Preface: A Biologist's View

> Es liegt ein tiefes und gründliches Glück darin, daß die Wissenschaft Dinge ermittelt, die standhalten und die immer wieder den Grund zu neuen Ermittlungen abgeben: – es könnte ja anders sein!
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> *Friedrich Nietzsche*
> Die fröhliche Wissenschaft

Molecular oxygen comprises about 20% of our atmosphere, but less than 5% of this amount is dissolved at equilibrium in water. As a consequence of this low solubility in seawater, in freshwater and in aqueous body fluids, living cells are subjected to a universal problem of low oxygen availability. Thus biologically relevant measurement of dissolved oxygen extends from a cellular scale where sensors with diameters of less than 10^{-6} m are employed, to the oceanic scale where in situ measurements are performed at depths beyond 10^4 m.

This book covers the wide spectrum of aquatic and physiological applications of polarographic oxygen sensors. It is intended as a basic introduction for the student, and as a readily available compilation of detailed information for the specialist. Assessments of various methods for monitoring aquatic environments and physiological processes aid in overcoming practical problems frequently encountered in the laboratory and in the field. Concomitant with the provision of experimental guidelines, topics of bioenergetics are addressed on the basis of respiratory oxygen exchange and related physiological mechanisms.

A respiratory physiologist would specify polarographic oxygen sensors as perfect oxygen conformers, their respiratory rate being linearly dependent on p_{O_2}. He would find that their oxygen consumption is proportional to the area of their oxygen-transducing membrane, with a Q_{10} of 1.4 and a constant of proportionality (about 2 nmol O_2 h^{-1} mm^{-2}) which might be typical of, for example, fish eggs. Although the increasing unpredictability of their oxygen consumption with increasing age would be understandable, he might be surprised that, despite their vulnerability to desiccation, oxygen consumption remained the same in air as in water. In these respects polarographic oxygen sensors are not different from organisms, except that microsensors consume oxygen proportional to their diameter instead of area. But do we know that microorganisms do not behave similarly?

These apparent phenomena are explained on the basis of physicochemical principles in Part I. Why is this understanding so important? Since oxygen concentration per unit partial pressure (c_{O_2}/p_{O_2} = solubility) is low in water, small concentration changes become apparent as large changes of p_{O_2}, signalled by the sensor. This feature predestines polarographic oxygen sensors for aquatic application: The sensor is 20 to 30 times more sensitive to respiratory rates in water than in the same volume of air.

The operational principle of polarographic oxygen sensors is based on oxygen diffusion to the polarized cathode, where oxygen reduction (in micromoles O_2 per second) generates the electrical signal (in amperes). According to Faraday's law the ratio is calculated as 2.591 μmol O_2 s^{-1} A^{-1} (= 9.328 nmol O_2 h^{-1} μA^{-1}). Variations in the construction of polarographic oxygen sensors are mainly related to the problem of how oxygen diffuses to the cathode. In this respect the actual design of every sensor necessarily involves a compromise, since optimising particular functions, such as sensitivity and response time, detracts from others, such as stability and stirring requirements. The optimal design therefore depends upon the application.

The many new commercial oxygen sensors that have come onto the market during the past few years include, to some extent, original ideas, or are merely copies of existing sensors. For instance, the information that a polarographic oxygen sensor for marine applications (InterOcean Systems, San Diego) is virtually the same sensor at a price six times that of the original (Ingold, CH) probably comes too late for some purchasers.

Proficiency in solving respirometric problems facilitates research into the physiological mechanisms and functional interpretations of gas exchange. With this in mind, respirometric and in situ monitoring methods, of which the polarographic oxygen sensor forms an integral part, are outlined in the detail that is of practical importance but usually neglected (Parts II and III). Methods related to studies of oxygen exchange are also dealt with. Responses to environmental variables and to toxicological or pharmacological agents, metabolic patterns and biological rhythms can be resolved by automatic long-term monitoring of oxygen consumption with polarographic oxygen sensors. In combination with simultaneous measurements of, e.g., locomotory activity, ventilatory rates, chloroplast migration, biomass production and notably heat dissipation such investigations can be most fruitful.

It is noteworthy that bioenergetics and the recognition of oxygen have a common root in Lavoisier's ingeneous concept of combustion and his classical experiments on direct and indirect calorimetry. Keeping in line with the extension of the direct and indirect calorimetric approach to the bioenergetics of aquatic animals, the thermodynamic interpretation of oxygen consumption in aquatic organisms is revised in an Appendix and more closely aligned to the needs of ecological energetics. Several case studies illustrate the practical application of the methods and point out concurrent conceptual advances.

The respirometers employed in these studies are no longer simply closed or open systems. Further differentiation has given rise to specific types such as the "rubber mask", "twin-flow" or "slurp gun" respirometers. Various types have invaded lakes, coastal regions and even the deep sea, yet respirometers are still most common in the shallow, constant temperature water baths on the bench. Restocking with new variations and their association with other instumental groups seems rewarding, especially in some laboratories where respirometers have become fossilized or extinct.

Previous summaries of the applications of polarographic oxygen sensors in medicine and cellular physiology can be found in Kessler M. et al., eds. (Oxygen Supply. Urban Schwarzenberg, München–Berlin–Wien, 1973) and Fatt I. (Polarographic Oxygen Sensors. CRC Press, Cleveland, 1975). For an extended theoretical discussion the reader is referred to Hitchman L.M. (Measurement of dissolved oxygen. Wiley, New York and Orbisphere Laboratories, Geneva, 1978).

We hope that the joy and benefits of interdisciplinary communication as experienced by the editors of this book may be shared by our readers. Ideas and technological advances in one field may unexpectedly provide the key to solving problems in other apparently unrelated disciplines (compare e.g. Chaps. I.4 and III.2, or p. 117 and 247). Thus perhaps even those readers whose special knowledge or special needs are neglected or inadequately dealt with may find some inspiration.

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