Lecture 5

Inductors

Transformers

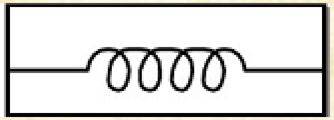
Inductors

Inductors

Inductor is a passive energy storage element that stores energy in the form of magnetic field.

Inductors are formed from coils of wire, often around a steel or ferrite core.

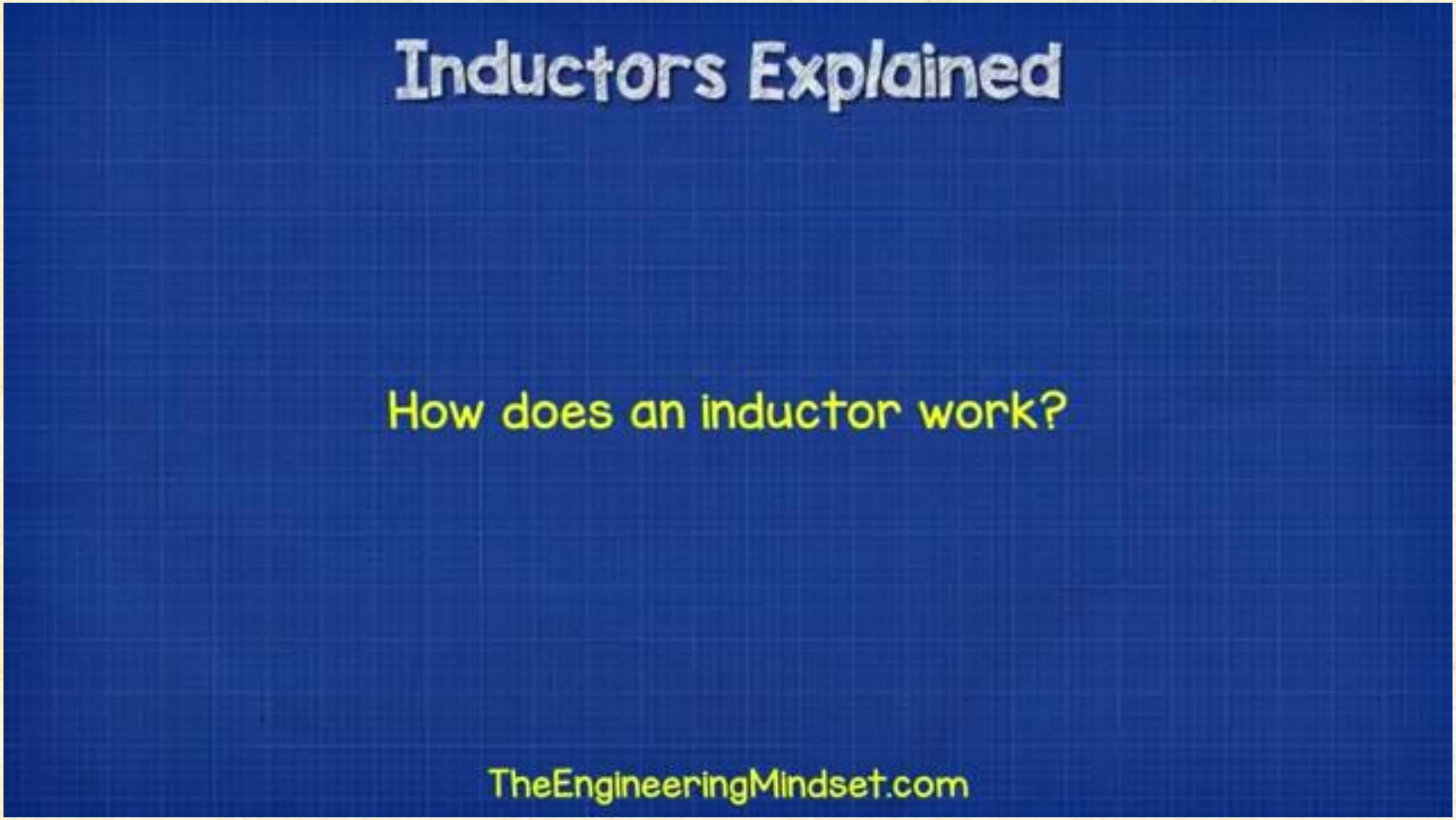
Unit of Inductors Henry (H)



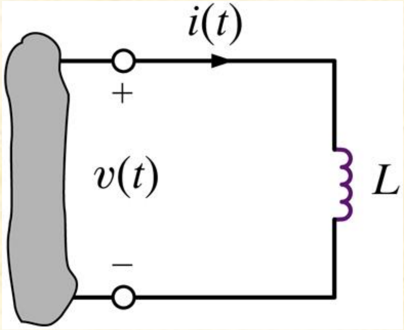
Symbol of Inductors (L)

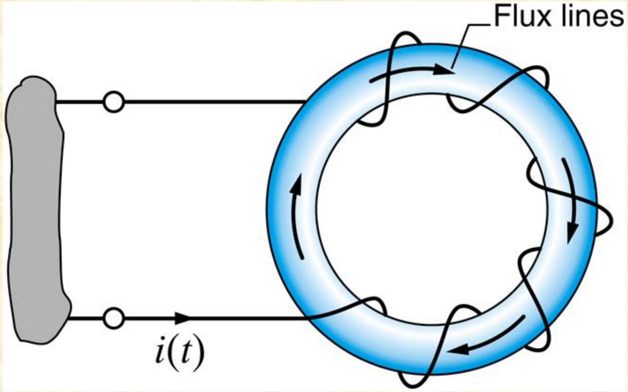
Inductor characteristic is governed by Faraday's law:

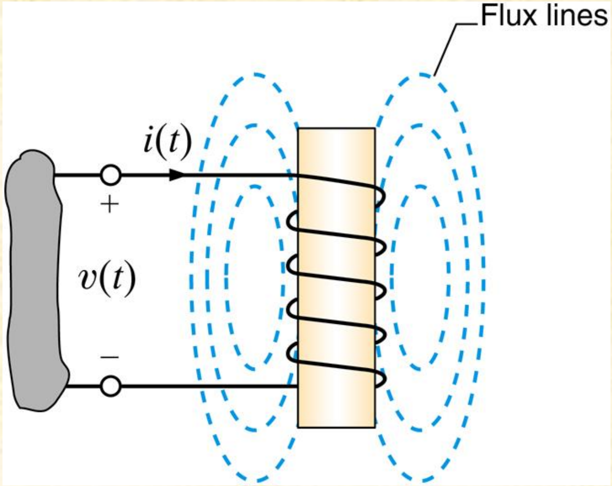
Inductors


Inductors Explained
How does an inductor work?
TheEngineeringMindset.com

V-I characteristic of an inductor







$$V(t) = \frac{d\lambda}{dt}$$

–V = voltage induced across an inductor

–λ = magnetic flux (unit: Webers, Wb) through the coil windings (a coil made using resistance-less wires) due to current flowing through inductor.

For an ideal coil, magnetic flux is proportional to current, so

$\lambda \propto I \;\; or \;\; \lambda = LI$

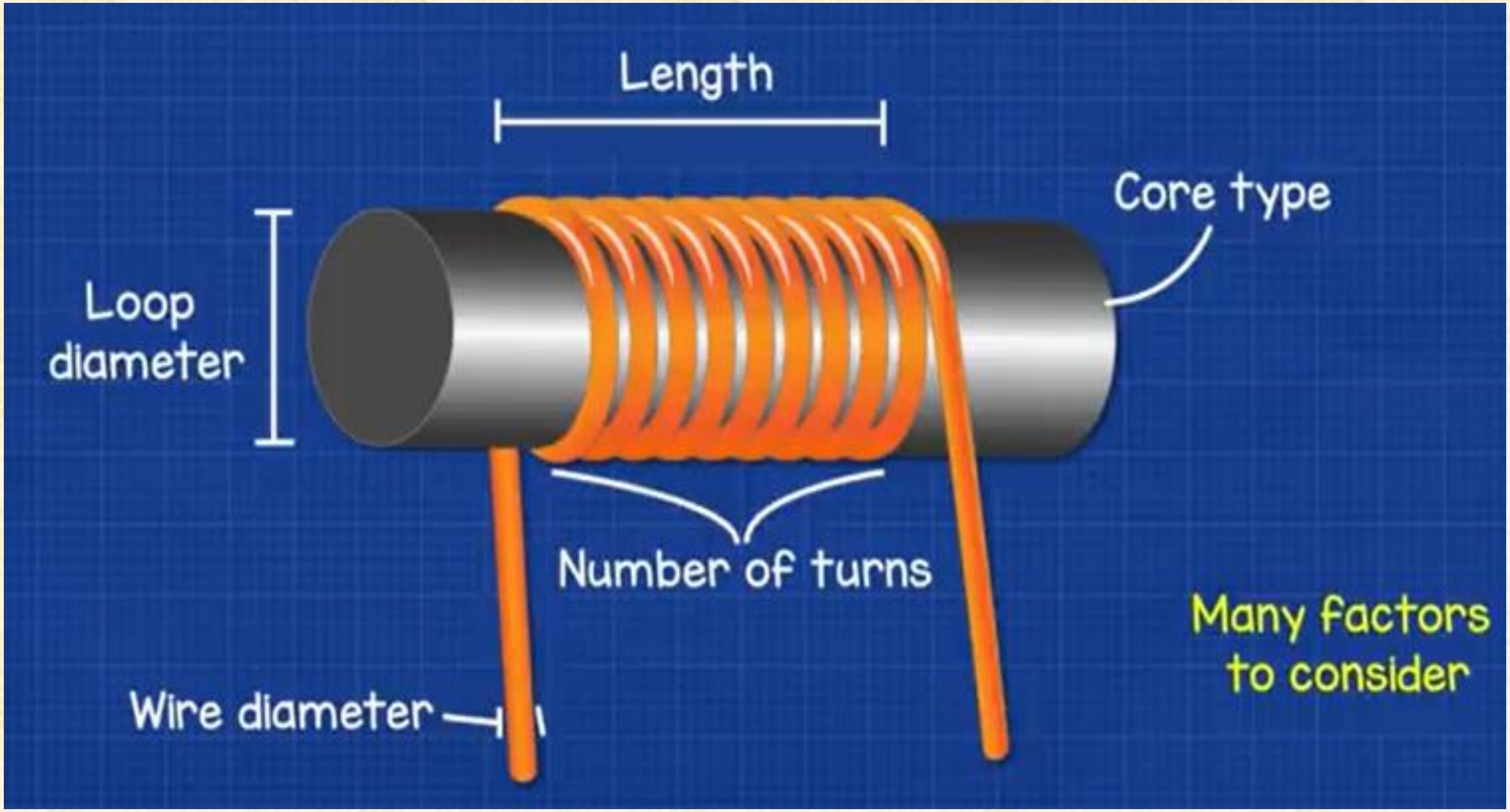
L is constant of proportionality, called inductance (unit: Henry, Wb/Amp).

So, now, the V-I characteristic of an inductor is:

$$V(t) = \frac{d}{dt}(\lambda) = \frac{d}{dt}(LI) = L\frac{dI}{dt}$$

The above V-I characteristics demonstrate that the current through an inductor can not be altered instantaneously.

Inductors Construction



Inductance of the coils

Four factors affect the amount of inductance for a coil. The equation for the inductance of a coil is

$$L = \frac{N^2 \mu A}{l}$$

where

L = inductance in Henries

N = number of turns of wire

μ = permeability of the core (H/m)

A = area of the core

l = coil length in meters

μ = permeability of the free space* permeability of the core

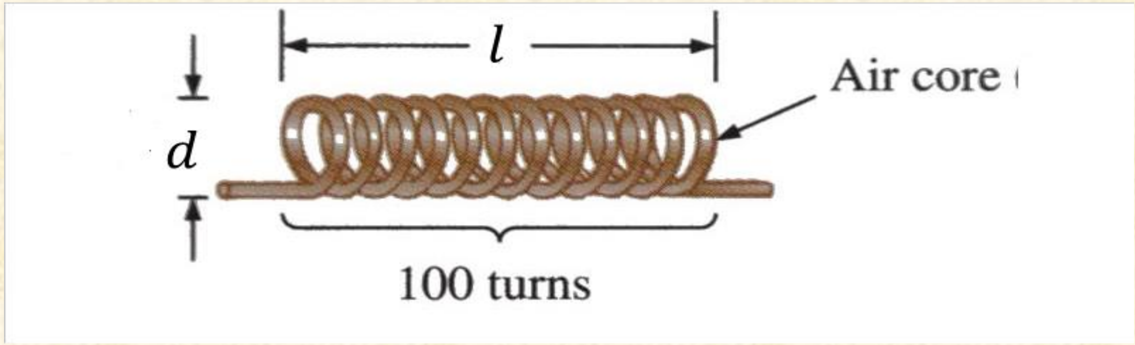
$$\mu = \mu_o \, X \, \mu_r$$

$$L = \frac{N^2 \ \mu_o \, \mu_r \, A}{l}$$

$$\mu_o = 4\pi \times 10^{-7} \text{ H/m}$$

$\mu_r = 1$ For air core

Example:



For the air-core coil

a) Find the inductance

$d = 6.35\ mm$ $\qquad l = 25.4\ mm$

$$L = \frac{N^2\ \mu_o\, \mu_r\, A}{l} \qquad \mu_r = 1 \qquad \mu_o = 4\pi \times 10^{-7}\ \text{H/m}$$

$$A = \frac{\pi\, d^2}{4} \qquad A = 3.17\ * 10^{-6}\ m^2$$

$$L = \frac{(100)^2\ * 4\pi * 10^{-7}\frac{H}{m} * 3.17 * 10^{-6}\ m^2}{25.4 * 10^{-3} m} = 1.558\ * 10^{-10}\ H$$

$$L = 15.58\ * \mu\, H$$

b) Find the inductance if a metallic core with μ_r = 2000 is inserted in the coil

$$\mu_r = 2000$$

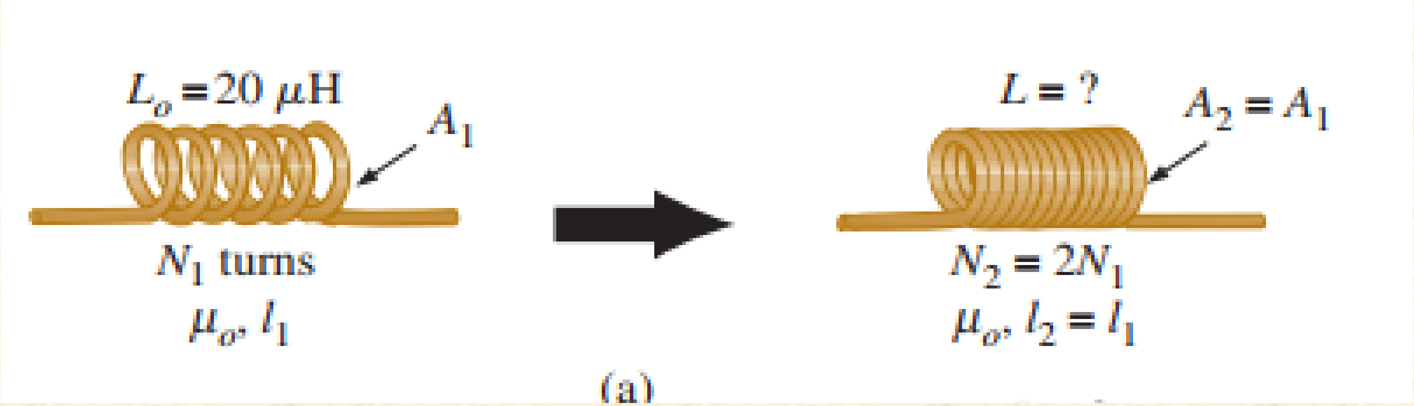
$$L = \frac{(100)^2 \ *4\pi*10^{-7}\frac{H}{m}*3.17 *10^{-6}\ m^2}{25.4*10^{-3}m} * 2000 = 3.13 * 10^{-7}\ H$$

$$L = 31.36\ * m\,H$$

Example:

In the next figures, if each inductor in the left column is changed to the type appearing in right column, find the new inductance level . For each change, assume that the other factors remain the same

Solution:

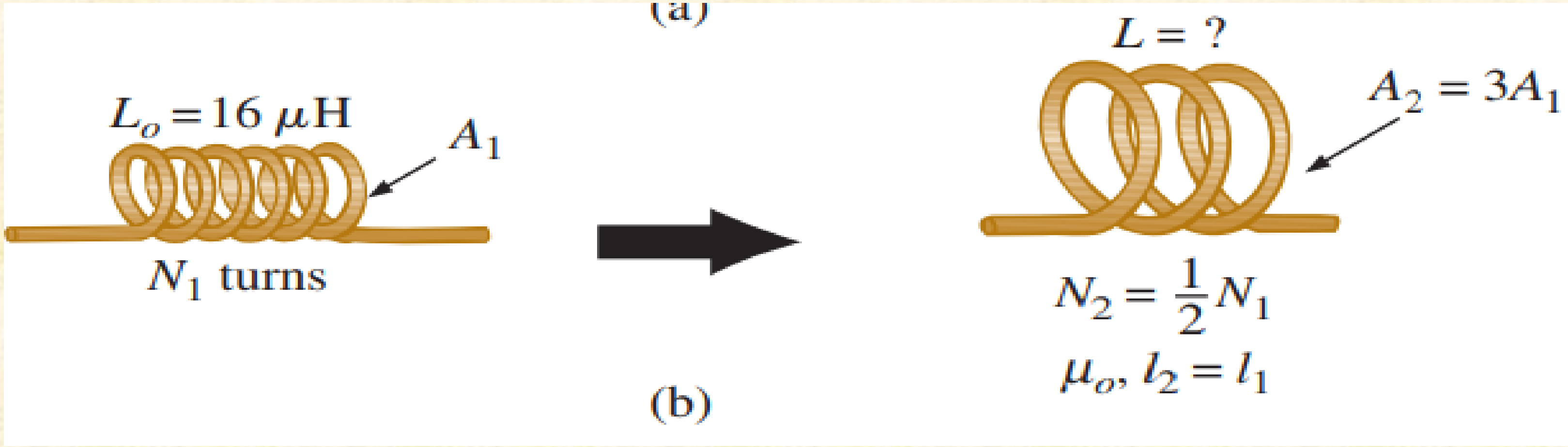


a- In figure a the only change was the number of the turns, but it's a squared factor, resulting in

$$L = \frac{N^2\ \mu_o\, \mu_r\, A}{l}$$

$$L = 2^2\ L_o$$

$$L = 4\ * 20 = 80\ \mu H$$

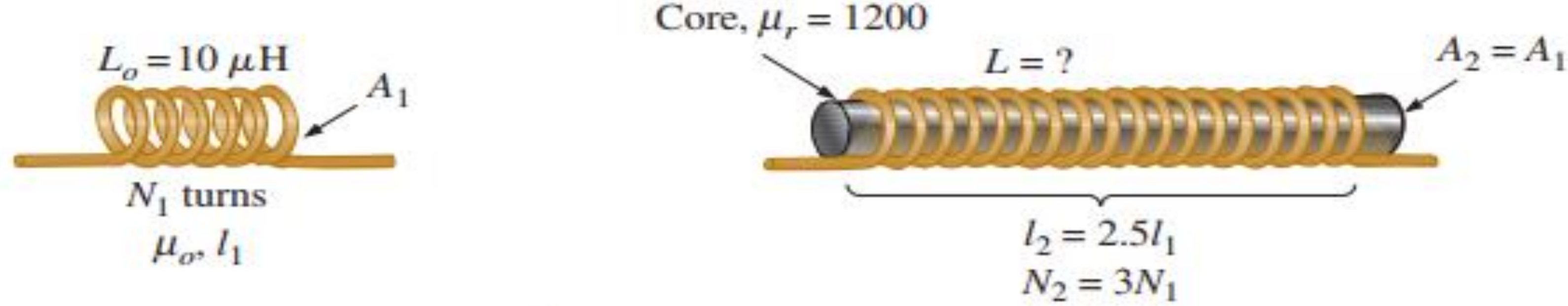


b- In this case, the area is three times the original size, and the number of turns is 1/2. Since the area is in the numerator, it increases

$$L = \frac{N^2\ \mu_o\, \mu_r\, A}{l}$$

$$L = (3) * \frac{1}{4} L_o \qquad L = (3) * \frac{1}{4} * 16$$

$$L = 12\ \mu H$$



(c)

c- Both μ and the number of turns have increased, although the increase in the number of turns is squared. The increased length reduces the inductance. Therefore,

$$L = \frac{N^2\ \mu_o\, \mu_r\, A}{l}$$

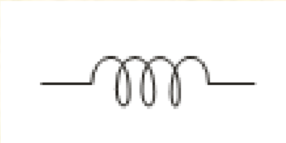
$$L = \frac{3^2\ * 1200}{2.5} L_o \qquad L = (4.32\ *\ 10^3) * 10$$

$$L = 34.2\ \ mH$$

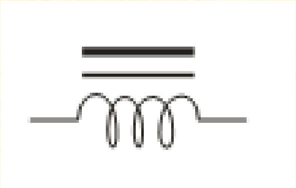
Symbols for inductors

Common symbols for inductors (coils)

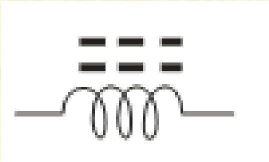
Air core



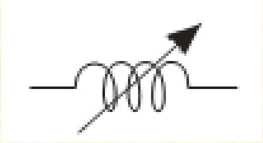
Iron core



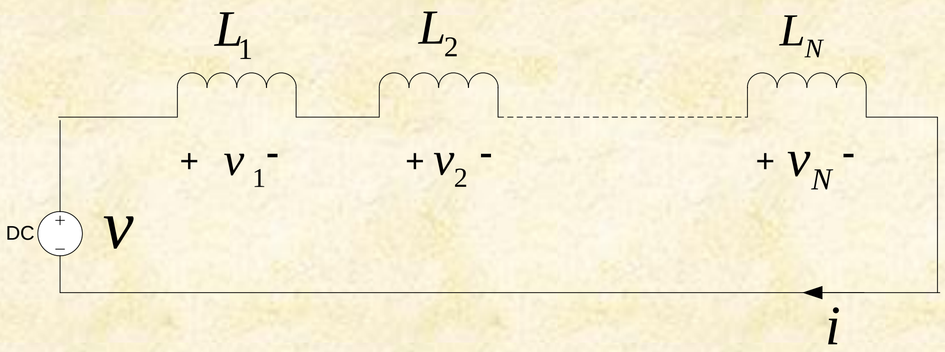
Ferrite core

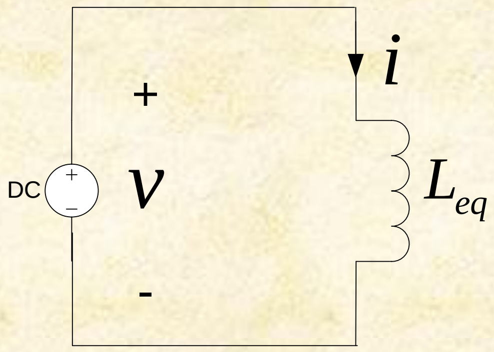


Variable



Inductors Connected in Series



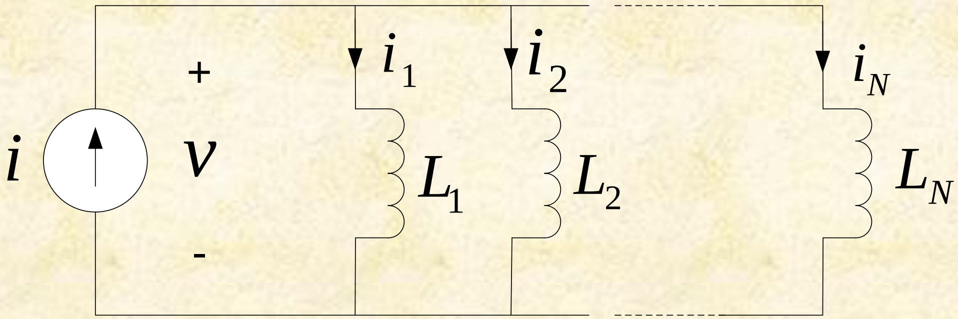


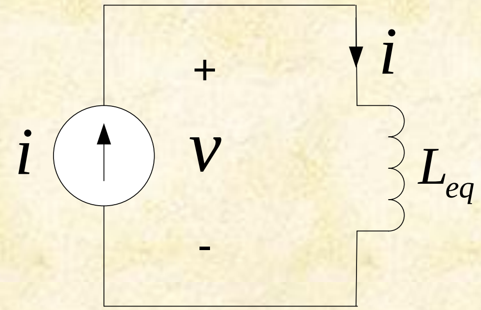
$$v_1 = L_1 \frac{di}{dt} \qquad v_2 = L_2 \frac{di}{dt} \qquad v_N = L_N \frac{di}{dt}$$

$$v = v_1 + v_2 + \cdots + v_N = \left(L_1 + L_2 + \cdots + L_N\right)\frac{di}{dt} = L_{eq}\frac{di}{dt}$$

$$L_{eq} = \sum_{k=1}^{N} L_k$$

Inductors Connected in Parallel





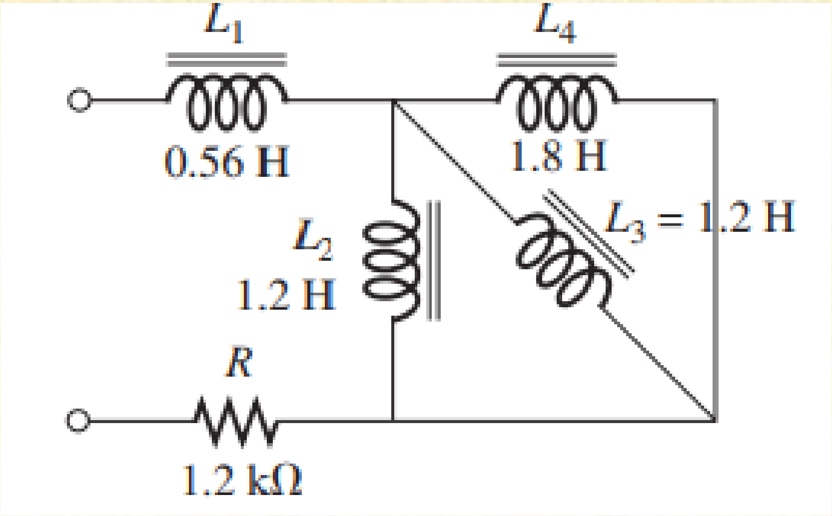
$$i_1 = \frac{1}{L_1}\int v\,dt \qquad i_2 = \frac{1}{L_2}\int v\,dt \qquad i_N = \frac{1}{L_N}\int v\,dt$$

$$i = i_1 + i_2 + \cdots + i_N = \left(\frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_N}\right)\int v\,dt = \frac{1}{L_{eq}}\int v\,dt$$

$$\frac{1}{L_{eq}} = \sum_{k=1}^{N}\frac{1}{L_k}$$

Example:

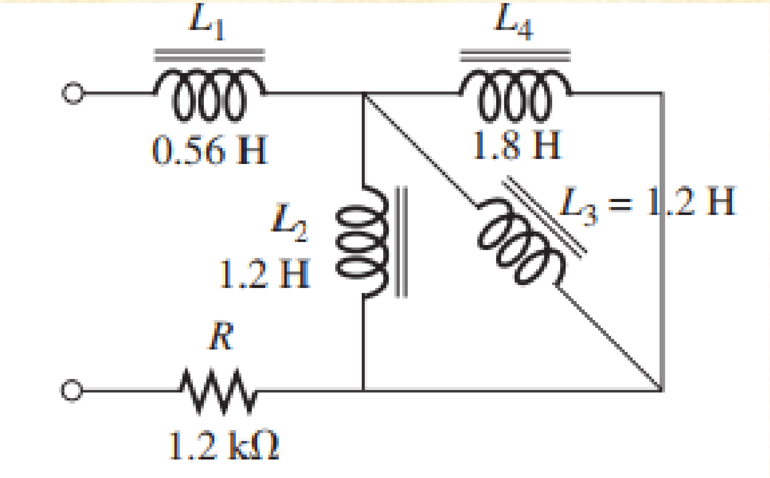
Reduce the network in the next figure to its simplest form



Solution:

Inductors L2 am L3 are equal in value and they are in parallel. Resulting in an equivalent parallel value of

$$\frac{1}{Lt1} = \frac{1}{L_2} + \frac{1}{L_3} \quad = \frac{1}{1.2} + \frac{1}{1.2} \quad l_{t1} = 0.6\ H$$

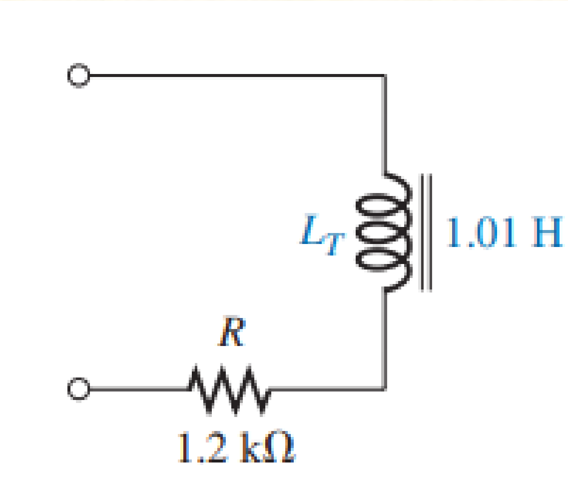


The resulting 0.6 H is then in parallel with 1.8 H inductor, then

$$Lt2 = \frac{Lt1 \ * \ L_4}{Lt1 + L_4} \qquad Lt2 = \frac{0.6 \ * \ 1.8}{0.6 + 1.8}$$

$$l_{t2} = 0.45\ H$$

Then L1 and /lt2 are series



$$l_T = L_1 + L_{t2} \qquad l_T = 0.56 + 0.45$$

$$l_T = 1.01\ H$$

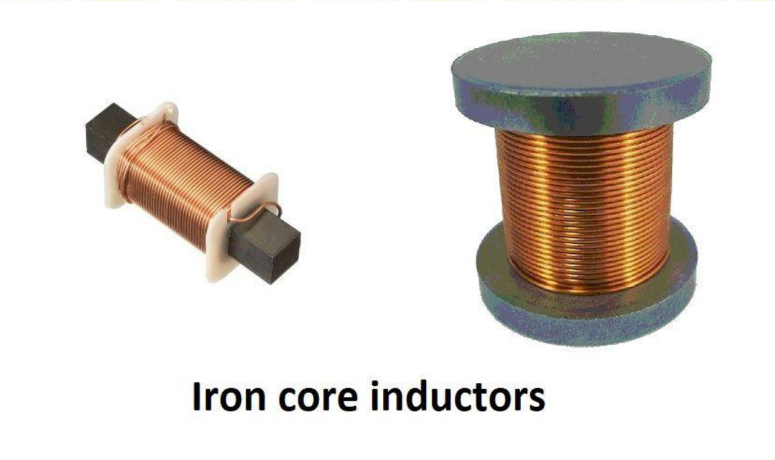
Type of Inductor

Air core inductors

This kind of inductor has no core – the core material is air! Since air has a relatively low permeability, the inductance of air core inductors is quite low – rarely above 5uH.

Iron core inductors

These take the form of iron-core inductors. They are usually used for low frequency line filtering, industrial power supplies and audio equipment.



Type of Inductor

Ferrite core inductors

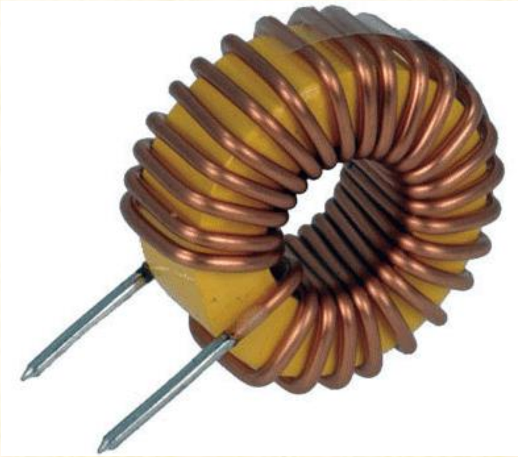
Ferrite is just a powder of oxides of iron. Ferrite core inductors are easily the most recognizable because of their dull grey-black colour. They also are very brittle and break easily. They are the most widely used kinds of inductors, since the permeability can be finely controlled by controlling the ratio of ferrite to epoxy in the mix.

Type of Inductor

Axial Inductors / Color ring inductor

Its make of a very thin copper wire is wrapped around a dumbbell-shaped ferrite core, and two lids are connected at the top and the bottom of the dumbbell core.

Toroidal coil



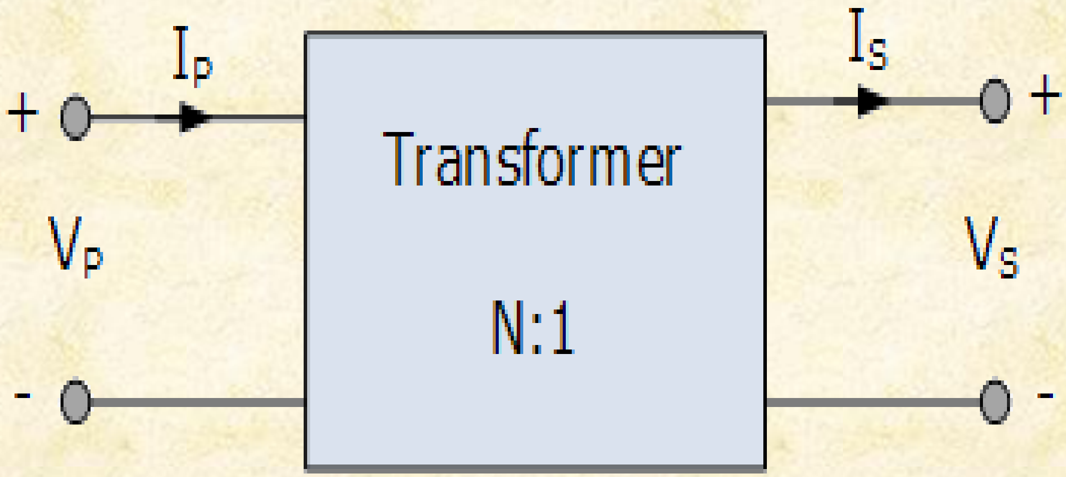
Due to the high magnetic field and high inductance value with fewer windings, the impedance is very less which helps to improve the efficiency of the inductor.

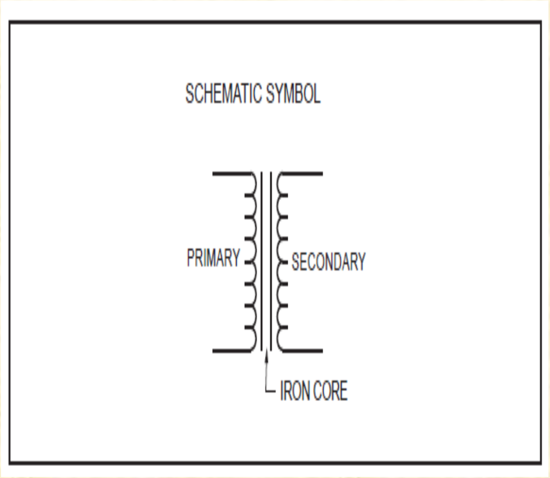
Transformers

Introduction to Electricity

Transformers

The transformer is a static device (i.e. the one which does not contain any rotating or moving parts) which is used to transfer electrical energy from one Ac circuit to another Ac circuit, with increase or decrease in voltage/current but without any change in frequency.

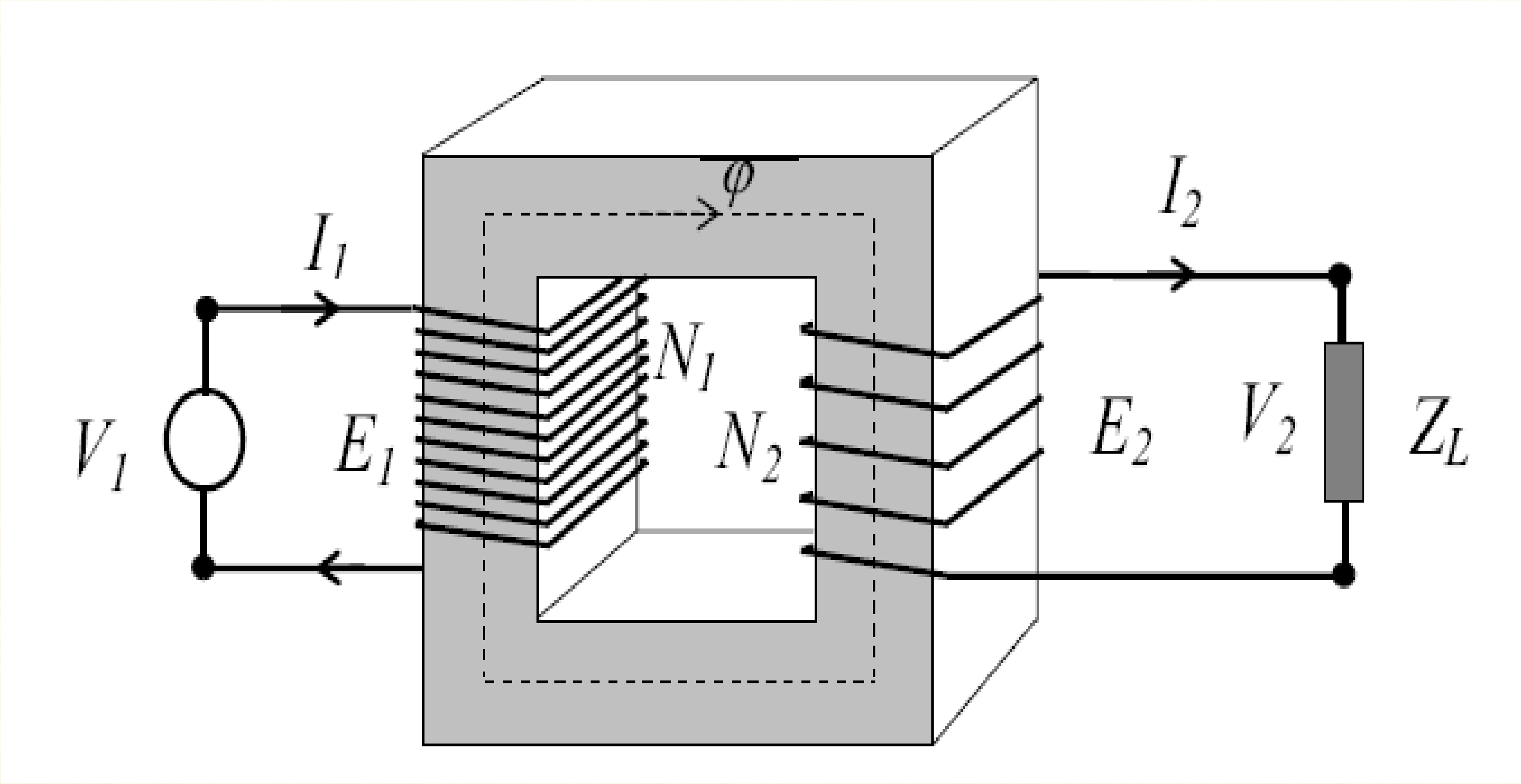




Introduction to Electricity

Transformers

Transformers are electrical devices used to convert or "transform" AC voltage from one level to another. (high to low or low to high)

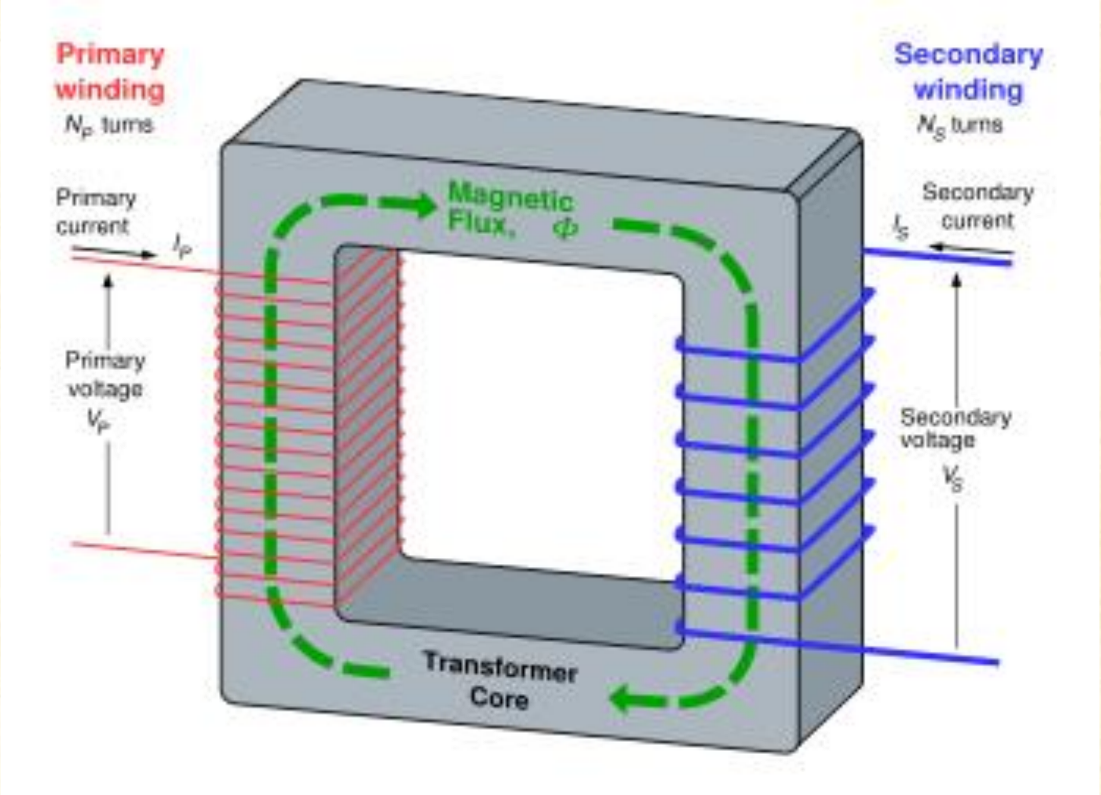


Input and output are AC

Parts of a Transformer

A transformer consists of 3 basic components

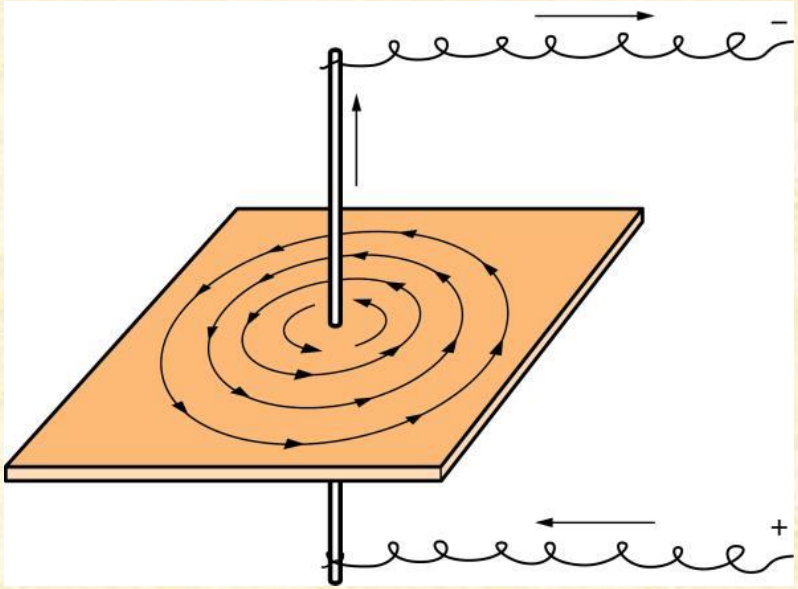
Primary Coil or Primary Winding : It is an electrical wire wrapped around the core on the input side

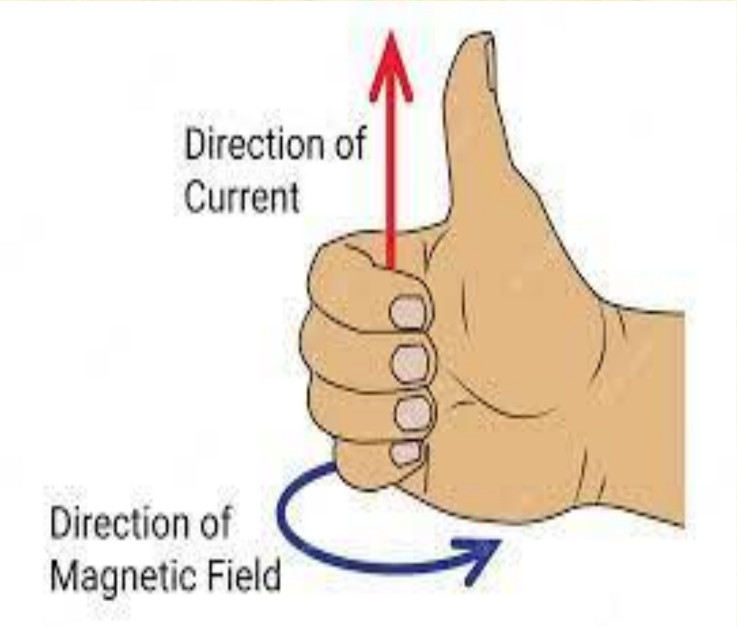


Secondary Coil or Secondary Winding: It is an electrical wire wrapped around the core on the output side

Core : A ferromagnetic material that can conduct a magnetic field through it. Example: Iron

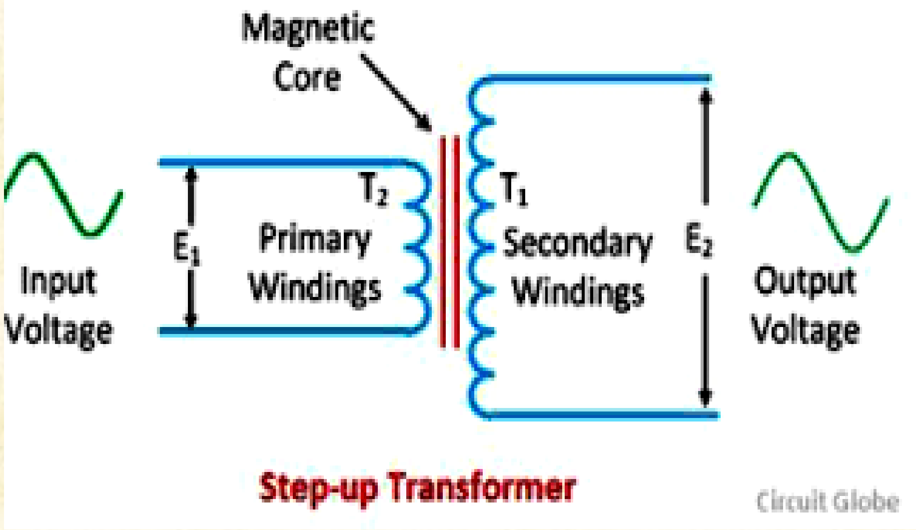
The right hand rule states that: to determine the direction of the magnetic force on a positive moving charge, point your right thumb in the direction of the current, your index finger in the direction of the magnetic field, and your middle finger will point in the direction of the resulting magnetic force



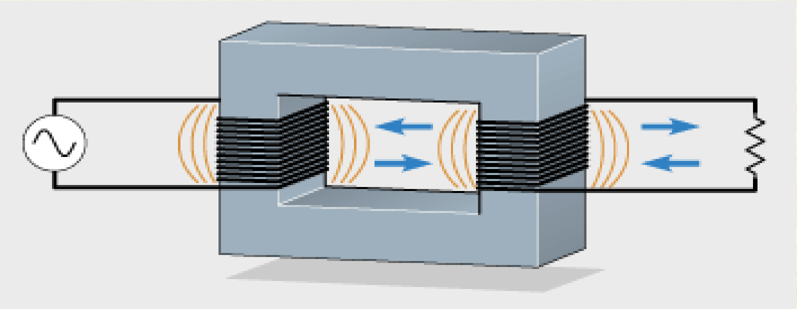


Transformer Operation

In a transformer, source of alternating current is applied to the primary winding.

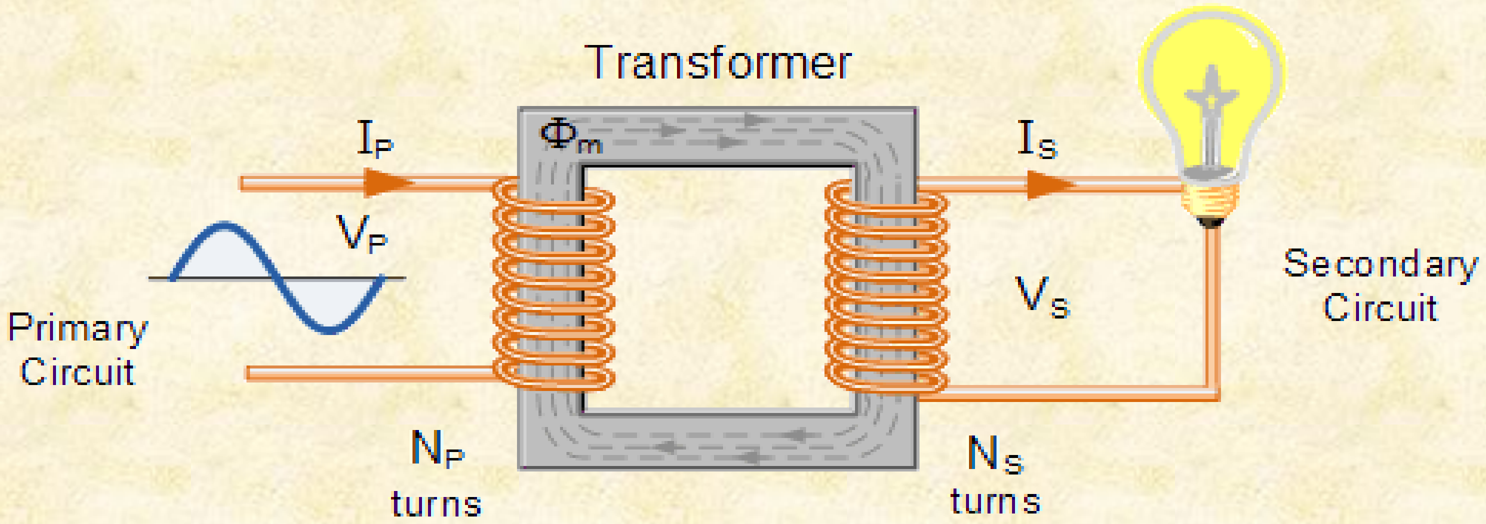


Due to this, the current in the primary winding (called as magnetizing current) produces alternating flux in the core of transformer.



This alternating flux gets linked with the secondary winding, and because of the phenomenon of mutual induction an emf gets induced in the secondary winding.

Voltage ratios of the transformer :



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

N_p : Number of turns in primary winding
N_s: Number of turns in secondary winding
V_p : voltage in primary winding
V_s: voltage in secondary winding

Transformation ratio (k):

The transformation ratio for voltage is defined as the ratio of secondary voltage to the primary voltage of a transformer.

$$k = \frac{V_p}{V_s}$$

Turns ratio:

The turns ratio of a transformer is defined as the ratio of the number of primary turns to the number of secondary turns.

$$a = \frac{N_p}{N_s}$$

Current ratios:

The transformer transfer electrical power from one side to the other (primary to secondary) with a very high efficiency (η).

If we assume that the power loss taking place in the transformer is very low (η = 100%) then, we can write that

power input = power output

$$V_p\, I_p \cos \varnothing_1 = V_s\, I_s \cos \varnothing_2$$

$\cos \varnothing_1$ and $\cos \varnothing_2$ are the power factors of the primary and secondary sides of the transformer. Practically they are of same value.

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

Specifications of transformer:

When transformer is to be purchased, we have to consider following specifications:

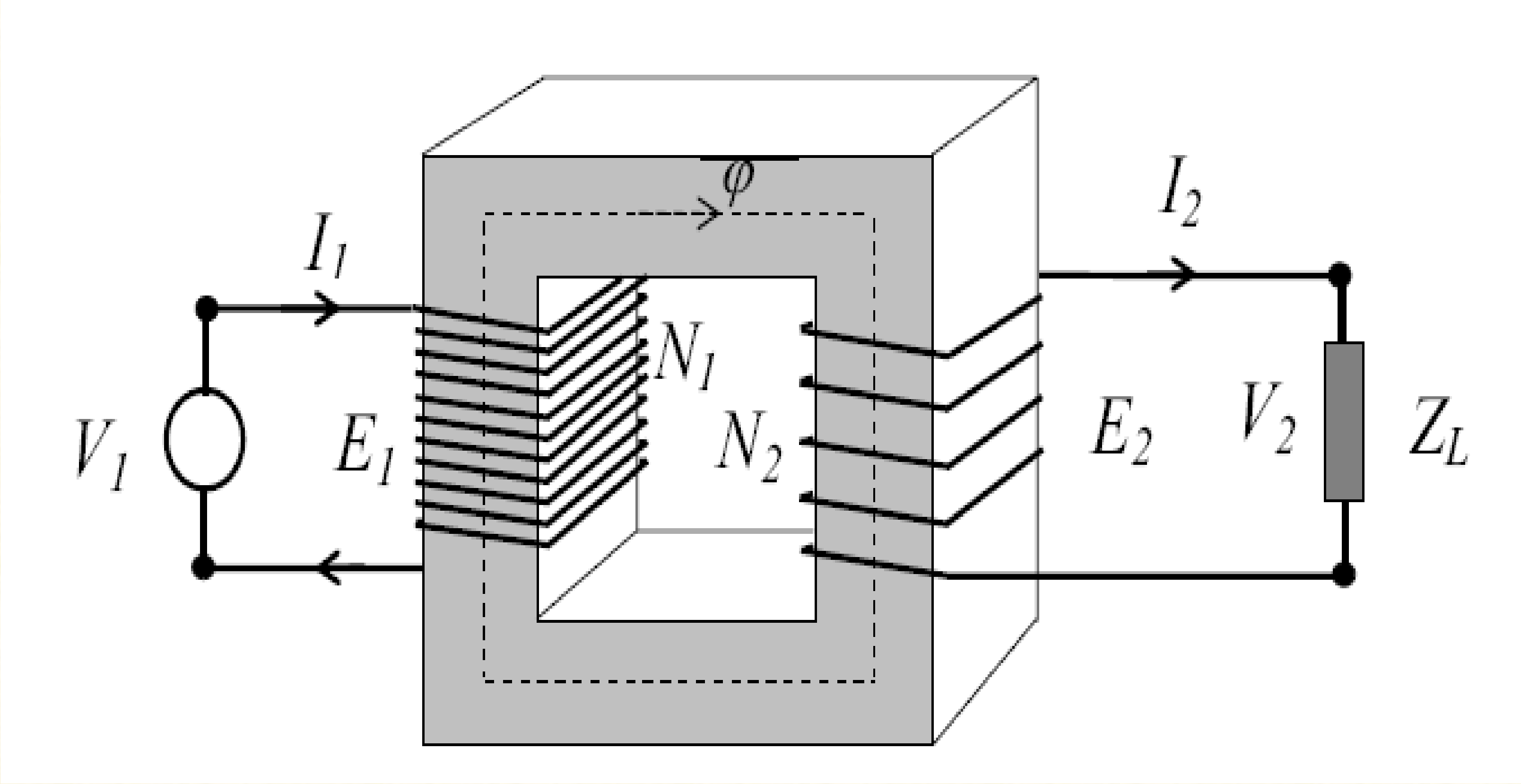
1. kVA rating
2. Number of phases
3. Primary voltage
4. Secondary voltage
5. Primary current
6. Secondary current
7. Frequency of operation
8. Types of cooling

Sr. No.	Specification/rating	Value
1.	kVA rating	5kVA
2.	Number of phases	1
3.	Primary voltage V_1	230 V
4.	Secondary voltage v_2	100 V
5.	Primary current I_1	21 A
6.	Secondary current I_2	50 A
7.	Frequency of operation	50 Hz
8.	Cooling	Open

Transformer Classification

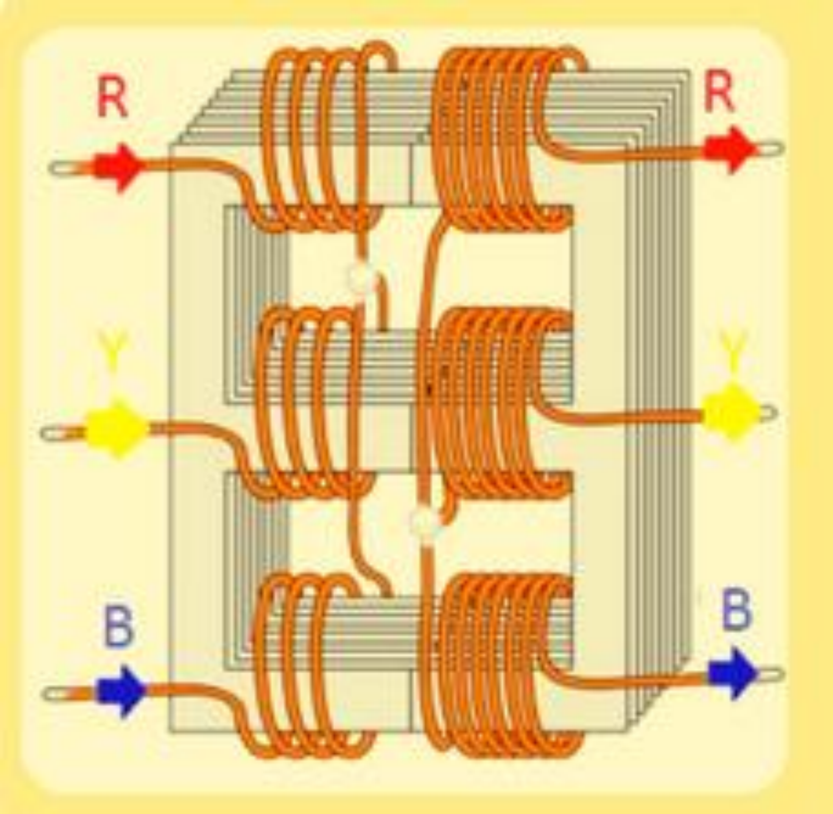
Transformers are classified, based on number of phases

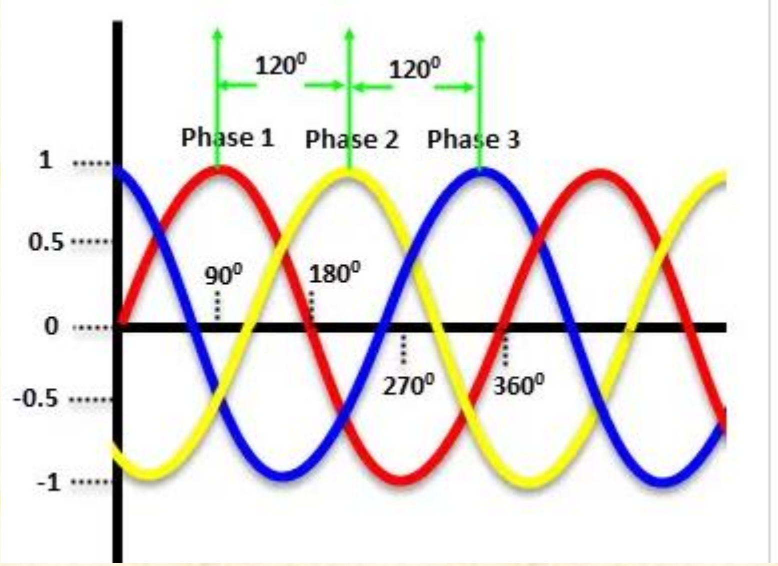
1- Single-phase transformer



Transformer Classification

2- Three -phase transformer

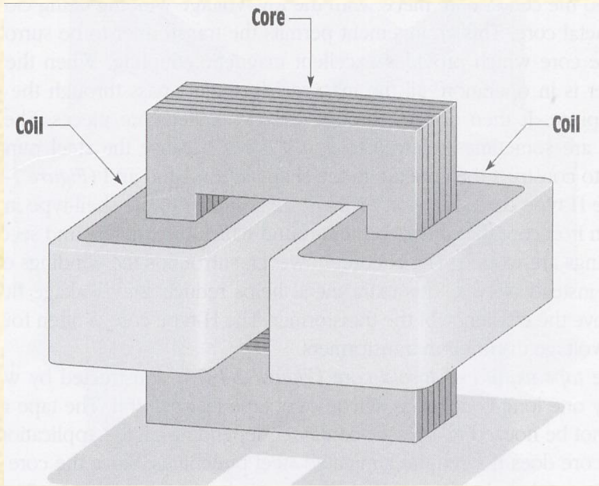


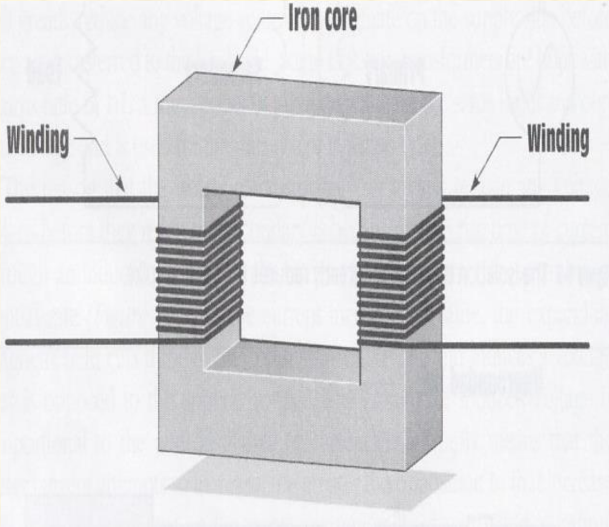


Transformer Classification

Transformers are classified, based on types of core structure, into: (both use thin laminations)

1- Core Type Transformer





The core has only one window.

Winding encircles the core.

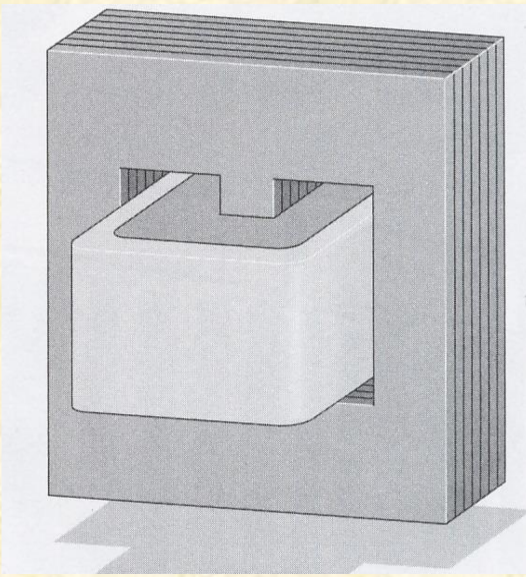
Cylindrical windings are used.

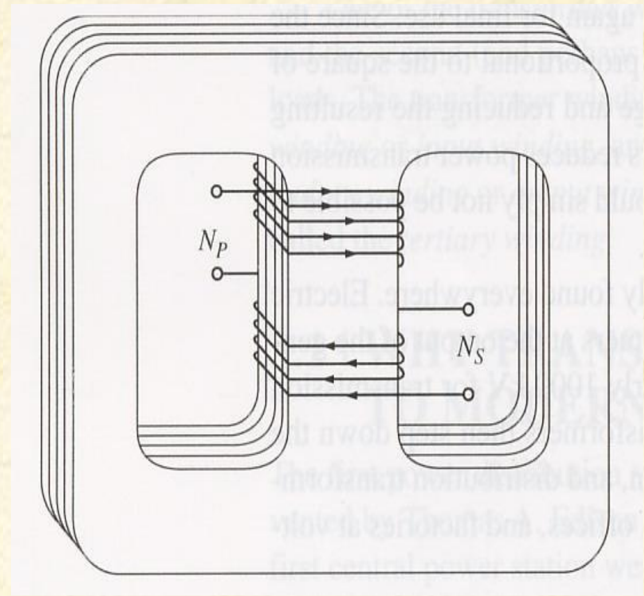
Better cooling since more surface is exposed to the atmosphere.

Easy to repair.

Transformer Classification

2- Shell type transformer:





The core has two windows.

Core encircles the windings.

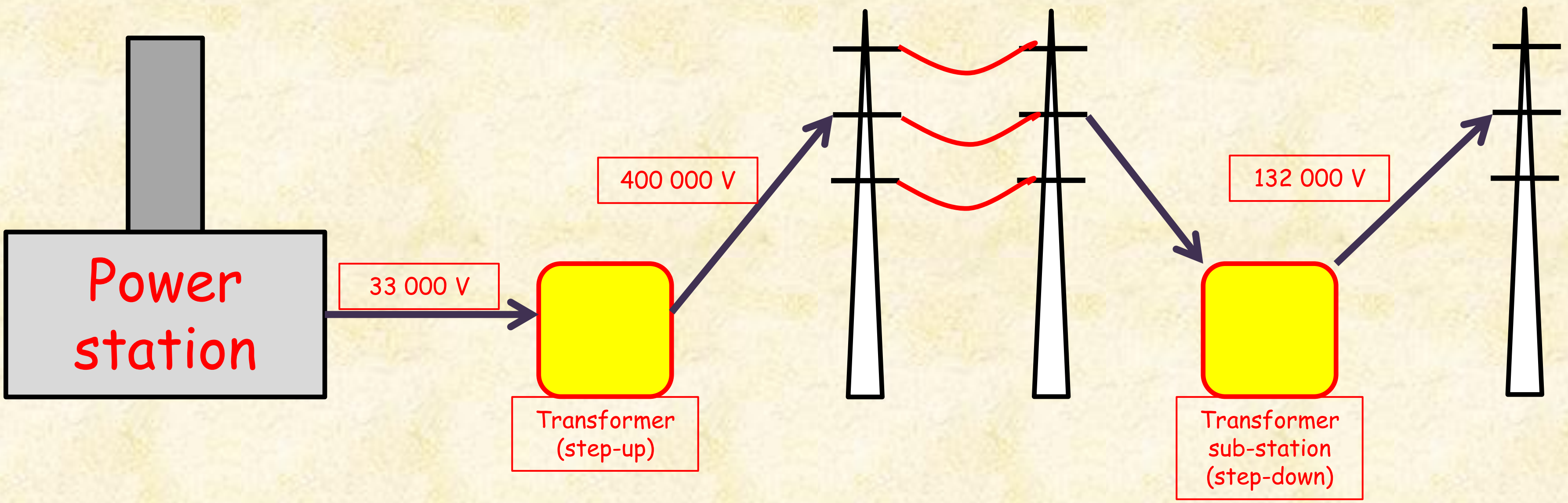
It is not so easy to repair.

Cooling is not very effective.

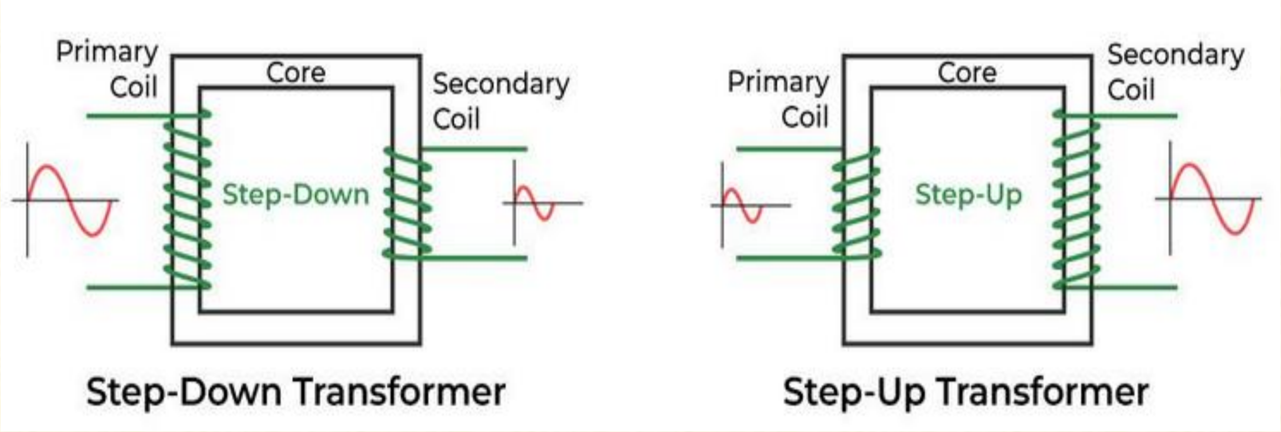
Sandwich type windings are used.

Transformer applications

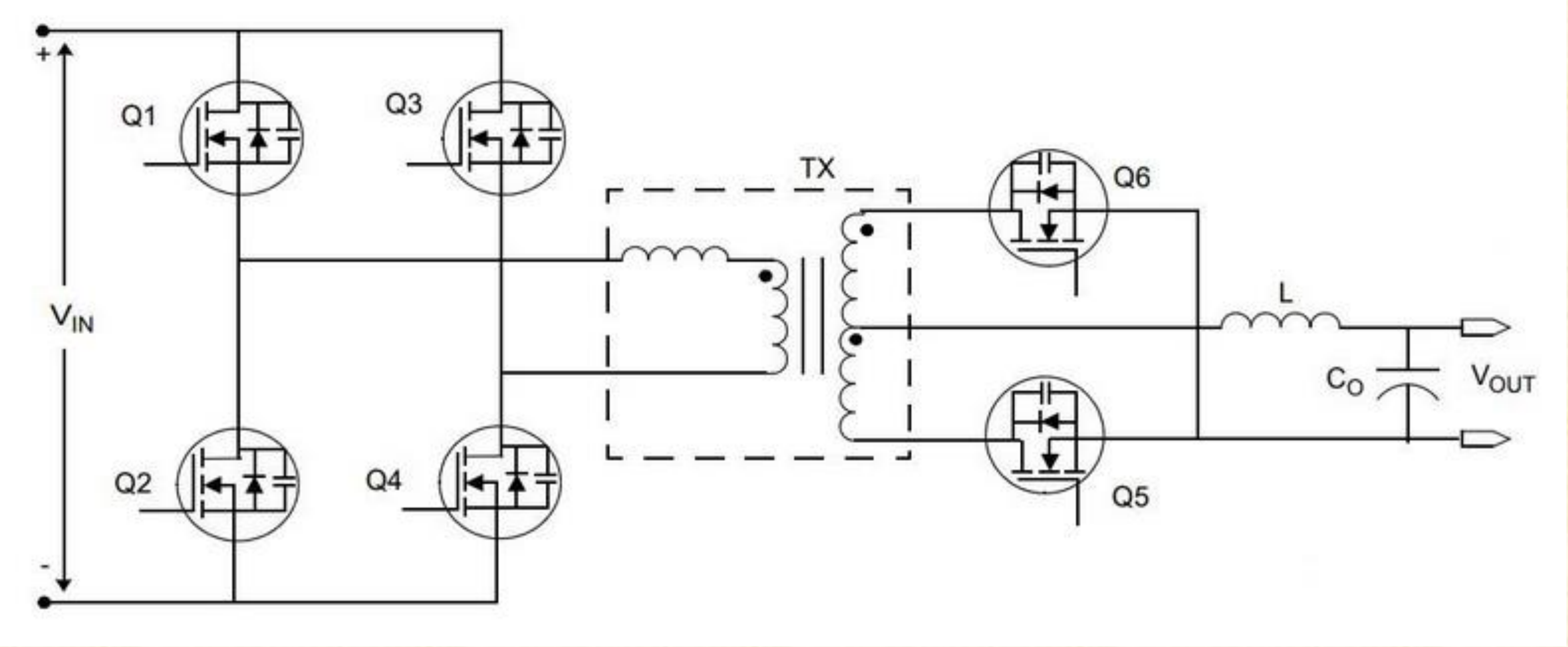
1. **Increase voltage of generator output**
   - *Transmit power and low current*
   - *Reduce cost of transmission system*



2- Adjust voltage to a usable level

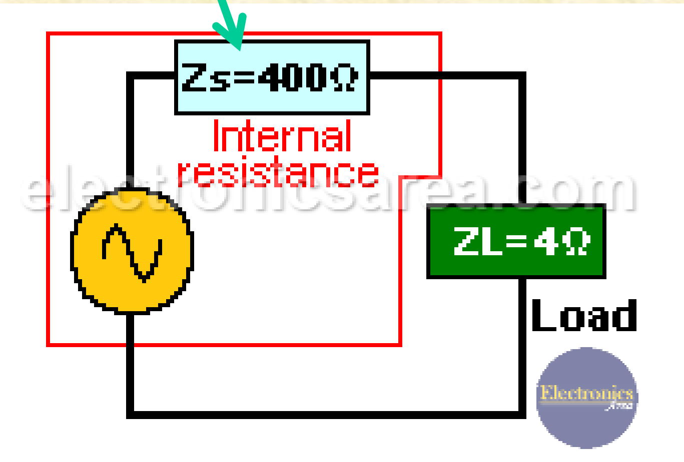


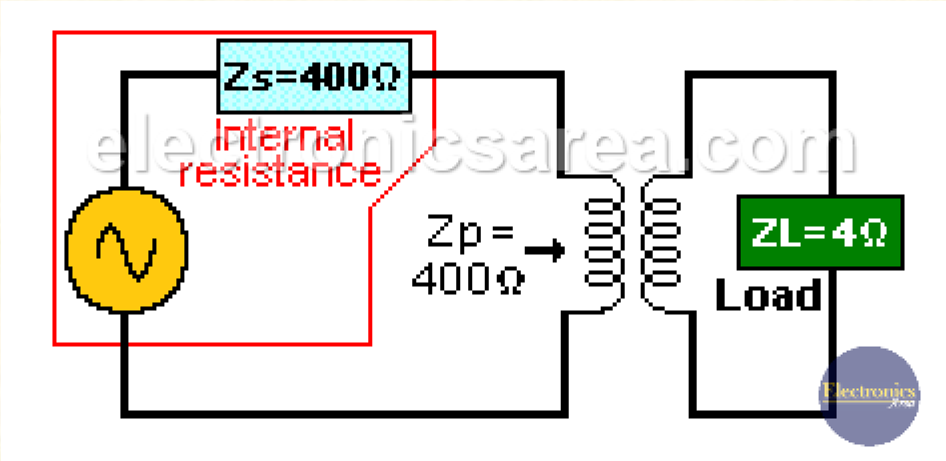
3- Create electrical isolation between two circuits.



4- Match load impedance

Speaker





Automotive applications

1- Electromagnetic relay

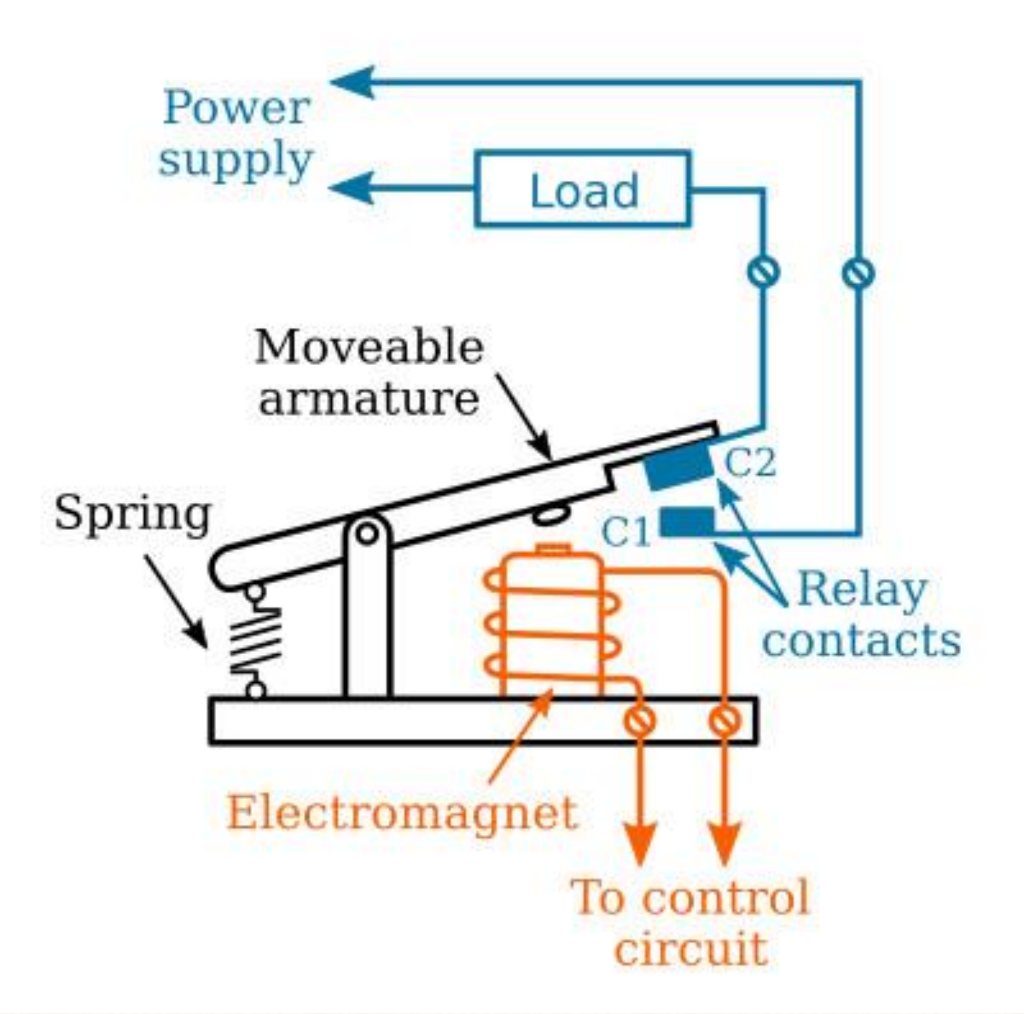
The electromechanical relay can be defined as an electrically operated switch that **completes or interrupts** a circuit by the physical movement of electrical contacts into contact with each other.

Purpose of electromagnetic relay

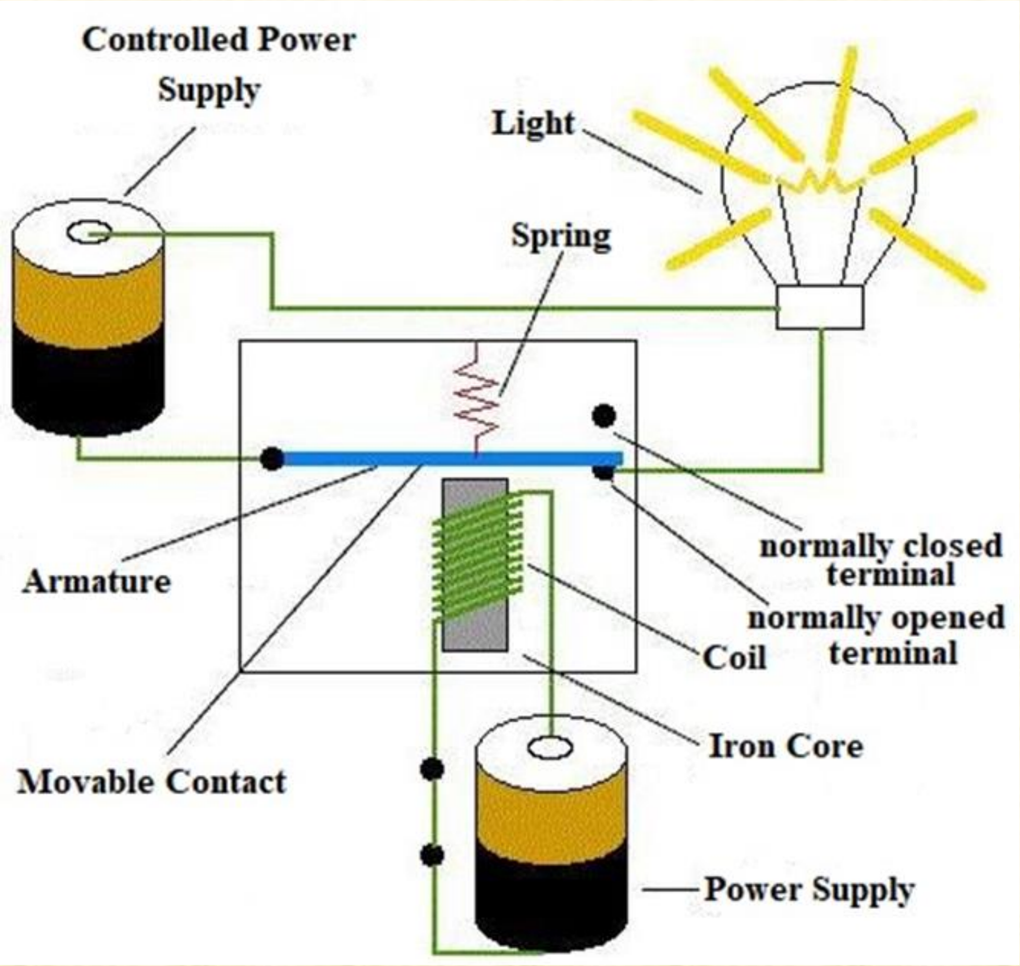
1. Isolate the controlling circuit from the controlled circuit.
2. Control high voltage system with low voltage.
3. Control high current system with low current.
4. Logic Functions.

Electromagnetic relay components

1. Electromagnetic coil
2. Moveable armature
3. Contact points
4. spring

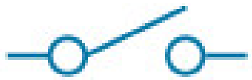


Electromagnetic relay work

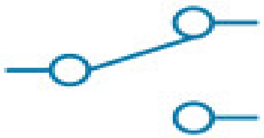


Electromagnetic relay components

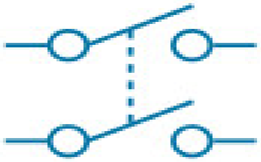
Contact points Arrangements



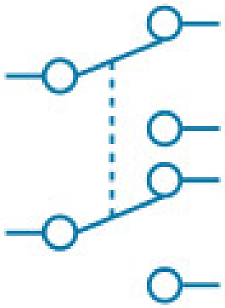
Single-pole Single-throw



Single-pole Double-throw



Double-pole Single-throw



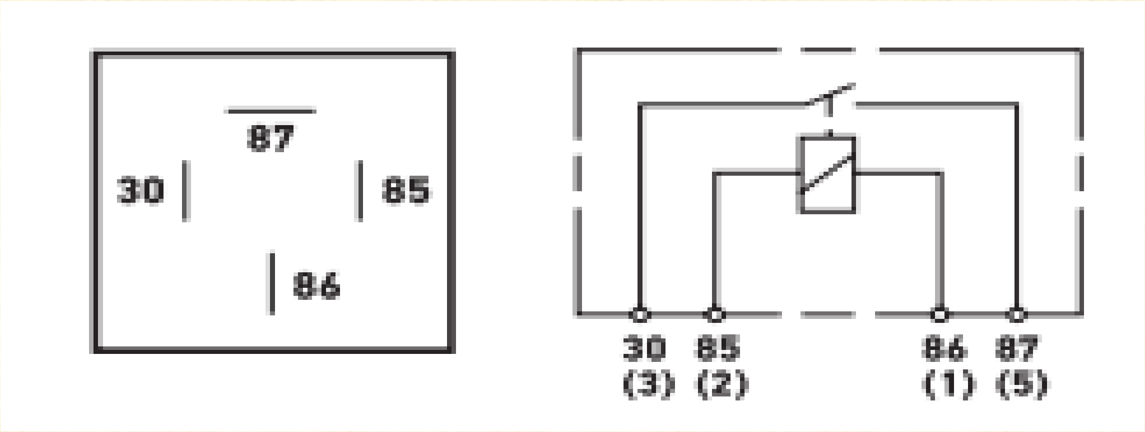
Double-pole Double-throw

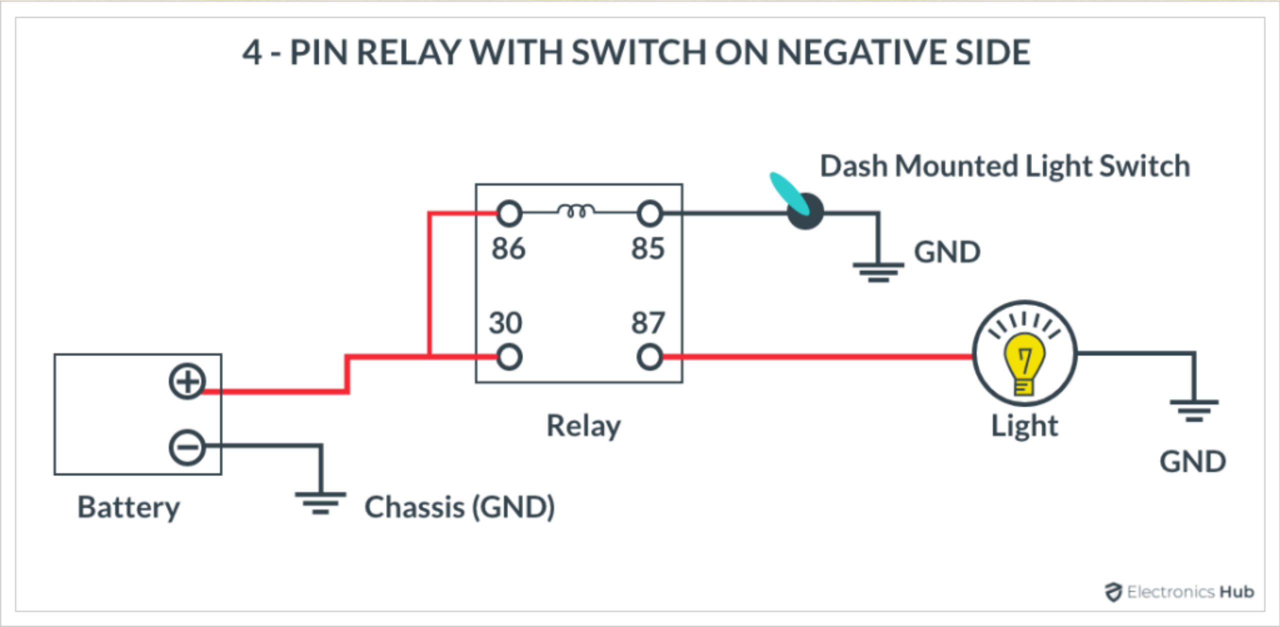
Types of contacts

SP - Single pole
DP - Double pole
ST - Single throw
DT - Double throw
NO - Normally open
NC - Normally closed

Number of pins

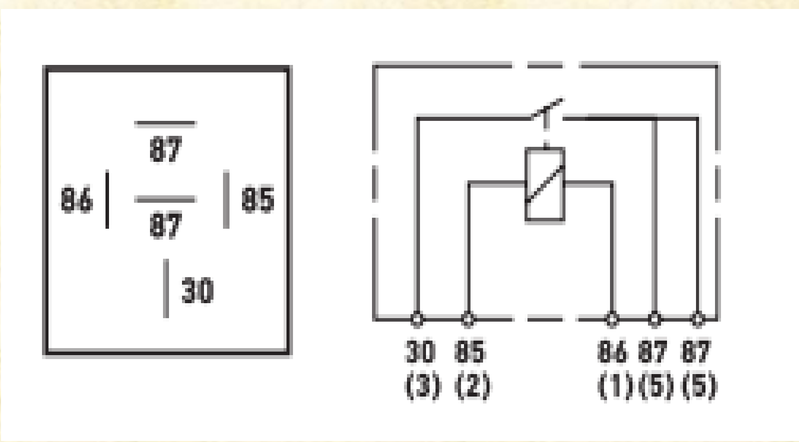
4- pin relay

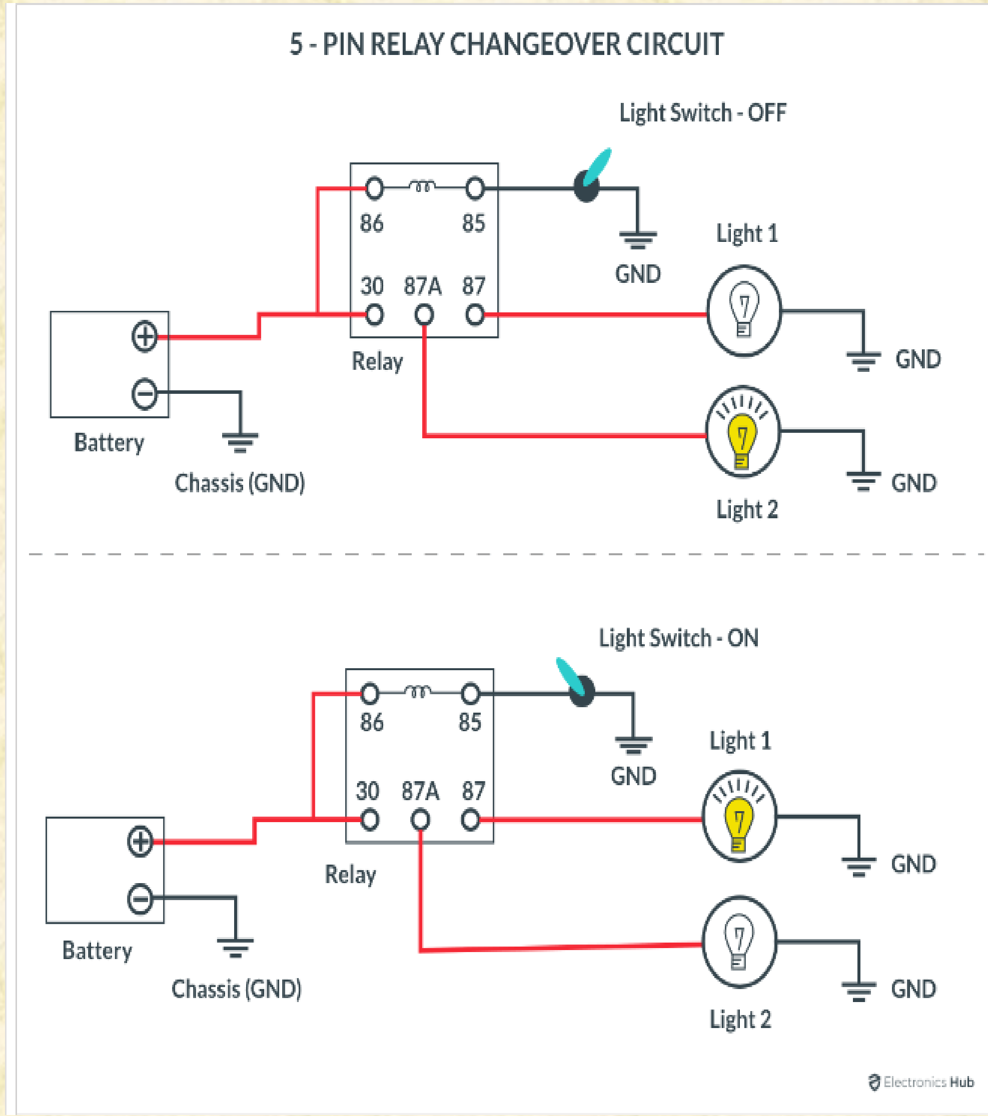




5- pin relay


12VDC
30/40A
87a
87
86
30
85

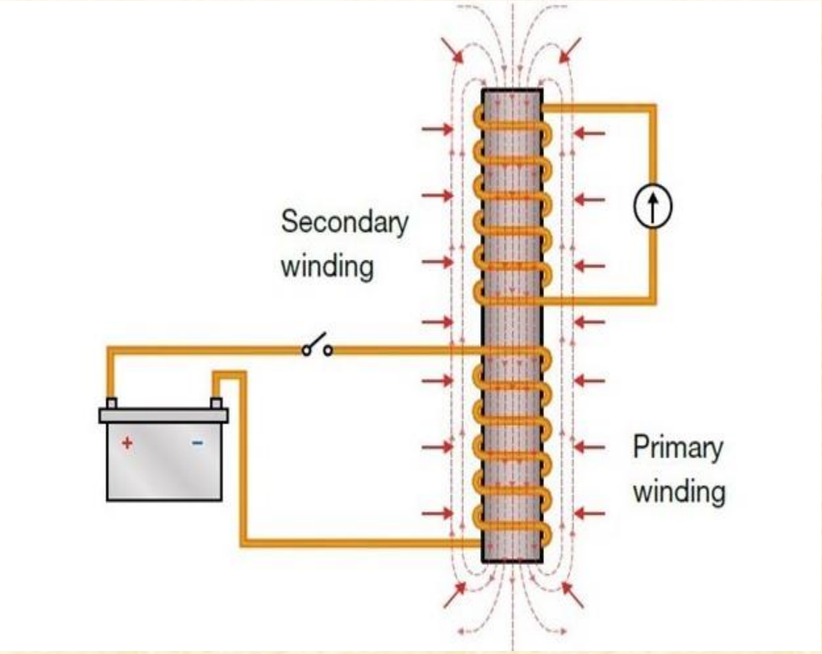

87
86
85
87
30
30 85
(3) (2)
86 87 87
(1) (5) (5)


5 - PIN RELAY CHANGEOVER CIRCUIT
Light Switch - OFF
86
85
30 87A 87
Relay
GND
Light 1
GND
Light 2
GND
Battery
Chassis (GND)
Light Switch - ON
86
85
30 87A 87
Relay
GND
Light 1
GND
Light 2
GND
Battery
Chassis (GND)
Electronics Hub

2- The Ignition Coil

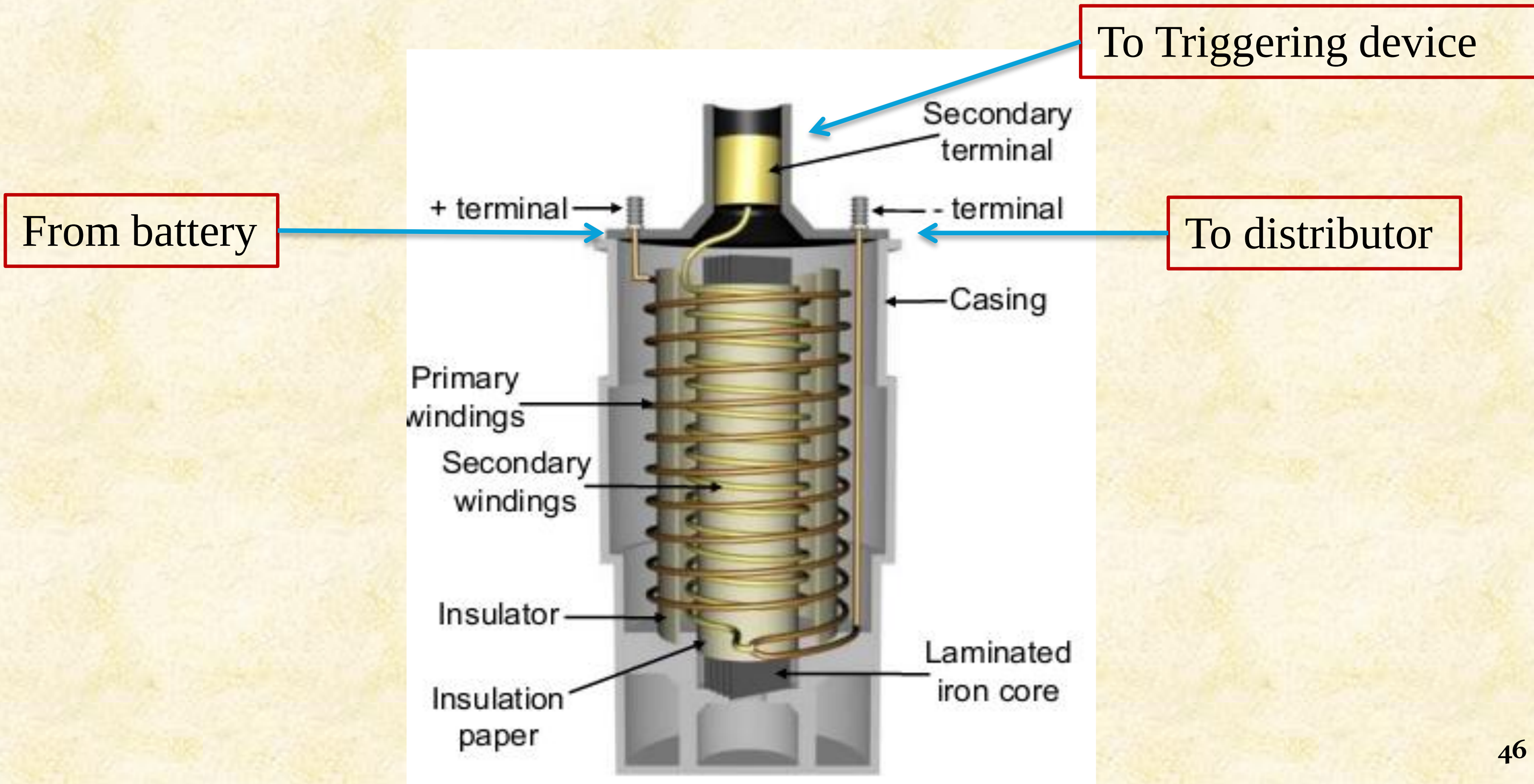
If two coils of wire are placed next to or around each other and an electric current is used to create a magnetic field around one coil (which we call the primary winding), the magnetic field will also surround the second coil (or secondary winding).

When the electric current is switched off and the magnetic field then collapses, it will induce a voltage into both the primary and the secondary windings. This is known as ‘mutual inductance’



The Ignition coil components

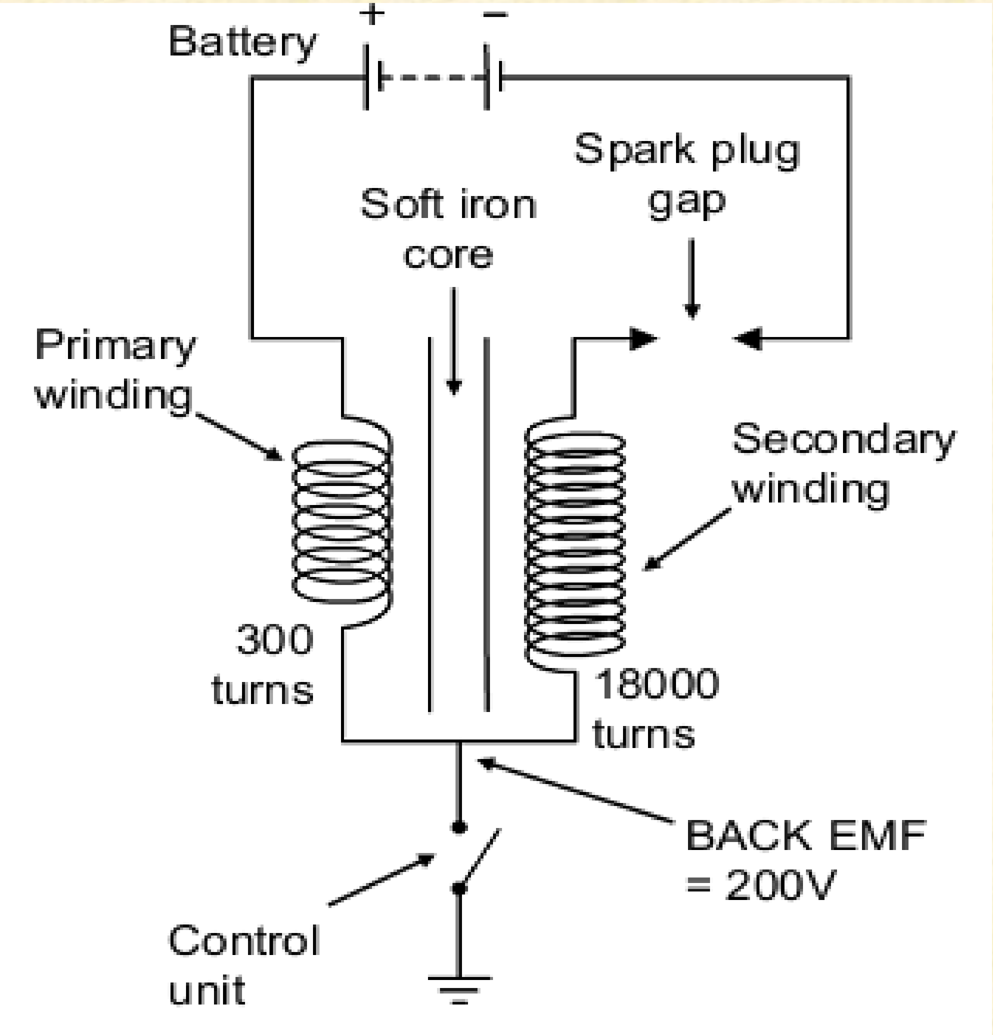
The ignition coil is actually a type of electric transformer that changes low-voltage electricity to high-voltage electricity.



The Ignition coil operation

The value of induced' voltage depends upon:

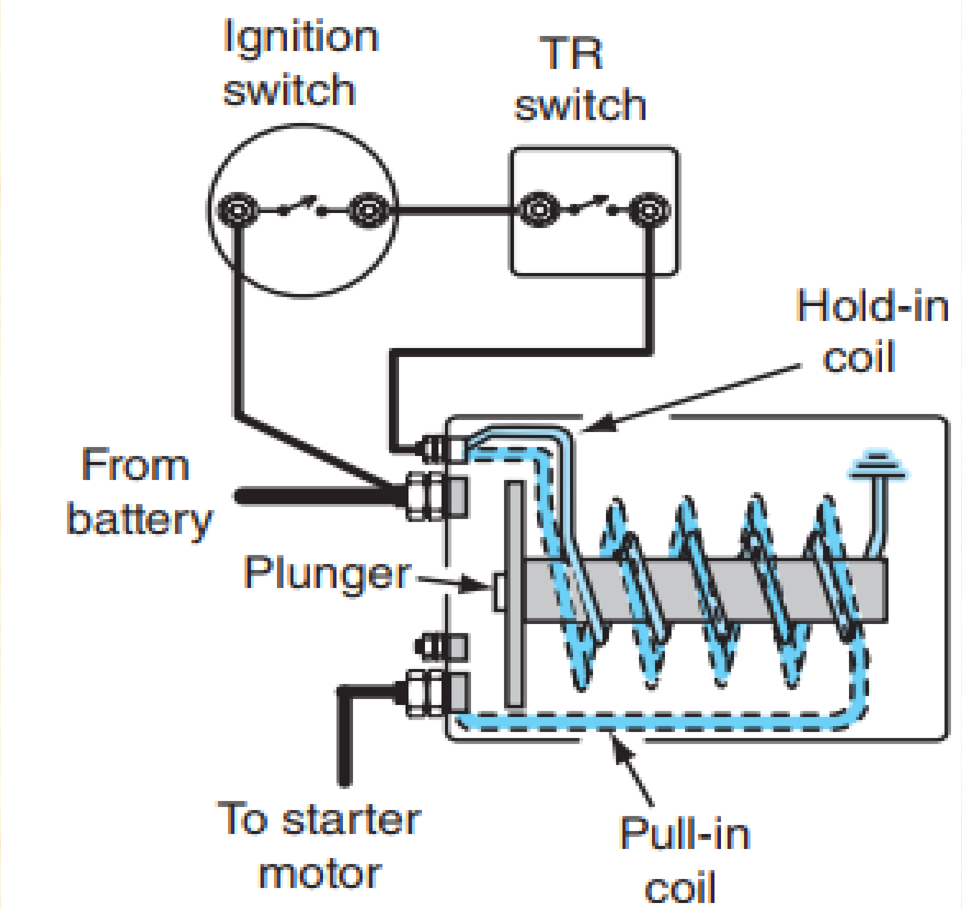
1. The primary current.
2. The turns ratio between the primary and secondary coils.
3. The speed at which the magnetism changes.



3- Starter Solenoid

The solenoid used to actuate a starter drive has two coils:

1. The pull-in coil
2. The hold-in coil.



Two main functions:

1. Switches high current flow by starter motor on/off
2. Engages starter drive with the ring gear

Solenoid Operation