2021 Undergraduate Research Showcase

Undergraduate Research and Scholarship Showcases

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Mechanical Stress Modulates the Ionic Conductance of Bilayer Lipid Membranes

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Mechanical stress modulates the ionic conductance of bilayer lipid membranes

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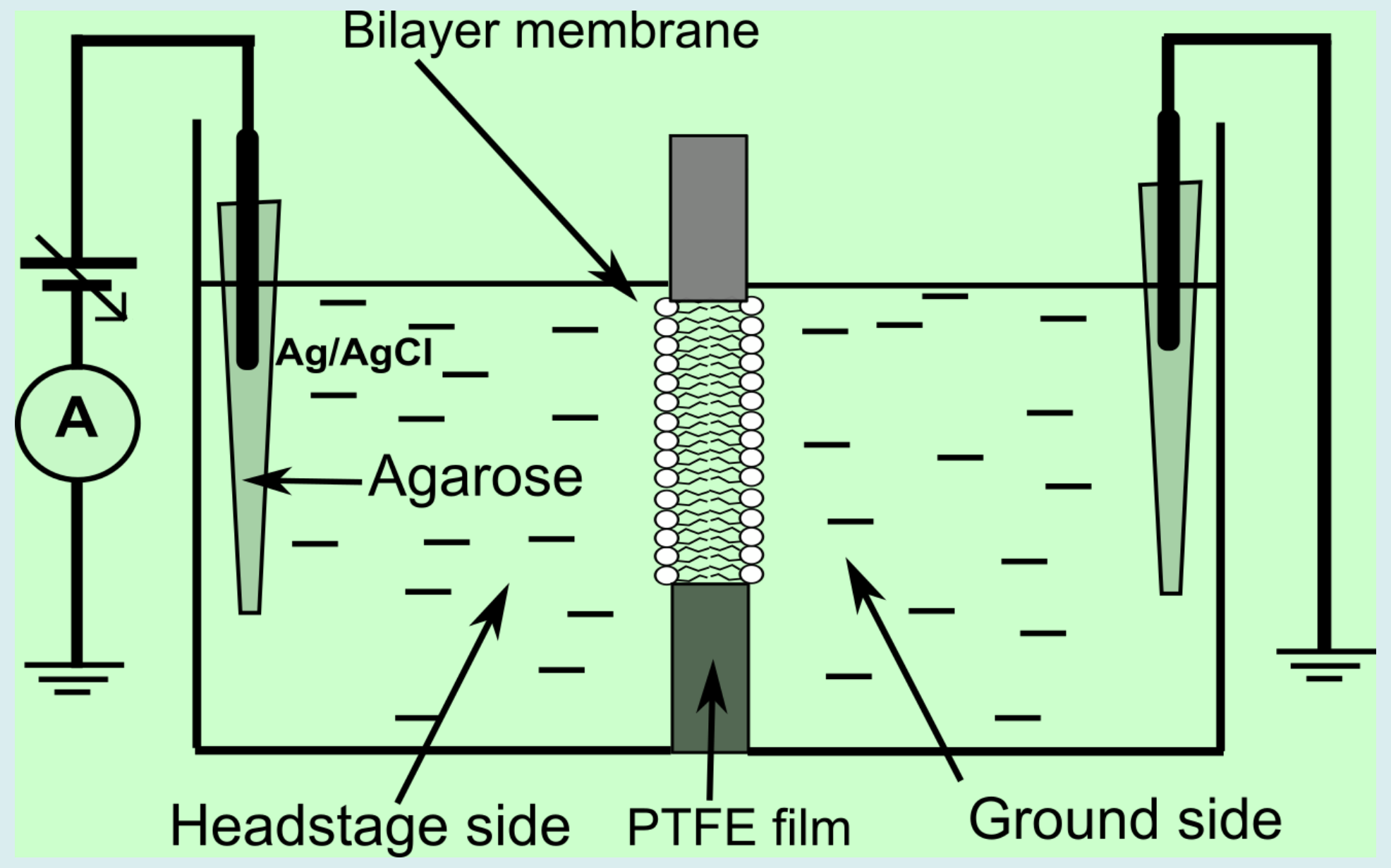
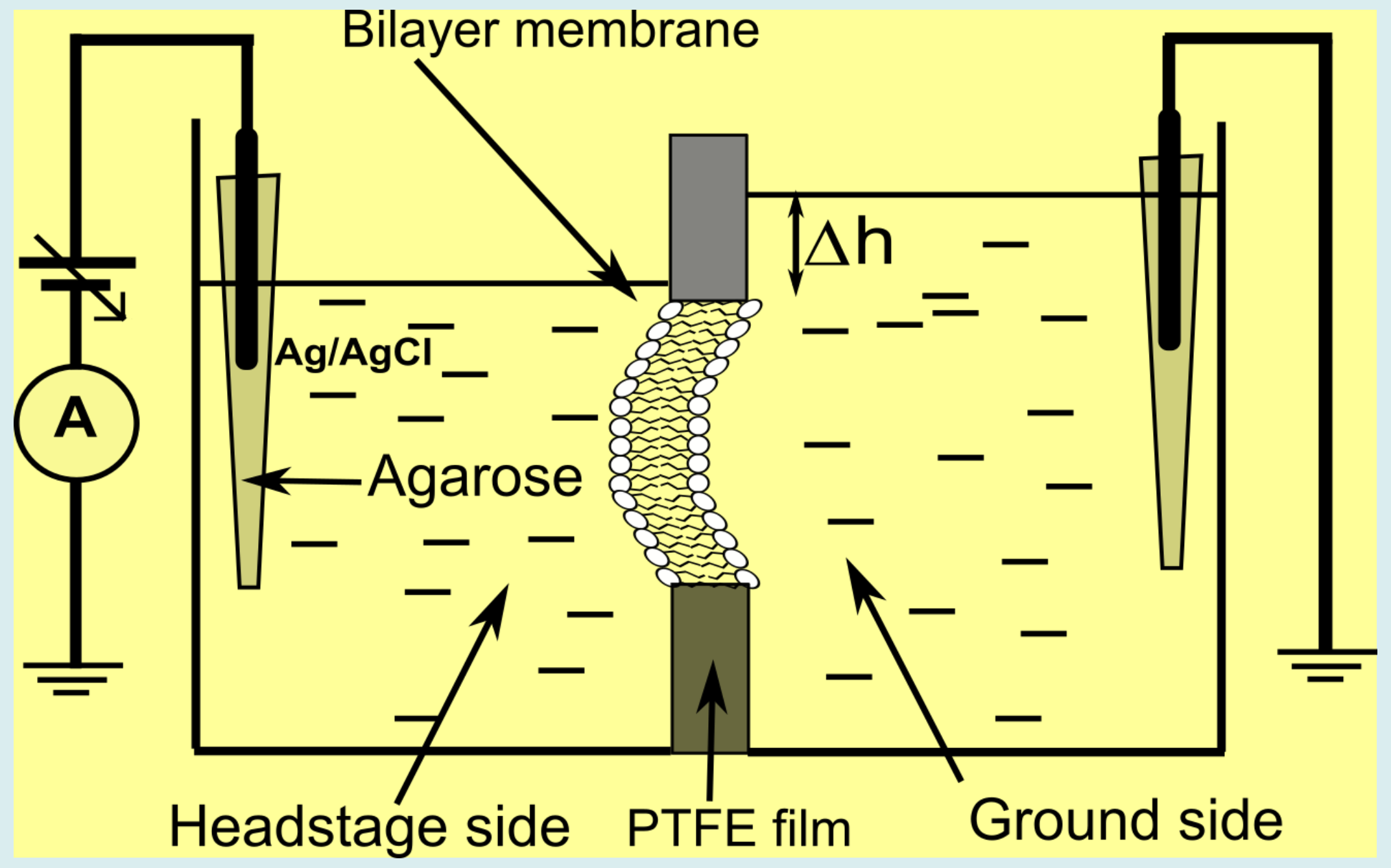
The modulation of the transmembrane voltage of receptor cells using mechanical stimuli is an essential component of touch and hearing senses. Such stimuli influence the conducting state of mechano-sensitive channels, which in turn adjusts the ionic permeation and consequently the transmembrane voltage. The necessity of ion channels in these transduction processes seems obvious due to the non-conductive nature of a lipid membrane. However, our electrophysiology experiments show that a bare, artificial lipid membrane exposed to mechanical stress allows the passage of inorganic ions. We concluded that lipid membranes may constitute an important component of the transduction mechanism under mechanical stimuli.

Experimental Setup

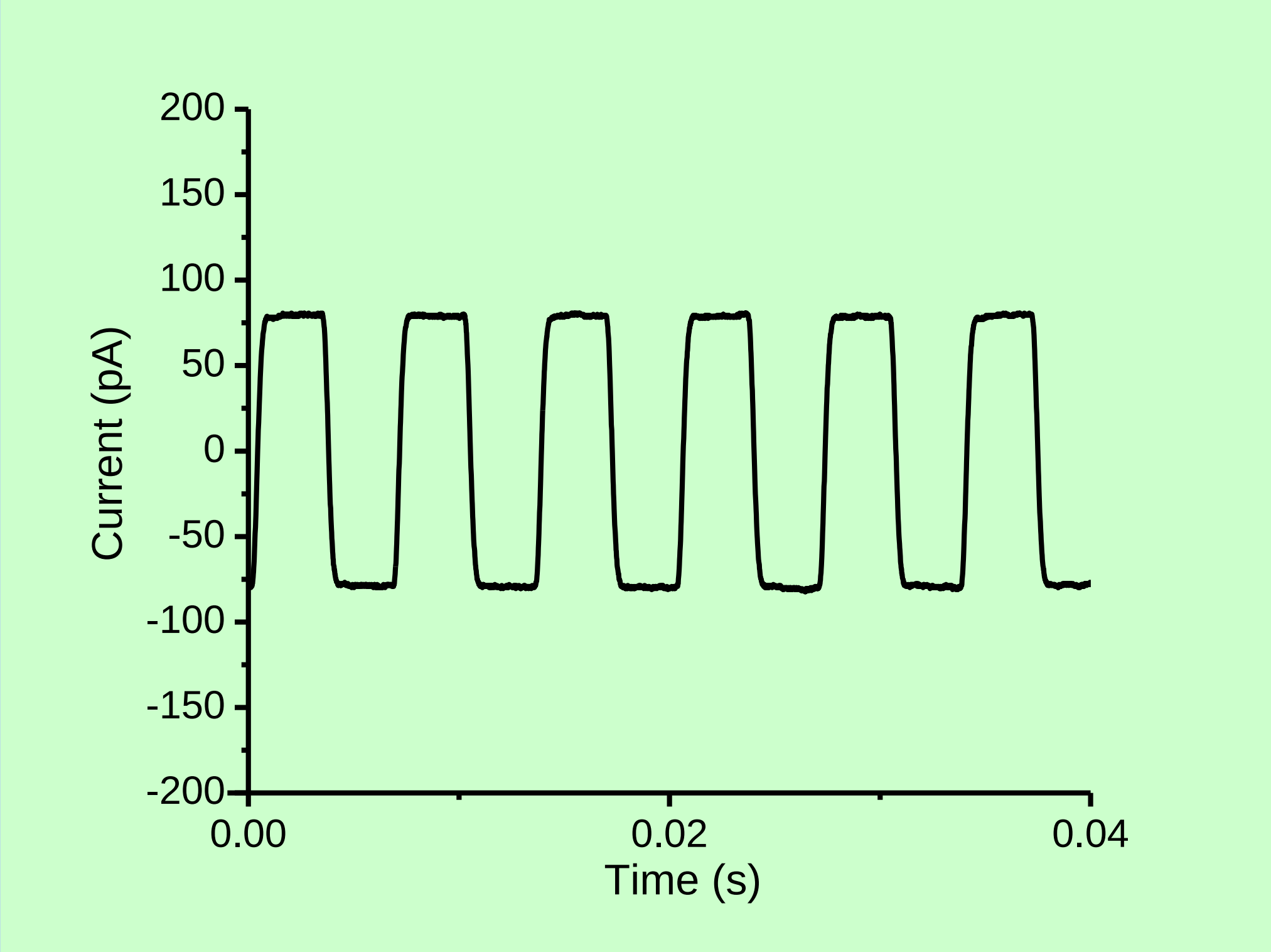


The bilayer lipid membrane setup consists of two Teflon reservoirs (1 mL each) separated by a thin Teflon film of thickness 120 microns, in which a small hole is created using an electric spark. The membrane is created by the painting method, and the lipid composition includes 10 mg asolectin and 4 mg cholesterol dissolved in 0.5 mL n-decane. The membrane is bathed by electrolyte solutions containing 135 mM KCl and 20 mM HEPES (pH = 7.2). Two Ag/AgCl electrodes placed into the bulk solutions are used for electrical connections to the Axopatch 200B electrophysiology amplifier.

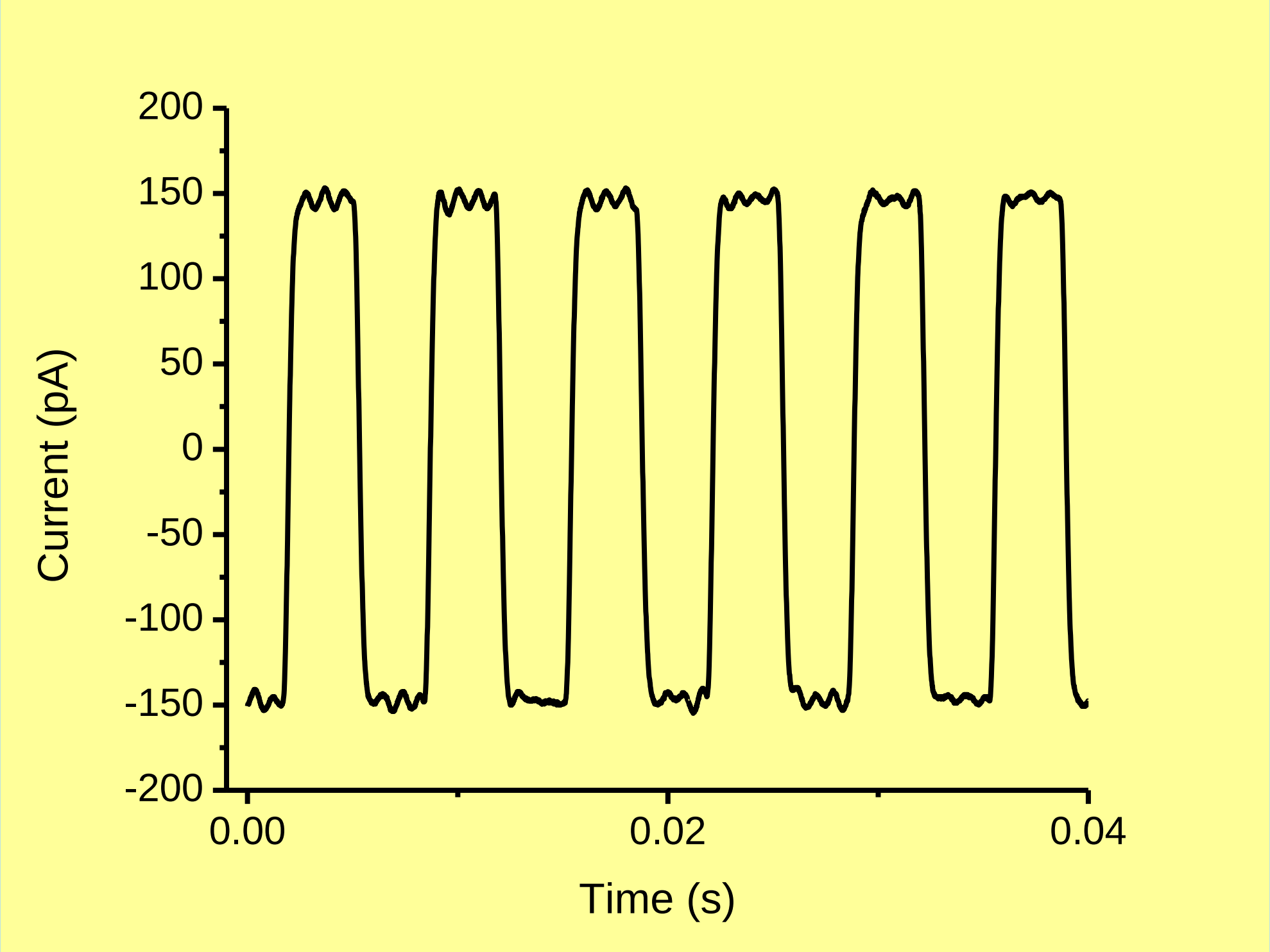


Mechanical stress is applied by adjusting the solution level in the ground reservoir, which curves the membrane and alters the surface area (and thus the capacitance). Membrane capacitance is measured from the magnitude of the rectangular current recorded in response to a triangle-wave voltage stimulus ($I_C = C\,dV/dt$, $dV/dt = \pm 1$, $C = |I_C|$); the conductance is inferred from ionic currents measured in response to linear voltage stimuli (i.e. the slope of the I-V plot).

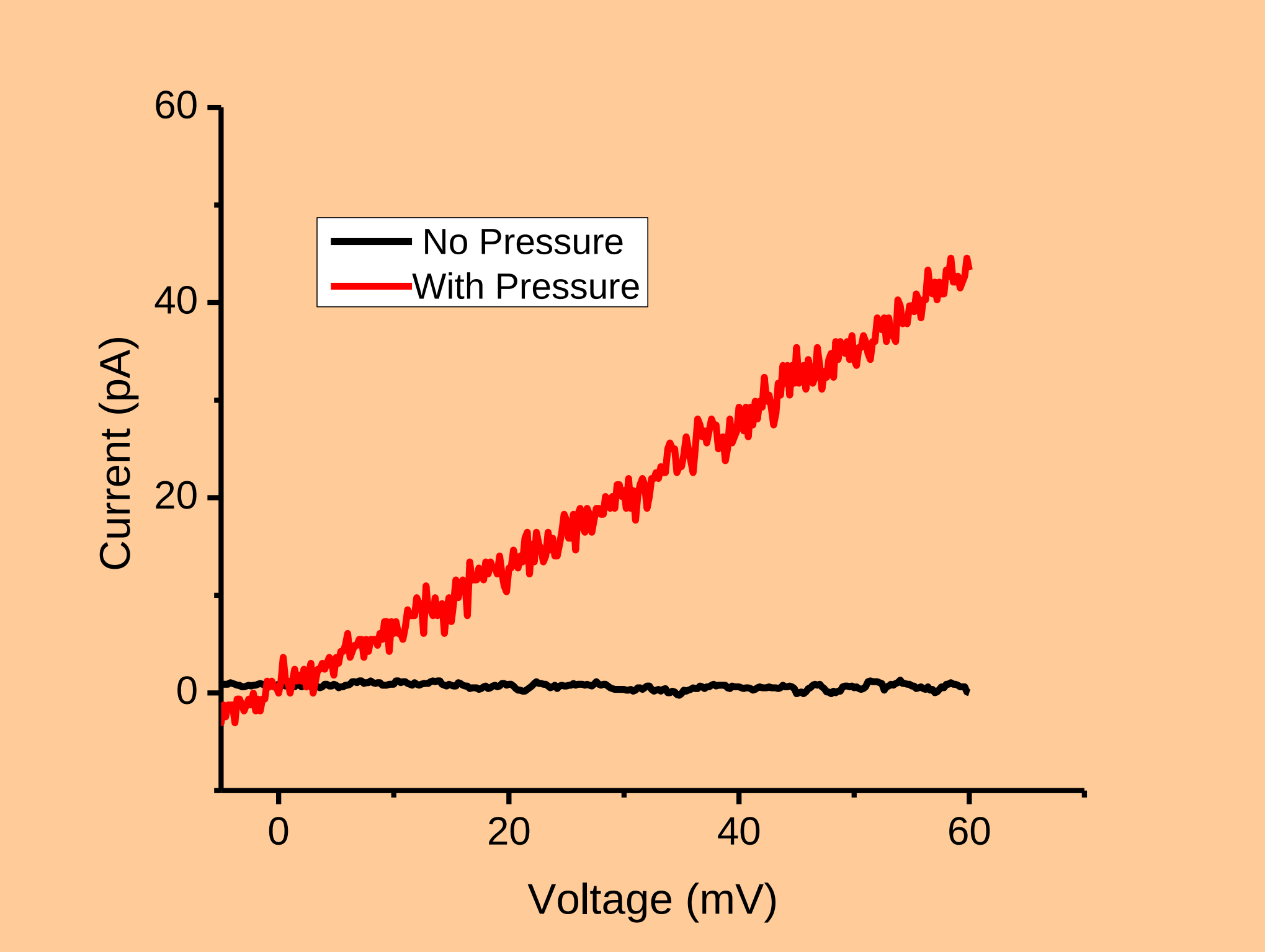
Results and Discussions



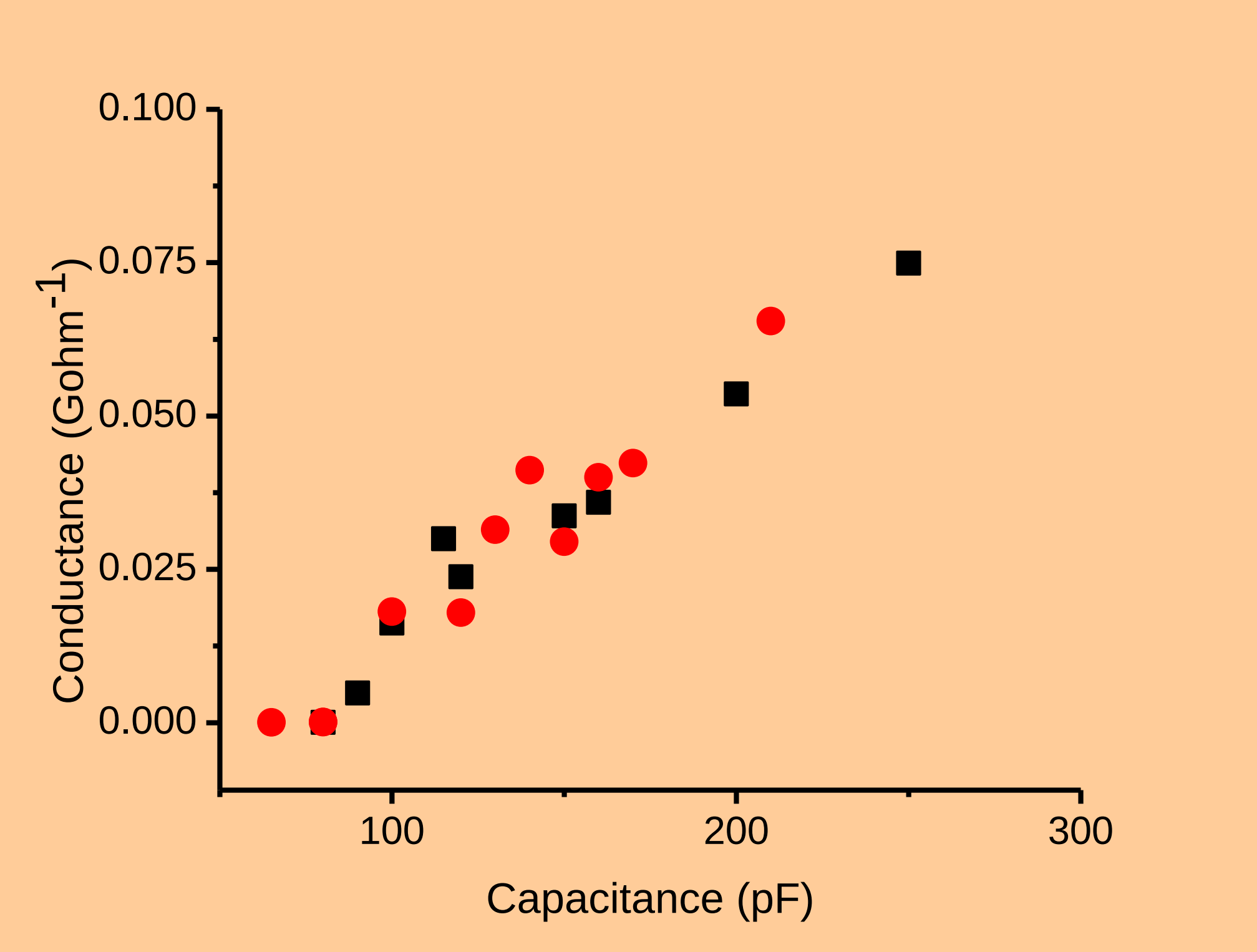
In the absence of any differential pressure, a capacitance of 60-80 pF is experimentally determined.



When a differential pressure is applied, the capacitance increases, likely a consequence of the enlarged surface area of the bilayer. The applied mechanical stress leads to a curved membrane and thus an increased surface area.



In the absence of pressure, the membrane is not permeable to monovalent ions, as inferred from the zero slope of the IV plot shown in black. In contrast, application of pressure leads to an increase in the membrane's conductance as it becomes permeable to inorganic ions (red line).



A monotonical increase in the membrane's conductance is recorded as the differential pressure increases. The mechanical stress adjusts the surface area and thus the membrane's capacitance. A stressed membrane is permeable to inorganic monovalent ions, as shown.

Conclusions

1) Mechanical stress applied to a planar membrane increases its permeability to inorganic monovalent cations.
2) The changes in permeability are reversible for a large range of applied pressures; nonetheless, a large pressure will always rupture the membrane.
3) It is not clear if whether membrane thins upon pressure-induced curving, which may also contribute to changes in capacitance and permeability.
4) The mechanism of conductance adjustment is obscure, but it may rely on small gaps created within the hydrophobic core of the membrane.
5) Leaky membranes may adjust the transmembrane voltage, therefore adjusting the response to electrical stimuli and cellular physiology.

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