Investigation of Light-Induced Ion Redistribution across the Thylakoid Membrane

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Introduction

Illuminated chloroplasts cause a pH increase in the external medium due to proton translocation into their interior aqueous phase. The amount of protons stored inside depends on the relative activities of the two antagonistic translocator devices embedded in the thylakoid membrane, which are the proton pumping electron transport chain and the backward translocating ATP-synthetase system, respectively.

Movements of other ions also occur. Cations uniformly move outward and anions inward. This indicates that simply charge compensation takes place which is controlled by the electric potential difference across the thylakoid membrane.

Depending on the location of the proton binding sites inside, proton translocation is coupled with space charge or surface charge changes inside. This has important consequences with respect to the magnitude of the resulting membrane potential (Donnan- or Gouy-Chapman-type) as dependent on the amount of protons stored inside and the ionic strength in the medium.

The transmembrane distribution of all other ions is simply coupled with the membrane potential according to the Boltzmann equation. Therefore, analysis of their distribution in dependence on suitable parameters should yield information on the character of the unknown membrane potential.

Experimental results

By means of ion-specific electrodes and in a medium of KCl and sucrose only, we studied the amplitudes of light-induced K^+ (outward) and Cl^- (inward) movements in dependence on the amount of H^+ accumulation inside. As expected, the charges of H^+, K^+ and Cl^- balance each other completely. However, the ratio between ΔK^+ and ΔCl^- changes from values well above to around 1 if ΔH^+ is increased from 0.1 up to 0.4 mol H^+ per mol chlorophyll.

Interpretation

The experimental results indicate qualitatively a potential negative inside in the dark and a change to a positive one at high ΔH^+. Using the theoretical treatment developed by U. Siggel (1981, J. Bioelectrochem. Bioenerget., Vol 8, in the press) a quantitative description is possible if the formalism of a surface potential on the basis of the Gouy-Chapman theory is applied. The following information is deduced (pH = 7 and 5 mM KCl):

membrane area per chlorophyll molecule, 230 Å^2
inside surface charge in the dark, $-0.94 \cdot 10^{-3} \cdot e^+ \text{Å}^{-2}$,
inside isoelectric pH value, 4.7,
inside membrane potential in the dark, -68 mV,
light-induced change of membrane potential, +80 mV (if $\Delta H^+ = 0.25$ mol per mol chlorophyll).