

## Reviewing for the final

Some of these ideas are definitions or assumptions of the model – those are the foothold ideas we use as the basis for reasoning. Other ideas are reasoned results – when it’s a reasoned result, you should be able to explain where it came from, how it arises from the definitions and assumptions of the model, and you should be able to respond to conflicting lines of reasoning. I’m not going to list all the results, just a few core examples. Memorize foothold ideas; use them to figure out these and other results.

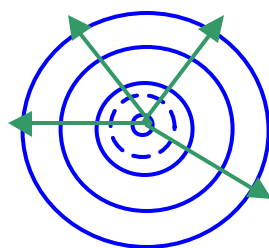
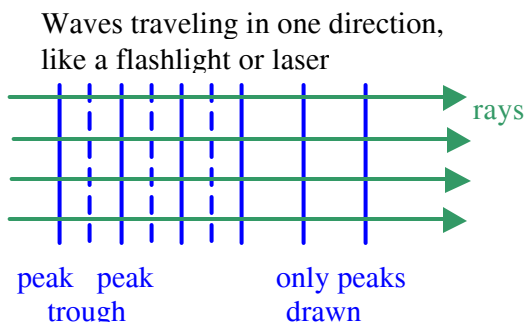
These ideas below are the new ideas since the last midterm. For the final you are also responsible for the stuff on both previous review sheets.

### Light: lenses and mirrors continued.

- Reasoned result/technique: to find images with lenses and curved mirrors – 3 rays: (1) Light that hits the lens parallel to the centerline bends through the focal point (or as if it were going through the focal point.) (2) Light coming from the focal point or toward the focal point comes out parallel to the centerline. (3) Light that hits the very center of the lens goes straight through. Light that hits the center of the mirror bounces back at equal angles as if it hit a vertical mirror.
- Definition: To focus an image with a lens or mirror means getting it so that the screen is at the image location (so that all rays from a *single point on the object* come to a *single point on the screen*.) [Make sure you are distinguishing between focusing and focal points.]
- Definition: The focal length ( $f$ ) is the distance from the focal point to the screen.
- Result: For a thin lens or a thin mirror the image distance and object distance are related by the thin lens/thin mirror formula:  $1/d_i + 1/d_o = 1/f$ . (For convex mirrors and diverging lenses,  $f$  is a negative number. Also, you need to remember where these formulas came from so you can figure out what positive or negative distances mean!!!!)
- Result: More curved mirrors/lenses have smaller focal lengths than less curved ones.

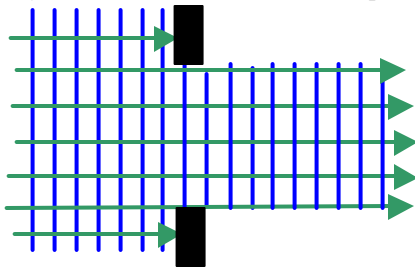
### Light: wave vs. particle models.

- Foothold: Speed of light in air =  $c = 3 \times 10^8$  m/s.
- Foothold: Speed of light in a different medium,  $v_{wave} = c/n$  ( $n$  = index of refraction.) (*Light as waves gives this, not light as particles.*)
- Results: If  $n$  increases,  $\lambda$  decreases, and  $f$  stays the same (or things would pile up!) – This gives Snell’s Law:  $n_1 \sin \theta_1 = n_2 \sin \theta_2$ . If Snell’s law is unsolvable there is no refraction, only reflections. This is called “Total internal reflection.”
- Definition: Light rays from the particle model are the lines perpendicular to the wavefronts. The wavefronts are the lines along which the peaks of the wave are at any moment (the lines you saw in the ripple tank. (See the lines in drawings below. The blue lines are the wavefronts and the green lines are the light rays your were working with in the particle model.

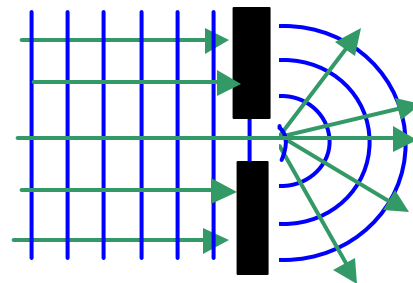


Waves traveling out in all directions from a single point, like a point source or light scattering when it hits a non-mirror.

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- **Foothold:** At an aperture, waves will get blocked just like the rays. The waves that go through either go through continuing in straight lines, if the aperture is big compared to the wavelength, or spread out like a point source if the aperture is small (close to wavelength size). (*The particle model predicts the first of these, but the wave model predicts both.*)



Larger opening than wavelength-  
straight lines continue

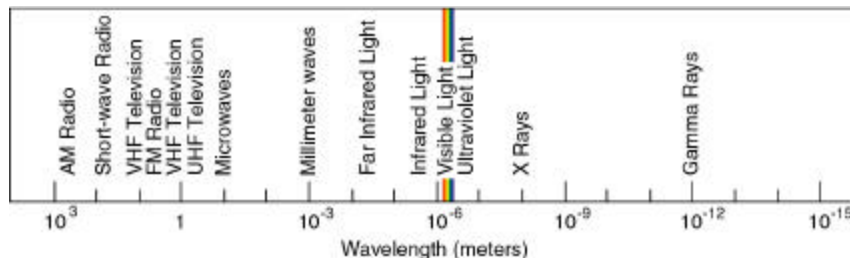


Small opening compared to wavelength –  
like a point source on other side

- **Result:** When you see more bright spots than apertures, like the pattern of bright spots we saw in lab, this can be explained by interference, *thinking of light as waves*.
- **Definitions:** Constructive interference – when waves at a given point are adding in amplitude (positive or negative). Examples are peaks and peaks overlapping, or troughs and troughs. Destructive interference is when waves at a given point are canceling (peaks and troughs, for example.)
- **Result:** Constructive interference points are louder, brighter, etc and the displacement at those points oscillates between big peaks and big troughs. Destructive interference points are softer, dimmer, etc. and not much disturbance at all is happening there.
- **Foothold:** Light exerts a (very small) force on an object when it hits it. (*Particle works, wave doesn't for this!*)
- **Result:** Light is like both waves and particles. Usually both models work, but sometimes only one does. A more sophisticated model of electric field waves (made by wiggling charges) predicts everything, but it's too weird to have good intuitions about, so we (students and real physicists both) end up using both the regular waves and particle models and keeping track of what works where. (The only difference is that a physicist or advanced student can explain *WHY*, using the field waves model, the other two models work sometimes and not others.)
- **Definition:** Light comes in little bundles or packets of waves. We call these light particles “photons.” They have no mass because they are just little packets of field waves. (But they do have

**Light: Color, the electromagnetic spectrum, and electromagnetic radiation.**

- **Foothold:** The frequency of light determines the color. (**Result:** The wavelength also determines the color in a given medium since the wavelength and frequency are related by the speed of light in that medium. We always see through the same medium, so we can talk about visible frequencies or visible wavelengths.) Only a small range of frequencies are visible.



- **Result:** The energy of each photon is determined by the frequency. (Def:  $E_{\text{photon}} = hf$ .  $h$  is a constant (joules/Hz) that is very very small because each photon has only a tiny bit of energy. ) The brightness of the light (amplitude of the wave) is equivalent to the number of photons.
- **Result:** The higher the energy, the more dangerous the photon. X-rays and g-rays have a tiny wavelength and can penetrate deeply into tissue, meaning they're less likely to be absorbed and pass through the skin. But, when they do get absorbed they are very damaging since they can knock electrons off atoms and break molecular bonds.

### Mass energy and Radioactive decay

(Basically, you're responsible for knowing this stuff only superficially.)

- **Foothold:** Every particle has energy (like a potential energy) stored in its mass. The amount of energy is given by the famous equation attributed to Einstein:  $E_{\text{mass}} = mc^2$ , where  $c$  is the speed of light as given above. (Check for yourself to make sure the units work, but you are not responsible for any mass energy calculations.) Mass doesn't have to be conserved, but total energy has to be conserved as always, so if some mass disappears, that amount of energy must show up in some other form. (Usually mass is conserved, except in rare cases which lead to radioactivity.)
- **Result:** Since a neutron is heavier than a proton, a neutron can decay to a proton (it can't decay just anything lighter, for reasons too complicated to discuss here.) But since charge is conserved still, there must be some other negative particle produced. Also, you need a second particle to conserve energy and momentum since the extra energy has to go somewhere and you can't have net zero momentum but net positive kinetic energy with only one particle. An obvious choice, which turned out to be true, was the electron. PLUS, it was found experimentally that not all the mass energy was going into the kinetic energies of the proton and electron, so there had to be another particle.  
Definition: This type of decay is called beta-decay.  $n \rightarrow p + e + \nu$ .
- **Result:** Heavy nuclei can also break apart into lighter nuclei, such as  $^{238}\text{U} \rightarrow ^{234}\text{Th} + ^4\text{He}$ . Usually, when a helium nucleus is created, it speeds away without its electrons. Definition: A helium nucleus is called an alpha particle ( $\alpha$ ) and this type of decay is called alpha-decay. Alpha emitters are very dangerous if swallowed.
- **Foothold:** Radioactive decay is probabilistic, with a fixed percentage of undecayed atoms likely to decay in a given time interval.
- **Result:** The number of atoms left undecayed ( $N$ ) after a time  $t$ , is related to the initial number of undecayed atoms ( $N_0$ ) by  $N = N_0 e^{-t/\tau}$ .  $\tau$  is a time constant related to the half-life  $\tau_{1/2}$  by  $\tau = \tau_{1/2} / 0.69$   
Definition: The half-life  $\tau_{1/2}$  is the time in which it is likely that 1/2 of the undecayed atoms will decay. The rate of decay is given by  $\Delta N / \Delta t = -(N_0 / \tau) e^{-t/\tau}$ .