Most experiments with conjugation are done with the F factor, which is present in low copy number. Direct cell-to-cell contact is required. This DNA molecule encodes at least 13 genes involved in its self-transfer from one cell to another.

In a population of *E. coli* there are frequently some cells with the F plasmid, which are termed $F^+$ (male). Other cells are $F^-$ (female). $F^+$ cells encode proteins to make a *sex pilus*. When $F^+$ and $F^-$ cells are mixed together, the sex pilus connects an $F^+$ to an $F^-$ cell (see Fig. 8.6). The sex pilus may act as a conduit for the transfer of a copy of the F plasmid to the $F^-$ cell. The actual process of transfer involves replication of the F plasmid.

This process is normal and does not involve transfer of chromosomal genes or recombination. A more rare event is when the F plasmid has been integrated into the chromosome itself to form a single, large, circular molecule. Thirteen sites for integration are known. Such cells are termed Hfr (for high-frequency recombination).

When transfer is initiated, the F plasmid moves not only itself, but also the attached chromosome, to the recipient cell. The time required to transfer a whole *E. coli* chromosome is 100 min. If contact between the two cells is broken during the transfer process, only a proportional amount of the chromosome will have been transferred (that is, at 50 min, about 50%). Since the transfer begins at a known point, Hfr cells can be used to map the location of genes on the chromosome. This technique for gene mapping is being replaced by methods for directly sequencing nucleotide sequences in DNA. If $F^+$ and $F^-$ cells differ in properties (e.g., the ability to make lysine), conjugation can be used to alter the properties of the $F^-$ cell.

Conjugation, transduction, and transformation all represent forms of gene transfer from one cell to another. However, gene transfer can occur within a cell.

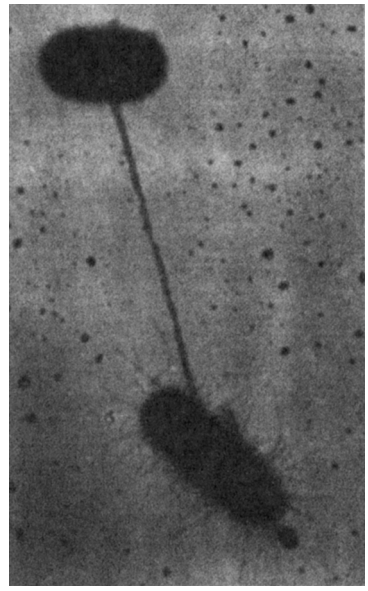

**Figure 8.6.** Direct contact between two conjugating bacteria is first made via a pilus. The cells are then drawn together for the actual transfer of DNA. (With permission, from T. D. Brock, K. M. Brock, and D. M. Ward, *Basic Microbiology with Applications*, 3d ed., Pearson Education, Upper Saddle River, NJ, 1986, p. 161.)