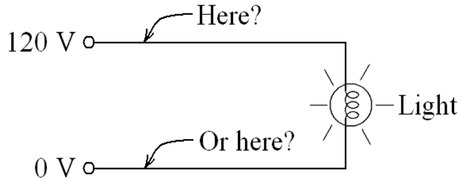
Too much current through a wire heats it too much (fire hazard).
  Fuse: melts when I is too big.
  Circuit Breakers: A switch is pulled open by a bimetallic strip or electromagnet.



Does it make any difference if a fuse (or a switch) is on the hot wire or the return wire?

Yes – Break the circuit on the hot side. Doing it the other way also makes the light go out, but its socket is still hot.

Electricity flowing through the body can cause two kinds of injury:
  -burns (caused by just a few amps in the person)
  -interference with nerve impulses to heart or lungs (fraction of an amp through the chest area.)

Why are technicians who work on live circuits advised to keep one hand in their pockets?

Any shock will only be to one hand, rather than completing a circuit through the chest.

A ground is a connection to the earth (a stake or water pipe), which can absorb or give off charge. It's good for devices to be grounded; if they malfunction, current will go through the ground wire instead of you. It's bad if you're grounded, because then you're the path current follows. (Current won't flow through you with nowhere to flow to, like with a bird sitting on a wire.)

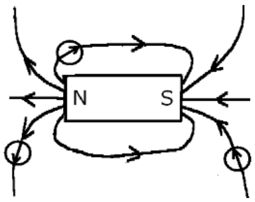
If it's the amount of current that hurts you, why do people talk about low voltages being safer than high ones?

You are a resistor; apply Ohm's law (V = IR): Higher voltage pushes more current through you.

Magnetism:

There are two kinds of magnetic poles, called north and south. (N and S are to magnetism what + and - are to electricity.) Opposites attract, likes repel.

A compass is a little magnet, mounted on a needle point so it is free to swing. Earth has a magnetic field, so the ends of the little magnet are pulled toward Earth's poles.



(When I draw pictures of magnetic fields, the arrows indicate the direction a compass would point.)

Magnetic fields come from and are felt by electric currents. (Demonstration: There is a field around a current carrying wire.)

In a permanent magnet, these currents are within its atoms: the movement and spin of the charged particles the atom is made of.

Earth's magnetic field comes from currents in its metallic core. (Not permanent magnetism, because it’s not a permanent field.)

Discussion:

1. Without a fuse or circuit breaker, the ________ (current? voltage?) in a circuit might get too high. If it gets too high, ________________________. (What would happen without the fuse or breaker?)

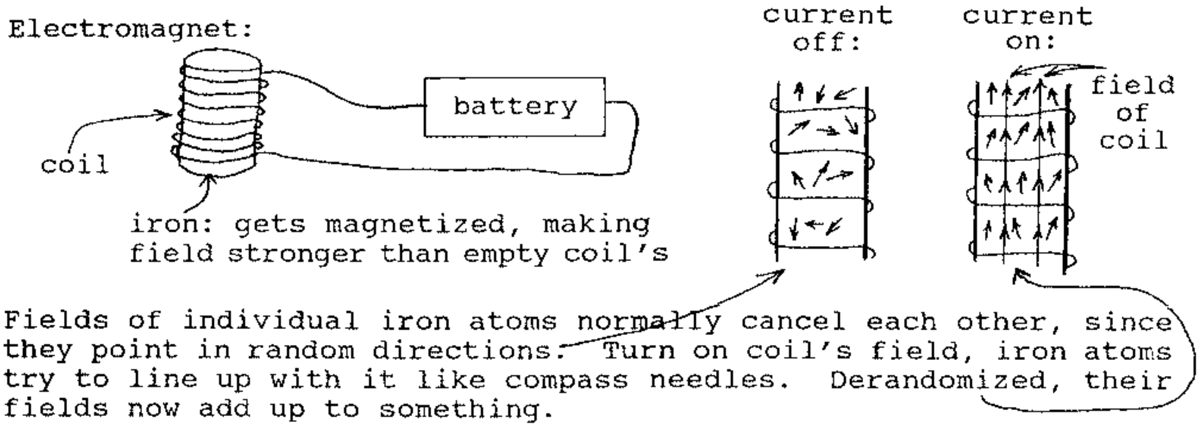
2. A beam of electrons is shooting through a vacuum.
   a. Does it have an electric field around it?
   b. Does it have a magnetic field around it?

3. An electric current is flowing through a copper wire.
   a. Does it have an electric field around it?
   b. Does it have a magnetic field around it?

4. A plastic rod has an excess of (stationary) electrons on it.
   a. Does it have an electric field around it?
   b. Does it have a magnetic field around it?

5. I've said that magnetic fields are found around electric currents, but permanent magnets work without having to be plugged in. Where does the field of a permanent magnet come from?

6. How is the earth's magnetic field created?



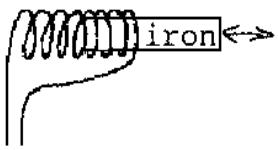
Fields of individual iron atoms normally cancel each other, since they point in random directions. Turn on coil's field, iron atoms try to line up with it like compass needles. Derandomized, their fields now add up to something.

Applications:

-Picking up iron objects.

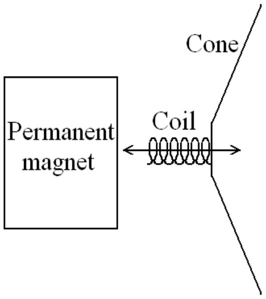
-Solenoid (throws switch to car's starter, throws valves in clothes washers & dish washers, moves clapper on doorbell, etc.)

Turn coil on: It attracts iron core.
Turn coil off: Spring pushes core back.



-Tape recorders (videotape, magnetic disks similar): Tape moves across an electromagnet connected to a microphone. As coil's field varies, different parts of tape are magnetized to different strengths.

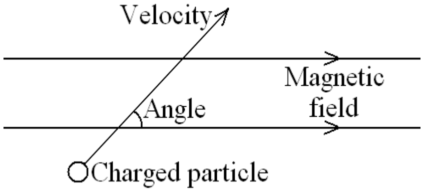
-Speaker: Changing current changes the strength of the electromagnet. The changing force shakes the paper cone, vibrating the air.



Aside from being field's source, currents (moving charges) are also what feel its effects.

Demonstration: A beam of electrons is moving through a vacuum tube. When a magnet is brought near, you can see the beam bend, showing that the field pushes on the electrons.

Force (perpendicular to both velocity and field) depends on:
- Angle (F largest when going across field.)
- Magnetic field strength
- Velocity
- Charge



(There is no magnetic force on a stationary charge. The faster it goes, the larger the force.)

Example: If I have a stationary charged pith ball,
a. Does it feel a force from a stationary bar magnet?
b. Does it produce a magnetic field around itself?

ans (both parts): <u>No</u>. You would have to have <u>moving</u> charge; that is, a current.

The same force exists if the charge moves through a wire instead of empty space. This force is what makes a motor go around:
A <u>motor</u> is an electromagnet being pushed around by another magnet's field.

<u>Discussion</u>:

1. If an electron is moving through an electric field, the force on it is the same regardless of its speed. Is this also true if it is a magnetic field instead?

2. What is meant by the "core" of a coil? State a situation where a coil's core moves.

3. If a current-carrying wire is placed in a magnetic field, it feels a force. Name a device that makes use of this force.

4. True or false: Iron atoms are electrically charged, while the atoms in a piece of wood are neutral.

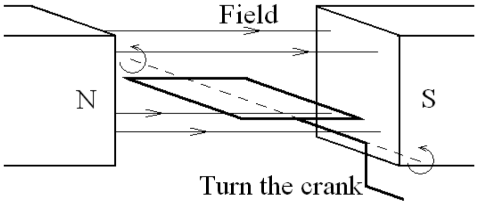
Section 10: Induction & Electronics

If you move a loop of wire toward a bar magnet, the free charges in the wire feel a force due to moving through a magnetic field (sec. 9), and this force pushes them around the loop. A current is induced. Any other situation with relative motion between the loop and the field does the same thing:

Faraday's Law: Voltage induced in a loop of wire = rate "amount of field" through loop changes.

(In a picture, "amount of field" is represented by the number of field lines through the loop.)

Generator: As you spin the loop, "amount of field" through it changes, inducing a current in it.

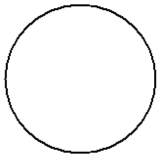


(As we will discuss below, any kind of generator starts out making AC. This can just flow out as is, or be converted to DC.)

Discussion:

1. If there is a change in how much of a magnetic field passes through a loop of wire, what happens to the wire?

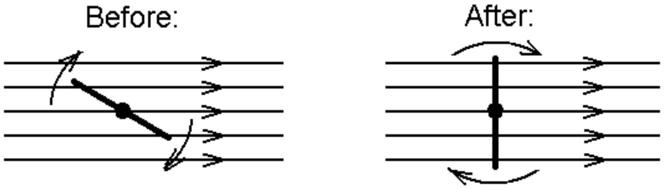
2. A loop of wire, containing no battery, is lying on the page. A magnet above the loop is falling toward it.
   a. Is the loop electrically charged?
   b. Does a current flow around the loop?



3. Decide whether AC or DC is induced in the rotating coil of a generator, as follows. (Note for nit-pickers: Faraday's law usually has a minus sign we're leaving out, which would reverse the voltage answers in (a) and (b), but have no effect on the final conclusion.)

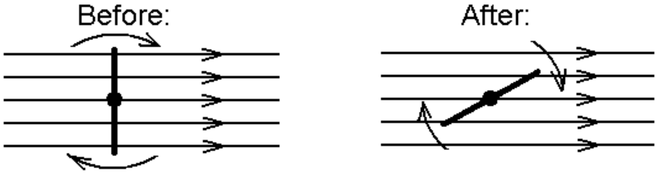
a. The picture shows a loop of wire, seen from the side. Does the "amount of field" through the loop increase or decrease? So, is the rate it changes positive or negative? So, is the induced voltage positive or negative?

A)



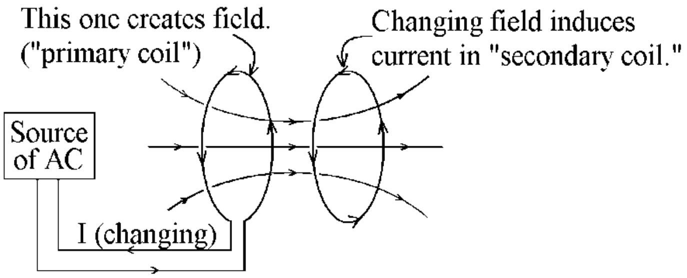
b. Next after that, does the "amount of field" through the loop increase or decrease? So, is the rate it changes positive or negative? So, is the induced voltage positive or negative?

B)



c. So, is the voltage AC or DC?

<u>Transformer</u>: A pair of coils arranged so that same magnetic field goes through both. Changing current in primary creates changing magnetic field which induces voltage in secondary.



The purpose of a transformer is to change voltages: Since a certain amount of V is induced in the secondary <u>per turn</u>, more turns there means more volts there.

$$\boxed{\frac{N_p}{N_s} = \frac{V_p}{V_s}}$$

N = number of turns, V = voltage, p for primary, s for secondary

Example: 120 V house current is stepped down to 12 V in a radio. If the secondary coil has 100 turns, how many should the primary have?

ans: $$\frac{N_p}{N_s} = \frac{V_p}{V_s} \Rightarrow \frac{N_p}{100} = \frac{120}{12} \Rightarrow N_p = 1000$$

Example: What is V_s if V_p is 120 V DC instead? Why?

ans: <u>0 V</u> Primary must make a <u>changing</u> B field to induce a voltage in the secondary.

This device is the main reason the power company makes AC not DC: For long distance power transmission, you want low I to reduce losses to heat (= I^2R). Low I means high V (P = VI). So, step the voltage up when the current leaves the generator, then step it back down for people's houses. Use AC so transformers will work.

Transformers also change voltages inside devices like televisions. The little thing you plug into the wall for an answering machine or cell phone charger contains a transformer. The ignition coil in a car is essentially a transformer.

Cars are DC, so how is the coil able to do this?

The primary current is turned on and off over and over. This gives the <u>changing</u> magnetic field needed to induce the spark (for the spark plugs) in the secondary.

<u>Discussion</u>:

1. Because the names are somewhat alike, people sometimes get transistors and transformers confused. Explain what each one is.

2. To minimize the power lost along power lines, the current should be as _______ (big? small?) as possible, and the voltage as _______ (big? small?) as possible.

3. A transformer's secondary coil has twice as many turns as its primary.
   a. If the primary is connected to 6 V of steady DC, how many volts are induced in the secondary?
   b. Would the answer be any different if the primary was being turned on and off instead?

4. A transformer's secondary coil has twice as many turns as its primary. When used with AC under ideal conditions (no losses such as heat), how would the power out of the secondary compare to the power into the primary?

5. Cars are DC. Explain how they get a transformer (the ignition coil) to work on DC.

Electronic Devices:

Inductors:

Self inductance: A voltage is induced in any coil with a changing magnetic field through it, including the coil producing that field.

This self-induced voltage opposes an alternating current trying to flow through the coil.

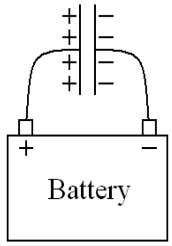
The faster the current changes, the larger the induced voltage. (A faster changing current produces a faster changing field. Faraday's law says a faster changing field induces more volts.)

Example: 1 amp of AC is sent through a coil. Then 1 amp of higher frequency AC goes through the same coil. Compare V.

ans: V is greater at higher f, because I changes faster.

So, a coil acts like a filter or a sieve: Low frequencies get through, high frequencies don't. (A coil used for this purpose is called an inductor.)

Capacitors: Plumbing analogy: A capacitor stores charge the way a tank stores water. If a set of metal plates is connected to a battery as shown, charge flows into them, pushed by repulsion from the battery's terminals. It flows until what's already on the plates repels the next bit of charge as strongly as the battery does. Aside from the brief time to charge it, DC won't flow with a capacitor present.

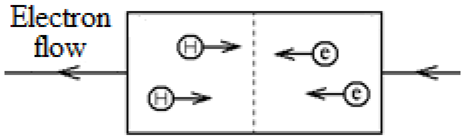


AC will flow: Charge goes into the capacitor, then goes back the way it came, then comes back in and so on. High frequencies get through, low frequencies don't. Current is opposed because charge trying to flow in is repelled by the charge already in the capacitor. A lower frequency means more time for charge to accumulate before the charge flows out again. Larger average charge means more repulsion means fewer amps.

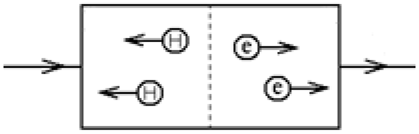
Diodes: Electricity flows through a diode in only one direction.

- Pure silicon is a fairly poor conductor.
- Impurity atoms that give off free electrons make it a better conductor.
- Other impurities that take on electrons also make it conduct better by creating positive “holes.”

A diode is a junction between a region with free electrons and a region with holes:



Wires dump many charges in at ends which combine at the junction, so current flows.

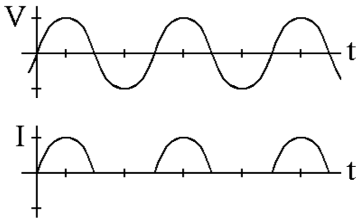


Pulling free charges out changes the junction into an insulator, so no current.

Used for changing AC into DC.

Transistors. (See section 8.) A transistor is a “valve” for electricity. Can be used for amplification.

Discussion:



1. The voltage applied to a certain device varies with time like the top graph. The bottom graph shows the resulting current. This device is a ________ .

2. The signal in the top graph is applied to one of the wires in a certain device. The bottom graph, drawn to the same scale, is the resulting voltage on another of this device’s wires. This device is a ________ .

3. a. What is a capacitor? (That is, how is one made?)
   b. What is an inductor? (That is, how is one made?)

4. a. What opposes the flow of alternating current through a capacitor? (That is, what causes the opposition?)
   b. What opposes it through an inductor?
   c. A resistor?

5. a. You increase the frequency of the alternating current in an inductor. Explain why this decreases the current in the circuit.
   b. You increase the frequency of the alternating current through a capacitor. Explain why this increases the current in the circuit.

6. Transformers and inductors both use induction. Explain the difference between these devices.

Section 11: Electromagnetic Waves & Interference

EM waves, such as light, work by induction: A changing electric field induces a changing magnetic field which induces a changing electric field which ...

For example, if a high frequency alternating current is in a wire, the magnetic field around it changes in proportion to the current, setting the process off. This is how a radio transmitter works.

Electromagnetic Spectrum:

low f (or long λ): Radio waves
Microwaves
Infrared
Visible ⟵ Roy G. Biv (white = mixture of all λ's)
Ultraviolet
X - rays
high f (short λ): gamma rays

These all are basically just light with a different frequency. All travel at the same speed in a vacuum.

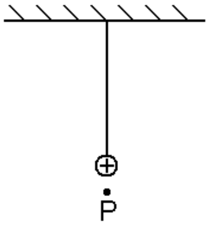
Frequencies higher than visible can be dangerous.

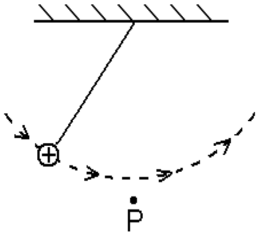
Discussion:

1. A wire carries a steady DC current.
   a. Is there a magnetic field outside of this wire?
   b. Is there an electric field outside of this wire?

2. A wire carries an alternating current.
   a. Is there a magnetic field outside of this wire?
   b. Is there an electric field outside of this wire?

3. A charged ball on a string hangs at rest, as shown.
   a. Is there an electric field at point P?
   b. Is there a magnetic field at point P?





4. A charged ball on a string swings as a pendulum, as shown.
   a. Is there an electric field at point P?
   b. Is there a magnetic field at point P?

5. An electromagnetic wave is going through empty space, far from any charges or currents. Where do the fields, which the wave is made of, come from?

6. Does an electromagnetic wave
   a. carry energy? b. carry electric charge?
   c. contain electrons? d. push on electrons it runs into?

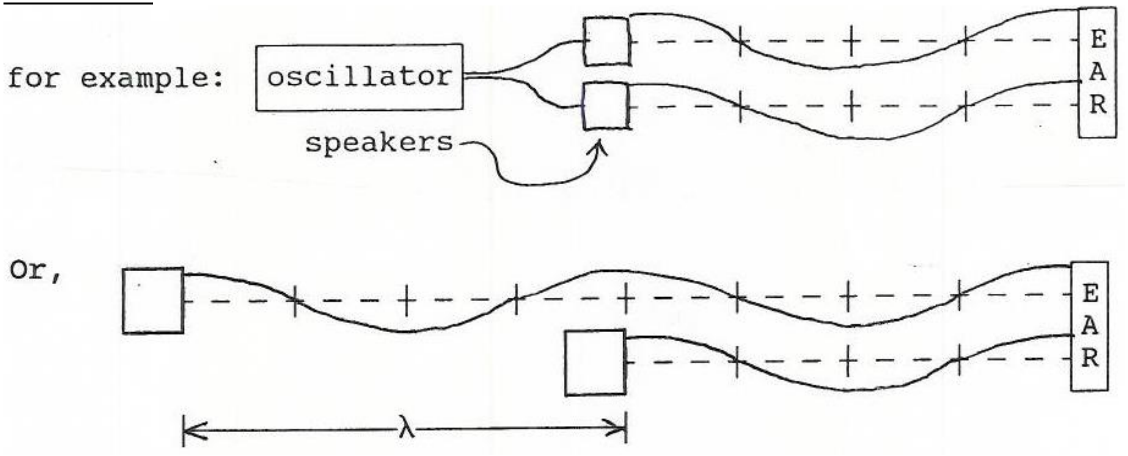
7. a. Name a kind of electromagnetic wave with a wavelength shorter than visible light.
   b. Name a kind of electromagnetic wave with a wavelength longer than visible light.

c. Name a kind of electromagnetic wave whose speed in a vacuum is faster than visible light.

8. How many m/s is the speed of radio waves in a vacuum?

9. When AC makes electrons in a wire jiggle back and forth, what do they give off?

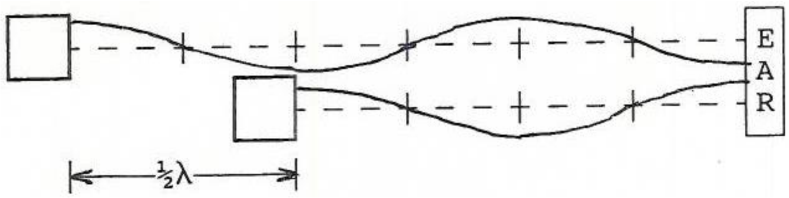
<u>Interference</u>:



Or, if you move the top speaker another wavelength, it's the same picture with one more wave drawn onto its left edge. In general,

<u>Constructive Interference if path difference = nλ</u>
where n = 0 or 1 or 2 or ...

On the other hand,

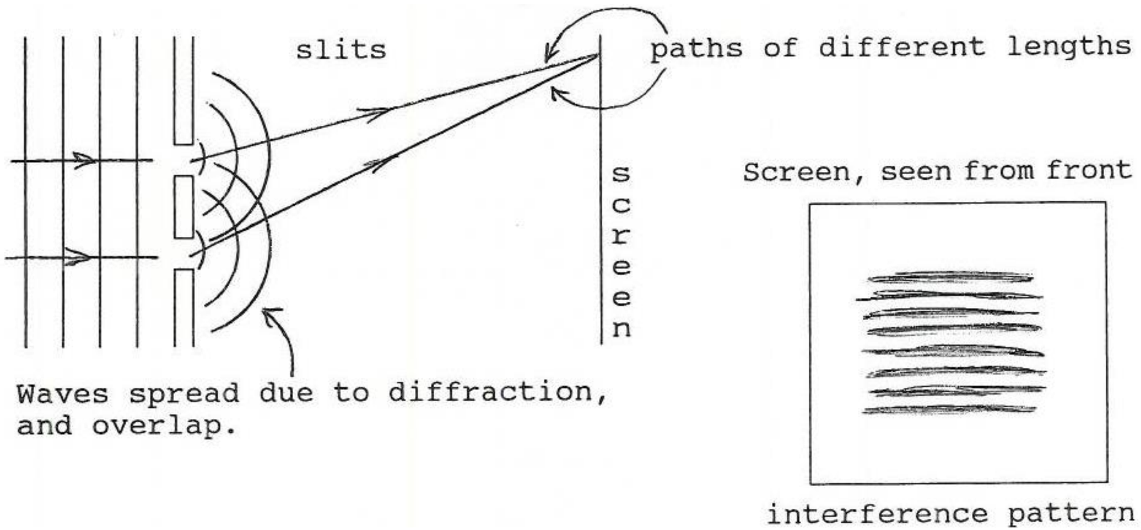


The positive parts of one wave arrive at the same time as the negative parts of the other, so they cancel. The same thing happens if the path difference is 1½λ or 2½λ or ...

<u>Destructive Interference if path difference = (n + ½)λ</u>

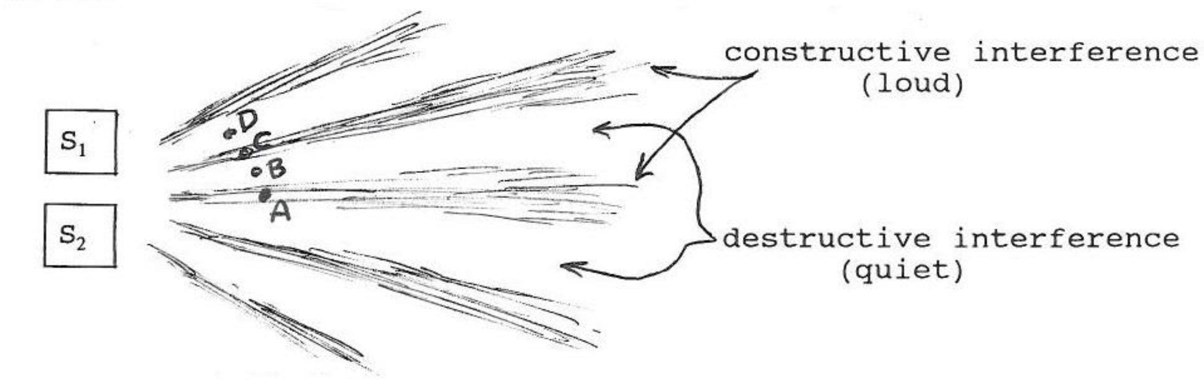
<u>Diffraction</u> = the bending of waves around an obstacle.
(For example, you can still hear me with my back turned because the sound diffracts around me.)

Diffraction can be used to create two interfering light waves. (<u>Double slit interference</u>)



(This is the experiment that first proved light is a wave.)

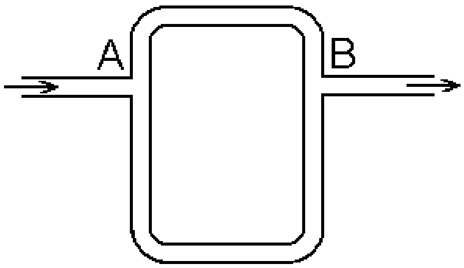
ex: The speakers give off sound of 2 m wavelength. Each labeled point is 5 m from S_2. How far are they from S_1?

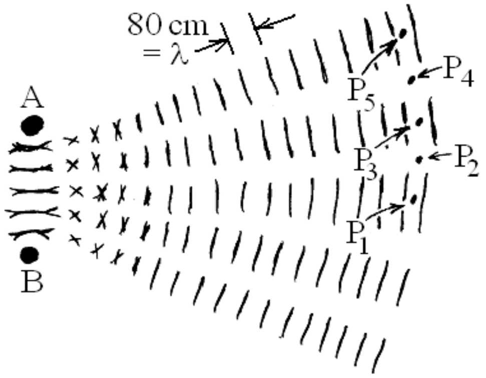


ans: A is <u>5 m</u> from S_1. Constructive interference is due to both paths being the same length.
B is <u>4 m</u> from S_1. Destructive interference is due to one path being half a wavelength longer than the other. $\frac{1}{2}\lambda = \frac{1}{2}(2\text{m}) = 1$ m. 5 m – <u>4 m</u> = 1 m.
C is <u>3 m</u> from S_1: Path diff. = $(1)\lambda = (1)(2\text{ m}) = 2$ m. 5 m – <u>3 m</u> = 2 m.
D is <u>2 m</u> from S_1: Path diff. = $1\frac{1}{2}\lambda = (1.5)(2\text{m}) = 3$ m. 5 m – <u>2 m</u> = 3 m.

<u>Discussion</u>:

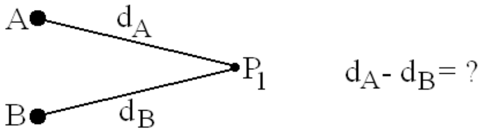
1. Sound with a wavelength of 20 cm travels through hard-walled tubes, as shown.
   a. If it is 50 cm from A to B along the upper tube, and 70 cm along the lower tube, what kind of interference occurs at point B?
   b. If it is 50 cm from A to B along the upper tube, and 80 cm along the lower tube, what kind of interference occurs at point B?





2. Identical sound waves, coming from speakers at A and B, each have a wavelength of 80 cm.

a. From point P_1, what is the distance to speaker A minus the distance to speaker B, in cm?



b. From point P_2, what is the distance to speaker A minus the distance to speaker B, in cm?

c – e. Repeat for P_3, P_4 and P_5.

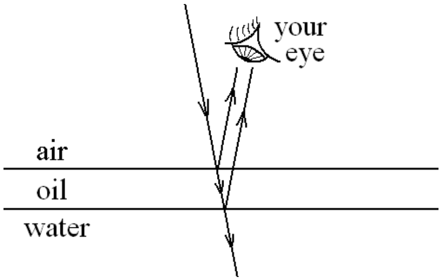
Diffraction Grating: many parallel slits or scratches.

Similar to two slits, except that the constructive areas are much sharper. Measuring their location is how the wavelength of light is measured. (The larger λ is, the more path difference is needed for constructive interference.)

With white light, constructive interference of each λ is at a slightly different angle, separating the light into a spectrum. (The instructor will demonstrate.)

The same principle gives colors on other things with close, evenly spaces lines, such as a compact disk.

Thin film interference: Instead of creating interfering rays by diffraction, reflect light from opposite sides of a film, like a layer of oil floating on a puddle:



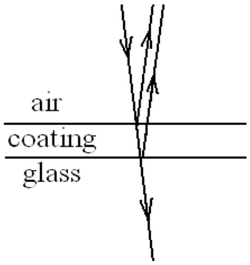
If the difference in length between the two rays that go to your eye (about twice the thickness of the oil) is a whole number of wavelengths, interference is constructive, and the oil looks shiny. If it's a whole number plus an extra half, destructive interference makes the puddle look clear (to a single λ).

In a parking lot, different parts of an oil slick are different thicknesses, which give constructive interference for different wavelengths. This is why you see different colors.

The colors in soap bubbles are caused the same way.

Nonreflective lenses: have a coating whose thickness gives destructive interference. This makes all the light go through it, instead of some being reflected. (The coating can't match all the λ's in white light, so certain colors are reflected some, making the lens look sort of purple.)

Example: How thick should the coating be to make the lens nonreflecting to 500 nm light?



ans:

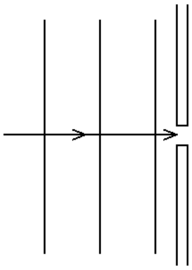
Path difference = ½λ for destructive int.
2T = 250 nm

T = 125 nm

Example: Should it be thicker or thinner to be nonreflecting to 600 nm light instead?

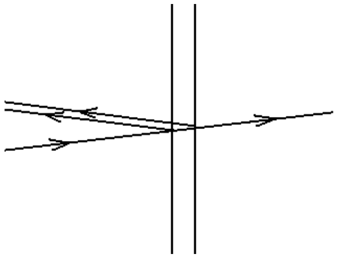
ans: Thicker, in order for the round trip through the film to be half of a longer wavelength.

Discussion:



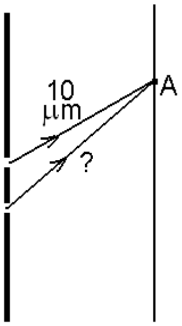
1. Sketch in what the waves do after passing through the small opening.

2. In a double-slit experiment, if one light ray is five wavelengths longer than the other ray, there will be ________ (constructive? destructive? something in-between?) interference at the point where they meet.



3. a. The thickness of the soap film is such that the reflected rays interfere destructively for blue wavelengths. The film will look bluish when seen from the ________. (left? right?)
b. The reflected rays interfere constructively for red wavelengths. The film will look reddish when seen from the ________. (left? right?)

4. Explain how reflected light is eliminated from a non-reflective lens.



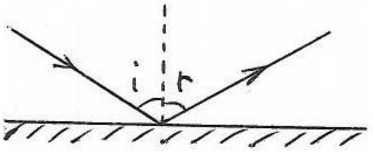
5. Light with a wavelength of .6 µm passes through a pair of slits and falls on a nearby screen. Point A is 10 µm from the closer slit.
a. If there is destructive interference at point A, what are two possible values for its distance from the other slit?
b. If there is constructive interference at point A, what are two possible values for its distance from the other slit?

Section 12: Optics

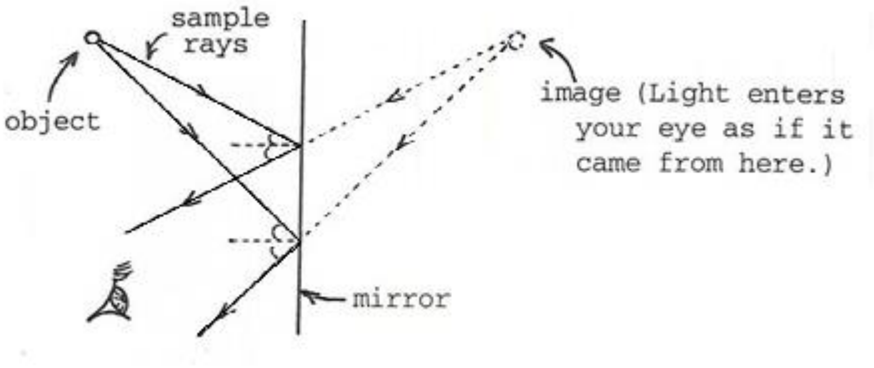
Reflection = a wave bounces off something.
Refraction = bending of a wave due to a change in its medium.

Law of reflection:

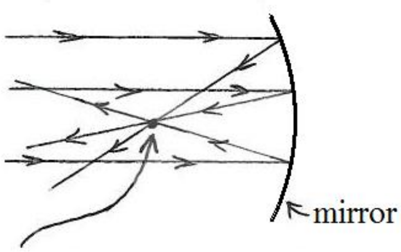
$$\boxed{i = r}$$



Flat mirror:

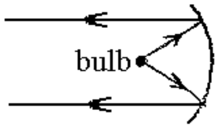


Converging mirror:

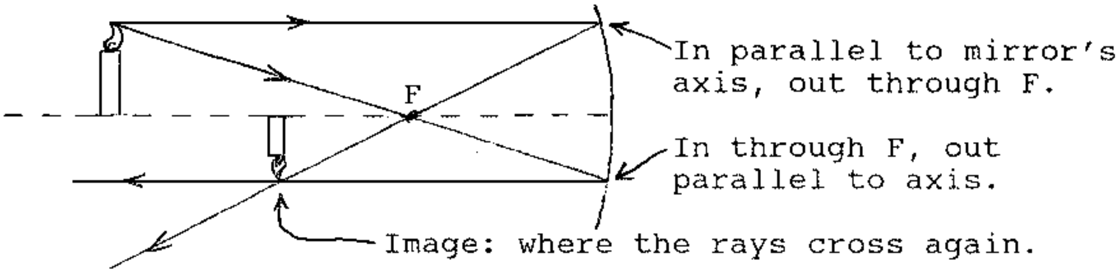


Focal point: where parallel rays cross after reflection.

examples: -Enlarging mirror
-Reflecting telescope
-Satellite dish (mirror for microwaves, which concentrates them on antenna.)
-Reflector for headlight, flashlight, etc:
Reverse the arrows:

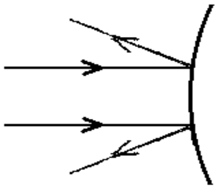


To find an image produced by one of these mirrors,



Diverging mirror:

-Used for wide angle view.

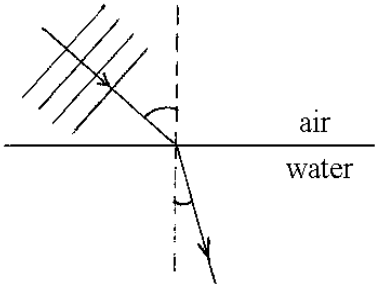


Refraction:

c = 3 x 10^8 m/s is the speed of light in a vacuum. Being in any material slows it down. The slower light goes, the higher the index of refraction (or "optical density") for that material.

$$\text{Index of refraction} = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}}$$

When light hits the boundary between two materials at an angle, there is a short time when each end of a wave is in a different material. Having each end going at a different speed makes it swing around, so ray changes direction where it crosses.



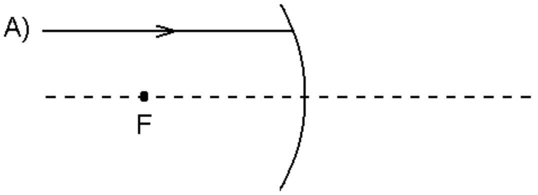
Angle is smaller in the material with the larger refractive index.

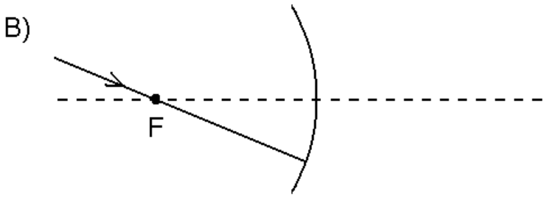
Discussion:

1. State the law of reflection, illustrating it with a diagram.

2. The speed of light in air is ________ (a little faster than? a little slower than? the same as?) the speed of light in a vacuum.

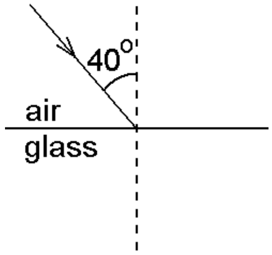
3. A ray strikes a mirror as shown. Sketch what it does next.





4. Multiple choice: You seem to see yourself behind a flat mirror because
   a. as they enter your eye, light rays from your face are spreading out as if they came from back there.
   b. the mirror makes light rays from your face converge on your eye.
   c. the mirror's focal point is back there.
   d. light is reflected internally in the mirror.

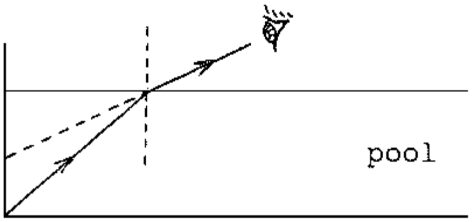
5. Light strikes the surface of some glass at 40° as shown. Draw in the reflected and refracted rays. Label each ray's direction as less than 40°, 40°, or



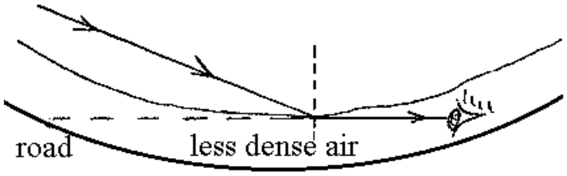
more than 40°.

Examples of Refraction:

- Refraction is why a pool or cup of water doesn't look as deep when full. Light from the bottom enters your eye as if from farther up.

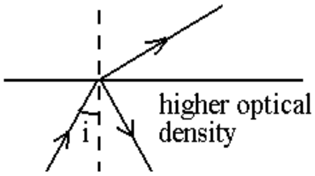


- Mirages (For example, the "wet spots" you see on a hot road that aren't there when you arrive): Light refracts when it enters the hot, less dense air near the road.



- Twinkling of stars: As air circulates around, how light refracts through the atmosphere constantly changes.

- Total internal reflection:



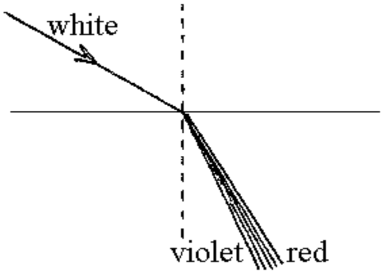
Say you're underwater, shining light toward the surface. As you increase the angle i, the angle in air always has to be larger (smaller index of refraction), so it gets to 90° first. Beyond this "critical angle," there is no refracted beam; all of the light goes into the reflected one.

ex: What if light (in air) fell on the surface from above: Could you have internal reflection in the air?

> ans: No. The angle in the higher index of refraction is always smaller, so you would never lose the refracted beam.

Fiber optics: Due to total internal reflection, light does not escape from inside a glass fiber. (I will demonstrate by shining a laser in the end of a bent glass rod.)

- Dispersion: As light goes through a material, some frequencies slow down more than others, causing them to refract through different angles. This separates the colors from a prism or a rainbow.



Discussion:

1. Is the speed of red light through a raindrop the same as the speed of blue light through the same

raindrop?

2. When the layer of air down near a road gets hotter than the air above it, what do you see?

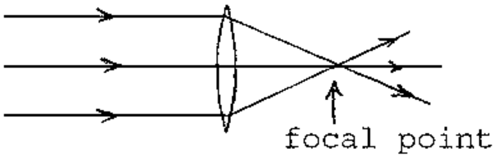
3. What keeps the light inside an optical fiber?

4. Separation of different colors because the light waves travel at different speeds is called ____________________.

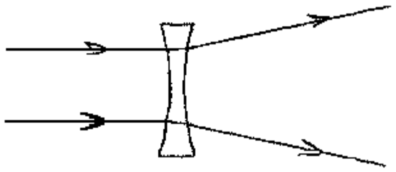
5. a. What process makes the colors seen in a soap bubble?
   b. What process makes the colors seen in a rainbow?
   c. What process makes the colors seen on a CD?

Refraction is also how lenses work:

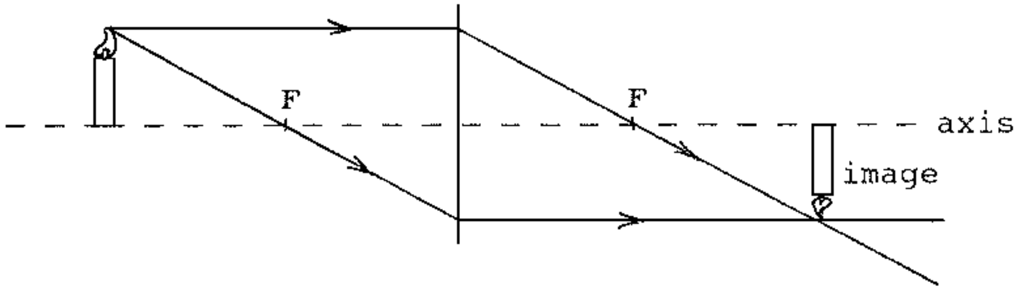
Converging lens:



Diverging lens:



Ray diagram similar to that for a mirror:



Applications:

1. Projecting an image (like diagram above)
   - Slide and movie projectors
   - Camera (Image is projected on film where light triggers chemical reactions in the illuminated areas.)
   - The eye (Image is projected on the retina. Its many nerve endings tell the brain which areas are illuminated.)

2. Magnifying glass. (Redirects rays so they enter eye as if from a larger object.)

<u>Discussion</u>:

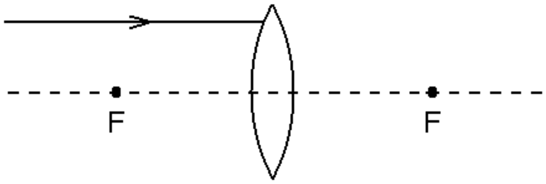
1. a. Make a sketch of a converging mirror, and two light rays which are parallel before they hit it. Show what the rays do after hitting the mirror. Label the focal point.
   b. Repeat for a converging lens.

2. A lens works by _____________. (What physical process?)

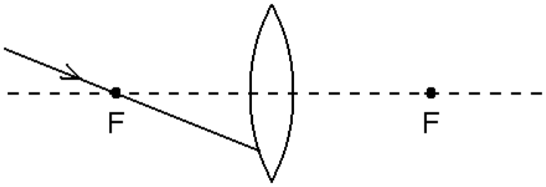
3. A candle is placed a few inches from a converging lens. Is the lens's focal point in the same place as the candle's image?

4. A ray strikes a lens as shown. Sketch in what the ray does next.

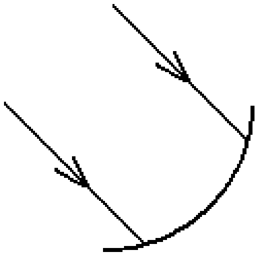
A)



B)



5. Microwaves hit a satellite dish, as shown.
   a. Sketch in what the rays do next, and label where the receiver is located.
   b. Which is the dish acting like: a lens or a mirror?



6. Name a device which makes use of a lens projecting an image onto a screen.

Review of Sections 9 – 12:

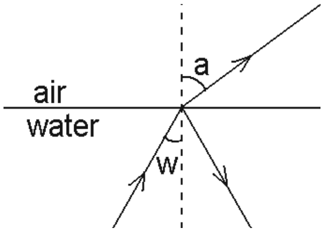
When most people have finished a group of questions, I will go over them. If you finish before that, go on to the next group.

1. What causes dispersion of light?

2. Playing magnetic tape tends to produce a high-pitched “hiss” in the background, which a good tape player filters out. In each case, state whether the hiss would get more prominent, less prominent or stay the same relative to the music:
    a. What if the signal went through a resistor?
    b. What if the signal went through an inductor?
    c. What if the signal went through a capacitor?

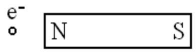
3. What always exists in the space around an electric current?

4. The picture shows a beam of light being shot at the surface of a pool from below. The angle in the water, w, is increased. As w approaches the critical angle for total internal reflection, what does a, the angle in the air, approach?



5. Two waves each have an amplitude of 1 cm. What is the amplitude of the combined wave if they are
    a. in phase?
    b. completely out of phase?

6. A stationary electron is sitting near a bar magnet, as shown. What is the direction of the force on this electron?



1. Two electrons are moving through the same uniform magnetic field. State two factors either of which could make the magnetic force on one electron larger than on the other electron.

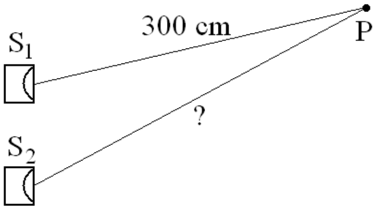
2. Give an example of what a diode can be used for.

3. The transformer in a cell phone charger takes in household voltage and steps it down to the voltage of the battery.
    a. Which of the transformer’s coils has more windings?
    b. Which of the transformer’s coils has more current? (Assuming the same power through both.)

4. a. Name three kinds of electromagnetic waves with frequencies higher than visible light.
    b. Name three kinds of electromagnetic waves with frequencies lower than visible light.

5. A lens works by bending light. This bending is called ________________________.

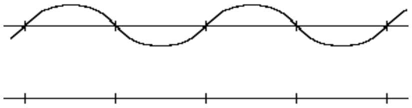
6. The wavelength of the sound from these speakers is 50 cm. Point P is in the first zone of destructive interference to the side of center (It is quiet there.) If point P is 300 cm from speaker 1, how far is it from speaker 2?



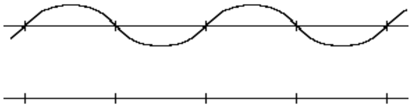
1. What does the power company do to reduce losses to heat along long distance transmission lines?

2. Magnetic fields are produced by electric currents. (Moving charges.) Explain, then,
   a. where the field of a permanent magnet comes from.
   b. where the earth's magnetic field comes from.

3. a. The top picture shows the wave coming from one slit in a double-slit experiment as it approaches a certain point on the screen. On the bottom picture, sketch in the wave from the other slit if the waves are interfering destructively at this particular point.



b. At a different point on the screen, the waves are interfering constructively instead. Fill in the wave from the other slit for that.



4. a. Draw two waves, one above the other, that are in phase with each other.
   b. Draw two waves, one above the other, that are completely out of phase with each other.

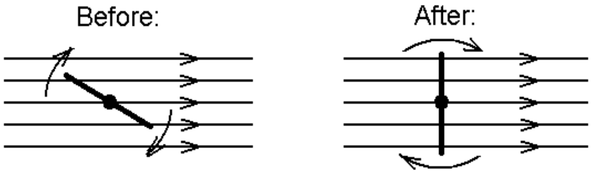
5. Give an example of what a transistor can be used for.

6. The "dish" used in receiving signals from a satellite does with microwaves what a __________ does with visible light.

1. A typical household circuit is protected by a 15 or 20 amp fuse or breaker. What do these protect you from? Do they help protect you from electrocution?

2. Briefly describe how each of these devices opposes an (alternating) current:
   (a) resistor, (b) inductor, (c) capacitor

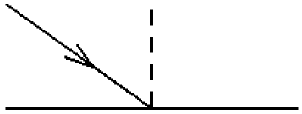
3. The picture shows a loop of wire, seen from the side. As it rotates, the "amount of magnetic field" through it increases. If this happens slowly, the voltage induced in it is ______ (less than? more than? the same as?) if it happened quickly.



4. Near the front of your eye is a lens made of transparent tissue. What is the function of this lens? (What does it do? Be more specific than "Helps you see.")

5. a. Give an example of a situation where colors are separated out of white light by thin film interference.
b. Give an example of a situation where colors are separated out of white light by some process other than thin film interference.

6. The picture shows a ray of light striking some surface. Draw in the reflected ray, and use the picture to state the law of reflection.

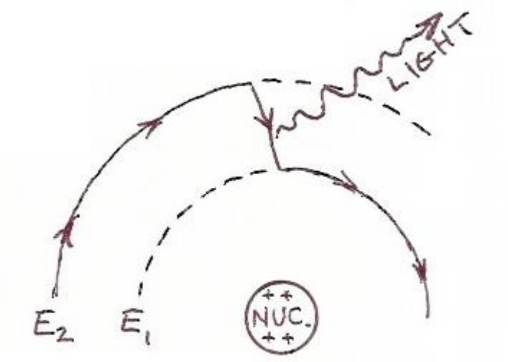


Section 13: The Atom

Continuous spectrum: All λ's present.
Emission spectrum: Only certain λ's present. (A pattern of bright colored lines on a dark background.)
Absorption spectrum: Only certain λ's absent. (Dark lines.)

Pattern of lines acts as a "fingerprint" to identify what made the spectrum. For example, this is how we know what stars are made of.

No one could explain line spectra, until Niels Bohr suggested that the electrons in atoms could only orbit the nucleus at certain special distances, restricting them to particular energy levels. Light is given off in a tiny flash called a photon when an electron drops from one energy level to another. The energy of the photon equals the energy lost by the electron when it dropped. The energy of a photon is related to the light's frequency, like so:

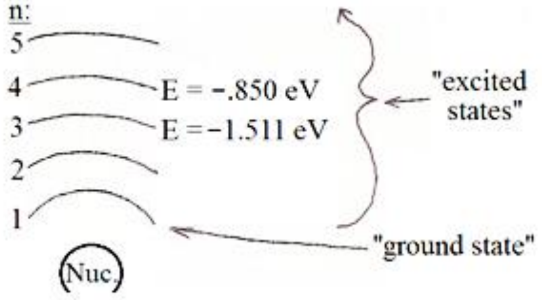


$\boxed{E = hf}$ h = Planck's constant = .00414 if E is measured in eV, and f in THz.

(1 eV = 1 electron-volt = the energy gained by an electron accelerated through 1 volt.)

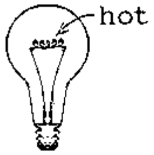
In many ways, these photons behave like particles of light.

ex: Energy levels in a hydrogen atom:



Find the frequency of the light given off when the electron drops from the fourth energy level to the third.

ans: Energy lost by electron = 1.512 - .850 = .662 eV = E of photon
From E = hf, f = E/h = (.662)/(.00414) = 160 THz



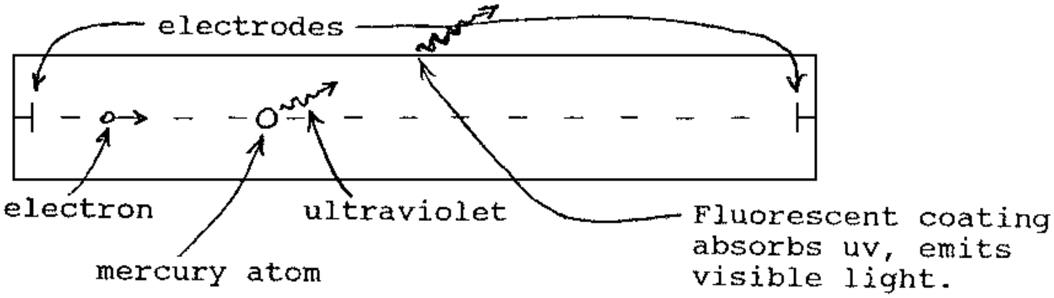
Light from an incandescent bulb is an example of a continuous spectrum. It's continuous because there is a continuous range of energies available to the electrons in the filament.

Neon sign has an emission spectrum: Excite gas in a glass tube with electricity. Gas glows as electrons fall back to lower levels. Only certain energies are available, so only certain wavelengths are emitted.

To get an absorption spectrum, pass a continuous spectrum through a gas. The gas will absorb the same λ's it would emit if hot.

Fluorescent lamp:

Fluorescence: One wavelength in, other(s) out.

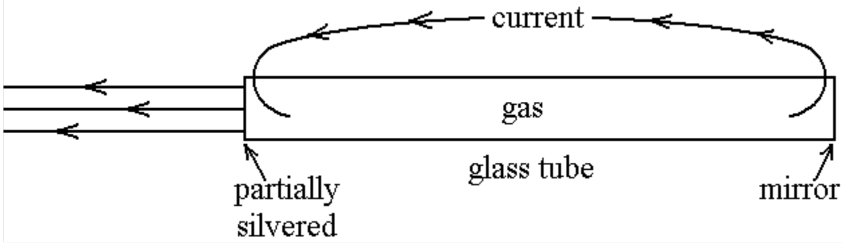


More efficient than incandescent. (Less energy outside visible wavelengths.)

Laser:

Stimulated emission: Electron is knocked down to a lower energy, instead of falling spontaneously.

example, Helium - neon laser: Neon atoms in tube undergo stimulated emission:



Discussion:

1. In a fluorescent light, a material coats the inside surface of the glass tube. What does this material do?

2. A photon slows down as it crosses from air into glass. Its frequency stays the same. Its energy ________. (Increases? Decreases? Stays the same?)

3. Explain how stimulated emission differs from spontaneous emission.

4. When an atom undergoes stimulated emission, how does the photon it gives off compare to the one that hit it?

The Nucleus:

Nucleus is held together against the repulsion between protons by Strong force: Protons and neutrons all attract each other.
(Very short range: Does not operate outside the nucleus.)

Number of protons in nucleus determines which element it is.

Isotopes: The different nuclei of an element: Differ in number of neutrons.

example: the 3 isotopes of hydrogen:

mass number = total number of nucleons (p's & n's)

$^{1}_{1}\mathrm{H}$ $\qquad$ $^{2}_{1}\mathrm{H}$ $\qquad$ $^{3}_{1}\mathrm{H}$

atomic number = number of protons

Example: how many neutrons in a $^{208}_{82}\mathrm{Pb}$ nucleus?
ans: 208 - 82 = 126

Radioactivity:

-Alpha "rays" (least penetrating):

example: $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$

alpha particle (helium nucleus, 2p's & 2n's)

Mass numbers add up to same thing on both sides.
Atomic numbers add up to same thing on both sides.

-Beta "rays" (intermediate penetration):

example: $^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$

beta particle (electron)

-Gamma rays (most penetrating) are photons. Emitted when an excited nucleus drops to a lower energy level.

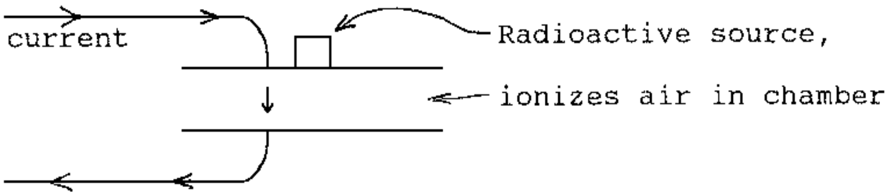
example: ${}^{123}_{53}\mathrm{I} \rightarrow {}^{123}_{53}\mathrm{I} + \gamma$

gamma ray (photon)

Applications:

-Radioactive tracers: Put something radioactive in a system; trace where it goes by where the radiation comes from.

-Smoke detectors:



If smoke is present, ions stick to smoke particles, changing electrical resistance of chamber.

-Radon: Radioactive gas from the ground. Seeps into homes in some areas.

Discussion:

1. a. What is an alpha particle?
   b. What is a beta particle?
   c. What is a gamma ray?

2. a. How many protons in a nucleus of ${}^{39}_{19}\mathrm{K}$?
   b. How many neutrons?

3. Complete the equations:

a. $${}^{64}_{29}\mathrm{Cu} \rightarrow {}^{64}_{30}\mathrm{Zn} + \underline{\hspace{3cm}}$$

b. $${}^{190}_{78}\mathrm{Pt} \rightarrow {}^{186}_{76}\mathrm{Os} + \underline{\hspace{3cm}}$$

c. $${}^{123}_{52}\mathrm{Te} \rightarrow {}^{123}_{52}\mathrm{Te} + \underline{\hspace{3cm}}$$

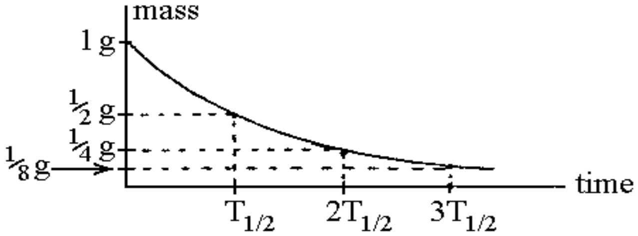
4. Many smoke detectors contain a small amount of radioactive material. What is it there for?

5. You mix a radioactive substance with a machine's lubricating oil. After giving it a good run, you find that no radiation is coming from a certain oil line. What would this tell you?

Section 14: Radioactivity & Nuclear Energy

Half-life: Time for half the nuclei of a substance to decay.

example: ^{14}C has a half-life of 5700 years, meaning that an object containing 1.0 gram of ^{14}C 5700 years ago would contain .5 gram today. (The rest decayed into ^{14}N.) 5700 years from now, it would be halved again, to .25 g.



Decay rate (or "activity") follows same pattern as number of nuclei.

Radioactive dating: Find an object's age by how much a substance, which the object normally contains, has decayed away.

example: carbon dating. All living things contain a certain concentration of ^{14}C. The more time has passed since something died, the less ^{14}C is left. A piece of wood with half that concentration would be 5700 years old (because that's ^{14}C's half life). If it had 1/4 of that concentration, it would be 2x5700 = 11400 years old. etc.

Longer lived elements are used by geologists to date rocks.

Nuclear reactions:

Shooting particles at a nucleus can transmute it into another element.

example: Bombarding uranium, the heaviest natural element, with neutrons can build it up into heavier elements which no one had seen before the 1930s. (As of today, many new elements have been made with this or similar methods.)

In 1939, it was discovered that the bombarding neutron sometimes splits the uranium nucleus, releasing energy. This is an example of a type of reaction called

Fission: Split a nucleus into smaller ones.
examples: original "A" bomb, nuclear reactors.

Another type of reaction is:
Fusion: Combine nuclei.
examples: H-bomb, the Sun.

Fission:

example: ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3({}^{1}_{0}n)$ + energy

$\nearrow$ (many other possibilities)

(Like the examples last week, mass numbers and atomic numbers must add up to same thing on both sides.)

Discussion:

1. A Geiger counter gets 8000 counts per minute from a certain source with a half-life of 5 years. How many years until its activity is 1000 counts per minute?

2. Explain the difference between fission and fusion.

3. Is it fission or fusion which creates the energy (or most of it) in
    a. A 1945-style "A-bomb"? b. an "H-bomb"?
    c. a nuclear power plant? d. the sun?

4. a. Write the equation for ${}^{235}_{92}U$ splitting into ${}^{140}_{54}Xe$ and ${}^{94}_{38}Sr$.
    b. Write the equation for ${}^{235}_{92}U$ splitting into ${}^{132}_{50}Sn$ and ${}^{101}_{42}Mo$.

Chain reaction: The neutrons released go on to split other ${}^{235}U$'s, releasing even more neutrons, etc.

Critical mass: The minimum mass needed to sustain a chain reaction. (If too few ${}^{235}U$'s are around to be split, neutrons escape from sample faster than new ones are released.)

Bomb: Get two pieces of ${}^{235}U$, each a little less than the critical mass. Drive them together when you want it to go off.

Reactor:

Reactor fuel is not enriched enough to explode. (That is, too small a % is ${}^{235}U$.)

But, it could have a meltdown (fuel melts through reactor floor), or a non-nuclear explosion. Damage to the reactor building would let out toxic substances.

Drawbacks to fission reactors:

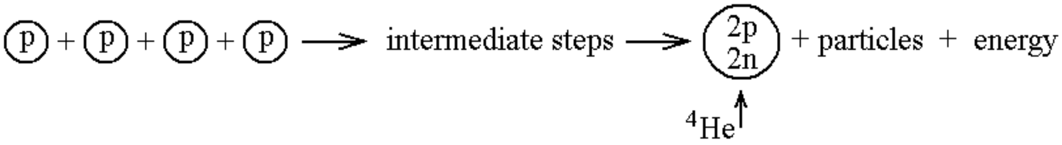
-accidents: Normally, reactor is much friendlier to surrounding environment than coal, oil, or hydro. But, an accident like Chernobyl can more than make up for that.

-waste disposal: Fuel rods come out of reactor considerably more radioactive than when they went in. Some of the isotopes last thousands of years. Where to put them where they will be safe for so long?

(To be fair, coal & oil have some pretty serious drawbacks too.)

Fusion:

Example:



Requires great temperature and/or pressure.

H-bomb does this by using fission ("A") bomb as a trigger.

Fusion reactor: Been trying since 1950's. Maybe someday. (If it ever works, seawater contains a million years worth of fuel, and it would make less radioactive waste than a fission reactor.)

Effects of radiation:

Ionizing radiation damages molecules in cells. If the cell can't repair the damage:

- Radiation sickness: Many dead/damaged cells, causing blood abnormalities at a certain dosage; nausea, hair loss, etc at a higher dosage; death at a still higher dose.

- Cancer: If there is damage to a cell's genetic material, it can start dividing out of control.

-Birth defects: Damage to genes in reproductive cells cause mutation which is passed down to all future generations.

There is no clear line between "safe" and "unsafe" levels of radiation. It's widely (although not universally) believed that there is even a small risk from natural background radiation.

Background radiation: Low levels of ionizing radiation are always present, partly form cosmic rays, and partly from traces of radioactive material naturally mixed into everything (rocks, soil, people, etc.).

Discussion:

1. What does it mean to say uranium has been "enriched"?

2. If a piece of pure ^{235}U has less than the critical mass.
   a. Is the uranium as enriched as it would be with a larger mass?
   b. are as many neutrons produced by each fission event as when the mass is more?
   c. Is the percent of neutrons that go on to split another atom as great as when the mass is more?

3. What is the difference between reactor fuel and weapons-grade uranium?

4. Give one advantage and one disadvantage of nuclear electric generation compared with fossil fuel generation.

5. Is radiation sickness an early stage of cancer?

6. Can an out-of-control reactor become an atomic bomb?