



**Figure 23.28** A typical construction of a simple transformer has two coils wound on a ferromagnetic core that is laminated to minimize eddy currents. The magnetic field created by the primary is mostly confined to and increased by the core, which transmits it to the secondary coil. Any change in current in the primary induces a current in the secondary.

For the simple transformer shown in [Figure 23.28](#), the output voltage  $V_s$  depends almost entirely on the input voltage  $V_p$  and the ratio of the number of loops in the primary and secondary coils. Faraday's law of induction for the secondary coil gives its induced output voltage  $V_s$  to be

$$V_s = -N_s \frac{\Delta\Phi}{\Delta t}, \quad 23.24$$

where  $N_s$  is the number of loops in the secondary coil and  $\Delta\Phi/\Delta t$  is the rate of change of magnetic flux. Note that the output voltage equals the induced emf ( $V_s = \text{emf}_s$ ), provided coil resistance is small (a reasonable assumption for transformers). The cross-sectional area of the coils is the same on either side, as is the magnetic field strength, and so  $\Delta\Phi/\Delta t$  is the same on either side. The input primary voltage  $V_p$  is also related to changing flux by

$$V_p = -N_p \frac{\Delta\Phi}{\Delta t}. \quad 23.25$$

The reason for this is a little more subtle. Lenz's law tells us that the primary coil opposes the change in flux caused by the input voltage  $V_p$ , hence the minus sign (This is an example of *self-inductance*, a topic to be explored in some detail in later sections). Assuming negligible coil resistance, Kirchhoff's loop rule tells us that the induced emf exactly equals the input voltage. Taking the ratio of these last two equations yields a useful relationship:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}. \quad 23.26$$

This is known as the **transformer equation**, and it simply states that the ratio of the secondary to primary voltages in a transformer equals the ratio of the number of loops in their coils.

The output voltage of a transformer can be less than, greater than, or equal to the input voltage, depending on the ratio of the number of loops in their coils. Some transformers even provide a variable output by allowing connection to be made at different points on the secondary coil. A **step-up transformer** is one that increases voltage, whereas a **step-down transformer** decreases voltage. Assuming, as we have, that resistance is negligible, the electrical power output of a transformer equals its input. This is nearly true in practice—transformer efficiency often exceeds 99%. Equating the power input and output,

$$P_p = I_p V_p = I_s V_s = P_s. \quad 23.27$$

Rearranging terms gives