Lecture 12: Illumination
CS 410

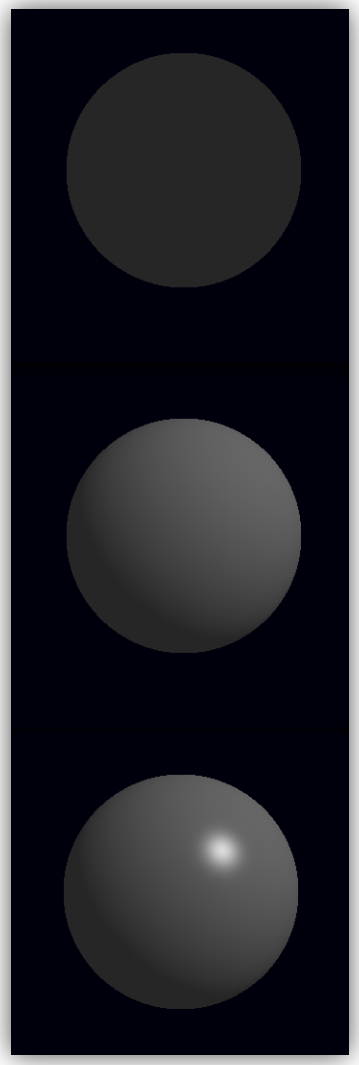
September 27, 2018

Goals of Reflectance

- Model simple light sources
  - Point light sources
  - Extended light sources
  - Ambient lighting
- Model lighting geometry
  - Angle between light ray and surface normal
  - Angle between surface normal and viewing ray
- Model surface reflections
  - Diffuse (Lambertian) reflections
  - Specular reflections
  - Phong reflectance

Reflectance - 3 Kinds

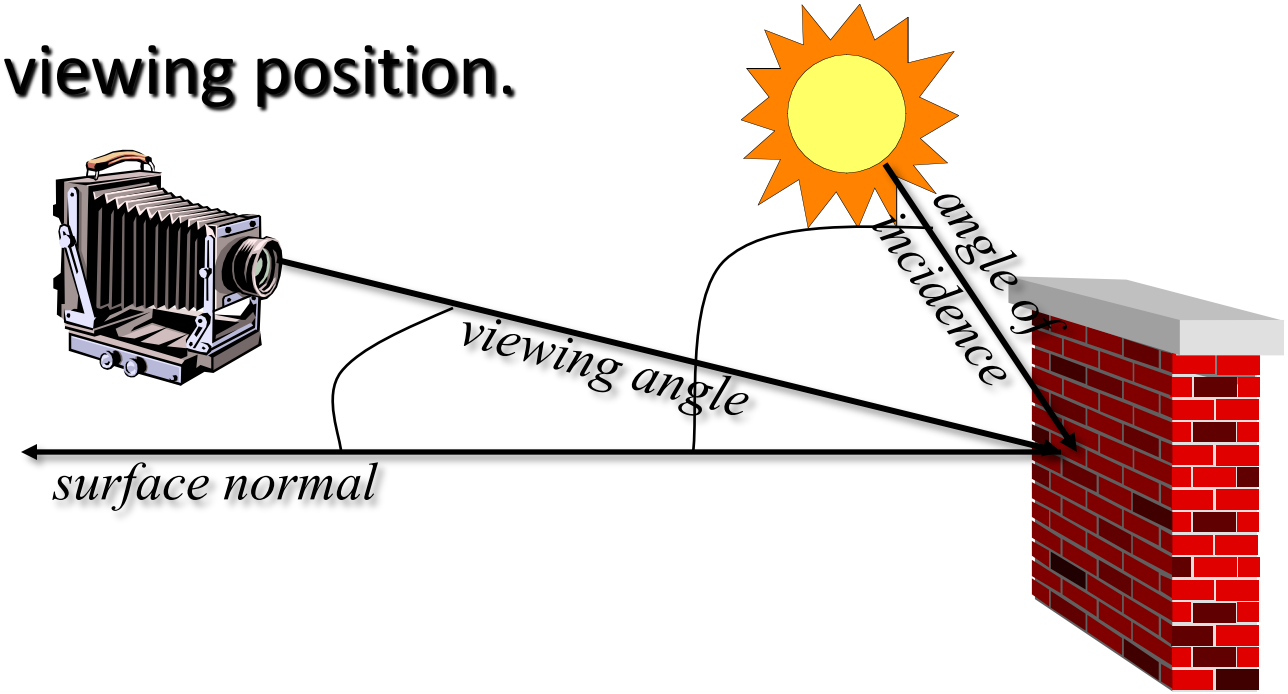
- Ambient reflection.
  - Models perfectly even illumination.
- Lambertian reflection.
  - Matte surfaces, dull rather than shiny.
- Specular reflection.
  - Bright highlights seen on polished surfaces.



Reflectance - Geometry

Reflectance functions are defined in terms of:

- **The position of a (point) light source**
- **The orientation of the reflecting surface**
- **The viewing position.**



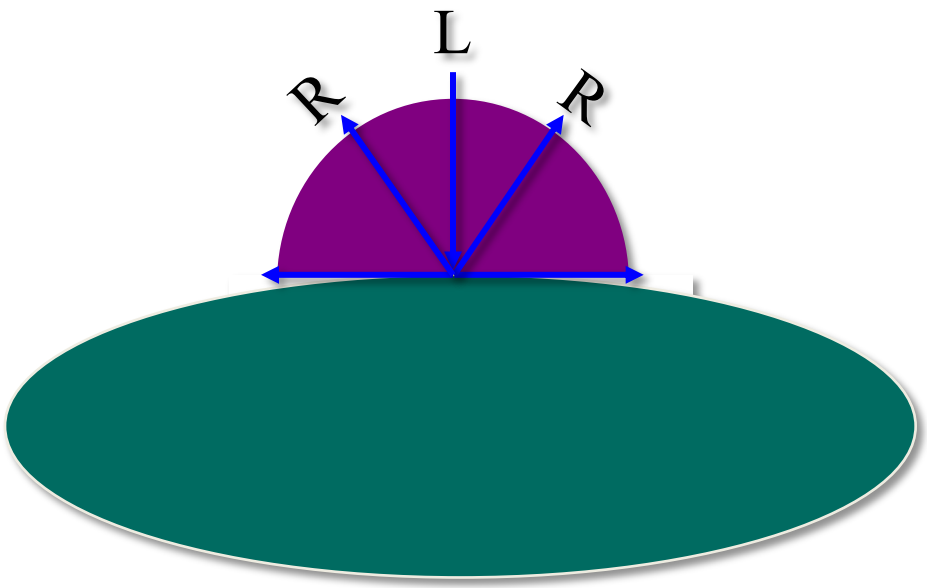
Reflectance Functions (III)

- Light rays, surface normals, and colors are expressed using vectors
  - Light often described as illumination I
  - Three components to illumination:

$$I = \begin{bmatrix} i_r \\ i_g \\ i_b \end{bmatrix}$$

Lambertion Reflection

- Consider a point light source and a Diffuse (Lambertian) Surface.
- Diffuse surfaces reflect light with equal intensity in all directions.



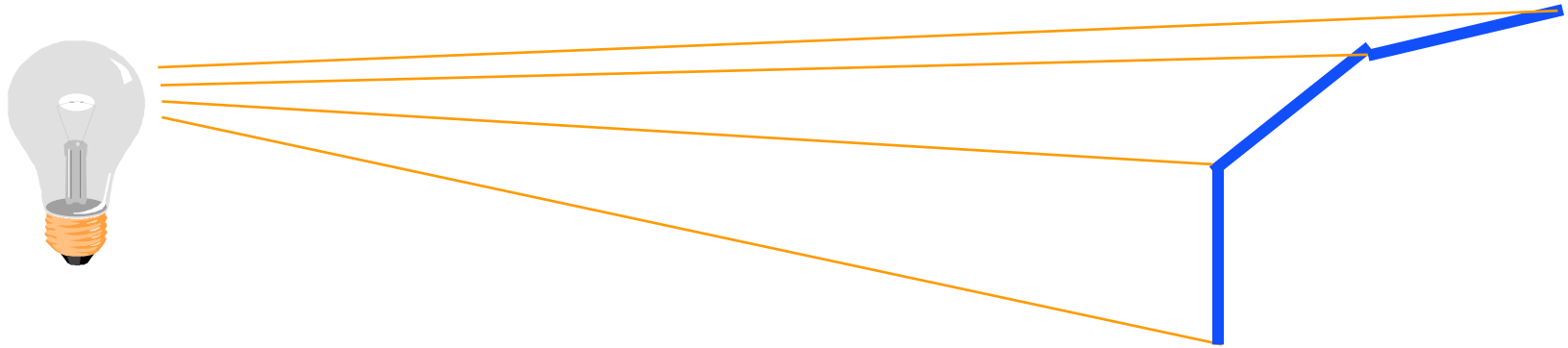
Lambertian Reflection.

The moon is cited as a good example of Lambertion reflection

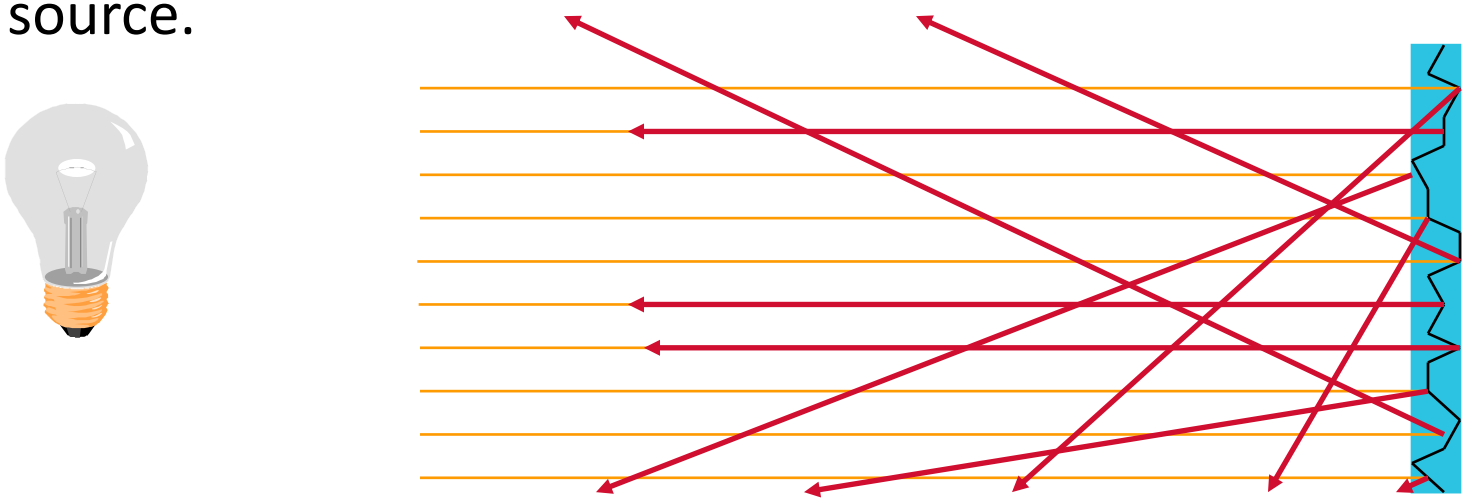
Image by Dmitry, dzz at Morgefile.

Maybe not such a great example … large dark patches …. But you can tell where the sun is …

A Touch of Physics



Light per unit area arriving depends upon angle to light source.



Light leaves in all directions, reflected off micro surfaces.

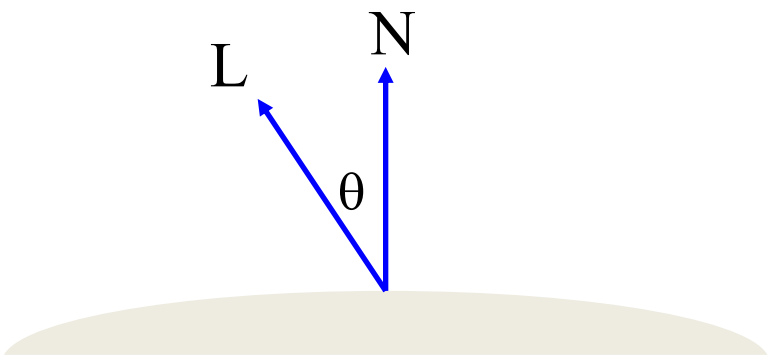
Diffuse Reflection

- Illumination/area drops by θ

$$i_r = b_r \cos\theta \quad i_g = b_g \cos\theta \quad i_b = b_b \cos\theta$$

- Where light L emits light with brightness B:

$$B = \begin{vmatrix} b_r \\ b_g \\ b_b \end{vmatrix}$$



Diffuse Reflection – Parameters

- Diffuse parameters modulate brightness

$$I = \begin{vmatrix} i_r \\ i_g \\ i_b \end{vmatrix} = \begin{vmatrix} k_r & 0 & 0 \\ 0 & k_g & 0 \\ 0 & 0 & k_b \end{vmatrix} \begin{vmatrix} b_r \\ b_g \\ b_b \end{vmatrix} \cos(\theta)$$

- The same statement, but more concise:

$$I_d = K_d B \cos(\theta)$$

The subscript *d* added to indicate diffuse illumination

Rare Case Still Worth Mention

- Use the full power of the 3x3 matrix
  - Comes in red, goes out green

$$I = \begin{vmatrix} i_r \\ i_g \\ i_b \end{vmatrix} = \begin{vmatrix} k_{rr} & k_{rg} & k_{rb} \\ k_{gr} & k_{gg} & k_{gb} \\ k_{br} & k_{bg} & k_{bb} \end{vmatrix} \begin{vmatrix} b_r \\ b_g \\ b_b \end{vmatrix} \cos(\theta)$$

Example of Non-Diagonal Reflectance Matrix

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/oilfilm.html

- Oil slicks reflect light of one color as another color
- Thin-film interference effect
- Given angles, can be modeled as a non-diagonal Kd matrix

Material Properties (II)

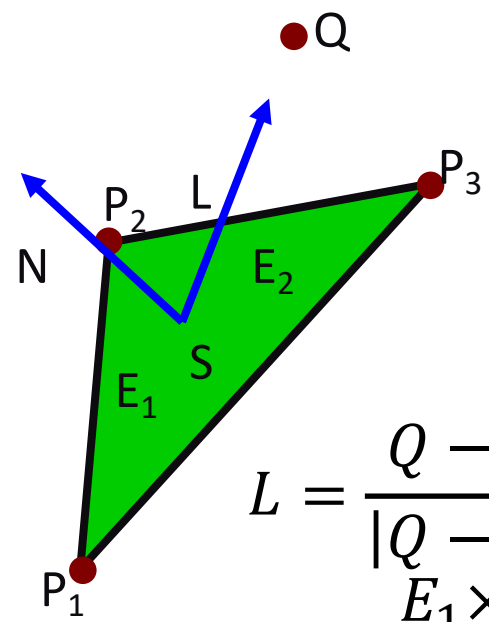
- There are some pragmatic constraints:
  - No term in K may exceed 1.0
  - No term in K may be negative
  - No column may have a sum exceeding 1
- But, …
- These constraints are not always enforced

There is an art to lighting a scene!

Diffuse Reflection – Computation

- The final term in diffuse reflection is cos(θ).
  - Defined by angle between the incoming light ray L and the surface normal N

Symbol	Description
N	Unit Length Surface Normal
L	Unit Length Vector to Light
Q	3D Position of the Light
S	3D Position on Surface
P1, P2 & P3	3D Vertices of the Triangle
E1 & E2	Two 3D Edges of the Triangle



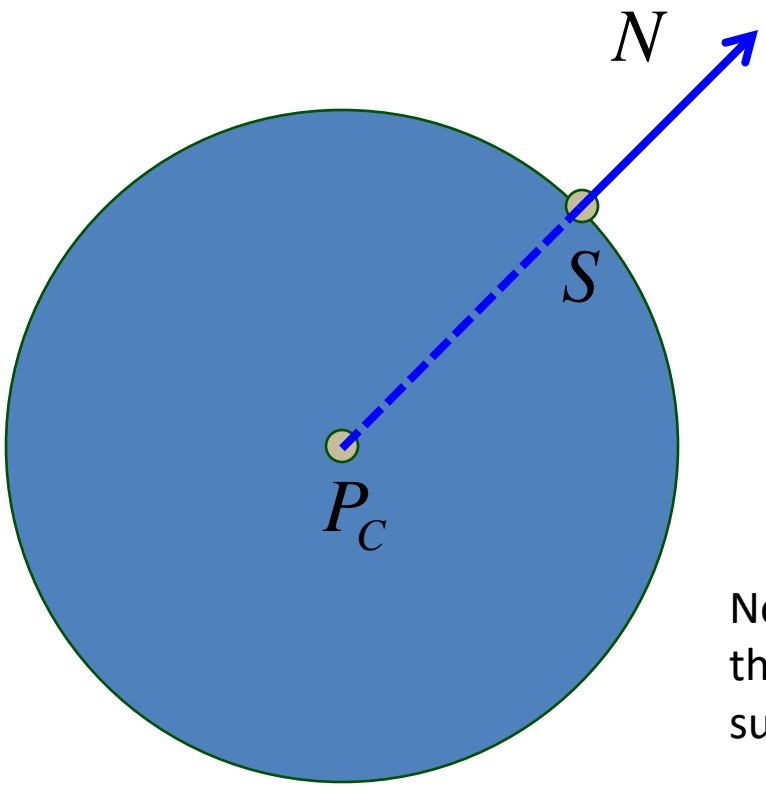
$$L = \frac{Q - S}{|Q - S|}$$

$$N = \frac{E_1 \times E_2}{|E_1 \times E_2|}$$

$$cos(\emptyset) = N \cdot L$$

Surface Normals - Sphere

- What about the surface normal for a sphere?



circle centered at P_C

surface point on sphere S

$$N = \frac{S - P_C}{\|S - P_C\|}$$

Note: the normal to a polygon is constant across the polygon; for a sphere it is a function of the surface point.

Many Light Sources

- For a single point light source:

$$I = K_d B\left(N \cdot L\right)$$

- For m point light sources

$$I = \sum_{i=1,m} K_d B_i \left(N \cdot L_i\right)$$

Ambient Reflection

- Ambient reflection is just diffuse reflection of light from the "ambient" light source
- Ambient light models background light
  - It is the same intensity everywhere
  - It is the same color everywhere
  - It comes from every angle
- So…

$$I_a = K_d B_a$$

Specular Reflection

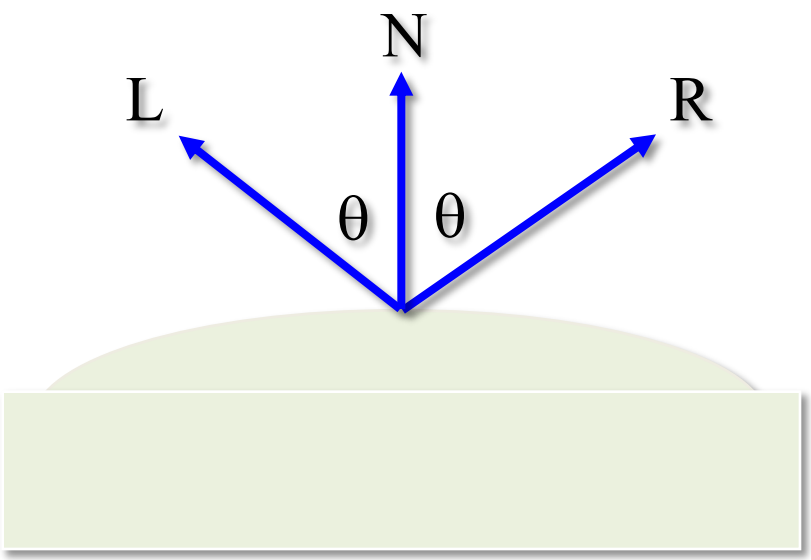
- Most surfaces do more.
- Consider two extremes:
  - 1: a diffuse surface,
  - 2: a mirror.
- Specular reflection component
  - Mirrors are extreme
  - Mirrors reflect about a single angle
- Metals, for example, combine
  - Diffuse and specular components.

Only Skin Deep

- Diffuse models light “deep” reflection
  - Enters through micro-holes in the surface
  - Bounced from facet to facet,
    - Possibly changing color
  - Exits at a random angle
- Specular reflection is “surface” reflection
  - Light hits a single surface facet, skips off.
  - The color of the light is unchanged.
  - The exit angle depends on the entry angle.
    - Catchy Phrase – ***equal and opposite***.

Limiting Case - Mirror

- Angle of incidence = Angle of reflection.
- Idealized form only applies to mirrors.



Reflection – Mirror Like Surface

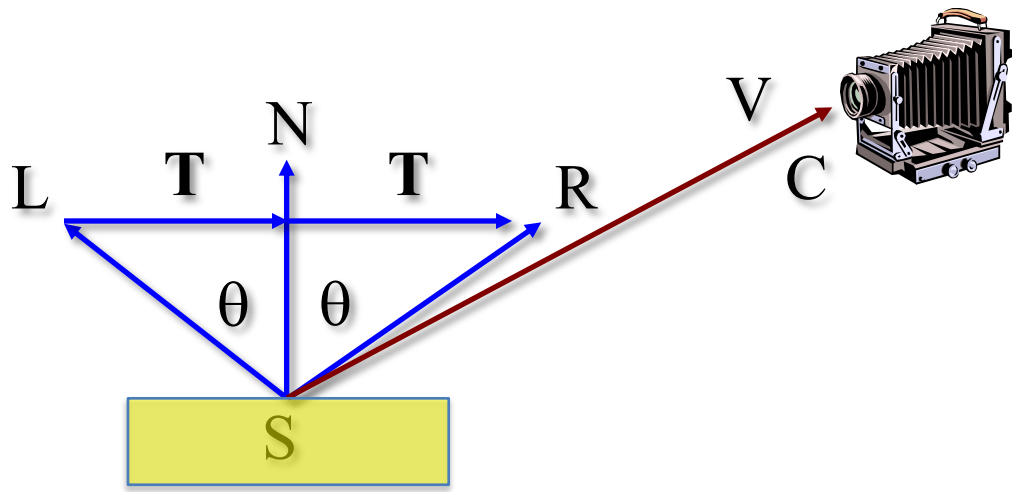
Light Source Reflecting

Reflection and Viewer

- V is the unit vector from the surface point to the camera:

  $V = (C - S)/|C - S|$

- Calculating R is more involved



Reflection Vector

- Let NL be the projection of L onto N
  - Assume N is a unit vector

    NL = (L·N)N
- T is defined as

    T = NL – L = (L·N)N – L
- R is L + 2T

$$R = L + 2\left(\left(L \cdot N\right)N - L\right)$$

$$= 2\left(L \cdot N\right)N - L$$

Back to Perfect (for now)

- If V ≠ R, there is no (pure) specular reflection.
- If V = R, then ….

- Note that k_s is a scalar, measuring the percent of light reflected.
  - Color reflected is that of the light source.

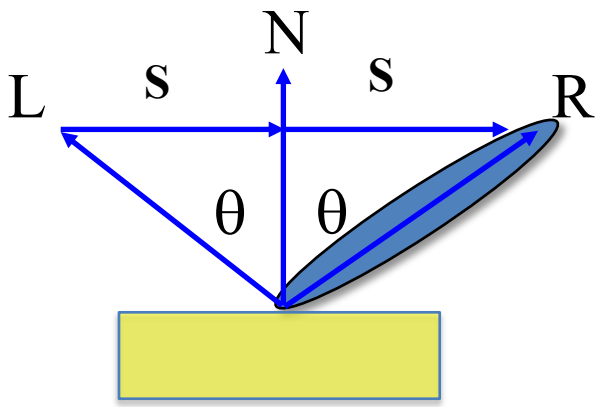
$$I = k_s B$$

$$= k_s \begin{vmatrix} b_r \\ b_g \\ b_b \end{vmatrix}$$

Warning: This is the correct mental model, it is not useful in practice.

Close Counts – Phong Reflection

- In Phong's model, reflection is strongest in the direction of the angle of reflection
- Drops off with the cosine of the deviation from the angle of reflection



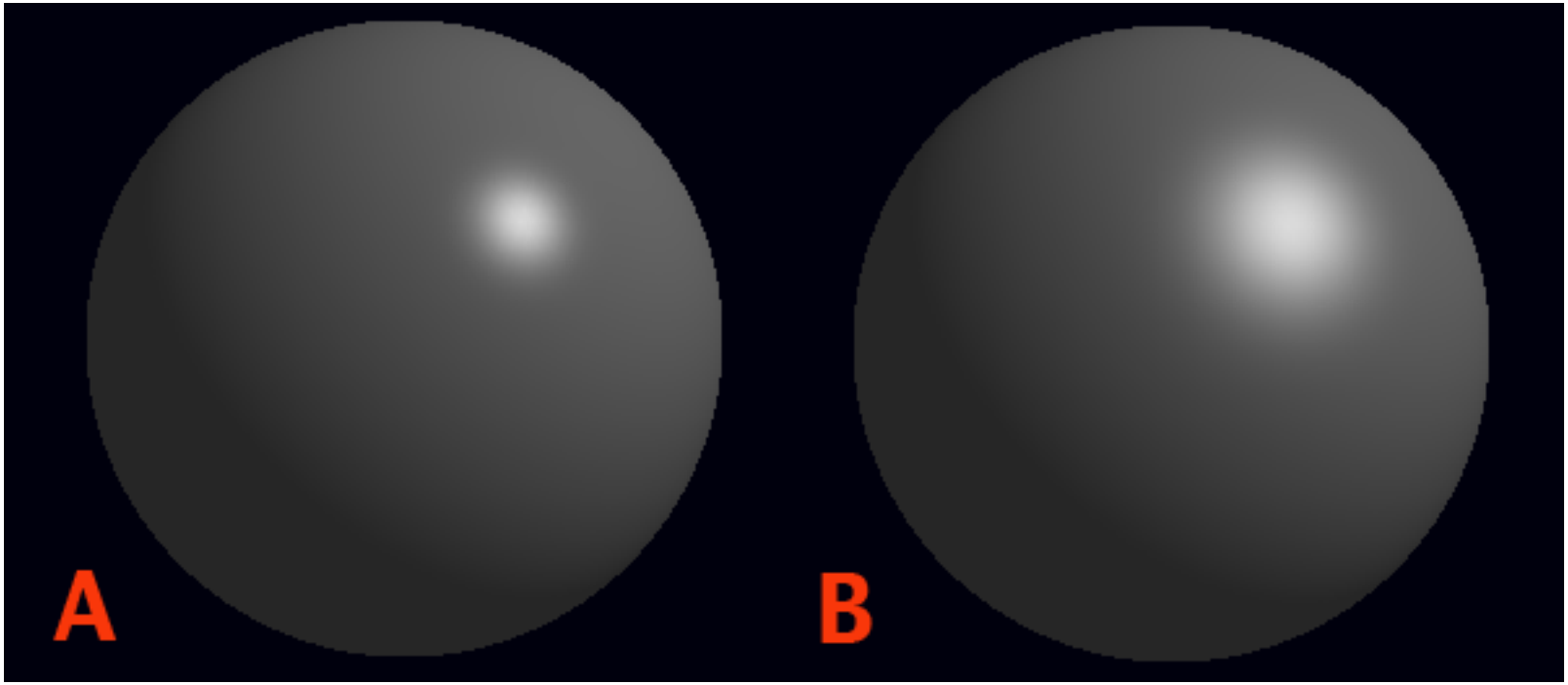
Phong Specular Highlights

$$I = k_s B\left(\cos\Phi\right)^{\alpha}$$

- Φ is the angle between the viewing ray and the angle of reflection.
- α is the so-called Phong constant, expressing how "shiny" an object is
  - Mirrors: α = 200
  - Dull objects: α = 5 … 50

Appearance with Changing α

- Consider which has the larger alpha?



Phong - The Algebra

- $\cos(\Phi) = V \cdot R = V \cdot (2(L \cdot N)N - L)$

$$I = k_s B \left(V \cdot R \right)^{\alpha}$$

$$I = k_s B \left(V \cdot \left(2 \left(L \cdot N \right) N - L \right) \right)^{\alpha}$$

Total Reflectance

- Reflectance off a surface point is the sum of:
- Reflection from the ambient light
- Diffuse reflection off of every point light
- Specular reflection off of every point light

$$I = K_a B_a + \sum_{i \in lights} \left(K_d B_i \left(L_{ip} \cdot N \right) + k_s B_i \left(V \cdot R_p \right)^{\alpha} \right)$$

$$R = 2(L \cdot N)N - L$$

No ‘Negative’ illumination

- The influence of a light source cannot be negative
  - They are light *emitters*
- We assume $N \cdot V \geq 0$
  - Where V points from surface toward fp
  - Otherwise, flip N
- Therefore, if $L_{ip} \cdot N < 0$, set it to 0
- Similarly, if $V \cdot R_p < 0$, set it to 0
- These situations occur when the light source is behind the surface
  - The light source is shining on the other side of the (opaque) surface