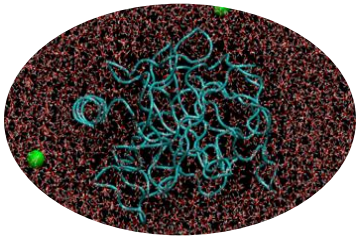
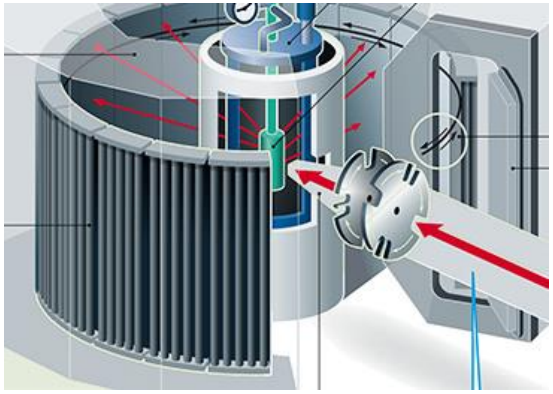
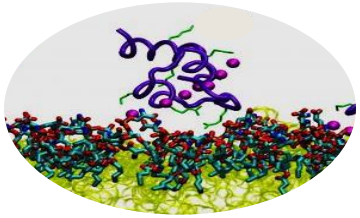
Playing Hide-and-Seek with Neutrons







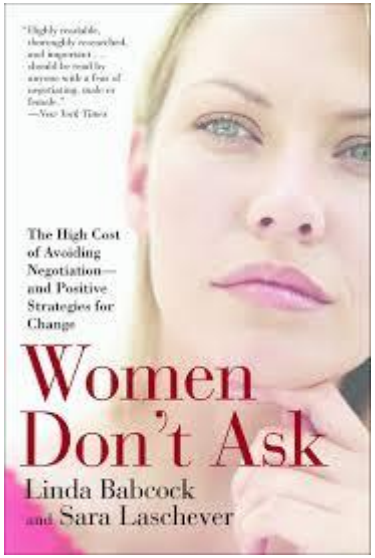
RANA ASHKAR

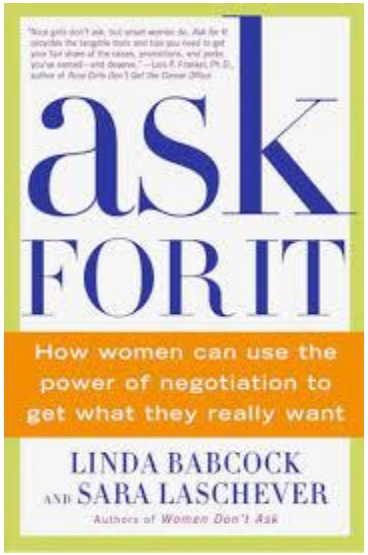
ASSISTANT PROFESSOR, PHYSICS DEPARTMENT, VIRGINIA TECH

VIRGINIA TECH™

BEFORE I START, MY ADVICE TO YOU

- ENCOURAGE YOUR STUDENTS TO FIGURE OUT THEIR STRENGTHS AND WEAKNESSES AND CHOOSE THEIR CAREER ACCORDINGLY
- BE AWARE THAT WOMEN AND MINORITIES CAN FEEL LARGER BARRIERS IN PURSUING STEM FIELDS
- MANY OF THESE OBSTACLES ARE DRIVEN BY STEREOTYPES AND LACK OF IMMEDIATE SUPPORT NETWORKS
- ENCOURAGE STUDENTS TO ENGAGE IN PROFESSIONAL DEVELOPMENT ACTIVITIES (e.g. CUWiP)
- ENCOURAGE STUDENTS TO SEEK GUIDANCE
- INFORM STUDENTS OF POSSIBLE RESEARCH OPPORTUNITIES IN UNIVERSITY LABS





WHAT IS NEEDED TO SUCCEED IN STEM

- GOOD MATHEMATICAL SKILLS
- GENERAL CURIOSITY FOR LEARNING AND EXPLORATION
- RECOGNITION OF KNOWLEDGE GAPS AND WILLINGNESS TO OVERCOME THEM
- WILLINGNESS TO ACCEPT FAILURE AND PUT IN THE WORK TO SUCCEED
- REALIZATION THAT SUCCESS IS NOT A STRAIGHT PATH AND CAN BE A RANDOM WALK
- LEARN TO WORK SMART RATHER THAN WORK HARD

STUDENT OPPORTUNITIES FOR RESEARCH

- SUMMER RESEARCH OPPORTUNITIES IN UNIVERSITY STEM LABS (most faculty have interest in mentoring high school science projects)
- SUMMER INTERNSHIPS IN NATIONAL FACILITIES (e.g. SHIP [summer high school intern program] program at NIST and HSRE [high school research experience] at ORNL)
- SUMMER RESEARCH EXPERIENCE FOR TEACHERS IN UNIVERSITY STEM LABS AND AT NATIONAL FACLITIES → TEACHERS CAN BE A FACILITATOR FOR THEIR STUDENTS IN PURSUING RESEARCH OPPORUNITIES
- CONSIDER INVITING RESEARCH-ACTIVE FACULTY TO TALK TO YOUR STUDENTS ABOUT THEIR RESEARCH AND INTERNSHIP OPENINGS IN THEIR LABS (you will be surprised how well that could work!)
- STEM IS BECOMING QUITE INTERDISCIPLINARY WHICH OFFERS REMARKABLE FELXIBLITY IN PURSUING RESEARCH INTERESTS AND FINDING CAREER OPPORTUNITIES REQUIRING SIMILAR ACQUIRED SKILLS

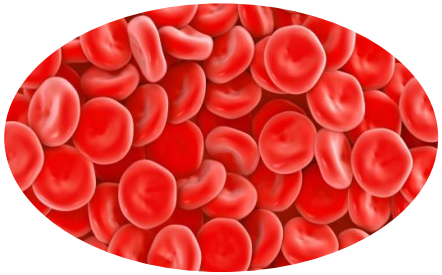
CARREER OPPORTUNITIES

- STEM FIELDS ARE A GOOD GATEWAY TO A RANGE OF CARREER OPPORTUNITIES
- MANY STUDENTS ARE UNDER THE IMPRESSION THAT GOING INTO STEM MEANS THAT THEY ARE LOCKED IN TEACHING OR ACADEMIC JOBS
- BUT THERE ARE MANY OTHER OPPRTUNITIES, INCLUDING INDUSTRY, PHARMA, NATIONAL FACILTIES, AND EVEN TECH STARTUPS
- AMONG NATIONAL FACILITIES ARE NASA AND NATIONAL LABS (e.g. National Institute of Standards and Technology, National Institute of Health, Oak Ridge National Lab, Jefferson Lab, etc.)
- NATIONAL FACILITIES OFFER CAREER ENVIRONMENTS THAT ARE INTERMEDIATE BETWEEN ACADEMIA AND INDUSTRY

WHAT I WORK ON: SOFT MATTER

Soft Matter

cells



rubbers

suspensions

Liquid crystals

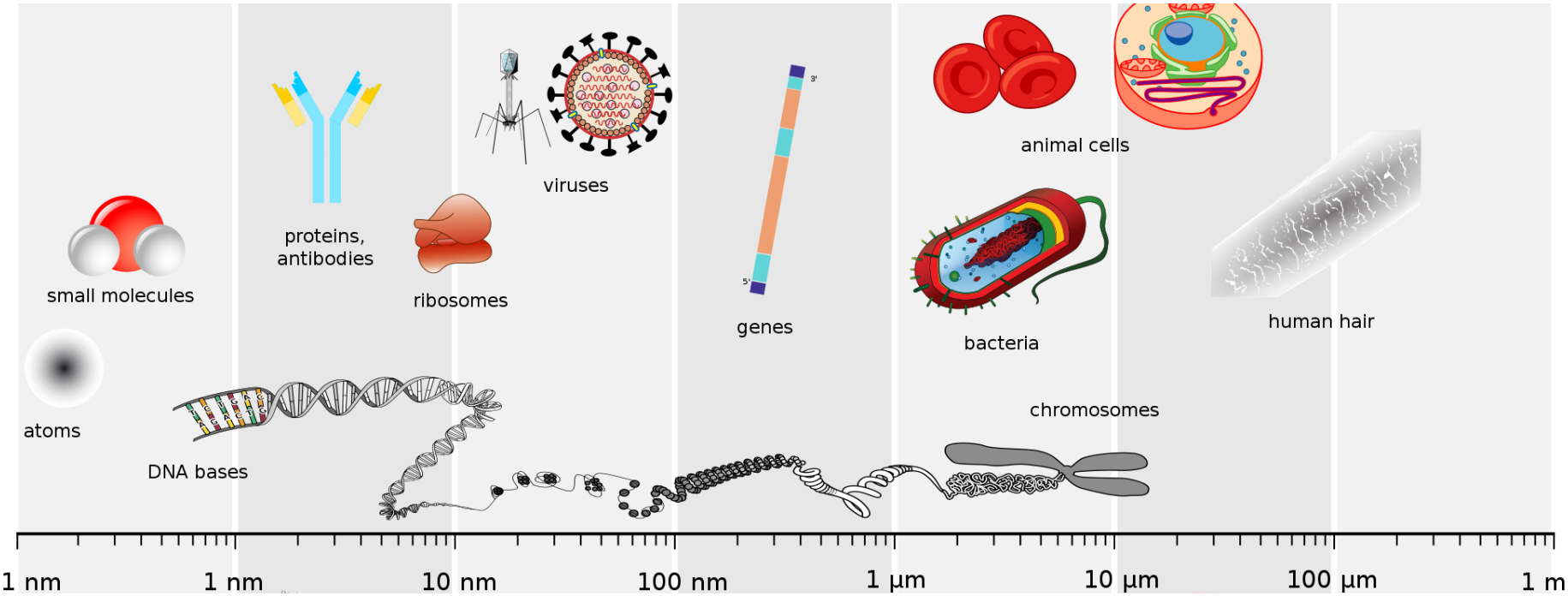
pastes

gels

surfactants

LENGTH SCALES AND ENERGY SCALES IN SOFT MATTER

https://commons.wikimedia.org/wiki/File:Biological_and_technological_scales_compared-en.svg

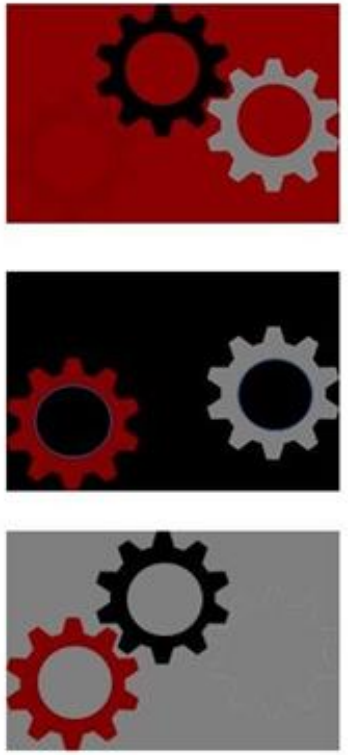


Time

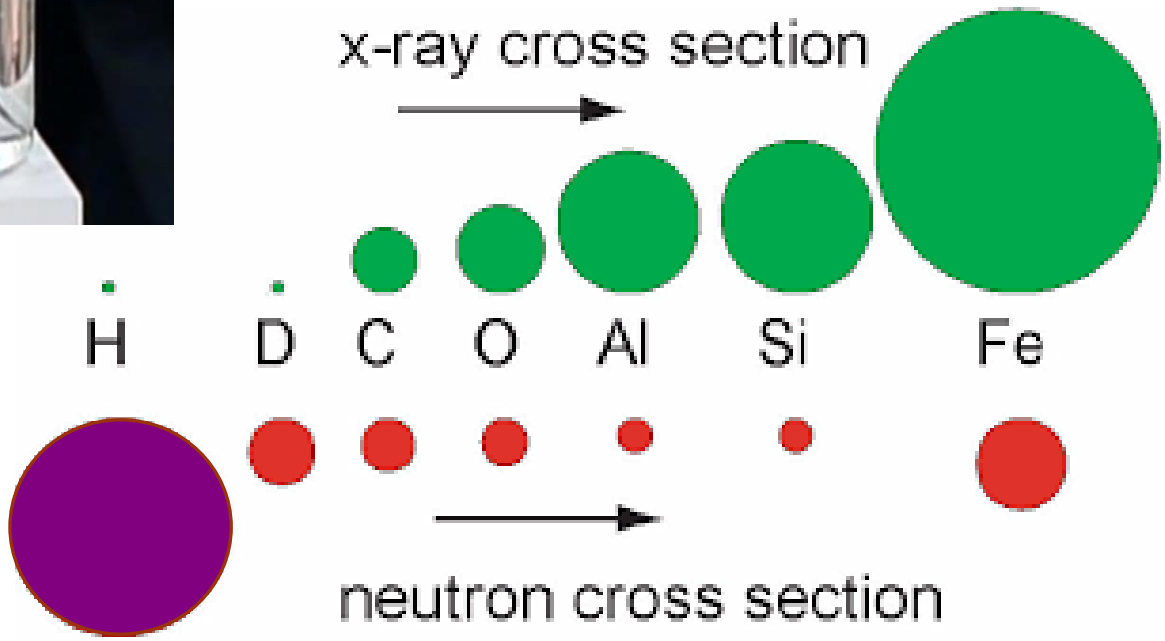
Energy

COMPLEX NANOMACHINERY: HOW CAN WE BUILD PREDICTIVE MODELS?

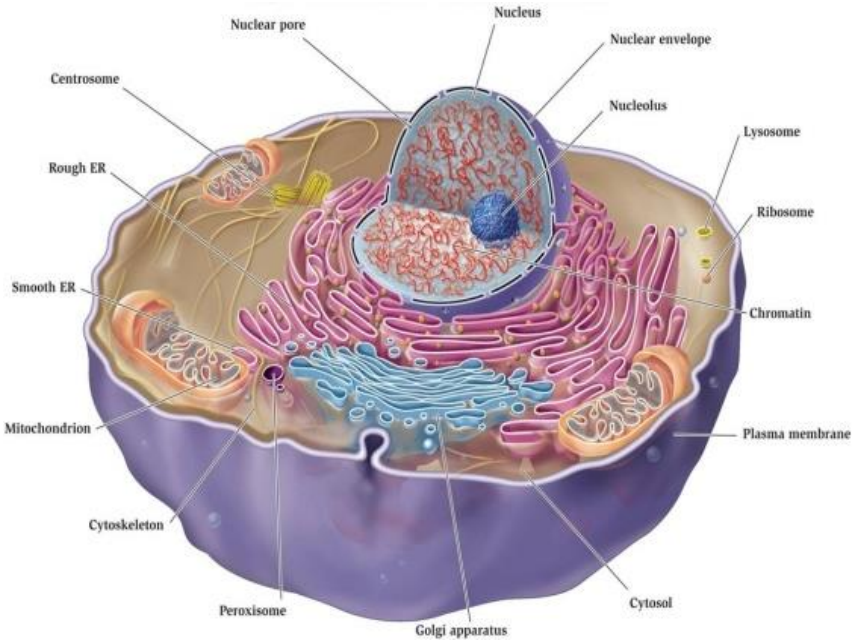
Machinery of Life is Complex
(Building a predictive understanding of life processes)

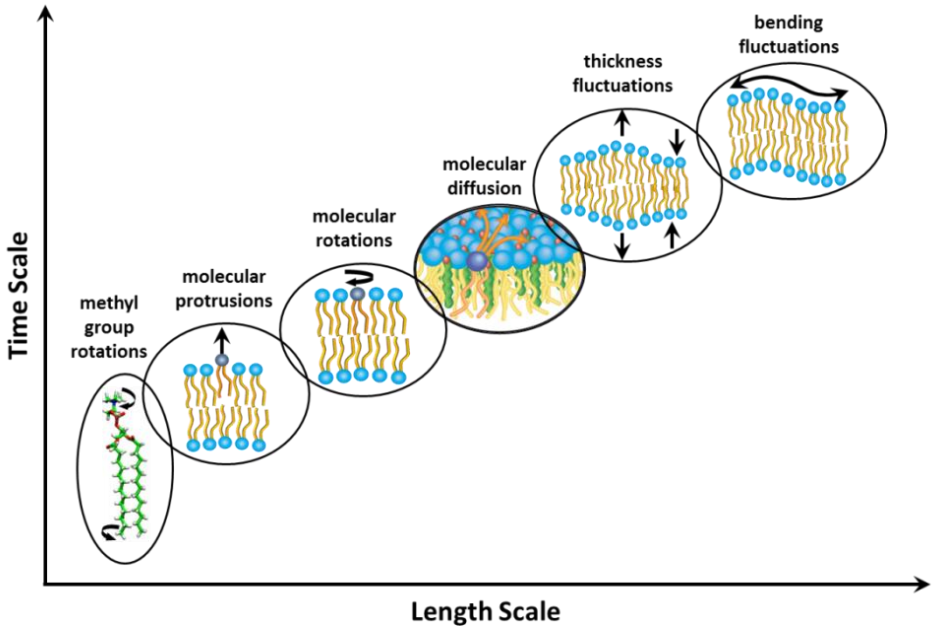


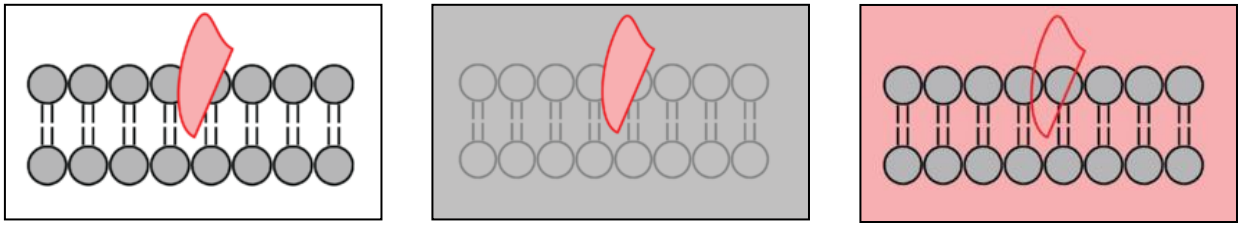
THE POWER OF NEUTRON SCATTERING IN SOFT MATTER



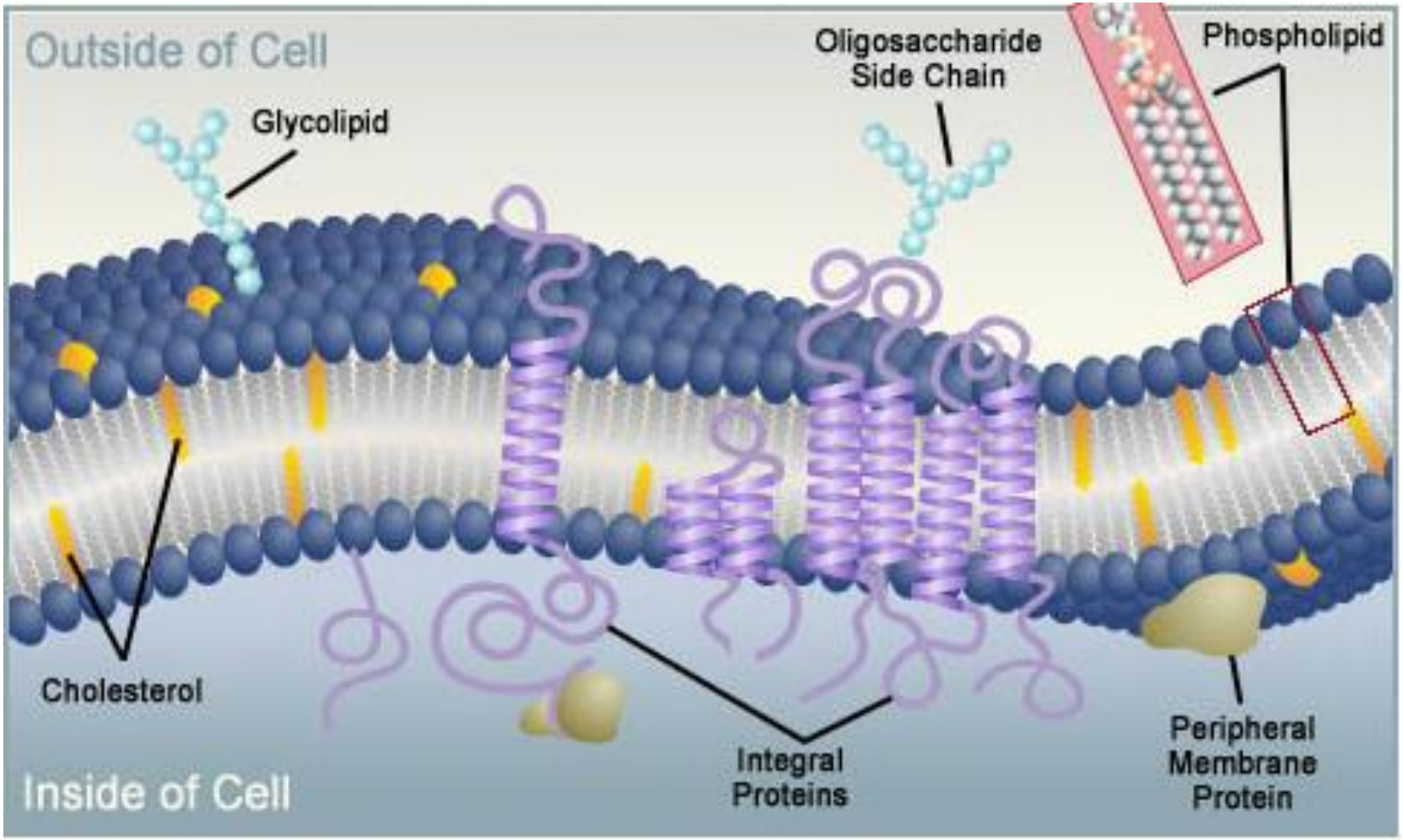
WHAT I STUDY: THE ASSEMBLY AND DYNAMICS IN LIPID MEMBRANES





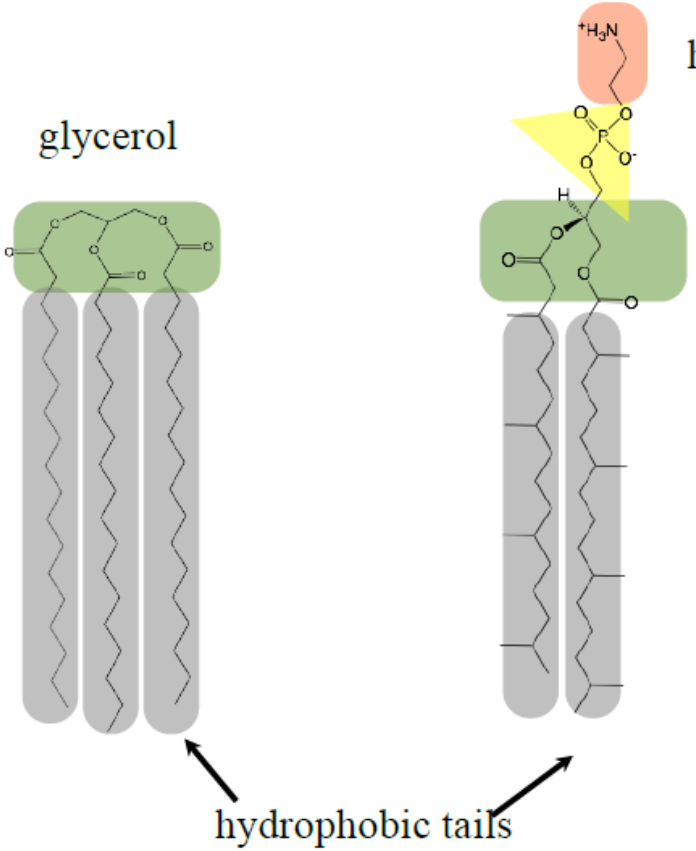


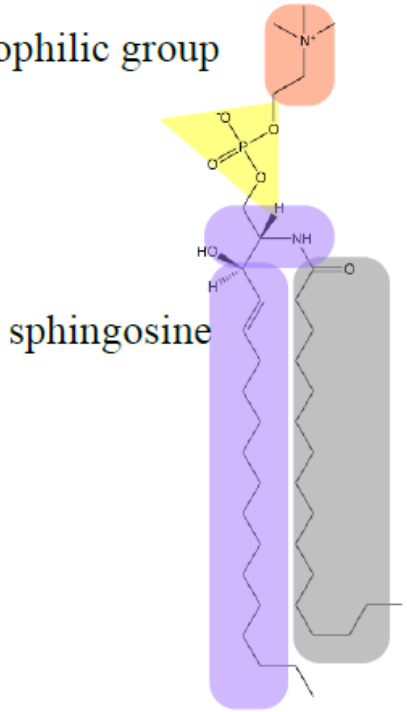
BIOMIMETIC MEMBRANES: SIMPLE MODELS OF COMPLEX CELL WALLS

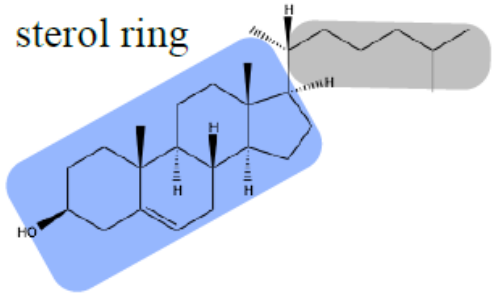


http://www.biology.arizona.edu/cell_bio/problem_sets/membranes/fluid_mosaic_model.html

CLASSIFICATION OF BIOLOGICAL LIPIDS







Triacylglycerol Phospholipid Sphingolipid Cholesterol

Storage lipids ——— Membrane Lipids ———

STRUCTURE OF PHOSPHOLIPIDS

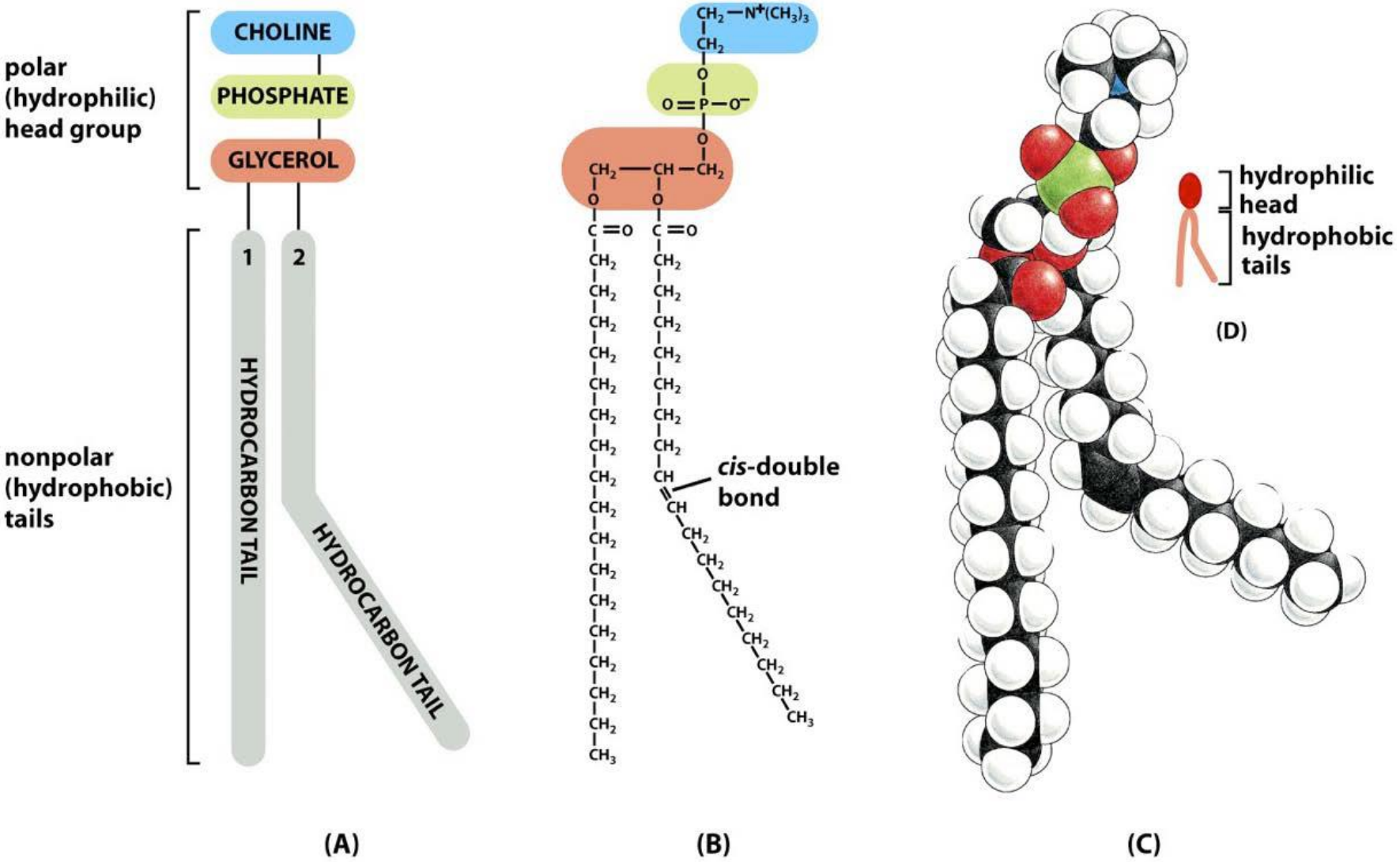
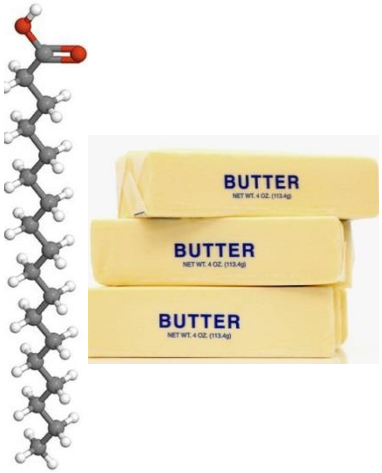
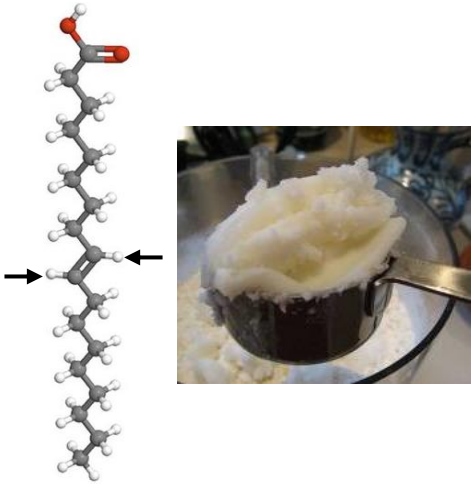
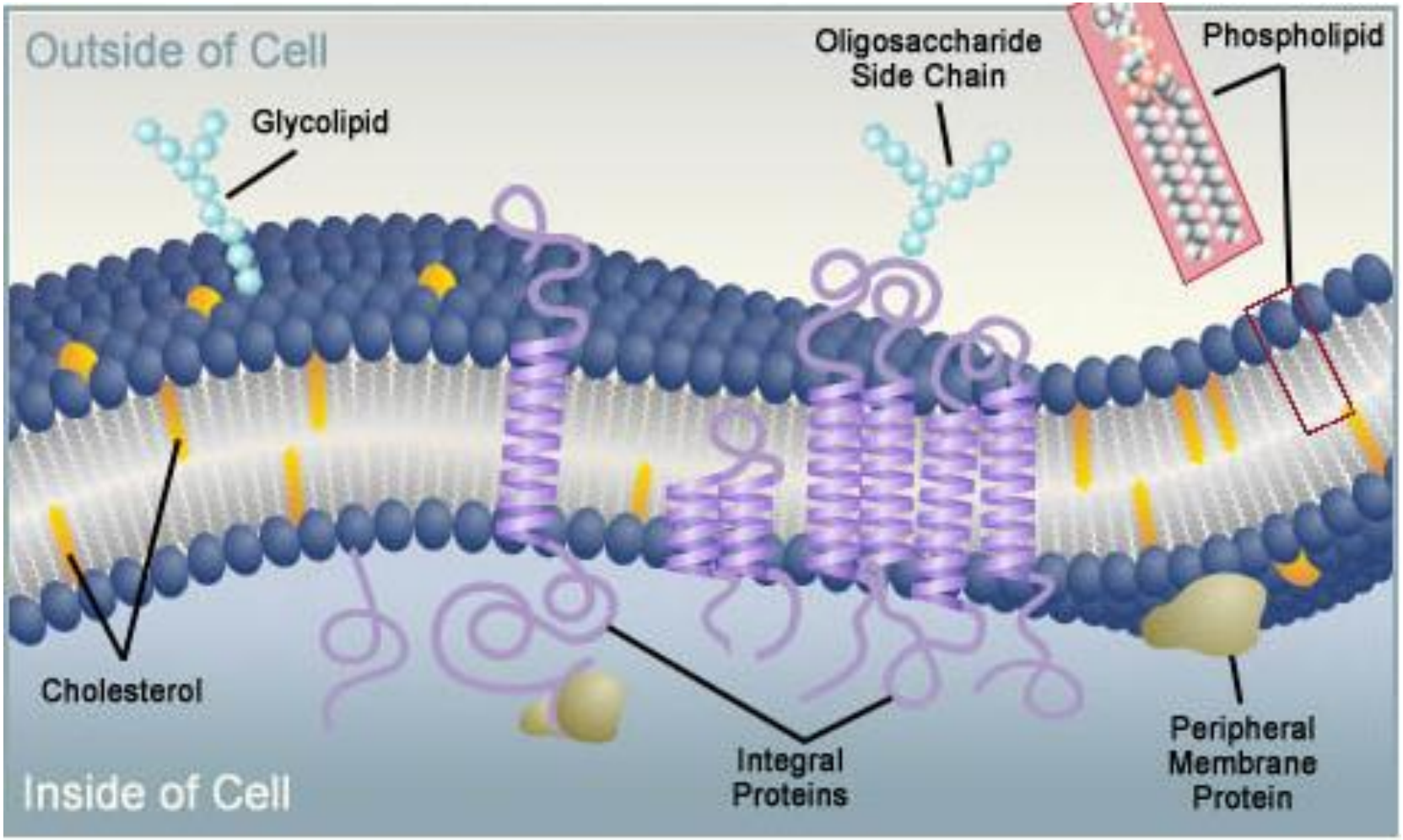


Figure 10-2 Molecular Biology of the Cell 5/e (© Garland Science 2008)

TYPES OF FATTY ACIDS

Type of Fat	Saturated	Unsaturated (cis)	Unsaturated (trans)
			
Carbon chain	Straight	Bent	Straight
Molecular Packing	Dense	Less Dense	Very Dense
Melting Point	High	Low	Very High

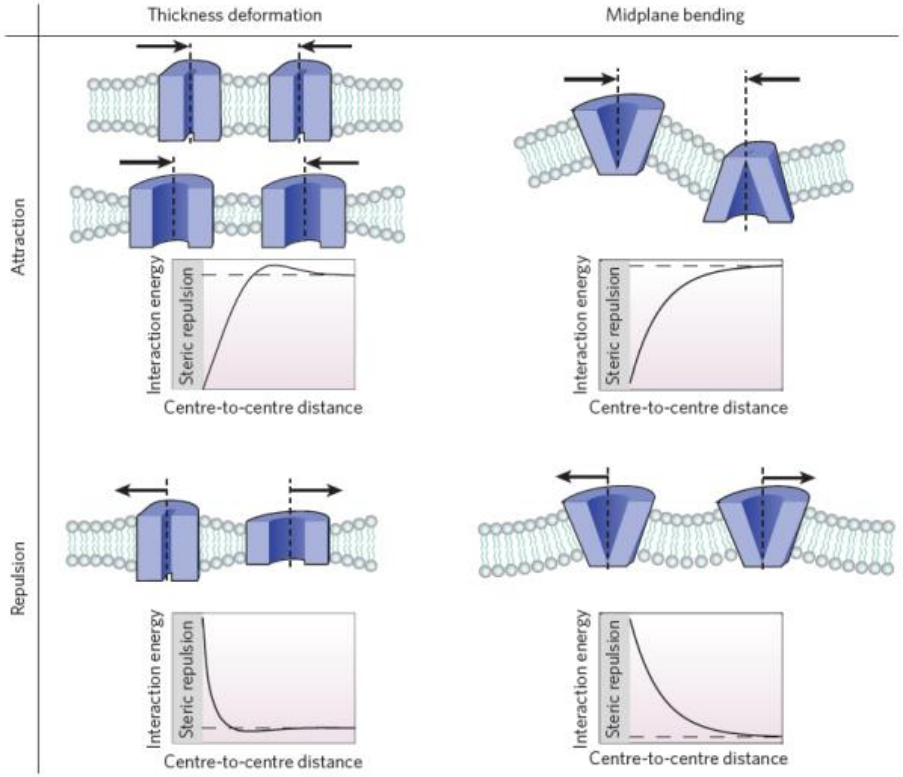
BIOMIMETIC MEMBRANES: SIMPLE MODELS OF COMPLEX CELL WALLS



http://www.biology.arizona.edu/cell_bio/problem_sets/membranes/fluid_mosaic_model.html

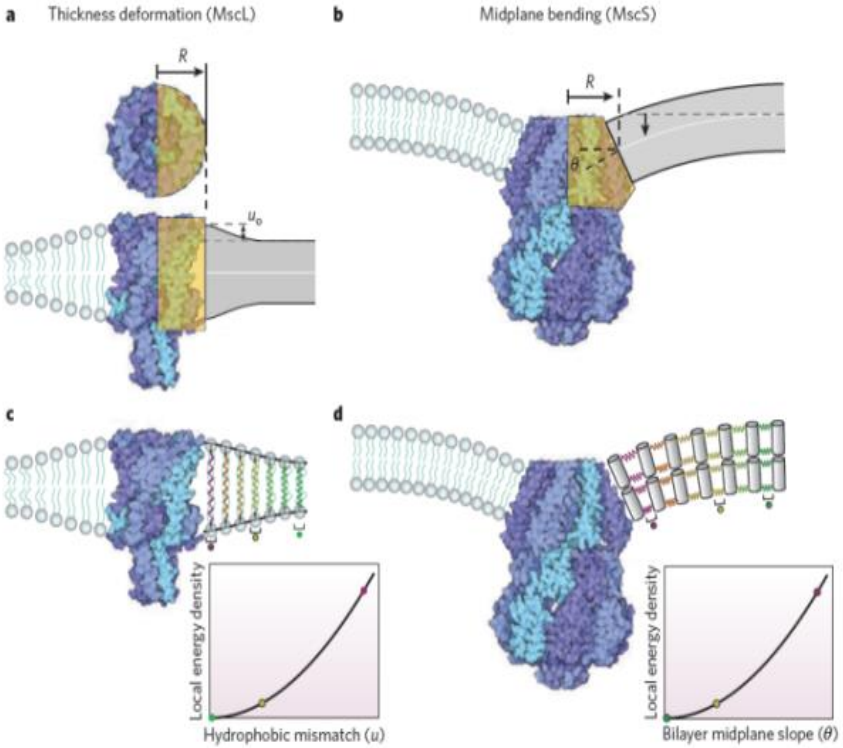
EMERGING ROLES OF LIPIDS

Effect on the gating behavior of mechanosensitive channels



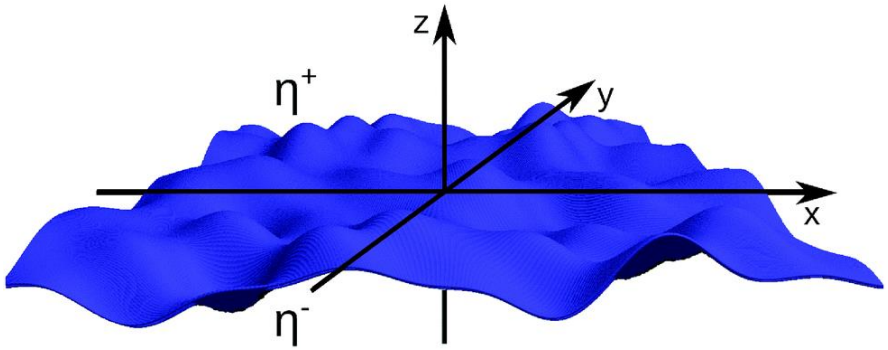
Phillips, Ursell, Wiggins & Sens, Nature **9** (2009)
Jensen & Mouritsen, *Biochim. Biophys. Acta* **1666** (2004)

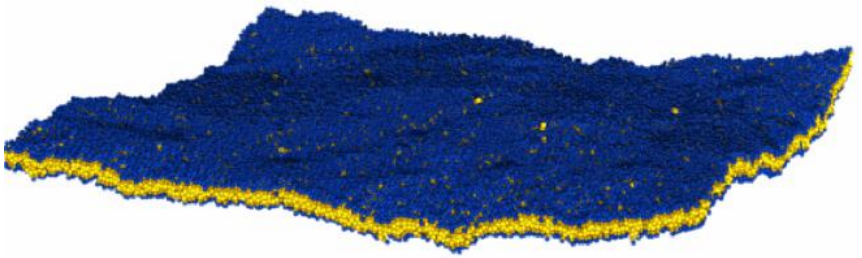
Effect on membrane protein functions and enzymatic activity



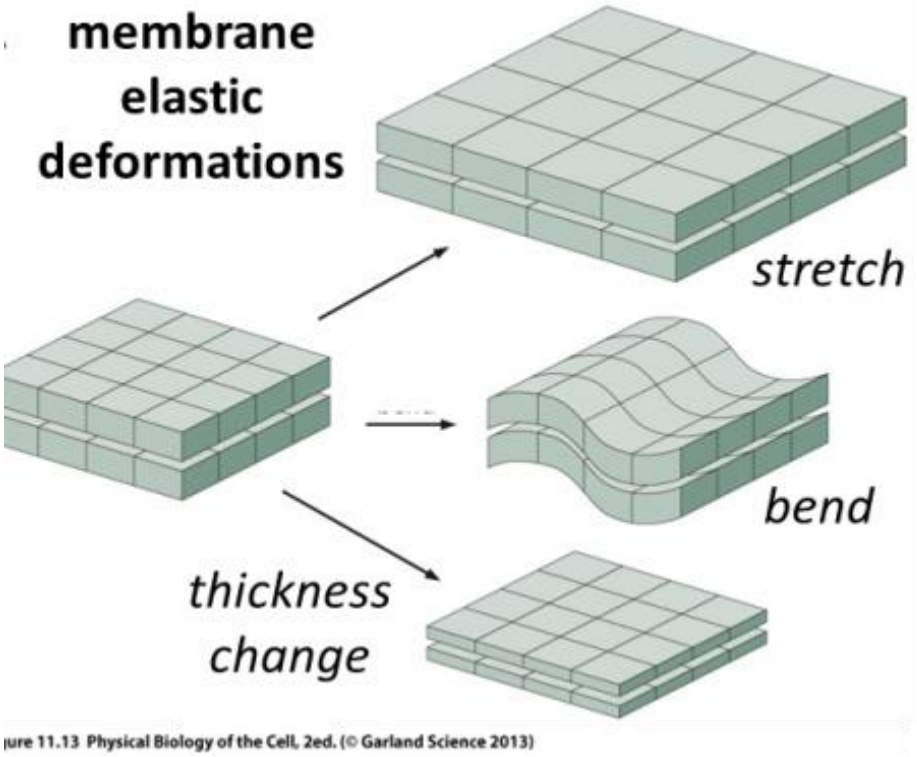
Perozo *et al*., *Nature Struct. Biol*. **9** (2002)

HELFRICH ELASTIC MEMBRANE MODEL





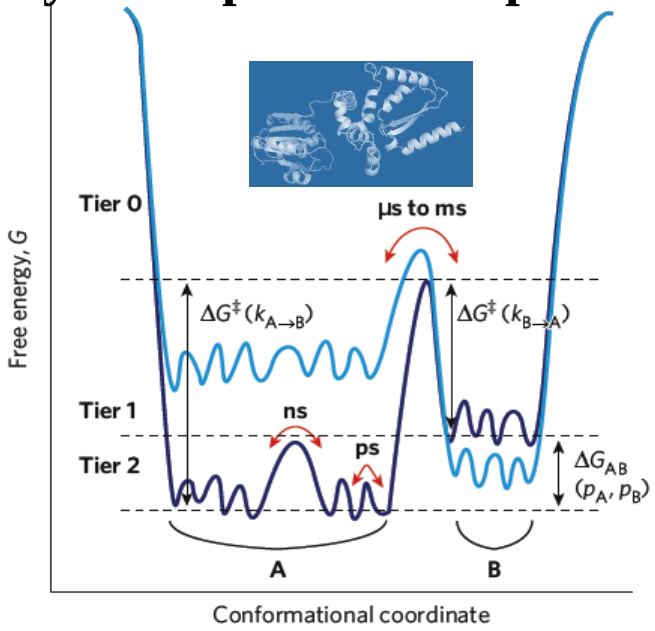
Harmandaris and Deserno. *J. Chem. Phys.* **125**, 204905 (2006)

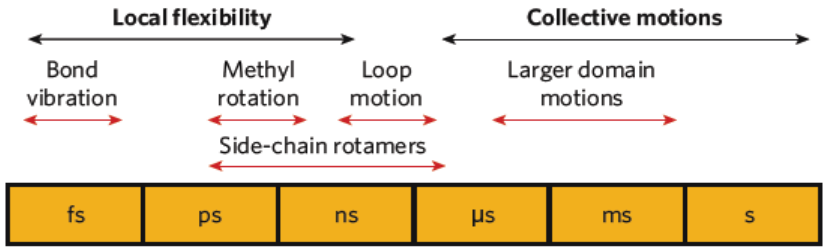


ure 11.13 Physical Biology of the Cell, 2ed. (© Garland Science 2013)

SYNERGISTIC PROTEIN-LIPID DYNAMICS

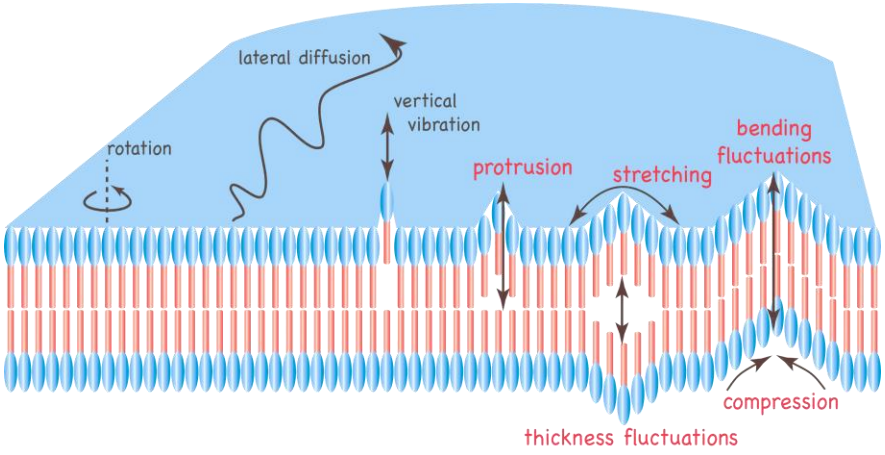
Dynamic processes in proteins

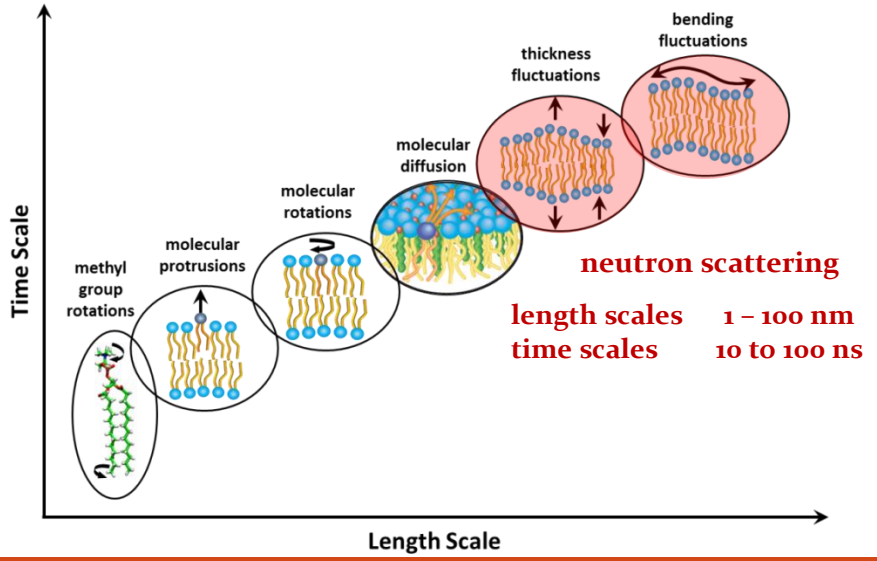




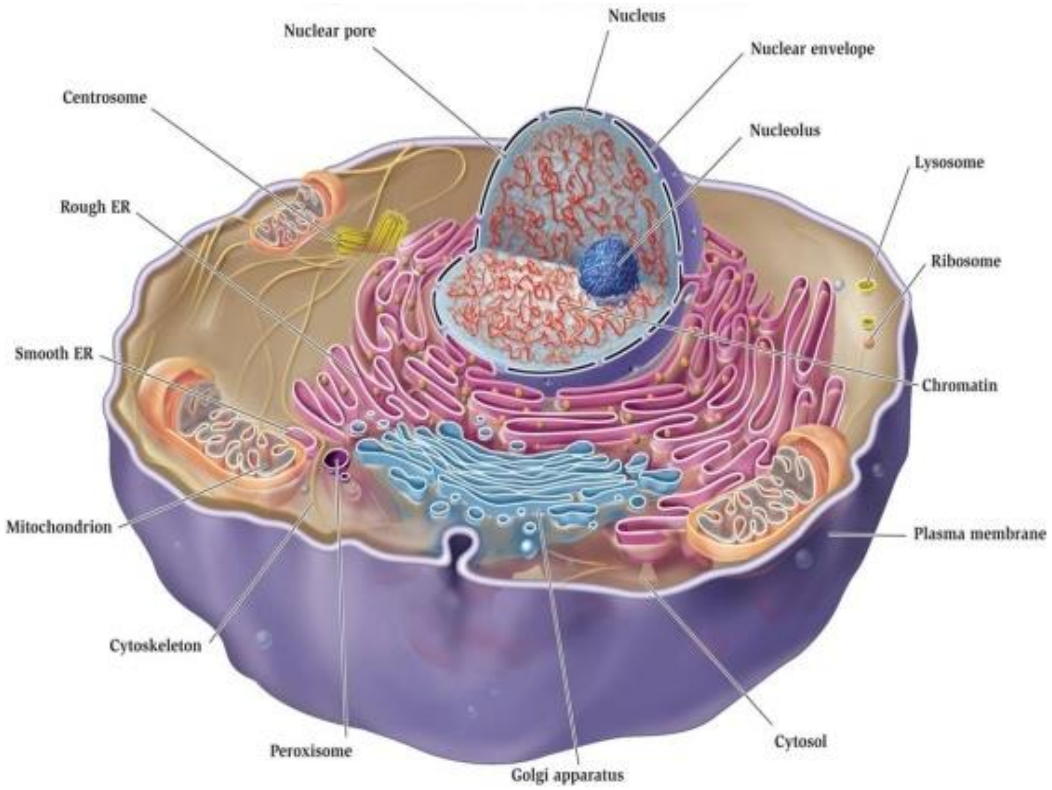
Henzler-Wildman & Kern, Nature **450** (2007)

Dynamic processes in lipid bilayers

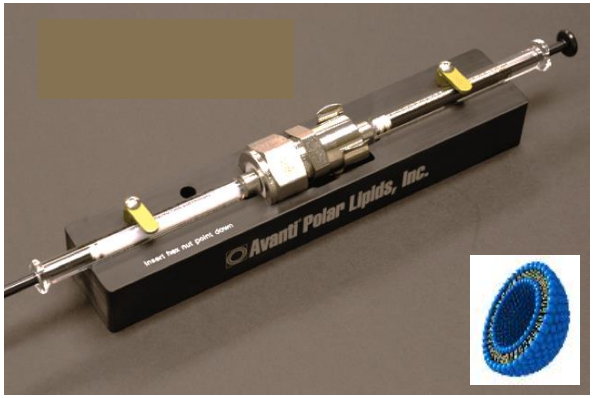




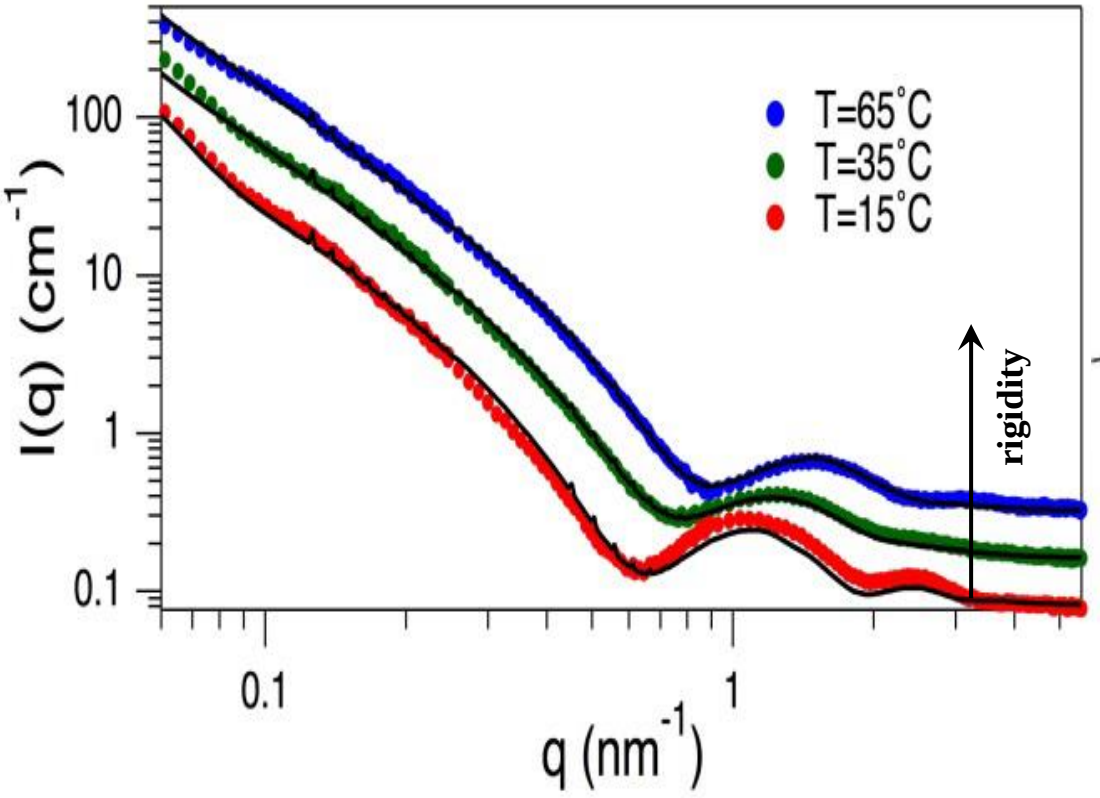
LET'S START WITH A SIMPLE SYSTEM



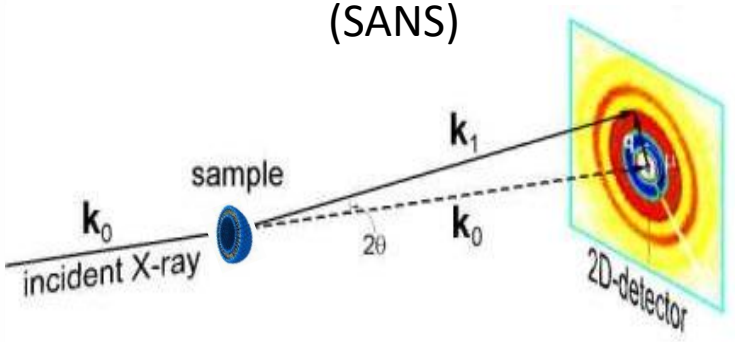
http://biology4isc.weebly.com/3-cell-membranes.html



MEASURING MEMBRANE STRUCTURE



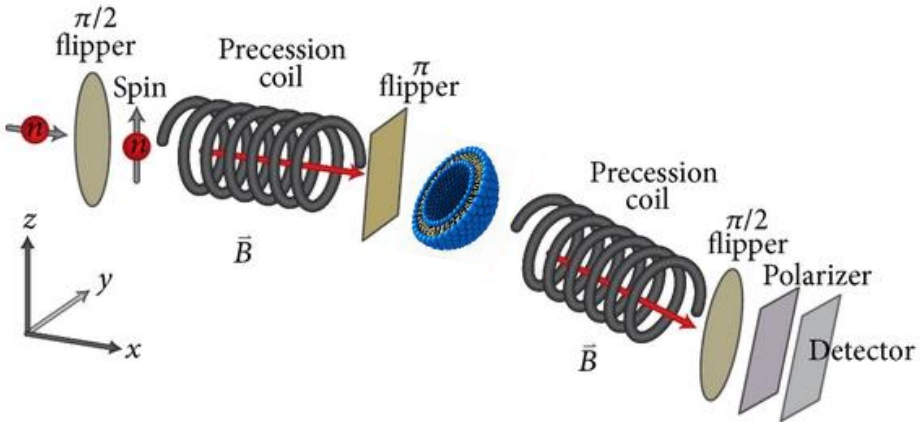
Small-Angle Neutron Scattering (SANS)

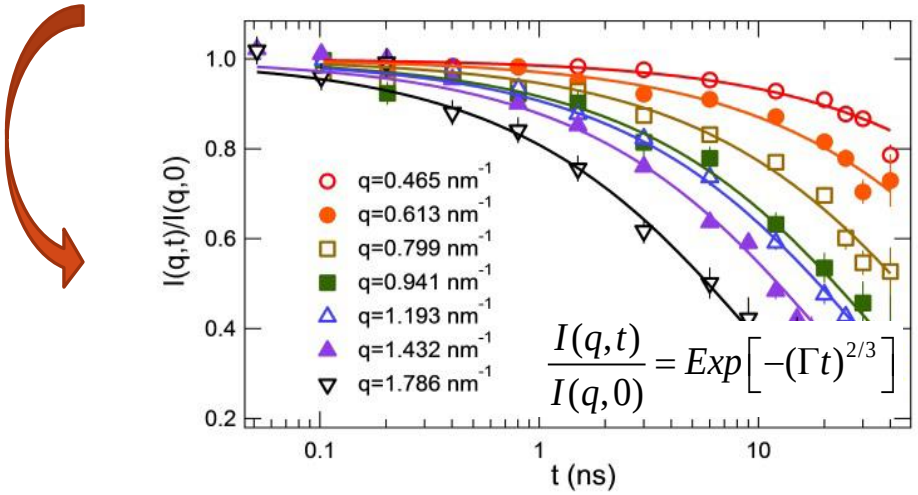


Core-Shell Model:

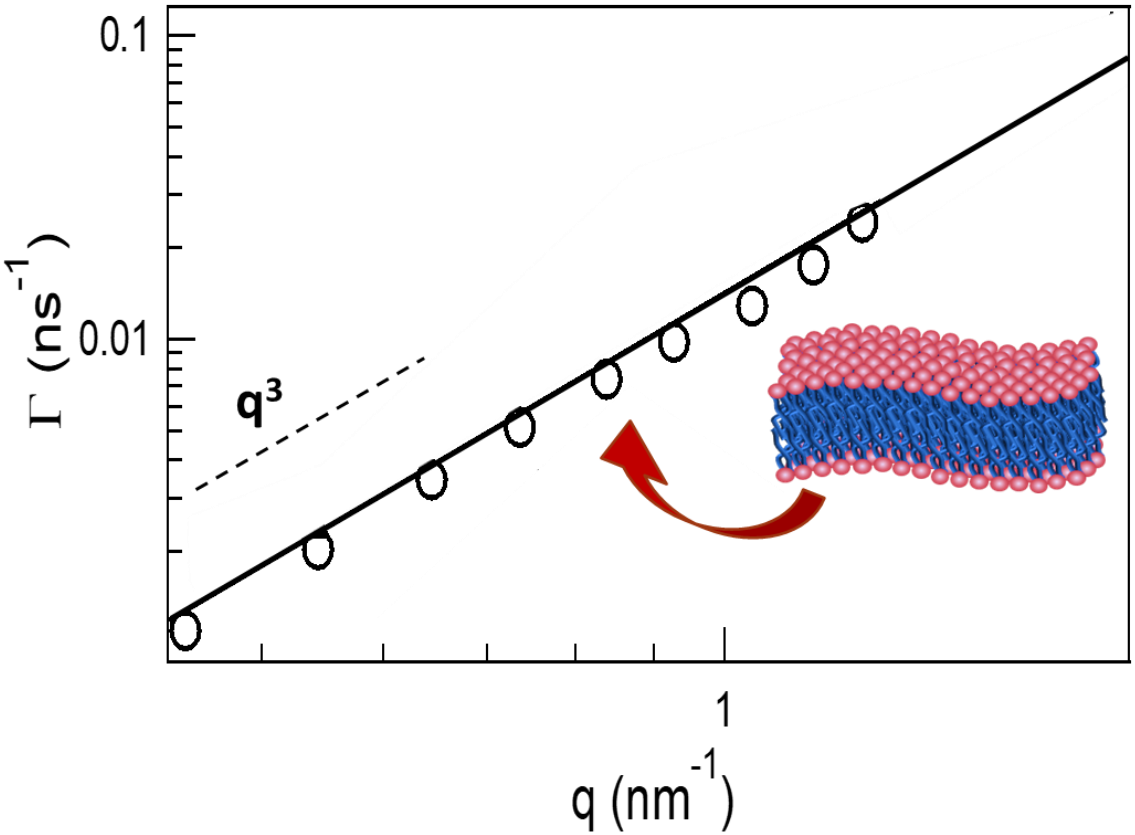
$$S(q) = \frac{1}{V_{shell}}\left[\frac{3V_o J_1(qR_o)}{qR_o} - \frac{3V_i J_1(qR_i)}{qR_i}\right]^2$$

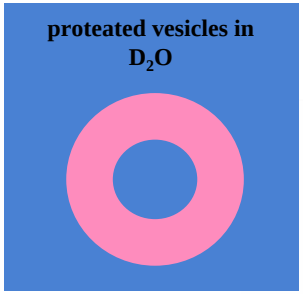
NEUTRON SPIN-ECHO SPECTROSCOPY (NSE) ON LIPID MEMBRANES

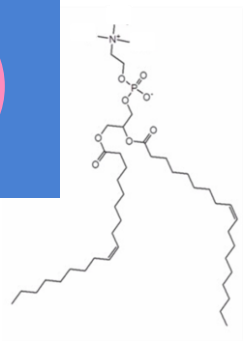




NSE ON PROTEATED VESICLES



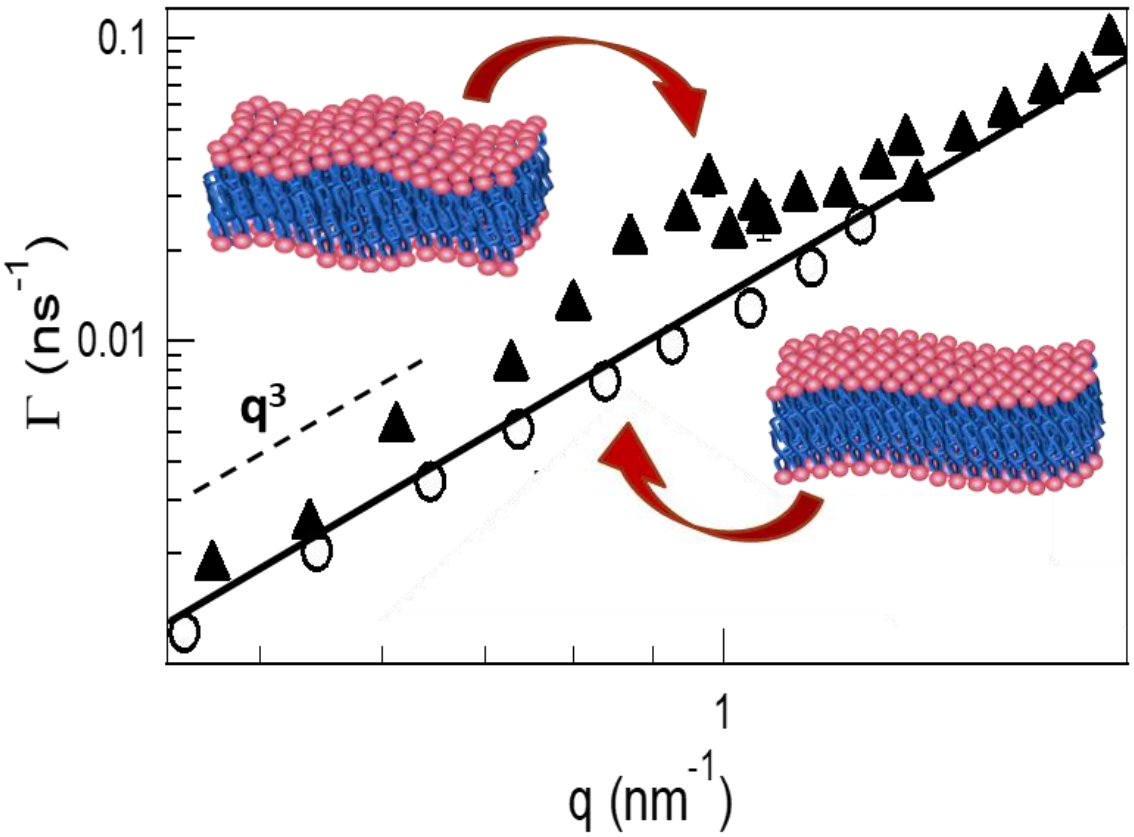


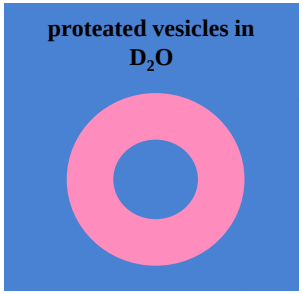


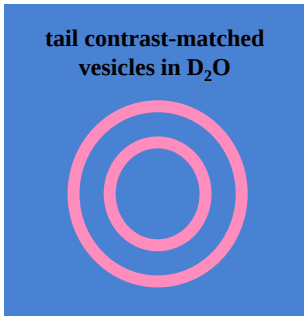
Zilman-Granek Theory: $\Gamma_{bend} = 0.0069 \frac{k_B T}{\eta_{D_2O}} \sqrt{\frac{k_B T}{\kappa}} q^3$

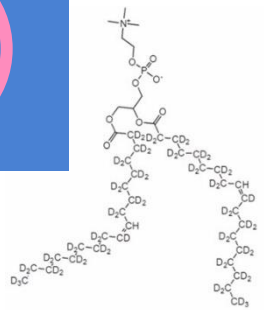
Zilman & Granek, *Chem.Phys.* **184** (2002)

NSE ON TAIL-DEUTERATED VESICLES



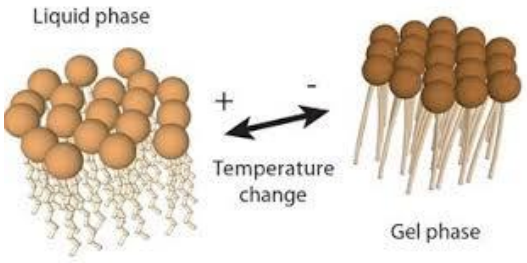


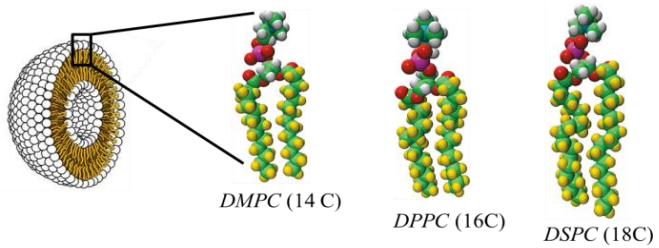




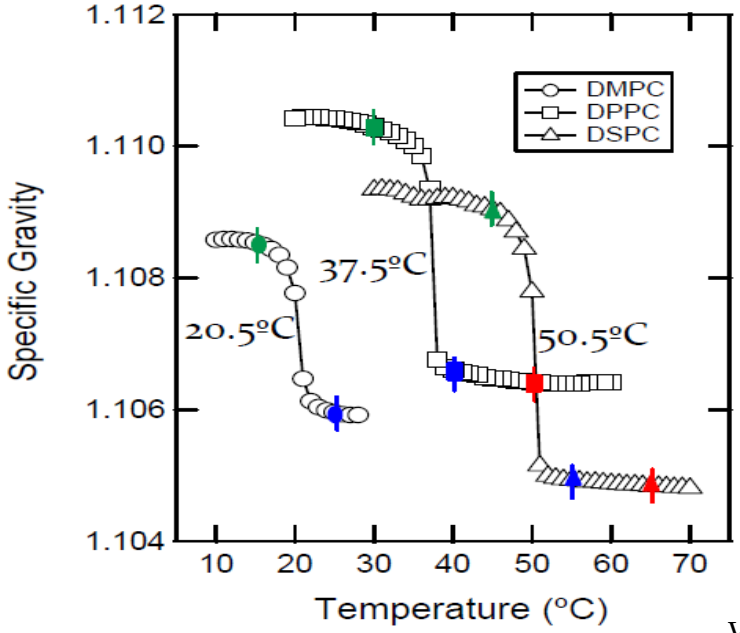
$$\frac{\Gamma}{q^3} = \frac{\Gamma_b}{q^3} + \frac{K_A k_B T}{\mu q_0^3 k_B T + 4\mu q_0 K_A A_0 (q - q_0)^2}$$

COLLECTIVE DYNAMICS IN SINGLE-COMPONENT BILAYERS

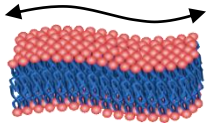


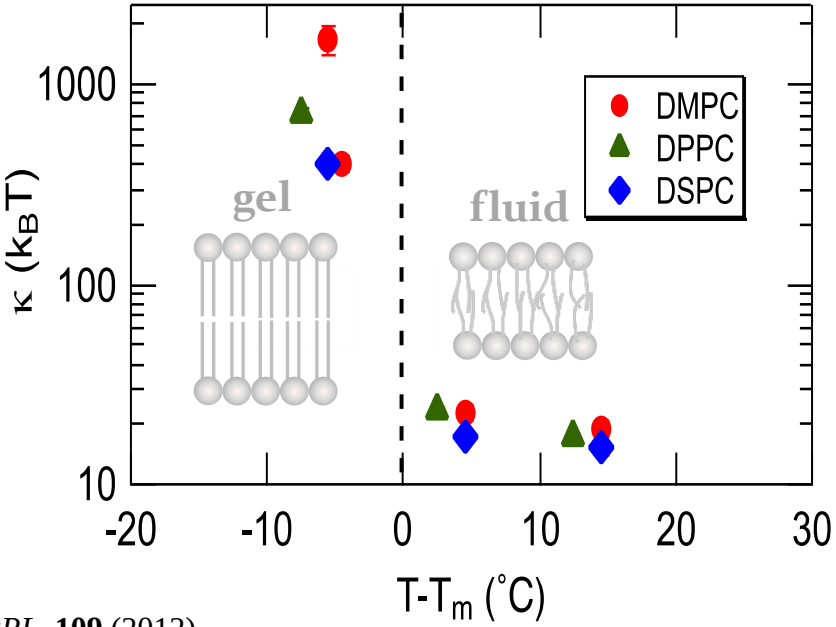


Phase Behavior



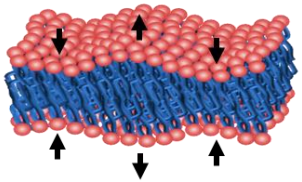
Bending Fluctuations

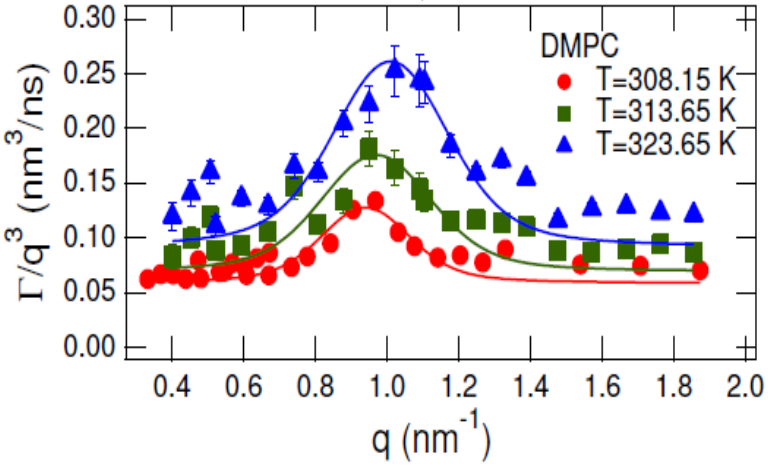


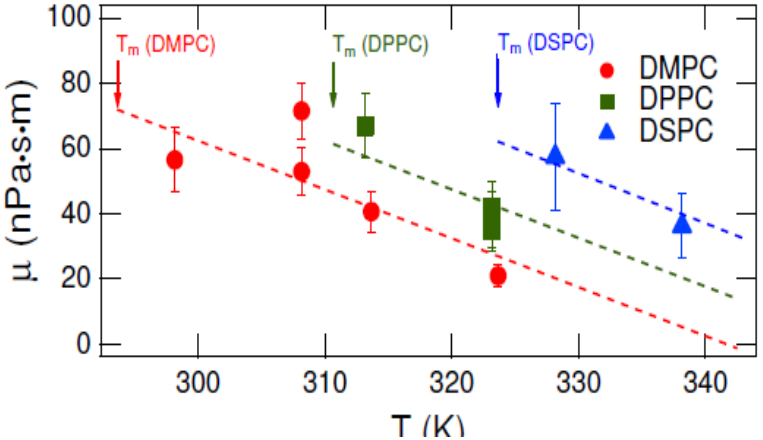


Woodka *et al.*, *PRL*. **109** (2012)

COLLECTIVE DYNAMICS DEPEND ON VISCOELASTIC MEMBRANE PROPERTIES

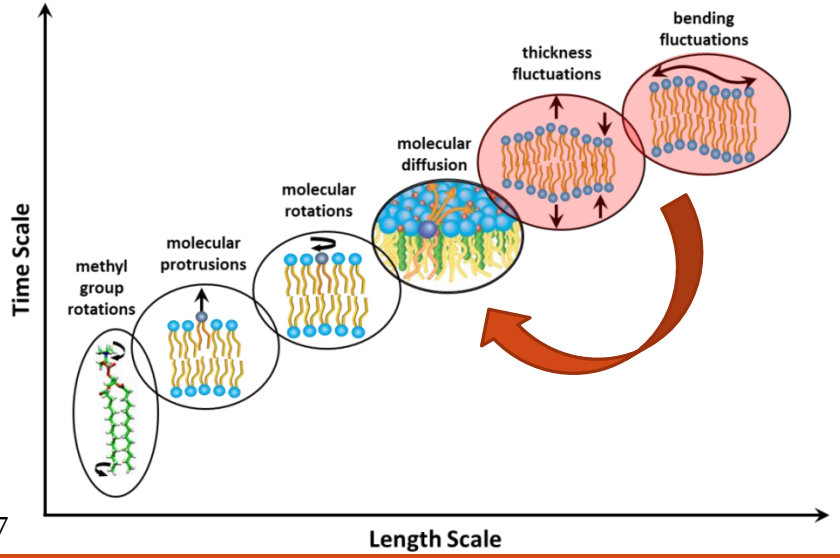






$$\frac{\Gamma}{q^3} = \frac{\Gamma_b}{q^3} + \frac{K_A k_B T}{\mu q_0^3 k_B T + 4\mu q_0 K_A A_0 (q - q_0)^2}$$

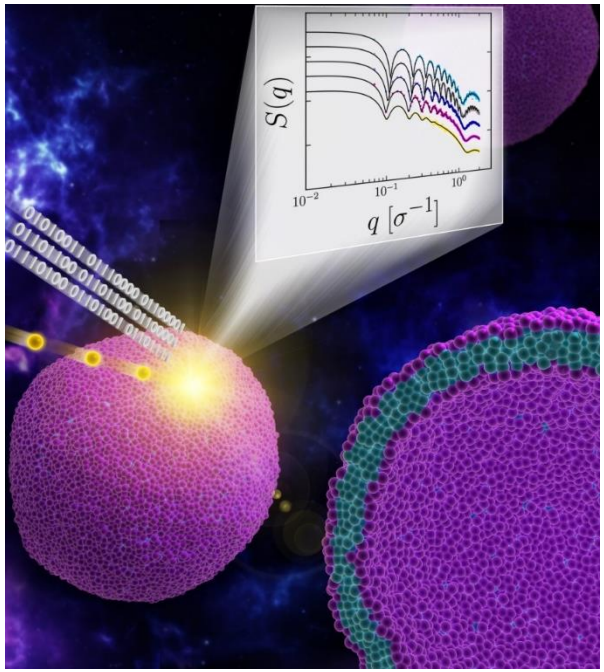
$$K_A = \beta\kappa / (2h_c)^2$$

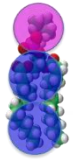


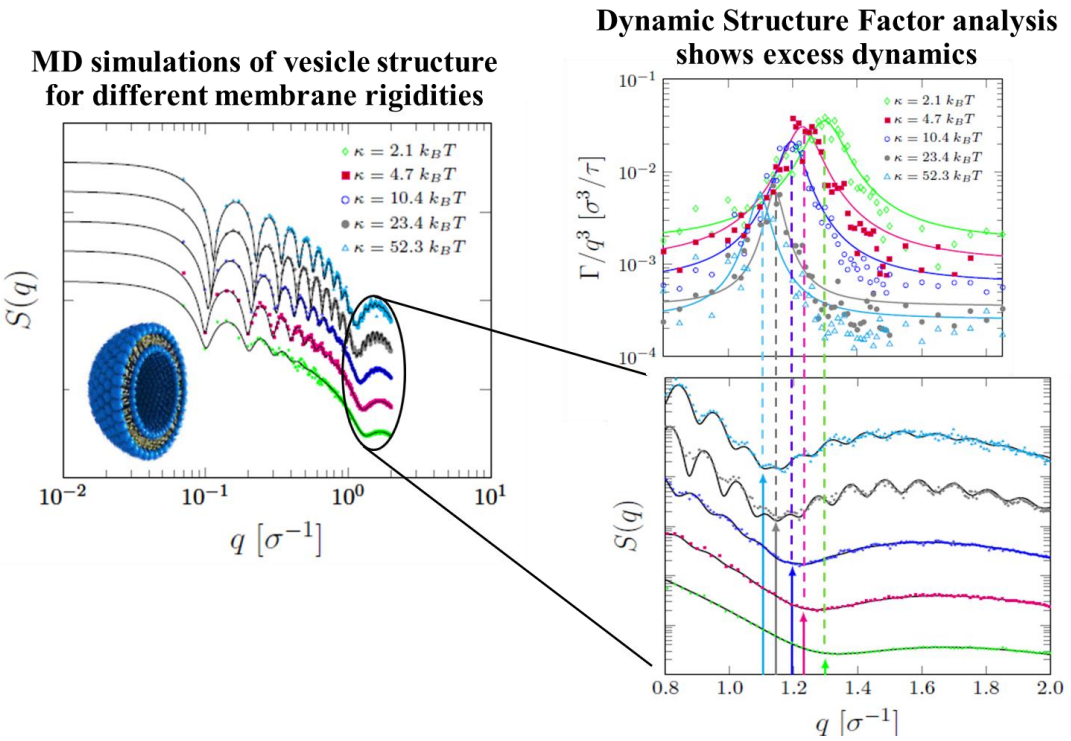
M. Nagao, E. Kelley, R. Ashkar, R. Bradbury, P. Butler, *J. Phys. Chem. Lett.* 2017

COMPUTER SIMULATIONS PROVIDE INSIGHTS INTO MOLECULAR BEHAVIOR

In collaboration with Bobby Sumpter and Jan-Michael Carrillo (ORNL)

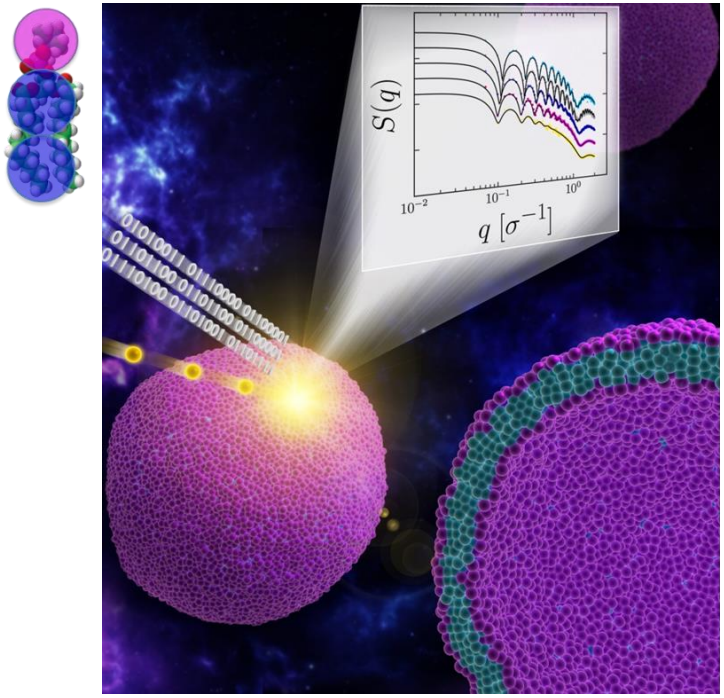




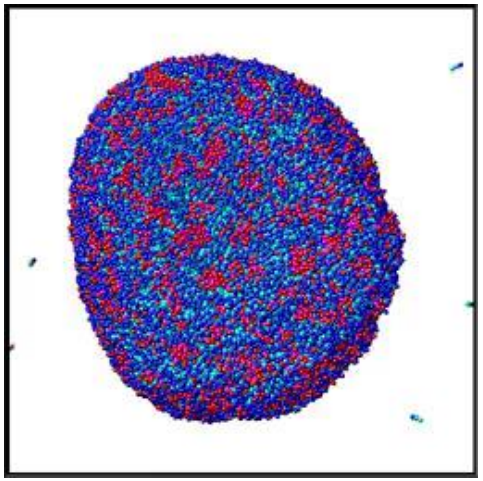


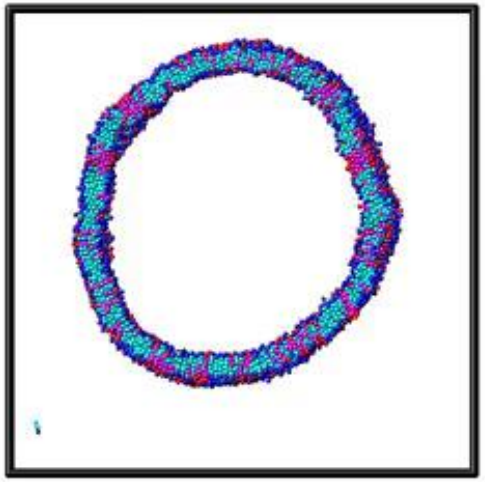
J.-M. Carrillo*, J. Katsaras, B. Sumpter, and R. Ashkar*,
J. Chem. Theory Comput. 2017

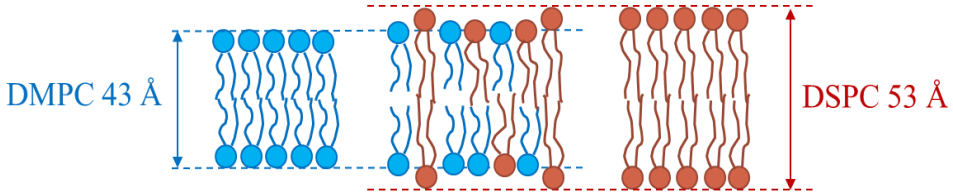
COMBINE WITH MD SIMULATIONS!



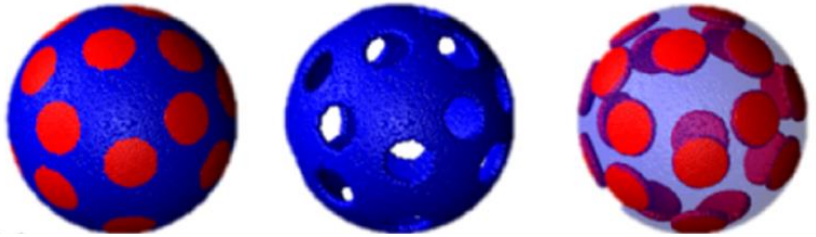
Courtesy of Jan-Michael Carrillo (ORNL)







Ashkar et al., *Biophys. J.* (**2015**)
Kelley et al., *PNAS* (**2020**) just accepted
Ashkar el al. (manuscript in preparation)

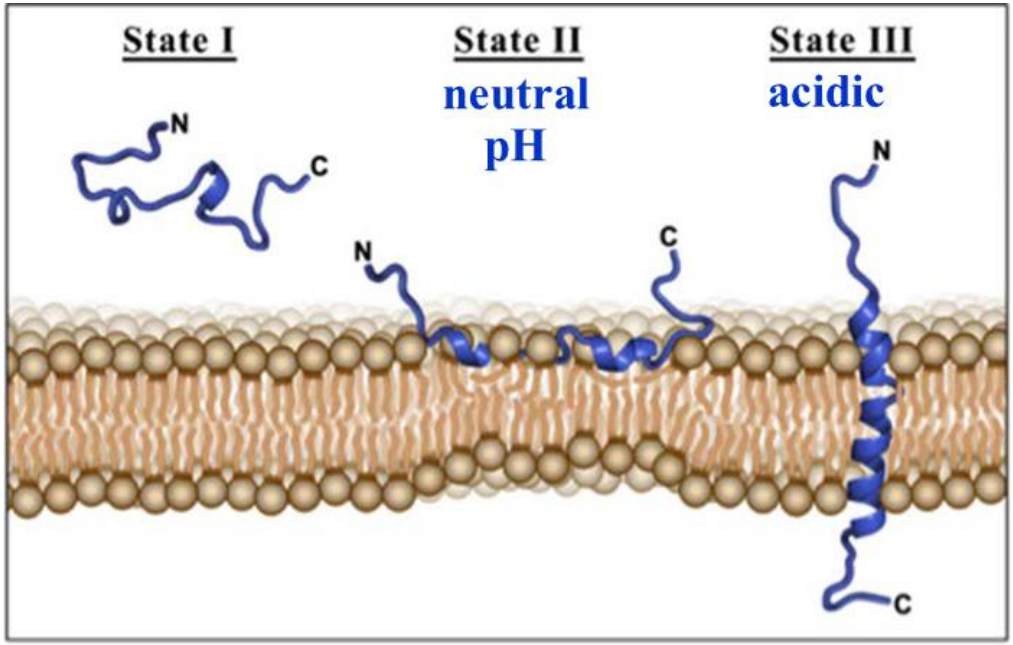


Nickels et al. *JACS* **2015**

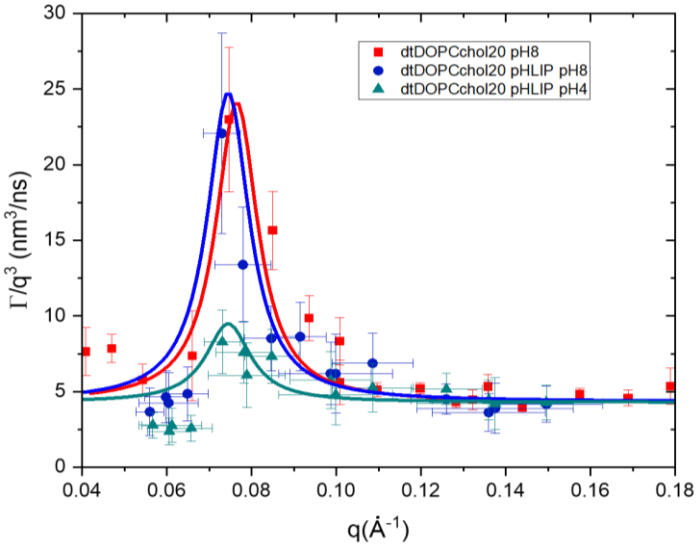
MEMBRANE FLUCTUATIONS AND PROTEIN FUNCTIONS

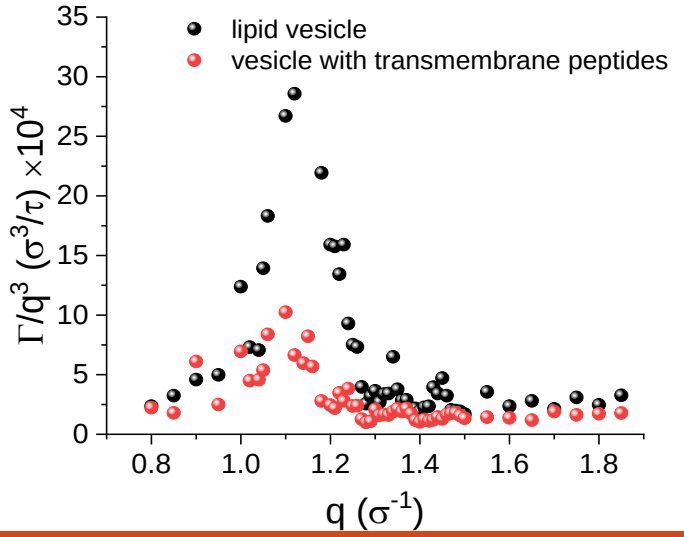
In collaboration with Francisco Barrera's group at UTK

The different states of pHLIP



Barrera, Fendos, and Engelman. *PNAS* **2012**

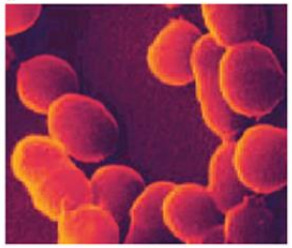




Scott el al. (submitted)

THE BEAUTIFUL & COMPLEX SHAPES OF CELLS AND CELL ORGANELLES

a



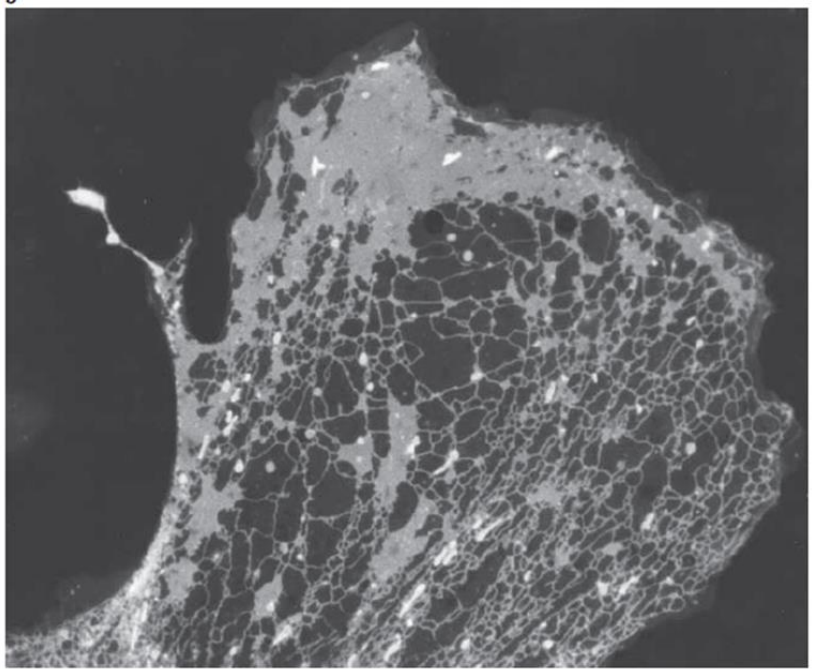
Cocci

Rods

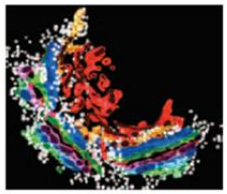
A spirochete

erythrocytes

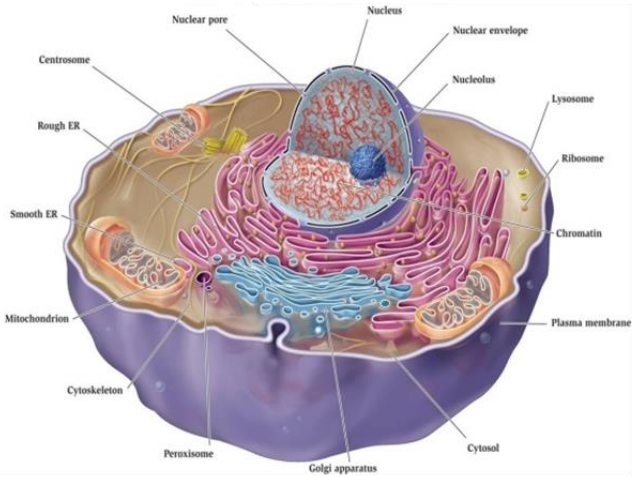
b



Endoplasmic reticulum



Golgi ribbon

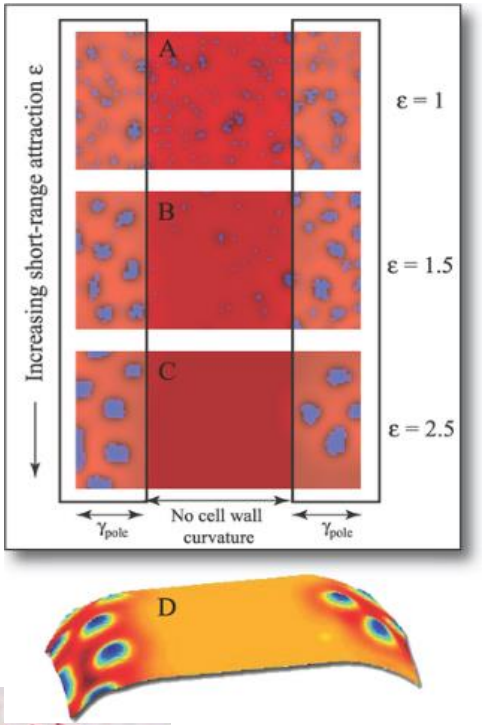


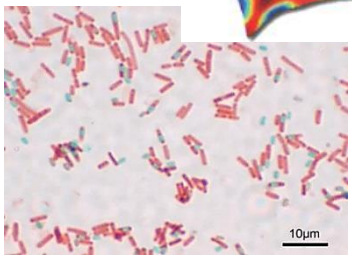
http://biology4isc.weebly.com/3-cell-membranes.html

Zimmerberg and Kozlov, *Nat Rev Mol Cell Biol* (**2006**)

NATURALLY OCCURING CURVATURE-MEDIATED LIPID REARRANGEMENTS

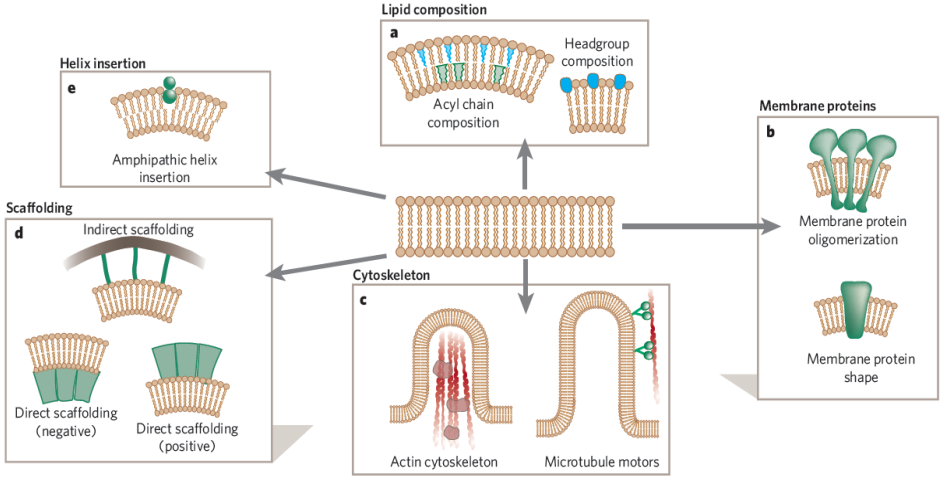
Polarized localization in B. Subtilis



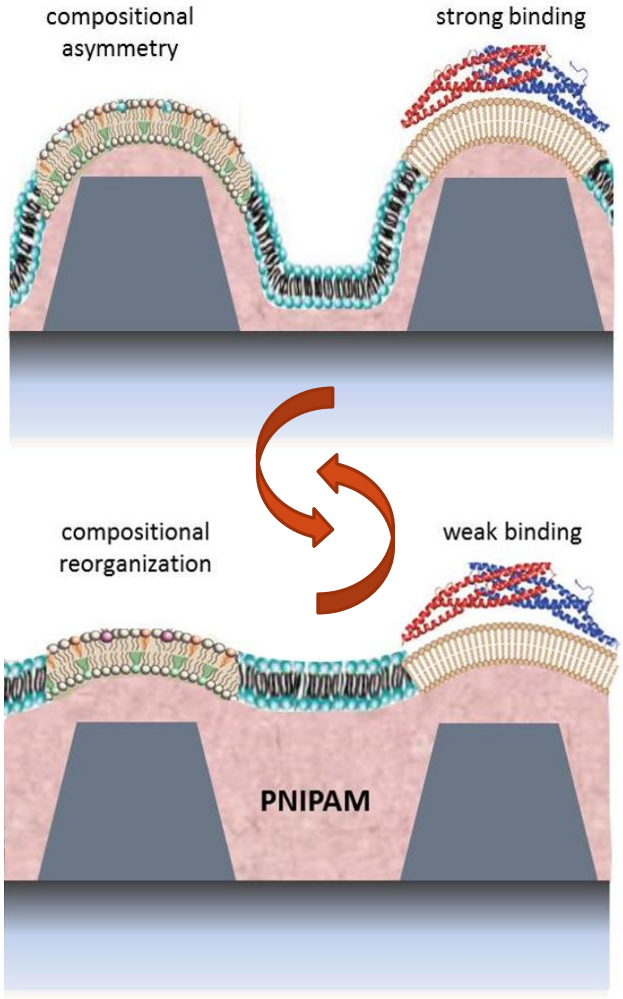


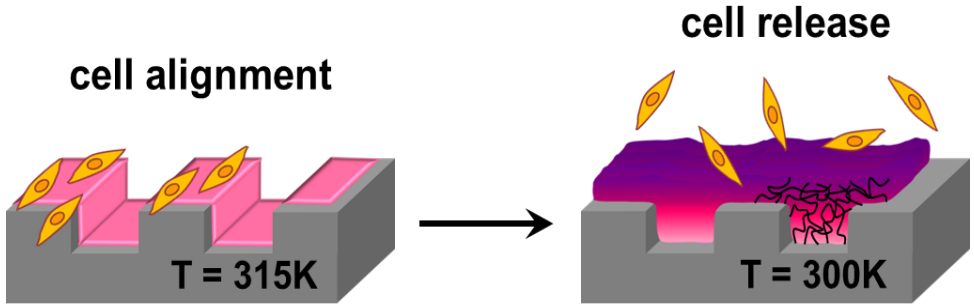
Huang et al. PlosOne **2006**

Mechanisms of generating curvature

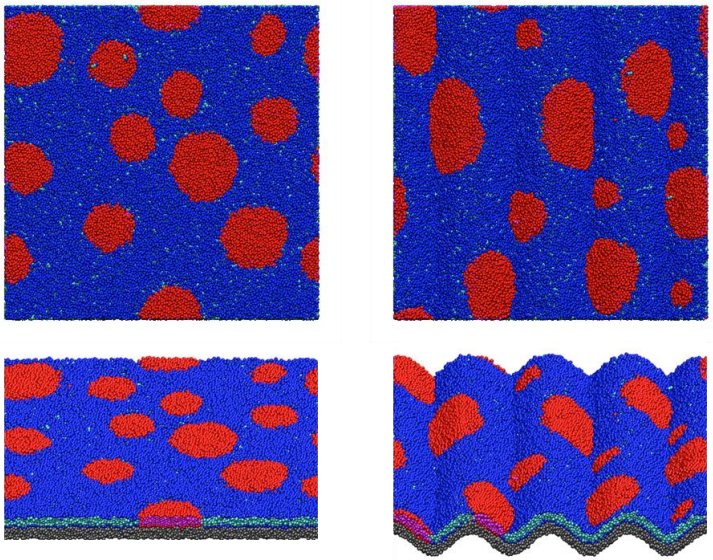


SMART METRIALS FOR CONTROLLED CURVATURE STUDIES





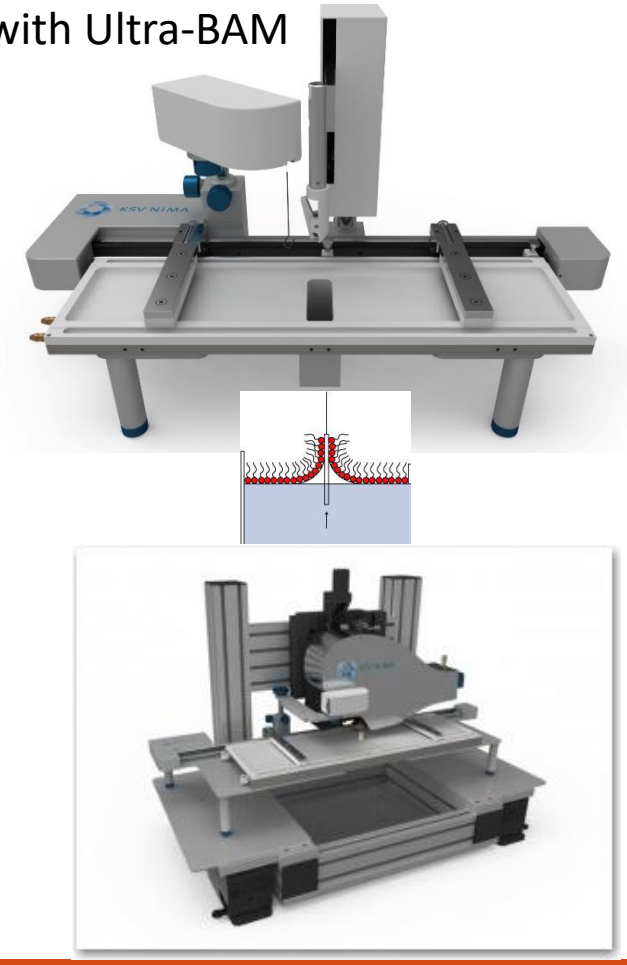
M. Zhernenkov*, **R. Ashkar***, et al. *ACS Appl. Mater. Interfaces*, **2015**, *7* (22)

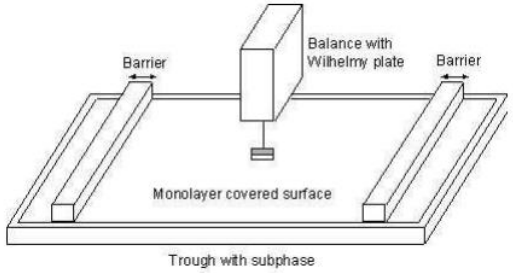


W. Li, ... **R. Ashkar*** and R. Kumar*. *Soft Matter*, **2019 (Back Cover)**

LAB CAPABILITIES AND POTENTIAL HS RESEARCH OPPORTUNITIES

Fully-equipped Langmuir trough with Ultra-BAM





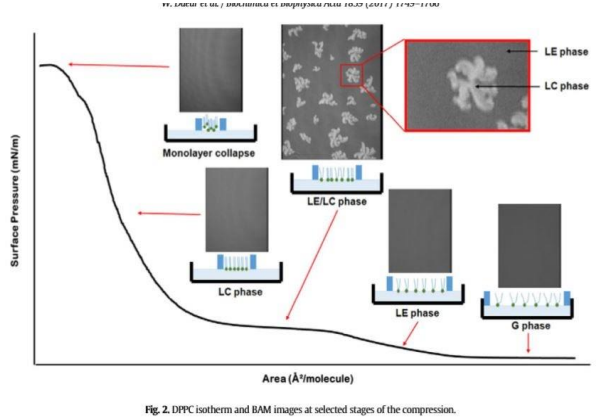
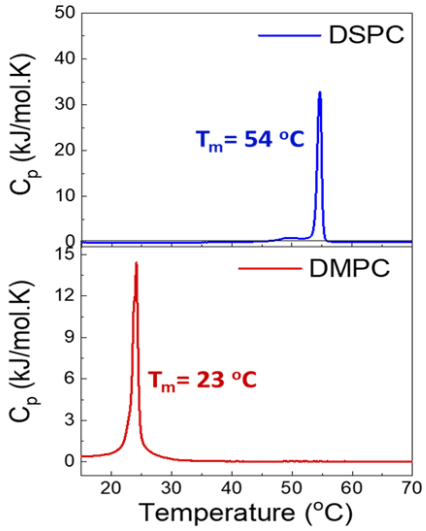
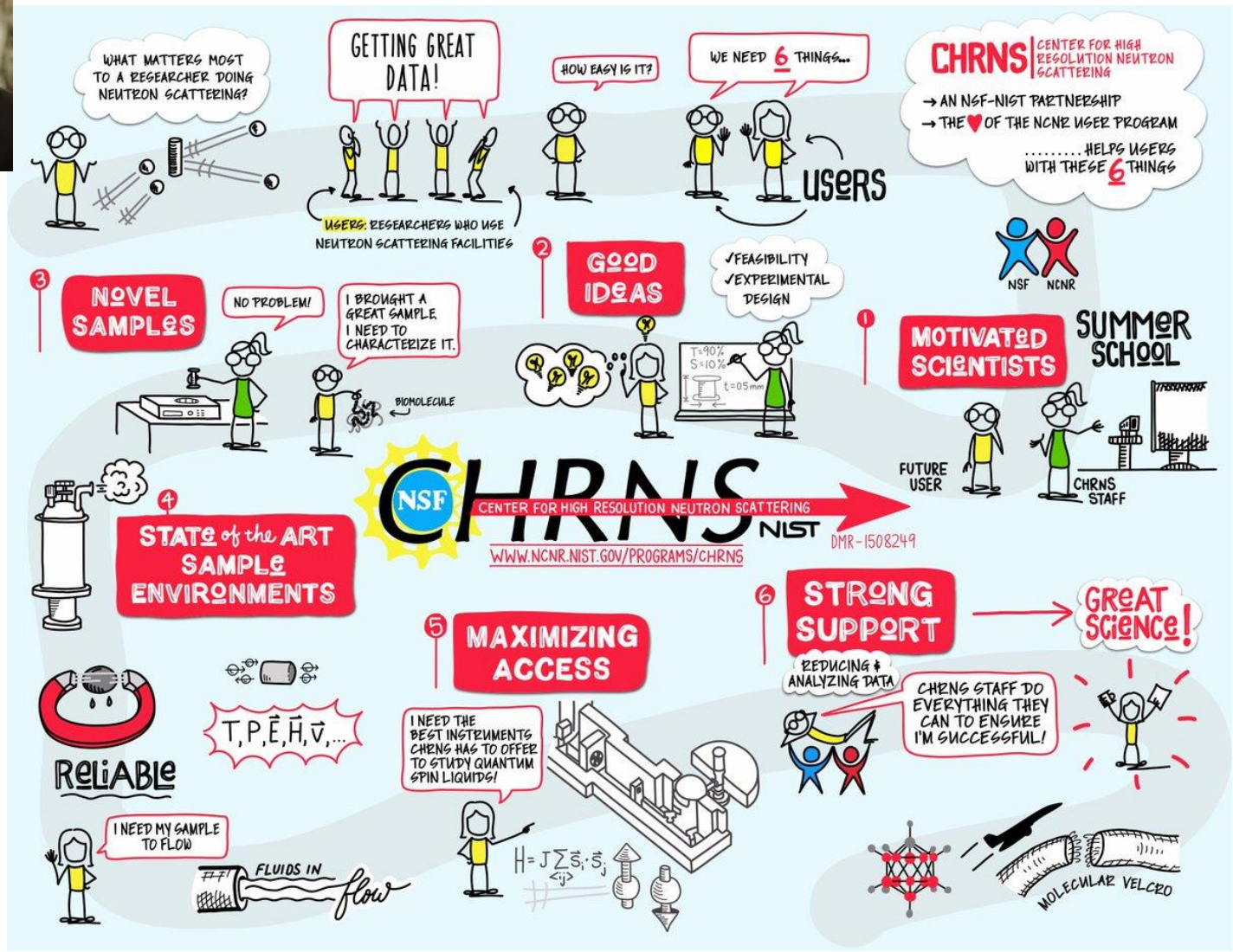


Fig. 2. DPPC isotherm and BAM images at selected stages of the compression.

Differential Scanning Calorimetry



WHAT GOES IN A NEUTRON SCATTERING EXPERIMENT?



https://twitter.com/Rob_Dimeo/status/884847067142795264

WHAT GOES IN A NEUTRON SCATTERING EXPERIMENT?

Thank you!
Questions?