This process of DNA replication is often presented as if it occurred in clockwork fashion—as if each molecule knew its role and went to its assigned place, like bees in a hive. But this is not the case. The forces of attraction between the electric charges of the molecules are rather weak and become significant only when the molecules can come close together and several "weak bonds" can be made. Indeed, if the shapes are not just right, there is almost no electrostatic attraction, which is why there are few mistakes. Thus, out of the random motion of the molecules, the electrostatic force acts to bring order out of chaos.

Another outcome of the random (thermal) velocities of molecules in the cell (kinetic theory) relates to *cloning*. Even at the level of *E. coli* bacteria, when a cell divides, the two new bacteria have nearly identical DNA. Even if the DNA were perfectly identical, the two bacteria would not end up behaving in the same way. The cells are *not* identical because (via kinetic theory) long protein, DNA, and RNA molecules get bumped into different shapes, and even the expression of genes can thus be different. Furthermore, loosely held parts of large molecules such as a methyl group (CH_3) can be knocked off by a particularly strong collision with another molecule in the cellular fluid. Hence, cloned organisms are not identical, even if their DNA were identical. Indeed, there can not really be genetic determinism.

* 16–12 Photocopy Machines and Computer Printers Use Electrostatics

PHYSICS APPLIED
Photocopy machines

Photocopy machines and laser printers make use of electrostatic attraction to print an image of the original. They each use a different technique to project the image onto a special cylindrical drum. In a *photocopier*, lenses and mirrors focus an image of the original sheet of paper onto the drum, much like a camera lens† focuses an image on film. The drum is typically made of aluminum, a good conductor, and its surface is coated with a thin layer of selenium. Selenium is a material that has the interesting property (called "photoconductivity") of being an electrical nonconductor in the dark, but becoming a conductor when exposed to light.

Step 1 in photocopying is the placing of a uniform positive charge on the drum's selenium layer by a charged rod or roller. This is done in the dark. In step 2, the image to be copied or printed is projected onto the drum. For simplicity, let us assume the image is a dark letter A on a white background (as on the page of a book) as shown in Fig. 16–46. The letter A on the drum is dark, but all around it is light. At all these light places, the selenium becomes conducting and electrons flow in from the aluminum beneath, neutralizing those positive areas. In the dark areas of the letter A, the selenium is nonconducting and so retains a positive charge, Fig. 16–46.

In step 3, a fine dark powder known as *toner* is given a negative charge, and brushed on the drum as it rotates. The negatively charged toner particles are attracted to the positive areas on the drum (the A in our case) and stick only there. In step 4, as the drum continues to rotate, it presses against a piece

†Cameras are discussed in Section 25–1, and images by lenses and mirrors in Chapter 23.

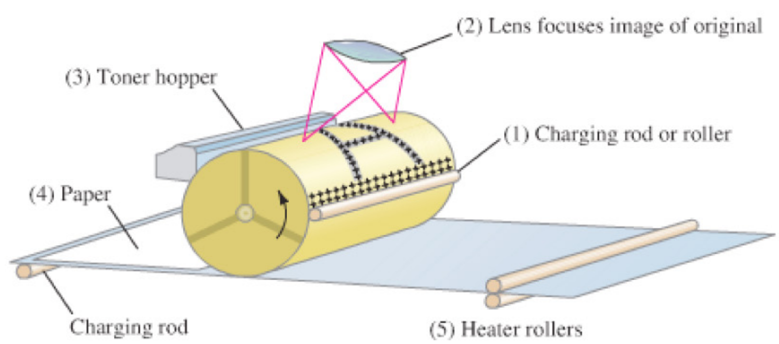

FIGURE 16–46 Inside a photocopy machine: (1) the selenium drum is given a + charge; (2) the lens focuses image on drum—only dark spots stay charged; (3) toner particles (negatively charged) are attracted to positive areas on drum; (4) the image is transferred to paper; (5) heat binds the image to the paper.