Electric Power Distribution

Introductory Question

- Electric power reaches our city via high voltage transmission lines. What fraction of the electric charges traveling on those transmission lines pass through this room?

A. About 1%
B. About 0.01%
C. Exactly 0%

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!

Clicker Question

- Two long wires will carry electrical power most efficiently from a generator to a community if the voltage difference between the wires is

A. large and the current they carry is large.
B. large and the current they carry is small.
C. small and the current they carry is large.
D. small and the current they carry is small.

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

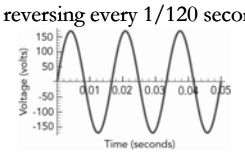
- Large currents are too wasteful for transmission
- High voltages are too dangerous for delivery
- So electric power distribution uses a hierarchy:
  - high-voltage circuits in the countryside
  - medium-voltage circuits in cities
  - low-voltage circuits in neighborhoods and homes
- Transformers transfer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

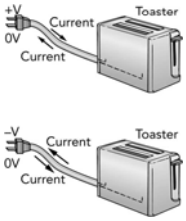
Question 3

- 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

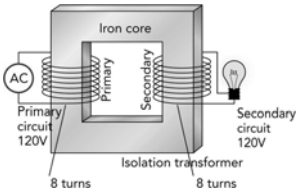
Lenz's Law

- 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!

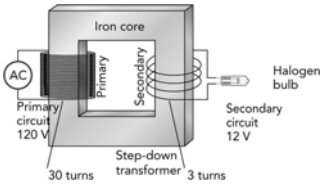
Clicker Question

- If you increase the number of turns of wire in the secondary coil of a transformer, each charge traveling through that wire will experience

A. the same forward force for a longer distance.
B. a larger forward force for a longer distance.
C. a larger forward force for the same distance.
D. the same forward force for the same distance.

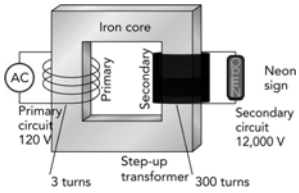
Step-Down Transformer

- 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



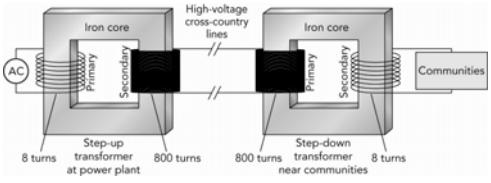
Step-Up Transformer

- 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



Introductory Question (revisited)

- Electric power reaches our city via high voltage transmission lines. What fraction of the electric charges traveling on those transmission lines pass through this room?

A. About 1%
B. About 0.01%
C. Exactly 0%

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