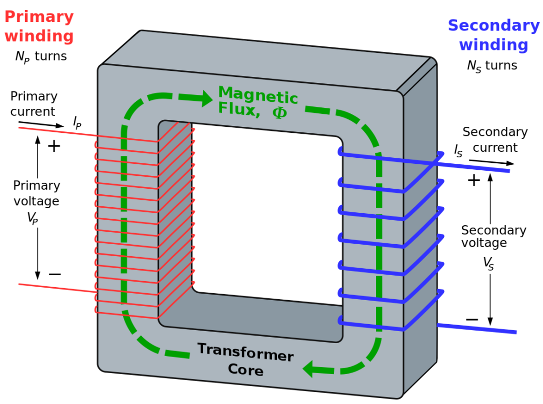
7.16 The operation of a transformer

Transformers are used to increase ('step up') or decrease ('step down') alternating voltages. Their anatomy is very simple.



They consist of a primary and secondary coil of wire wrapped around a soft iron core. Both primary and secondary coils of wire are coated in electrically insulating material.

(1)✐ Why does the wire need to be insulated?

When an alternating potential difference is applied across the primary coil, an alternating emf is induced across the secondary coil.

The ratio of coils of wire ('turns') on the primary and secondary is equal to the ratio of potential differences across the primary and secondary coils:

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

(2)✐ A transformer has 100 turns on the primary coil and 300 turns on the secondary coil. If an input, alternating potential difference of 12V (root-mean-square value) is applied, what is the potential difference across the secondary coil?

The transformer works by electromagnetic induction in the following way:

1) *An alternating potential difference across the primary coil causes an alternating current to flow in the primary coil.*
2) *An alternating current in the primary coil produces a changing magnetic flux through the soft iron core.*
3) *The changing magnetic flux in the soft iron core links to the secondary coil.*
4) *A changing magnetic flux through the secondary coil induces an emf across the secondary coil. (Faraday's law states that 'the induced emf in a coil is equal to the rate of change of flux linkage through the coil'. See section 7.14)*
5) *The emf across the secondary coil causes a current to flow in any complete circuit attached to the secondary coil.*

(3)✐ What is a 'soft iron' core, and why is it needed in this case?

(4)✐ *Transformers don't work with direct current supplies. With reference to Faraday's law, explain why not.*

Power and efficiency

In the following discussion, voltages and currents are the root-mean-square values. (see section 7.15)

The electrical power input to a transformer (P_{in}) is given by:

$$P_{in} = I_p V_p$$

where I_p *= current in the primary coil.*

The electrical power output from a transformer (P_{out}) is given by:

$$P_{out} = I_s V_s$$

where I_s *= current in the secondary coil.*

Therefore, the efficiency of the transformer is given by:

$$Efficiency = \frac{power\ out}{power\ in} = \frac{P_{out}}{P_{in}} = \frac{I_s V_s}{I_p V_p}$$

(5)✐ *If a transformer is 100% efficient, and the voltage is stepped up by a factor of 3, what happens to the current?*

(6)✐ *Calculate the output current for the following transformer with an efficiency of 85%.* $V_p = 120V, I_p = 2A, N_p = 500, N_s = 200$

As the soft iron core is an electrical conductor, a changing magnetic flux in the core will induce an emf (called 'back emf') in the core itself. Lenz's law states that *'the direction of the current is always such as to oppose the change that causes the current'*. The currents produced in the core are called 'eddy currents'. These cause the core to heat up and reduce the efficiency of the transformer.

(7)✐ *How does laminating the core reduce eddy currents? (do some research)*

Power transmission

In the National Grid, voltages are stepped up to very high voltages before transmission across the network. The reason for this is that power losses are reduced. Power is lost through heating of the transmission cables.

The power loss (P_l), due to the resistance (R) of the transmission cables is given by:

$$P_l = I^2 R$$

where I is the current.

(8)✐ From this equation, what two things can be done to reduce power loss?

(9)✐ Why does stepping up the voltage reduce power loss?

(10)✐ A town requires a supply of 100MW at 230V. A power station 10km away is used to supply the town. Transmission cables have a resistance of 1Ω *per kilometre. Work out the power loss in the transmission cables for a transmission voltage of i) 100kV and ii)400kV.*

(11)✐ In the problem, above, what would recommend as the best solution?