other strand; similarly, a G is always opposite a C. This important ordering effect occurs because the shapes of A, T, C, and G are such that a T fits closely only into an A, and a G into a C; and only in the case of this close proximity of the charged portions is the electrostatic force great enough to hold them together even for a short time (Fig. 16–44b), forming what are referred to as "weak bonds." The electrostatic force between A and T, and between C and G, exists because these molecules have charged parts. These charges are due to some electrons in each of these molecules spending more time orbiting one atom than another. For example, the electron normally on the H atom of adenine (upper part of Fig. 16–44b) spends some of its time orbiting the adjacent N atom (more on this in Chapter 29), so the N has a net negative charge and the H a positive charge. This H^+ atom of adenine[†] is then attracted to the O^- atom of thymine. These net + and − charges usually have magnitudes of a fraction of e (charge on the electron) such as $0.2e$ or $0.4e$.

How does the arrangement shown in Fig. 16–44 come about? It occurs when the DNA replicates (duplicates) itself just before cell division. Indeed, the arrangement of A opposite T and G opposite C is crucial for ensuring that the genetic information is passed on accurately to the next generation. The process of replication is shown in a simplified form in Fig. 16–45. The two strands of DNA separate (with the help of enzymes, which also operate via the electrostatic force), leaving the charged parts of the bases exposed. Once replication starts, let us see how the correct order of bases occurs by focusing our attention on the G molecule indicated by the arrow on the lowest strand in Fig. 16–45. There are many unattached nucleotide bases of all four kinds bouncing around in the cellular fluid. The only one of the four bases that will experience attraction to our G, if it bounces close to it, will be a C. The charges on the other three bases are not arranged so that they can get close to those on the G, and thus there will be no significant attractive force exerted on them—remember that the force decreases rapidly with distance $(\propto 1/r^2)$. Because the G does not attract an A, T, or G appreciably, an A, T, or G will be knocked away by collisions with other molecules before enzymes can attach it to the growing chain (number 3). But the electrostatic force will often hold a C opposite our G long enough so that an enzyme can attach the C to the growing end of the new chain.

PHYSICS APPLIED

DNA replication

Thus we see that electrostatic forces are responsible for selecting the bases in the proper order during replication, so the genetic information is passed on accurately to the next generation. Note in Fig. 16–45 that the new number 4 strand has the same order of bases as the old number 1 strand; and the new number 3 strand is the same as the old number 2. So the two new double helixes, 1–3 and 2–4, are identical to the original 1–2 helix.

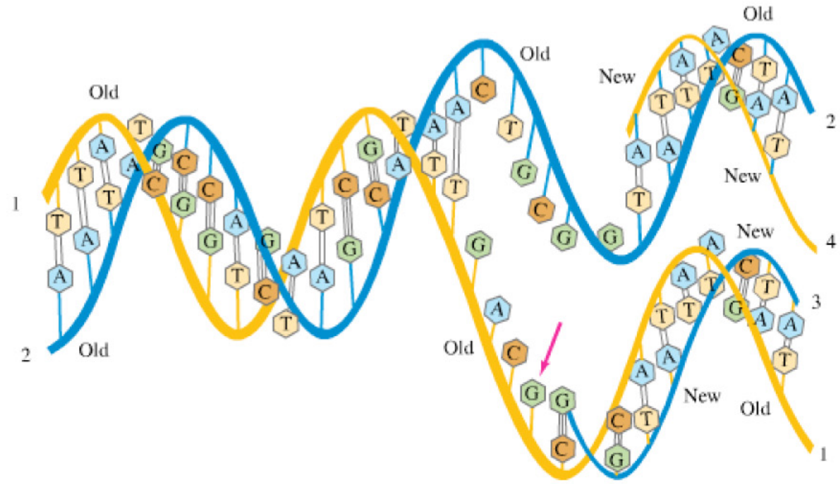

FIGURE 16–45 Replication of DNA.

[†] When H^+ is involved, the weak bond it can make with a nearby negative charge, such as O^-, is relatively strong among weak bonds (partly because H^+ is so small) and is referred to as a "hydrogen bond" (Section 29–3).