Electricity and Magnetism
Transformers and Alternating Current

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Last time

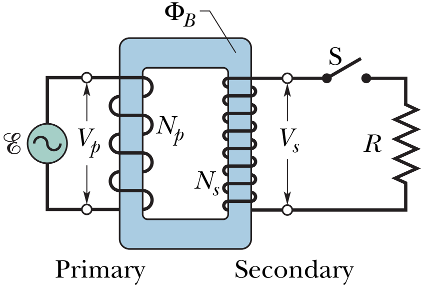
- RLC circuits and oscillations
- alternating current

Overview

- alternating current
- transformers
- rectifiers and filters

Transformers

Transformers change $\Delta V_{\rm rms}$ and $I_{\rm rms}$ simultaneously, while keeping the average power $P_{\rm avg} = I_{\rm rms}\Delta V_{\rm rms}$ (resistive load) constant (conservation of energy).



This works via mutual inductance. If the current in the first coil did not constantly change (AC) this would not work.

$$\Delta v_s = \Delta v_p \frac{N_s}{N_p}$$

Transformers

The reason for the voltage relation is that the iron core ideally contains all the magnetic flux lines produced.

Then the emf per turn $\mathcal{E}_t = -\frac{\mathrm{d}\Phi}{\mathrm{d}t}$ is the same in both solenoids.

$$\Delta v_p = -N_p \frac{\mathrm{d}\Phi}{\mathrm{d}t} \text{ and } \Delta v_s = -N_s \frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

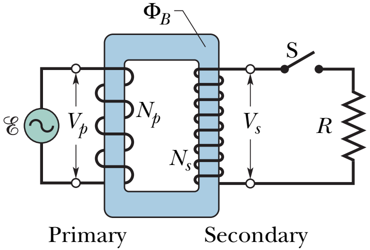
$$\Delta v_s = \Delta v_p \frac{N_s}{N_p}$$

Transformers

Let ΔV now refer to the rms voltage.

If $\Delta V_s > \Delta V_p$ (and therefore $N_s > N_p$), the transformer is called a **step-up transformer**.

This is a step up transformer:



If $\Delta V_s < \Delta V_p$ (and therefore $N_s < N_p$), the transformer is called a **step-down transformer**.

Example from Lecture 21

A power station supplies current $I = 5$ A and potential difference $\Delta V = 1200$ kV to a particular installation along the electric grid. How much power is supplied to the installation?

$$P = I\,\Delta V = (5\text{ A})(1.2 \times 10^6\text{ V}) = 6\text{ MW}$$

Suppose the power station is 1000 km from the installation and delivers the power over copper wires. Assume the resistivity of copper is $1.69 \times 10^{-8}\ \Omega$ m and the radius of the high tension wire is 2 cm. What is the resistance of the wire delivering the electricty?

$$R = \frac{\rho L}{A} = 13.4\ \Omega$$

Example from Lecture 21

How much power is dissipated as heat in the transmission lines to the installation (current $I = 5$ A and potential difference $\Delta V = 1200$ kV are supplied to the station)?

$$P = I^2R = (5\text{ A})^2(13.4\ \Omega) = 336\text{ W}$$

How much power would be dissipated as heat in the transmission lines to the installation if instead the station supplied 6 MW of power with current $I = 500$ A and potential difference $\Delta V = 12$ kV?

$$P = I^2R = (500\text{ A})^2(13.4\ \Omega) = 3.36\text{ MW}$$

Much more loss!

Transformers

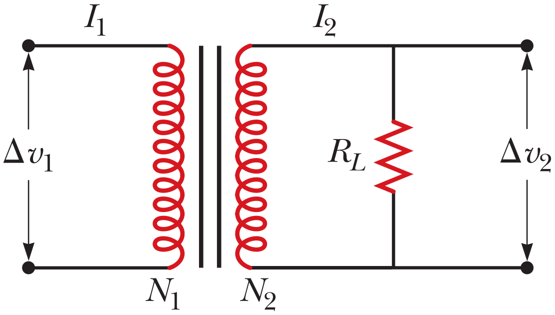
Transmitting power at very high voltage and low current is much more efficient, though very high voltages are not safe or practical for household use.

Transformers allow for the voltage to be adjusted as needed.

This is the main reason why alternating current "won out" over direct current for use as the mains power delivered to consumers.

Transformers

The circuit diagram for a transformer looks like:



R_L is the load resistance.

The equivalent resistance, as seen by the generator on the primary side ($R_{eq} = \Delta V_p / I_p$) is:

$$R_{eq} = \left(\frac{N_p}{N_s}\right)^2 R_L$$

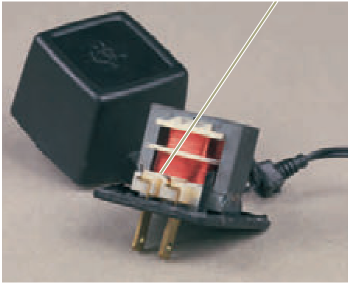
Transformers

$$R_{eq} = \left(\frac{N_p}{N_s}\right)^2 R_L$$

Since the "effective resistance" is different from the actual load resistance R_L, transformers are also used for **load matching**.

Maximum power is delivered when the emf source's internal resistance, $r = R_L$.

Sometimes, this is not possible, but using a transformer we can make $R_{eq} = r$.



Transformer Question

An alternating-current emf device in a certain circuit has a **smaller resistance than that of the resistive load** in the circuit; to increase the transfer of energy from the device to the load, a transformer will be connected between the two.

(i) Should Ns be greater than or less than Np?

(ii) Will that make it a step-up or step-down transformer?

A (i) greater; (ii) step-up

B (i) greater; (ii) step-down

C (i) less; (ii) step-up

D (i) less; (ii) step-down

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Rectifers

What if a device needs a DC source, but is powered by the mains supply? Or, how do the lab power supplies work? They take in AC and output DC.

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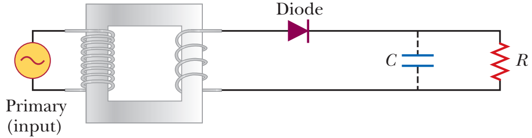
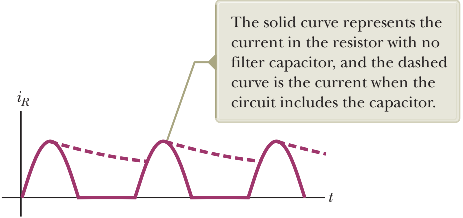
What if a device needs a DC source, but is powered by the mains supply? Or, how do the lab power supplies work? They take in AC and output DC.

This is done using a **rectifier**.



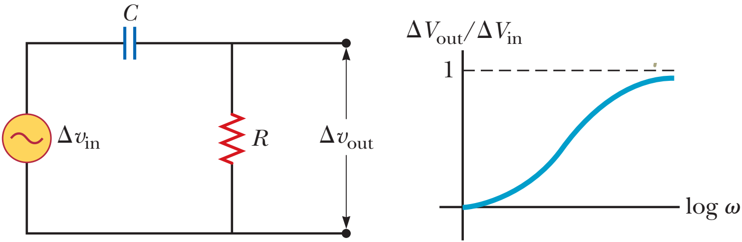
The diode only allows current through in one direction.



Filters

We can also select varying current signals based on their frequencies.

A **high-pass filter**.

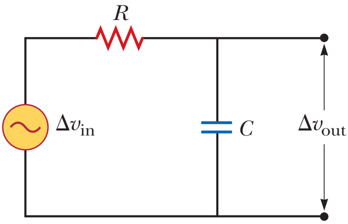


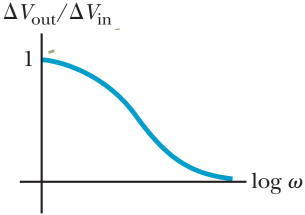
Only high frequencies (large ω) reach Δv_{out}.

Filters

We can also select varying current signals based on their frequencies.

A **low-pass filter**.





Only low frequencies (large ω) reach Δv_{out}.

Summary

- transformers
- filters and rectifiers

Collected Homework 4! due Thursday.

Final Exam Tuesday, Mar 27, 9:15-11:15am, S35 (here).

Homework

Serway & Jewett:

- NEW: Ch 32, Probs: 45, 53, 57, 59
- NEW: Ch 33, onward from page 1021. Obj. Qs: 12, 13; Conc. Qs.: 8, 9; Probs: 1, 3, 5, 49, 51, 53, 57