Section 3.2.4 – Transformers

Transformers

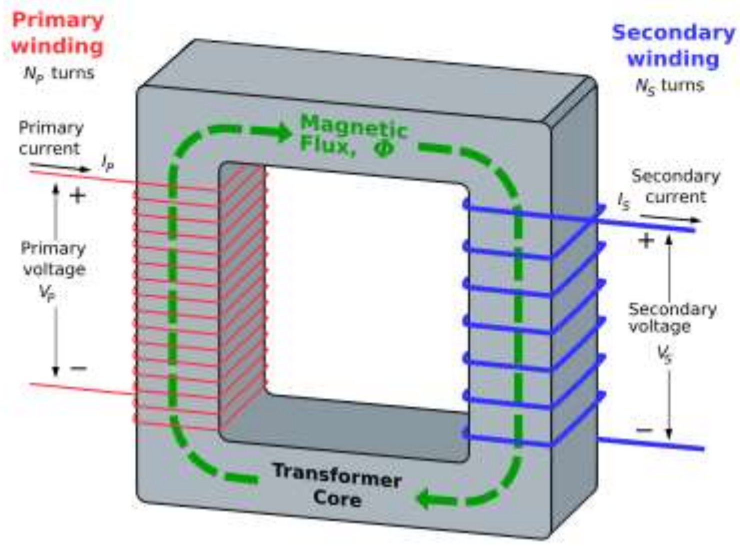


Figure 1

A transformer as shown in **Figure 1** is a device that consists of an **iron core** and an input and output, or rather a **primary coil** and a **secondary coil**. When an **AC voltage** is applied to the primary coil an **alternating magnetic field** is established within the **iron core**. This in turn will induce an **alternating voltage** in the **secondary coil.**

The induced voltage (or current) located at the secondary coil depends upon the:

- input voltage
- number of turns in both the primary and secondary coils

Transformer Equations

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

Where V_S = Voltage in the secondary coil
V_P = Voltage in the primary coil
N_S = Number of turns in the secondary coil
N_P = Number of turns in the primary coil
I_P = Current in the primary coil
I_S = Current in the secondary coil

An **ideal transformer** would be **100%** efficient. That is all electrical power in is transferred into electrical power out. In reality this isn't the case. Power is lost in:

- both the primary and secondary coils (minor loss)
- eddy currents within the iron core (major loss)

To overcome power loss within the core, they are constructed with alternate layers of iron and insulation. Such transformers are approximately 99% efficient.

Ideally: Power in the primary coil = Power in the secondary coil

$$P_P = P_S$$

$$\therefore \quad V_P I_P = V_S I_S$$

Classification

If $\mathbf{V_S > V_P}$ — Transformer is classified as a "**Step-Up**" transformer
If $\mathbf{V_S < V_P}$ — Transformer is classified as a "**Step-Down**" transformer

Example 1

In a particular transformer, the primary coil is wound with 240 coils and the secondary coil is wound with 720 coils. If 24 V AC is connected to the input terminals, calculate the output voltage, assuming no power loss. Classify this transformer as either step-up or step-down.

N_P = 240 turns
N_S = 720 turns
V_P = 24 V AC
V_S = ?

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \quad \therefore V_S = V_P \times \frac{N_S}{N_P}$$

$$V_S = 24 \times \frac{720}{240}$$

= **<u>72 V AC</u>**

As $V_S > V_P$, this is a step-up transformer.

Example 2

A step-up transformer is connected to an AC generator that delivers 120 V and 80 A. The ratio of the number of turns in the secondary to the number of turns in the primary is 500.

a. What is the voltage in the secondary coil?
b. What is the power input?
c. What is the maximum power output?
d. What is the maximum current in the secondary coil?

Part A.

V_P = 120 V
I_P = 80 A
N_S/N_P = 500
V_S = ?

$V_S = V_P \times (N_S/N_P)$
= 120 x 500
= 60 000 V
= **<u>60 kV</u>**

Part B.

V_P = 120 V
I_P = 80 A
N_S/N_P = 500
P_P = ?

$P_P = V_P \times I_P$
= 120 x 80
= 9 600 W
= **<u>9.6 kW</u>**

Part C.

P_S (max) = ?
Max. possible power output occurs if transformer is 100% efficient.
P_S (max) = P_P = **<u>9.6 kW</u>**

Part D.

$P_S = 9.6 \times 10^3$ W
$V_S = 60 \times 10^3$ V
I_S = ?

$P_S = V_S \times I_S$
$\therefore I_S = P_S/V_S$
$= 9.6 \times 10^3/60 \times 10^3$
= **<u>0.16 A</u>**

or

I_P = 80 A
N_S/N_P = 500
I_S = ?

$I_S/I_P = N_P/N_S$
$\therefore I_S = I_P \times N_P/N_S$
= 80 x (1/500)
= **<u>0.16 A</u>**

Eddy Currents

We already know that an **EMF is induced** when a **change of magnetic flux** occurs. This EMF will be induced in any conductor experiencing a change of flux, whether it is intended or not. The current that this EMF produces is called an **eddy current**.

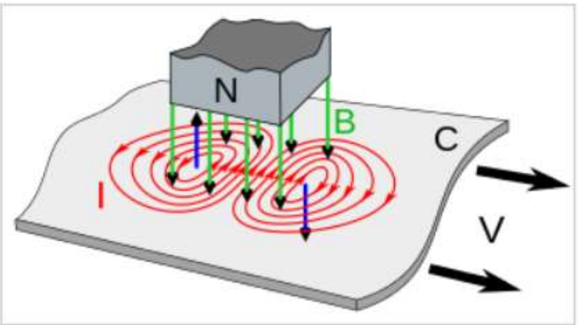


Figure 2

Eddy currents (I, red) induced in a conductive metal plate (C) as it moves to right under a magnet (N). The magnetic field (B, green) is directed down through the plate, as shown in **Figure 2.**

The increasing field at the leading edge of the magnet (left) **induces a counterclockwise current**, which by Lenz's law creates its own **magnetic field (left blue arrow) directed up**, which opposes the magnet's field, producing a retarding force.

Similarly, at the trailing edge of the magnet (right), a **clockwise current and downward counterfield** is created (right blue arrow) also producing a retarding force.

Eddy currents can cause **heating** in the **soft iron core** of a transformer. To overcome this, transformers are often made of **thin layers of soft iron** separated by **insulated layers**, as shown in **Figure 3**. This reduces the build-up of eddy currents and reduces the heating effect within the transformer.

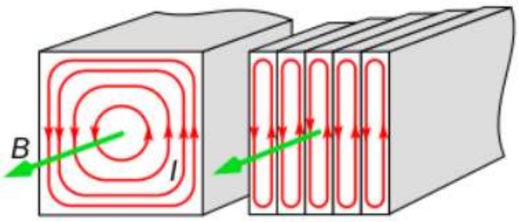


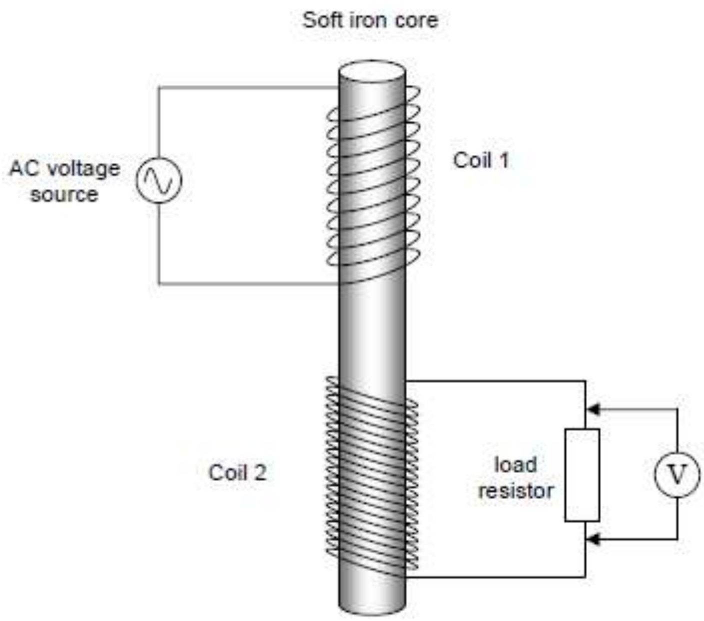
Figure 3

Exam Style Questions

Questions 1 to 4 relate to the following information

A student is investigating the operation of a transformer she has built using some wire coils and a soft iron rod. The diagram below shows her experimental set up.

Coil 1 has 10 loops and **Coil 2** has 20 loops.



Question 1.

The AC voltage source supplies 20 V into Coil 1.
Calculate the reading on the voltmeter across the load resistor in Coil 2?

V_2 = ?
V_1 = 20 V
N_2 = 20 loops
N_1 = 10 loops

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\therefore V_2 = V_1 \times \frac{N_2}{N_1}$$

$$= 20 \text{ x } \frac{20}{10}$$

$$= 40 \text{ Volts}$$

40 V

What is the major assumption you have made in this calculation?

Assumption:

That her transformer is "ideal" or that the power in the first coil ($P_{coil\ 1}$) is equal to the power in the second coil ($P_{coil\ 1}$)

Question 2.

Explain the purpose of the soft iron core in this experiment.

The soft iron core links the two coils magnetically, OR
It carries the magnetic field from coil1 to coil 2

Questions 3and 4 require the following further information

In a further experiment the input voltage from the power supply is altered and the voltage across the load resistor is now measured to be 50 V. The load resistor is 560 Ω.

Question 3.

What is the power being consumed by the load resistor?

P = ?
V_2 = 50 V
R = 560 Ω

$$P = \frac{V^2}{R}$$

$$\therefore\ P = \frac{50^2}{560}$$

= 4.46 Watts

4.46 W

Question 4.

What is the current running through the power supply?

I_1 = ?
I_2 = 0.09 A
N_1 = 10 loops
N_2 = 20 loops

$$I_2 = \frac{P_2}{V_2}$$

$$\therefore\ I_2 = \frac{4.46}{50}$$

= 0.09 A

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

$$\therefore\ \frac{I_2}{I_1} = \frac{N_2}{N_1}$$

$$\therefore\ I_2 = I_1 \times \frac{N_2}{N_1}$$

$$= 0.09 \text{ x } \frac{20}{10}$$

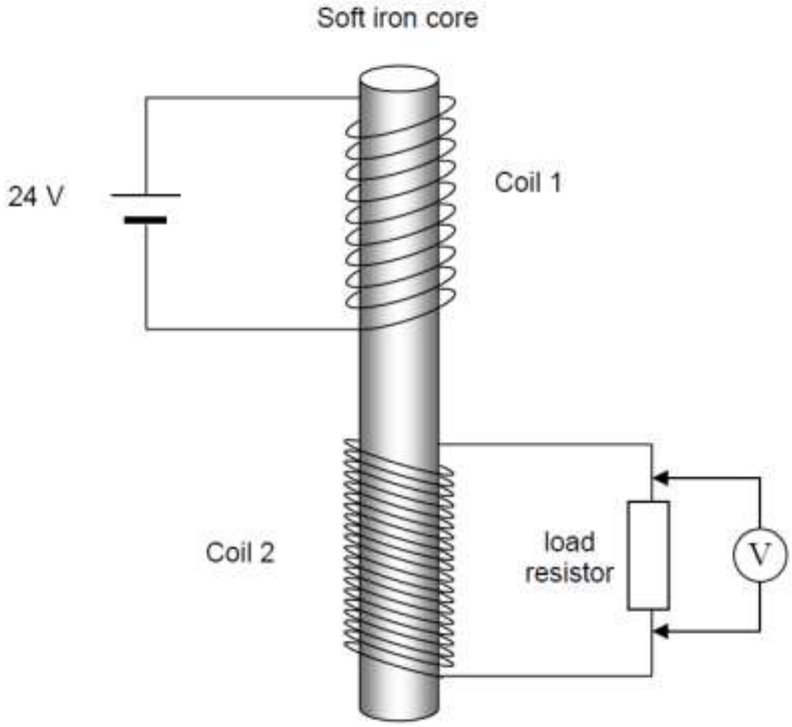
= 0.18 A

0.18 A

Questions 5 and 6 refer to the following information

A student is investigating the operation of a transformer she has built using some wire coils and a soft iron rod. The diagram below shows her experimental set up.

Coil 1 has 10 loops and **Coil 2** has 20 loops.



Question 5.

What is the reading on the voltmeter across the load resistor in **Coil 2**?

0 V

Explain your answer:

No voltage is produced if DC is supplied to coil 1. To operate properly a transformer needs a changing voltage in the primary coil to produce a changing flux hence inducing a voltage in the secondary coil.

Question 6.

Give one change that will cause a higher voltage to be induced in coil 2

- Change the supply to coil 1 to AC

Give one other change that would further increase the voltage induced in coil 2.

- Increase the number of coils in coil 2
- Decrease the number of coils in coil 1
- Increase the 24 V supply to coil 1