Electric Power Distribution

Turn off all electronic devices

Observations about Electric Power Distribution

- Household electricity is alternating current (AC)
- Household voltages are typically 120V or 240V
- Power is distributed at much higher voltages
- Power transformers are common around us
- Power substations are there, but harder to find

4 Questions about Electric Power Distribution

1. Why isn't power transmitted via large currents?
2. Why isn't power delivered via high voltages?
3. What is "alternating current" and why use it?
4. How do transformers transfer power from circuit to circuit?

Question 1

Q: Why isn't power transmitted via large currents?

A: Too much power would be wasted in the wires.

- Current-carrying wires consume and waste power
  - power wasted = current · voltage drop in wire
  - voltage drop in wire = resistance · current (Ohm's law)
  - power wasted = resistance · current^2.
- Large currents waste large amounts of power

Question 2

Q: Why isn't power delivered via high voltages?

A: High voltage power is dangerous.

- High voltages can produce large voltage gradients
- Current may flow through unintended paths
  - a spark hazard,
  - a fire hazard,
  - and a shock hazard.

The Voltage Hierarchy

- Electric power delivered to a consumer is

  power delivered = current · voltage drop
- Large currents are too wasteful for transmission
- High voltages are too dangerous for delivery
- So electric power distribution uses a hierarchy:
  - high-voltage transmission circuits in the countryside
  - medium-voltage circuits in cities
  - low-voltage delivery circuits in neighborhoods
- Transformers transfer power between circuits!

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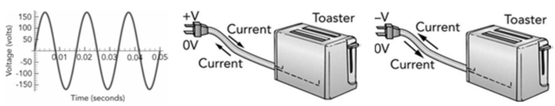
Question 3

Q: What is "alternating current" and why use it?

A: Fluctuating current → so transformers will work

In alternating current,

- the voltages of the power delivery wires alternate,
- so the electric fields in the wires alternate,
- and the resulting currents alternate, too.



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AC and Transformers

Alternating voltage in the US

- completes 60 cycles per second,
- so voltage and current reverse every 1/120 second.

AC complicates the design of electronic devices

AC permits the easy use of transformers,

- which can move power between circuits:
- from a low-voltage circuit to a high-voltage circuit
- from a high-voltage circuit to a low-voltage circuit

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Question 4

Q: How do transformers transfer power from circuit to circuit?

A: Their changing magnetic fields induce currents in the circuits

A transformer has two coils: a primary coil and a secondary coil

If the primary coil's current changes with time,

- the time-changing current produces a time-changing magnetic field,
- the time-changing magnetic field produces an electric field,
- and the electric field pushes on current moving in the secondary coil!

If the current in the secondary coil is caused by that electric field,

- current is said to be induced in the secondary coil,
- and the electric field does work on this induced current.
- Energy is transferred from primary current to secondary current!

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Electromagnetism (Version 2)

Magnetic fields are produced by

- magnetic poles and subatomic particles,
- moving electric charges,
- and changing electric fields [more later…].

Electric fields are produced by

- electric charges and subatomic particles,
- moving magnetic poles,
- and changing magnetic fields.

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Electromagnetic Induction

- Moving poles or changing magnetic fields
  - produce electric fields,
  - which propel currents through conductors,
  - which produce magnetic fields.
- Changing magnetic effects induce currents in conductors
  - Those induced currents also produce magnetic fields,
  - and may induce additional currents, and so on…

Lenz's Law

When a changing magnetic field induces a current in a conductor, the magnetic field from that current opposes the change that induced it

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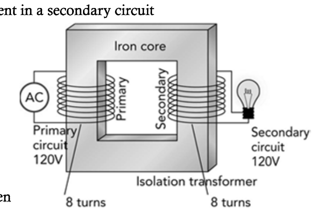
Transformers

In a transformer,

- The alternating current in a primary circuit
- induces an alternating current in a secondary circuit

A transformer

- transfers power between its circuits
- transfers no charges between its circuits
- Its circuits are electrically isolated from one another
- No current can flow between its circuits



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Transformer Currents

- Transformer contains 3 conceptual currents
  - A magnetizing current flows in the primary, but transfers zero power
  - A secondary current flows in the secondary, consuming power
  - A load current flows in the primary, providing power
- The magnetic effects of the secondary and load currents cancel!
  - The products of a coil's turns times its current are equal
  - The few turns in a coil, the more current it carries
  - The more turns in a coil, the less current it carries

$$\text{turns}_{\text{primary}} \cdot \text{current}_{\text{primary}} = \text{turns}_{\text{secondary}} \cdot \text{current}_{\text{secondary}}$$

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Transformer Voltages

- The transformers induced electric field does +/– work on currents
  - Each turn provides another opportunity for +/– work
  - The more turns in a coil, the greater its voltage difference
  - The few turns in a coil, the smaller its voltage different

$$\text{voltage}_{\text{primary}} / \text{turns}_{\text{primary}} = -\,\text{voltage}_{\text{secondary}} / \text{turns}_{\text{secondary}}$$

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Power Transfer

A transformer transfers energy between circuits

- The same electromagnetic induction effects that do work on its secondary current do negative work on its primary current
- Energy is transferred from primary current to secondary current
- It consumes power from the current in its primary coil
- It provides power to the current in its secondary coil

$$\text{turns}_{\text{primary}} \cdot \text{current}_{\text{primary}} = \text{turns}_{\text{secondary}} \cdot \text{current}_{\text{secondary}}$$

$$\text{voltage}_{\text{primary}} / \text{turns}_{\text{primary}} = -\,\text{voltage}_{\text{secondary}} / \text{turns}_{\text{secondary}}$$

$$\text{power}_{\text{primary}} = -\text{power}_{\text{secondary}}$$

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Current and Voltage

A transformer transfers energy between circuits

- The same electromagnetic induction effects that do work on its secondary current do negative work on its primary current
- Energy is transferred from primary current to secondary current
- It consumes power from the current in its primary coil
- It provides power to the current in its secondary coil

$$\text{power}_{\text{primary}} = -\text{power}_{\text{secondary}}$$

Magnetic fields of those two power currents cancel

Since power is the product of voltage · current,

$$\text{voltage}_{\text{primary}} \cdot \text{current}_{\text{primary}} = -\,\text{voltage}_{\text{secondary}} \cdot \text{current}_{\text{secondary}}$$

A transformer can exchanging voltage for current or vice versa!

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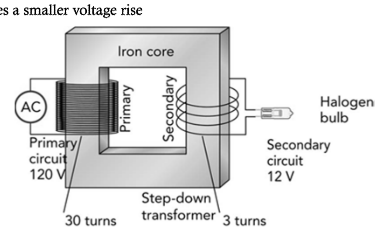
Step-Down Transformer

A step-down transformer

- has relatively few turns in its secondary coil
- so charge is pushed a shorter distance
- and experiences a smaller voltage rise

A larger current at smaller voltage flows in the secondary circuit



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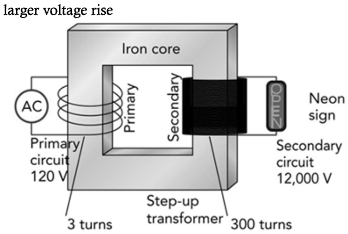
Step-Up Transformer

A step-up transformer

- has relatively many turns in its secondary coil
- so charge is pushed a longer distance
- and experiences a larger voltage rise

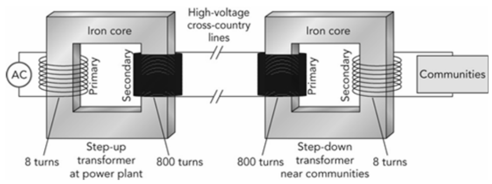
A smaller current at larger voltage flows in the secondary circuit



Power Distribution System

A step-up transformer increases the voltage for efficient long-distance transmission

A step-down transformer decreases the voltage for safe delivery to communities and homes

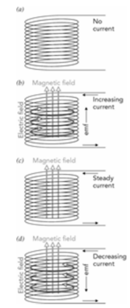


Inductor

Electric and magnetic fields both contain energy

Electromagnet has magnetic energy

- Stores energy as current increases
- Releases energy as current decreases
- Exhibits Lenz's law
  - Current change induces opposing current
  - Opposes any changes in current
- Known as an <u>inductor</u>



Summary about Electric Power Distribution

Electric power is transmitted at high voltages

Electric power is delivered at low voltages

Transformers transfer power between circuits

Transformers require AC power to operate

The power distribution system is AC