

7 Literaturverzeichnis

Albert, A. D., Young, J. E. und Yeagle, P. L. (1996) Rhodopsin-cholesterol interactions in bovine rod outer segment disk membranes, *Biochim. Biophys. Acta* **1285**, 47-55

Albert, A. D., Watts, A., Spooner, P., Groebner, G., Young, J. und Yeagle, P. L. (1997) A distance measurement between specific sites on the cytoplasmic surface of bovine rhodopsin in rod outer segment disk membranes, *Biochim. Biophys. Acta* **1328**, 74-82

Alcala, J. R., Gratton, E. und Prendergast, F. G. (1987) Fluorescence lifetime distributions in proteins, *Biophys. J.* **51**, 597-604

Alexiev, U. (1994) Protonenbewegung und Oberflächenpotentialänderungen während des Photozyklus der membranständigen Protonenpumpe Bacteriorhodopsin, Dissertation, FU-Berlin

Altenbach, C., Yang, K., Farrens, D. L., Farahbakhsh, Z. T., Khorana, H. G. und Hubbell, W. L. (1996) Structural features and light-dependent changes in the cytoplasmic interhelical E-F loop region of rhodopsin: A site-directed spin-labeling study, *Biochemistry* **35**, 12470-12478

Altenbach, C., Klein-Seetharaman, J., Hwa, J., Khorana, H. G. und Hubbell, W. L. (1999a) Structural features and light-dependent changes in the sequence 59-75 connecting helices I and II in rhodopsin: A site-directed spin-labeling study, *Biochemistry* **38**, 7945-7949

Altenbach, C., Cai, K., Khorana, H. G. und Hubbell, W. L. (1999b) Structural features and light-dependent changes in the sequence 306-322 extending from helix VII to the palmitoylation sites in rhodopsin: A site-directed spin-labeling study, *Biochemistry* **38**, 7931-7937

Amos, L. A., Henderson, R. und Unwin, P. N. T. (1982) Three-dimensional structure determination by electron microscopy of two-dimensional crystals, *Prog. Biophys. Mol. Biol.* **39**, 183-231

Arnis, S. und Hofmann, K. P. (1993) Two different forms of metarhodopsin II: Schiff base deprotonation precedes proton uptake and signaling state, *Proc. Natl. Acad. Sci. USA* **90**, 7849-7853

Arnis, S., Fahmy, K., Hofmann, K. P. und Sakmar, T. P. (1994) A conserved carboxylic acid group mediates light-dependent proton uptake and signaling by rhodopsin, *J. Biol. Chem.* **269**, 23879-23881

Auer, M., Scarborough, G. A. und Kühlbrandt, W. (1998) Three-dimensional map of the plasma membrane H⁺-ATPase in the open conformation, *Nature* **392**, 840-843

Baldwin, J. M. (1993) The probable arrangement of the helices in G protein-coupled receptors, *EMBO J.* **12**, 1693-1703

Baldwin, J. M. , Schertler, G. F. X. und Unger, V. M. (1997) An alpha-carbon template for the transmembrane helices in the rhodopsin family of G-protein-coupled receptors, *J. Mol. Biol.* **272**, 144-164

- Bartlett, G. R. (1959) Phosphorous assay in column chromatography, *J. Biol. Chem.* **234**, 466-468
- Behrens, W. (1996) Neue methodische Ansätze zur Strukturuntersuchung der Loops des Membranproteins Bacteriorhodopsin, Dissertation, FU-Berlin
- Behrens, W., Alexiev, U., Mollaaghbab, R., Khorana, H. G. und Heyn, M. P. (1998a) Structure of the interhelical loops and carboxyl terminus of bacteriorhodopsin by X-ray diffraction using site-directed heavy-atom labeling, *Biochemistry* **37**, 10411-10419
- Behrens, W., Otto, H., Stuhrmann, H. B. und Heyn, M. P. (1998b) Sulfur distribution in bacteriorhodopsin from multiple wavelength anomalous diffraction near the sulfur K-edge with synchrotron X-ray radiation, *Biophys. J.* **75**, 255-263
- Birnbaumer, L. (1992) Receptor-to-effector signaling through G proteins: roles for $\beta\gamma$ dimers as well as α subunits, *Cell* **71**, 1069-1072
- Blackman, S. M., Piston, D. W. und Beth, A. H. (1998) Oligomeric state of human erythrocyte band 3 measured by fluorescence resonance energy homotransfer, *Biophys. J.* **75**, 1117-1130
- Blundell, T. L. und Johnson, L. N. (1976) Protein crystallography, Academic Press, New York
- Bownds, D. und Wald, G. (1965) Reaction of the rhodopsin chromophore with sodium borohydride, *Nature* **205**, 254-257
- Boyer, P. D. (1954) Spectrophotometric study of the reaction of protein sulphydryl groups with organic mercurials, *J. Am. Chem. Soc.* **76**, 4331-4337
- Brown, M. F., (1994) Modulation of rhodopsin function by properties of the membrane bilayer, *Chemistry and Physics of Lipids* **73**, 159-180
- Bullough, P. A. und Henderson, R. (1987) Use of spot scan procedure for recording low-dose micrographs of beam sensitive specimens, *Ultramicroscopy* **21**, 223-230
- Cai., K., Langen, R., Hubbell, W. L. und Khorana, H. G. (1997) Structure and function in rhodopsin: Topology of the C-terminal polypeptide chain in relation to the cytoplasmic loops, *Proc. Natl. Acad. Sci. USA* **94**, 14267-14272
- Cai, K., Klein-Seetharaman, J., Farrens, D. L., Zhang, C., Altenbach, C., Hubbell, W. L. und Khorana, H. G. (1999) Single-cysteine substitution mutants at amino acid positions 306-321 in rhodopsin, the sequence between the cytoplasmic end of helix VII and the palmitoylation sites: Sulphydryl reactivity and transducin activation reveal a tertiary structure, *Biochemistry* **38**, 7925-7930
- Ceska, T. A. und Henderson, R. (1990) Analysis of high-resolution electron diffraction patterns from purple membrane labelled with heavy-atoms, *J. Mol. Biol.* **213**, 539-560
- Chen, Y. S. und Hubbell, W. L. (1978) Reactions of the sulphydryl groups of membrane-bound bovine rhodopsin, *Membrane Biochem.* **1**, 107-130

Collaborative Computational Project, Number 4. (1994) The CCP4 Suite: Programs for Protein Crystallography, *Acta Cryst. D* **50**, 760-763

Conklin, B. R. und Bourne, H. R. (1993) Structural elements of G α subunits that interact with G $\beta\gamma$ receptors and effectors, *Cell* **73**, 631-641

Corless, J. M., McCaslin, D. R. und Scott, B. L. (1982) Two-dimensional rhodopsin crystals from disk membranes of frog retinal rod outer segments, *Proc. Natl. Acad. Sci. USA* **79**, 1116-1120

Crowther, R. A., Henderson, R. und Smith, J. M. (1996) MRC image processing programs, *J. Struct. Biol.* **116**, 9-16

Daemen, F. J. D. (1973) Vertebrate rod outer segment membranes, *Biochim. Biophys. Acta* **300**, 255-288

Dale, R. E., Eisinger, J. und Blumberg, W. E. (1979) The orientational freedom of molecular probes: The orientation factor in intramolecular energy transfer, *Biophys. J.* **26**, 161-194

Davies, A., Schertler, G. F. X., Gowen, B. E. und Saibil, H. R. (1996) Projection structure of invertebrate rhodopsin, *J. Struct. Biol.* **117**, 36-44

De Grip, W. J., Bonting, S. L. und Daemen, F. J. M. (1975) Biochemical aspects of the visual process XXVIII. Classification of sulphydryl groups in rhodopsin and other photoreceptor membrane proteins, *Biochim. Biophys. Acta* **396**, 104-115

De Grip, W. J. (1982) Purification of bovine rhodopsin over concanavalin A-sepharose, *Methods Enzymol.* **81**, 197-207

De Grip, W. J. und Daemen, F. J. M. (1982) Sulphydryl chemistry of rhodopsin, *Methods Enzymol.* **81**, 223-236

DeLange, F., Merkx, M., Bovee-Geurts, P. H. , Pistorius, A. M., und De Grip, W. J. (1997) Modulation of the metarhodopsin I/metarhodopsin II equilibrium of bovine rhodopsin by ionic strength: Evidence for a surface-charge effect, *Eur. J. Biochem.* **243**, 174-180

Dickopf, S., Mielke, T. und Heyn, M. P. (1998) Kinetics of the light-induced proton translocation associated with the pH-dependent formation of the metarhodopsin I/II equilibrium of bovine rhodopsin, *Biochemistry* **37**, 16888-16897

Döring, K., Beck, W., Konermann, L. und Jähnig, F. (1997) The use of a long-lifetime component of tryptophan to detect slow orientational fluctuations of proteins, *Biophys. J.* **72**, 326-334

Dong, W.-J., Chandra, M., Xing, J., Solaro, J. und Cheung, H. C. (1997) Conformation of the N-terminal segment of a monocysteine mutant of troponin I from cardiac muscle, *Biochemistry* **36**, 6745-6753

Dratz, E. A., van Breemen, J. F. L., Kamps, K. M. P., Keegstra, W. und van Bruggen, E. F. J. (1985) Two-dimensional crystallization of bovine rhodopsin, *Biochim. Biophys. Acta* **832**, 337-342

Drenth, J., Jansonius, J. N., Koekoek, R., Swen, H. M. und Wolthers, B. G. (1968) Structure of papain, *Nature* **218**, 929-932

Dreyfus, H., Virmaux-Colin, N., Harth, S. und Mandel, P. (1982) Methods for determination of gangliosides in retinas and rod outer segments, *Methods Enzymol.* **81**, 304-309

Eftink, M. R., Selva, T. J. und Wasylewski, Z. (1987) Studies of the efficiency and mechanism of fluorescence quenching reactions using acrylamide and succinimide as quenchers, *Photochem. Photobiol.* **46**, 23-30

Essen, L.-O., Siegbert, R., Lehmann, W. D. und Oesterhelt, D. (1998) Lipid patches in membrane protein oligomers: Crystal structure of the bacteriorhodopsin-lipid complex, *Proc. Natl. Acad. Sci. USA* **95**, 11673-11678

Fahmy, K., Jäger, F., Beck, M., Zvyaga, T. A., Sakmar, T. P. und Siebert, F. (1993) Protonation states of membrane-embedded carboxylic acid groups in rhodopsin and metarhodopsin II: A Fourier-transform infrared spectroscopy study of site-directed mutants, *Proc. Natl. Acad. Sci. USA* **90**, 10206-10210

Fahmy, K. und Sakmar, T. P. (1993) Regulation of the rhodopsin-transducin interaction by a highly conserved carboxylic acid group, *Biochemistry* **32**, 7229-7236

Fahmy, K., Siebert, F. und Sakmar, T. P. (1994) A mutant rhodopsin photoproduct with a protonated Schiff base displays an active-state conformation: a Fourier-transform infrared spectroscopy study, *Biochemistry* **33**, 13700-13005

Farahbakhsh, Z. T., Ridge, K. D., Khorana, H. G. und Hubbell, W. L. (1995) Mapping light-dependent structural changes in the cytoplasmic loop connecting helices C and D in rhodopsin: A site-directed spin labeling study, *Biochemistry* **34**, 8812-8818

Farrens, D. L. und Khorana, H. G. (1995) Structure and function in rhodopsin: Measurement of the rate of metarhodopsin II decay by fluorescence spectroscopy, *J. Biol. Chem.* **270**, 5073-5076

Farrens, D. L., Altenbach, C., Yang, K., Hubbell, W. L. und Khorana, H. G. (1996) Requirement of rigid-body motion of transmembrane helices for light activation of rhodopsin, *Science* **274**, 768-770

Faruqi, A. R., Henderson, R. und Subramaniam, S. (1999) Cooled CCD detector with tapered fibre optics for recording electron diffraction patterns, *Ultramicroscopy* **75**, 235-250

Fliesler, S. J. und Anderson, R. E. (1982) Chemistry and metabolism of lipids in the vertebrate retina, *Prog. Lipid. Res.* **22**, 79-131

Förster, T. (1948) Intermolecular energy migration and fluorescence, *Ann. Phys. (Leipzig)* **2**, 55-75

Franke, R. R., Sakmar, T. P., Graham, R. M. und Khorana, H. G. (1992) Structure and function in rhodopsin: Studies of the interaction between the rhodopsin cytoplasmic domain and transducin, *J. Biol. Chem.* **267**, 14767-14774

- Fujiwara, T. und Nagayama, K. (1985) The wobbling-in-a-cone analysis of internal motion in macromolecules, *J. Chem. Phys.* **83**, 3110-3177
- Fukada, M. N., Papermaster, D. S. und Hargrave, P. A. (1979) Rhodopsin carbohydrate. Structure of small oligosaccharides attached at two sites near the NH₂ terminus, *J. Biol. Chem.* **254**, 8201-8207
- Garavito, R. M., Markovic-Housley, Z. und Jenkins, J. (1986) The growth and characterization of membrane protein crystals, *J. Crystal Growth* **76**, 701-709
- Gläsel, M. (2000) Aufbau einer Apparatur zur zeitkorrelierten Einzelphotonenzählung an Synchrotronstrahlungsquellen, Dissertation, FU-Berlin
- Glaeser, R. M., Baldwin, J. M., Ceska, T. A. und Henderson, R. (1986) Electron diffraction analysis of the M₄₁₂ intermediate of bacteriorhodopsin, *Biophys. J.* **50**, 913-920
- Govindjee, R., Kinoshita, K., Ikegami, A. und Ebrey, T. G. (1984) Conformational changes of bacteriorhodopsin as probed by a fluorescent dye, *Biophys. J.* **45**, 214a
- Granzin, J., Wilden, U., Choe, H. W., Labahn, J., Krafft, B. und Büldt, G. (1998) X-ray crystal structure of arrestin from bovine rod outer segments, *Nature* **391**, 918-921
- Grassetti, D. R. und Murray, J. F. (1967) Determination of sulphydryl groups with 2,2'- or 4,4'-Dithiodipyridine, *Arch. Biochem. Biophys.* **119**, 41-49
- Grigorieff, N., Ceska, T. A., Downing, K. H., Baldwin, J. M. und Henderson, R. (1996) Electron-crystallographic refinement of the structure of bacteriorhodopsin, *J. Mol. Biol.* **259**, 393-421
- Grinvald, A. und Steinberg, I. Z. (1974) On the analysis of fluorescence decay kinetics by the method of least squares, *Anal. Biochem.* **59**, 583-593
- Hamm, H. E., Deretic, D., Arendt, A., Hargrave, P. A., König, B. und Hofmann, K. P. (1988) Site of G protein binding to rhodopsin mapped with synthetic peptides from the α-subunit, *Science* **241**, 832-835
- Hamman, B. D., Oleinikov, A. V., Jokhadze, G. G., Traut, R. R. und Jameson, D. M. (1996) Rotational and conformational dynamics of *Escherichia coli* ribosomal protein L7/L12, *Biochemistry* **35**, 16672-16679
- Han, M. und Smith, S. O. (1995) NMR constraints on the location of the retinal chromophore in rhodopsin and bacteriorhodopsin, *Biochemistry* **34**, 1425-1432
- Han, M., Lin, S. W., Smith, S. O. und Sakmar, T. P. (1996a) The effects of amino acid replacements of glycine 121 on transmembrane helix 3 of rhodopsin, *J. Biol. Chem.* **271**, 32330-32336
- Han, M., Lin, S. W., Minkova, M., Smith, S. O. und Sakmar, T. P. (1996b) Functional interaction of transmembrane helices 3 and 6 in rhodopsin: Replacement of phenylalanine 261 by alanine causes reversion of phenotype of a glycine 121 replacement mutant, *J. Biol. Chem.* **271**, 32337-32342

Handbook of Chemistry and Physics (1986), 67th edition, R. C. Weast ed., CRC Press Inc., Boca Raton, Florida

Haran, G., Haas, E., Szpikowska, B. K. und Mas, M. T. (1992) Domain motions in phosphoglycerate kinase: Determination of interdomain distance distributions by site-specific labeling and time-resolved fluorescence energy transfer, Proc. Natl. Acad. Sci. USA **89**, 11764-11768

Hargrave, P. A., McDowell, J. H., Curtis, D. R., Wang, J. K., Juszczak, E., Fong, S. L., Mohanna-Rao, J. K. und Argos, P. (1983) The structure of bovine rhodopsin, Biophys. Struct. Mech. **9**, 235-244

Hargrave, P. A. und McDowell, J. H. (1992) Rhodopsin and phototransduction: a model system for G protein-linked receptors, FASEB J. **6**, 2323-2331

Hauss, T., Grzesiek, S., Otto, H., Westerhausen, J. und Heyn, M. P. (1990) Transmembrane location of retinal in bacteriorhodopsin by neutron diffraction, Biochemistry **29**, 4904-4913

Havelka, W. A., Henderson, R., Heymann, J. A. W. und Oesterhelt, D. (1993) Projection structure of halorhodopsin from *Halobacterium halobium* at 6 Å resolution obtained by electron cryo-microscopy, J. Mol. Biol. **234**, 837-846

Havelka, W. A., Henderson, R. und Oesterhelt, D. (1995) Three-dimensional structure of halorhodopsin at 7 Å resolution, J. Mol. Biol. **247**, 726-738

Henderson, R. und Unwin, P. N. T. (1975) Three-dimensional model of purple membrane obtained by electron microscopy, Nature **257**, 28-32

Henderson, R., Baldwin, J. M., Downing, K. H., Lepault, J. und Zemlin, F. (1986) Structure of purple membrane from *Halobacterium halobium*: Recording, measurement and evaluation of electron micrographs at 3.5 Å resolution, Ultramicroscopy **19**, 147-178

Henderson, R., Baldwin, J. M., Ceska, T. A., Zemlin, F., Beckmann, E. und Downing, K. H. (1990) Model for the structure of bacteriorhodopsin based on high-resolution electron cryo-microscopy, J. Mol. Biol. **213**, 899-929

Henderson, R. (1992) Image contrast in high-resolution electron microscopy of biological macromolecules: TMV in ice, Ultramicroscopy **46**, 1-18

Herzyk, P. und Hubbard, R. E. (1998) Combined biophysical and biochemical information confirms arrangement of transmembrane helices visible from the three-dimensional map of frog rhodopsin, J. Mol. Biol. **281**, 741-754

Heyn, M. P. (1979) Determination of lipid order parameters and rotational correlation times from fluorescence depolarization experiments, FEBS Letts. **108**, 359-364

Heyn, M. P. (1989) Order and viscosity of membranes: Analysis by time-resolved fluorescence depolarization, Methods Enzymol. **172**, 462-471

Hoel, P. G. (1971) Introduction to mathematical statistics, Fourth Ed., John Wiley & Sons, New York, 164

Hofmann, K. P., Jäger, S. und Ernst, O. P. (1995) Structure and function of activated rhodopsin, Israel J. Chem. **35**, 339-355

Hubel, D. H. (1990) Auge und Gehirn: Neurobiologie des Sehens, 2. Aufl., Spektrum der Wissenschaft Verlagsgesellschaft, Heidelberg, 11-66

Jäger, F., Fahmy, K., Sakmar, T. P. and Siebert, F. (1994) Identification of glutamic acid 113 as the Schiff base proton acceptor in the metarhodopsin II photointermediate of rhodopsin, Biochemistry **33**, 10878-10882

Jap, B. K., Zulauf, M., Scheybani, T., Hefti, A., Baumeister, W., Aebi, U. und Engel, A. (1992) 2D crystallization: From art to science, Ultramicroscopy **46**, 45-84

Johnson, M. L. (1994) Use of least-squares techniques in biochemistry, Methods Enzymol. **240**, 1-22

Juszczak, L. J., Zhang, Z.-Y., Wu, L., Gottfried, D. S. und Eads, D. D. (1997) Rapid loop dynamics of *yersinia* protein tyrosine phosphatases, Biochemistry **36**, 2227-2236

Kamps, K. M. P., De Grip, W. J. und Daemen, F. J. M. (1982) Use of a density modification technique for isolation of the plasma membrane of rod outer segments, Biochim. Biophys. Acta **687**, 296-302

Karnik, S. S., Sakmar, T. P., Chen, H.-B. und Khorana, H. G. (1988) Cysteine residues 110 and 187 are essential for the formation of correct structure in bovine rhodopsin, Proc. Natl. Acad. Sci. USA **85**, 8459-8463

Karnik, S. S. und Khorana, H. G. (1990) Assembly of functional rhodopsin requires a disulfide bond between cysteine residues 110 and 187, J. Biol. Chem. **265**, 17520-17524

Karolin, J. F. M., Wilcynska, M., Ny, T. und Johansson, L. B.-A. (1998) Donor-donor energy migration for determining intramolecular distances in proteins: I. Application of a model to the latent plasminogen activator inhibitor-I (PAI-I), Biophys. J. **74**, 11-21

Kawato, S., Kinoshita, K. und Ikegami, A. (1977) Dynamic structure of lipid bilayers studied by nanosecond fluorescence techniques, Biochemistry **16**, 2319-2324

Khorana, H. G. (1992) Rhodopsin, photoreceptor of the rod cell, J. Biol. Chem. **267**, 1-4

Kibelbek, J., Mitchell, D. C., Beach, J. M. und Litman, B. J. (1991) Functional equivalence of metarhodopsin II and the G_t-activating form of photolyzed bovine rhodopsin, Biochemistry **30**, 6761-6768

Kimura, Y., Vassilyev, D. G., Miyazawa, A., Kidera, A., Matsushima, M., Mitsuoka, K., Murata, K., Hirai, T. und Fujiyoshi, Y. (1997) Surface of bacteriorhodopsin revealed by high-resolution electron crystallography, Nature **389**, 206-211

Kinoshita, K., Kawato, S. und Ikegami, A. (1977) A theory of fluorescence polarization decay in membranes, Biophys. J. **20**, 289-305

Klein-Seetharaman, J., Hwa, J., Cai, K., Altenbach, C., Hubbell, W. L. und Khorana, H. G. (1999) Single-cysteine substitution mutants at amino acid positions 55-75, the sequence connecting the cytoplasmic ends of helices I and II in rhodopsin: Reactivity of the sulphydryl groups and their derivatives identifies a tertiary structure that changes upon light-activation, *Biochemistry* **38**, 7938-7944

Kliger, D. S. und Lewis, J. W. (1995) Spectral and kinetic characterization of visual pigment photointermediates, *Israel J. Chem.* **35**, 289-307

König, B., Arendt, A., McDowell, J. H., Kahlert, M., Hargrave, P. A. und Hofmann, K. P. (1989) Three cytoplasmic loops of rhodopsin interact with transducin, *Proc. Natl. Acad. Sci. USA* **86**, 6878-6882

Krebs, A., Villa, C., Edwards, P. C. und Schertler, G. F. X. (1998) Characterisation of an improved two-dimensional p22₁2₁ crystal from bovine rhodopsin, *J. Mol. Biol.* **282**, 991-1003

Krebs, M. P., Behrens, W., Mollaaghbab, R., Khorana, H. G. und Heyn, M. P. (1993) X-ray diffraction of a cysteine-containing bacteriorhodopsin mutant and its mercury derivative. Localization of an amino acid residue in the loop of an integral membrane protein, *Biochemistry* **32**, 12830-12834

Kühlbrandt, W. (1988) Three-dimensional crystallization of membrane proteins, *Q. Rev. Biophys.* **21**, 429-477

Kühlbrandt, W. (1992) Two-dimensional crystallization of membrane proteins, *Q. Rev. Biophys.* **25**, 1-49

Kühlbrandt, W., Wang, D. N. und Fujiyoshi, Y. (1994) Atomic model of plant light-harvesting complex by electron crystallography, *Nature* **397**, 614-621

Laemmli, U. K. (1970) Cleavage of structural proteins during the assembly of the head of bacteriophage T4, *Nature* **227**, 680-685

Lakowicz, J. R. (1999) Principles of fluorescence spectroscopy, Second Edition, Plenum Press, New York

Lamba, O. P., Borchman, D. und O'Brien, P. J. (1994) Fourier transform infrared study of the rod outer segment disk and plasma membranes of vertebrate retina, *Biochemistry* **33**, 1704-1712

Lambright, D. G., Noel, J. P., Hamm, H. E. und Sigler, P. B. (1994) Structural determinants for activation of the α -subunit of a heterotrimeric G protein, *Nature* **369**, 621-628

Lambright, D. G., Sondek, J., Bohm, A., Skiba, N. P., Hamm, H. E. und Sigler, P. B. (1996) The 2.0 Å crystal structure of a heterotrimeric G protein, *Nature* **379**, 311-319

Langen, R., Cai, K., Altenbach, C., Khorana, H. G. und Hubbell, W. L. (1999) Structural features of the C-terminal domain of bovine rhodopsin: A site-directed spin-labeling study, *Biochemistry* **38**, 7918-7924

Lin, S. W. und Sakmar, T. P. (1996) Specific tryptophan UV-absorbance changes are probes of the transition of rhodopsin to its active state, *Biochemistry* **35**, 11149-11159

Lipari, G. und Szabo, A. (1980) Effect of vibrational motion on fluorescence depolarization and nuclear magnetic resonance relaxation in macromolecules and membranes, *Biophys. J.* **30**, 489-506

Luecke, H., Richter, H.-T. und Lanyi, J. K. (1998) Proton transfer pathways in bacteriorhodopsin at 2.3 Angstrom resolution, *Science* **280**, 1934-1937

Marque, J., Kinoshita, K., Govindjee, R., Ikegami, A., Ebrey, T. G. und Otomo, J. (1986) Environmental modulation of C-terminus dynamic structure in bacteriorhodopsin, *Biochemistry* **25**, 5555-5559

McDowell, J. H. und Kühn, H. (1977) Light-induced phosphorylation of rhodopsin in cattle photoreceptor membranes: Substrate activation and inactivation, *Biochemistry* **16**, 4054-4060

Merbs, S. L. und Nathans, J. (1992) Absorption spectra of human cone pigments, *Nature* **356**, 433-435

Mitchell, D. C., Kibelbek, J. und Litman, B. J. (1991) Rhodopsin in dimyristoylphosphatidyl-choline-reconstituted bilayers forms metarhodopsin II and activates G_t, *Biochemistry* **30**, 37-42

Nathans, J. und Hogness, D. S. (1983) Isolation, sequence analysis, and intron-exon arrangement of the gene encoding bovine rhodopsin, *Cell*, **34**, 807-814

Nathans, J. (1992) Rhodopsin: Structure, function and genetics, *Biochemistry* **31**, 4923-4931

Nishimoto, E., Yamashita, S., Szabo, A. G. und Imoto, T. (1998) Internal motion of lysozyme studied by time-resolved fluorescence depolarization of tryptophan residues, *Biochemistry* **37**, 5599-5607

Noel, J. P., Hamm, H. E. and Sigler, P. B. (1993) The 2.2 Å crystal structure of transducin-α complexed with GTPγS, *Nature* **366**, 654-663

Nogales, E., Wolf, S. G. und Downing, K. H. (1998) Structure of the αβ tubulin dimer by electron crystallography, *Nature* **391**, 199-203

O'Connor, D. V. und Phillips, D. (1984) Time-correlated single photon counting, Academic Press, New York

Oesterhelt, D. (1976) Bacteriorhodopsin als Beispiel einer lichtgetriebenen Protonenpumpe, *Angew. Chemie* **1**, 16-24

Okada, T., Le Trong, I., Fox, B. A., Behnke, C. A., Stenkamp, R. E. und Palczewski, K. (2000) X-ray diffraction analysis of three-dimensional crystals of bovine rhodopsin obtained from mixed micelles, *J. Struct. Biol.* **130**, 73-80

Ovchinnikov, Y. A., Abdulaev, N. G., Feigina, M. Y., Artamonov, I. D., Zolatarev, A. S., Kostina, M. B., Bogachuk, A. S. Miroshnikov, A. I., Martinov, V. I. und Kudelin, A. B. (1983) The complete amino acid sequence of visual rhodopsin, *Bioorg. Khim.* **8**, 1011-1014

Ovchinnikov, Y. A., Abdulaev, N. G. und Bogachuk, A. S. (1988) Two adjacent cysteine residues in the C-terminal cytoplasmic fragment of bovine rhodopsin are palmylated, *FEBS Lett.* **230**, 1-5

Palczewski, K., Buczylko, J., Kaplan, M. W., Polans, A. S. und Crabb, J. W. (1991) Mechanism of rhodopsin kinase activation, *J. Biol. Chem.* **266**, 12949-12955

Palczewski, K., Buczylko, J., Ohguro, H., Annan, R. S., Carr, S. A., Crabb, J. W., Kaplan, M. W., Johnson, R. S. und Walsh, K. A. (1994) Characterization of a truncated form of arrestin isolated from bovine rod outer segments, *Protein Sci.* **3**, 314-324

Papermaster, D. S. und Dreyer, W. J. (1974) Rhodopsin content in the outer segment membranes of bovine and frog retinal rods, *Biochemistry* **13**, 2438-2444

Parkes, J. H. und Liebman, P. A. (1984) Temperature and pH dependence of the metarhodopsin I-metarhodopsin II kinetics and equilibria in bovine rod disk membrane suspensions, *Biochemistry* **23**, 5054-5061

Pebay-Peyroula, E., Rummel, G., Rosenbusch, J. P. und Landau, E. M. (1997) X-ray structure of bacteriorhodopsin at 2.5 Angstroms from microcrystals grown in lipidic cubic phases, *Science* **277**, 1676-1681

Perutz, M. F., Muirhead, H., Cox, J. M., Goaman, L. C. G., Mathews, F. S., McGandy, E. L. und Webb, L. E. (1968) Three-dimensional Fourier synthesis of horse oxyhaemoglobin at 2.8 Å resolution: (I) X-ray analysis, *Nature* **219**, 29-32

Plöhn, H. J. und Büldt, G. (1986) The determination of label positions in membrane proteins by neutron and anomalous X-ray diffraction of powder samples, *J. Appl. Cryst.* **19**, 255-261

Pober, J. S. und Stryer, L. (1975) Light dissociates enzymatically-cleaved rhodopsin into two different fragments, *J. Mol. Biol.* **95**, 477-481

Pober, J. S. (1982) Proteolysis of rhodopsin, *Methods Enzymol.* **81**, 236-239

Pöhlmann, T. (1999) Röntgenstrukturuntersuchungen an Helix C des Membranproteins Bacteriorhodopsin, Diplomarbeit, FU-Berlin

Pogozheva, I. D., Lomize, A. L. und Mosberg, H. I. (1997) The transmembrane 7- α -bundle of rhodopsin: Distance geometry calculations with hydrogen bonding constraints, *Biophys. J.* **72**, 1963-1985

Pulvermüller, A., Palczewski, K. und Hofmann, K. P. (1993) Interaction between photoactivated rhodopsin and its kinase: stability and kinetics of complex formation, *Biochemistry* **32**, 14082-14088

Raman, D., Osawa, S. und Weiss, E. R. (1999) Binding of arrestin to cytoplasmic loop mutants of bovine rhodopsin, *Biochemistry* **38**, 5117-5123

- Rando, R. R. (1992) Molecular mechanisms in visual pigment regeneration, *Photochem. Photobiol.* **56**, 1145-1156
- Rao., V. R. und Oprian , D. D. (1996) Activating mutations of rhodopsin and other G protein-coupled receptors, *Annu. Rev. Biophys. Biomol. Struct.* **25**, 287-314
- Resek, J. F., Farahbakhsh, Z. T., Hubbell, W. L. und Khorana, H. G. (1993) Formation of the meta II photointermediate is accompanied by conformational changes in the cytoplasmic surface of rhodopsin, *Biochemistry* **32**, 12025-12032
- Ridge, K. D., Zhang, C. und Khorana, H. G. (1995) Mapping of the amino acids in the cytoplasmic loop connecting helices C and D in rhodopsin. Chemical reactivity in the dark state following single cysteine replacements, *Biochemistry* **34**, 8804-8811
- Rigaud, J. L., Mosser, G., Lacapere, J. J., Olofsson, A., Levy, D. und Ranck, J. L. (1997) Bio-beads: An efficient strategy for two-dimensional crystallization of membrane proteins, *J. Struct. Biol.* **118**, 226-235
- Robertson, G. A., Bello, A. C., Stevenson, III, W. D. und Rockey, J. H. (1974) Characterization of a photoexposed sulphydryl group of bovine rhodopsin available for chemical modification, *Biochem. Biophys. Res. Commun.* **59**, 1151-1156
- Rosenhagen, H. (1994) Untersuchungen von ausgesuchten Oberflächenaminosäuren von Bakteriorhodopsin mittels zeitaufgelöster Fluoreszenzdepolarisation, Diplomarbeit, TU-Berlin
- Sakmar, T. P., Franke, R. R. und Khorana, H. G. (1989) Glutamic-acid 113 serves as the retinylidene Schiff base counterion in bovine rhodopsin, *Proc. Natl. Acad. Sci. USA* **86**, 8309-8313
- Sakmar, T. P. (1998) Rhodopsin: A prototypical G protein-coupled receptor, *Prog. Nucleic Acid Res. Mol. Biol.* **59**, 1-34
- Schertler, G. F. X., Villa, C. und Henderson, R. (1993) Projection structure of rhodopsin, *Nature* **362**, 770-772
- Schertler, G. F. X. und Hargrave, P. A. (1995) Projection structure of frog rhodopsin in two crystal forms, *Proc. Natl. Acad. Sci. USA* **92**, 11578-11582
- Schertler, G. F. X. (1999) Electron-crystallographic analysis of two-dimensional rhodopsin crystals, in: *Structure-function analysis of G protein-coupled receptors* (Wess, J., ed.) Wiley-Liss, Inc., New York, 233-287
- Schneider, W. P., Wensel, T. G., Stryer, L. und Oi, V. T. (1988) Genetically engineered immunoglobulins reveal structural features controlling segmental flexibility, *Proc. Natl. Acad. Sci. USA* **85**, 2509-2513
- Seiff, F., Wallat, I., Ermann, P. und Heyn, M. P. (1985) A neutron diffraction study on the location of the polyene chain of retinal in bacteriorhodopsin, *Proc. Natl. Acad. Sci. USA* **82**, 3227-3231

- Sheikh, S. P., Zvyaga, T. A., Lichtarge, O., Sakmar, T. P. und Bourne, H. R. (1996) Rhodopsin activation blocked by metal-ion-binding sites linking transmembrane helices C and F, *Nature* **383**, 347-350
- Shichi, H., Lewis, M. S., Irreverre, F. und Stone, A. L. (1969) Biochemistry of visual pigments: Purification and properties of bovine rhodopsin, *J. Biol. Chem.* **244**, 529-536
- Smith, W. C., McDowell, J. H., Dugger, D. R., Miller, R., Arendt, A., Popp, M. P. und Hargrave, P. A. (1999) Identification of regions of arrestin that bind to rhodopsin, *Biochemistry* **38**, 2752-2761
- Sondek, J., Bohm, A., Lambright, D. G., Hamm, H. E. und Sigler, P. B. (1996) Crystal structure of a G_A protein $\beta\gamma$ dimer at 2.1 Å resolution, *Nature* **379**, 369-374
- Strader, C. D., Fong, T. M., Tota, M. R., Underwood, D. und Dixon, R. A. F. (1994) Structure and function of G protein-coupled receptors, *Annu. Rev. Biochem.* **63**, 101-132
- Straßburger, J. M., Gärtner, W. und Braslavsky, S. E. (1997) Volume and enthalpy changes after photoexcitation of bovine rhodopsin: Laser-induced optoacoustic studies, *Biophys. J.* **72**, 2294-2303
- Straume, M., Mitchell, D. C., Miller, J. L. und Litman, B. J. (1990) Interconversion of metarhodopsins I and II: A branched photointermediate decay model, *Biochemistry* **29**, 9135-9142
- Stryer, L. (1988) Molecular basis of visual excitation, *Cold Spring Harb. Symp. Quant. Biol.* **53**, 283-294
- Szabo, A. (1984) Theory of fluorescence depolarization in macromolecules and membranes, *J. Chem. Phys.* **81**, 150-167
- Tanaka, F. und Mataga, N. (1982) Dynamic depolarization of interacting fluorophores: Effect of internal rotation and energy transfer, *Biophys. J.* **39**, 129-140
- Tanaka, F., Tamai, N., Mataga, N., Tonomura, B. und Hiromi, K. (1994) Analysis of internal motion of single tryptophan in Streptomyces subtilisin inhibitor from its picosecond time-resolved fluorescence, *Biophys. J.* **67**, 874-880
- Tanaka, F. (1998) Theory of time-resolved fluorescence under the interaction of energy transfer in a bichromophoric system: Effect of internal rotations of energy donor and acceptor, *J. Chem. Phys.* **109**, 1084-1092
- Thon, F. (1966) Zur Defokussierungsabhängigkeit des Phasenkontrasts bei der elektronenmikroskopischen Abbildung, *Z. Naturforschung* **21a**, 476-478
- Thorgeirsson, T. E., Lewis, J. W., Wallace-Williams, S. E. und Klier, D. S. (1993) Effects of temperature on rhodopsin photointermediates from lumirhodopsin to metarhodopsin II, *Biochemistry* **32**, 13861-13872
- Unger, V. M. und Schertler, G. F. X. (1995) Low resolution structure of bovine rhodopsin determined by electron cryo-microscopy, *Biophys. J.* **68**, 1776-1786

Unger, V. M., Hargrave, P. A., Baldwin, J. M. und Schertler, G. F. X. (1997) Arrangement of rhodopsin transmembrane α -helices, *Nature* **389**, 203-206

van der Meer, W., Pottel, H., Herreman, W., Ameloot, M., Hendrickx, H. und Schröder, H. (1984) Effect of orientational order on the decay of the fluorescence anisotropy in membrane suspensions, *Biophys. J.* **46**, 515-523

van Rhee, A. M. und Jacobson, K. A. (1996) Molecular architecture of G protein-coupled receptors, *Drug Devel. Res.* **37**, 1-38

Wahl, P. (1975) Theoretical determination of decay, quantum yield and anisotropy of chromophores attached to macromolecules and performing a local brownian motion, *Chem. Phys.* **7**, 220-228

Weitz, C. J. und Nathans, J. (1993) Rhodopsin activation: Effects on the metarhodopsin I-metarhodopsin II equilibrium of neutralization or introduction of charged amino acids within putative transmembrane segments, *Biochemistry* **32**, 14176-14182

Wess, J., Blin, N., Mutschler, E., Bluml, K. (1995) Muscarinic acetylcholine receptors: structural basis of ligand binding and G protein coupling, *Life Sci.* **56**, 915-922

Wiegand, R. D. und Anderson, R. E. (1982) Determination of molecular species of rod outer segment phospholipids, *Methods Enzymol.* **81**, 297-304

Wilden, U. und Kühn, H. (1982) Light-dependent phosphorylation of rhodopsin: Number of phosphorylation sites, *Biochemistry* **21**, 3014-3022

Wilden, U., Hall, S. W. und Kühn, H. (1986) Phosphodiesterase activation by photoexcited rhodopsin is quenched when rhodopsin is phosphorylated and binds the intrinsic 48-kDa protein of rod outer segments, *Proc. Natl. Acad. Sci. USA* **83**, 1174-1178

Wu, P. und Brand, L. (1994) Resonance energy transfer: Methods and applications, *Anal. Biochem.* **218**, 1-13

Wu, C.-W. und Stryer, L. (1972) Proximity relationships in rhodopsin, *Proc. Natl. Acad. Sci. USA* **69**, 1104-1108

Yang, K., Farrens, D. L., Altenbach, C., Farahbakhsh, Z. T., Hubbell, W. L. und Khorana, H. G. (1996a) Structure and function in rhodopsin. Cysteines 65 and 316 are in proximity in a rhodopsin mutant as indicated by disulfide formation and interactions between attached spin labels, *Biochemistry* **35**, 14040-14046

Yang, K., Farrens, D. L., Hubbell, W. L. und Khorana, H. G. (1996b) Structure and function in rhodopsin. Single cysteine substitution mutants in the cytoplasmic interhelical E-F loop region show position-specific effects in transducin activation, *Biochemistry* **35**, 12464-12469

Yau, K.-W. (1994) Phototransduction mechanism in retinal rod and cones, *Invest. Ophthalmol. Vis. Sci.* **35**, 9-32

Yeagle, P. L., Alderfer, J. L. und Albert, A. D. (1997) Three-dimensional structure of the cytoplasmic face of the G protein receptor rhodopsin, *Biochemistry* **36**, 9649-9654

Yguerabide, J. (1972) Nanosecond fluorescence spectroscopy of macromolecules, Meth. Enzymol. **26**, 498-578

Yguerabide, J. (1994) Theory for establishing proximity relations in biological membranes by excitation energy transfer measurements, Biophys. J. **66**, 683-693

Yoshida, T., Willardson, B. M., Wilkins, J. F., Jensen, G. J., Thornton, B. D. und Bitensky, M. W. (1994) The phosphorylation state of phosducin determines its ability to block transducin subunit interactions and inhibit transducin binding to activated rhodopsin, J. Biol. Chem. **269**, 24050-24057

Yu, H. und Oprian, D. D. (1999) Tertiary interactions between transmembrane segments 3 and 5 near the cytoplasmic side of rhodopsin, Biochemistry **38**, 12033-12040

Zhang, P. J., Toyoshima, C., Yonekura, K., Green, N. M. und Stokes, D. L. (1998) Structure of the calcium pump from sarcoplasmatic reticulum at 8 Å resolution, Nature **392**, 835-839

Zhukovsky, E. A., Robinson, P. R. and Oprian, D. D. (1991) Transducin activation by rhodopsin without a covalent bound to the 11-*cis*-retinal chromophore, Science **251**, 558-560