

# References

- Adam, G.: Z. Naturforsch. 23 b, 181 (1968)
- Adam, G.: In: Snell, F., Wolken, J., Iverson, G.J., Lam, J. (Eds.): *Physical Principles of Biological Membranes*. Gordon and Breach Science. New York: 1970
- Balslev, I., Degn, H.: J. Theor. Biol. 49, 173 (1975)
- Bass, L., Moore, W.J.: J. Membrane Biol. 12, 361 (1973)
- Bebber, H.J.: Diploma Thesis. Aachen 1975
- Bernstein, J.: Pflügers Arch. ges. Physiol. 92, 521 (1902)
- Bernstein, J.: *Elektrobiologie*. Braunschweig: Vieweg 1912
- Blumenthal, R., Changeux, J.P., Lefever, R.: J. Membrane Biol. 2, 351 (1970)
- Callen, H.B.: *Thermodynamics*. New York, London, Sydney: Wiley 1960
- Chapman, D., Leslie, R.B.: *Molecular Biophysics*. Contemporary Science Paperbacks Edingburgh and London: Oliver and Boyd 1967
- Clarke, B.L.: Stability of Complex Reaction Networks, in: *Advances in Chemical Physics*. I. Prigogine, S.A. Rice (Eds.), Vol. XLIII. New York, Chichester, Brisbane, Toronto: J. Wiley & Sons 1980
- Cole, K.S.: *Membranes, Ions and Impulses*. Berkeley and Los Angeles: University of California Press 1968
- Danielli, J.F., Davson, H.: J. cell. comp. Physiol. 5, 495 (1935)
- De Groot, S.R.: *Thermodynamics of Irreversible Processes*. Amsterdam: North Holland Publishing 1951
- De Groot, S.R., Mazur, P.: *Nonequilibrium Thermodynamics*. Amsterdam: North Holland Publishing 1962
- Evans, F.J., van Dixhoorn, J.J.: Towards More Physical Structure in Systems Theory, in *Physical Structure in Systems Theory*. J.J. van Dixhoorn, F.J. Evans (Eds.) New York, London, Toronto, Sydney, San Francisco: Academic Press 1974
- Forst, W.: *Theory of Unimolecular Reactions*. New York, London: Academic Press 1973
- Glandsdorff, P., Prigogine, I.: *Thermodynamic Theory of Structure, Stability and Fluctuations*. London, New York, Sydney, Toronto: Wiley-Interscience 1971
- Goel, N.S., Maitra, S.C., Montroll, E.W.: *On the Volterra and other Nonlinear Models of Interacting Populations*. New York, London: Academic Press 1971
- Gotoh, H.: J. theor. Biol. 53, 309 (1975)
- Griffith, J.S.: J. theor. Biol. 20, 202 (1968)
- Haken, H.: Phys. Lett. 46A, 443 (1974)
- Haken, H.: Rev. Mod. Phys. 47, 67 (1975)
- Haken, H.: *Synergetics. An Introduction*. 2nd Ed. Berlin, Heidelberg, New York: Springer 1978
- Hamdorf, K., Schwemmer, J.: Photogeneration and the Adaptation Process in Insect Photoreceptors, in *Photoreceptor Optics*. A.W. Snyder, R. Menzel (Eds.). Berlin, Heidelberg, New York: Springer 1975
- Heckmann, K., Lindemann, B., Schnäkenberg, J.: Biophys. J. 12, 683 (1972)
- Hill, T.L.: *Thermodynamics for Chemists and Biologists*. Reading (Mass.), Menlo Park (Calif.), London, Don Mills (Ontario): Addison-Wesley 1968
- Hill, T.L., Chen, Yi-Der: Biophys. J. 11, 685 (1971)
- Hodgkin, A.L., Huxley, A.F.: J. Physiol. (Lond.) 117, 500 (1952)
- Hodgkin, A.L.: *The Conduction of the Nervous Impulse*. Liverpool: Liverpool University Press 1967
- Hook, C.: Diploma Thesis, Aachen 1975
- Hunding, A.: Biophys. Struct. Mechanism 1, 47 (1974)
- Janssen, H.K.: Z. Physik 270, 67 (1974)

- Karnopp, D., Rosenberg, R.C.: *Analysis and Simulation of Multiport Systems*. Cambridge (Mass.): MIT Press 1968
- Karremann, G.: *Bull. Math. Biol.* 35, 149 (1973)
- Katchalsky, A.: Thermodynamics of Bio-Networks, in: Proceedings of the Third International Conference from Theoretical Physics to Biology. Basel: S. Karger 1973
- Katchalsky, A., Curran, P.F.: *Nonequilibrium Thermodynamics in Biophysics*. Cambridge (Mass.): Harvard University Press 1967
- Laidler, K.J., Bunting, P.S.: *The Chemical Kinetics of Enzyme Action*. Oxford: Clarendon Press 1973
- Landau, L.D., Lifshitz, E.M.: *Statistical Physics*. Course of Theoretical Physics, 2nd Ed., Vol. 5, p. 275 - 277. Oxford, London, Edinburgh, New York, Toronto, Sydney, Paris, Braunschweig: Pergamon Press 1968
- Landauer, R.: *J. Appl. Phys.* 33, 2209 (1962)
- Lasalle, J., Lefshetz, S.: *Stability by Liapunov's Direct Method*. New York: Academic Press 1961
- Lavenda, B.H.: *Quart. Rev. Biophys.* 5, 429 (1972)
- Leiseifer, H.: Diploma Thesis, Aachen 1975
- Lindemann, B.: In: Parson, D.S., Kramer, M. (Eds.): *Intestinal Permeation*. Amsterdam: Excerpta Medica 1976
- Lotka, A.J.: *J. phys. Chem.* 14, 271 (1910)
- Mac Arthur, R.H.: *Theor. Pop. Biol.* 1, 1 (1970)
- May, R.M.: *Stability and Complexity in Model Ecosystems*. Princeton (New Jersey): Princeton University Press 1973
- Mc Ilroy, D.K.: *Math. Biosci.* 7, 313 (1970 a)
- Mc Ilroy, D.K.: *Math. Biosci.* 8, 109 (1970 b)
- Meixner, J.: *Network Theory in its Relation to Thermodynamics*, in: Proceedings of the Symposium on Generalized Networks, p. 13 - 25. New York: Polytechnic Press of the Polytechnic Institute of Brooklyn 1966
- Minorsky, N.: *Nonlinear Oscillations*. Huntington (New York): Robert E. Krieger 1974
- Morowitz, H.J.: *Entropy for Biologists*. New York, London: Academic Press (1970)
- Nicolis, G., Portnow, J.: *Chem. Rev.* 73, 365 (1973)
- Nicolis, G., Prigogine, I.: *Self-Organisation in Nonequilibrium Systems*. New York, London, Sydney, Toronto: John Wiley & Sons 1977
- Noyes, R.M., Field, R.J.: *Ann. Rev. phys. Chem.* 25, 95 (1974)
- Oster, G.F., Perelson, A.S., Katchalsky, A.: *Quart. Rev. Biophys.* 6, 1 (1973)
- Paynter, H.: *Analysis and Design of Engineering Systems*. Cambridge (Mass.): MIT Press 1961
- Prigogine, I., Defay, R.: *Chemical Thermodynamics*. Longmans, Green and Co.: London and Harlow 1954
- Prigogine, I., Lefever, R.: *J. Chem. Phys.* 48, 1695 (1968)
- Richter, P.H., Procaccia, I., Ross, J.: Chemical Instabilities, in: *Advances in Chemical Physics*. I. Prigogine, S.A. Rice (Eds.), Vol. XLIII. New York, Chichester, Brisbane, Toronto: J. Wiley & Sons 1980
- Robinson, P.J., Holbrook, K.A.: *Unimolecular Reactions*. London, New York, Sydney, Toronto: Wiley Interscience 1972
- Sauer, F.: In: Orloff, J., Berliner, R.W. (Eds.): *Handbook of Physiology, Sec. 8: Renal Physiology*. Washington/D.C.: The American Physiological Society 1973
- Schlögl, F.: *Z. Physik* 253, 147 (1972)
- Schlögl, R.: *Stofftransport durch Membranen*. Darmstadt: Dr. Dietrich Steinkopf 1964
- Schmidt, R.F. (Ed.): *Fundamentals of Neurophysiology*. Berlin, Heidelberg, New York: Springer 1975
- Schnakenberg, J.: *J. theor. Biol.* 81, 139 (1979)
- Schnakenberg, J., Tiedge, J.: *J. Franklin Inst.* 308, 327 (1979)
- Scott, A.C., Luzader, S.D.: *Physics Scripta* 20, 395 (1979)
- Selkov, E.E.: *Eur. J. Biochem.* 4, 79 (1968)
- Stieve, H.: Photorezeption und Ihre molekularen Grundlagen, in: *Biophysik*. W. Hoppe et al. (Eds.). Berlin, Heidelberg, New York: Springer 1977
- Stieve, H. et al.: KFA Jülich, Internal Report KFA-INB-IB-1/78, Jülich: 1978
- Stieve, H.: Charge Separation by Rhodopsin-Containing Photosensory Membranes, in: *Light-Induced Charge Separation in Biology and Chemistry*. H. Gerischer, J.J. Katz (Eds.), pp. 503-523. Berlin: Dahlem Konferenzen 1979, Verlag Chemie

- Tellegen, B.D.H.: Philips Res. Rep. 7, 259 (1952)
- Thoma, J.U.: *Introduction to Bond Graphs and their Applications*. Oxford, New York, Toronto, Sydney, Paris, Braunschweig: Pergamon Press 1975
- Tyson, J.J.: J. chem. Phys. 58, 3919 (1973)
- Tyson, J.J.: J. math. Biol. 1, 311 (1975)
- Tyson, J.J.: The Belousov-Zhabotinskii Reaction, Lecture Notes in Biomathematics, Vol. 10. Berlin, Heidelberg, New York: Springer 1976
- Verhulst, P.F.: Nouv. Mem. Acad. Roy. Bruxelles 18, 1 (1845)
- Verhulst, P.F.: Nouv. Mem. Acad. Roy. Bruxelles 20, 1 (1847)
- Volterra, V.: J. Conseil Permanent Intern. Exploration Mer III, 1 (1928); translated in: Chapman, R.N.: *Animal Ecology*. New York: McGraw Hill 1931
- Winfree, A.T.: The Geometry of Biological Time, Biomathematics, Vol. 8. Berlin, Heidelberg, New York: Springer 1980

# Subject Index

- Action potential 14
- Activation energy 19
- Active center 17, 103
  - transport 45, 82
- Adam's model for nervous excitation 17
- Adaptation 97
- Affinity 44
  - , forward, reverse 62
- Amplification 94, 96, 97
- Asymptotic stability 95, 129, 134
- Autocatalytic feedback loop 99
  - reaction 23, 44, 101, 127
- Axoplasm 14
  
- Bath systems 39, 43, 118
- Bifurcation 111, 137
- Black box approach 3, 9, 66
- Bragg-Williams approximation 19
- Bump 94
  
- Capacitance, electric 89
  - , generalized 56, 115
  - , material 11
  - matrix 57, 116, 119, 127
- Carriers 69, 80
- Catalysis 6, 43
- Chemical potential 10, 33, 41
  - reaction 43
- Closed loop 130
  
- Competition for pores 72
- Conduction channels 15
- Conductivity 15, 16, 93
- Conservation of matter, electric charge 92
- Conservative oscillation 24
- Constitutive relation 57, 58, 60, 117
- Continuity equation 92
- Cooperativity 17
- Coupling of fluxes 85, 91
- Cross-coefficient 84
  
- Diffusion 65
  - coefficient 10, 65
- Dilute solution 50
- Directional field 135, 136
- Dissipative structure 102
  
- Ecological degeneracy 22, 109
- Einstein relation 13
- Electrochemical potential 18, 43, 71
- Electroneutrality 93
- Energy exchange 31
  - , internal 32
- Entropy 35
  - production 38
- Enzyme 6, 25, 43, 83, 85
- Equation of motion 136, 138
- Equilibrium 34, 45, 123, 126
- Evolution criterion 128, 129

- Excess entropy production 127
- Excitation, autocatalytic 103
  - of membranes 13, 17, 20, 103
- Extensive variable 34
  
- Faraday's number 42
- Feedback 16, 18, 25, 99, 110
- Fick's first law 10, 65
- Free energy 39, 46
  - enthalpy 40
  
- Gibbs-Duhem relation 47
- Gibbs' free energy 40, 47
  - fundamental relation 46, 115
- Glandsdorff-Prigogine criterion 126
- Global stability 99, 133, 136, 138
  
- Hodgkin-Huxley equations 13, 85
- Hodgkin-Huxley network 15
  
- Ideal mixtures 48
- Inhibition 24, 25, 106
- Instability of fluctuations 28
- Intensive variables 34
- Internal energy 32
- Ising model 17, 19, 103, 106
  
- Junction 59, 62, 63
  
- Kirchhoff's current law KCL 12, 59, 123
  - voltage law KVL 62, 123
- Latency time 94, 96
- Liapunov function 122, 123, 137
- Limit cycle 28, 100, 109
- Lindemann's model 76
- Linear approximation 66, 67
  - irreversible thermodynamics 50
- Lipid 69
- Local equilibrium 117
  - stability 99
- Loop 130
- Loop-free network 130, 134
  
- Macroscopic variable 30
- Macro-state 30
- Malthusian population growth 21, 23
- Master equation 8, 16, 17
- Mean field approximation 19
- Membrane 9
  - excitation 13, 20, 103
  - , nervous 13
  - voltage 14, 71, 74
- Metabolic reaction 6, 24
- Michaelis-Menten kinetics 6, 113
- Micro-state 30
- Minimal entropy production 52, 129
- Model 1, 2, 4, 5
- Modulus of a transducer 64
- Multi-ports 58
- Multi-stationarity 21, 100, 108
  
- Nernst-Planck equations 89, 93
- Nernst potential 14, 15, 75
- Nervous conduction 14
  - excitation 13, 17
  - membrane 13
- Networks 55
- N-ports 58

- Ohm's law 10, 93
- One-port element 58
- Onsager's reciprocity relations 52
- Oscillation, conservative 24
  - , limit cycle type 28
  - , Volterra-Lotka type 24
- Overshooting relaxation 76
  
- Parametric coupling 106
- Partial pressure 49
- Perfect gases 48
- Phase space 135
  - - analysis 136
  - transition 102, 109, 113
- Phenomenological coefficients 51
- Photoreceptor potential 94
- Polypeptide 6
- Pore 69
  - blocking 71
- Port 58
- Pressure 40
  
- Rate constant 7, 60
  - equation 8
  - , forward, reverse 7
  - , reaction 6, 7, 44
- Reaction, autocatalytic 23
  - , chemical 43
  - , higher order 62
  - rate 6, 7, 44
  - , unimolecular 60
- Reciprocity relation 52
- Reference potential 10, 50, 59
  - state 51, 62
- Relaxation 9, 11
  - time 9, 13
- Resistance 10, 15
- Resistivity 91
- Resting potential 14
- Rhodopsin 95
  
- Saturation of flux 71, 78, 81, 84
  - of population growth 24
- Self-blocking of pores 76
- Solitary solution 17
- Stability 115
  - , asymptotic 99, 133, 138
  - of equilibrium 120, 126
  - of fluctuations 27, 28
  - , global 99, 133, 136, 138
  - , local 99
  - of steady states 21, 126
- State variable 32
- Steady state 7, 21, 99
- Stoichiometric coefficients 43
- Storage of matter 56
  
- Tellegen's theorem 123
- Temperature 36
- Thermodynamic equilibrium 34
  - fluxes 50
  - forces 50
  - systems 30
- Thermodynamics, first law of 31
  - , second law of 34
- Trajectory 22, 135
- Transducer 63
- Transfer of electric charge 42
  - of heat 36
  - , irreversible and reversible 38
  - of matter 41
- Transport across membranes 69
- Two-port element 60
  
- Unimolecular reactions 60
- Uniqueness of steady states 129
- Unit membrane model 69
  
- Valency of ions 42
- Verhulst saturation term 24
- Volterra-Lotka model 21, 107