Electromagnetic Induction

Electromagnetic Induction

Electric current can produce magnetic fields,
but (changing) magnetic fields can also produce current!

- Electric current can be produced in a wire by simply moving a magnet into or out of a wire
- The relative motion between the wire and magnetic field induces voltage which produces current.

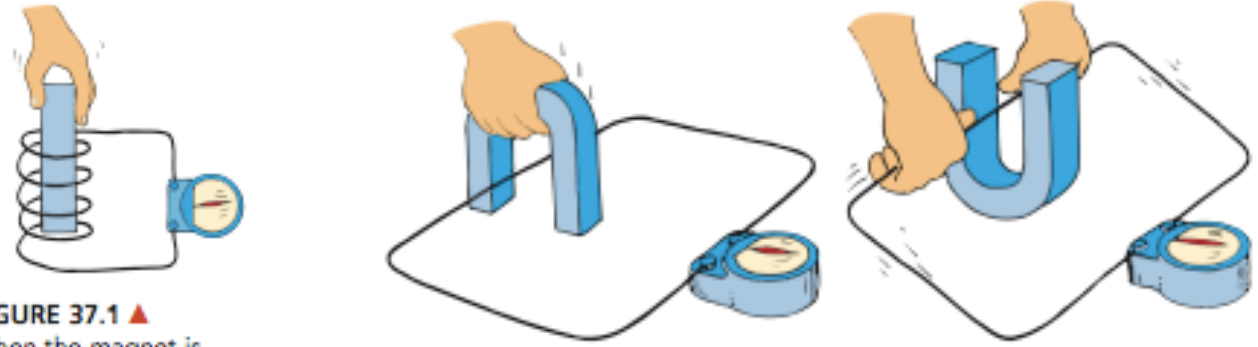
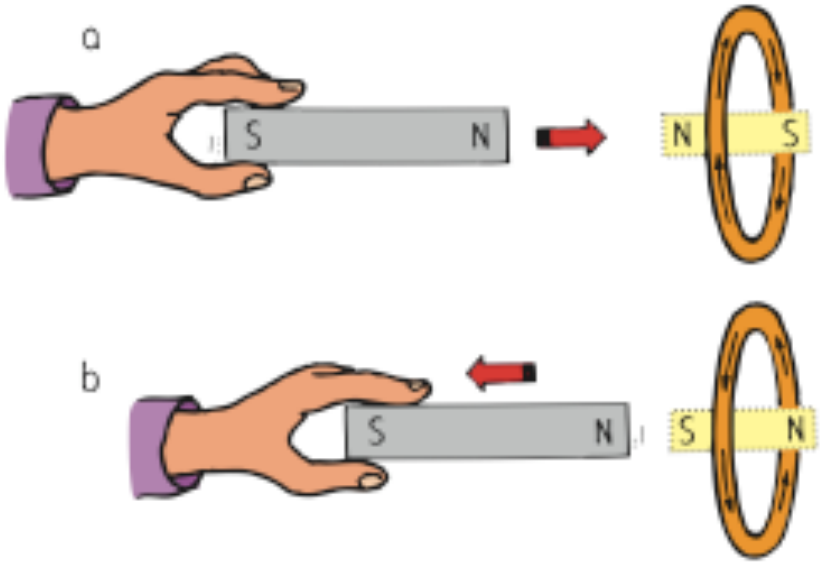


FIGURE 37.1 ▲
When the magnet is plunged into the coil, voltage is induced in the coil and charges in the coil are set in motion.

Lenz's Law

- Direction of the induced current is such that the magnetic field resulting from the induced current opposes the change in the field caused by the induced current.

- Work is done in pushing the magnet into the loop.
- The induced current in the loop creates a magnetic field that repels the approaching magnet.
- For example, in the top figure, the north pole of a bar magnet is pushed toward a single loop. The current induced in the loop produces a magnetic field that repels the approaching bar magnet.
- In the bottom figure, when the magnet is pulled away from the loop, the induced current produces a magnetic field that attracts the receding bar magnet.
- Both cases require work input. If you try to push a magnet into a coil with more loops, it requires even more work.



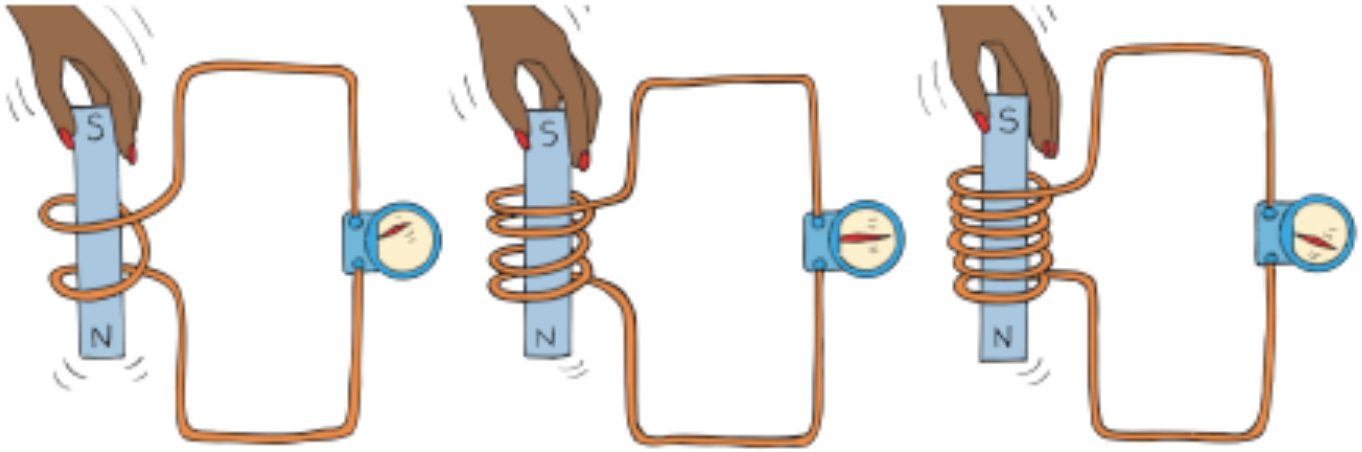
Flux

- **Magnetic Flux** = the amount of magnetic field passing through a given area
  - Measured in units of Webers (Wb)
- If the loop of wire lies parallel to the field, the flux through the loop will be zero.

$$\Phi = AB$$

Φ = flux (Wb)
A = area of loop (m^2)
B = magnetic field (T)

Ex: Eleanor is undergoing an MRI procedure and is placed inside a chamber housing the coil of a large electromagnet that has a radius of 25.0 cm. A flux of 0.290 Wb passes through the coil opening. What is the magnetic field inside the coil?



greater number of loops
= greater induced voltage
= greater current

- **Faraday's Law: Induced voltage in a coil is proportional to:**
  - **The number of loops**
  - **The area of each loop**
  - **The rate at which the magnetic field changes within those loops**

$$\text{potential difference} = \frac{(\text{number of turns})(\text{change in flux})}{\text{elapsed time}}$$

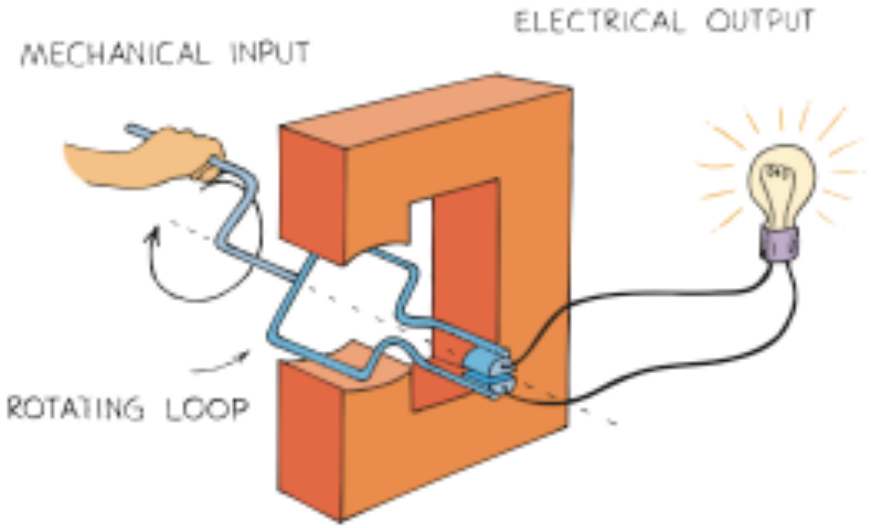
$$V = \frac{N\Delta\phi}{\Delta t}$$

V = voltage [V]
N = number of turns/loops
t = time
$\emptyset = flux$

Ex: The hood ornament on Abe's sedan is shaped like a ring 8.00 cm in diameter. Abe is driving toward the west so that Earth's $5.00*10^{-5}$ T field provides no flux through the hood ornament. What is the induced voltage in the metal ring as Abe turns from this street onto one where he is traveling north, if he takes 3.0 s to make the turn?

Generators & Motors

- Generator = A machine that produces electric current by rotating a coil within a stationary magnetic field



- A motor converts electrical energy into mechanical energy.
- A generator converts mechanical energy into electrical energy.

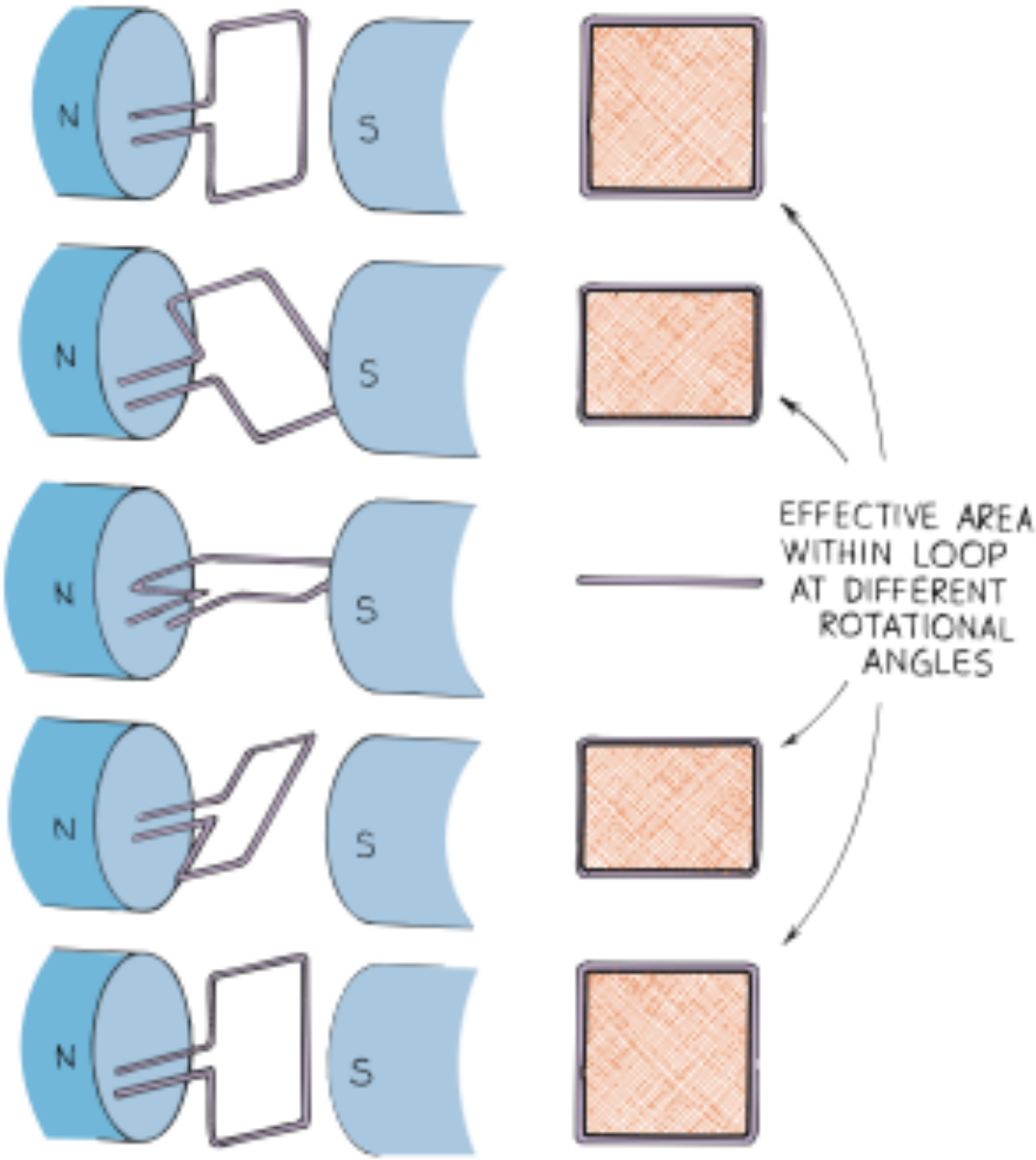
a. The loop starts by enclosing the maximum number of field lines.

b. As the loop rotates, fewer field lines pass through it.

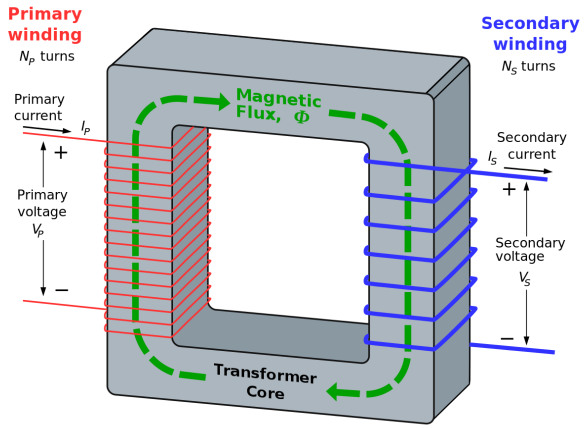
c. In this position, the loop encloses no field lines.

d. Now the loop encloses more field lines again.

e. After half a turn, the loop again encloses the maximum number of field lines.

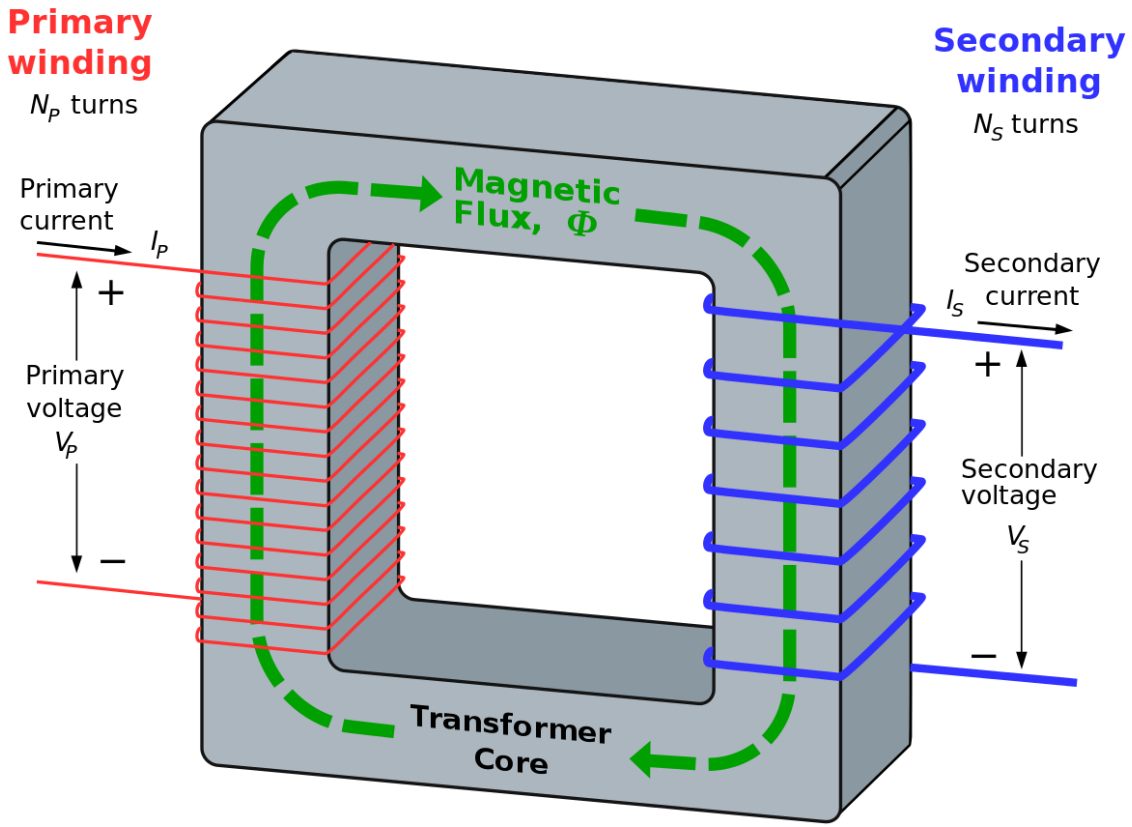


Transformers



- A transformer is a device for increasing or decreasing voltage through electromagnetic induction.
- A transformer works by inducing a changing magnetic field in one coil, which is carried through the core and induces an alternating current (and induced voltage) in a nearby second coil.
- Voltages may be <u>stepped up</u> ($V_2 > V_1$) or <u>stepped down</u> ($V_1 > V_2$) with a transformer.
- Energy (& power) are conserved.

Transformers



$$\frac{V_{primary}}{N_{primary}} = \frac{V_{secondary}}{N_{secondary}}$$

$$VI_{primary} = VI_{secondary}$$

V = voltage [V]

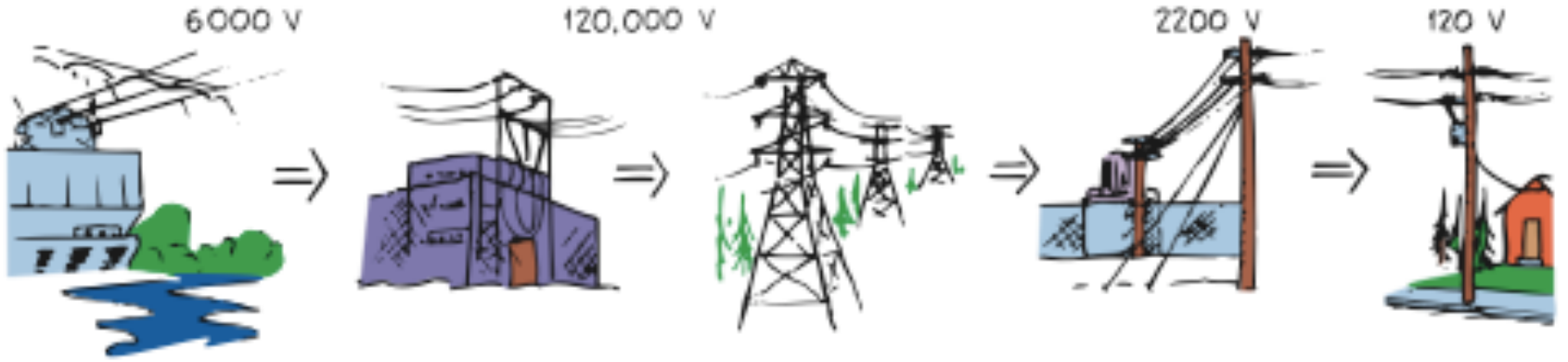
N = number of turns

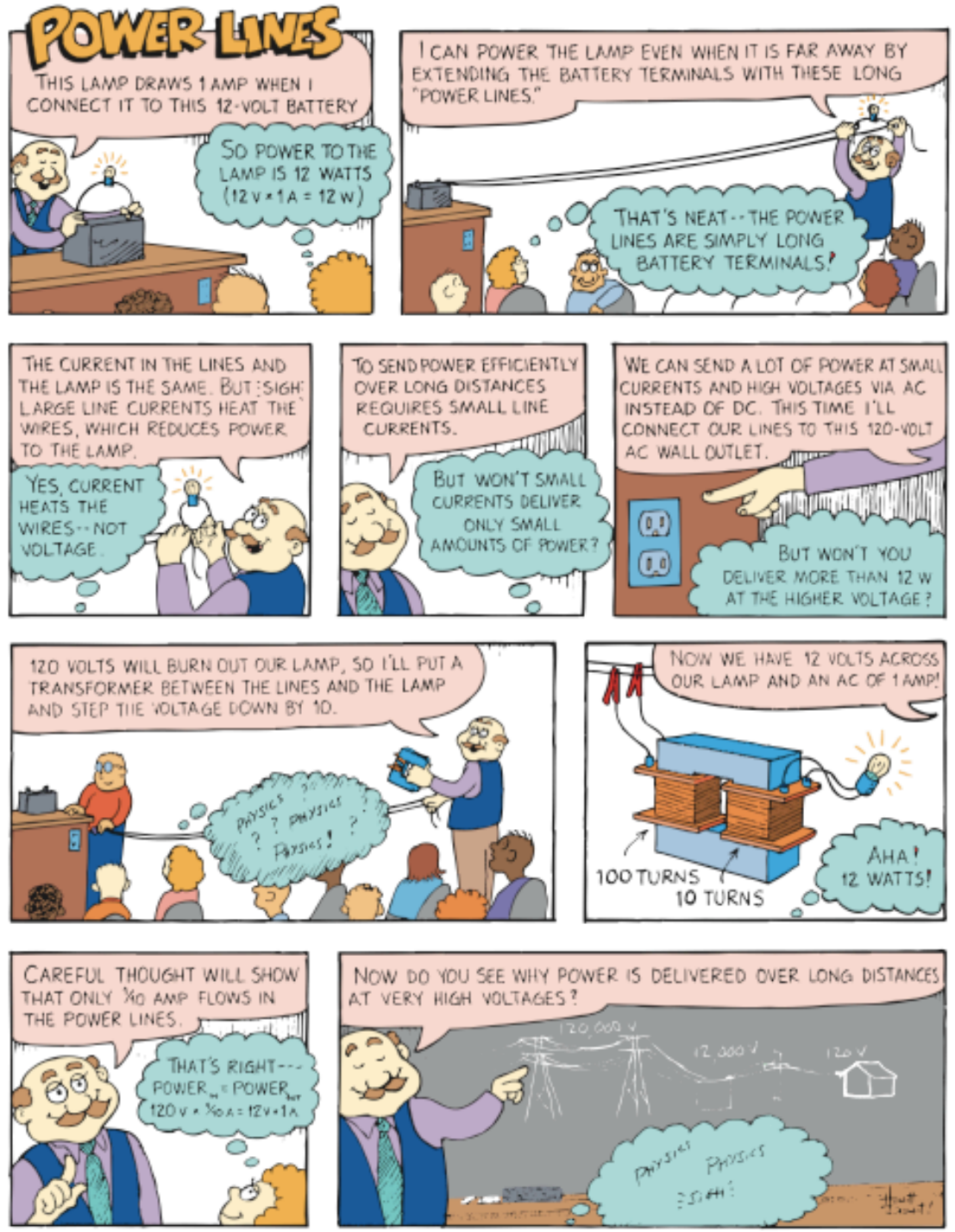
I = current [A]

Power Transmission

$$VI_{primary} = VI_{secondary}$$

- Power is transmitted great distances at high voltages and correspondingly low currents, a process that otherwise would result in large energy losses owing to the heating of the wires.
- Power may be carried from power plants to cities at about 120,000 volts or more, stepped down to about 2400 volts in the city, and finally stepped down again by a transformer to provide the 120 volts in our houses




POWER LINES
THIS LAMP DRAWS 1 AMP WHEN I CONNECT IT TO THIS 12-VOLT BATTERY
SO POWER TO THE LAMP IS 12 WATTS (12 V × 1 A = 12 W)
I CAN POWER THE LAMP EVEN WHEN IT IS FAR AWAY BY EXTENDING THE BATTERY TERMINALS WITH THESE LONG "POWER LINES."
THAT'S NEAT -- THE POWER LINES ARE SIMPLY LONG BATTERY TERMINALS!
THE CURRENT IN THE LINES AND THE LAMP IS THE SAME. BUT [SIGH] LARGE LINE CURRENTS HEAT THE WIRES, WHICH REDUCES POWER TO THE LAMP.
YES, CURRENT HEATS THE WIRES -- NOT VOLTAGE.
TO SEND POWER EFFICIENTLY OVER LONG DISTANCES REQUIRES SMALL LINE CURRENTS.
BUT WON'T SMALL CURRENTS DELIVER ONLY SMALL AMOUNTS OF POWER?
WE CAN SEND A LOT OF POWER AT SMALL CURRENTS AND HIGH VOLTAGES VIA AC INSTEAD OF DC. THIS TIME I'LL CONNECT OUR LINES TO THIS 120-VOLT AC WALL OUTLET.
BUT WON'T YOU DELIVER MORE THAN 12 W AT THE HIGHER VOLTAGE?
120 VOLTS WILL BURN OUT OUR LAMP, SO I'LL PUT A TRANSFORMER BETWEEN THE LINES AND THE LAMP AND STEP THE VOLTAGE DOWN BY 10.
PHYSICS ? ? PHYSICS ? PHYSICS!
NOW WE HAVE 12 VOLTS ACROSS OUR LAMP AND AN AC OF 1 AMP!
100 TURNS
10 TURNS
AHA! 12 WATTS!
CAREFUL THOUGHT WILL SHOW THAT ONLY 1/10 AMP FLOWS IN THE POWER LINES.
THAT'S RIGHT -- $POWER_{in} = POWER_{out}$
120 V × 1/10 A = 12 V × 1 A
NOW DO YOU SEE WHY POWER IS DELIVERED OVER LONG DISTANCES AT VERY HIGH VOLTAGES?
120,000 V
12,000 V
120 V
PHYSICS PHYSICS