

---

# **PLANT MEMBRANE TRANSPORT: THE CURRENT POSITION**

---

Editors

**J. DAINTY, M. DE MICHELIS,  
E. MARRÈ and F. RASI-CALDOGNO**

---

---

**ELSEVIER**

# **PLANT MEMBRANE TRANSPORT: THE CURRENT POSITION**

Proceedings of the Eighth International Workshop on  
Plant Membrane Transport, Venice, Italy, 25–30 June 1989

*Editors:*

**J. DAINTY  
M.I. DE MICHELIS  
E. MARRÈ  
F. RASI-CALDOGNO**



**1989**

**ELSEVIER AMSTERDAM • NEW YORK • OXFORD**

© 1989 Elsevier Science Publishers B.V. (Biomedical Division)

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the publisher. Elsevier Science Publishers B.V., Biomedical Division, P.O. Box 1527, 1000 BM Amsterdam, The Netherlands.

No responsibility is assumed by the Publisher for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. Because of rapid advances in the medical sciences, the Publisher recommends that independent verification of diagnoses and drug dosages should be made.

Special regulations for readers in the USA – This publication has been registered with the Copyright Clearance Center Inc. (CCC), 27 Congress Street, Salem, MA 01970, USA. Information can be obtained from the CCC about conditions under which photocopies of parts of this publication may be made in the USA. All other copyright questions, including photocopying outside the USA, should be referred to the copyright owner, Elsevier Science Publishers B.V., unless otherwise specified.

ISBN 0 444 81328 4

*This book is printed on acid-free paper.*

*Published by:*

Elsevier Science Publishers B.V.  
(Biomedical Division)  
P.O. Box 211  
1000 AE Amsterdam  
The Netherlands

*Sole distributors for the USA and Canada:*

Elsevier Science Publishing Company Inc.  
655 Avenue of the Americas  
New York, NY 10010  
USA

Printed in The Netherlands

## PREFACE

The Eighth International Workshop on Plant Membrane Transport was held in Venice from 25 to 30 June, 1989. Such International Workshops started in 1968 at Reinhartsbrunn and have taken place roughly every three years since. They started, and have continued, in the belief that no matter how specialized the particular fields of the contributors might be, they all represent complementary parts of a whole; the particular transport processes must be seen as integrated with other cell activities and these with the organism and indeed with life in general. The scope of the subject of plant membrane transport has evolved over the twenty year period of these workshops. In the early days, at least as reported at these meetings, research on transport was carried out from a rather biophysical point of view. One might argue that such a physico-chemical approach is a logical one for setting out the overall constraints on transport processes, although it perhaps more likely reflected the prejudices of the organisers of the first workshops. Be that as it may, the necessary integration of biophysics with biochemistry and, in general, with cell physiology was then just beginning. But soon integration between these approaches and their methodologies was rather satisfactorily accomplished. More recently we have the gratifying fruits of the utilization of the methods of molecular biology and molecular genetics as is evident for instance in the progress in the understanding of the nature and activity of membrane transport ATPases.

The eighth workshop was organized around five major topics and all the contributions, of whatever length, are included in this book. In addition there were five Round Table Discussions which are also completely reported. We believe that the book contains a complete and comprehensive account of the state of knowledge of and research into plant membrane transport as seen in the middle of 1989 and the integrated approach – biophysical, biochemical, cell physiological, molecular biological – is clearly evident.

Two of the five major topics are concerned with the bounding membranes: the plasma membrane and the tonoplast. Many of the papers on these membranes are concerned with what might be considered the primary active transport process, that of pumping protons either to the exterior or to the vacuole, and with the subsequent secondary transports using the proton motive force created by the primary pumps, whether powered by ATP or by pyrophosphate. Another group of papers is concerned with the passive ion channels through these membranes. The important, yet contentious, subject of redox systems at the plasma membrane is also thoroughly discussed. The essential role of calcium and how its level in the cytoplasm is controlled is another major topic extensively reported here. Both the calcium pumping ATPases of the plasma membrane and of the endoplasmic reticulum and the proton/calcium exchanger of the tonoplast are discussed; and such questions as how the cytoplasmic level of  $\text{Ca}^{2+}$  regulates the opening of ion channels, how calcium channel activity is related to inositol triphosphate, and how calcium transport is controlled by gibberellic acid, are treated. Perhaps the area in which our understanding lacks most is that of the relation between metabolism and transport and here many other contributions are grouped. Metabolic aspects particularly arise when considering the

action of hormones, phytotoxins – fusicoccin especially –, calmodulin and again calcium, and all these are the subjects of some of the papers in this area as of course are general questions on the regulation of proton pumps and on the metabolism of nitrate, malate and other crucial metabolites. The fifth major topic is the molecular biology of transport; discussed here are molecular cloning and analyses of the plasma membrane (E-P) proton ATPase, the tonoplast V-proton ATPase and translocating proteins such as the chloroplast phosphate translocator and the proton/glucose cotransporter.

Three special topics of great, or so it seemed to us, contemporary interest were chosen and Round Table Discussions were organised around each of them and are fully reported on in the book. ‘Problems and utility of patch-clamp’ is concerned with a valuable electrophysiological technique which is a very fashionable; some of the difficulties and pitfalls in its use are discussed. ‘Water’ is always an exciting, contentious and important aspect of membrane transport and some interesting polemics developed. And the apoplast, discussed in ‘What is happening in the apoplast’ is a very neglected part of the plant, sitting next to the plasma membrane.

It will be clear from a perusal of the book that the workshop was largely concerned with so-called fundamental research. But of course, transport has obvious roles in applied research, which in itself is both valuable and necessary; and it is helpful in extending and deepening our basic understanding. There were two ‘applied’ Round Table Discussions: on ‘Transport and translocation as limiting factors in plant productivity’ and on the ‘Role of transport processes in resistance and adaptation to stress’. In these fully-reported discussions there is an attempted integration of fundamental knowledge for the solution of applied problems; they illustrate that transport processes are involved in these problems, whether those of mineral nutrition, gas exchange through stomata, translocation of nutrients, water relations, stress or hormone transport and distribution.

It has been a pleasure for us to organize this important meeting and edit this book, which we believe and hope will prove invaluable not only to all research workers on plant membrane transport but to all plant scientists whether students or workers in wider fields. The next Plant Membrane Transport International Workshop will be held at Asilomar in California in 1992 and we expect it to be just as successful as the Venice meeting has been.

The Workshop would not have been possible without the generous financial support and the constant interest of the Istituto Nazionale per la Cerealicoltura of the Ministero Italiano Agricoltura e Foreste, the Consiglio Nazionale delle Ricerche and the Regione Veneto. We also wish to acknowledge the support of the following institutions: Università degli Studi di Milano, Dipartimento di Biologia dell’Università degli Studi di Milano, Ente Nazionale per le Energie Alternative, Azienda di Promozione Turistica di Venezia, Istituto Universitario di Architettura di Venezia, Cassa di Risparmio di Venezia, Assessorato ai Lavori Pubblici del Comune di Venezia. We also add a special thanks for the kind, friendly hospitality of the Scuola Grande di San Giovanni Evangelista; the atmosphere of the Scuola Grande greatly enhanced our meeting.

Milan, July 1989

**Jack Dainty**  
**Maria Ida De Michelis**  
**Erasmus Marrè**  
**Franca Rasi-Caldogno**

# CONTENTS

## TRANSPORT AT THE PLASMA MEMBRANE

Transport at the plasma membrane of plant cells: A review <i>D. Sanders and C.L. Slayman</i>	3
Some problems concerning proton cotransport at the plasma membrane <i>R.M. Spanswick</i>	13
Plasmalemma transport in the life of the cell: Chara uses both sodium and protons as chemiosmotic drivers <i>N.A. Walker, F.A. Smith and S.R. McCulloch</i>	19
Oscillations and inversions in the extracellular current profiles of Chara and Nitella <i>W.J. Lucas and J. Fisahn</i>	25
Transport systems at Chara plasmalemma <i>M.J. Beilby</i>	31
Involvement of redox activity at the plasmalemma with signal transduction <i>B. Rubinstein, J.D. Chalmers, P.D. Reid and A.I. Stern</i>	35
Redox activities measured with inside-out and right-side out plasma membrane vesicles from sugar beet leaves <i>P. Askerlund and C. Larsson</i>	43
Detergent effects on redox enzymes of the plasma membrane <i>V. Valenti, P. Pupillo and F. Guerrini</i>	49
Transmembrane electron transfer of NADH loaded right side out vesicles <i>M. Böttger</i>	55
A transport mutant for the study of plant root iron absorption <i>M.A. Grusak, R.M. Welch and L.V. Kochian</i>	61
Sodium fluxes in perfused Chara corallina cells <i>H.M. Brindley</i>	67
Spatial variation of electro-chemical properties of characean internodes: Influences of several inhibitors on the membrane <i>K. Ogata</i>	69
Plasma membrane properties of starved sugarbeet cell suspensions and callus <i>E. Zamski, J. Van Staden and J. Pearce</i>	71
The ion-selective microelectrode technique for measuring ion fluxes at plant-solution boundaries <i>I. Newman and P. Ryan</i>	73
The alkaline tetraphenylborates as chemiostatic agents for maintaining a low and controlled $K^+$ -activity in the high-affinity $K^+$ uptake process <i>M. Bellando</i>	75

H <sup>+</sup> pump and functional state of plant cell plasmalemma <i>L.N. Vorobiev, N.N. Yegorova and A.B. Rubin</i>	77
Lipid soluble distribution probes are mismeasures of membrane potential in walled eukaryotic cells <i>A. Ballarin-Denti, C.L. Slayman and H. Kuroda</i>	79
Double fixed charge membrane: A model for proteins in the cell membrane of Chara <i>T.C. Chilcott and H.G.L. Coster</i>	81
Alteration of nonelectrolyte permeability by lipid-protein interactions in vivo <i>E.J. Stadelmann and I. Chung</i>	83
The implication of the kinetic data of H <sup>+</sup> -pump of the Chara membrane <i>U. Kishimoto</i>	85
Electrical tolerance in Chara plasmalemma: Effect of divalent cations on breakdown potential <i>T.-A. Ohkawa and I. Tsutsui</i>	87
Ca <sup>2+</sup> regulated Cl <sup>-</sup> channels in the Chara corallina plasma membrane <i>I. Tsutsui, S.-I. Yamagishi and T.-A. Ohkawa</i>	89
Voltage-dependent potassium channels in the plasma membrane of root hairs <i>A.M. Grabov</i>	91
Difference between metabolic control of transport at plasmalemma and in plasmodesmata in Nitella <i>D.S. Fensom and K. Trebacz</i>	93
The influence of some chemical and physical factors on membrane uptake and transnodal transport in Nitella flexilis <i>K. Trebacz and D.S. Fensom</i>	97
The proton-sucrose symport in plasmalemma vesicles isolated from mature leaf tissue <i>D.R. Bush</i>	99
Reconstituted plasma membrane vesicles from Schizosaccharomyces pombe: Generation of $\Delta\mu_{H^+}$ and H <sup>+</sup> /sugar symport <i>T. Mair, M. Höfer and E. Gießler-Andersen</i>	101
Amino acid uptake into yeast plasma membrane vesicles driven by incorporated cytochrome C oxidase <i>M. Opekarova, M. Calahorra, J. Ramírez and A. Peña</i>	103
Optimal conditions for the production and isolation of sealed inside-out plasma membrane vesicles <i>C. Larsson, P. Askerlund, M.G. Palmgren, K. Fredrikson, M. Sommarin and S. Widell</i>	105
Lysophospholipids stimulate plasma membrane H <sup>+</sup> -ATPase <i>M.G. Palmgren and M. Sommarin</i>	107
Lysophosphatidylcholine effect on plasma membrane ATPase activity <i>M. Rakotomavo, I. Bourdil, V. Santoni, J.-P. Blein and M. Rossignol</i>	109

Plasma membrane-bound $H^+$ -ATPase from maize root cells: Effects of sterols	
<i>A. Grandmougin, P. Benveniste and M.A. Hartmann</i>	111
Effect of sterols on reconstituted plasma membrane $H^+$ -ATPase from maize roots	
<i>A. Grandmougin, P. Benveniste and M.A. Hartmann</i>	113
Effects of phospholipases on plasma membrane vesicles from corn seedling roots	
<i>T.A. Palladina, G.F. Nasirova and V.K. Pedchenko</i>	115
NADH-ferricyanide reductase activities associated with plasma membranes of corn roots	
<i>I. Bourdil and J.P. Blein</i>	117
Involvement of hydrogen peroxide and iron ions in NADH oxidation of radish plasma membrane vesicles	
<i>A. Vianello, A. de Marco and F. Macri'</i>	119
Plasma membrane redox system in Elodea leaf cells. Its possible role in transport regulation	
<i>M. Stall, H.B.A. Prins, J.T.M. Elzenga and A.H. De Boer</i>	121
Is the plasmalemma redox system involved in Anion transport?	
<i>R. Rybová, L. Něspůrková, R. Metlička and K. Janáček</i>	123
Hexabromoiridate (IV) as a new electron acceptor for the standard-system: Comparison with hexachloroiridate (IV) and hexacyanoferrate (III)	
<i>S. Lühje and M. Böttger</i>	125
Membrane potential depolarisation by hexacyanoferrate (III), hexabromoiridate (IV) and hexachloroiridate (IV)	
<i>O. Doring, S. Lühje and M. Böttger</i>	127

## TRANSPORT AT THE TONOPLAST

Studies on the structure and evolution of the vacuolar $H^+$ -ATPase	
<i>L. Taiz, J.P. Gogarten, H. Kibak, I. Struve, P. Bernasconi, T. Rausch and S. Lee Taiz</i>	131
Comparative studies on the electrical properties of the $H^+$ translocating ATPase and pyrophosphatase of the vacuolar-lysosomal compartment	
<i>R. Hendrich, A. Kurkdjian, J. Guern and U.I. Flügge</i>	139
Regulatory properties of $H^+$ -pumping enzymes at the tonoplast. Conformational change of the $H^+$ -pyrophosphatase at chilling temperatures	
<i>A. Hager and C. Lanz</i>	145
Transport proteins in plants with Crassulacean Acid Metabolism: Immunological characterization of ATPase subunits	
<i>H.-P. Haschke, C. Bremberger and U. Lüttge</i>	149
Carrier-mediated uptake of malate in isolated vacuoles from Catharanthus Roseus cells	
<i>G. Marigo and H. Bouyssou</i>	155



Vacuolar transport studies with tonoplast vesicles obtained by free-flow electrophoresis	
<i>H. Canut, I. Joffroy, S. Baudracco, G. Marigo and A.M. Boudet</i>	161
Organic-acid transport at the tonoplast of the CAM plant <i>Kalanchoe daigremontiana</i>	
<i>P.J. White and J.A.C. Smith</i>	167
Behaviour of $K^+$ and $Cl^-$ channels in the cytoplasmic drop membrane of <i>Chara corallina</i> using a transient detection method of analysing single-channel recordings	
<i>S.D. Tyerman, G.P. Findlay and B.R. Terry</i>	173
$K^+$ channels in the tonoplast of <i>Acer pseudoplatanus</i> cells	
<i>P. Lado, R. Colombo and R. Cerana</i>	179
Characterisation of chloride transport at the tonoplast of higher plants using a chloride-sensitive fluorescent probe	
<i>A.J. Pope and R.A. Leigh</i>	185
Tonoplast $H^+$ -ATPase pump of <i>Acer pseudoplatanus</i>	
<i>A. Pugin</i>	191
The pyrophosphate-dependent proton pump of maize roots	
<i>A. Chanson and P.-E. Pilet</i>	193
Sucrose uptake into tonoplast vesicles of red beet	
<i>L. Williams and D.P. Briskin</i>	195
Sucrose transport and energization at the tonoplast of sugarcane	
<i>H.J. Preisser, R. Wendler and E. Komor</i>	197
Amino acid transport across the tonoplast of barley mesophyll cells: Regulation by external amino acids	
<i>K.-J. Dietz and E. Martinoia</i>	199
ATP-dependent betacyanin release from isolated vacuoles measured by means of computer aided microphotometry	
<i>C. Lommel, B. Hoffmann, H. Weintraut and F.W. Bentrup</i>	201
Characterization of transtonoplastic transport of Malonyl-ACC, the conjugated form of the ethylene precursor	
<i>M. Bouzayen, G. Marigo, A. Latché and J.-C. Pech</i>	205
Artefacts associated with the use of acridine orange to measure sodium/proton exchange in tonoplast vesicles	
<i>L.J. Clark and R.A. Leigh</i>	207
Electrical properties of the tonoplast in <i>Chara</i>	
<i>J.R. Smith</i>	209
Comparative analysis of vacuolated and evacuated protoplasts by micro-SDS-PAGE	
<i>E.M. Hoffmann, M. Guttenberger and R. Hampp</i>	211

## CALCIUM AND MEMBRANE TRANSPORT

Calcium channels, cytosol calcium and plasma membrane phosphorylation: An integrated calcium stat system	
<i>S. Gilroy, M. Fricker, D. Blowers, H. Harvey, M. Collinge and A.J. Trewavas</i>	215

The calcium pump of the plasma membrane of higher plants <i>F. Rasi-Caldogno, M.C. Pugliarello, C. Olivari and M.I. De Michelis</i>	225
The calcium pumping ATPase of the plant plasma membrane <i>D.E. Evans, F.M. Dewey and S.A. Briars</i>	231
Calcium transport into the endoplasmic reticulum of barley aleurone is regulated by gibberellic acid <i>D.S. Bush, A.K. Biswas and R.L. Jones</i>	237
Solubilization and reconstitution of the oat root vacuolar $H^+ / Ca^{2+}$ exchanger <i>K.S. Schumaker and H. Sze</i>	243
$IP_3$ opens calcium channels of the red beet vacuole tonoplast <i>J. Alexandre, J.-P. Lassalles and R.T. Kado</i>	249
A role for voltage- and calcium-regulated ion channels in the mediation of stomatal movements <i>J.I. Schroeder</i>	255
Intracellular $Ca^{2+}$ regulates membrane conductances of ions in characean cells <i>M. Tazawa, T. Mimura and M. Katsuhara</i>	261
$Ca^{++}$ gating of $H^+$ fluxes between localized and delocalized gradients in thylakoids <i>R.A. Dilley and G.G. Chiang</i>	265
Cytoplasmic calcium and calcium transport in <i>Fucus serratus</i> rhizoids <i>C. Brownlee, A.M. Hetherington and J.W. Wood</i>	271
Role of plasma membrane transport in cytosolic calcium homeostasis in <i>Neurospora</i> <i>A.J. Miller and D. Sanders</i>	273
Uptake and release pathways for calcium across the tonoplast <i>S. Blackford, J.M. Brosnan and D. Sanders</i>	275
Verapamil-binding fraction forms $Ca^{2+}$ channels in planar lipid bilayers <i>M. Tester and H.J. Harvey</i>	277
Microsomal membrane function in ripening calcium treated apples <i>S. Lurie, J.D. Klein and M. Zeidman</i>	279
Calcium-dependent phosphorylation of tonoplast proteins in the CAM plant <i>Kalanchoë daigremontiana</i> <i>B.M. Graham, D.P. Blowers, A.J. Trewavas and J.A.C. Smith</i>	283
Effects of calcium ions on membrane transport in <i>Hydrodictyon reticulatum</i> <i>L. Něspůrková, R. Rybová and K. Janáček</i>	285
The $Ca^{++}$ dependent activation of $K^+$ channels in <i>Eremosphaera</i> <i>B. Forster, M. Thaler, W. Urbach and W. Simonis</i>	287
Effects of calcium on ion fluxes in 'isolated' guard cells of <i>Commelina communis</i> L. <i>P. Parmar</i>	289
A potential role of the phosphatidylinositol pathway in mediating stomatal responses to light <i>Y. Lee and S.M. Assmann</i>	291

## TRANSPORT PROCESSES: METABOLIC IMPLICATIONS AND ASPECTS OF CONTROL

Metabolism – compartmentation – transport <i>W. Tanner and N. Sauer</i>	295
Metabolism-transport interactions: Regulation of and by the plasmalemma proton pump <i>E. Marrè and F. Rasi-Caldogno</i>	307
Proton transport, metabolism and pH regulation in <i>Chara corallina</i> <i>F.A. Smith and R.J. Reid</i>	317
Malate compartmentation between cytoplasm and vacuoles, studied by $^{13}\text{C}$ -NMR <i>K. Chang and J.K.M. Roberts</i>	323
Specific glutamate cotransport into mesophyll cells and efflux of the major metabolite 4-aminobutyric acid <i>A.W. Bown, I. Chung, W. Snedden and B. Shelp</i>	329
Nitrate uptake in roots: Induction and charge balance <i>W.R. Ullrich, H. Jaenicke and G. Brandl</i>	335
Sucrose uptake and sucrose hydrolysis by plant cells: Quantitative aspects <i>E. Komor, M. Stanzel and R. Wendler</i>	339
Thylakoid and plasmalemma fluxes <i>U.P. Hansen, H. Dau, K.H. Vanselow, J. Fisahn, S. Stein and J. Kolbowski</i>	345
Polar transport of $\text{H}^+$ and $\text{OH}^-$ in <i>Elodea</i> and <i>Potamogeton</i> <i>H. Miedema, T.J.M. Elzenga, A.H. de Boer and H.B.A. Prins</i>	351
Calmodulin in metabolic reactivation of germinating seeds <i>M. Cocucci and N. Negrini</i>	355
The role of cytosolic pH and free calcium for primary action of auxin in <i>zea mays</i> <i>H. Felle and W. Peters</i>	361
Effects of ABA on ion fluxes in guard cells <i>E.A.C. MacRobbie</i>	367
On the mechanism of FC-induced activation of the plasma membrane $\text{H}^+$ -ATPase <i>M.I. De Michelis, M.C. Pugliarello, C. Olivari and F. Rasi-Caldogno</i>	373
Interaction between plasma membrane $\text{H}^+$ -ATPase and phytotoxins: Use of reconstituted systems <i>M. Rossignol, I. Bourdil, V. Santoni and J.-P. Blein</i>	379
Extending the NMR method to whole plants <i>G.G. Fox, B.C. Loughman, R.G. Ratcliffe and D.J. Rigden</i>	385
The chemical basis of pH changes during trans-plasmalemma ion transport <i>C.I. Ullrich and J. Guern</i>	387
pH-regulation and membrane potential of the extremely acid resistant green alga <i>Dunaliella acidophila</i> <i>H. Gimmmler, U. Weis and C. Weiss</i>	389

ATP level and proton pump activity in Elodea leaves <i>N. Beffagna, G. Romani and E. Marrè</i>	391
Cytosolic control of vacuolar amino acid transport in <i>Penicillium cyclopium</i> <i>W. Roos</i>	393
Cortical cell fluxes of ammonium and nitrate in excised root segments using 15-N <i>A.E.S. Macklon and M.M. Ron</i>	397
Inhibition of phosphate and sulphate uptake in corn roots by binding molecules <i>J.-C. Davidian and A. Massonneau</i>	399
The sulphate transporter in roots: Physiological behaviour and attempted identification <i>D. Clarkson, M. Hawkesford and L. Saker</i>	401
Polyamine transport in cellular and subcellular compartments <i>N. Bagni and R. Pistocchi</i>	403
Uptake of quinine and of cinchonamine in cell suspension cultures of <i>Chinchona robusta</i> and of <i>Catharanthus roseus</i> <i>T.J.M. Blom and T.B. v. Vliet</i>	405
Malate transport in CAM plants under anaerobic condition <i>S. Watanabe, K. Nishida, N. Tamai, K. Wada and S. Hoshina</i>	407
K <sup>+</sup> channels from thylakoid membrane vesicles incorporated into planar bilayers <i>M.R. Blatt and M. Tester</i>	409
Simulation of the flash induced P <sub>700</sub> <sup>+</sup> reduction kinetics using a modified simplex method <i>S. Mauro, R. Vandeloise and E. Vander Donckt</i>	411
The role of K <sup>+</sup> uptake in light-stimulated growth of <i>Phaseolus vulgaris</i> L. leaves <i>E. van Volkenburgh</i>	413
Solute transport in <i>Agrobacterium tumefaciens</i> -induced crown galls in <i>Kalanchoe daigremontiana</i> plants <i>S. Marx, C. Ullrich and A.J.E. van Bel</i>	415
Fluxes and deposition rates in growing tissue and implications for the mechanism of osmotic adjustment <i>W.K. Silk</i>	417
Membrane effect of extracellular substances produced by hydrocarbon utilizing <i>Pseudomonas aeruginosa</i> bacteria <i>W. Ziegler, E. Horská and J. Pokorný</i>	421
Significant participation of protons in the control of IAA-induced growth <i>H. Lüthen and M. Böttger</i>	423
The chemiosmotic transport of auxin at the plasmalemma <i>S.A. Brunn and P. Haworth</i>	425
Effect of phytohormones on the ATPase and protein kinase activities of microsomal fraction from barley roots <i>N.I. Tikhaya, S.Y. Selivankina and G.V. Novikova</i>	427

Phospholipid-dependent protein kinase: Regulation of tonoplast and plasma membrane $H^+$ -ATPases	
<i>G.F.E. Scherer, G. Martiny-Baron and R. Nickel</i>	431
The fusicoccin-receptor: Part of a signal transduction chain in the plasma membrane?	
<i>A.H. de Boer, H. Miedema, D. Marmé, G. Gaul and H.B.A. Prins</i>	433
Relationship between the plasma membrane $H^+$ -ATPase and the fusicoccin-binding protein	
<i>M.G. Cocucci and E. Marrè</i>	435

## BIOCHEMISTRY AND MOLECULAR BIOLOGY OF TRANSPORT

Molecular biology of plasma membrane $H^+$ -ATPase	
<i>R. Serrano, A. Cid, J.M. Pardo, F. Portillo and C.G. Vallejo</i>	439
Molecular analysis of cation-sensitive ion-translocating ATPases in tomato	
<i>A.B. Bennett, N.N. Ewing, L.E. Wimmers and D.J. Meyer</i>	449
The plasma membrane $H^+$ -ATPase of <i>Nicotiana plumbaginifolia</i>	
<i>B. Michelet, C. Perez, A. Goffeau and M. Boutry</i>	455
The proton ATPase multigene family in <i>Arabidopsis thaliana</i>	
<i>J.F. Harper and M.R. Sussman</i>	461
Probing for the molecular mechanisms of active transport	
<i>C.L. Slayman, I. Klodos and G. Nagel</i>	467
Cloning of the inducible $H^+$ /glucose cotransporter from <i>Chlorella kessleri</i>	
<i>N. Sauer, K. Wolf, G. Schnellbögl and W. Tanner</i>	473
Photoaffinity labelling of the sugar beet vacuolar membrane by an [ $^3H$ ] amiloride analog	
<i>B.J. Barkla, J.H.M. Charuk, E.J. Cragoe Jr and E. Blumwald</i>	479
Partial purification and reconstitution into lipid vesicles of the tonoplast-bound malate carrier	
<i>E. Martinoia and E. Vogt</i>	485
Molecular cloning of the chloroplast phosphate translocator	
<i>U.I. Flügge, K. Fischer, A. Gross, D.L. Willey and T.A. Link</i>	491
Molecular cloning of $H^+$ -ATPases in tomato	
<i>N.N. Ewing, L.E. Wimmers, D.J. Meyer and A.B. Bennett</i>	497
Structure of a plasma membrane ( $H^+$ )ATPase gene from <i>Arabidopsis thaliana</i> and aminoacid sequence of three isoforms	
<i>J.M. Pardo and R. Serrano</i>	499
Molecular cloning of a putative $Ca^{2+}$ -ATPase in tomato	
<i>L.E. Wimmers, N.N. Ewing and A.B. Bennett</i>	501
Active site on plasma membrane $H^+$ -ATPase from mung bean ( <i>Vigna radiata</i> L.) roots	
<i>K. Kasamo</i>	503

Kinetic evidence for salt-induced interaction of active sites in plasma membrane ATPase of citrus cells <i>G. Ben-Hayyim and U. Ran</i>	505
Characterization of the peptide transport system synthesised in germinating barley embryos <i>J.W. Payne and D.J. Hardy</i>	507
Identification and characterization of the arginine carrier from the tonoplast of <i>Neurospora crassa</i> <i>R.L. Weiss and Y. Lee Paek</i>	509

## PROBLEMS AND UTILITY OF PATCH CLAMP

Use and misuse of patch clamp in plant physiology <i>D. Gradmann</i>	513
A multi-state anion channel in the plasmalemma of <i>Amaranthus tricolor</i> <i>M. Boulton, D.C. Elliott, G.P. Findlay, B.R. Terry and S.D. Tyerman</i>	517
Patch clamp studies on root cell membranes of a salt tolerant and a salt sensitive <i>Plantago</i> species <i>F.J.M. Maathuis and H.B.A. Prins</i>	521
Ion channels in corn plasmalemma <i>K. Fairley and N.A. Walker</i>	525
Potassium currents in protoplasts from primary pulvinar motor cells of <i>Mimosa pudica</i> : A patch-clamp study <i>H. Stoeckel and K. Takeda</i>	527
K <sup>+</sup> Channels in plasmalemma of motor cells of <i>Samanea saman</i> <i>N. Moran and R.L. Satter</i>	529
Activity of anion channels in the plasma membrane of guard cells <i>B.U. Keller, R. Hedrich and K. Raschke</i>	531
Channels in tonoplasts of <i>Helianthus tuberosus</i> and <i>Chara connivens</i> <i>K. Köhler and I. Marten</i>	533
Selectivity and TEA inhibition of a single K <sup>+</sup> channel of <i>Chara corallina</i> <i>F. Homble, B. Fuks and R. Lannoye</i>	535
Closure of tonoplast K <sup>+</sup> channels by depolarizing voltages in <i>Acer pseudoplatanus</i> <i>R. Cerana, R. Colombo and P. Lado</i>	537
Vacuolar ion channels from halophytes and glycophytes. A comparative study <i>O. Pantoja, J. Dainty and E. Blumwald</i>	539
Stoichiometry, poise and function of the tonoplast H <sup>+</sup> -translocating phyrophosphatase: The role of patch clamp studies <i>J.M. Davies, P.A. Rea and D. Sanders</i>	541
A voltage-dependent chloride channel in the photosynthetic membrane of a higher plant <i>G. Schönknecht, R. Hedrich, W. Junge and K. Raschke</i>	543

Ion channels in CF <sub>0</sub> CF <sub>1</sub> proteliposomes <i>H. Lühning, W. Hanke, E.C. Apley and R. Wagner</i>	545
Noise reduction by fiber optic in electrophysiology <i>C. Marrè</i>	547

## WATER

Water transport in plants: Coupling with other processes <i>E. Steudle</i>	551
Comparative measurements of the xylem pressure of Nicotiana plants by means of the pressure bomb and -probe <i>U. Zimmermann and A. Balling</i>	555
Turgor pressure and membrane transport <i>A.D. Tomos</i>	559
Water transport across roots <i>K. Katou</i>	563
Wall relaxation and water uptake in growing cells <i>D.J. Cosgrove</i>	567
An artificial osmotic cell: A model system for studying phenomena of negative pressure and for determining concentrations of solutes <i>H. Heydt and E. Steudle</i>	571
Negative pressures in an artificial osmotic cell produced by extracellular freezing <i>J.J. Zhu, E. Steudle and E. Beck</i>	573
Comparison of the pressure probe and pressure chamber for studies of leaf-cell water relations <i>J.A.C. Smith and R. Murphy</i>	575
Pressure-clamp experiments on plant cells using a manually operated pressure probe <i>R. Murphy and J.A.C. Smith</i>	577
Root pressure measurements on intact root systems: Combination of root pressure probe and pressure chamber <i>R. Lütgenau and E. Steudle</i>	579
Pressure probe measurements in individual root cells of plants <i>U. Zimmermann and J. Rygol</i>	581
Axial and radial hydraulic properties of roots of Zea mays <i>J. Frensch and E. Steudle</i>	585
Simultaneous determination of transport coefficients of cortical cells and of roots of maize <i>G.L. Zhu and E. Steudle</i>	587
Increase of hydraulic conductivity during hypersensitive reaction induced by bacteria inoculation into Nautilocalyx leaves <i>J. Pavlovkin and E. Brinckmann</i>	589
Stomatal response to air humidity in Tradescantia – possible mechanism <i>E.-D. Schulze and H. Nonami</i>	591

## WHAT IS HAPPENING IN THE APOPLAST?

Physiological characteristics of the cell wall apoplast	
<i>A. Mizuno and K. Katou</i>	595
Selective cation binding by the cell wall	
<i>J. Dainty and C. Richter</i>	599
Estimation of ionic mobilities in flax cell walls	
<i>P. Touchard, M. Demarty, C. Ripoll, C. Morvan and M. Thellier</i>	603
Leaf apoplast pH estimation in <i>Phaseolus vulgaris</i>	
<i>J.A. Raven and G.D. Farquhar</i>	607
Surface pH, bicarbonate and $H^+$ -cotransport coupling in corn roots	
<i>H. Sentenac, J.-B. Thibaud and C. Grignon</i>	611
Fibrillar structure of Ca-polygalacturonate as a model for soil-root interface: Metal ion absorption and its effect on the free space volume of the system	
<i>C. Gessa, S. Deiana and S. Marceddu</i>	615
The primary cell wall as ultrafilter membrane and its use in exclusion chromatography	
<i>H. Woehlecke, R. Ehwald, U. Klein and H. Göring</i>	617

## TRANSPORT AND TRANSLOCATION

Growth limitation and nutrient transport in <i>Ricinus</i> and sugarcane	
<i>E. Komor, G. Orlich and R. Veith</i>	621
Grain filling patterns in bread wheat ( <i>T. aestivum</i> , L.) as affected by simulated environmental stresses	
<i>B. Borghi, M. Corbellini, M. Guiducci and M. Monotti</i>	625
Control of starch synthesis in potato tubers by turgor-sensitive sucrose transport at the plasmalemma?	
<i>K.J. Oparka, K.M. Wright and D.A.M. Prior</i>	629
Transport of nutrients into and out of plant vacuoles in relation to nutrient supply	
<i>R.A. Leigh and A.J. Pope</i>	633
Sucrose uptake by purified plasma membrane vesicles	
<i>R. Lemoine and S. Delrot</i>	637
Unloading in the seed of <i>Ricinus</i>	
<i>F. Didehvar and D.A. Baker</i>	641
Amino acid transport in developing pea seeds	
<i>F.C. Lanfermeijer, M.A. van Oene and A.C. Borstlap</i>	643
Sugar transport in mesocarp tissue of developing peach fruit	
<i>R. Pinton, G. Vizzotto, Z. Varanini, G. Costa and A. Maggioni</i>	645
Transport properties of microsomal vesicles from peach mesocarp during fruit development	
<i>Z. Varanini, R. Pinton, G. Vizzotto and A. Maggioni</i>	647
Changes in ATPase activity with development in <i>Ricinus</i> cotyledons	
<i>J.L. Hall, S.J. Nelson and L. Williams</i>	649



Properties of the stelar plasma membrane ATPase of Zea mays roots <i>D.S. Cowan, J.L. Hall and D.T. Clarkson</i>	651
Hexose transport in petiole parenchyma of celery leaves <i>F. Keller and B. Diettrich</i>	653

## **ROLE OF TRANSPORT PROCESSES IN RESISTANCE AND ADAPTATION TO STRESS**

The critical role of the hydroxyl radical in microbial infection of plants <i>M.G. Klotz, R. Hoffmann and A. Novacky</i>	657
The adjustment of growth and $K^+$ transport in Helianthus annuus during salinization <i>J.M. Cheeseman</i>	663
Are there separate $Na^+/H^+$ and $K^+/H^+$ antiporters? <i>Y. Braun, M. Hassidim, S. Cooper, H.R. Lerner and L. Reinhold</i>	667
The transport of $^{24}Na^+$ by root membrane vesicles from the halophyte, Spergularia marina <i>L.K. Wickens and J.M. Cheeseman</i>	671
Mechanism of activation of a sodium/proton antiporter <i>J. Garbarino and F.M. Dupont</i>	673
Carbohydrate metabolism in Citrus calli; relevance to salt tolerance <i>Y. Libal, R. Mittler, G. Ben-Hayyim and E. Tel-Or</i>	675
Role of $Ca^{2+}$ in controlling ion fluxes in turgor regulation and salinity responses in two species of Chara <i>M.A. Bisson</i>	677
The effect of calcium on ion distribution and partitioning in salt stressed barley plants <i>J.-M. Stassart</i>	679
Membrane-associated and intracellular free calcium levels in root cells under NaCl stress <i>D. Bittisnich, D. Robinson and M. Whitecross</i>	681
Adaptation of a glycophyte to NaCl stress <i>G.N. Amzallag, H.R. Lerner and A. Poljakoff-Mayber</i>	683
Analysis of the biochemical composition of tonoplast from the halophyte Suaeda maritima <i>R.P. Leach, K.P. Wheeler, T.J. Flowers and A.R. Yeo</i>	685
Cytochrome oxidase and $H^+$ -ATPase activities in plasma-membranes of the marine cyanobacterium Spirulina subsalsa and their possible role in salt tolerance <i>R. Gabbay-Azaria, M. Schonfeld and E. Tel-Or</i>	687
<b>List of Participants</b>	689
<b>Index of authors</b>	703
<b>Subject index</b>	707