precipitation. UF separations operate under mild conditions (T = 20° to 30°C, P = 5 to 50 psi) and are energy efficient, inexpensive, nondestructive, and easy to operate.

Microfiltration is used primarily to concentrate bacterial and yeast suspensions and provide a cell-free supernatant. Cross-flow filtration and improved membranes have been key to making this process viable. In many applications it has replaced centrifugation. Initial devices were primarily open plate and frame, owing to possible blockages, although hollow-fiber systems are now available. Application to animal cells, which are mechanically fragile, is possible but difficult, owing to high levels of hydrodynamic sheer that can break cells.

11.4.9. Chromatography

Chromatography separates mixtures into components by passing a fluid mixture through a bed of adsorbent material. We will be interested primarily in *elution chromatography*. Typically a column is packed with adsorbent particles, which may be solid, a porous solid, a gel, or a liquid phase immobilized in or on a solid. A *mobile phase* or fluid phase with a mixture of solutes is injected. This pulse is followed by a solvent or eluent. The pulse enters as a narrow concentrated peak, but exits dispersed and diluted by additional solvent. Different solutes in the mixture interact differently with the adsorbent material (*stationary phase*); some interact weakly and some interact strongly. Solutes that interact weakly with the matrix pass out of the column rapidly (see Fig. 11.27), while those that interact strongly with the matrix exit slowly. These differential rates of migration separate the

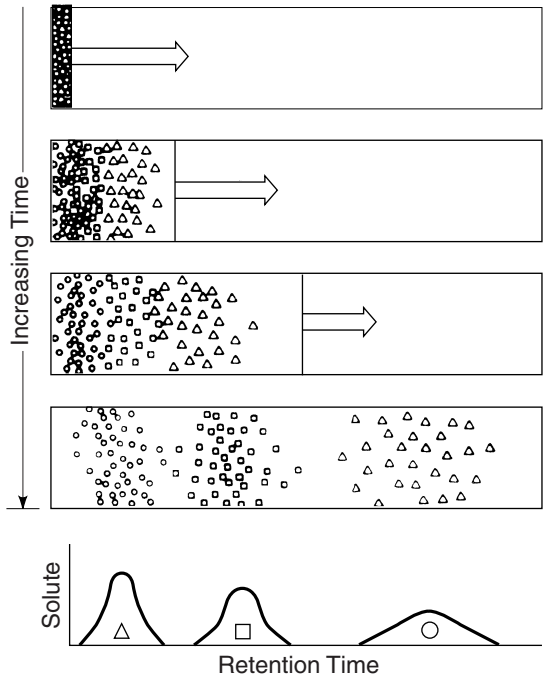

Figure 11.27. Concentrations in elution chromatography. Three solutes, shown schematically as circles, squares, and triangles, are injected into one end of a packed bed. When solvent flows through the bed from left to right, the three solutes move at different rates because of different adsorption. They exit at different times, and hence are separated. (With permission, from P. A. Belter, E. L. Cussler, and W. S. Hu, *Bioseparations: Downstream Processing for Biotechnology*, John Wiley & Sons, New York, 1988, p. 184.)