29 Transformers

While a very strong magnet held stationary inside a coil will not induce a voltage (there is no relative motion), if the magnetic field gets stronger a voltage will be induced. This is because the increase in magnetic field at the coil could have been caused by an ordinary magnet moving closer. Permanent magnets cannot change strength readily, but you can change the strength of an electromagnet if you change the current flowing in it.

This is the principle of the transformer. Transformers only work on alternating current (a.c.). The current in the primary coil causes it to become an electromagnet. The continually changing current produces a continually changing magnetic field in an iron core. This in turn induces a continually changing voltage in the nearby secondary coil wound round the iron core. A transformer won't work on direct current (d.c.) because a stationary magnet will only produce a steady magnetic field - and steady, stationary magnetic fields do not induce voltages. A transformer does not change the frequency of the alternating current.

Transformers have two coils

- the primary coil, connected to an a.c. supply of known voltage, and
- the secondary coil, which does work on other components using energy from the primary.

The voltage across the secondary coil, V_s, is not usually the same as the primary coil's supply voltage, V_p. It could be greater (a step-up transformer) if the number of turns on the secondary is greater, $N_\mathrm{s} > N_\mathrm{p}$, or less if the number of turns on the secondary is fewer, $N_\mathrm{s} < N_\mathrm{p}$.

$$\text{secondary (a.c.) voltage} = \text{primary (a.c.) voltage} \times \frac{\text{no. of turns on secondary}}{\text{no. of turns on primary}}$$

$$\frac{V_\mathrm{s}}{V_\mathrm{p}} = \frac{N_\mathrm{s}}{N_\mathrm{p}} \qquad \text{or} \qquad \frac{N_\mathrm{p}}{V_\mathrm{p}} = \frac{N_\mathrm{s}}{V_\mathrm{s}}$$

This means that the number of 'turns per volt' is the same on both coils.

Example 1 – A transformer has an input voltage of 240 V a.c. and output of 48 V. If there are $3\,000$ turns on the primary coil, how many are there on the secondary?

$V_s/V_p = N_s/N_p$, so $48/240 = N_s/3\,000$.
Thus $0.2 = N_s/3\,000$, so $N_s = 0.2 \times 3\,000 = 600$ turns.
Or, you could solve it like this: the primary coil has $3\,000/240 = 12.5$ turns/volt
So the secondary must have $48 \times 12.5 = 600$ turns.

29.1 Complete the table below. Each row is a separate question.

a.c. Voltage (V)		No. of turns on coil		Step up or down?
Primary	Secondary	Primary	Secondary	
240	(a)	$2\,000$	200	(b)
$11\,000$	240	(c)	600	(d)
$23\,000$	$230\,000$	(e)	$1\,000$	(f)
240	12	(g)	300	(h)
240	4.96	$1\,500$	(i)	(j)

29.2 A doorbell for a house works from 8.0 V a.c. To operate the bell from the 240 V mains supply, a transformer can be used.

(a) How many turns would be in the primary winding for each turn in the secondary winding?

(b) Would the transformer be a step-up or a step-down type?

29.3 To produce an output of 48 V a.c. from an input of 240 V a.c., how many turns would be required in the primary winding if there were 100 turns in the secondary?

29.4 The input voltage to a step-down transformer is 240 V a.c. at a frequency of 50 Hz. The primary winding has $6\,000$ turns and the secondary 300 turns.

(a) What is the voltage output?

(b) What is its output frequency?

29.5 A step-up transformer has 500 turns in the primary coil and $10\,000$ turns in the secondary coil. A voltage of 250 V a.c. is applied to the primary at 50 Hz.

(a) What is the voltage of the output at the secondary?

(b) What is the frequency of the output at the secondary?

29.6 A 12 volt car battery is placed across the primary coil of a $1{:}20$ step-up transformer. What is the output voltage across the secondary?

29.7 These questions should show you why we bother with transformers on our electrical distribution system. Calculate:

(a) The current needed to distribute the $2\,000$ MW generated at 22 kV at a large power station.

(b) The current needed to carry $2\,000$ MW if the voltage is 400 kV.

The cables used have a total resistance of $9.0\ \Omega$.

(c) Calculate the power wasted in heating the wire if the current from 22 kV flows in the wire.

(d) Calculate the power wasted if the current carrying $2\,000$ MW at 400 kV passes through the wire.

29.8 A computer power supply unit can be switched to work on European (230 V a.c.) or United States (115 V a.c.) mains. In the European setting, there are 2000 turns on the primary coil. When switched into United States mode, how many turns are now on the primary?

29.9 If 0.45 A were flowing in the primary of part (a) in the above table, what would the current in the secondary be if the transformer were 100 % efficient? *[Hint: Power $=$ Current $\times$ Voltage.]*

29.10 The power station generator of 29.1(e) produces a current of 22 kA. If the transformer is 97 % efficient, what will the output current onto the 230 kV national grid be? *NB - Your answer to Q29.1(e) does not need changing.*

$^{19}/_{25}$