

# Literaturverzeichnis

- [Abd79] Abdourakhmanov, I. A.; Ganago, A. O.; Erokhin, Y. E.; Solov'ev, A. A.; Chugunov, V. A. (1979) Orientation and linear dichroism of the reaction centers from rhodopseudomomas sphaeroides R-26. *Biochim. Biophys. Acta* **546**, 183–186.
- [Ahl84] Ahl, P. L.; Cone, R. A. (1984) Light activates rotations of bacteriorhodopsin in the purple membrane. *Biophys. J.* **41**, 1039–1049.
- [Ame89] Ames, J. B.; Fodor, S. P. A.; Gebhard, R.; Raap, J.; van den Berg, E. M. M.; Lugtenburg, J.; Mathies, R. A. (1989) Bacteriorhodopsin's M<sub>412</sub> intermediate contains a 13-*cis*,14-*s-trans*,15-*anti*-Retinal Schiff base chromophore. *Biochemistry* **28**, 3681–3687.
- [Bal96a] Balashov, S. P.; Imasheva, E. S.; Govindjee, R.; Sheves, M.; Ebrey, T. G. (1996) Titration of aspartate-85 in bacteriorhodopsin: what it says about chromophore isomerization and proton release. *Biophys. J.* **70**, 473–481.
- [Bal96b] Balashov, S. P.; Imasheva, E. S.; Govindjee, R.; Sheves, M.; Ebrey, T. G. (1996) Evidence that aspartate-85 has a higher  $pK_a$  in all-trans than in 13-cis bacteriorhodopsin. *Biophys. J.* **71**, 1973–1984.
- [Bar83] Barabás, K.; Dér, A.; Dancsházy, Zs.; Ormos, P.; Keszthelyi, L. (1983) Electro-optical measurements an aqueous suspension of purple membrane from *halobacterium halobium*. *Biophys. J.* **43**, 5–11.
- [Bec78] Becher, B.; Tokunaga, F.; Ebrey, G. (1978) Ultraviolet and visible absorption spectra of purple membrane protein and phototcycle intermediates. *Biochemistry* **17**, 2293–2300.
- [Bor59] Born, M.; Wolf, E. (1959) *Principles of Optics*. Pergamon Press, New York.
- [Bor98] Borucki, B.; Otto, H.; Heyn, M. P. (1998) Linear dichroism measurements on oriented purple membranes between parallel polarizers: Contribution of linear birefringence and applications to chromophore isomerization. *J. Phys. Chem.* **102**, 3821–3829.
- [Bra96] Braiman, M. S.; Dioumaev, A. K.; Lewis, J. R. (1996) A large photolysis-induced  $pK_a$  increase of the chromophore counterion in bacteriorhodopsin: Implications for ion transport mechanism of retinal proteins. *Biophys. J.* **70**, 939–947.
- [Bro95] Brown, L. S.; Sasaki, J.; Kandori, H.; Maeda, A.; Needleman, R.; Lanyi, J. K. (1995) Glutamic acid 204 is the terminal proton release group at the extracellular surface of bacteriorhodopsin. *J. Biol. Chem.* **270**, 27122–27126.

- [Coj97] Cojocaru, E. (1997) Direction cosines and vectorial relations for extraordinary–wave propagation in uniaxial media. *Appl. Opt.* **36**, 302–306.
- [Czé90] Czégé, J.; Reinisch, L. (1990) Cross-correlated photon scattering during the photocycle of bacteriorhodopsin. *Biophys. J.* **58**, 721–729.
- [Dér85] Dér, A.; Hargittai, P.; Simon, J. (1985) Time-resolved photoelectric signals from oriented purple membranes immobilized in gel. *J. Biochem. Biophys. Meth.* **54**, 295–300.
- [Dér95] Dér, A.; Tóth-Boconádi, R.; Keszthelyi, L.; Kramer, H.; Stoeckenius, W. (1995) Orientation of purple membranes in combined electric and magnetic fields. *FEBS Letts.* **377**, 419–420.
- [Dic98] Dickopf, S. (1998) *Zeitaufgelöste Photospannungsmessungen und Absorptionsspektroskopie an den Retinalproteinen Bacteriorhodopsin und Rhodopsin. Untersuchungen mit Doppelblitzanregung.* Dissertation, Freie Universität Berlin.
- [Dre88] Dresselhaus, D. (1988) *Strukturuntersuchungen am Photozyklus des Membranproteins Bacteriorhodopsin mittels Neutronenstreuung und magnetischer Doppelbrechung und Kozeption eines Neutronendiffraktometers.* Dissertation, Technische Universität Berlin.
- [Dri84] Drikos, G.; Rüppel, H. (1984) Polarized UV–absorption spectra of retinal isomers – II. On the assignment of the low and high energy absorption bands. *Photochem. Photobiol.* **40**, 93–104.
- [Ear86] Earnest, T. N.; Roepe, P.; Braiman, M. S.; Gillespie, J. Rothschild, K. J. (1986) Orientation of bacteriorhodopsin chromophore probed by polarized fourier transform infrared difference spectroscopy. *Biochemistry* **25**, 7793–7798.
- [Esq96] Esquerra, R. M.; Che, D.; Shapiro, D. B.; Lewis, J. W.; Bogomolni, R. A.; Fukushima, J.; Kliger, D. S. (1996) Chromophore reorientations in the early photolysis intermediates of bacteriorhodopsin. *Biophys. J.* **70**, 962–970.
- [Fah89] Fahmy, K.; Siebert, F.; Großjean, M. F.; Tavan, P. (1989) Photoisomerization in bacteriorhodopsin studied by FTIR, linear dichroism and photoselection experiments combined with quantum chemical theoretical analysis. *J. Mol. Struct.* **214**, 257–288.
- [Fis79] Fischer, U.; Oesterhelt, D. (1979) Chromophore equilibria in bacteriorhodopsin. *Biophys. J.* **28**, 211–230.
- [Fow75] Fowles, G. R. (1975) *Introduction to Modern Optics.* Holt, Rinehart and Winston, New York.
- [Gan80] Ganago, A. O.; Fok, M. V.; Abdourakhmanov, I. A.; Solov'ev, A. A.; Erokhin, Y. E. (1980) Analysis of linear dichroism of reaction centers oriented in polyacrylamide gel. *Mol. Biol. (Mosc.)* **14**, 381–389.
- [Gen98] Genick, U. K.; Soltis, S. M.; Kuhn, P.; Canestrelli, I. L.; Getzoff, E. D. (1998) Structure at 0.85 Å resolution of an early protein photocycle intermediate. *Nature* **392**, 206–209.

- [Ger94] Gergely, C.; Ganea, C.; Váró, G. (1994) Combined optical and photoelectric study of the photocycle of 13-*cis* bacteriorhodopsin. *Biophys. J.* **67**, 855–861.
- [Ger97] Gergely, C.; Zimányi, L.; Váró, G. (1997) Bacteriorhodopsin intermediate spectra determined over a wide pH range. *J. Phys. Chem.* **101**, 9390–9395.
- [Gov90] Govindjee, R.; Balashov, S. P.; Ebrey, T. G. (1990) Quantum efficiency of the photochemical cycle of bacteriorhodopsin. *Biophys. J.* **58**, 597–608.
- [Gro86] Groma, G. I.; Dancsházy, Zs. (1986) How many *M* forms are there in the bacteriorhodopsin photocycle? *Biophys. J.* **50**, 357–366.
- [Gri96] Grigorieff, N.; Ceska, T. A.; Downing, K. H.; Baldwin, J. M.; Henderson, R. (1996) Electron-crystallographic refinement of the structure of bacteriorhodopsin. *J. Mol. Biol.* **259**, 393–421.
- [Hak83] Haken, H. (1983) *Synergetik. Eine Einführung*. Springer-Verlag, Berlin.
- [Hau90] Hauß, T.; Grzesiek, S.; Otto, H.; Westerhausen, J.; Heyn, M. P. (1990) Transmembrane Location of retinal in bacteriorhodopsin by neutron diffraction. *Biochemistry* **29**, 4904–4913.
- [Hau94] Hauß, T.; Büldt, G.; Heyn, M. P.; Dencher, N. A. (1994) Light-induced isomerization causes an increase in the chromophore tilt in the M-Intermediate of bacteriorhodopsin: a neutron diffraction study. *Proc. Natl. Acad. Sci. USA* **91**, 11854–11858.
- [Hen75] Henderson, R.; Unwin, P. N. T. (1975) Three-dimensional model of purple membrane obtained by electron microscopy. *Nature* **257**, 28–32.
- [Hen90] Henderson, R.; Baldwin, J. M.; Ceska, T. A.; Zemlin, F.; Beckmann, E.; Downing, K. H. (1990) Model for the structure of bacteriorhodopsin based on high-resolution electron cryo-microscopy. *J. Mol. Biol.* **213**, 899–929.
- [Hen92] Henry, E. R.; Hofrichter, J. (1992) Singular Value Decomposition: Application to analysis of experimental data. *Methods Enzymol.* **210**, 129–192.
- [Hey77] Heyn, M. P.; Cherry, R. J.; Müller, U. (1977) Transient and linear dichroism studies on bacteriorhodopsin: determination of the orientation of the 568 nm all-trans retinal chromophore. *J. Mol. Biol.* **117**, 607–620.
- [Hey88] Heyn, M. P.; Westerhausen, J.; Wallat, I.; Seiff, F. (1988) High sensitive neutron diffraction of membranes: Location of the schiff base end of the chromophore of bacteriorhodopsin. *Proc. Natl. Acad. Sci. USA* **85**, 2146–2150.
- [Hey92] Heyn, M. P.; Otto, H. (1992) Photoselection and transient linear dichroism with oriented immobilized purple membranes: Evidence for motion of the C(20)-methyl group of the chromophore towards the cytoplasmic side of the membrane. *Photochem. Photobiol.* **56**, 1105–1112.
- [Hof89] Hofrichter, J.; Henry, E. R.; Lozier, R. H. (1989) Photocycles of bacteriorhodopsin in light- and dark-adapted purple membrane studied by time-resolved absorption spectroscopy. *Biophys. J.* **56**, 693–706.

- [Hol88] Holz, M.; Lindau, M.; Heyn, M. P. (1988) Distributed kinetics of the charge movements in bacteriorhodopsin: evidence for conformational substates. *Biophys. J.* **53**, 623–633.
- [Kap96] Kappert, J. (1996) *Polarisierte Absorptionsspektroskopie an durch uniaxiales Pressen orientierten Chromoproteinen*. Diplomarbeit, Freie Universität Berlin.
- [Kar82] Karvaly, B.; Fukumoto, J. M.; Hopewell, W. D.; El-Sayed, M. A. (1982) Polarized photochemistry on bacteriorhodopsin. Dichroism of the early photochemical intermediate K<sub>610</sub>. *J. Phys. Chem.* **86**, 1899–1908.
- [Kes80] Keszthelyi, L. (1980) Orientation of membrane fragments by electric field. *Biochim. et Biophys. Acta* **598**, 429–436.
- [Kho79] Khorana, H. G.; Gerber, G. E.; Herlihy, W. C.; Gray C. P.; Anderegg, R. J.; Nihei, K.; Biemann, K. (1979) Amino acid sequence of bacteriorhodopsin. *Proc. Natl. Acad. Sci. USA* **76**, 5046–5050.
- [Kim97] Kimura, Y.; Vassylyev, D. G.; Miyazawa, A.; Kidera, A.; Matsushima, M.; Mitsouka, K.; Murata, K.; Hirai, T.; Fujiyoshi, Y. (1997) Surface of bacteriorhodopsin revealed by high-resolution electron crystallography. *Nature* **389**, 206–211.
- [Kli90] Kliger, D. S.; Lewis, J. W.; Randall, C. E (1990) *Polarized Light in Optics and Spectroscopy*. Academic Press, San Diego.
- [Kou85] Kouyama, T.; Bogomolni, R. A.; Stoeckenius, W. (1985) Photoconversion from the light-adapted to the dark-adapted state of bacteriorhodopsin. *Biophys. J.* **48**, 201–208.
- [Kub82] Kuball, H.-G.; Altschuh, J. (1982) Optical activity of oriented molecules. Comparison of the optical rotatory dispersion and the circular dichroism through the Kramers–Kronig Transform. *Chem. Phys. Lett.* **87**, 599–603.
- [Lan95] Lanyi, J. K.; Váró, G. (1995) The photocycles of bacteriorhodopsin. *Isr. J. Chem.* **35**, 365–385.
- [Lew85] Lewis, B. A.; Rosenblatt, C.; Griffin, R. G.; Courtemanche, J.; Herzfeld J. (1985) Magnetic birefringence studies of dilute purple membrane suspensions. *Biophys. J.* **47**, 143–150.
- [Lin89] Lin, S. W.; Mathies, R. A. (1989) Orientation of the protonated retinal Schiff base in bacteriorhodopsin from absorption linear dichroism. *Biophys. J.* **56**, 653–660.
- [Lin84] Lindau, M. (1984) *Lichtinduzierte Ladungsbewegung des Rhodopsins*. Dissertation, Technische Universität Berlin.
- [Liu87] Liu, S. Y.; Ebrey, T. G. (1987) The quantum efficiency for the interconversion of the blue to the pink forms of purple membrane. *Photochem. Photobiol.* **46**, 263–267.
- [Lue98] Luecke, H.; Richter, H.-T.; Lanyi, J. K. (1998) Proton transfer pathways in bacteriorhodopsin at 2.3 Angstrom Resolution. *Science* **280**, 1934–1937.

- [Lug86] Lugtenburg, J.; Muradin-Szweykowska, M.; Heeremans, C.; Pardoen, J. A.; (1986) Mechanism for the opsin-shift of retinal's absorption in bacteriorhodopsin. *J. Am. Chem. Soc.* **108**,3104–3105.
- [Mae80] Maeda, A.; Iwasa, T.;Yoshizawa, T. (1980) Formation of 9-cis and 11-cis-retinal pigments from bacteriorhodopsin by irradiating purple membrane in acid. *Biochemistry* **19**,3825–3831.
- [Mar83] Maret, G.; Weill, G. (1983) Magnetic birefringence study of the electrostatic and intrinsic persistence length of DNA. *Biopolymers* **22**,2727-2744.
- [Mat91] Mathies, R. A.; Lin, S. W.; Ames, J. B.; Pollard, W. T.; (1991) From femtoseconds to biology: Mechanism of bacteriorhodopsin's light–driven proton pump. *Ann. Rev. Biophys. Biophys. Chem.* **20**,491–518.
- [Mau87a] Maurer, R.; Vogel, J.; Schneider, S. (1987) Analysis of flash photolysis data by a global fit with multi-exponentials– I. Determination of the minimal number of intermediates in the photocycle of bacteriorhodopsin by the 'stability criterion'. *Photochem. Photobiol.* **46**,247–253.
- [Mau87b] Maurer, R.; Vogel, J.; Schneider, S. (1987) Analysis of flash photolysis data by a global fit with multi-exponentials– II. Determination of consistent natural rate constants and the absorption spectra of the transient species in the bacteriorhodopsin photocycle from measurements at different temperatures. *Photochem. Photobiol.* **46**,255–262.
- [Mit61] Mitchell, P. (1961) Coupling of phosphorylation to electron and hydrogen transfer by chemi-osmotic type of mechanism. *Nature* **191**,144–148.
- [Nag91] Nagle, J. F. (1991) Solving complex photocycle kinetics. *Biophys. J.* **59**,476–487.
- [Nag95] Nagle, J. F.; Zimányi, L.; Lanyi, J.K. (1995) Testing bR photocycle kinetics. *Biophys. J.* **68**,1490–1499.
- [Nor77] Nordén, B.; Lindblom, G, Jonáš, I. (1977) Linear dichroism spectroscopy as a tool for studying molecular orientation in model membrane systems. *J. Phys. Chem.* **81**,2086–2093.
- [Oes74] Oesterhelt, D.; Stoeckenius, W. (1974) Isolation of the cell membrane of Halobacterium halobium and its fractionation into red and purple membranes. In: *Methods in Enzymology* **31**,667–678.
- [O'Ko59] O'Konski, C. T.; Yoshioka, K.; Orttung, W. H. (1959) Electric properties of macromolecules. IV. Determination of electric and optical parameters from saturation of electric birefringence in solutions. *J. Phys. Chem.* **63**,1558–1565.
- [Ons31] Onsager, L. (1931) Reciprocal relations in irreversible processes. *Phys. Rev.* **37**,405–426.
- [Ott91] Otto, H.; Heyn, M. P. (1991) Between the ground– and M–state of bacteriorhodopsin the retinal transition dipole moment tilts out of the plane of the membrane by only 3°. *FEBS Letts.* **293**,111–114.

- [Ott95] Otto, H.; Zscherp, C.; Borucki, B.; Heyn, M. P. (1995) Time-resolved polarized absorption spectroscopy with isotropically excited oriented purple membranes: The orientation of the electronic transition dipole moment of the chromophore in the O-intermediate of bacteriorhodopsin. *J. Phys. Chem.* **99**, 3847–3853.
- [Ovc79] Ovchinnikov, Y. A.; Abdulaev, N. G.; Feigina, M. Y.; Kiselev, A. V.; Lobanov, N. A. (1979) The structural basis of the functioning of bacteriorhodopsin: an overview. *FEBS Lett.* **100**, 219–224.
- [Peb97] Pebay-Peyroula, E.; Rummel, G.; Rosenbusch, J. P.; Landau, E. H. (1997) X-ray structure of bacteriorhodopsin at 2.5 Angstroms from microcrystals grown in lipidic cubic phases. *Science* **277**, 1676–1681.
- [Pet39] Peterlin, A.; Stuart, H. A. (1939) Über die Bestimmung der Größe und Form, sowie der elektrischen, optischen und magnetischen Anisotropie von submikroskopischen Teilchen mit Hilfe der künstlichen Doppelbrechung und der inneren Reibung. *Z. Physik* **112**, 129–149.
- [Pre92] Press, W. H.; Teuklowsky, S. A.; Vetterling, W. T.; Flannery, B. P. (1992) Numerical Recipes in Fortran, The Art of Scientific Computing, Second Editon, Cambridge University Press.
- [Röm94] Römer, H. (1994) *Theoretische Optik* VCH-Verlagsgesellschaft, Weinheim.
- [Sas97] Sass, H. J.; Schachowa, I. W.; Rapp, G.; Koch, M. H. J.; Oesterhelt, D.; Dencher, N. A.; Büldt, G. (1997) The tertiary structural changes in bacteriorhodopsin occur between M states: X-ray diffraction and Fourier transform infrared spectroscopy. *EMBO J.* **16**, 1484–1491.
- [Sch85] Scherrer, P.; Stoeckenius, W. (1985) Effects of tyrosine-26 and tyrosine-64 nitration on the photoreactions of bacteriorhodopsin. *Biochem.* **24**, 7733–7740.
- [Sch89] Scherrer, P.; Mathew, M. K.; Sperling, W.; Stoeckenius, W. (1989) Retinal isomer ratio in dark-adapted purple membrane and bacteriorhodopsin monomers. *Biochem.* **28**, 829–834.
- [Sch91] Schertler, G. F. X.; Lozier, R.; Michel, H.; Oesterhelt, D. (1991) Chromophore motion during the bacteriorhodopsin photocycle: polarized absorption spectroscopy of bacteriorhodopsin and its M-state in bacteriorhodopsin crystals. *EMBO J.* **10**, 2353–2361.
- [Sei85] Seiff, F.; Wallat, I.; Ermann, P.; 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.
- [Sei86] Seiff, F.; Westerhausen, J.; Wallat, I.; Heyn, M. P. (1986) Location of the cyclohexene ring of the chromophore of bacteriorhodopsin by neutron diffraction with selectively deuterated retinal. *Proc. Natl. Acad. Sci. USA* **83**, 7746–7750.
- [Sha63] Shah, M. J. (1963) Electric birefringence of bentonite. II. An extension of saturation birefringence theory. *J. Phys. Chem.* **67**, 2215–2219.

- [Sha95] Shapiro, D. B.; Goldbeck, R. A.; Che, D.; Esquerra, R. M.; Paquette, S. J.; Klier, D. S. (1995) Nanosecond optical rotatory dispersion spectroscopy: Application to photolyzed hemoglobin–CO kinetics. *Biophys. J.* **68**, 326–334.
- [Sin95] Sineshchekov, V. A. (1995) Photobiophysics and photobiochemistry of the heterogeneous phytochrome system. *Biochim. Biophys. Acta* **1228**, 125–164.
- [Son94] Song, Q.; Harms, G. S.; Wan, C.; Johnson, C. K. (1994) Reorientations in the bacteriorhodopsin photocycle. *Biochem.* **33**, 14026–14033.
- [Son96] Song, Q.; Harms, G. S.; Johnson, C. K. (1996) Chromophore reorientation relative to the membrane plane detected by time-resolved linear dichroism during the bacteriorhodopsin photocycle in oriented purple membrane. *J. Phys. Chem.* **100**, 15605–15613.
- [Thi94] Thiedemann, G. U. (1994) *Zeitaufgelöste optische Spektroskopie an Bacteriorhodopsin: Photozyklusintermediate, Einfluß von Wasser*. Dissertation, Freie Universität Berlin.
- [Tka89] Tkachenko, N. V.; Savransky, V. V; Sharonov, A. Y (1989) Time-resolved refractive index change during the bacteriorhodopsin photocycle. *Eur. Biophys. J.* **17**, 131–136.
- [Ulr94] Ulrich, A. S.; Watts, A.; Wallat, I.; Heyn, M. P. (1994) Distorted structure of the retinal chromophore in bacteriorhodopsin resolved by deuterium–NMR. *Biochemistry* **33**, 5370–5375.
- [Wan93] Wan, C.; Qian, J.; Johnson, C. K. (1993) Light-induced reorientations in the purple membrane. *Biophys. J.* **65**, 927–938.
- [Wei96] Weidlich, O.; Schalt, B.; Friedman, N.; Sheves, M.; Lanyi, J. K.; Brown, L. S.; Siebert, F. (1996) Steric interaction between the 9-methyl group of the retinal and tryptophan 182 controls 13-*cis* to all-*trans* reisomerization and proton uptake in the bacteriorhodopsin photocycle. *Biochemistry* **35**, 10807–10814.
- [Xie87] Xie, A. H.; Nagle, J. F.; Lozier, R. H. (1987) Flash spectroscopy of purple membrane. *Biophys. J.* **51**, 627–635.
- [Zei92] Zeisel, D.; Hampp, N. (1992) Spectral relationship of light-induced refractive index and absorption changes in bacteriorhodopsin films containing wildtype BR<sub>WT</sub> and the variant BR<sub>D96N</sub>. *J. Phys. Chem.* **96**, 7788–7792.
- [Zha94] Zhang, C.; Song, Q. W.; Gross, R. B.; Birge, R. R (1994) Determination of the refractive index of a bacteriorhodopsin film. *Optics Letters* **19**, 1409–1411.
- [Zim93] Zimányi, L.; Lanyi, J.K. (1993) Deriving the intermediate spectra and photocycle kinetics from time-resolved difference spectra of bacteriorhodopsin. *Biophys. J.* **64**, 240–251.
- [Zsc93] Zscherp, C. (1993) *Zeitaufgelöste Absorptionsanisotropie am Membranprotein Bacteriorhodopsin. Aufbau einer Blitzlichtapparatur und Untersuchung der Dynamik der Chromophororientierung*. Diplomarbeit, Freie Universität Berlin.

