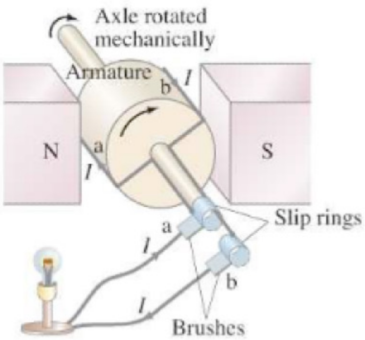


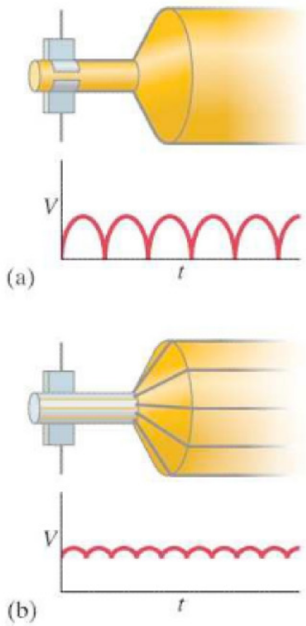
FIGURE 21–15 An ac generator.

21–5 Electric Generators

We discussed alternating currents (ac) in Section 18–7. Now we examine how ac is generated, by an **electric generator** or **dynamo**, one of the most important practical results of Faraday's great discovery. A generator transforms mechanical energy into electric energy, just the opposite of what a motor does. A simplified diagram of an **ac generator** is shown in Fig. 21–15. A generator consists of many loops of wire (only one is shown) wound on an *armature* that can rotate in a magnetic field. The axle is turned by some mechanical means (falling water, steam turbine, car motor belt), and an emf is induced in the rotating coil. An electric current is thus the *output* of a generator. Suppose in Fig. 21–15 that the armature is rotating clockwise; then right-hand-rule-3 applied to charged particles in the wire (or Lenz's law) tells us that the (conventional) current in the wire labeled b on the armature is outward; therefore the current is outward at brush b. (Each brush is fixed and presses against a continuous slip ring that rotates with the armature.) After one-half revolution, wire b will be where wire a is now in the drawing, and the current then at brush b will be inward. Thus the current produced is alternating.

The frequency f is 60 Hz for general use in the United States and Canada, whereas 50 Hz is used in many countries. Most of the power generated in the United States is done at steam plants, where the burning of fossil fuels (coal, oil, natural gas) boils water to produce high-pressure steam that turns a turbine connected to the generator axle (Fig. 15–21). At nuclear power plants, the nuclear energy released is used to produce steam to turn turbines. Indeed, a heat engine (Chapter 15) connected to a generator is the principal means of generating electric power. The frequency of 60 Hz or 50 Hz is maintained very precisely by power companies.

FIGURE 21–16 (a) A dc generator with one set of commutators, and (b) a dc generator with many sets of commutators and windings.



A **dc generator** is much like an ac generator, except the slip rings are replaced by split-ring commutators, Fig. 21–16a, just as in a dc motor. The output of such a generator is as shown and can be smoothed out by placing a capacitor in parallel with the output (Section 19–6). More common is the use of many armature windings, as in Fig. 21–16b, which produces a smoother output.

Automobiles used to use dc generators. Today they mainly use **alternators**, which avoid the problems of wear and electrical arcing (sparks) across the split-ring commutators of dc generators. Alternators differ from generators in that an electromagnet, called the *rotor*, is fed by current from the battery and is made to rotate by a belt from the engine. The magnetic field of the turning rotor passes through a surrounding set of stationary coils called the *stator*, inducing an alternating current in the stator coils, which is the output. This ac output is changed to dc for charging the battery by the use of semiconductor diodes, which allow current flow in one direction only.

Deriving the Generator Equation

FIGURE 21–17 The emf is induced in the segments ab and cd, whose velocity components perpendicular to the field $\vec{\mathbf{B}}$ are $v \sin\theta$.

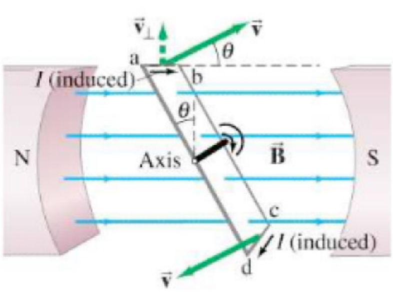


Figure 21–17 shows the wire loop on a generator armature. The loop is being made to rotate clockwise in a uniform magnetic field $\vec{\mathbf{B}}$. The velocity of the two lengths ab and cd at this instant are shown. Although the sections of wire bc and da are moving, the force on electrons in these sections is toward the side of the wire, not along the wire's length. The emf generated is thus due only to the force on charges in the sections ab and cd. From right-hand-rule-3, we see that the direction of the induced current in ab is from a toward b. And in the lower section, it is from c to d; so the flow is continuous in the loop. The magnitude of the emf generated in ab is given by Eq. 21–3, except that we must take the component of the velocity perpendicular to B:

$$\mathscr{E} = Blv_{\perp},$$

where l is the length of ab. From Fig. 21–17 we can see that $v_{\perp} = v\sin\theta$, where θ is the angle the face of the loop makes with the vertical. The emf induced in cd has the same magnitude and is in the same direction. Therefore their emfs add,