As indicated in Table 6.1, values of Y_{X/O_2} can vary from 0.17 to 1.5 g biomass/g O_2, depending on substrate and organism.

Information from some measurements can be usefully combined. A particularly important derived parameter is the respiratory quotient (RQ), which is defined as the moles of CO_2 produced per mole of oxygen consumed. The RQ value provides an indication of metabolic state (for example, aerobic growth versus ethanol fermentation in baker's yeast) and can be used in process control.

We have already discussed (Chapter 5) the P/O ratio, which is the ratio of phosphate bonds formed per unit of oxygen consumed (g mole P/g atom O). The P/O ratio indicates the efficiency of conversion of reducing power into high-energy phosphate bonds in the respiratory chain. For eucaryotes, the P/O ratio approaches 3 when glucose is the substrate, while it is significantly less in procaryotes. A closely related parameter is the proton/oxygen ratio (H/O). This ratio is the number of H^+ ions released per unit of oxygen consumed. Electron generation is directly related to proton release. Usually 4 mol of electrons are consumed per mole of oxygen consumed. The generation of electrons results in the expulsion of H^+ that can be used directly to drive the transport of some substrates or to generate ATP.

The complexity of mass and energy balances for cellular growth can be decreased greatly through the recognition that some parameters are nearly the same irrespective of the species or substrate involved. These parameters can be referred to as *regularities*. For example, we have shown in Table 7.1 that $Y^M_{X/\mathrm{ATP}} \geq 10.5$ g dry wt/mol ATP. Three important regularities (identified first by I. G. Minkevich and V. K. Eroshin) are 26.95 kcal/g equivalent of available electrons transferred to oxygen (coefficient of variation of 4%), 4.291 g equivalent of available electrons per quantity of biomass containing 1 g atom carbon, and 0.462 g carbon in biomass per gram of dry biomass. It has also been observed that $Y_{X/e-} = 3.14 \pm 0.11$ g dry wt/g equivalent of electrons. These observed average values of cell composition and yields facilitate estimates of other growth-related parameters.

7.3. STOICHIOMETRIC CALCULATIONS

7.3.1. Elemental Balances

A material balance on biological reactions can easily be written when the compositions of substrates, products, and cellular material are known. Usually, electron–proton balances are required in addition to elemental balances to determine the stoichiometric coefficients in bioreactions. Accurate determination of the composition of cellular material is a major problem. Variations in cellular composition with different types of organisms are shown in Table 7.3. A typical cellular composition can be represented as $CH_{1.8}O_{0.5}N_{0.2}$. One mole of biological material is defined as the amount containing 1 gram atom of carbon, such as $CH_\alpha O_\beta N_\delta$.

Consider the following simplified biological conversion, in which no extracellular products other than H_2O and CO_2 are produced.

$$CH_mO_n + a\,O_2 + b\,NH_3 \longrightarrow c\,CH_\alpha O_\beta N_\delta + d\,H_2O + e\,CO_2 \qquad (7.3)$$