Lecturer 05

Magnetic and Non-Magnetic

Magnetic materials are materials having a magnetic domain and are attracted to an external magnetic field. These materials are strongly attracted by magnets. These materials are basically divided into two groups as magnetically hard and soft materials. Magnetically soft materials can be easily magnetized, but their magnetism is temporary. Magnetically hard materials can be magnetized using a strong magnetic field, and their magnetic properties are permanent.

Apart from that, the magnetic materials are divided into several groups based on the magnetic properties.

Examples for magnetic materials include ferrite (pure iron), magnetite, cobalt, nickel, iron and their metal alloys, etc.

Non-magnetic materials are materials that are not attracted to an external magnetic field. This means non-magnetic materials are not attracted to a permanent magnet. These materials show no response to a magnetic field. That is because the magnetic domains of a non-magnetic material are arranged in a random manner that causes the magnetic moments of these domains to be cancelled out.

The examples of non-magnetic materials include some metals and alloys such as steel etc. And also, polymer materials, wood and glass are also non-magnetic materials.

Paramagnetic substances

Paramagnetic substances are those which are attracted by magnets and when placed in a magnetic field move from weaker to stronger parts of the field.

Paramagnetic materials examples

Familiar examples are:

- aluminum
- manganese
- platinum,
- crown glass
- the solution of salts of iron and oxygen

Property of paramagnetic

- If a bar of paramagnetic material is suspended in between the pole pieces of an electromagnet, it sets itself parallel to the lines of force.
- When a bar of paramagnetic material is placed in a magnetic field the lines of force tend to accumulate in it.
- When a paramagnetic gas is allowed to ascend between the poles pieces of an electromagnet it spreads along the direction of the filed.

Diamagnetic Substances

Diamagnetic substances are those which are repelled by magnets and when placed in magnetic field move from stronger to weaker part of the field.

Diamagnetic materials examples

Familiar examples of these are:

- bismuth
- phosphorus
- antimony
- copper
- water
- alcohol
- hydrogen

Properties of Diamagnetic materials

- When a diamagnetic substance is placed in a magnetic field it sets itself at right angles to the direction of the lines of force.
- When diamagnetic material is placed within a magnetic field the lines of force tend to go away from the material.
- When a diamagnetic gas is allowed to ascend between, the poles piece of an electromagnet it spreads across the field.

Ferromagnetic Substances

Ferromagnetic substances are those which are attracted by the magnets and can also be magnetized.

Ferromagnetic materials examples

Familiar examples are:

- iron
- nickel
- cobalt and their alloys

Properties of Ferromagnetic Substances

- The ferromagnetic substance shows the properties of the paramagnetic substance to a much greater degree.
- The susceptibility has a positive value and the permeability is also very large.
- The intensity of magnetization I is proportional to the magnetizing field H for a small value.

Types of Magnets

The three types of magnets are temporary, permanent, and electromagnets.

1. **Temporary magnets become magnetized in the presence of a magnetic field. They lose their magnetism gradually, when the magnetic field is removed. Some irons and iron alloys, as well as paper clips and nails, function as temporary magnets.**
2. **Permanent magnets do not easily lose their magnetism. These magnets may be naturally-occurring (“rare-earth”) elements, or**

chemical compounds. Permanent magnet examples include Alnico (an alloy of aluminum, nickel, and cobalt) and ferrites (ceramic-like material made from a mix of iron oxides with nickel, strontium, or cobalt).

3. **Electromagnets are created by running an electrical current through a coil with a metal core. The energized coil creates a magnetic field. It consists of a coil wound over a soft iron core. When current is passed through a coil, it produces magnetic field which magnetizes the core into bar magnet with north and south polarities. More current and more turn produces a stronger magnetic field, so we have strong electromagnet. When current is switched off, the magnetic field disappear.**

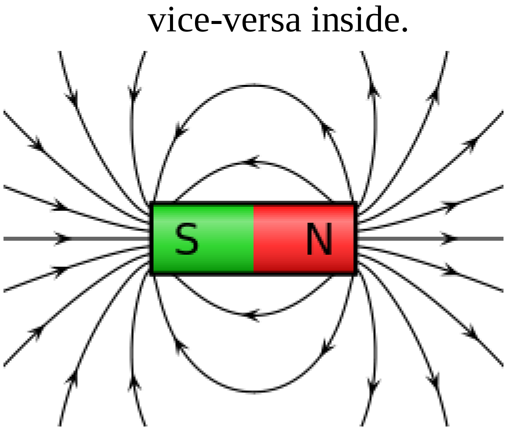
   Electromagnets are preferred for applications that require strength including rail road tracks, motor engines, MRI machines, and cranes. They're also used in computer and television hardware.

Magnetic field

A magnetic field is a picture that we use as a tool to describe how the magnetic force is distributed in the space around magnet. The magnetic field is described mathematically as a *vector field*. This vector field can be plotted directly as a set of many vectors drawn on a grid. Each vector points in the direction that a compass would point and has length dependent on the strength of the magnetic force.

Properties of magnetic field lines:

- They are drawn locally as parallel trajectories.
- They never intersect each other (if they do, it means that one pole is pointing in two directions).
- They start from North and terminate at South, outside the magnet, and vice-versa inside.

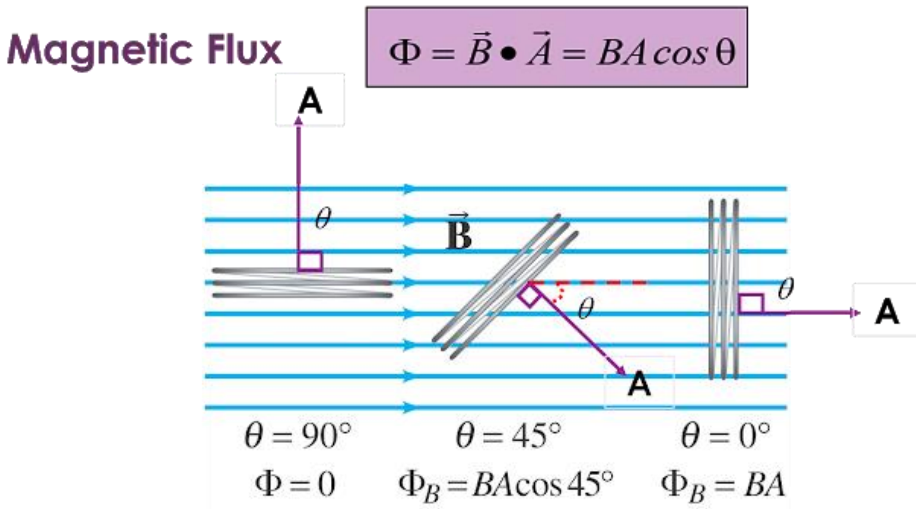


Magnetic flux

Magnetic flux is a measurement of the total magnetic field which passes through a given area. It is a useful tool for helping describe the effects of the magnetic force on something occupying a given area.

$\Phi = B\,A\cos\theta$

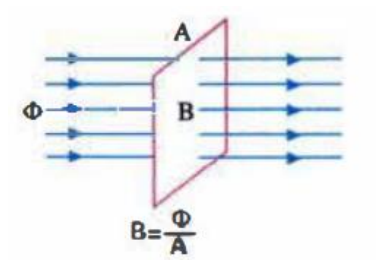
The measurement of magnetic flux is tied to the particular area chosen.



The unit of magnetic flux is Weber(Wb)

Magnetic Flux Density (B)

It is the flux per unit area. Its unit is Tesla (T) or Wb/m^2



magnetic field strength = flux density

= flux per unit area

$$B = \frac{\phi}{A}$$

$$\boxed{\phi = BA}$$

Example

If the flux density in a certain magnetic material is 0.23 T and the area of the material is 0.38 $in.^2$, what is the flux through the material?

Solution First, 0.38 $in.^2$ must be converted to square meters. 39.37 in. = 1 m; therefore,

$$A = 0.38\ in.^2[1\ m^2/(39.37\ in.)^2] = 245 \times 10^{-6}\ m^2$$

The flux through the material is

$$\phi = BA = (0.23\ T)(245 \times 10^{-6}\ m^2) = \mathbf{56.4\ \mu Wb}$$

Example

In a certain magnetic field the cross-sectional area is 0.5 m^2 and the flux is 1500 μWb. What is the flux density?

Example

What is the flux in a magnetic material when the flux density is 2500×10^{-6} T and the cross-sectional area is 150 cm^2?

Magnetic Field Strength (H)

The intensity of the magnetic field is also called magnetizing force. As each magnet has its own magnetic field directed from north to south. When a magnetic material is placed in magnetic field, it become more magnetized whereas non-magnetic material remains unaffected.

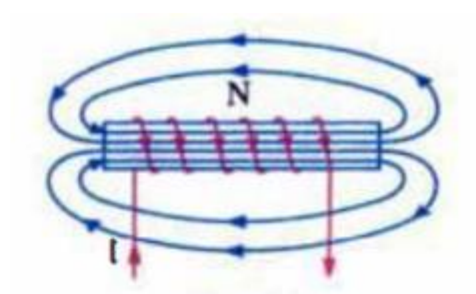
The magnetic field intensity in a material is defined to the magnetomotive force (F_m) per unit length (L). the unit of magnetic field intensity (H) is ampere-turns.

$$\mathbf{H} = \frac{\mathbf{F_m}}{\mathbf{L}}$$

Where F_m = NI. Note that the magnetic field intensity (H) depends on the number of turns(N) of the coil of wire, the current (I) through the coil and the length(L) of the material. It does not depend upon the type of the material. The unit of H is newton/weber.

Magnetizing Force of Solenoid

If L is the length of the iron core, the value of the magnetizing force produced by the electromagnet is



$$\mathbf{H} = \frac{\mathbf{F_m}}{\mathbf{L}} = \frac{NI}{L} = \mathbf{A/m}$$

Permeability (μ)

The ease with which a magnetic field can be established in a given material is measured by the permeability of the material. The higher the permeability, the more easily the magnetic field can be established.

A material's permeability depends on its type. The permeability of a vacuum (μ_o) is $4\pi \times 10^{-7}$Wb/At. m (weber/ampere-turn. m) and used as reference. Permeability of ferromagnet is hundreds of times greater than vacuum. The relative permeability (μ_r) of the material is the ratio of absolute permeability (μ) to permeability of the vacuum (μ_o)

$$\mu_r = \frac{\mu}{\mu_0}$$

It is unitless quantity.

Ohm's law for magnetic circuits

Like electric circuits, in magnetic circuits there are three quantities which are interconnected. These three quantities are

1. Magnetomotive force
2. Magnetic flux
3. Reluctance

Reluctance

The opposition to the establishment of a magnetic field in a material is called reluctance. The value of reluctance is directly proportional to the length (l) of the magnetic path, and inversely proportional to the permeability (μ) and to cross-sectional area (A) of the material and expressed as

$$\mathfrak{R} = \frac{l}{\mu A}$$

Reluctance in magnetic circuit is analogous to resistance in electric circuit. The unit of reluctance is

$$\mathfrak{R} = \frac{l}{\mu A} = \frac{\text{m}}{(\text{Wb/At}\cdot\text{m})(\text{m}^2)} = \frac{\text{At}}{\text{Wb}}$$

Ampere-turn/weber

Magnetomotive Force (m m f)

The current in a conductor produces a magnetic field. The cause of a magnetic field is called the magnetomotive force (mmf). The unit of mmf, the ampere-turn(At). The formula for mmf is

$\mathbf{F_m = NI}$

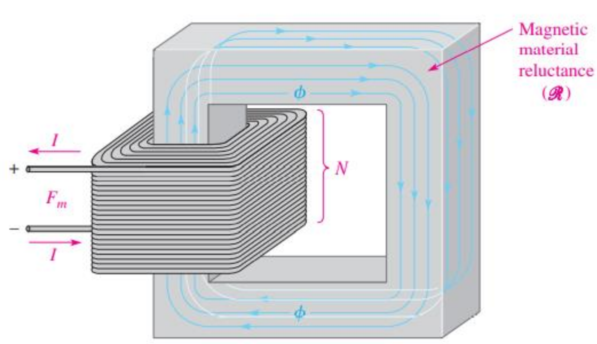
Where F_m is the magnetomotive force, N is the number of turns of wire and I is the current.

The amount of flux depends on the magnitude of the mff and on the reluctance of the material, as expressed by the following equation:

$$\phi = \frac{F_m}{\mathfrak{R}}$$

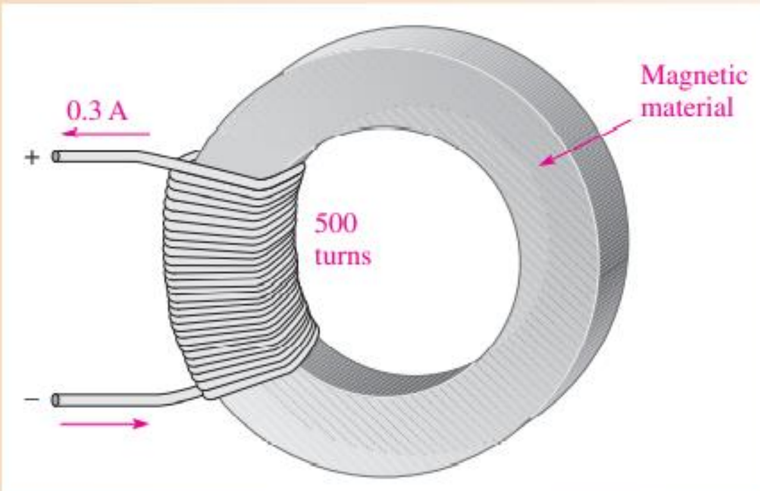
This equation known as ohm's law for electromagnetic circuits because the flux (ϕ) is analogous to current, the mmf (F_m) is analogous to voltage and the reluctance ($\mathcal{R}$) is analogous to resistance.

The basic electromagnetic circuit



Example

How much flux is established in the magnetic path of Figure 14 if the reluctance of the material is 2.8×10^5 At/Wb?



$$\phi = \frac{F_m}{\mathcal{R}} = \frac{NI}{\mathcal{R}} = \frac{(500\ \text{t})(0.3\ \text{A})}{2.8 \times 10^5\ \text{At/Wb}} = 5.36 \times 10^{-4}\ \text{Wb} = \mathbf{536\ \mu Wb}$$

Example

There is 0.1 ampere of current through a coil with 400 turns.

(a) What is the mmf?

(b) What is the reluctance of the circuit if the flux is 250 μWb?

Solution **(a)** $N = 400$ and $I = 0.1$ A

$$F_m = NI = (400\ \text{t})(0.1\ \text{A}) = \mathbf{40\ At}$$

(b) $$\mathcal{R} = \frac{F_m}{\phi} = \frac{40\ \text{At}}{250\ \mu\text{Wb}} = \mathbf{1.60 \times 10^5\ At/Wb}$$

Transformer

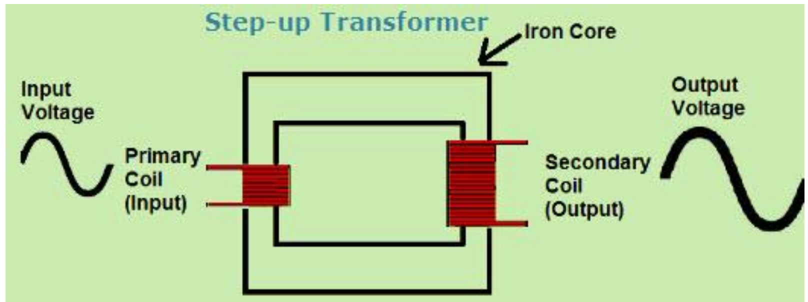
Transformer is an electrical apparatus designed to convert alternating current from one voltage to another. It can be designed to "step up" or "step down" voltages and works on the magnetic induction principle. A voltage is then induced in the other coil, called the secondary or output coil.

There are two types of transformer categorized on the basis of a number of turns in the primary and secondary windings and the induced emf.

1. **Step-up transformer**

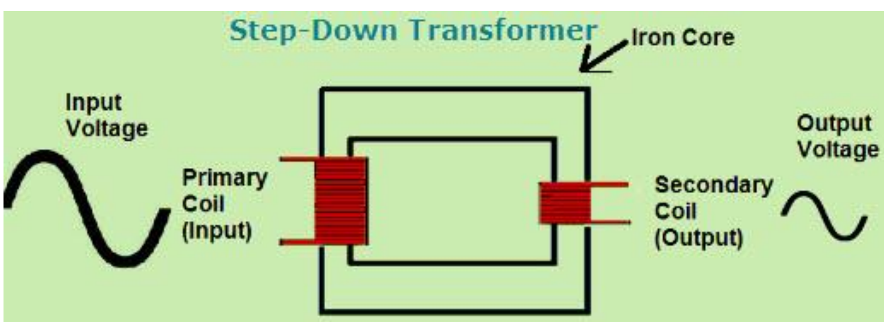
Step-up transformer transforms a low voltage, high current AC into a high voltage, low current AC system In this type of transformer the number of turns in the secondary winding is greater than the number of turns in the primary winding. If

($V_2 > V_1$) the voltage is raised on the output side and is known as Step-up transformer.



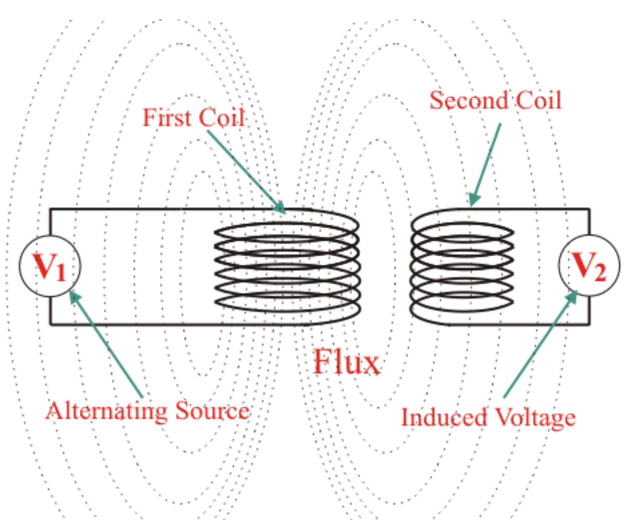
2. **Step down transformer**

Step down transformer converts a high primary voltage associated with the low current into a low voltage, high current. With this type of transformer, the number of turns in the primary winding is greater than the number of turns in the secondary winding. If ($V_2 < V_1$) the voltage level is lowered on the output side and is known as Step down transformer.



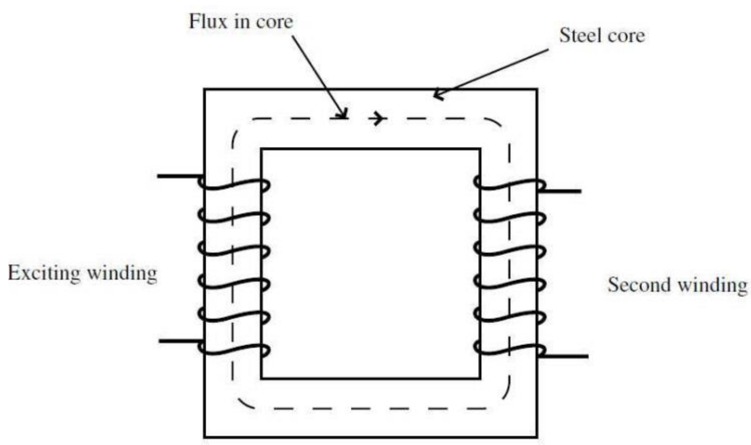
Air Core Transformer

Both the primary and secondary windings are wound on a non-magnetic strip where the flux linkage between primary and secondary windings is through the air. Compared to iron core the mutual inductance is less in air core, i.e. the reluctance offered to the generated flux is high in the air medium. But the hysteresis and eddy current losses are completely eliminated in air-core type transformer.



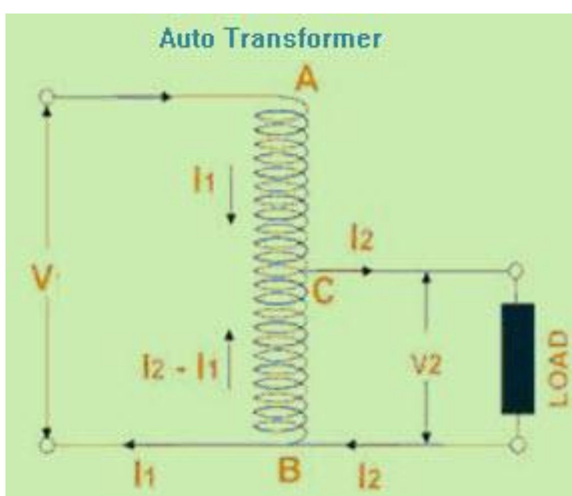
Iron Core Transformer

Both the primary and secondary windings are wound on multiple iron plate bunch which provide a perfect linkage path to the generated flux. It offers less reluctance to the linkage flux due to the conductive and magnetic property of the iron. These are widely used transformers in which the efficiency is high compared to the air core type transformer.



AutoTransformer

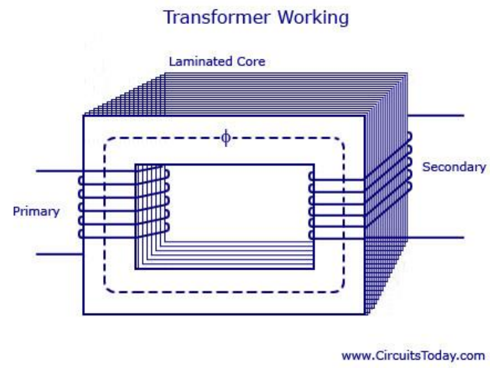
Standard transformers have primary and secondary windings placed in two different directions, but in autotransformer windings, the primary and the secondary windings are connected to each other in series both physically and magnetically as shown in the figure below.



On a single common coil which forms both primary and secondary winding in which voltage is varied according to the position of secondary tapping on the body of the coil windings.

Transformer – Working Principle

The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance. The working principle of the transformer can be understood from the figure below.



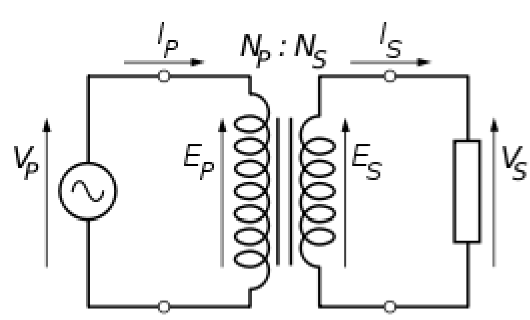
Transformer Working

As shown above the electrical transformer has primary and secondary windings. The core laminations are joined in the form of strips in between the strips you can see that there are some narrow gaps right through the cross-section of the core. These staggered joints are said to be ‘imbricated’. Both the coils have high mutual inductance. A mutual electro-motive force is induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage. Most of the alternating flux developed by this coil is linked with the other coil and thus produces the mutual induced electro-motive force. The so produced electro-motive force can be explained with the help of Faraday’s laws of Electromagnetic Induction as

$$e=M*dI/dt$$

If the second coil circuit is closed, a current flow in it and thus electrical energy is transferred magnetically from the first to the second coil. The alternating current supply is given to the first coil and hence it can be called as the primary winding. The energy is drawn out from the second coil and thus can be called as the secondary winding.

Ideal power equation of Transformer



$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

If the secondary coil is attached to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Ideally, the transformer is perfectly efficient. All the incoming energy is transformed from the primary circuit to the magnetic field and into the secondary circuit. If this condition is met, (i.e, in Ideal transformer) the input electric power must equal the output power**:**

$$P_{\text{incoming}} = I_{\text{p}} V_{\text{p}} = P_{\text{outgoing}} = I_{\text{s}} V_{\text{s}},$$

$$\frac{V_{\text{s}}}{V_{\text{p}}} = \frac{N_{\text{s}}}{N_{\text{p}}} = \frac{I_{\text{p}}}{I_{\text{s}}}.$$

giving the ideal transformer equation:

Example: A transformer has 400 turns on the primary and 1200 turns on the secondary. If 120 volts of AC current are applied across the primary, what voltage is induced into the secondary?

EXAMPLE: A transformer has 400 turns on the primary and 1200 turns on the secondary. If 120 volts of AC current are applied across the primary, what voltage is induced into the secondary?

Given	Solution
$E_S = ?$	$\frac{E_S}{E_P} = \frac{N_S}{N_P}$
$E_P = 120\ V$	
$N_S = 1200$ turns	$\frac{E_S}{120} = \frac{1200}{400}$
$N_P = 400$ turns	
	$E_S = 360\ V$

(The ideal transformer as a circuit element)

If the voltage is increased, then the current is decreased by the same factor. The impedance in one circuit is transformed by the square of the turns ratio. For example, if an impedance Zs is attached across the terminals of the secondary coil, it appears to the primary circuit to have an impedance of $(Np/Ns)^2$ Zs. This relationship is reciprocal, so that the impedance Zp of the primary circuit appears to the secondary to be $(Ns/Np)^2$Zp.