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BIOPHYSICAL ELECTROCHEMISTRY OF BIOLOGICAL MEMBRANES: WHAT SHOULD BE KNOWN BY LIFE SCIENTISTS

Justin Teissié

Institut de Pharmacologie et de Biologie Structurale-CNRS
Université de Toulouse, Toulouse, France

Fundamentals on biological membranes
1- What is a biological membrane?
2- Chemical composition
Phospholipids, Sterols, Proteins
3- Structural organization
Shape deformations, invaginations, internal dynamics
4- A biological membrane is a fluid mosaic.
Self organization in domains due to clustering, « rafts »
5- Movements in membranes
Rotation, diffusion, wobbling in polar head regions as well as in the fatty acid chains
6- The membrane interface is electrically charged
Interfacial distribution of soluble charged species close to the interface (the Gouy Chapman model)
7- Water at membrane interfaces
Hydration forces

The membrane interface is electrically charged

Biological membranes should be considered as negatively charged interfaces. This results from the electrical charges that are carried by proteins and lipids. As a consequence, in the bulk solution, close to the membrane, a diffuse layer of counter charges is present to obtain an electroneutrality (so called Gouy layer). Repulsive forces are present against negatively charged interacting molecules and polyelectrolytes (such as nucleic acids). A mathematical description of the local electrical potentials can be obtained under the simplifying assumptions that the membrane is flat and that the electrical charges are homogeneously distributed. This is far from the biological fact (microdomains, invaginations). This nevertheless gives a fair description and supports most of the experimental observations. It is observed that under "physiological" ionic conditions (more than 100 mM in monovalent ions) the thickness of the Gouy layer is about 1 nm. The consequence is that a dramatic change in potentials occurs on this thin distance (i.e. a sharp gradient) resulting in huge local electric fields. As a result, water molecules close to the membrane are affected. Water molecules are electrical dipoles. The local field induces a torque, that results in a well defined orientation of dipoles. Interfacial water molecules are different from bulk water. A local order is present. The ordered dipole layer associated to the water molecules results in a field of constraints at the interface, called the hydration forces. A repulsion is therefore observed when 2 membranes are brought in close contact preventing their spontaneous close contact. Fusion is prevented under normal conditions and a stress is needed to trigger the intermixing.

As the membrane surface is not flat, is affected by different categories of movement (lateral, rotational, transversal) and that charges are very local, we must conclude that very large fluctuations in those fields are present in the real systems.

A critical feature of biological membranes is the electrical dipole present on the polar heads of lipids. It was shown to rotate (a fast tumbling) around an axis perpendicular to the membrane plane with a well defined orientation (wobbling is present but with a reduced amplitude). This orientation is the opposite of the one of the dipoles present along the glycerol backbone. As a result, a very local inversion of dipolar potentials is present across the membrane interface.

Furthermore the orientation of the polar-heads is under the control of the electrical charges present at the interfaces. Polar heads are interfacial electrometers.

Interaction of membranes with charged species will strongly affect this local organization and the associated local fields.

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