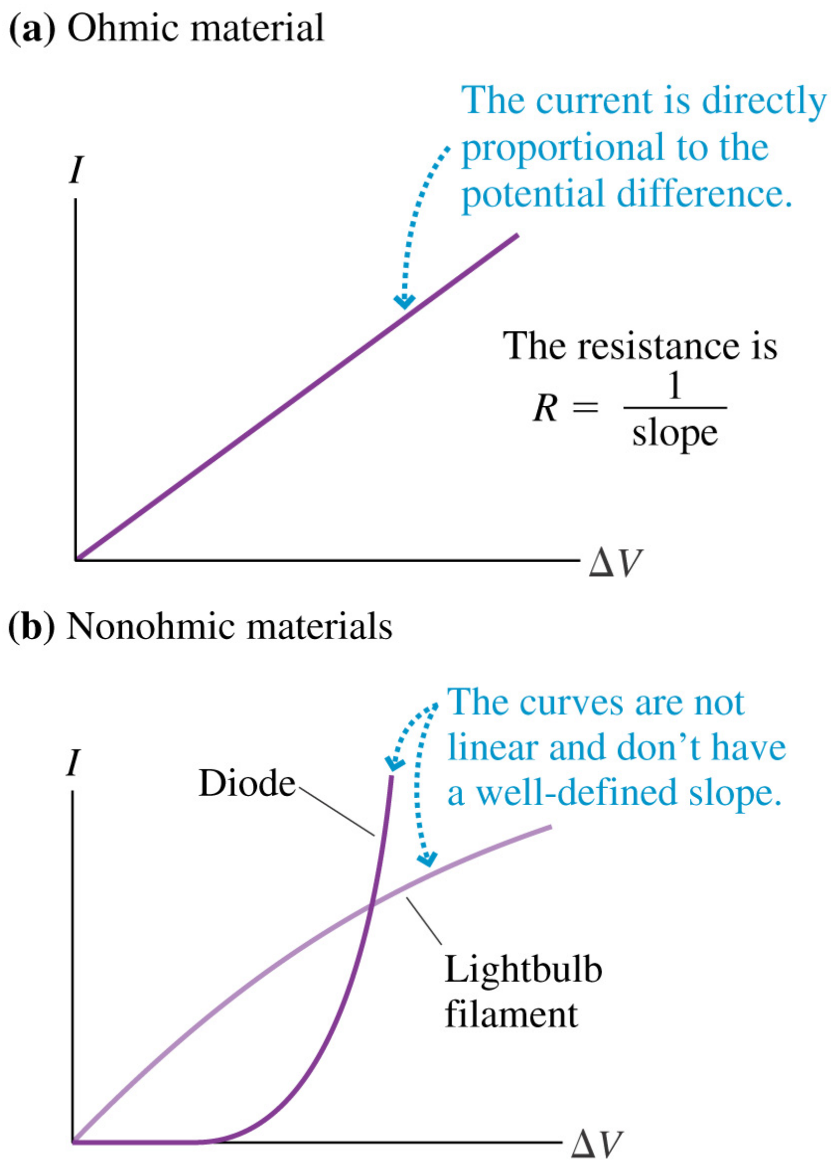
Announcements

- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM
  - Tues 12-3 PM
    - note this Tues only 12-4 PM
  - Wed 6-9 PM
    - note this Wed only 10-noon
  - Fri 10 AM-noon
- LON-CAPA #6 due Oct. 18
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Ohm's law

- Ohm found that, for some materials, the resistance is independent of the current, i.e. the current is directly proportional to the potential difference
  - these materials are said to follow Ohm's law
- Other materials are said to be non-Ohmic



Ohm's law

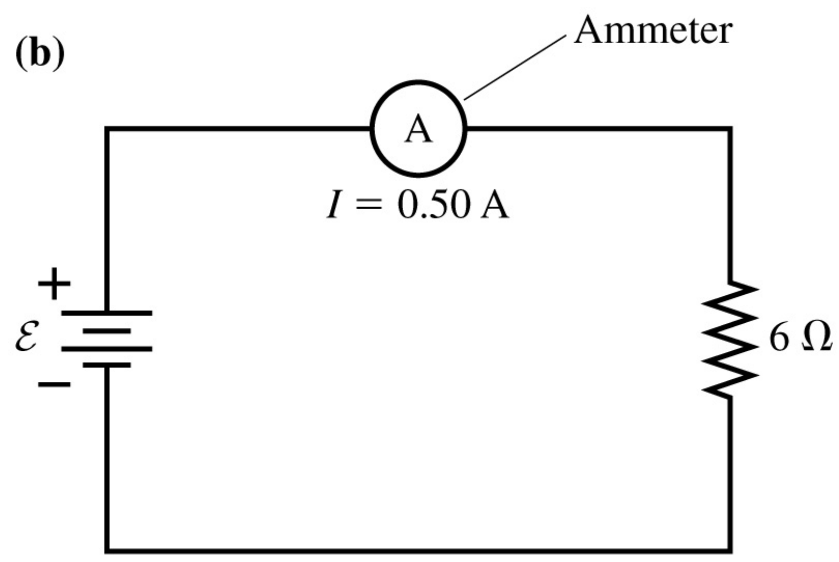
- I=V/R
- V=IR
- R=V/I
  - relates the current, voltage and resistance

- How much current flows through a lamp with a resistance of 60 Ω when the voltage across the lamp is 12 V?
  - I=V/R=12 V/60 Ω = 0.2 A

- What is the resistance of a toaster that draws a current of 12 A when connected to a 120 V circuit?
  - R=V/I=120 V/12 A= 10 Ω

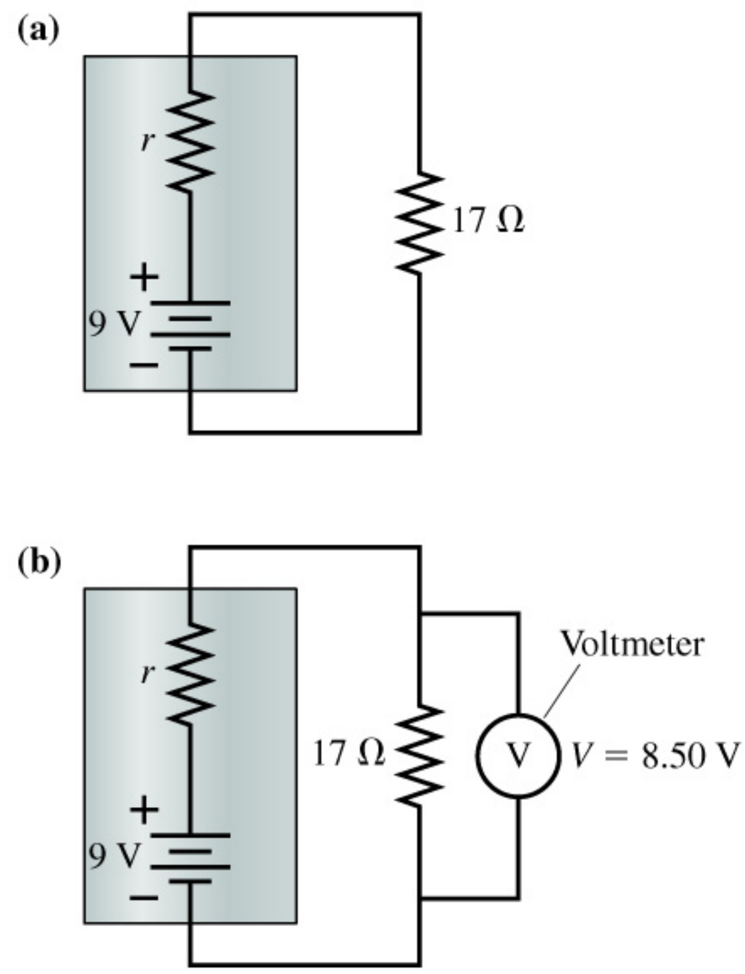
Ammeters

- An ammeter is a device that measures the current in a circuit
- It's stuck directly in the path of the current (i.e. in series) so you would like its resistance to be as small as possible so that it doesn't affect the circuit too much
  - an ideal ammeter would have zero resistance
- Nowadays ammeters are digital devices but old-fashioned ones use a galvanometer
  - how a galvanometer works depends on the interactions of currents and magnetic fields



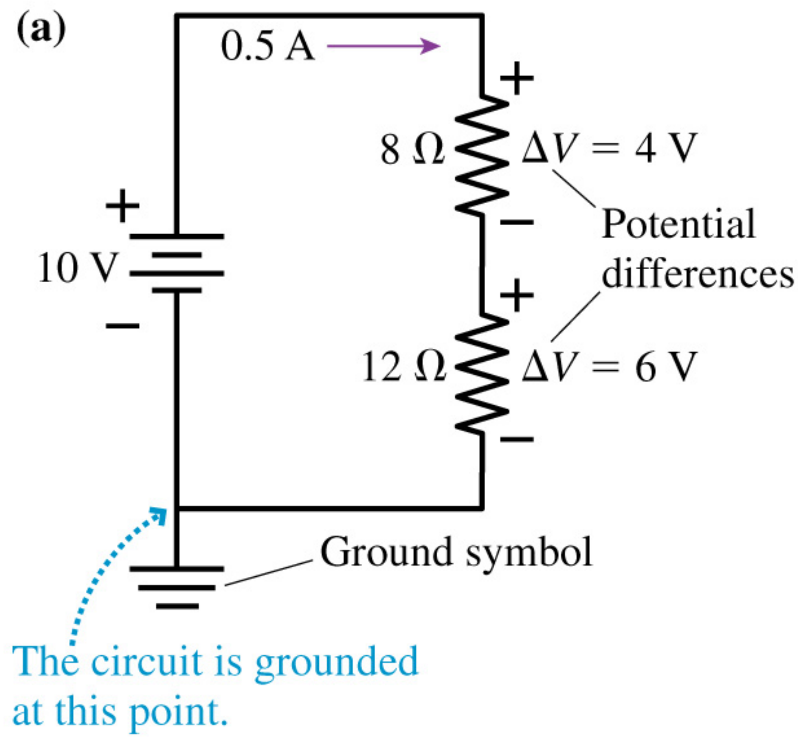
Voltmeters

- If I want to measure a voltage in a circuit, I use a voltmeter
- A voltmeter is placed in parallel in the circuit, so you would like its resistance to be as large as possible in order to affect the circuit as little as possible
  - an ideal voltmeter would have infinite resistance
- Modern voltmeters are digital but the old-fashioned ones used a galvanometer



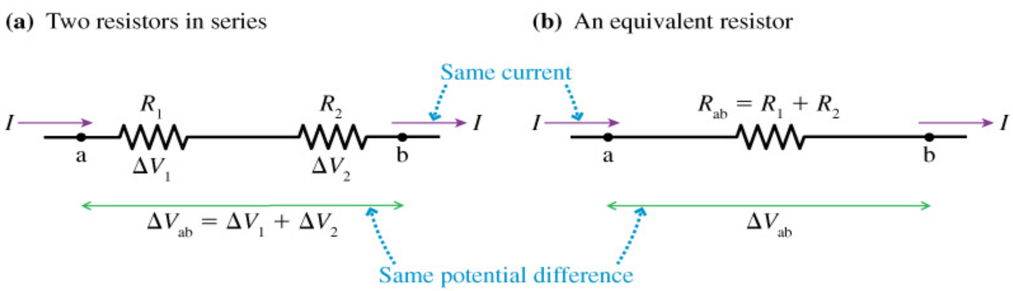
Grounded

- We've emphasized so far that it's potential differences that we're interested in rather than absolute potentials
- It's useful, though, to tie a particular point of a circuit to a reference potential, i.e. to ground
  - plus a useful safety feature
- That way multiple circuits can be used at the same time and their reference potentials will be the same



Resistors in series

- Consider two (or more) resistors in series
- The same current passes through both resistors
  - how could it be otherwise?
- The total voltage drop across the two resistors is the sum of the voltage drops across each resistor
- We'd like to find an equivalent resistance for which the current would be the same given the same voltage drop
- We can do so using Ohm's law
- So equivalent resistance for resistors in series is the sum of the individual resistances



$$\Delta V_{ab} = \Delta V_a + \Delta V_b = IR_1 + IR_2$$

$$I = \frac{\Delta V_{ab}}{R_1 + R_2} = \frac{\Delta V_{ab}}{R_{eq}}$$

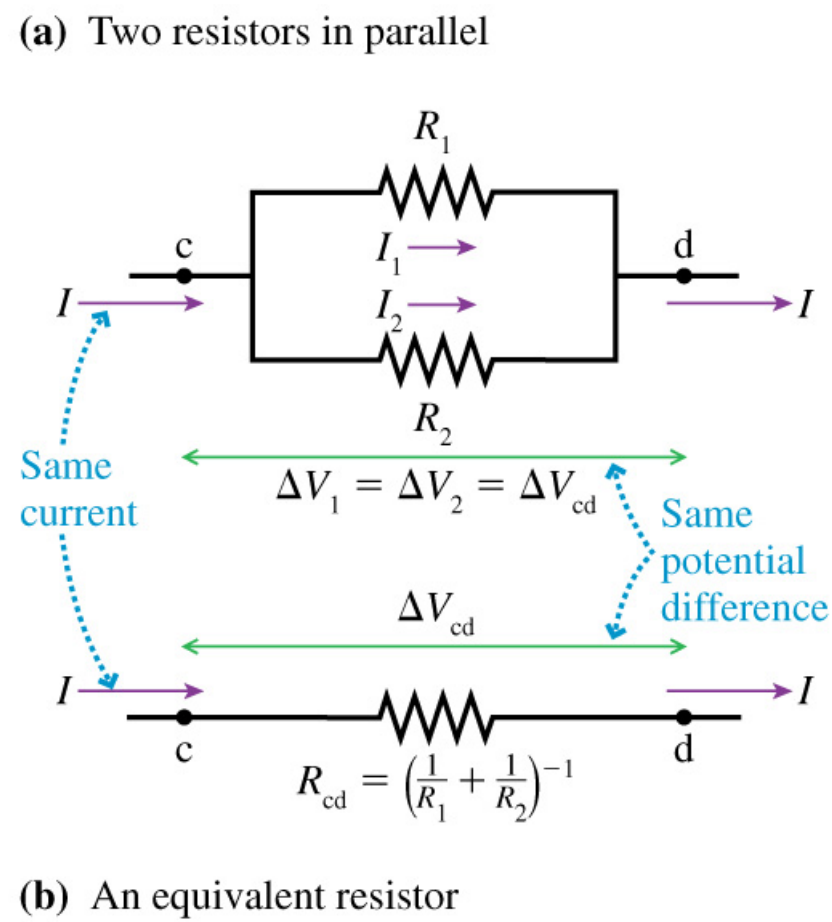
$$R_{eq} = R_1 + R_2 (+R_3 + \ldots)$$

Resistors in parallel

- In this case, the current splits up when going through R_1 and R_2, but we know that the voltage across R_1 and R_2 are the same
- Replace by an equivalent resistance

$$I = I_1 + I_2 = \frac{\Delta V}{R_1} + \frac{\Delta V}{R_2} = \frac{\Delta V}{R_{eq}}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \left(\frac{1}{R_3} + \ldots\right)$$



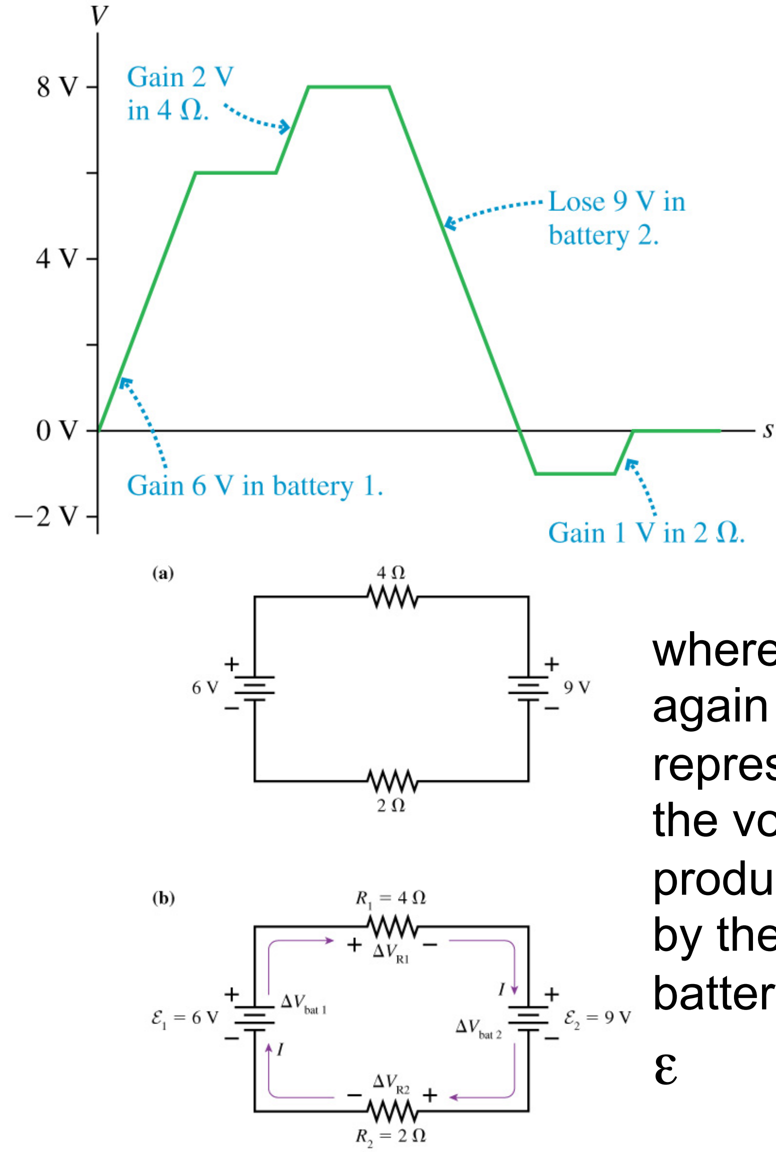
Note that the equivalent resistance is smaller than any of the individual resistances

Energy considerations

- When charge q goes from - terminal of battery to + terminal it gains a potential energy of $\Delta U = q\varepsilon$
- The rate at which energy is gained is given by

$$P = \frac{\Delta U}{\Delta t} = \frac{\Delta(q\varepsilon)}{\Delta t} = \frac{\Delta q}{\Delta t}\varepsilon = I\varepsilon$$

- with units of J/s(=Watts)

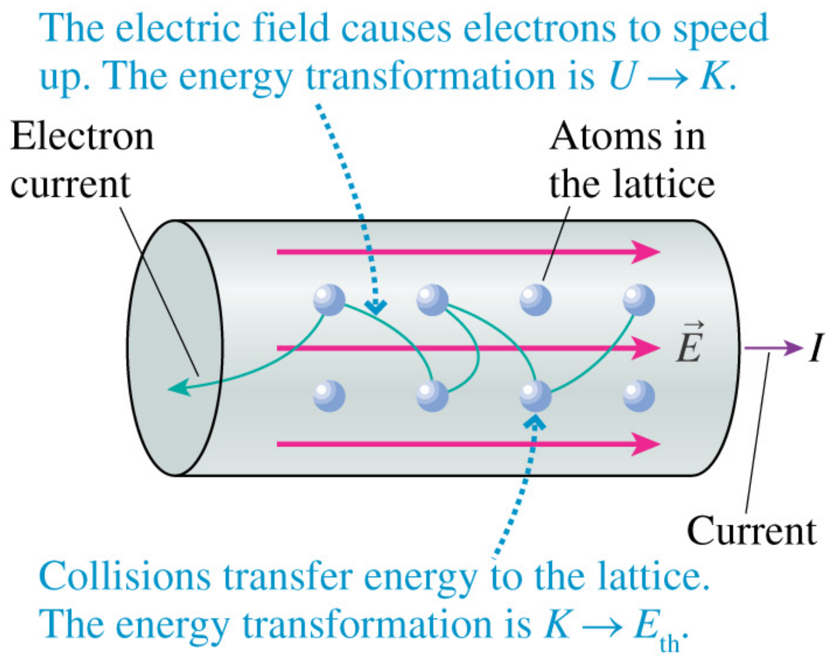


where again we represent the voltage produced by the battery by ε

Energy gained is energy lost

- Energy added by battery is lost by electrons during their collisions with atoms and eventually ends up as heat
  - i.e. the resistor gets warm
- Consider the work done by the electric field for an electron travelling a distance d

$$W = F\Delta s = qEd$$



- The energy transferred to the lattice when the electron collides with an atom then is

$$\Delta E_{collision} = \Delta K = qEd$$

- In a length L, the energy transferred is

$$\Delta E = qEL = q\Delta V_R$$

- The power dissipated in the resistor then can be written as

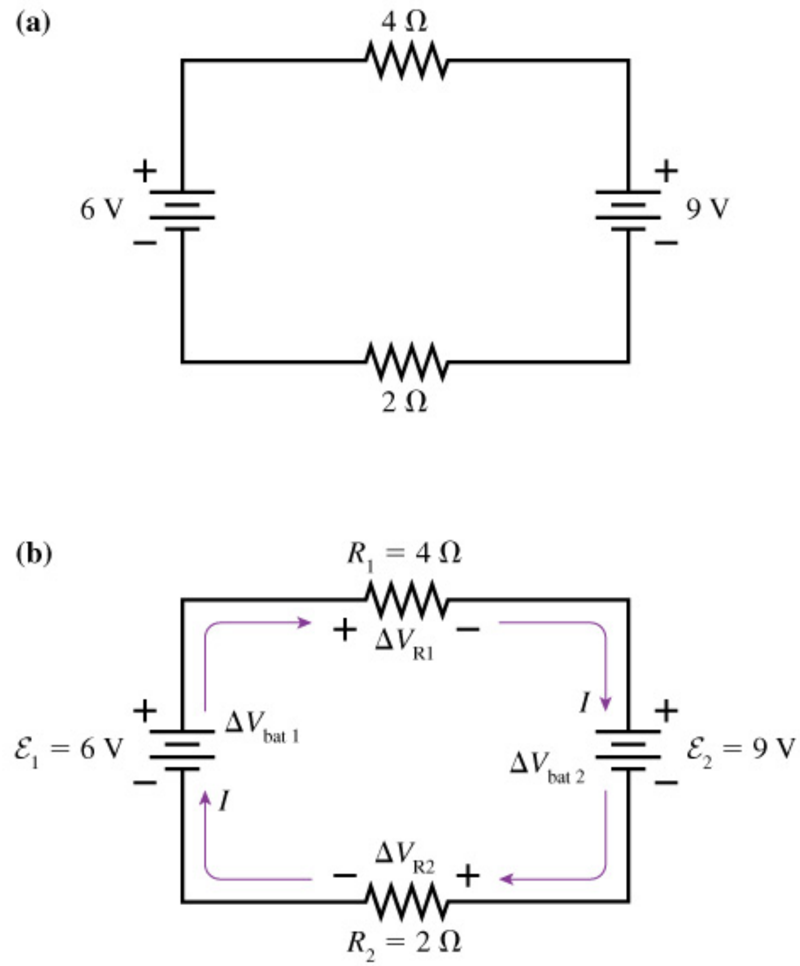
$$P_R = \frac{dE}{dt} = \frac{dq}{dt}\Delta V_R = I\Delta V_R = P_{battery}$$

Power in electrical circuits

- Can write the power in the following forms

$$P = I\Delta V_R = I^2 R = \frac{\Delta V_R^{\ 2}}{R}$$

- If I integrate power over time, I have units of energy
  - kW-hr
  - 1000 J/s*3600s =3.6X10^6 J/kW-hr



Problem

- Suppose a 12-V battery is connected across a 100 Ω resistor. How many electrons flow through the resistor in 1 minute?

$$I = \frac{V}{R} = \frac{12V}{100\Omega} = 0.12A$$

$$Q = I\Delta t = (0.12C/s)(60s) = 7.2C$$

$$7.2C/(1.6E-19C/e) = 4.83E19 electrons$$

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$$P_{resistor} = I^2 R = (0.12A)^2(100\Omega) = 1.44W$$

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Problem

- Suppose a 12-V battery is connected across a 100 Ω resistor. How many electrons flow through the resistor in 1 minute?
- What is the power produced by the battery?
- What is the power lost in heating up the resistor?

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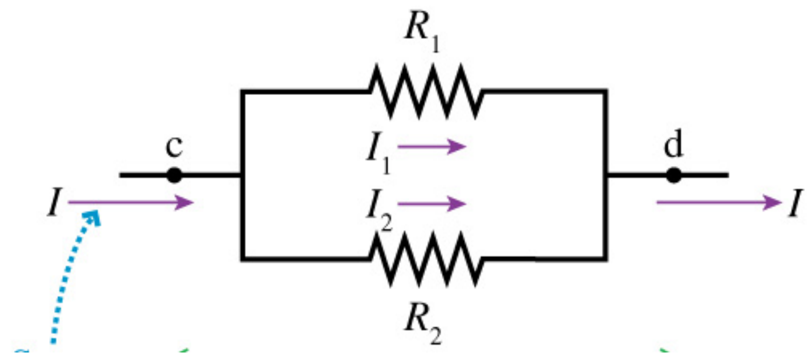
Iclicker question

- Suppose $R_1=R_2=8\Omega$
- What is the equivalent resistance?
  - A) 8Ω
  - B) 16Ω
  - C) $4\ \Omega$
  - D) 64Ω
  - E) 2Ω



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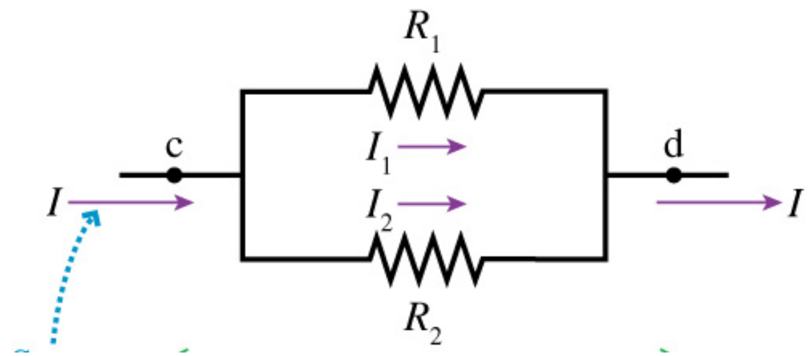
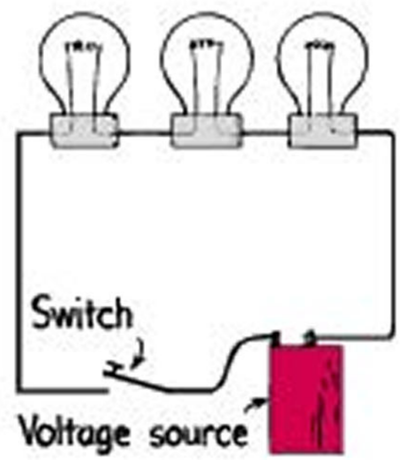
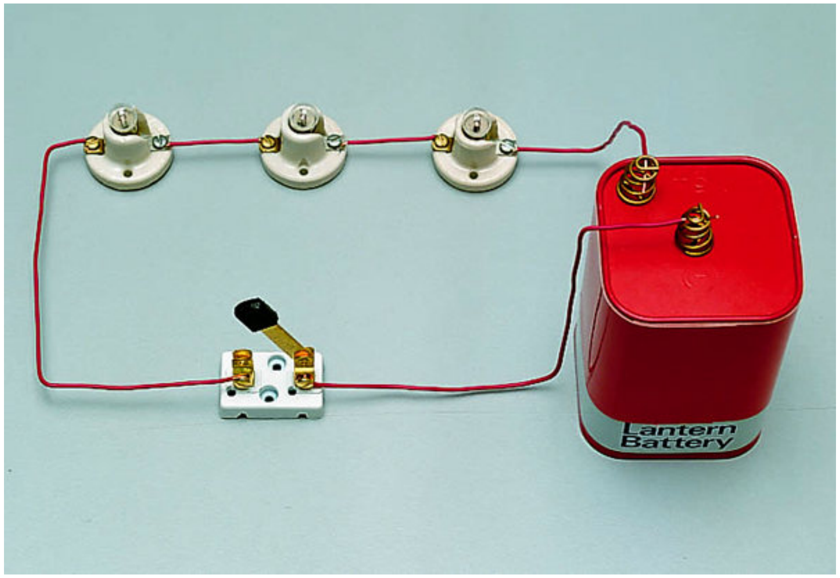


Series electrical circuit

- Any path electrons can flow along is an electrical circuit
- For the electrical current of electrons to flow, there must be continuity, i.e. no gaps
- In a series circuit, the circuit elements (in the case on the right, 3 light bulbs) are connected in series
- The same current flows through each of the bulbs (and through the battery)
  - the current can't bunch up anywhere just as the flow of water through a pipe can't bunch up anywhere



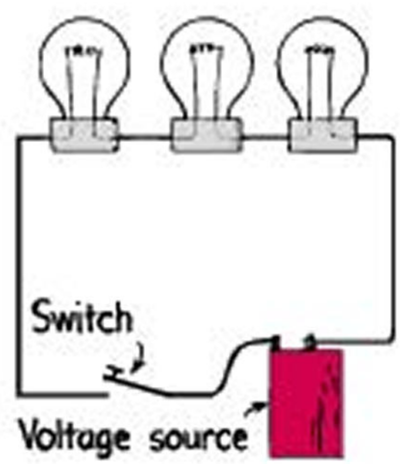


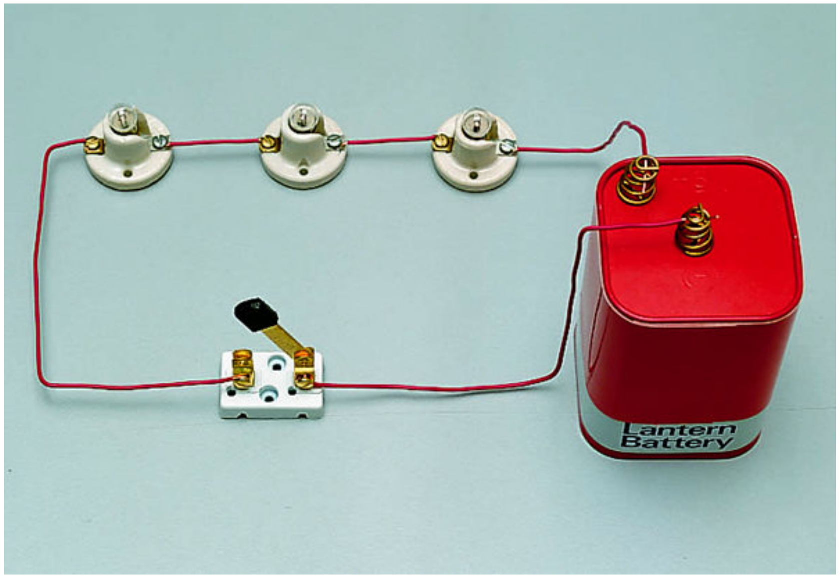
Series electrical circuit

- The current in the circuit is given by

$$I = \frac{V}{R_{eq}} = \frac{V}{R_1 + R_2 + R_3}$$

- The more light bulbs I add in series, the larger the resistance and thus the smaller the current
- The voltage drop across each resistor is equal to IR
- Since $P=I^2R$, the light bulbs are less bright than if only 1 bulb were in the circuit
- If one light bulb fails, the circuit fails and no bulbs light up



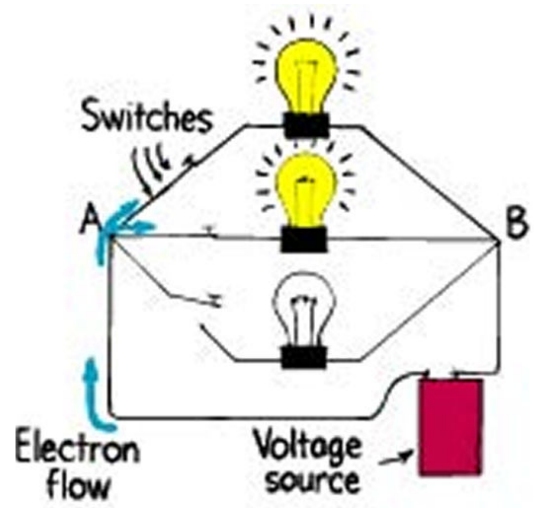


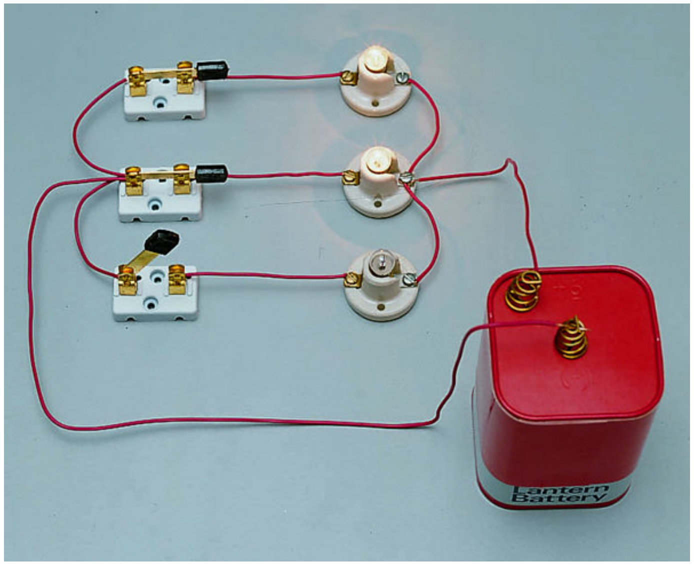
Parallel circuits

- In a parallel circuit, the 3 resistors (light bulbs) are connected in parallel
- The current of electrons passing through the battery is split into 3 branches

$$I = I_1 + I_2 + I_3 = \frac{V}{R_{eq}} \qquad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

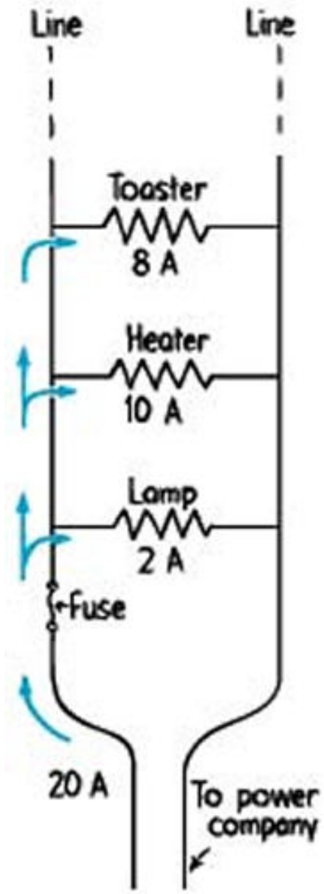
- The same voltage (in this case the voltage of the battery) appears across each of the light bulbs
- And since $P=I^2R=V^2/R$, each of the light bulbs glows with the same brightness as if it were in the circuit by itself
- The more light bulbs I add in parallel, the smaller is the total resistance





Household circuits

- Are wired in parallel, so that multiple appliances can be used at the same time
- The more appliances connected, the more current is drawn
- In order to prevent too much current being drawn, a fuse (circuit breaker) is part of the circuit



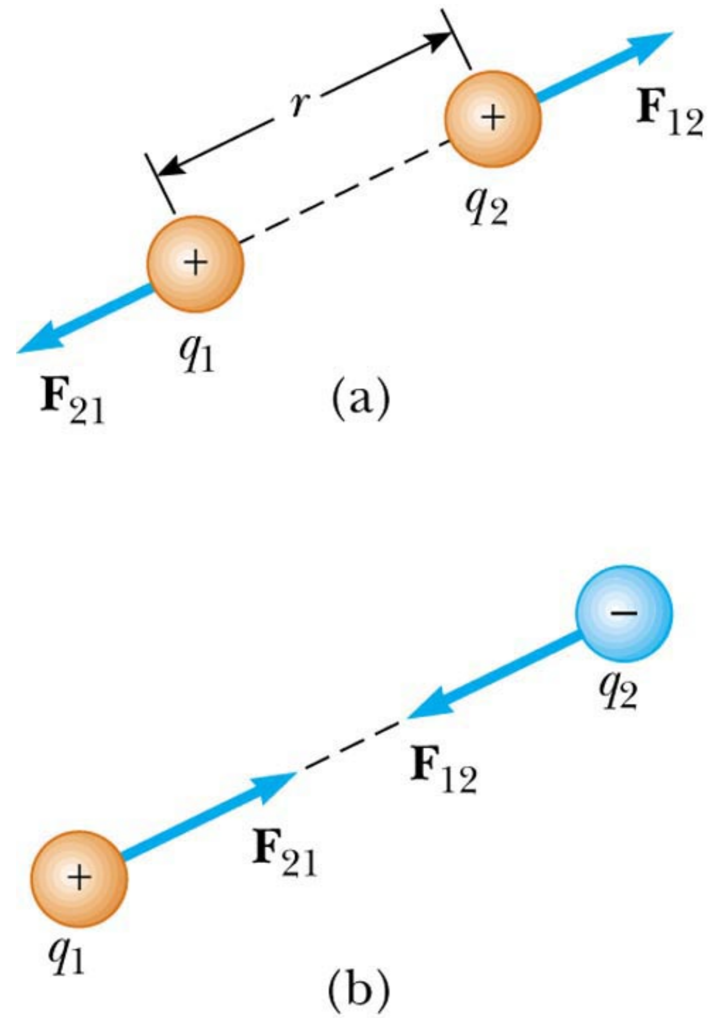
Electrical shock

- Any current passing through your body depends on the voltage difference applied across your body and the electrical resistance of the body
- Dry skin has an electrical resistance of 100,000 Ω
- Skin saturated with saltwater has an electrical resistance of 100 Ω
- Effects of currents
  - 0.001 A can be felt
  - 0.005 A is painful
  - 0.010 A causes muscle spasms
  - 0.015 A causes loss of muscle control
  - 0.07 A can be fatal if it lasts more than 1 s
- The electric chair was invented by a dentist, hence the use of a chair for the execution

Magnetic forces

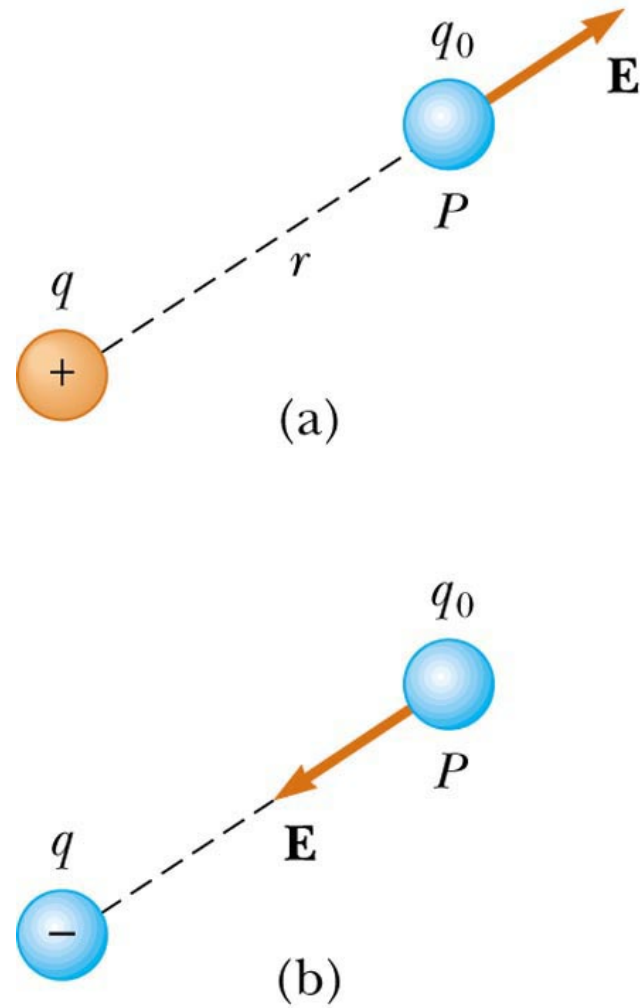
- Up til now, we've been dealing with electrostatic forces, i.e. forces between static charges
- We've used Coulomb's law to calculate the size of the force

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}$$



Fields

- We then introduced the idea of an electric field
- The idea of a field can be a difficult concept to grasp
- But we are going to encounter it again, when we talk about magnetic forces



Magnetic forces

- For electrostatic forces, I have positive and negative charges
- For magnetic forces, I have N and S poles
- I find that N poles repel N poles, S poles repel S poles, and N and S poles attract each other

Some materials are naturally occuring permanent magnets. One example is magnetite. Some materials can have magnetism induced. This occurs, for example, when I place a piece of iron near a magnet. Some materials are attracted to a magnet and some are not.

Magnesia

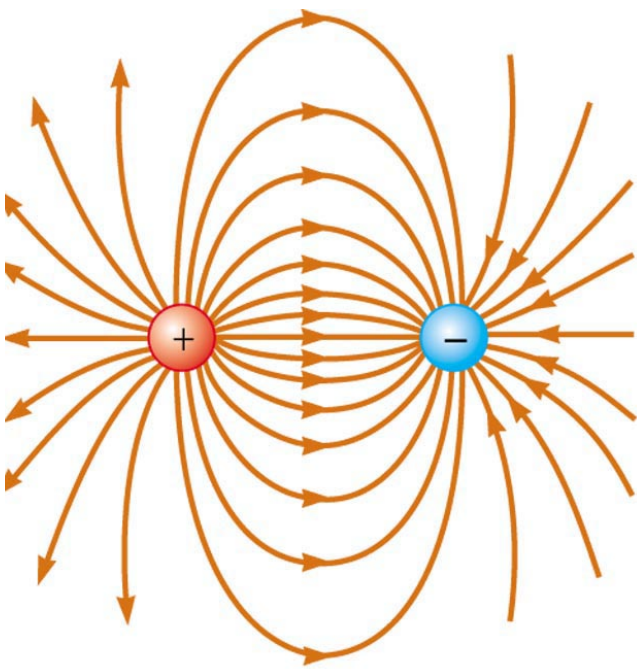
- The word magnesia comes from the region in Asia Minor in which rocks with magnetite ore were relatively common

What causes magnetism?

- The culprit again is the electron, but in this case the electron has to be moving
  - as in an electric current
  - or as in an atom where's it's spinning on its axis and is travelling in a circle around the nucleus
- But we'll need to go over some more material before we can understand the last statement and the connection between these two statements

Electric and Magnetic Fields

Just as we want to define an electric field for electrostatic forces, we also want to define a magnetic field for magnetic forces.



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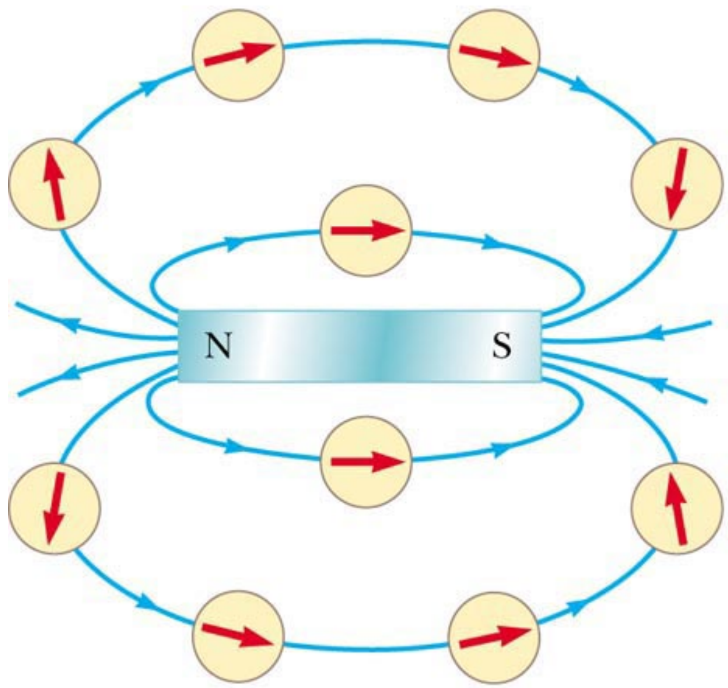

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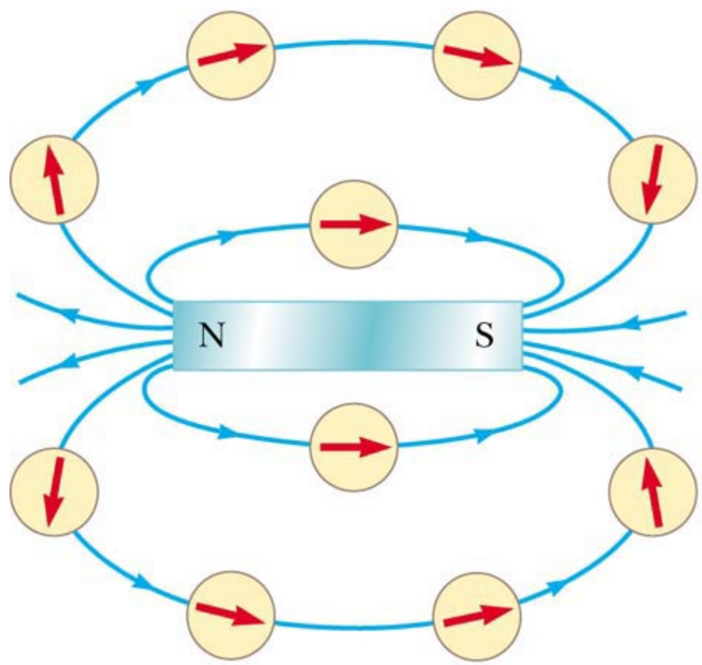
Magnetic field lines

- And for convenience, we'll also want to talk about magnetic field lines
- Similar rules as for electric field lines
  - a tangent to a field line is the direction of the magnetic field at that position in space
  - the field lines are closer together where the magnetic field is stronger



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Electric and Magnetic Fields

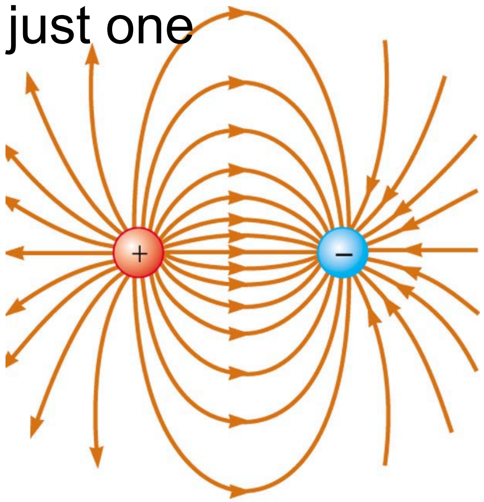
Note some similiarities:

•magnetic field lines originate on N poles and terminate on S poles

But there are differences:

•I can separate the + charge and the - charge of an electric dipole, leaving me with a single electric charge

Can't do that with a magnetic dipole: a N pole is always accompanied by a S pole and vice versa; unfortunately there are no magnetic monopoles, or maybe just one



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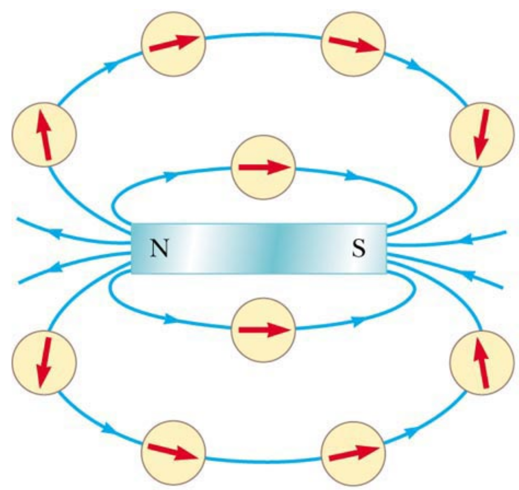

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and later we'll find that magnetism is caused by the movement of electrons inside of atoms

Magnetic monopoles

Blas Cabrera

From Wikipedia, the free encyclopedia

For the exiled Spanish physicist in the first half of the 20th century, see Blas Cabrera Felipe.

Blas Cabrera is a physicist at Stanford University best known for his experiment in search of magnetic monopoles. He is the son of Spanish physicist Nicolás Cabrera and the grandson of Blas Cabrera Felipe, also a Spanish physicist.

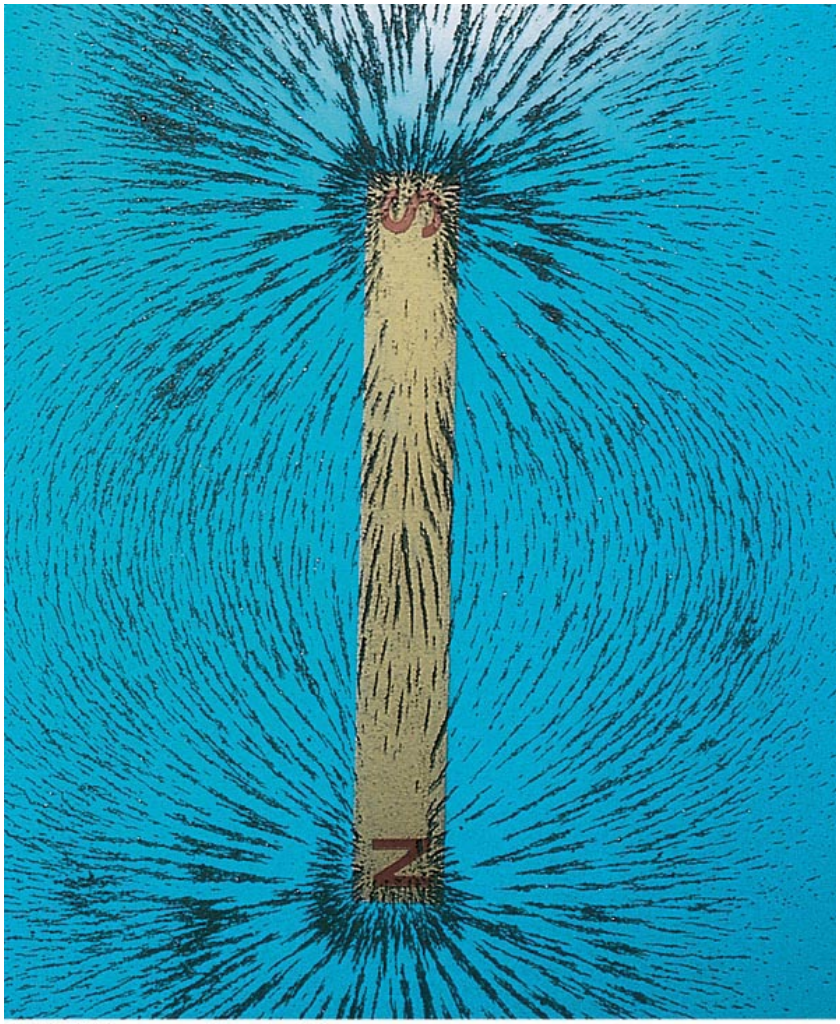
On the night of February 14, 1982, his detector recorded an event which had the perfect signature hypothesized for a magnetic monopole. After he published his discovery,[1] a number of similar detectors were built by various research groups, and Cabrera's laboratory itself received a large grant to build an improved detector.[*citation needed*] However, no similar event has been recorded since, and his research group has since dropped the search. He is now a leader of the Cryogenic Dark Matter Search experiment.

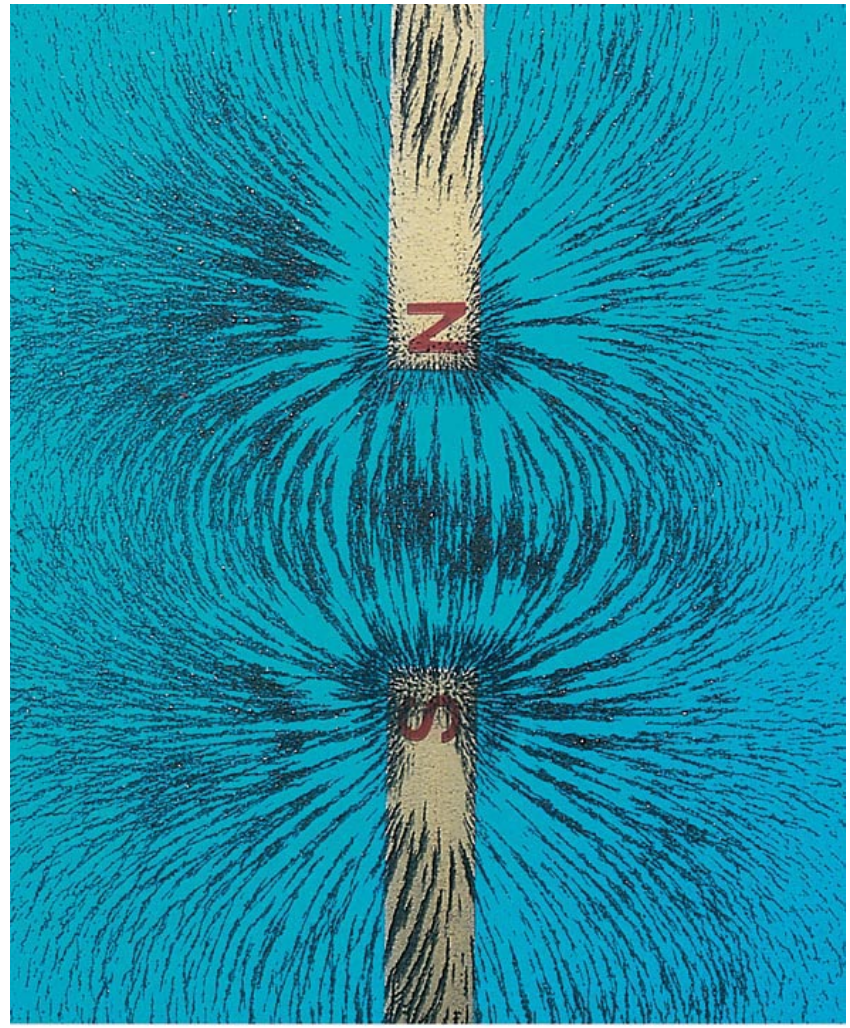
References [edit]

1. ^ Blas Cabrera (1982-05-17). "First Results from a Superconductive Detector for Moving Magnetic Monopoles". *Physical Review Letters* (American Physical Society) **48** (20): 1378–1381. Bibcode 1982PhRvL..48.1378C. doi:10.1103/PhysRevLett.48.1378.

A requirement of science is reproducibility. Maybe that monopole was real, and he was just extremely lucky, but no one was able to replicate the experiment.

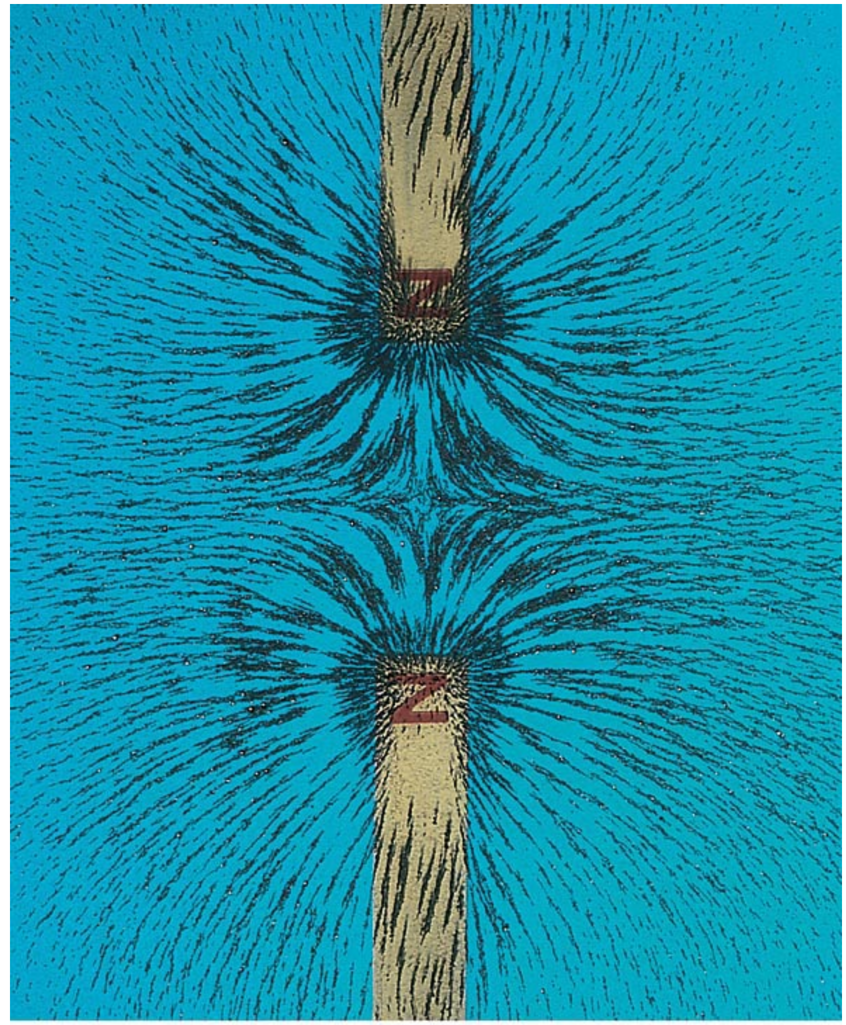
Demonstrations of magnetic field lines





Two N poles

- Magnetic fields cancel in region between poles



Connection with electric currents

- The connection between electric currents and magnetic fields was discovered by Hans Christian Oersted in 1819 while doing a classroom demonstration

→ demo