can be incorporated ultimately in the plant chromosome. Unfortunately, most cereal plants are not readily susceptible to *Agrobacterium* infection.

The *biolistic process* for obtaining plant transformation is to coat small (1-μm diameter) projectiles (e.g., of tungsten) and shoot these into cells at high velocity. Results with this approach have been remarkably successful, and this technique is fairly general.

Another fairly general approach is *electroporation,* which involves a brief high-voltage electric discharge that renders cells permeable to DNA. Electroporation can be used with animal, plant, fungal, and bacterial systems. The formation of *protoplasts* can enhance transfection but is not essential. A protoplast is a cell in which the outer cell envelope has been removed so that only the cytoplasmic membrane remains.

Chemically or electrically mediated *protoplast fusion* is another technique for transferring genetic information from one cell to another. Such approaches have been particularly useful with some fungi for which few or no plasmids have been identified. Protoplast fusion can be interspecies and can result in stable hybrids with desired properties due to recombination events between the two genomes or extrachromosomal pieces of DNA.

For most animal cells, genetic manipulation can be accomplished by modifying viruses to become vectors. For example, in the insect cell system a *baculovirus* can be modified so as to place a desired gene under the control of a very strong promoter at the expense of a gene product that is unessential for viral replication in cell culture.

Although the basic conceptual approach to genetic engineering is rather straightforward, its implementation can vary widely in difficulty. The level of difficulty depends on the nature of the gene product and its corresponding gene, as well as the character of the desired host cell. Techniques to improve the ease of obtaining desirable genetic modification will undoubtedly continue to be developed. The ultimate limitation will be human imagination and wisdom.

8.5. GENOMICS

Genomics is the set of experimental and computational tools which allow the genetic blueprints of life to be read. A *genome* is an organism's total inheritable DNA. We now have complete genomic information on about 50 microbes, as well as representative animals and plants. Most importantly, we have the genomic sequence for humans. This sequence information is simply a string of nucleotide letters. *Functional genomics* is the process of relating genetic blueprints to the structure and behavior of an organism. To completely relate physiological behavior to this sequence of nucleotides is an extremely challenging problem. It is a problem to which bioengineers can make a significant contribution.

Much of the progress in molecular biology has been due to a reductionist approach in which a subcomponent has been isolated and studied in detail. This approach has been very fruitful in learning about the detailed mechanisms at the heart of living systems. The detailed sequence information now available is the ultimate limit in reduction in biology. There is increasing interest in asking how the individual subcellular components work together. Function arises from the complex interactions of the components. A systems engineering approach allows one to integrate component parts into a functional whole.