



Figure 6.7. Arrhenius plot of growth rate of *E. coli* B/r. Individual data points are marked with corresponding degrees Celsius. *E. coli* B/r was grown in a rich complex medium (●) and a glucose-mineral salts medium (○). (With permission, after S. L. Herendeen, R. A. VanBogelen, and F. C. Neidhardt, "Levels of Major Protein of *Escherichia coli* during Growth at Different Temperatures," *J. Bacteriol.* 139:195, 1979, as drawn in R. Y. Stanier and others, *The Microbial World*, 5th ed., Pearson Education, Upper Saddle River, NJ, 1986, 207.)

maintain intracellular pH at a relatively constant level in the presence of fluctuations in environmental pH. When pH differs from the optimal value, the maintenance-energy requirements increase. One consequence of different pH optima is that the pH of the medium can be used to select one organism over another.

In most fermentations, pH can vary substantially. Often the nature of the nitrogen source can be important. If ammonium is the sole nitrogen source, hydrogen ions are released into the medium as a result of the microbial utilization of ammonia, resulting in a decrease in pH. If nitrate is the sole nitrogen source, hydrogen ions are removed from the medium to reduce nitrate to ammonia, resulting in an increase in pH. Also, pH can change because of the production of organic acids, the utilization of acids (particularly amino acids), or the production of bases. The evolution or supply of CO₂ can alter pH greatly in some systems (e.g., seawater or animal cell culture). Thus, pH control by means of a buffer or an active pH control system is important. Variation of specific growth rate with pH is depicted in Fig. 6.8, indicating a pH optimum.

Dissolved oxygen (DO) is an important substrate in aerobic fermentations and may be a limiting substrate, since oxygen gas is sparingly soluble in water. At high cell concentrations, the rate of oxygen consumption may exceed the rate of oxygen supply, leading to oxygen limitations. When oxygen is the rate-limiting factor, specific growth rate varies with dissolved-oxygen concentration according to saturation kinetics; below a critical concentration, growth or respiration approaches a first-order rate dependence on the dissolved-oxygen concentration.

Above a *critical oxygen concentration*, the growth rate becomes independent of the dissolved-oxygen concentration. Figure 6.9 depicts the variation of specific growth rate with dissolved-oxygen concentration. Oxygen is a growth-rate-limiting factor when the