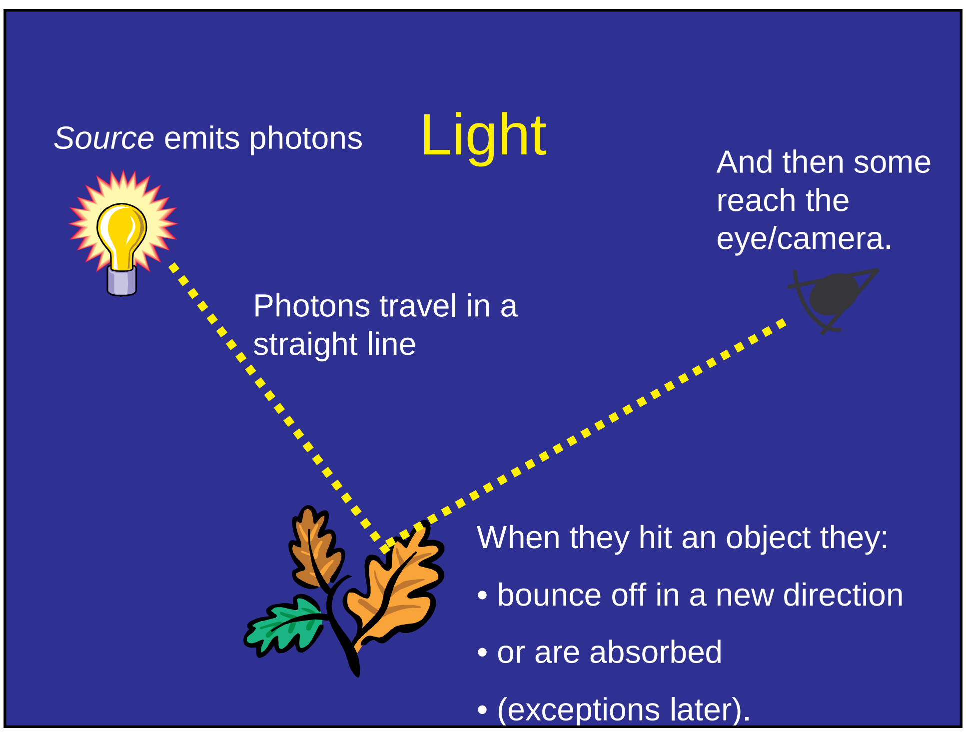
Lighting affects appearance

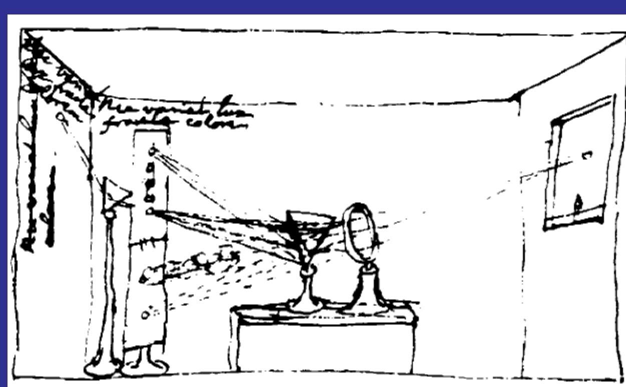


Source emits photons
Light
And then some reach the eye/camera.
Photons travel in a straight line
When they hit an object they:
• bounce off in a new direction
• or are absorbed
• (exceptions later).

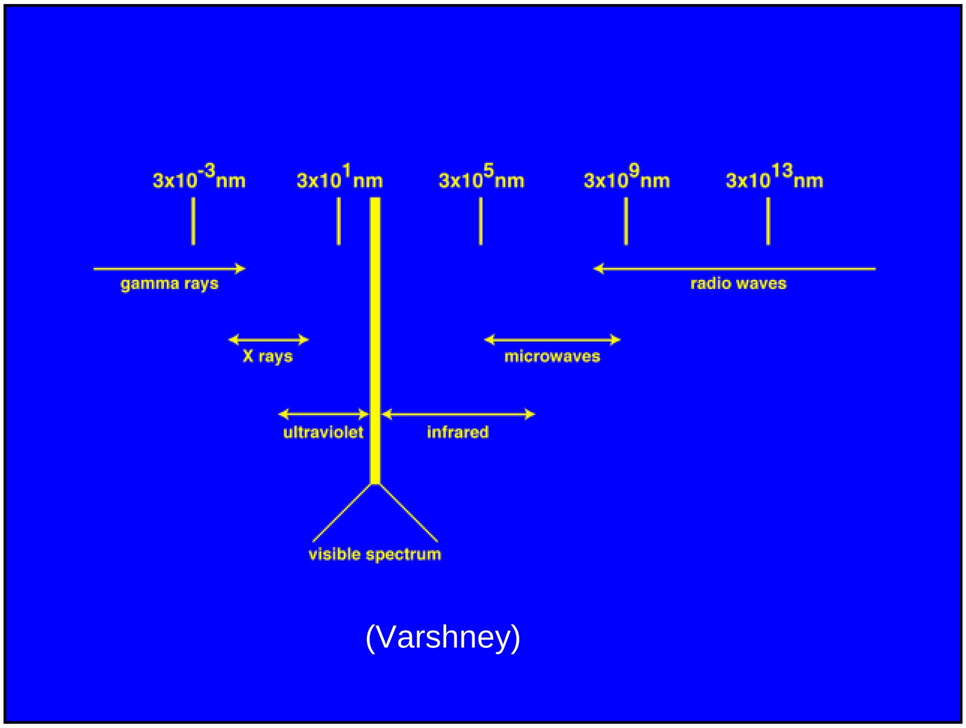
Basic fact: Light is linear

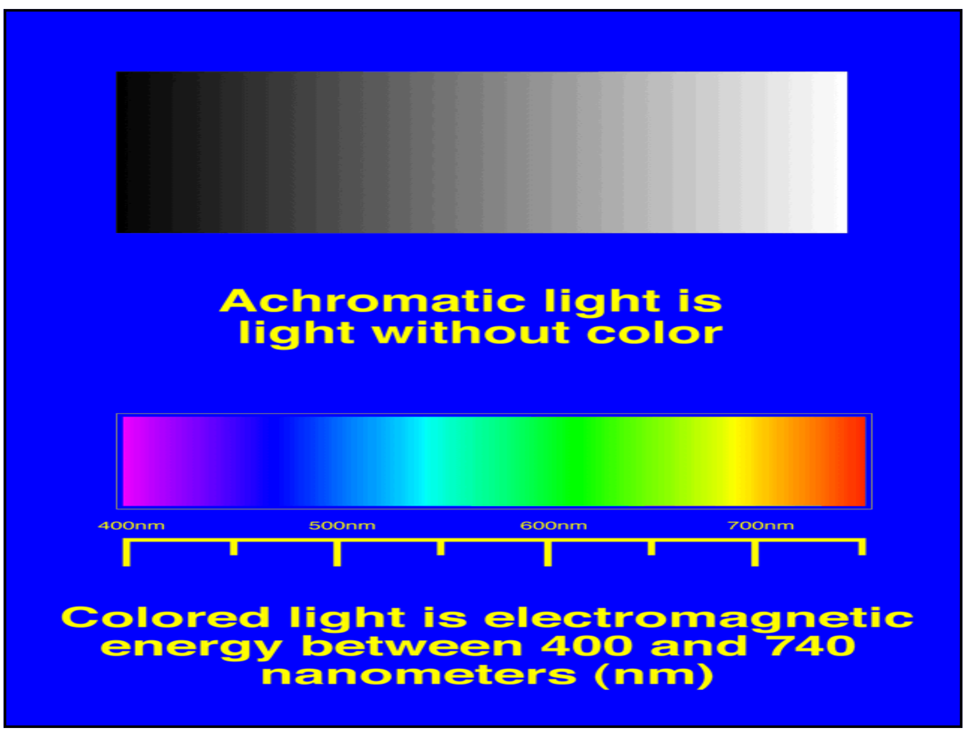
- Double intensity of sources, double photons reaching eye.
- Turn on two lights, and photons reaching eye are same as sum of number when each light is on separately.
- This means we can render lights separately

Newton’s drawing:

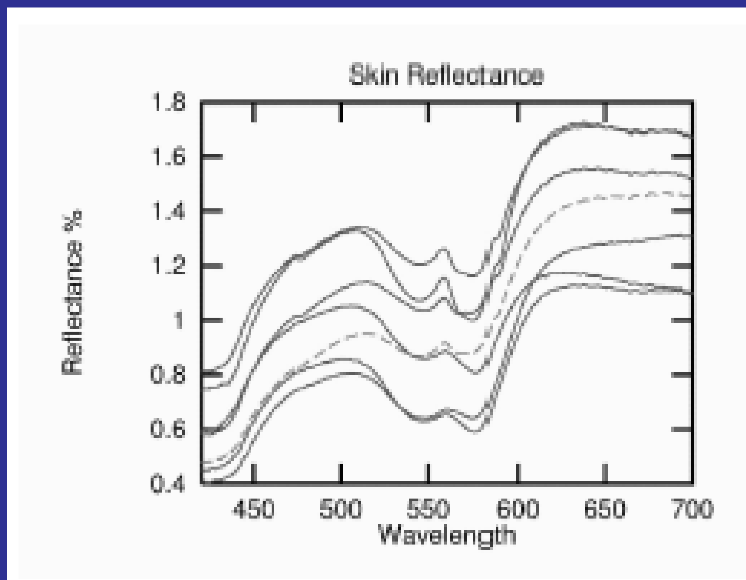


(Wandell)


3x10-3nm
3x101nm
3x105nm
3x109nm
3x1013nm
gamma rays
radio waves
X rays
microwaves
ultraviolet
infrared
visible spectrum
(Varshney)

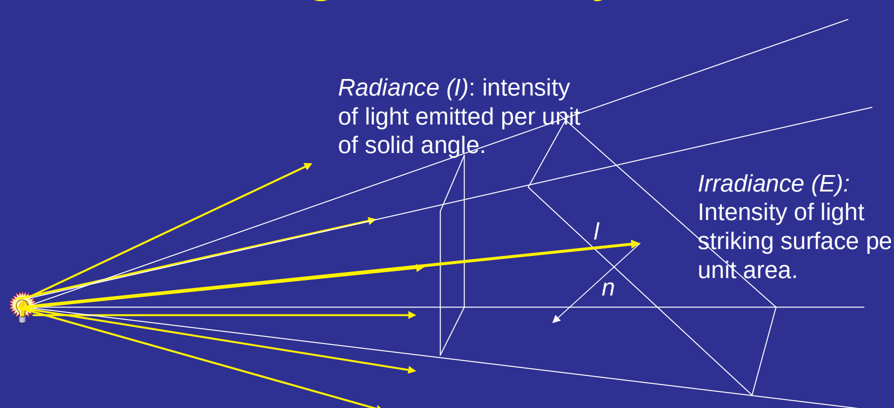

Achromatic light is light without color
400nm
500nm
600nm
700nm
Colored light is electromagnetic energy between 400 and 740 nanometers (nm)

Color is a function



(Angelopoulou)

Light Intensity



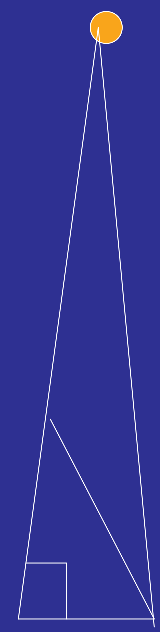
Because of foreshortening, as *<l,n>* decreases, the same light is spread over more and more area. In this picture,

E = I<n,l>*

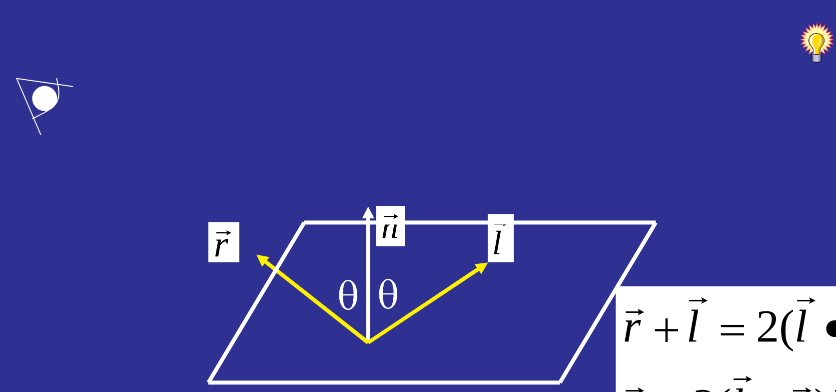
Intensity of light also decreases with square of distance.

Why is intensity linearly related to cosine theta?

Let’s just take a 1D example. Imagine a distant point source. All light it emits passes through a circle a distance r from the point, with a length 2pi*r. Now, imagine a small patch of material of length 1. The light striking this patch also strikes a part of the circle. If the patch is very small, the angle between the light ray and the circle is a right angle. So if the patch is length 1, the part of the circle that the patch shadows is cos theta. The total light striking the patch is cos(theta)/2pi*r, which grows linearly with cos(theta).



Light Reflection: Mirror



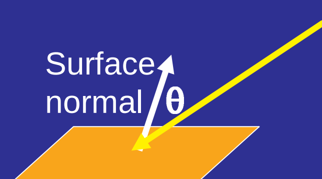
$$\vec{r} + \vec{l} = 2(\vec{l} \bullet \vec{n})\vec{n}$$

$$\vec{r} = 2(\vec{l} \bullet \vec{n})\vec{n} - \vec{l}$$

Light Reflection: Lambertian

- Amount of light striking surface proportional to cos θ
    - Angle between light direction and surface.
- Equal brightness in all directions
- Albedo is fraction of light reflected.
- Diffuse objects (chalk, cloth, matte paint).
- Brightness doesn't depend on viewpoint.

This surface appears to be foreshortened according to *cos*θ. So, if light striking a pixel at any angle is the same, the amount of light must increase with *cos*θ. That is, more light in direction of surface normal.



Lambertian + Point Source

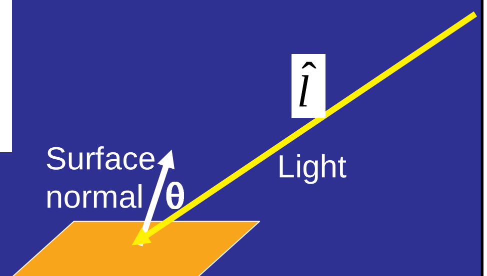
$$\vec{l} = l \bullet \hat{l} \quad \begin{cases} \hat{l} \text{ is direction of light} \\ l \text{ is intensity of light} \end{cases}$$

$$i = \max(0, \lambda(\vec{l} \bullet \hat{n}))$$

i is radiance

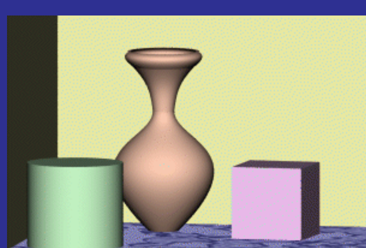
λ is *albedo*

$\hat{n}$ is surface normal



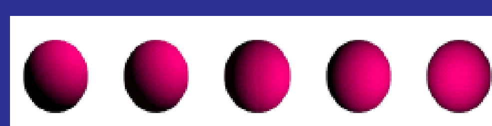
Note: color depends on surface. With mirror, color only depends on light.

Lambertian Examples



Scene

(Oren and Nayar)



Lambertian sphere as the light moves.

(Steve Seitz)

Ambient

- Assume Lambertian surface normal receives equal light from all directions.

$$i = a\lambda$$

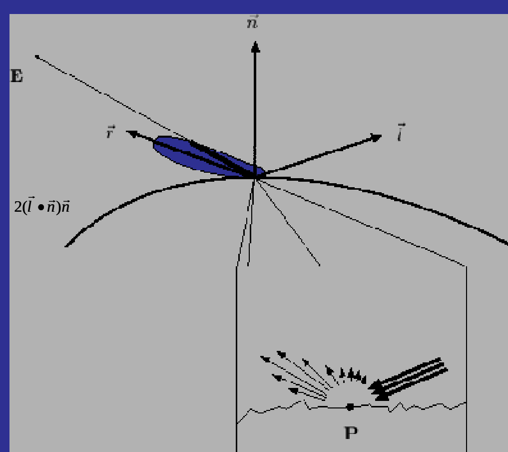
- Diffuse lighting, no cast shadows.
- Ambient (and point) light can be colored

Specular surfaces

•Brightness depends on viewing direction.

•Specularity is spread out.

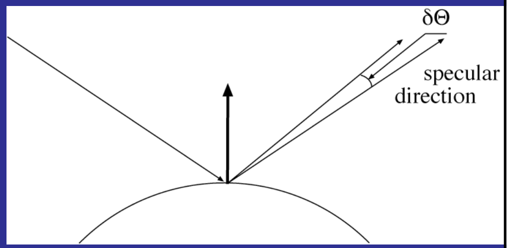
- •Mirror, smooth light all bounces same way.
- •Slightly rougher, direction of bounce varies.
- •Diffuse, many bounces



(http://graphics.cs.ucdavis.edu/GraphicsNotes/Shading/Shading.html)

Phong's model

- Empirical model (*eg.,* hack)
- Phong's model
  – reflected energy falls off as: $\cos^n(\delta\vartheta)$
    - n very big, this is like mirror.
    - As n gets smaller, specularity more spread out.
    - Good model for plastic
    - Specularity color of source.

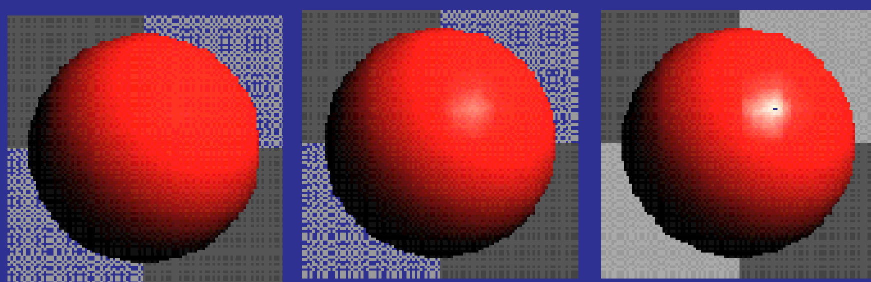


(Forsyth & Ponce)

Lambertian + specular

- Two parameters: how shiny, what kind of shiny.
  - Many objects combine shiny and diffuse material
    - Wood with veneer; glossy paint, plastic, greasy skin.
  - Some fraction of light reflected as diffuse, some as specular.

Lambertian+Specular+Ambient

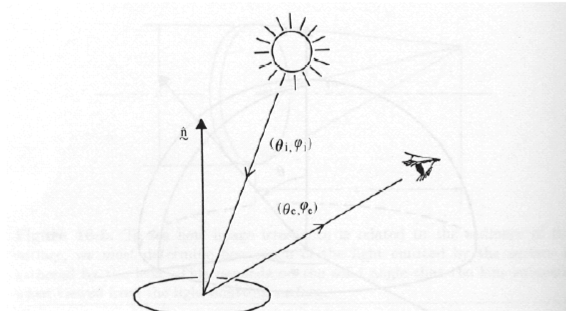


(http://graphics.cs.ucdavis.edu/GraphicsNotes/Shading/Shading.html)

More complex reflectances

- Physically realistic models
  - Torrance Sparrow models roughness of surfaces and shadowing of microfacets.
    - Specular peak can deviate from mirror direction.
    - Can produce much greater specularity at low incident angles.
  - Fresnel term. Specularity varies with incident angle.
    - Glass only specular as angle approaches 90 degrees.
- Models built from observation.
  - Measurement for every lighting direction and viewing direction.
  - A function describing this is called a *BRDF*
  - 4D function (can be reduced to 3D if there is rotational symmetry).

BRDF



Horn, 1986

Figure 10-7. The bidirectional reflectance distribution function is the ratio of the radiance of the surface patch as viewed from the direction (θ_e, ϕ_e) to the irradiance resulting from illumination from the direction (θ_i, ϕ_i).

$$BRDF = f(\theta_i, \phi_i, \theta_e, \phi_e) = \frac{L(\theta_e, \phi_e)}{E(\theta_i, \phi_i)}$$

BRDF Not Always Appropriate

BRDF

BSSRDF

http://graphics.stanford.edu/papers/bssrdf/

(Jensen, Marschner, Levoy, Hanrahan)

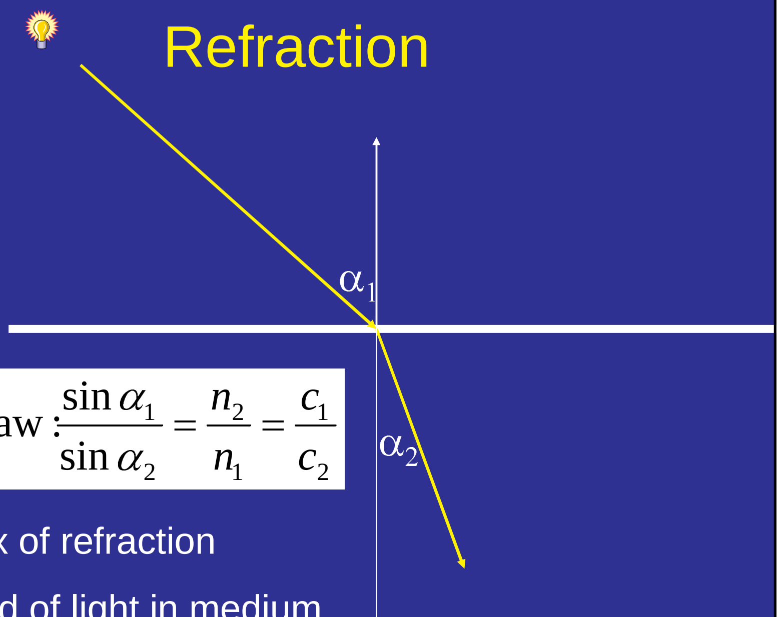
Luminescence

- Surface shifts color of light.
- Can reflect more light of a color than is present in source.
- This is why objects can glow in “black” light.

Transparency

- Some fraction of light passes through material.
- Varying this fraction for different colors produces colored, transparent objects.

Refraction



Snell's Law: $$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2}$$

n is index of refraction

c is speed of light in medium.

Illumination Attenuation

Light scatters from particles in the air. Fog or hazy air has more particles, more scattering.