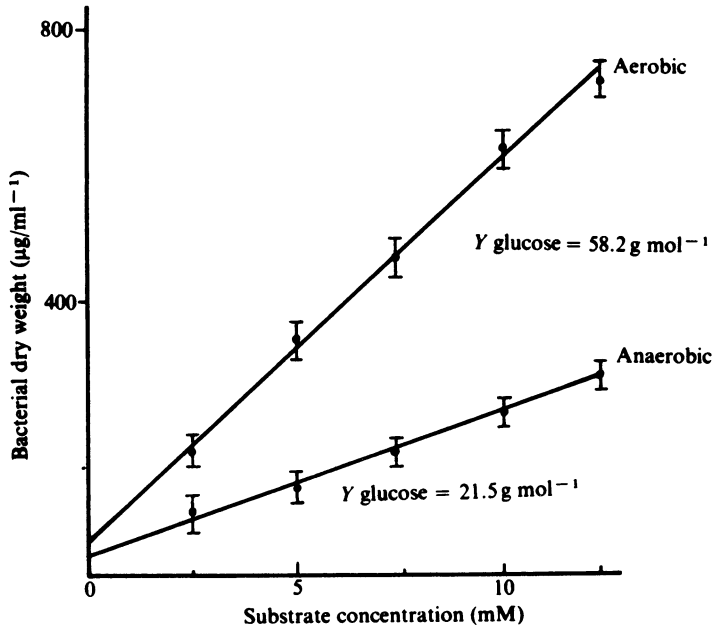

Figure 6.5. Aerobic and anaerobic growth yields of *Streptococcus faecalis* with glucose as substrate. (With permission, from B. Atkinson and F. Mavituna, *Biochemical Engineering and Biotechnology Handbook*, Macmillan, Inc., New York, 1983.)

Cellular maintenance represents energy expenditures to repair damaged cellular components, to transfer some nutrients and products in and out of cells, for motility, and to adjust the osmolarity of the cells' interior volume. Microbial growth, product formation, and substrate utilization rates are usually expressed in the form of specific rates (e.g., normalized with respect to X), since bioreactions are autocatalytic. The specific rates are used to compare the effectiveness of various fermentation schemes and biocatalysts.

Microbial products can be classified in three major categories (see Fig. 6.6):

1. Growth-associated products are produced simultaneously with microbial growth. The specific rate of product formation is proportional to the specific rate of growth, μ_g. Note that μ_g differs from μ_{net}, the net specific growth rate, when endogeneous metabolism is nonzero.

$$q_P = \frac{1}{X}\frac{dP}{dt} = Y_{P/X}\mu_g \tag{6.16}$$

   The production of a constitutive enzyme is an example of a growth-associated product.
2. Nongrowth-associated product formation takes place during the stationary phase when the growth rate is zero. The specific rate of product formation is constant.