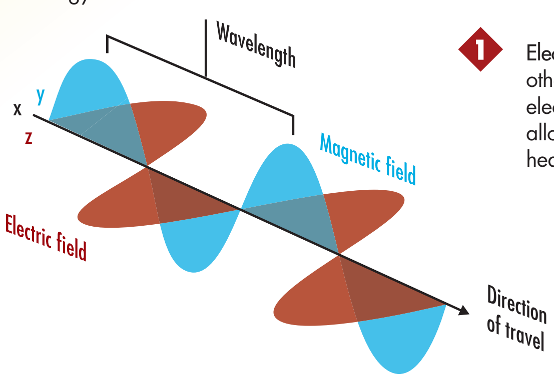
How Electromagnetism Is the Ghost in the Machine

THIS BOOK BEGINS with a quote from Arthur C. Clarke: "Any sufficiently advanced technology is indistinguishable from magic." Well, we're still not past the first chapter and it's already time to start the magic show. Like good magicians, electricity and magnetism—the twin powers of **electromagnetism**—hide what they are doing. They mostly show the results—the rabbit coming out of the hat, not how it got into the hat.

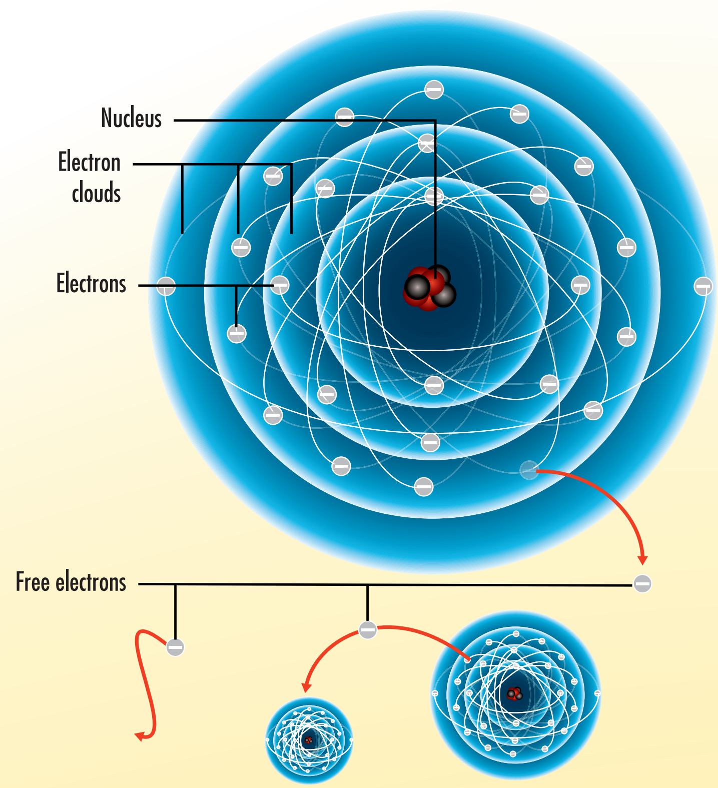
We can see the effects of magnetism on iron filings, refrigerator doors, and the giant generators that supply much of our energy, but we cannot see magnetism itself. It's the silent partner in the electromagnetic spectrum.

We can see electricity in the form of lightning and sparks from a shorting wall plug, and we can certainly feel electricity when static electricity (a build-up of surplus electrons) jumps from our fingers on a cold day.

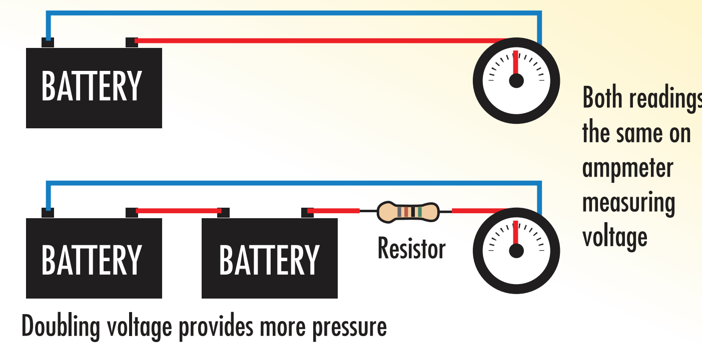
Combined, magnetism and electricity form the electromagnetic spectrum—the full frequency range of the mysterious waves that permeate the universe. This partnership continues into other areas, where these conjoined energy ghosts form the basis for most of modern technology.

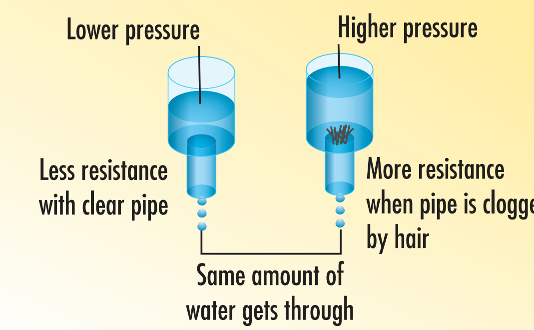


1 Electricity and magnetism cannot survive without each other. The previous illustration shows how magnetic and electric fields cooperate in a boot-strapping operation that allows electromagnetic waves, such as light, radio, and heat, to travel through a vacuum.



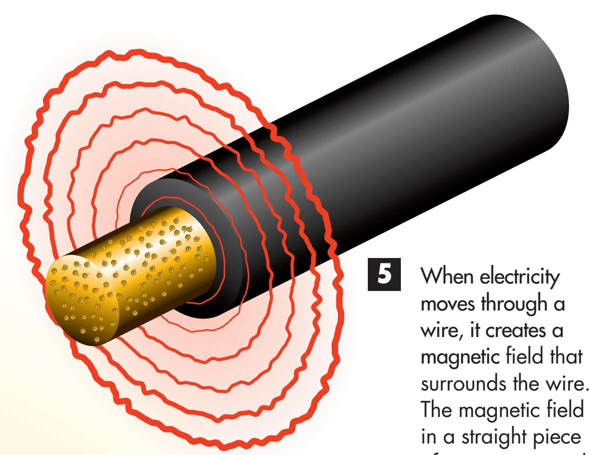
2 Let's start with the *electro* half of electromagnetism. In some atoms, such as copper and silver, the attraction is weak between the atoms' core—a **nucleus** made of positively charged protons—and the negatively charged **electron clouds** in the atoms' outer layers. In such **conductive** materials it's possible for electrons to jump freely from one atom to another. This movement of electrons, which occurs only under the right circumstances, is **electricity**, and it travels at the same speed as light (another form of electromagnetism)—186,000 miles each second.





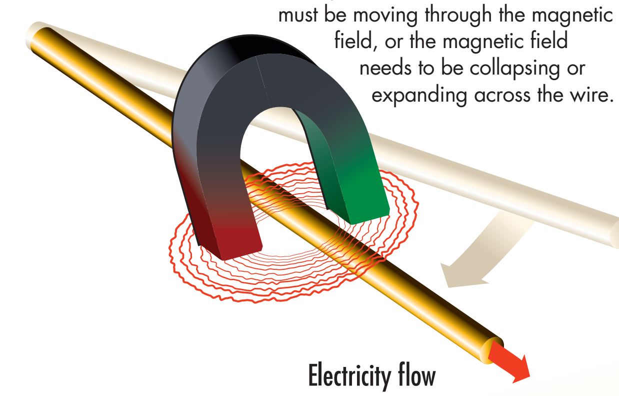
3 We apply three measurements when working with electricity: voltage, amperage, and resistance. It's convenient to think of **voltage,** or **charge,** as being like water pressure—how much power is behind electricity. **Amperage**, or **amps**, is the measure of how much electricity is flowing through wires, similar to how we measure the gallons of water that pass through pipes. **Resistance** is how the material through which the electricity is flowing. In the examples here, higher water pressure overcomes a clogged pipe, and doubling the voltage pushes through the same amount of current despite the addition of a resistor.

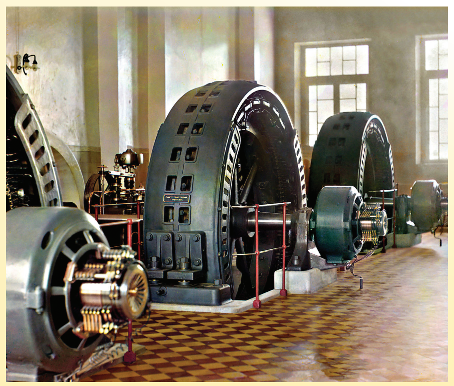
4 In some materials, such as rubber and glass, electrons are more closely bound to their nuclei and do not easily move from one atom to another. These **nonconductive** materials are **insulators**. Still other materials, such as **silicon**, can act as either conductors or insulators under different conditions. These are **semiconductors**, an important component of microchips and transistors.



5 When electricity moves through a wire, it creates a magnetic field that surrounds the wire. The magnetic field in a straight piece of wire is too weak to pick up even the smallest iron filings.

6 Conversely, when a wire moves through a magnetic field, the interaction creates an electrical current in the wire. Note that in order for either of these phenomena to work, the wire must be moving through the magnetic field, or the magnetic field needs to be collapsing or expanding across the wire.





7 Both the magnetic fields caused by electricity moving through a wire and electricity created from magnetism can be made more powerful if the wires are wrapped around iron cores. Almost all electricity we use comes from **generators**, in which massive magnets surround equally massive coils of wire. Water from a dam, or steam created by a nuclear plant or fuel-burning plant, spins the wire coil rapidly, creating a high-voltage **alternating current** that is transmitted via thick, low-resistance cables to electrical substations throughout urban areas.