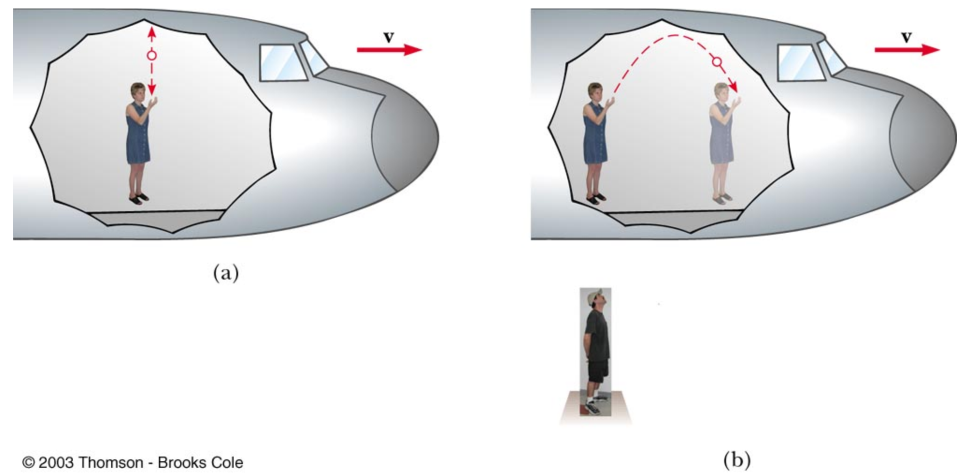
Announcements

- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- 2nd hour exam on Tuesday Nov. 6
  - part of today's lecture will be a review
  - bring a picture ID with you for the exam
  - one 8.5X11" sheet of handwritten notes allowed
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Frames of reference

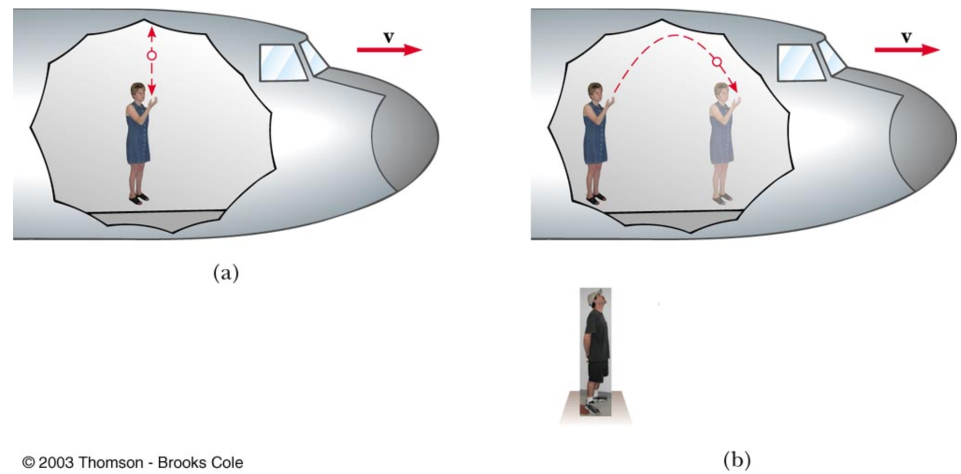
- Need to define a frame of reference
  - for example a coordinate system for making measurements
- Consider a person on an airplane tossing a ball in the air and catching it
- The person on the plane has one frame of reference
- A person observing from the ground has another frame of reference
- This is an example of a *gedanken*, a thought experiment



Newton's first law (law of inertia) should be the same in both (inertial) frames of reference
According to principle of Galilean relativity, laws of mechanics must be the same in all inertial frames of reference

Frames of reference

- The observer on the plane sees the ball go straight up and come straight down
- The observer on the ground sees the ball follow a parabolic path, since the ball has the horizontal velocity of the plane (from his perspective)
- Both observers agree that the ball obeys the law of gravity and Newton's law of motion; both see the same amount of time for the ball to come back into the hand



According to principle of Galilean relativity, laws of mechanics must be the same in all inertial frames of reference

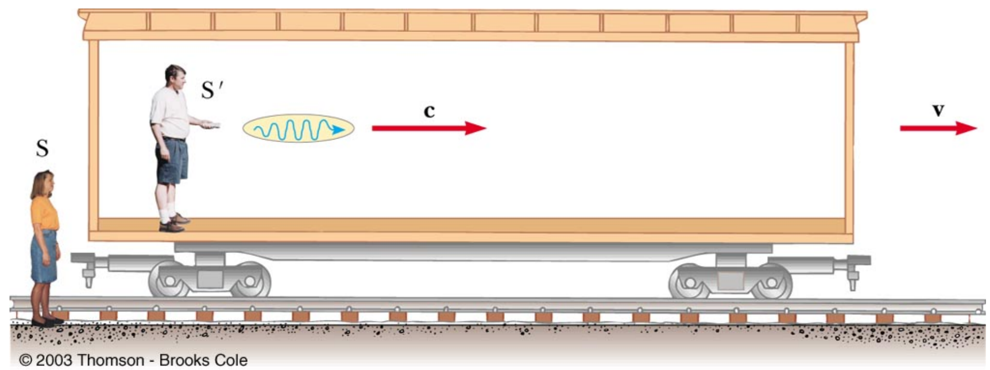
There is no preferred frame of reference for describing the laws of mechanics

iclicker question

- The special theory of relativity can be summarized as (1) the laws of physics are the same in all inertial frames of reference and
- (2)
  - a) light consists of oscillating electric and magnetic fields
  - b) the speed of light is the same in every reference frame
  - c) light waves travel through the ether
  - d) the ether does not exist
  - e) answer e does not exist

All is not well with Galilean relativity

- Speed of light is supposed to have one value in vacuum
  - 3×10^8 m/s
  - …or more precisely 2.99792458×10^8 m/s
- But consider the gedanken experiment to the right
- The observer inside a railway car (S') travelling at a velocity v shines a flashlight
- He measures the light beam as travelling at c (3×10^8 m/s)



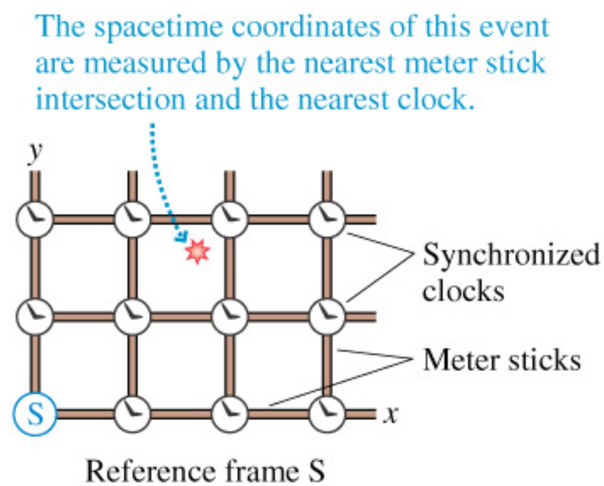
The woman S standing by the side of the track measures the speed of light at what value?
Common sense says c+v.
But if the answer is c+v, then Maxwell's description of electricity and magnetism is not right, because he said (and his equations demonstrated) that light can only travel at the speed of light.

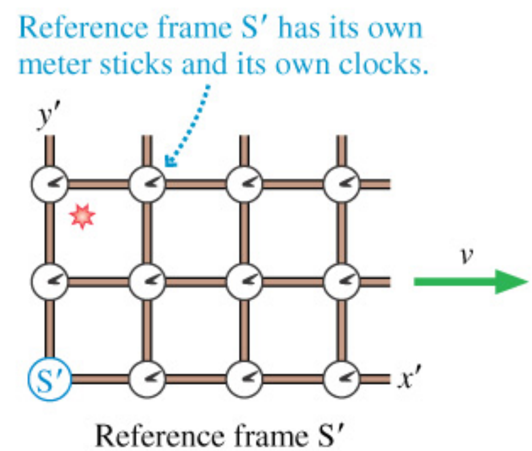
Albert Einstein

- Einstein realized that it was necessary to reconsider the meaning of space and time, and how they are measured. Space and time are not independent concepts but are intrinsically linked with each other.
  - no such thing as absolute length or absolute time
  - perhaps time is not the same in 2 inertial reference frames

Spacetime

- We identify an event with spacetime coordinates (x,y,z,t)
  - we can imagine a reference frame(s) with a bunch of meter sticks and clocks
- The same event will have different coordinates in different reference frames
  - space coordinates are also different in Galilean relativity
  - but now we include t
  - a difference from the Newtonian point of view

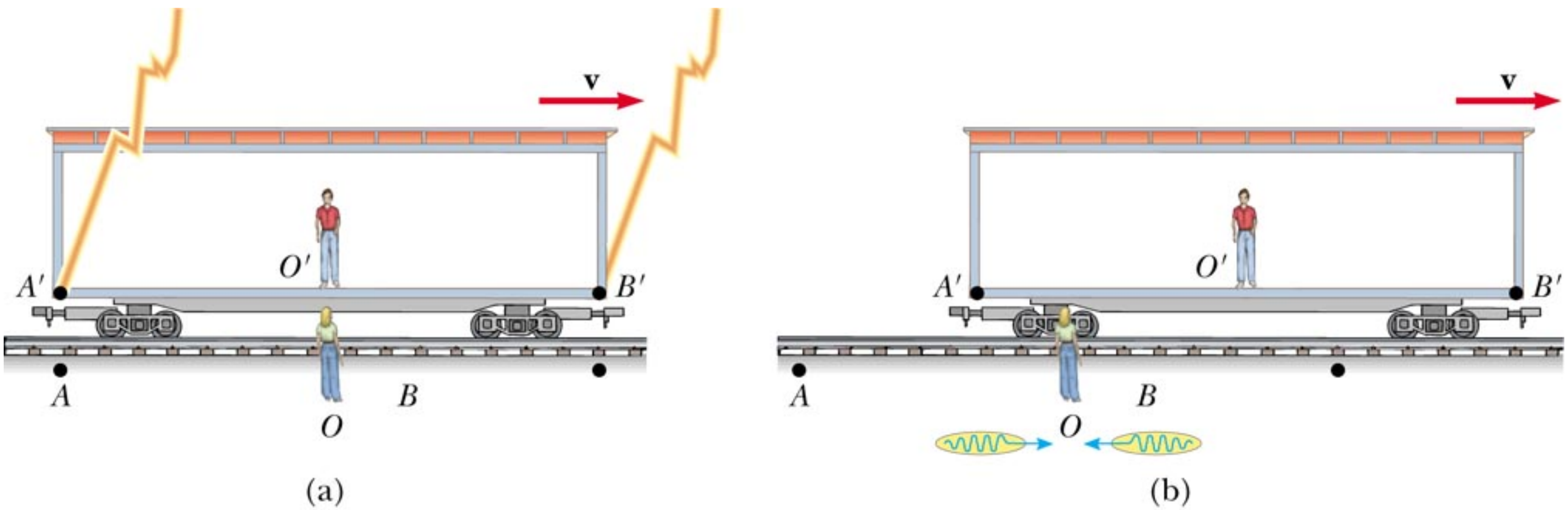




video

Another gedanken

Consider a train moving with velocity v, two observers O and O’, and lightning striking the two ends of the boxcar

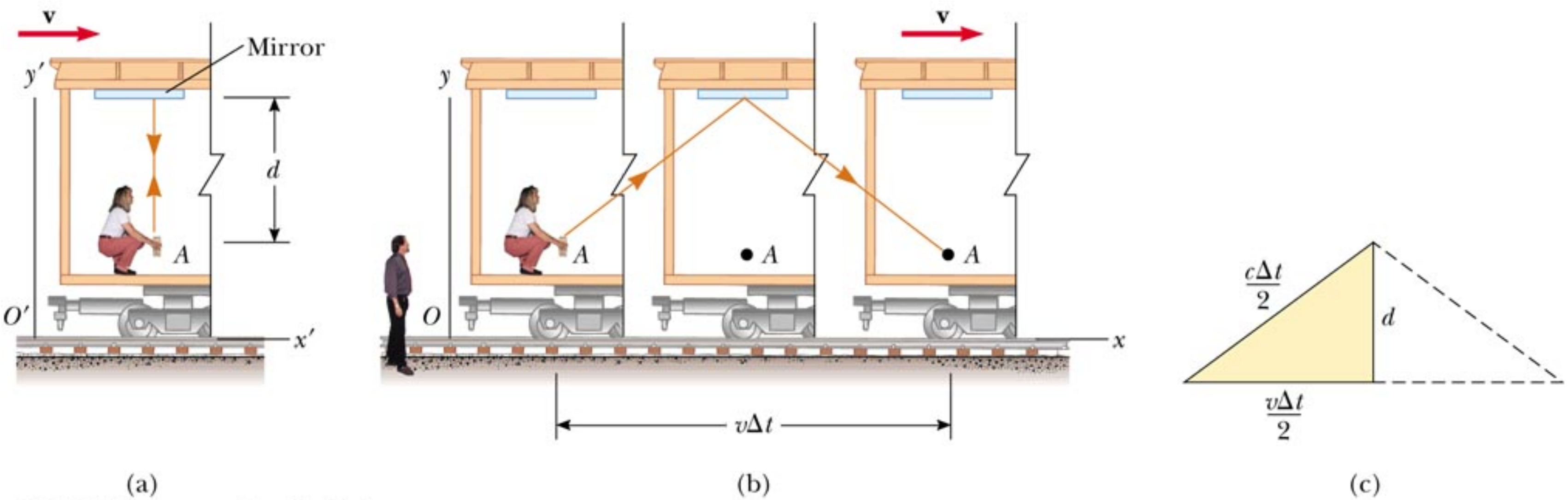


Light signals reach O at the same time; she concludes the two lightning strikes were simultaneous.
Light from B’ reaches observer O’ before the light from A’; observer O’ concludes that the lightning struck at B’ before it did at A’.
Two events which appear to be simultaneous in one frame of reference are not, in another frame
That’s what Einstein realized in the video when he was walking with his friend.

Simultaneity lost

- Simultaneity is not an absolute concept but one that depends on the state of motion of the observer

Time Dilation: another gedanken

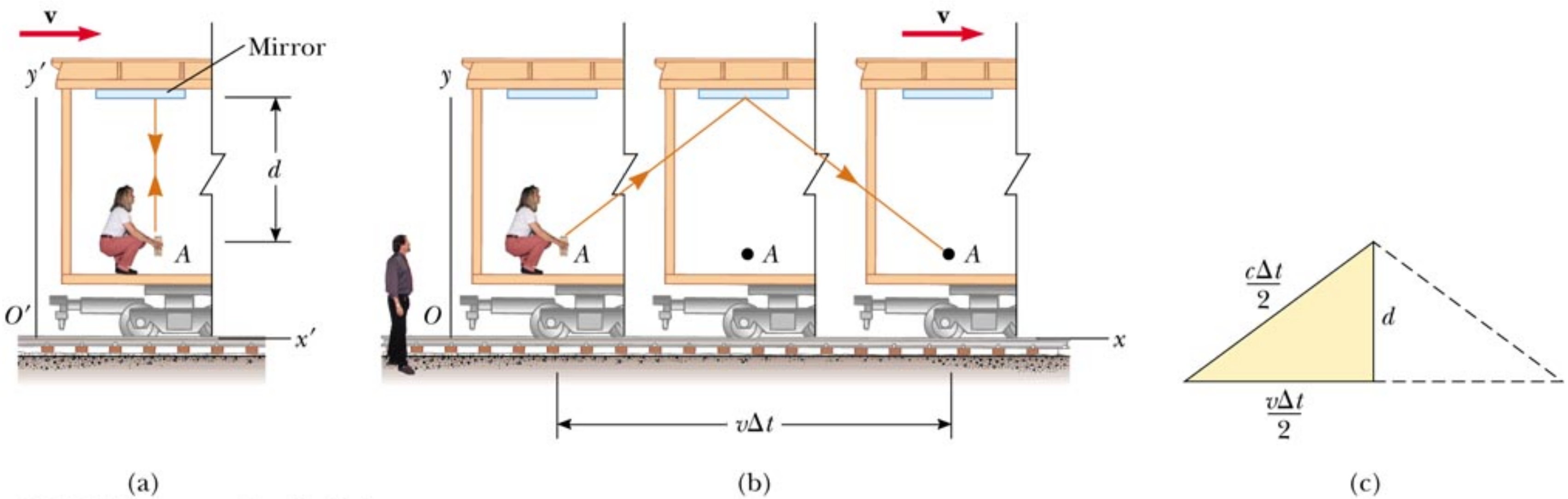


Simultaneity is out the window. Observers in different reference frames may also measure different time intervals between a pair of events.

Consider a boxcar moving to the right with a velocity v. Observer O' shines a laser and observes it reflecting from a mirror on the ceiling. She's timing this and observes the total time for the laser to reflect and come back to be: $\Delta t=2d/c$

Now observer O, standing alongside the track, is also observing this event. Because of the velocity of the boxcar, observer O sees that the laser light has to travel along a longer path: $\sqrt{d^2+(v\Delta t/2)^2}$

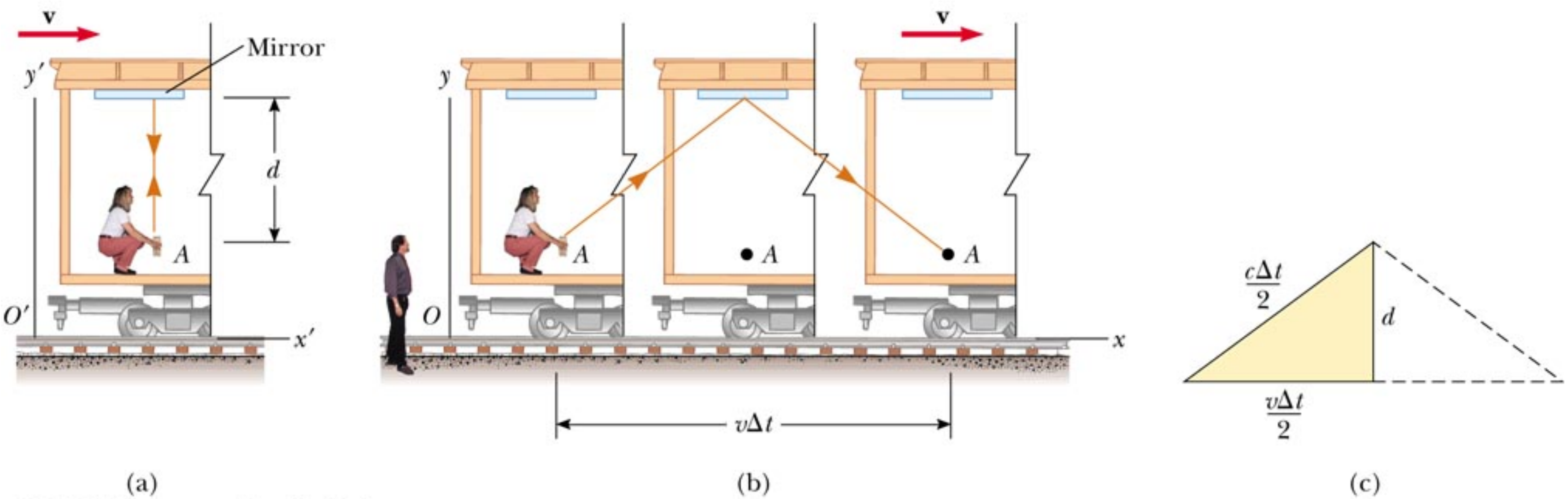
Time Dilation: another gedanken



Now the speed of light c is the same in both frames of reference. Thus, observer O must measure a longer time for the light to reflect from the mirror than observer O’. In other words, time appears to move more slowly in the boxcar according to observer O than according to observer O’.

By how much?

Time Dilation: another gedanken



solve for Δt

Don’t worry about the algebra

$$\Delta t = \gamma \Delta t'$$

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\beta^2}}$$

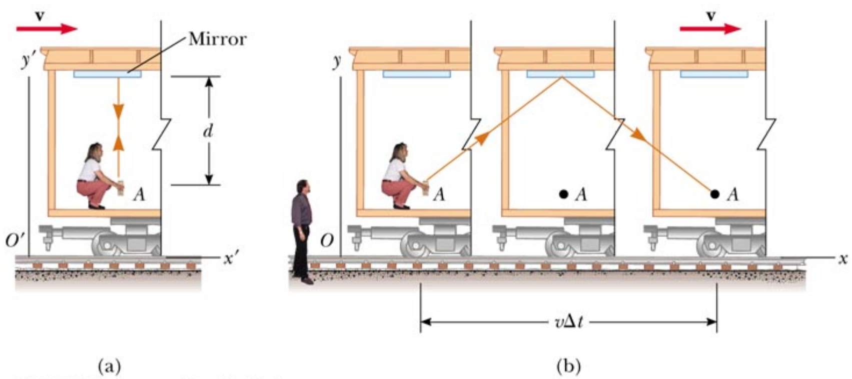
$$\left(\frac{c\Delta t}{2}\right)^2 = \left(\frac{v\Delta t}{2}\right)^2 + d^2$$

$$\Delta t = \frac{2d}{\sqrt{c^2 - v^2}} = \frac{2d}{c\sqrt{1-\frac{v^2}{c^2}}}$$

Define Δt’ = 2d/c, the time measured by observer O’
We’ll call this the proper time.

Time dilation

- So…the time inverval between two events measured by an observer moving with respect to a clock is longer than the time interval between two events measured by an observer at rest with respect to the clock
- …i.e., a clock moving past an observer at a speed v runs more slowly than identical clock at rest with respect to the observer, by a factor γ^{-}



Δt_p, the proper time

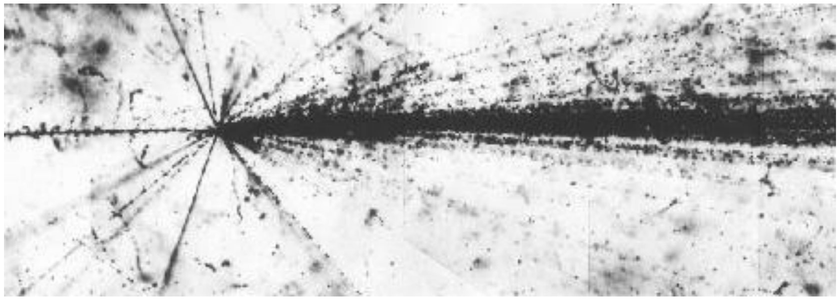
Everything depends on γ

Velocity (m/s)	γ
100 m/s	1
1000 m/s	1
10,000 m/s	1.000000001
100,000 m/s	1.000000056
1,000,000 m/s	1.000005556
10,000,000 m/s	1.000556019
100,000,000 m/s	1.060660172
200,000,000 m/s	1.341640787
290,000,000 m/s	3.905667329

Cosmic rays

- Some come from the sun (relatively low energy) and some from catastrophic events elsewhere in the galaxy/ universe

Collision of a high energy cosmic ray particle with a photographic emulsion

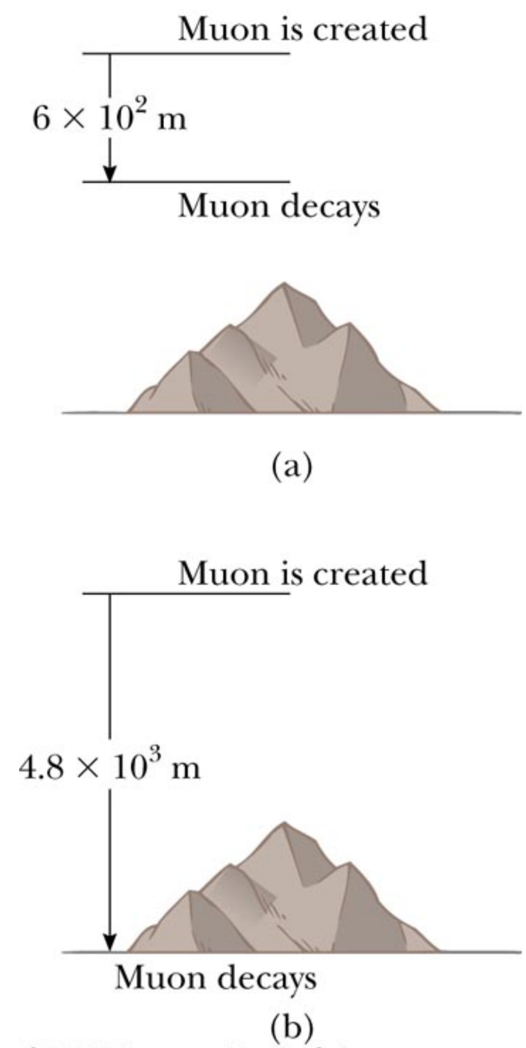


Crab nebula

Cosmic rays interact with the Earth's upper atmosphere and produce a shower of particles; eventually only subatomic particles called muons are left.

Another example:cosmic ray muons

- Time dilation works for clocks, heartbeats, anything…
- Consider muons produced in the upper atmosphere
  - they have a lifetime of 2.2 μs
  - if they travel close to the speed of light, you might think they could only travel ($3X10^8$ m/s X 2.2 X 10^{-6} s = 600 m) before decaying
  - 2.2 μs is how long they live in their rest frame
  - but if they are travelling at 0.99c, then γ=7.1 and $\gamma c\Delta t_p$=4800 m (not 600 m)



Review for 2nd exam: temperature and heat

- Understand the Farenheit, Celcius (Centigrade) and Kelvin temperature scales and how to convert from one to the other
  - understand what is meant by absolute zero
- Connection between kinetic energy of a molecule and temperature
  - $KE=1/2mv^2=3/2k_BT$
- Units for heat
  - Joules
- It takes 4.18 J to raise 1 g of H_20 by 1^o C
- 1 food Calorie = 1000 calories

Three laws of thermodynamics

- First law
  - whenever heat is added to a system, it transforms to an equal amount of some other form of energy
- Second law
  - heat never spontaneously flows from a cold substance to a hot substance
- Third law
  - no system can reach absolute zero

Entropy

- In natural processes, *high-quality* energy tends to transform into *lower-quality* energy
  - order tends to disorder
  - entropy, a measure of disorder, always increases for a closed system
  - time's arrow always points from order to disorder
- The increase in entropy is equal to the amount of heat added to the system divided by the temperature at which it was added

$$\Delta S = \frac{\Delta Q}{T}$$

- We can also write the entropy of a system as $S = k_B \ln(W)$, where k_B is the Boltzmann constant and W is the number of possible states for a system
  - the larger the number of possible states, the larger the entropy

Specific heat capacity

- The specific heat capacity (sometimes just called specific heat) of a substance is the quantity of heat required to change the temperature of a unit mass by 1 degree C
  - can think of it as thermal inertia since it signifies the resistance of a substance to a change in temperature
- If the specific heat capacity c is known for a substance, then the heat transferred is equal to the specific heat capacity X mass X change in temperature

$$Q = cm\Delta T$$

  - where Q is the quantity of heat

Heat transfer

- Heat transfers from warmer to cooler things
- This process occurs in 3 ways
  - conduction
  - convection
  - radiation

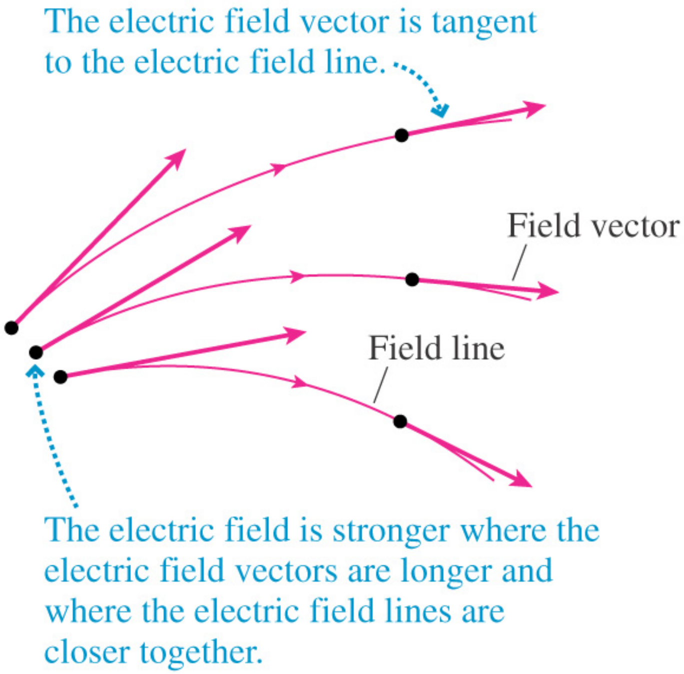
Electrostatics

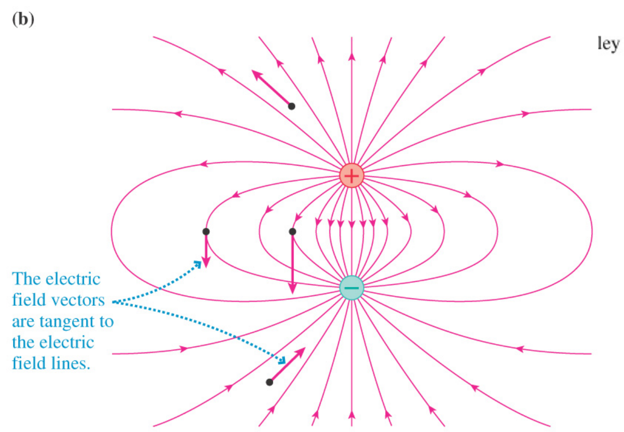
- If outermost electrons are free to move within the material, we call the material a conductor
- If they're not free to move (but can still be rubbed off), we call the material an insulator
- Coulomb's law for the force between two charges and the similarities and differences with Newton's law for gravitation

$$F = k\frac{q_e q_p}{r^2} \qquad F = G\frac{m_e m_p}{r^2}$$

Drawing/interpreting electric (and magnetic) field lines

- Pretty useful idea but we need some guidelines
  - electric field lines point in direction of field at that point in space
  - the total number of electric field lines is proportional to the size of the charge
  - close to an electric charge, the field lines look like that due to the point charge alone
  - the density of field lines is proportional to the strength of the electric field
  - electric field lines originate on + charges and terminate on - charges
  - no 2 field lines can cross in free space
    - don't cross the streams





Electric potential and potential energy

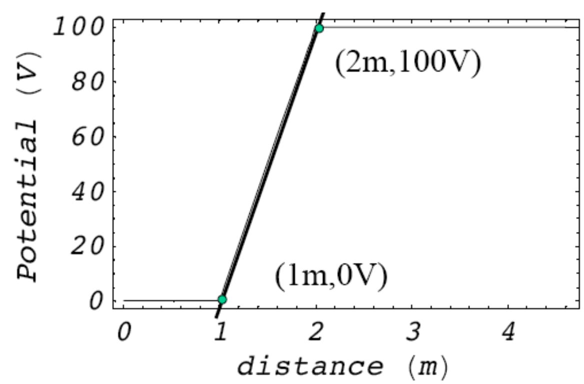
$$\text{electric potential} = \frac{\text{electric potential energy}}{\text{amount of charge}}$$

- The unit of measurement for electric potential is the Volt, so electric potential is often called voltage
  - 1 Volt = 1 Joule/Coulomb
- Know how a battery works
  - the electrons are not supplied by the battery, they're already in the conductor
  - the battery just supplies the work necessary to move the electrons from a lower potential to a higher potential

- Electric potential – SI unit is the Volt (V)
- Electric field is rate of change of potential

$$E = -\frac{\Delta V}{\Delta x}$$

- The minus sign means that electric fields point from + to – charge.



What is the magnitude of the electric field at:
- 0.5 m?
- 1.5 m?
- 3.0 m?

The field is 0 V/m at 0.5 m and 3.0 m since the slope is zero.

$$\left|E(\text{at } 1.5\text{m})\right| = \frac{\Delta V}{\Delta x} = \frac{(100V - 0V)}{(2m - 1m)} = 100\frac{V}{m}$$

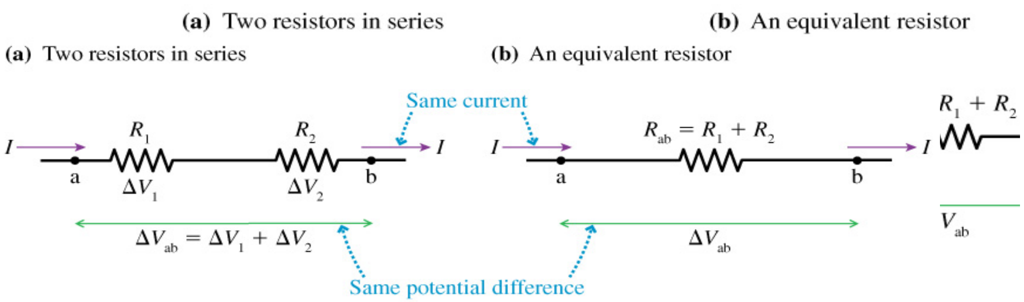
Ohm's law

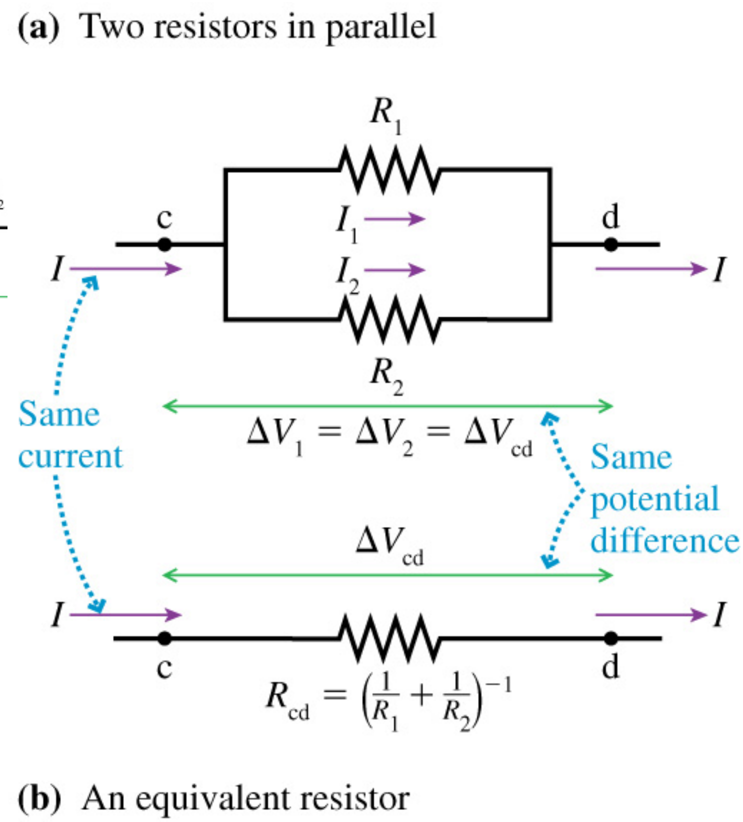
- I=V/R
- V=IR
- R=V/I
  - relates the current, voltage and resistance

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

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

Resistors in series and parallel





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

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

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

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

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

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

Electric and Magnetic Fields

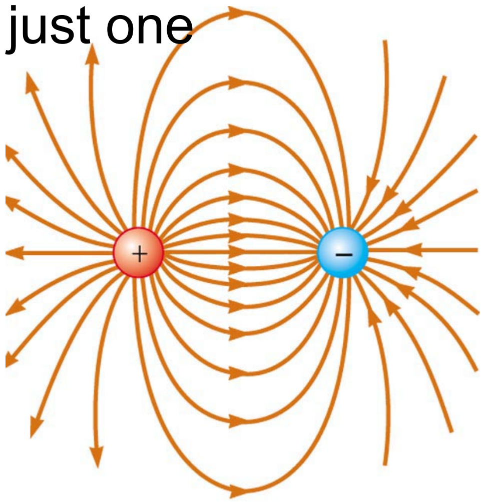
Note some similiarities:

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

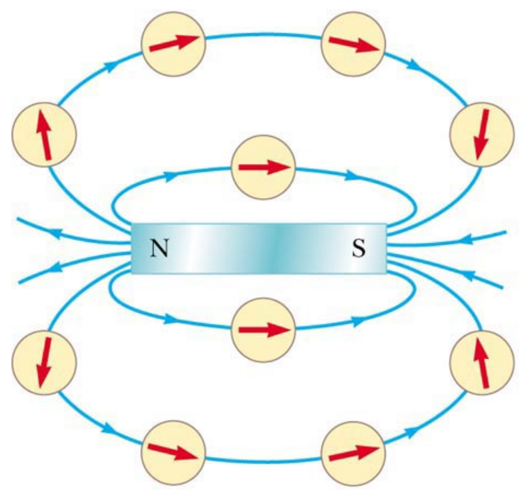
But there are differences:

•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



(a)



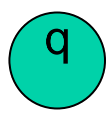
(a)

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

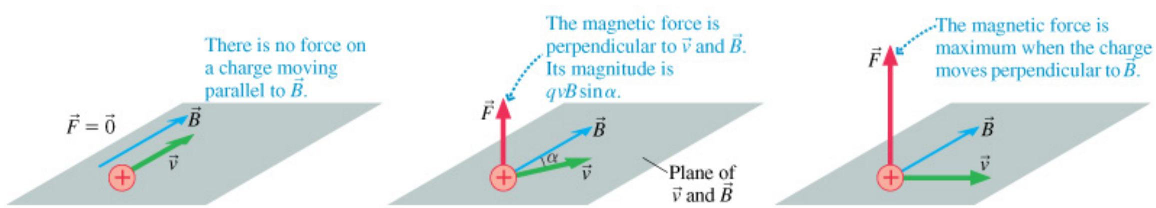
Magnetic forces on electric charges

- So we believe in the existence of magnetic fields
  - and magnets exert forces on each other
- What kind of force is exerted on an electric charge?
- Suppose I do a series of experiments involving electric charges and magnetic fields

a charge q in a region of magnetic field



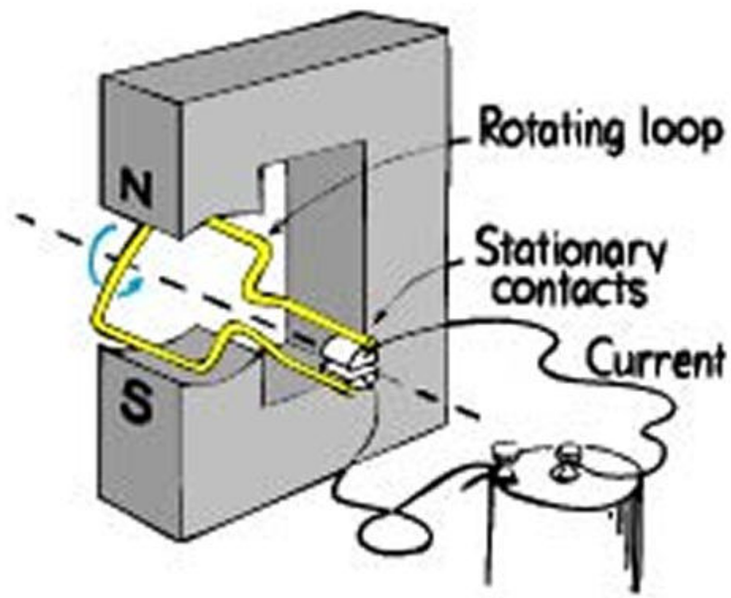
1. The force on q is proportional to the magnitude of q
2. The force on q is proportional to the magnitude of B
3. The force on a negative charge is opposite the force on a positive charge
4. The force is proportional to the velocity v
5. The magnitude and direction of F depends on the angle between v and B



$F=qvB\sin\theta$

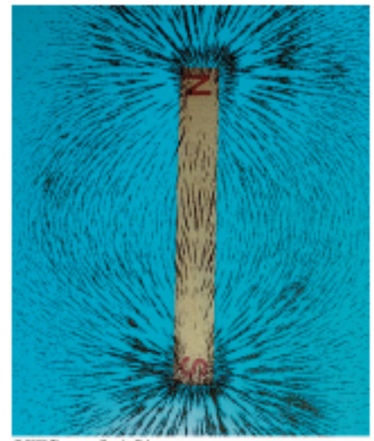
Electric motors

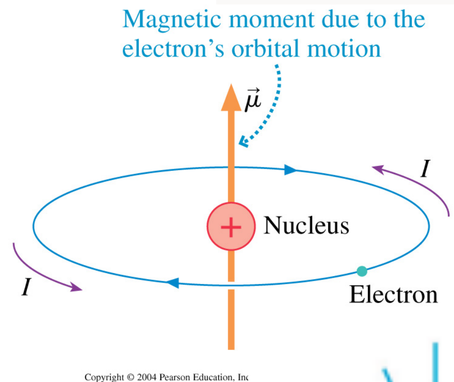
- How does an electric motor work?
- A current flows through a loop inside a magnetic field
- There's a force (actually a torque) because of the current interacting with the magnetic field that causes the loop to rotate
  - current in the motor made to change direction every time the coil makes a half rotation
- The rotating coil can be used to run clocks, operate gadgets etc
  - electricity goes in, work comes out (plus heat)

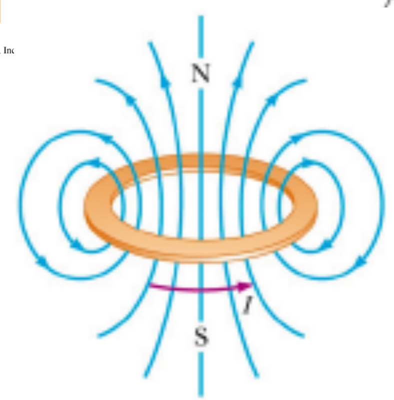


Magnetism in materials

- What causes magnetism in materials?
- We said it has something to do with current loops
- Where do the current loops come from?
- Well the electrons are orbiting around the nucleus and each electron is spinning like a top
- Both of these actions produce current loops, which then produce magnetic moments
- In most materials, the magnetic effects from the electrons cancel each other out
- For some materials this doesn't happen, and they have magnetic properties



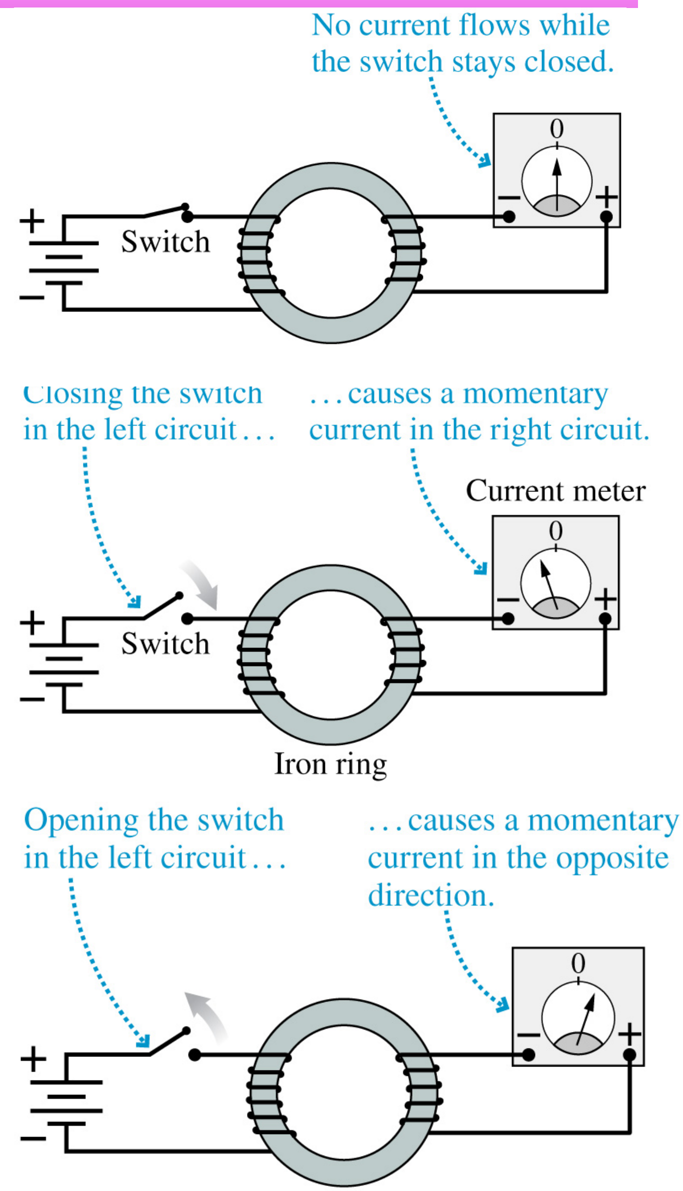




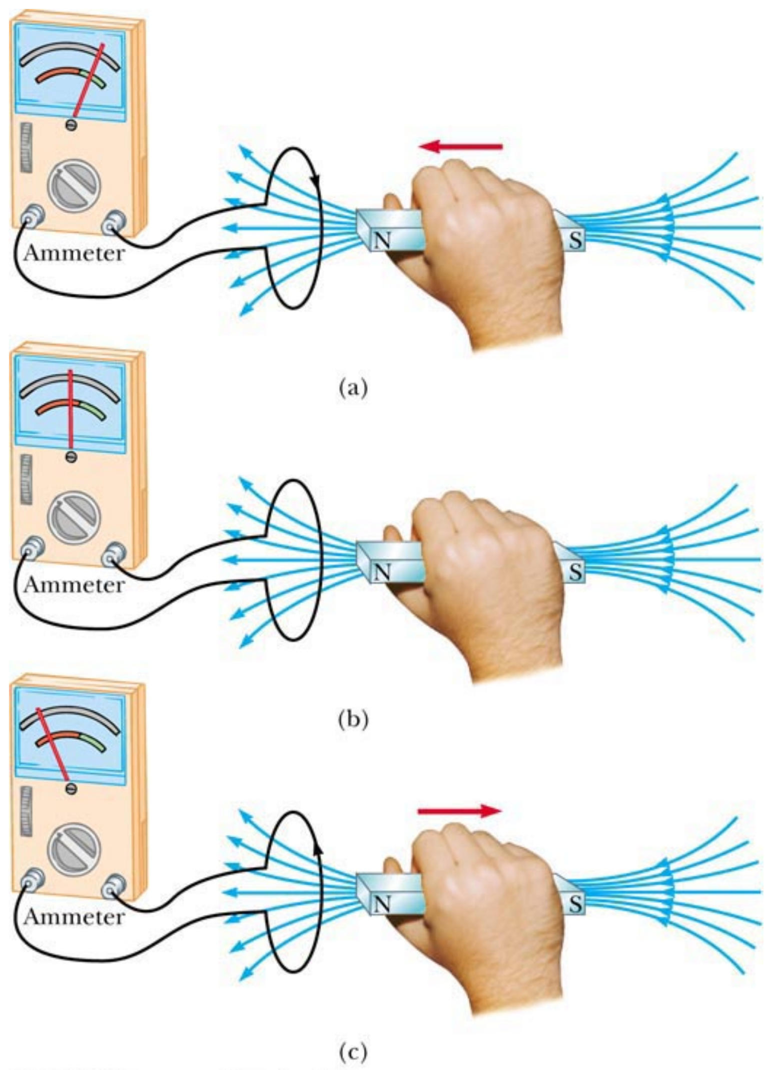
Faraday's law of induction

- A strong magnetic field does not create an electric current
- But he did notice a current in the meter when he first closed the switch and just after he opened it again
- So it's not a magnetic field that creates an electric current; it's a changing magnetic field
- And not the magnetic field per se, but the magnetic flux
  - just think of the flux as the number of magnetic field lines

$$\varepsilon = -\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(BA)}{\Delta t}$$

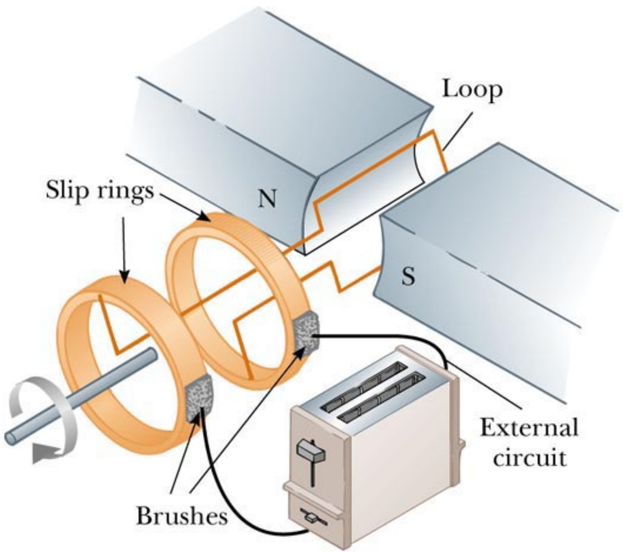


- The force on the bar magnet resulting from the current induced in the coil
  - A) **opposes the motion causing the change in flux**
  - B) is in the same direction as the motion causing the change in flux
  - C) is independent of the motion causing the change in flux



Generators and motors

What's the difference between them?



(a)

$\mathcal{E}_{ma}$

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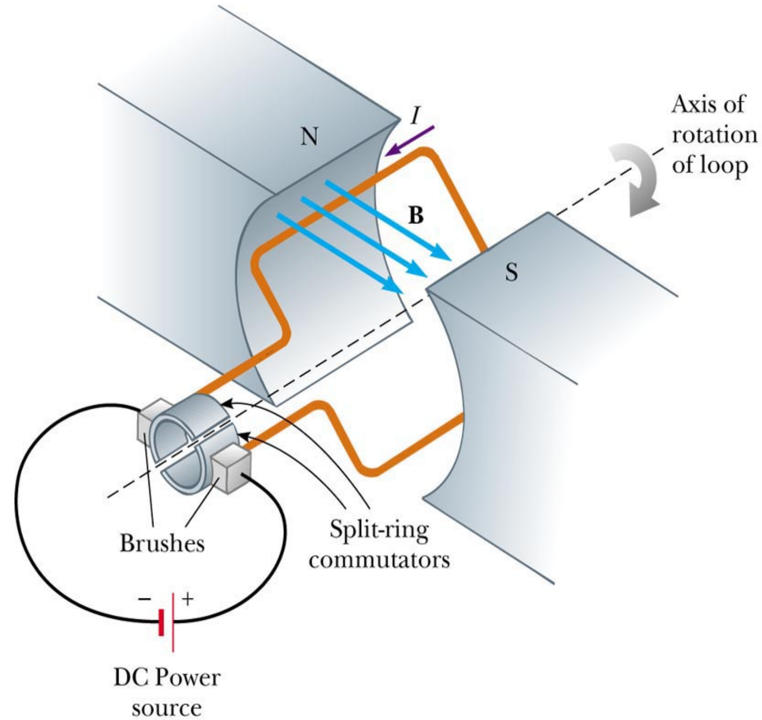
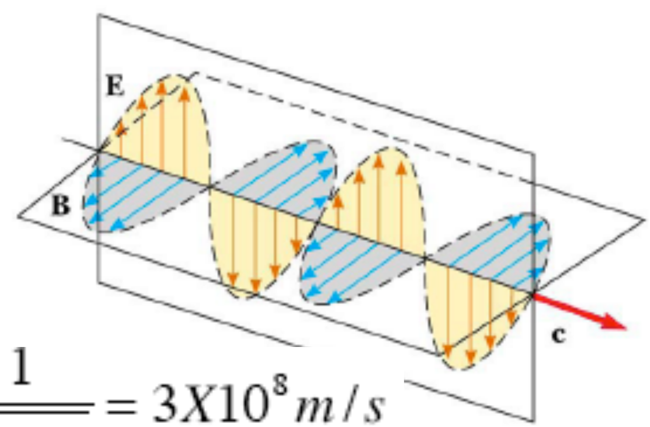


A generator turns mechanical work into electrical energy.
A motor turns electrical energy into mechanical work.
A motor is a generator run in reverse.

Electromagnetic waves

- Stationary electric charges produce electric fields
- Electric charges in uniform motion (currents) produce electric and magnetic fields
- Accelerated electric charges produce electric fields, magnetic fields, and electromagnetic waves

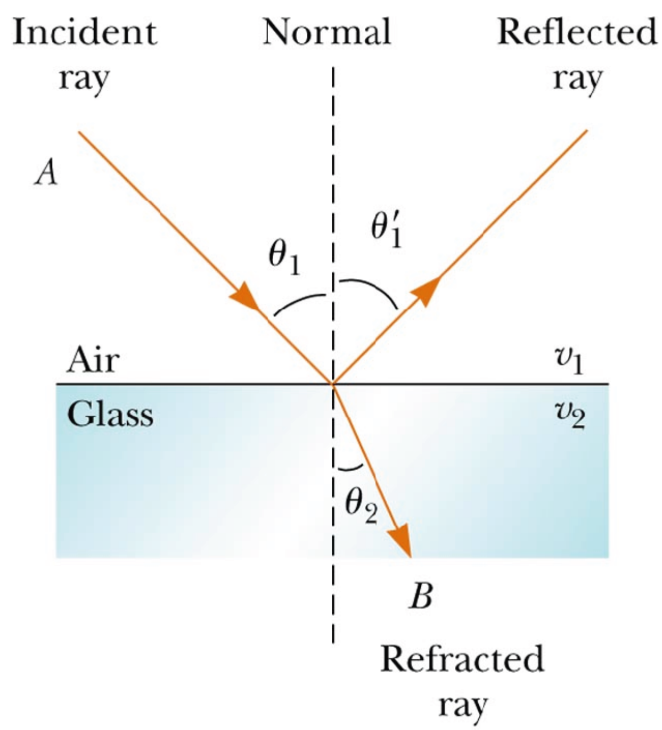


$$c = \frac{1}{\sqrt{\mu_o \varepsilon_o}} = 3X10^8 m/s$$

- All electromagnetic waves travel through vacuum with a speed c (3×10^8 m/s)
- For all EM waves, $c=\lambda f$ (true for any type of wave)
- $\lambda = c/f$
- The visible portion of the spectrum forms a tiny portion of the total EM spectrum

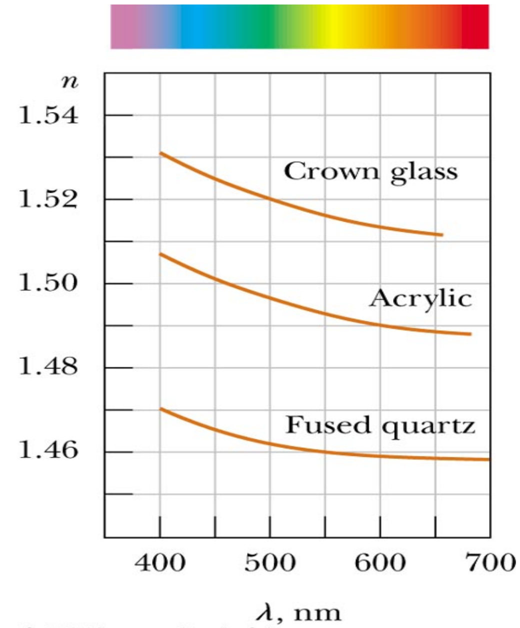
Review: refraction and dispersion

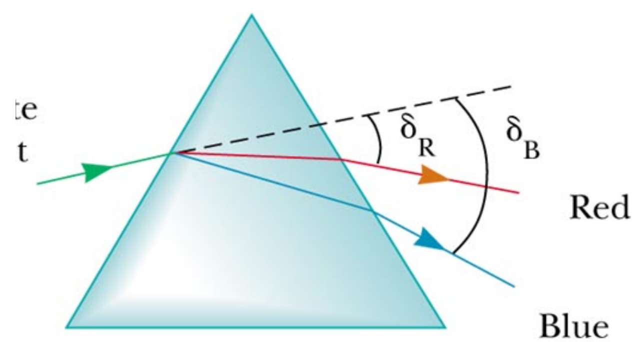
- Light travels at a speed c in vacuum, but slower in other media
- Define n = c/v, where v is the speed that light travels in a given medium (glass, water, etc)
- So, as light travels from air to glass, its speed changes; its frequency does not, so its wavelength must
  - $\lambda_1 = \lambda_o/n$
- I can re-write the proportionality that we had before
  - $\sin\theta_1/\sin\theta_2 = v_2/v_1$
- as
  - $\sin\theta_1/\sin\theta_2 = n_2/n_1$
  - $n_1 \sin\theta_1 = n_2 \sin\theta_2$



 (a)

Snell's law





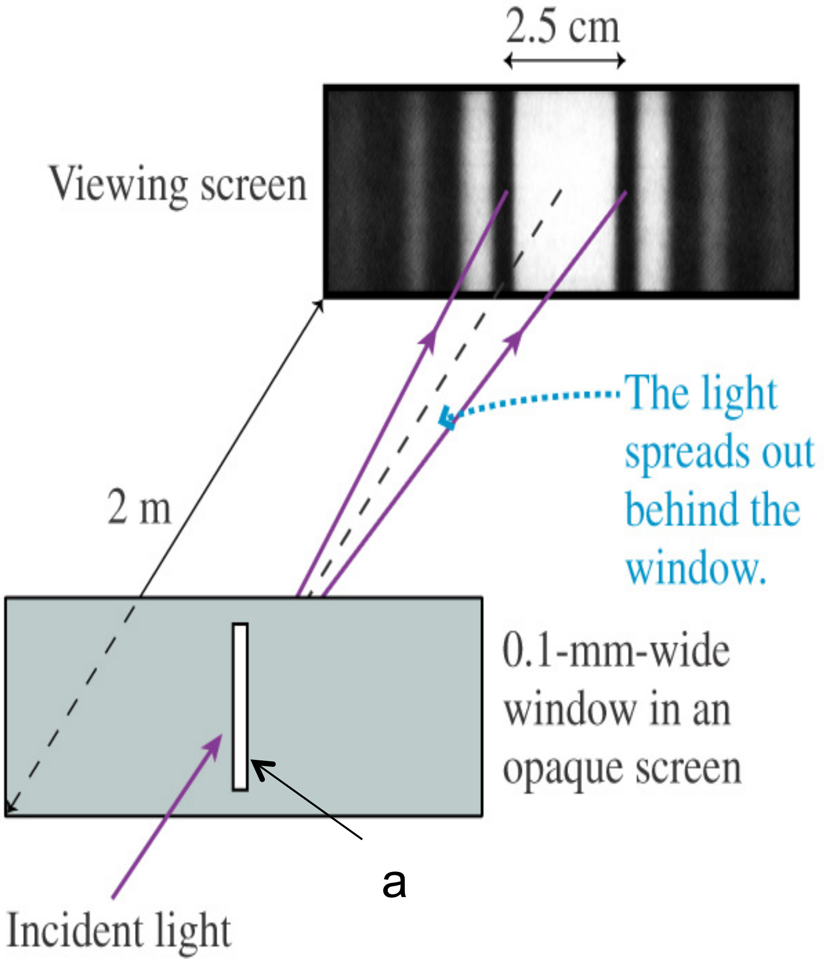
(b)

You should know

- Why the sky is blue
- Why sunsets are red
- Why clouds are white

Wave optics: diffraction

- Like water waves passing through a breakwater, light waves spread out when passing through a narrow opening
- This is called diffraction
- We can say that the light waves spread out a great deal because they are passing through a very narrow opening
  - compared to the size of their wavelength λ



angles of dark fringes are given by formula $a\sin\theta = m\lambda$ ($m=+/-1,+/-2,\ldots$), so angle from center to first dark fringe is approximately λ/a

Interference

A series of bright and dark fringes appears on the screen. Bright for constructive interference and dark for destructive interference.