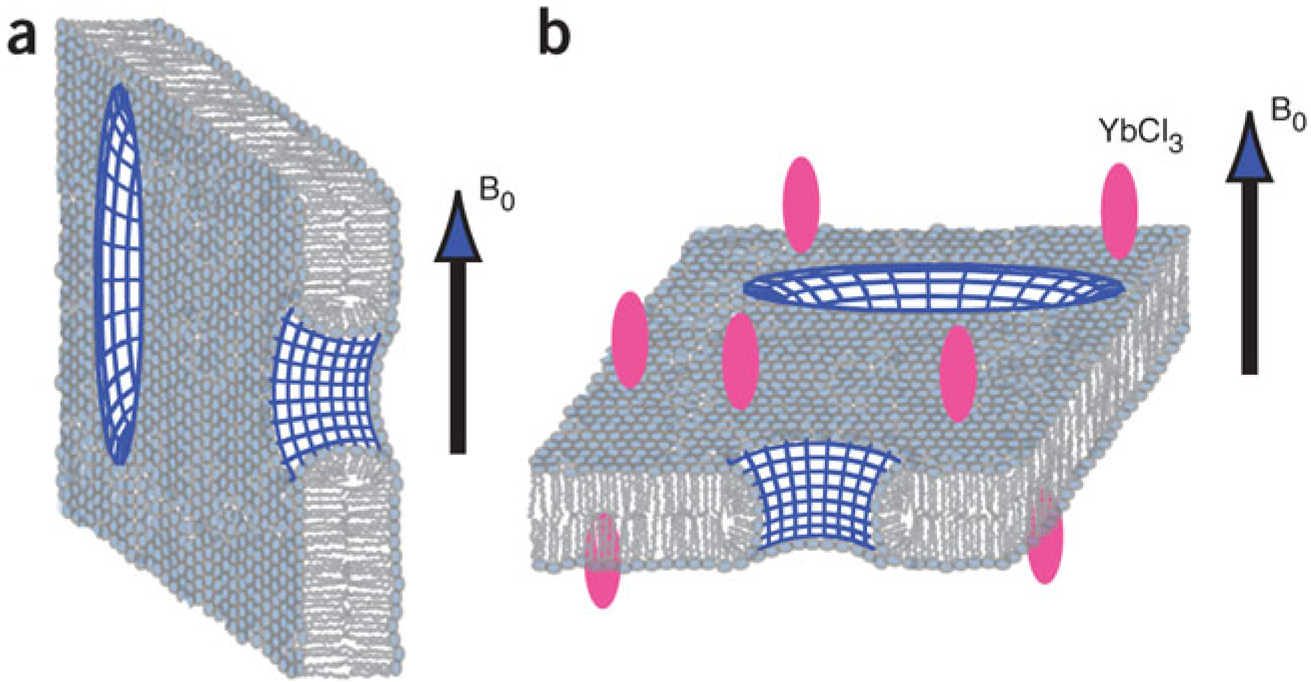
Triba et al. (2005) Biophys. J. 88, 1887.

Bicelle morphologies



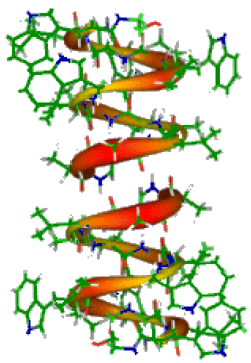
Zandomeneghi et al. (2003) J. Biomol. NMR 25, 113.

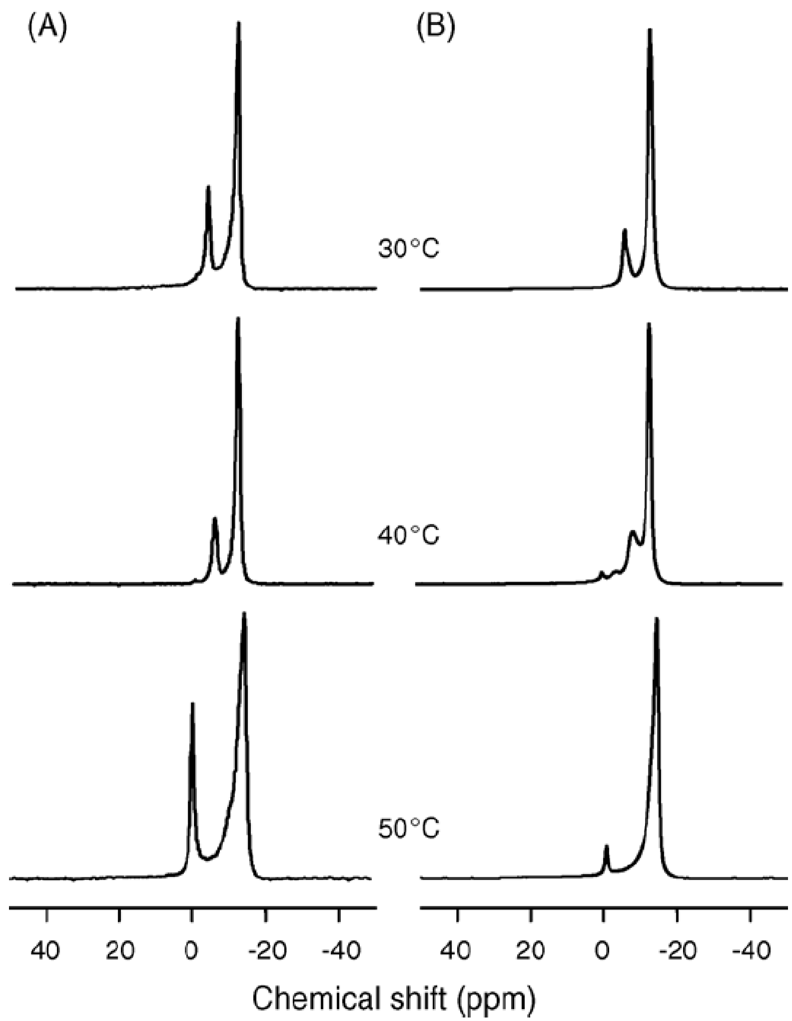
Bicelles flipped with lanthanides



Angelis and Opella (2007) Nature Protocols, 2, 2332.

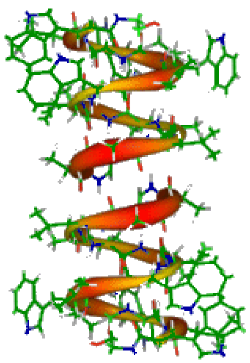
Effect of gramidicin on bicelle alignment (lipid:peptide 25:1)

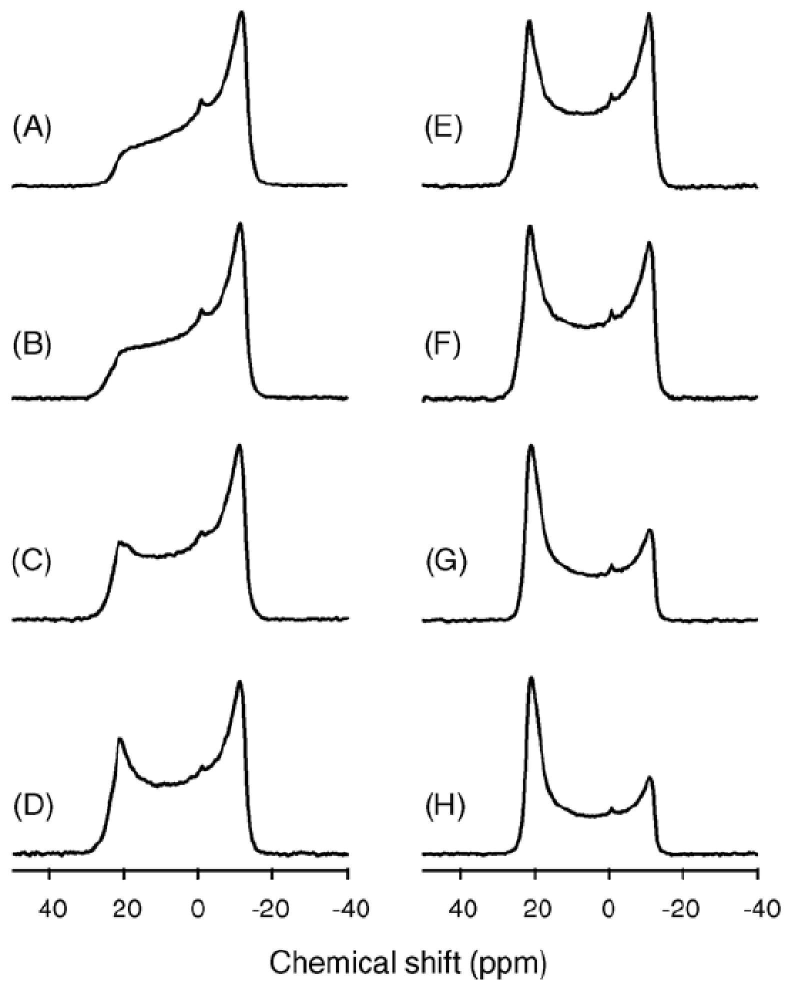




Marcotte et al. (2006) Chem. Phys. Lipids 139, 137.

Effect of gramidicin on bicelle alignment (lipid:peptide 10:1)

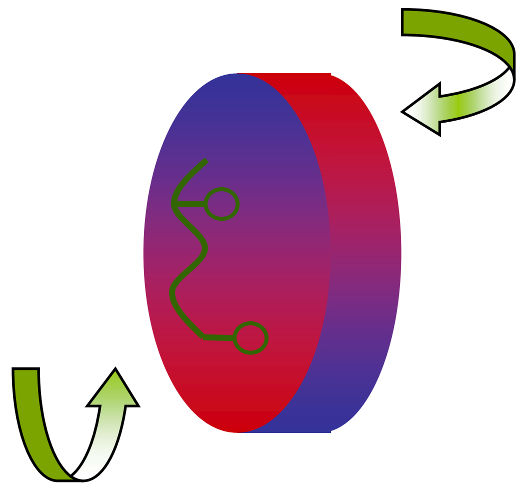




Marcotte et al. (2006) Chem. Phys. Lipids 139, 137.

Fast tumbling bicelles

- Fast tumbling bicelles
  - Small (~ 100 Å)
  - Discoidal morphology
  - Fast rotation motion in solution
    - Isotropic peaks in NMR



Luchette et al. (1997) Biochim. Biophys. Acta 1513, 83.

Conclusions

- Solid-state NMR is well suited to investigate the effects of membrane peptides and proteins on lipid bilayers
- Several techniques available
  - MAS
  - Static spectra
  - Oriented samples
- Understanding the effects of membrane peptides and proteins on lipid bilayers can provide useful and complementary information of the biological process investigated

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Thank you for your attention!