the cytoplasm in the form of granules. The most common are glycogen granules, volutin granules (containing polymetaphosphate) and lipid granules (containing poly β-hydroxybutyric acid). Other granules, such as sulphur and iron, may also be found in the more primitive bacteria.

Flagella. A flagellum is made up of protein called flagellin and it operates by forming a rigid helix that turns rapidly like a propeller. This can propel a motile cell up to 200 times its own length in 1 second. Under the microscope bacteria can be seen to exhibit two kinds of motion: swimming and tumbling. When tumbling, the cell stays in one position and spins on its own axis but when swimming, it moves in a straight line. Movement towards or away from a chemical stimulus is referred to as chemotaxis. The flagellum arises from the cytoplasmic membrane and is composed of a basal body, hook and filament. The number and arrangement of flagella depend upon the organism and vary from a single flagellum (monotrichous) to a complete covering (peritrichous).

Pili and fimbriae. These terms are often used interchangeably but in reality these structures are functionally distinct from each other. Fimbriae are smaller than flagella and are not involved in motility. They are found all over the surface of certain bacteria (mainly Gram-negative cells) and are believed to be associated with adhesiveness and pathogenicity. They are also antigenic. Pili (of which there are different types) are larger and of a different structure to fimbriae and are involved in the transfer of genetic information from one cell to another. This is of major importance in the transfer of drug resistance between cell populations.

Endospores. Under conditions of specific nutrient deprivation some genera of bacteria, in particular *Bacillus* and *Clostridium*, undergo a differentiation process at the end of logarithmic growth and change from an actively metabolizing vegetative form to a resting spore form. The process of sporulation is not a reproductive mechanism, as found in certain actinomycetes and filamentous fungi, but serves to enable the organism to survive periods of hardship. A single vegetative cell differentiates into a single spore. Subsequent encounter with favourable conditions results in germination of the spore and the resumption of vegetative activities.

Endospores are very much more resistant to heat, disinfectants, desiccation and radiation than are vegetative cells, making them difficult to eradicate from foods and pharmaceutical products. Heating at 80°C for 10 minutes would kill most vegetative bacteria, whereas some spores will resist boiling for several hours. The sterilization procedures now routinely used for pharmaceutical products are thus designed specifically with reference to the destruction of the bacterial spore.

The mechanism of this extreme heat resistance was a perplexing issue for many years. At one time it was thought to be due to the presence of a unique spore component, dipicolinic acid (DPA). This compound is found only in bacterial spores where it is associated in a complex with calcium ions. The isolation of heat-resistant DPA-less mutants, however, led to the demise of this theory. Spores do not have a water content appreciably different from that of vegetative cells, but the distribution within the different compartments is unequal and this is thought to generate the heat resistance. The central core of the spore houses the genetic information necessary for growth after germination and this becomes dehydrated by expansion of the cortex against the rigid outer protein coats. Water is thus squeezed out of the central core. Osmotic pressure differences also help to maintain this water imbalance. Endospores are also highly unusual because of their ability to remain dormant and ametabolic for prolonged periods of time. Bacterial spores have been isolated from lake sediments where they were deposited 1000 years previously and there have even been claims of spores revived from geological specimens up to 40 million years old.

The sequence of events involved in sporulation is illustrated in Figure 13.5. It is a continuous process, although for convenience it may be divided into six stages. The complete process takes about 8 hours, although this may vary depending on the species and the conditions used. Occurring simultaneously with the morphological changes is a number of biochemical events that have been shown to be associated with specific stages and occur in an exact sequence. One important biochemical event is the production of antibiotics. Peptides possessing antimicrobial activity have been isolated from the majority of *Bacillus* species and many of these have found pharmaceutical applications. Examples of antibiotics include bacitracin, polymyxin and gramicidin. Similarly, the proteases produced by *Bacillus* species during sporulation are used extensively in a wide variety of industries.