

# PHYS 10164

## Experiment

# 10

## Transformer

### 1. Introduction

In this experiment you will study electrical characteristics of transformers. In early nineteenth century Oersted discovered that magnetic field always surrounds a current-carrying conductor. Later M. Faraday demonstrated that a change in magnetic flux,  $\Phi$ , generates an electromotive force,  $\varepsilon$ :

$$\varepsilon = -\frac{d\Phi}{dt} \quad (1)$$

The negative sign is in recognition of the Lenz's law.

An iron-core transformer, Fig. 1, is an important device used in alternating current (AC) circuits, which involve these two discoveries. A transformer allows efficiently increase or decrease the line voltage. In its simplest form, the AC transformer consists of two coils of wire wound up around a core of iron as illustrated in Fig. 1.

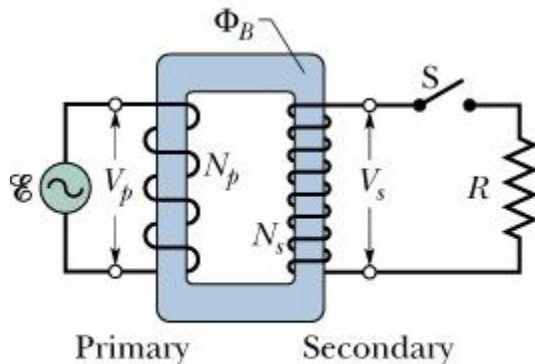


Fig. 1. A schematics of an ideal transformer.  $N_p$  and  $N_s$  are numbers of turns in the primary and secondary coils, respectively.

The core directs the magnetic flux produced by alternating current in the first coil, called the primary, the other coil, called the secondary coil. The core has also another function. It can increase the magnitude of the magnetic flux. The changing flux through the secondary coil induces an alternating electromotive force of the same frequency on its terminals. Thus, electrical power may be transmitted.

The efficiency of commercial transformers is usually better than 90%. For the sake of simplicity, we will first focus on an ideal transformer, which, by definition, has an efficiency of 100%. Later, we will consider energy losses in actual transformers.

When the magnetic flux through a coil of  $N$  turns changes at the rate  $d\Phi/dt$ , the induced electromotive force  $E$  is given by

$$\varepsilon = -N \frac{d\Phi}{dt} \quad (2)$$

Thus, the voltage across the primary is expressed by

$$\varepsilon_p = -N_p \frac{d\Phi}{dt} \quad (3)$$

Since it is an ideal transformer, all magnetic field lines remain within the iron core and the induced electromotive force in the secondary coil can be expressed as:

$$\varepsilon_s = -N_s \frac{d\Phi}{dt} \quad (4)$$

Often, instead of the symbol  $\varepsilon$ , the electromotive force, we use the effective voltage  $V$ .

$$V = \sqrt{2}\varepsilon$$

Solving Eq. 3 for  $d\Phi/dt$  and substituting the result in Eq. 4, gives:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \quad (5)$$

When the primary coil has fewer turns than the secondary, the voltage across the terminals of the secondary coil will be greater than the primary voltage by the ratio  $N_s/N_p$ . Such a transformer is called a step-up transformer. When the number of turns in the secondary coil is less than in the primary, the secondary voltage is reduced and such a transformer is called a step-down transformer.

The ideal transformer has zero power loss, that is, the power input in the primary,  $V_p I_p \cos\theta_p$ , ( $\theta$  is the phase angle between  $V$  and  $I$ ) must be equal the power output in the secondary,  $V_s I_s \cos\theta_s$ . Since  $\theta_p = \theta_s$ , for the ideal transformer

$$V_p I_p = V_s I_s \quad (6)$$

Combining Eq. 6 and Eq. 5 we find

$$I_p = I_s \frac{N_s}{N_p} \quad (7)$$

This equation states that the current ratio is inversely proportional to the turn ratio of the coils. In welding operations, when heat is generated by high currents and for the safety reasons, the associated voltage is small, the step-down transformers are used. The step-up transformers are used at the generators to produce high voltages for efficient transmission of power. Step-down transformers are used at the other end of the transmission line to reduce the voltage to the convenient level.

## 2. Energy losses in transformers

Efficiency of a transformer is defined as a ratio of the output power to the input power. In commercial transformers the efficiency is usually better than 0.9. The power losses in transformers are primarily due to loss of the flux, Eddy currents, magnetization and demagnetization of the core, and resistance heating in the coils, and the change in the phase angle,  $\theta_s$ .

To reduce the Eddy currents the core is built from laminated and insulated sheets of the metal. The resistance of thin sheets of metal is increased and resistance of the core prevents the buildup of large Eddy currents.

To reduce heat losses in the coils they are built from metals of small resistance.

Magnetization and demagnetization of the core requires energy. It is often called the hysteresis loss. To minimize this loss special metal alloys are used, usually it is silicon steel.

Flux leakage is typically caused by breaks between elements of the core. To minimize these losses the cores are made from a single piece of a metal. In the experiment, the core is made of two parts, the U-shape core and the yoke.

### 3. Experiment

Assemble a transformer using two coils, one with 1000 turns and the other with 500 turns. Place the iron core in the shape of letter U into both coils and attach the iron yoke, with the bare side inward, to both ends of the U-core. Mount the transformer onto the breadboard and connect the primary coil to the power supply.

#### 3a. Transformer characteristics with no load on the secondary

Connect the terminals of the secondary coil to a voltmeter. **Make sure that the AC voltage and the range up to 20 volts are selected.** Connect another voltmeter to the terminals of the primary of the transformer. Increase the voltage of the power source and record both the primary and the secondary voltages.

Table 1. Primary and secondary voltage; no load

$V_p$	$V_s$	$V_s/V_p$

Repeat the measurements with the coils exchanged.

Table 2. Transformer with the coils exchanged; no load.

$V_p$	$V_s$	$V_s/V_p$

In the report compare quotients  $V_s/V_p$  and  $N_s/N_p$ .

Turn the power off and remove the yoke from the transformer, but leave the U-core inside.

Repeat the last measurement for one arrangement of coils. Fill out the Table:

Table 3. Transformer without the yoke.

$V_p$	$V_s$	$V_s/V_p$

3b. Transformer characteristics with a load on the secondary

Using the 500 turn coil as a primary connect the circuit as diagrammed in Fig. 2. Use a  $1.00\ \Omega$  resistor. Remember to connect the ammeters in series, see Fig. 3. Remember to set the ammeters to measure current and select the 20 A range. Connect the wires to COM and 20 A ports on the meters. Increase the voltage output of the power supply and record primary and secondary voltages and currents. Record data in Table 4.

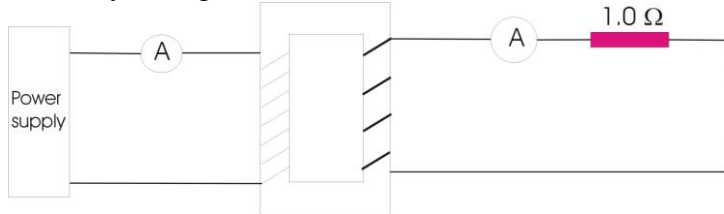


Fig. 2. Experimental setup for current transformation.

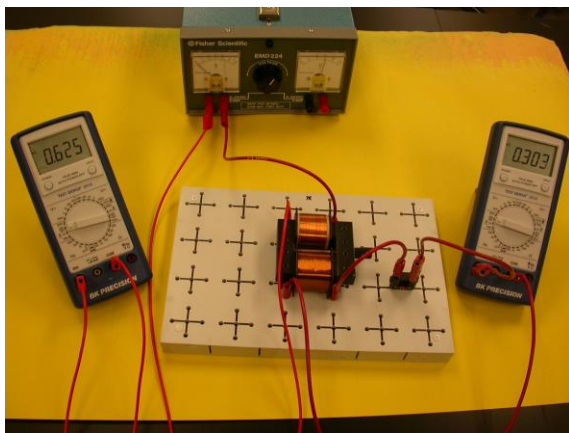


Fig. 3. Photo of the experimental setup.

Table 4. Primary and secondary currents.

$I_p$	$I_s$	$I_s/I_p$

4. Report.

In the introduction explain the nature of the Eddy currents. In the discussion section compare quotients  $V_s/V_p$  and  $N_s/N_p$ . Are these ratios similar? Compare the values  $I_s/I_p$  with the ratio of the turns,  $N_s/N_p$ . Are these quotients similar?