Electric Power Distribution

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

- Why isn't power transmitted at low voltages?
- Why isn't power delivered at high voltages?
- What is "alternating current" and why use it?
- How does a transformer transfer power?

Question 1

- Why isn't power transmitted at low voltages?

Electric Power and a Wire

- An electric current passing through a wire converts electrical power in thermal power

  power wasted = current · voltage drop in wire.
- Since the wire obeys Ohms law,

  voltage drop in wire = resistance · current,
- the power that wire wastes is

  power wasted = resistance · current^2.
- Doubling current quadruples wasted power!

Large Currents are Wasteful

- The goal of a power distribution system is to transmit lots of electric power to a city,

  power transmitted = current · voltage drop at city,
- while wasting little electric power in the wires,

  power wasted = resistance · current^2.
- That energy efficiency can be achieved by using
  - a small current,
  - a huge voltage drop,
  - and low-resistance wires.

Question 2

- Why isn't power delivered at high voltages?

High Voltages are Dangerous

- When large voltage drops are available,
  - strong electric fields are present,
  - charges experience enormous forces,
  - and currents tend to flow through unexpected paths.
- High-voltage electrical power in a home is
  - a spark hazard,
  - a fire hazard,
  - and a shock hazard.

The Voltage Hierarchy

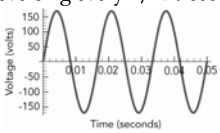
- Large currents are too wasteful for transmission
- High voltages are too dangerous for delivery
- So electric power distribution uses a hierarchy:
  - high-voltage circuits in the countryside
  - medium-voltage circuits in cities
  - low-voltage circuits in neighborhoods and homes
- Transformers transfer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

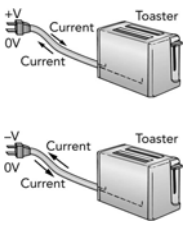
Question 3

- What is "alternating current" and why use it?

Alternating Current (AC)

- In alternating current,
  - the voltages of the power delivery wires alternate
  - and the resulting currents normally alternate, too.
- Alternating voltage in the US
  - completes 60 cycles per second,
  - reversing every 1/120 second.





AC and Transformers

- AC has little effect on simple electric devices (e.g., lightbulbs, space heaters, toasters)
- AC is a nuisance for electronic devices (e.g., computers, televisions, sound systems)
- 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

Question 4

- How does a transformer transfer power?

Electromagnetism (Version 2)

- Magnetic fields are produced by
  - magnetic poles (but free poles don't seem to exist),
  - moving electric charges,
  - and changing electric fields [more later…].
- Electric fields are produced by
  - electric charges,
  - moving magnetic poles,
  - and changing magnetic fields.

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
- Induced currents produce magnetic fields

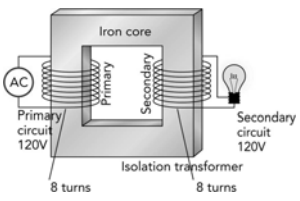
Lenz's Law

- Lenz's law predicts the nature of the induced magnetic fields:

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

Transformer

- Alternating current in one circuit can induce an alternating current in a second circuit
- A transformer
  - uses induction
  - to transfer power between its circuits
  - but doesn't transfer any charges between its circuits



Current and Voltage

- A transformer must obey energy conservation
- Power arriving in its primary circuit must equal power leaving in its secondary circuit
- Since power is the product of voltage · current,
  - a transformer can exchanging voltage for current
  - or current for voltage!

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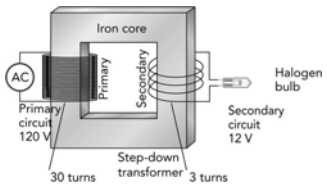
Step-Down Transformer

- 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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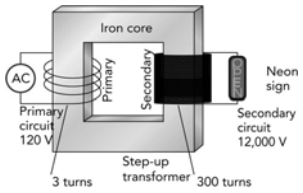
Step-Up Transformer

- 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



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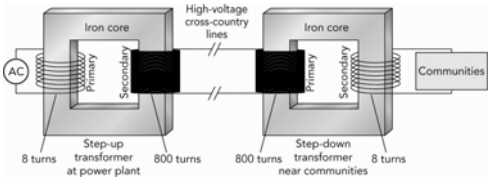
Power Distribution System

- 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



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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