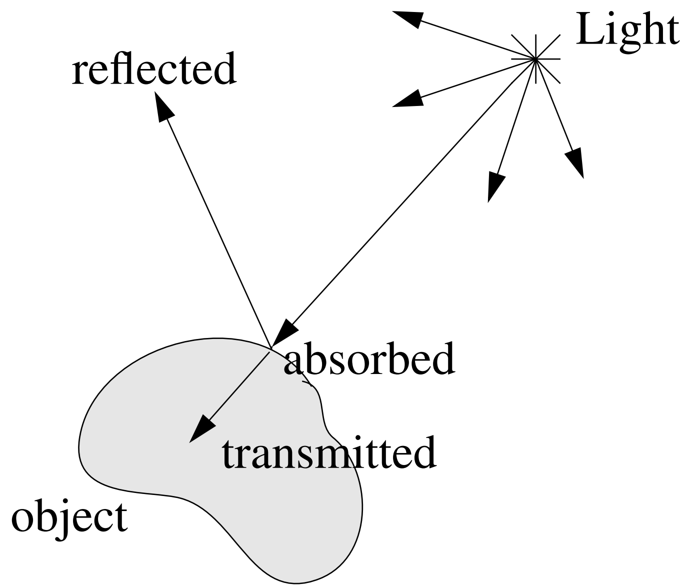
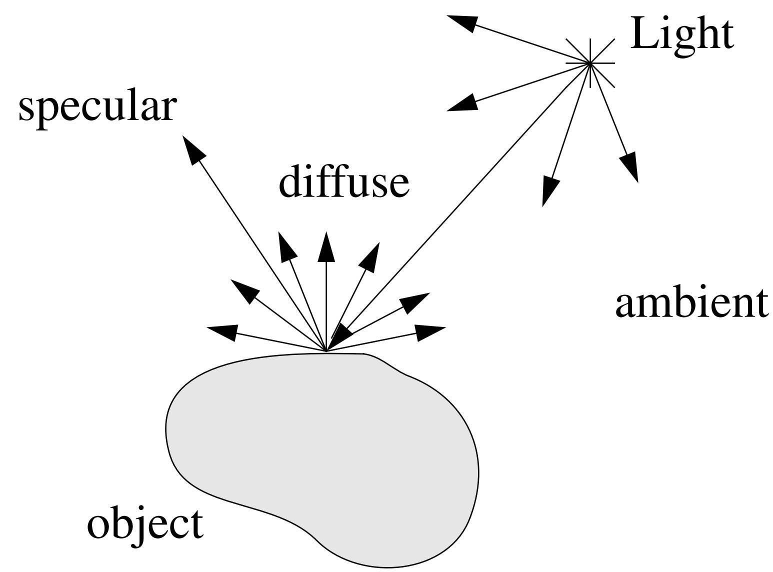
Illumination

Total light decomposition



Light = reflected + transmitted + absorbed

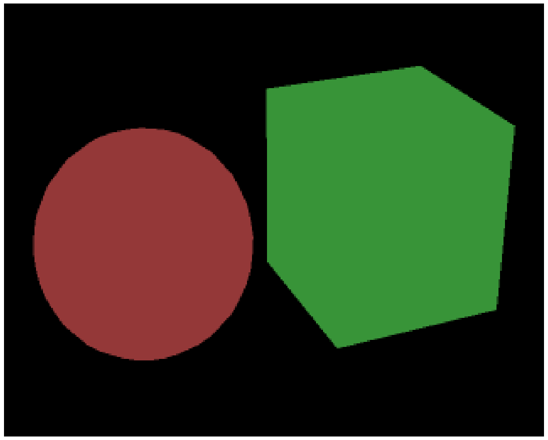
Reflected light



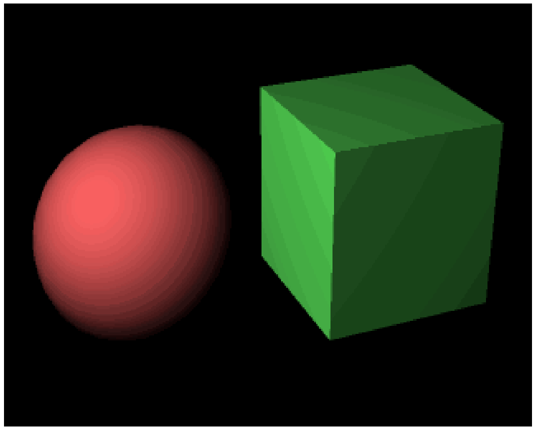
Reflected light = ambient + diffuse + specular

$$I = I_a + I_d + I_s$$

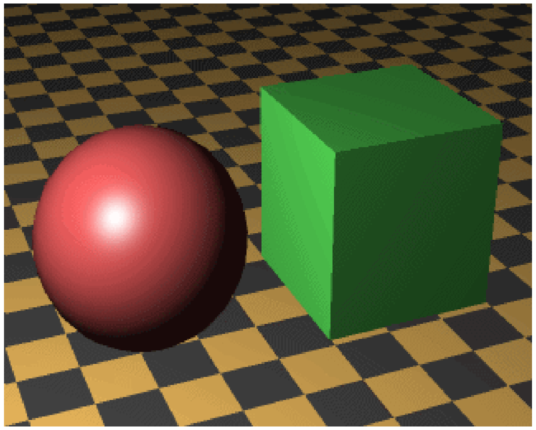
Illumination - Examples



ambient



ambient + diffuse

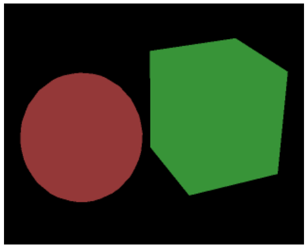


ambient + diffuse + specular

(and a checkerboard)

Ambient Reflection

- Uniform background light
- $I_a = k_a I_A$
  - I_A: ambient light
  - k_a: material's ambient reflection coefficient
- Models general level of brightness in the scene
- Accounts for light effects that are difficult to compute (secondary diffuse reflections, etc)
- Constant for all surfaces of a particular object and the directions it is viewed at

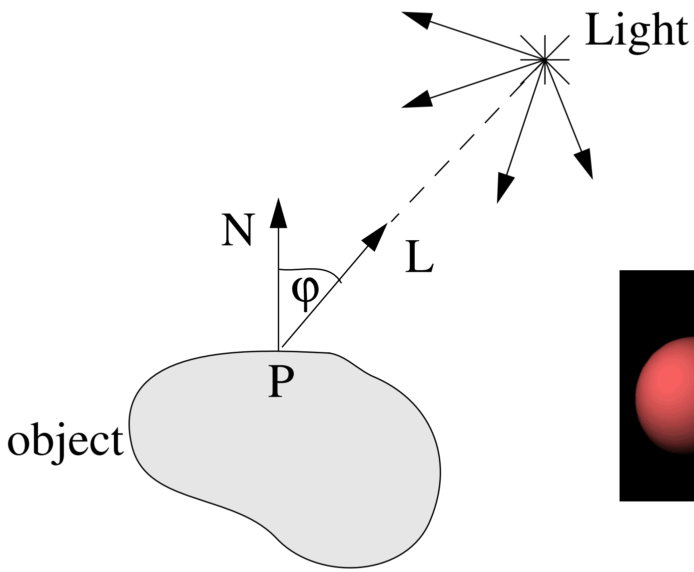


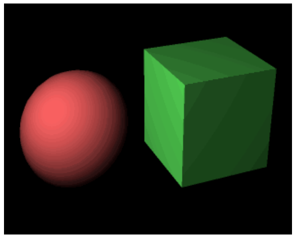
Diffuse Reflection

- Models dullness, roughness of a surface
- Equal light scattering in all directions
- For example, chalk is a diffuse reflector

Dot product:

$N \cdot L = (N_x L_x + N_y L_y + N_z L_z)$





$$L = \frac{Light - P}{|Light - P|} = \frac{(Light_x - P_x)}{|L'|}, \frac{(Light_y - P_y)}{|L'|}, \frac{(Light_z - P_z)}{|L'|}$$

$$|L'| = \sqrt{(Light_x - P_x)^2 + (Light_y - P_y)^2 + (Light_z - P_z)^2}$$

<u>Lambertian cosine law:</u>

$I_d = k_d \, I_L \cos\varphi = k_d \, I_L \, N \cdot L$

I_L: intensity of lightsource

N: surface normal vector

L: light vector (unit length)

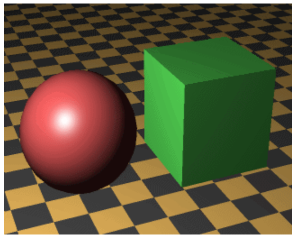
φ: angle of light incidence

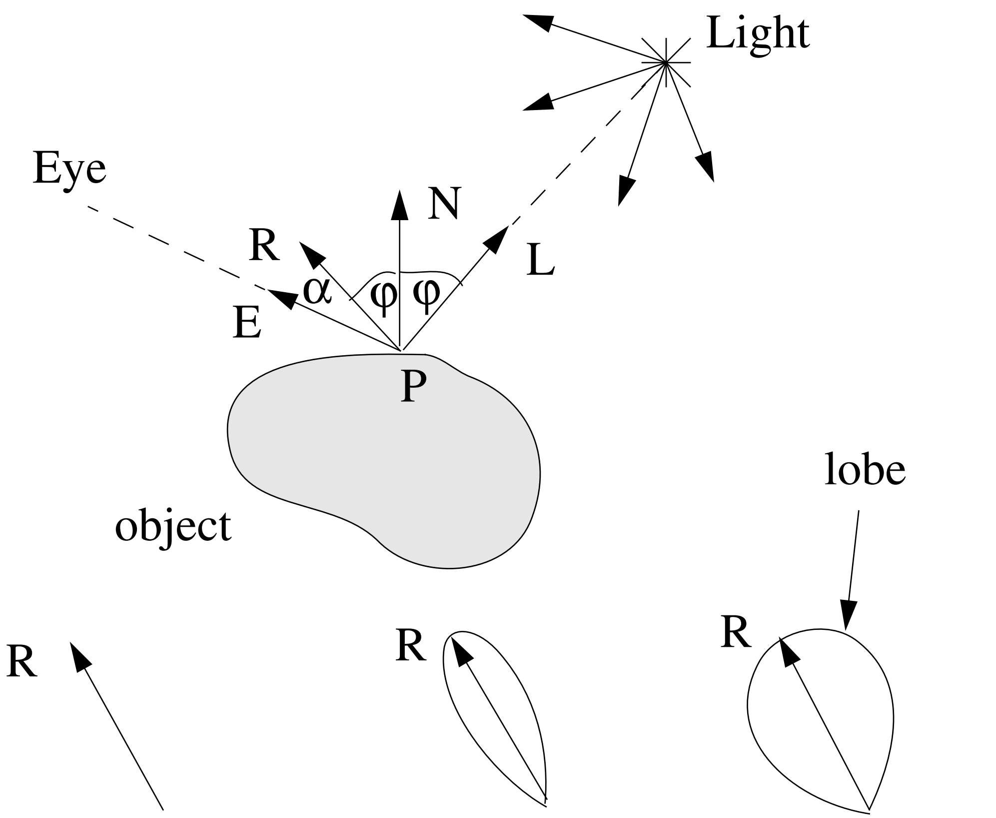
k_d: diffuse reflection coefficient
(material constant)

Note: $I_d = 0$ for $N \cdot L < 0$

Specular Reflection - Fundamentals

- Models reflections on shiny surfaces (polished metal, chrome, plastics, etc.)
- Ideal specular reflector (perfect mirror) reflects light only along reflection vector R
- Non-ideal reflectors reflect light in a lobe centered about R
    - cos(α) models this lobe effect
    - the width of the lobe is modeled by Phong exponent ns, it scales cos(α)





ns = ∞ (perfect mirror) | ns large (100) (shiny surface) | ns small (8) (dull surface)

<u>Phong specular reflection model:</u>

$I_s = k_s\, I_L \cos^{ns} \alpha = k_s\, I_L\, (E \cdot R)^{ns}$

I_L: intensity of lightsource

L: light vector

R: reflection vector = 2 N (N·L) - L

E: eye vector = (Eye-P) / |Eye-P|

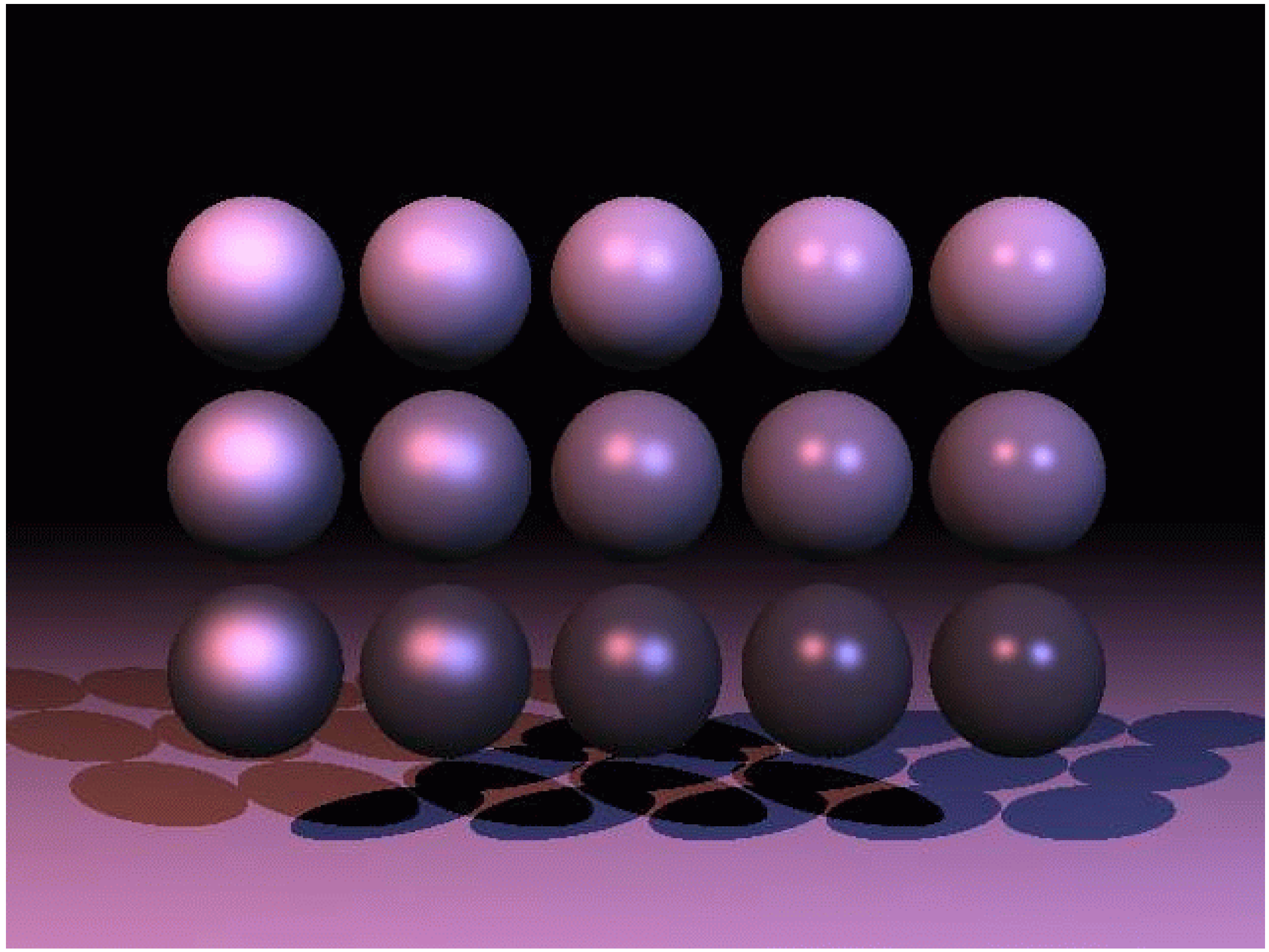
α: angle between E and R

ns: Phong exponent

k_s: specular reflection coefficient

Specular and Diffuse Reflection - Varying the Coefficients

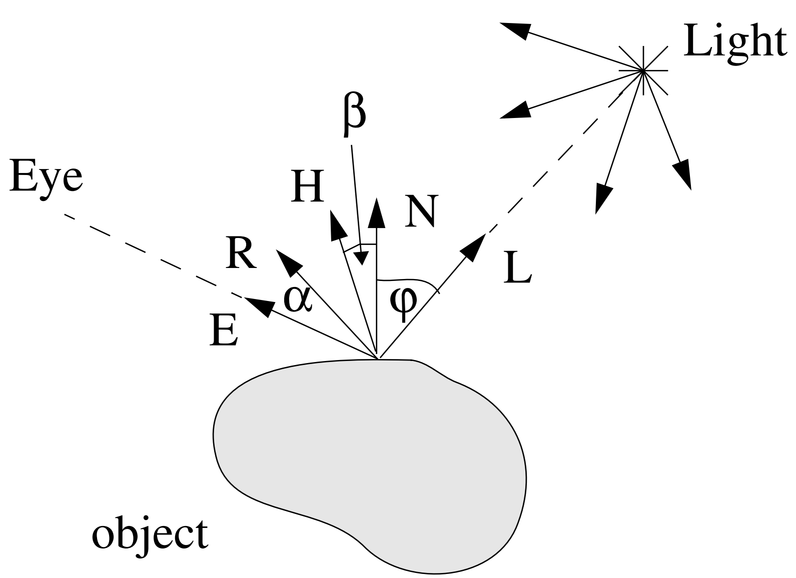
diffuse coefficient k_d



Phong exponent ns

Specular Reflection - Using the Half Vector

- Sometimes the half vector H is used instead of R in specular lighting calculation
- Both alternatives have similar effects



Phong specular reflection model:

$I_s = k_s\, I_L \cos^{ns} \beta = k_s\, I_L\, (H \cdot N)^{ns}$

I_L: intensity of lightsource

L: light vector

H: half vector = $(L + E) / |L + E|$

R: reflection vector

E: eye vector

Total Reflected Light

- Total reflected light (for a white object):

$$I = k_a I_A + k_d I_L N \cdot L + k_s I_L (H \cdot N)^{ns}$$

- Multiple lightsources:

$$I = k_a I_A + \sum (k_d I_i N \cdot L_i + k_s I_i (H_i \cdot N)^{ns})$$

- Usually, I is a color vector of (R=red, G=green, B=blue)
- Object has a color vector $C_{obj} = (R_{obj}, G_{obj}, B_{obj})$
- Object reflects I, modulated by C_{obj}
- Color C reflected by object:

$$C = C_{obj} (k_a I_A + \sum (k_d I_i N \cdot L_i)) + \sum (k_s I_i (H_i \cdot N)^{ns})$$

- In many applications, the specular color is not modulated by object color
  - specular highlight has the color of the lightsource
- Note: (R, G, B) cannot be larger than 1.0 (later scaled to [0, 255] for display)
  - either set a maximum for each individual term or clamp final colors to 1.0