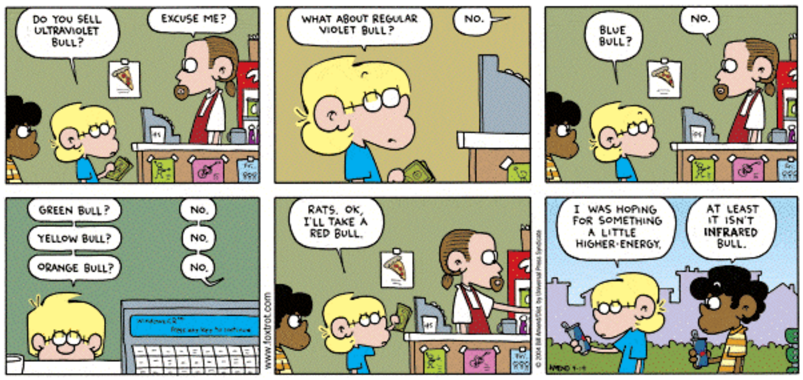
April 14, 2017 Physics 132 Prof. E. F. Redish

- **Theme Music: The Rolling Stones**
  Paint it Black
- **Cartoon: Bill Amend**
  FoxTrot



Outline

- Spectral analysis
- Models of light
  - The photon model
  - Absorption and emission of photons
  - Line spectra

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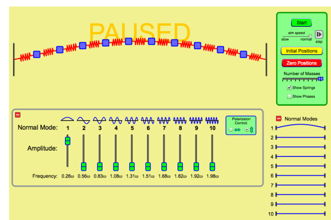
Spectral analysis: Normal modes

- Any arbitrary wave signal on a stretched string can be broken up into different standing waves.

$$f(x,t)=\sum_{1}^{\infty}A_n\sin(k_n x)\cos(\omega_n t)$$

$$k_n=\frac{n\pi x}{L} \qquad \omega_n=k_n v_0$$



http://phet.colorado.edu/en/simulation/normal-modes

Spectral analysis: traveling waves

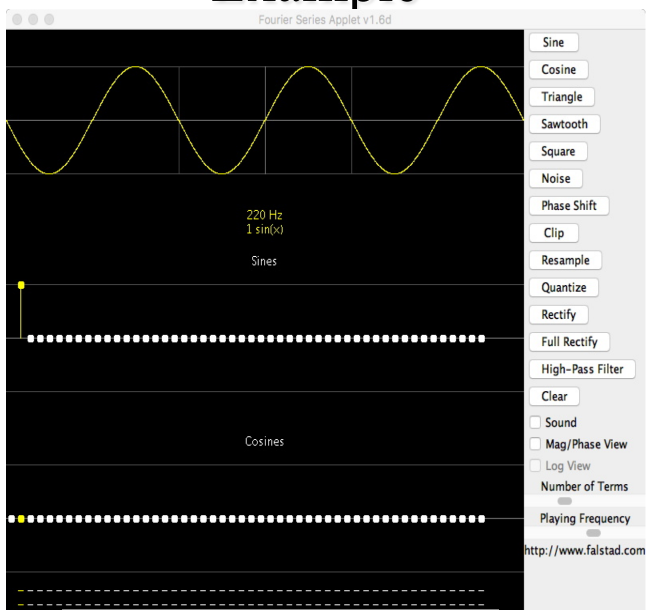
- Any arbitrary traveling wave signal can be broken up into different frequencies (colors, tones).

$$f(x,t)=\sum_{1}^{\infty}A_n\sin(k_n x)\cos(\omega_n t) \qquad \text{standing waves}$$

$$f(x,t)=\int_{0}^{\infty}\tilde{f}(k)\sin(k(x-v_0 t))\,dk \qquad \text{travelling waves}$$

- A plot or a histogram of the amount of each wave contained in a signal (A_n or $\tilde{f}(k)$) it is called a *spectrum*. (Typically this is plotted as a function of *f*, λ, or 1/λ.)

Example



4/14/17 *http://www.falstad.com/fourier/* **5**

Light: Three models

- Newton's particle model (rays)
  - Models light as bits of energy traveling very fast in straight lines like tiny particles. Each has a color. Intensity is the number of particles you get per second.
- Huygens's/Maxwell wave model
  - Models light at waves (transverse EM waves). Color is determined by frequency, intensity by square of a total oscillating amplitude. (Allows for cancellation – interference.)
- Einstein's photon model
  - Models light as "wavicles" or "quantons", quantum particles whose energy is determined by frequency and that can interferer with themselves.

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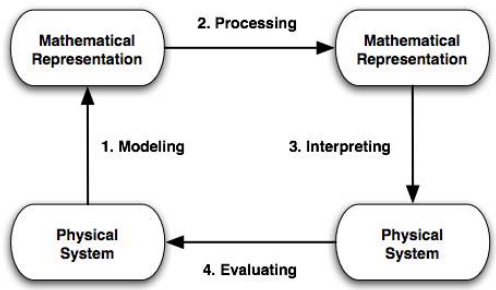
Reading question

- Light is waves, light is rays, light is photons! Nothing is consistent! Why don't we just give up and say we have no idea what light is?



Foothold Ideas: The Photon Model

- When it interacts with matter, light behaves as if it consisted of packets (photons) that carry both energy and momentum according to:

$$E = \hbar\omega \qquad p = \hbar k \qquad \hbar = \frac{h}{2\pi}$$

$$E = hf \qquad p = \frac{E}{c} = \frac{h}{\lambda}$$

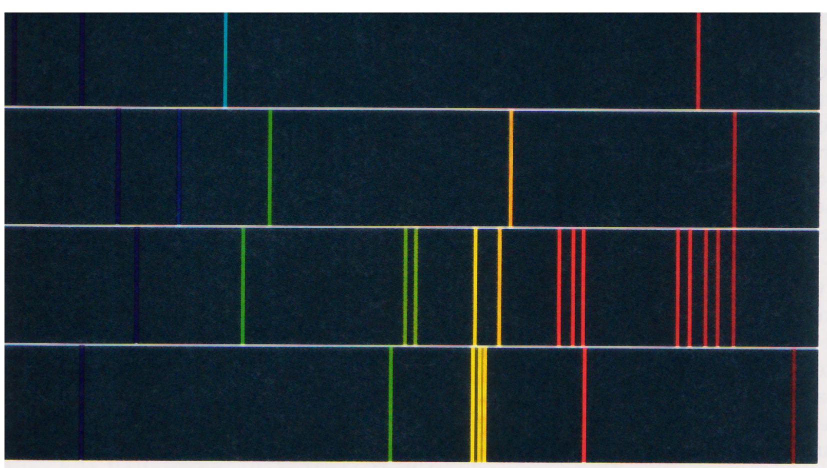
with $hc \sim 1234$ eV-nm.

  - These equations are somewhat peculiar. The left side of the equations look like particle properties and the right side like wave properties.

Line Spectra

- When energy is added to gases of pure atoms or molecules by a spark, they give off light, but not a continuous spectrum.
- They emit light of a number of specific colors — *line spectra.*
- The positions of the lines are characteristic of the particular atoms or molecules.

Line Spectra



Foothold Ideas: The Nature of Matter

- Atoms and molecules naturally exist in states having specified energies. EM radiation can be absorbed or emitted by these atoms and molecules.
- When light interacts with matter, both energy and momentum are conserved.
- The energy of radiation either emitted or absorbed therefore corresponds to the difference of the energies of states.

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Implications

- This property of matter lets us do some rather remarkable things:
  - chemical flame tests
  - identify the composition of the sun and distant stars
  - identify the composition of a plume of smoke emitted from a smokestack
  - determine the relative composition of atoms in a rock and therefore determine its source

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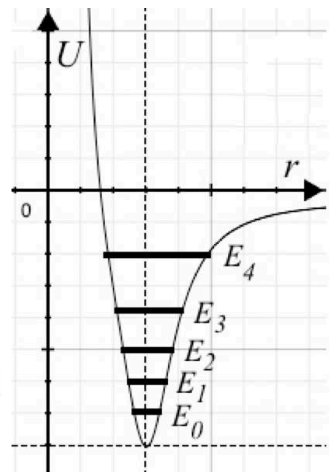
Discrete molecular states

- We've already used the idea that quantum systems (e.g., a 2-atom molecule interacting by a potential U), can only be in discrete energy states.
- This is because electrons are wavelike and create standing waves.
- Allowed frequencies are related to allowed energies by $E_n = hf_n$ (analogous to photons)



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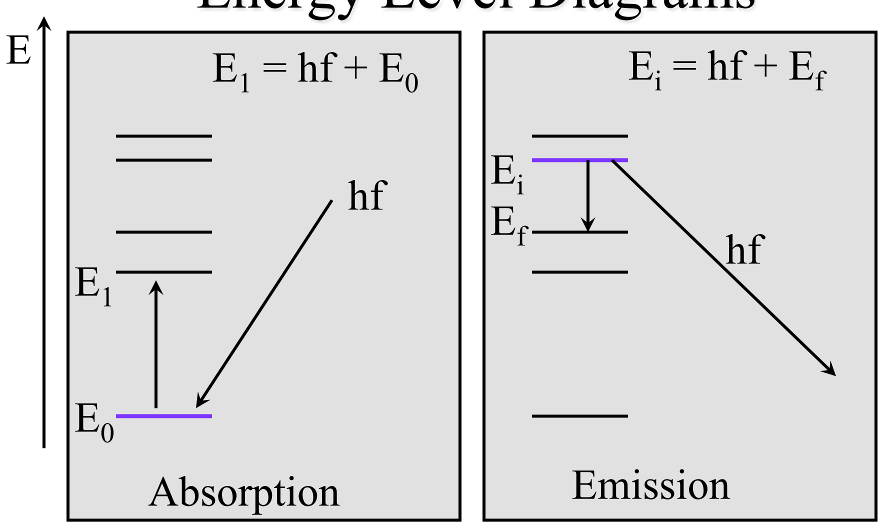
Energy Level Diagrams



Photons can be absorbed or emitted by a system, adding or removing energy from it. (The PE is typically not shown.)

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