Electric Generators

Electric motor vs. generators

An electric motor transforms electrical energy into mechanical energy. We make an electric motor by placing a current-carrying loop in a uniform magnetic field that causes a torque in the loop.

An electric generator transforms mechanical energy into electrical energy. That is, it generates electricity. We make an electric generator by placing a loop in a uniform magnetic field the same way we do in making an electric motor and then use mechanical work to rotate the loop.

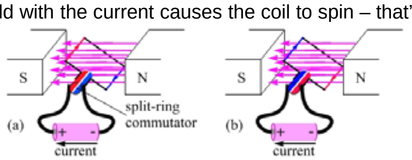
They are essentially the same device – a coil in a magnetic field!

Electric motor vs. generator

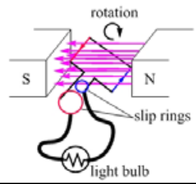
If a current is passed through the coil, the interaction of the magnetic field with the current causes the coil to spin – that's a motor.

Motor:

simulation



Generator:

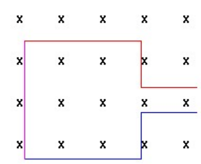


If we spin the coil, the changing flux through the coil induces a current – now it's a generator.

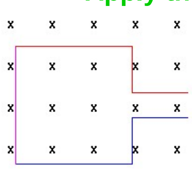
Direction of the induced current?

If the loop spins so the magnetic flux through the loop decreases, in what direction is the induced current in the loop?

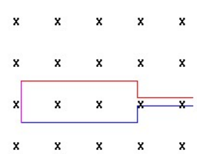
1. Clockwise
2. Counterclockwise
3. There is no induced current



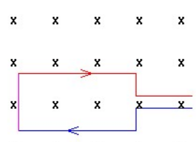
Apply the pictorial method



Before



After



To oppose

Electric generators

Let's say we spin a coil of *N* turns and area *A* at a constant rate in a uniform magnetic field *B*. By Faraday's law, the induced emf is given by:

$$\varepsilon = -N\frac{\Delta(BA\cos\theta)}{\Delta t}$$

B and *A* are constants, and if the angular speed ω of the loop is constant the angle is: $\theta = \omega t$.

The induced emf is: $\varepsilon = -NBA\frac{\Delta(\cos\omega t)}{\Delta t} = \omega NBA\sin(\omega t)$

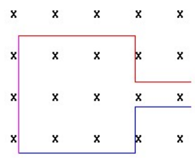
Spinning a loop in a magnetic field at a constant rate is an easy way to generate AC electricity. The peak voltage is:

$$\varepsilon_{max} = \omega NBA$$

Maximum current?

At what instant is the magnitude of the current maximum?

1. When the plane of the loop is perpendicular to the field (maximum area)
2. When the plane of the loop is parallel to the field (zero area)
3. Because the loop is spinning at a constant rate, the magnitude of the current is constant



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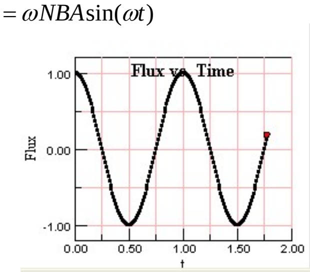
Maximum current

The magnitude of the current is proportional to the slope of the flux graph, so let's draw the flux graph.

$$\varepsilon = -NBA\frac{\Delta(\cos\omega t)}{\Delta t} = \omega NBA\sin(\omega t)$$

From the graph shown at right, the slope of the flux graph (and hence the induced current) is the largest when the flux is zero.



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Transformers

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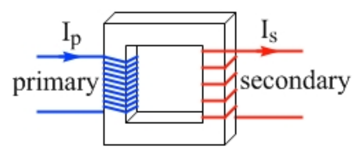
Transformers

A transformer is a device for changing the voltage of an AC signal. A transformer has two coils linked by a ferromagnetic core so the magnetic flux from one passes through the other. When the flux generated by one coil changes (as it does continually if the coil is connected to an AC power source), the flux passing through the other will change, inducing a voltage in the second coil. With AC power, the voltage induced in the second coil will also be AC.



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Transformers

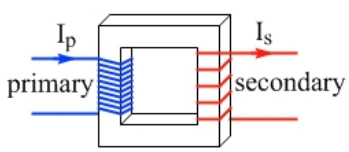
Both coils are exposed to the same changing flux, so:

$$-\frac{\Delta\Phi}{\Delta t} = \frac{\Delta V_p}{N_p} = \frac{\Delta V_s}{N_s}$$ (Recall: $\varepsilon = -N(\Delta\Phi/\Delta t)$)

where ΔV_p (ΔV_s) is the voltage in the primary (secondary) coil and N_p (N_s) the number of turns in the primary (secondary) coil. Energy (or, equivalently, power) has to be conserved, so:

$$\Delta V_p I_p = \Delta V_s I_s$$

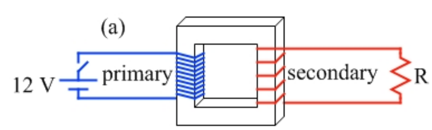
$$\frac{N_p}{N_s} = \frac{\Delta V_p}{\Delta V_s} = \frac{I_s}{I_p}$$



DC transformer

The primary coil (with N_p turns) of a transformer is connected to a battery. The secondary coil (with N_s turns) is connected to a resistor. When the switch on the primary side is closed, what is the current through the resistor?

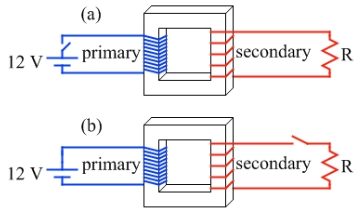
1. zero - there is no current
2. constant and equal to N_p / N_s times the current in the primary
3. constant and equal to N_s / N_p times the current in the primary
4. there is a brief current and then the current drops to zero



DC transformer, II

The switch is now moved to the secondary side. When the switch is closed, what is the current through the resistor?

1. zero - there is no current
2. constant and equal to N_p / N_s times the current in the primary
3. constant and equal to N_s / N_p times the current in the primary
4. there is a brief current and then the current drops to zero



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Power transmission

Electricity is often generated a long way from where it is used, and is transmitted long distances through power lines. Although the resistance of a short length of power line is relatively low, over a long distance the resistance can become substantial. A power line of resistance R causes a power loss of I^2R ; this is wasted as heat. By reducing the current, therefore, the I^2R losses can be minimized.

Power companies use step-up transformers to boost the voltage to hundreds of kV (Recall: $I_s = I_p(\Delta V_p/\Delta V_s)$ so I_s is reduced when the voltage is stepped up) before it is transmitted down a power line, reducing the current and minimizing the power lost in transmission lines. Step-down transformers are used at the other end, to decrease the voltage to the 120 V used in household circuits.

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