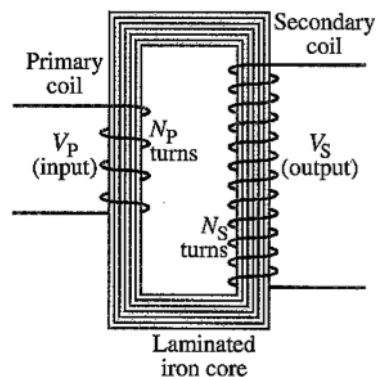


## Transformers

A transformer is a device for increasing or decreasing an AC voltage. They are found everywhere: in TV sets to convert 120 V to the higher voltages needed for the backlight, in the power bricks of many electronic devices to convert 120 V to lower voltages for recharging their batteries, and on hydro poles to convert high voltages from the electrical company to the low voltages (120 V or 240 V) used in homes.

A **transformer** consists of two coils of wire known as the **primary** and **secondary** coils. The two coils can be interwoven (with insulated wire), or they can be linked by an iron core, as shown below.



When an AC voltage is applied to the primary coil, the changing magnetic field it produces will induce an AC voltage of the same frequency in the secondary coil. However, the two voltages will be different, according to the number of loops in each coil.

From Faraday's law, the voltage induced in the secondary coil is

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

Where  $N_s$  is the number of turns in the secondary coil, and  $\Delta\Phi/\Delta t$  is the rate at which the magnetic flux changes.

The input voltage on the primary coil is also given by Faraday's law as

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

Where  $N_p$  is the number of turns in the primary coil.

The term  $\Delta\Phi/\Delta t$  is the same in both of these equations, since the same flux passes through each coil. Dividing these two equations shows that

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

This is called the **transformer equation**. It tells us how the secondary (output) voltage is related to the primary (input) voltage. The ratio  $N_s/N_p$  is referred to as the **turns ratio** of the transformer.

According to the transformer equation, if the secondary coil contains more loops than the primary coil ( $N_s > N_p$ ), the secondary voltage will be greater than the primary voltage. This is called a **step-up transformer**.

According to the transformer equation, if the secondary coil contains less loops than the primary coil ( $N_s < N_p$ ), the secondary voltage will be lower than the primary voltage. This is called a **step-down transformer**.

A well designed transformer is more than 99% energy efficient, meaning very little energy is lost as heat. In other words, the power input and power output are essentially the same. Thus,

$$I_p V_p = I_s V_s$$

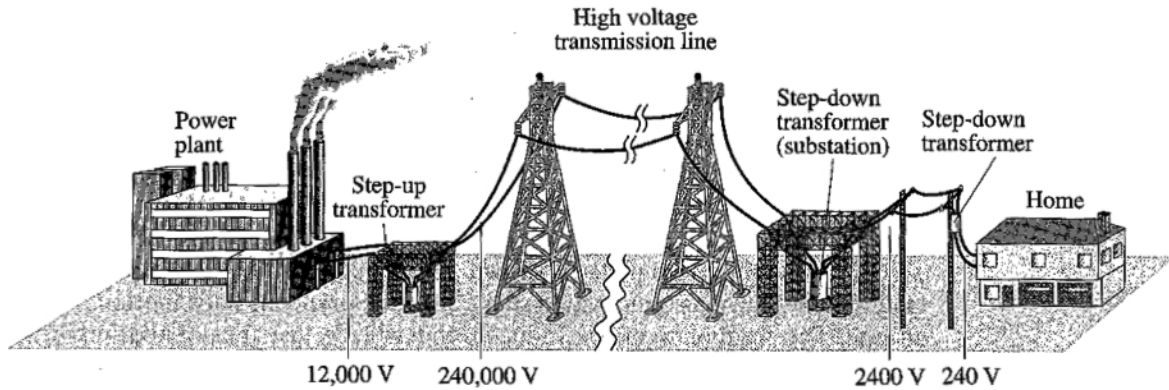
or

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

**Note:** A transformer operates on AC only. A DC current in the primary coil does not produce a changing flux and, therefore, induces no voltage in the secondary.



Transformers play an important role in the transmission of electricity. Power plants are often situated some distance from metropolitan areas, so electricity must then be transmitted over long distances. The diagram below shows how transformers are involved in the process:



There is always some power loss in the transmission lines, and this loss can be minimized if the power is transmitted at high voltage, using transformers, as the following example shows.

### Example 2

An average of 120 kW of electric power is sent to a small town from a power plant 10 km away. The transmission lines have a total resistance of  $0.40 \Omega$ . Calculate the power loss if the power is transmitted at

a) 240 V.

b) 24000 V.

## Transformers Worksheet

1. The batteries in a portable CD player are recharged by a unit that plugs into a wall socket. Inside the unit is a step-down transformer with a turns ratio of  $1/13$ . The wall socket provides  $120\text{ V}$ . What voltage does the secondary coil of the transformer provide? ( $9.2\text{ V}$ )
2. In some places, insect “zappers,” with their blue lights, are a familiar sight on a summer night. These devices use a high voltage to electrocute insects. One such device uses an AC voltage of  $4320\text{ V}$ , which is obtained from a standard  $120\text{ V}$  outlet by means of a transformer. If the primary coil has 21 turns, how many turns are in the secondary coil? (756)
3. Electric doorbells found in many homes require  $10\text{ V}$  to operate. To obtain this voltage from the standard  $120\text{ V}$  supply, a transformer is used. Is a step-up or step-down transformer needed, and what is the turns ratio  $N_s/N_p$ ? (step-down,  $1/12$ )
4. A step-down transformer (turns ratio =  $1/8$ ) is used with an electric train to reduce the voltage from the wall receptacle ( $120\text{ V}$ ) to a value needed to operate the train. When the train is running, the current in the secondary coil is  $3.4\text{ A}$ . What is the current in the primary coil? ( $0.425\text{ A}$ )
5. The secondary coil of a step-up transformer provides the voltage that operates an electrostatic air filter. The turns ratio of the transformer is  $43/1$ . The primary coil is plugged into a standard  $120\text{ V}$  outlet. The current in the secondary coil is  $1.5 \times 10^{-3}\text{ A}$ . Find the power consumed by the air filter. ( $7.7\text{ W}$ )
6. In a television set the power needed to operate the picture tube is  $95\text{ W}$  and is derived from the secondary coil of a transformer. There is a current of  $5.3\text{ mA}$  in the secondary coil. The primary coil is connected to a  $120\text{ V}$  receptacle. Find the turns ratio  $N_s/N_p$  of the transformer. ( $149/1$ )