Competition is an indirect interaction between two populations that has negative effects on both. In competition, each population competes for the same substrate. Two populations or microorganisms with similar nutrient requirements usually compete for a number of common, required nutrients when grown together.

The outcome of competition between two species for the *same growth-limiting substrate* in an open system (e.g., a chemostat) is determined by the specific growth-rate-limiting substrate concentration relationship. Two different cases can be distinguished in a mixed culture of two competing species (Fig. 16.1):

1. μ_a is always greater than μ_b. The organisms with the fastest growth rate will displace the others from the culture. This is known as the *exclusion principle.*
2. Crossover in μ-S relationship. In this case, the faster-growing organism is determined by the dilution rate. Depending on the dilution rate, three different cases may be identified:
   - **a.** At the crossover point $D = \mu_x$; $S = S_x$, two species could be maintained in a chemostat at $D = \mu_x$. However, this is an unstable operating point.
   - **b.** If $D > \mu_x$, then $\mu_a > \mu_b$, and B will be washed out; A will dominate.
   - **c.** If $D < \mu_x$, then $\mu_b > \mu_a$, and A will be washed out; B will dominate.

In a batch system, both species would exist in culture media. The ratio of number density of species at a given time will be determined by the relative magnitudes of the specific growth rates and the initial concentrations of cells.

Neutralism is an interaction where neither population is affected by the presence of the other. That is, there is no change in the growth rate of either organism due to the presence of the other. Neutralism is relatively rare. One example of neutralism is the growth of yogurt starter strains of *Streptococcus* and *Lactobacillus* in a chemostat. The total counts of these two species at a dilution rate of 0.4 h^{-1} are quite similar whether the populations are cultured separately or together. Neutralism may occur in special environments where each species consumes different limiting substrates and neither species is affected by the end products of the other.

Mutualism and *protocooperation* are more common than neutralism and may involve different mechanisms. In both cases, the presence of each population has a positive effect on the other. For mutualism, the interaction is essential to the survival of both species. In protocooperation, the interaction is nonessential. One mechanism is the mutual exchange of required substances or the removal of toxic end products by each organism.

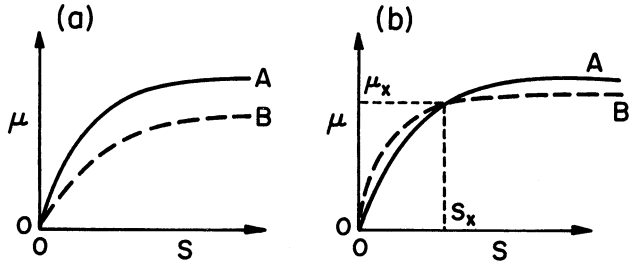

Figure 16.1. μ-S relationship for two competing species (*A* and *B*) in a mixed culture. Case (a) corresponds to $\mu_{mA} > \mu_{mB}$ and $K_{SA} \leq K_{SB,}$ while case (b) corresponds to a case where $\mu_{mA} > \mu_{mB}$, but $K_{SB} < K_{SA}$. In case (b), the growth curves cross and *A* and *B* could potentially coexist at $D = \mu_x$ and $S = S_x$ in a chemostat.