Illumination

Basic Terms

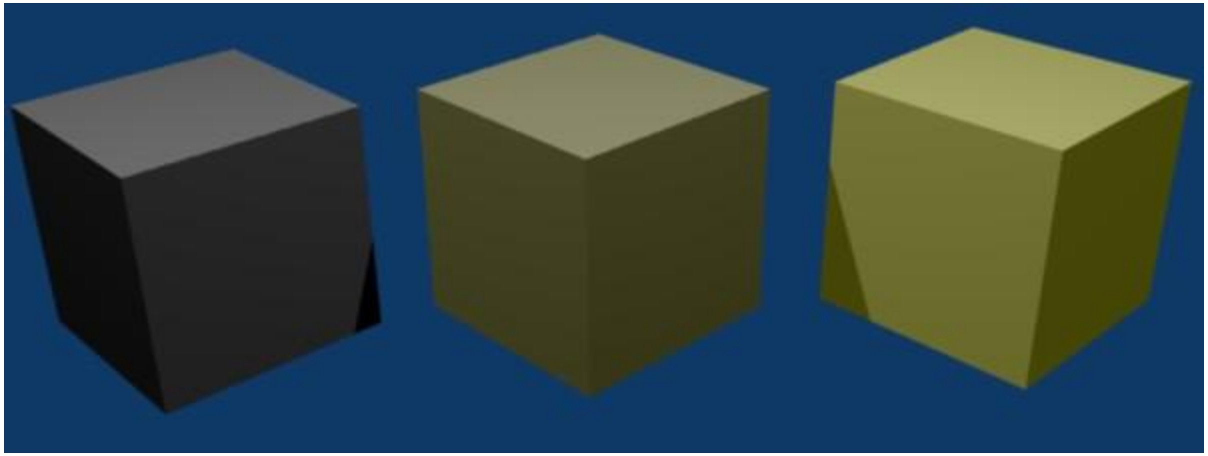
- Illumination: the transport of energy from light sources to surfaces & points
  - Local illumination
  - Global illumination
- Lighting model or Illumination model: Express the factors determining a surface's color or luminous intensity (outgoing or reflected light) at a particular 3D point

Components of Illumination

- Two components of illumination:
  1. **Light sources**
  2. **Surface properties**
- Light source described by a luminance/intensity ‘I’
  - Each color is described separately
  - I = [I r I g I b] T (I for intensity)
- Types of Light Sources:
  1. Ambient Light
  2. Diffuse Light
  3. Spot Light

Ambient Light

- No identifiable source or direction
- Product of multiple reflections of light from the many surfaces present in the environment
- Computationally inexpensive



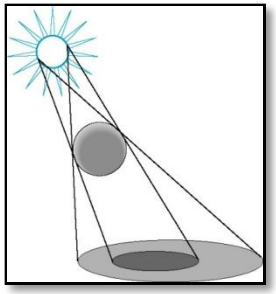
Ambient Light

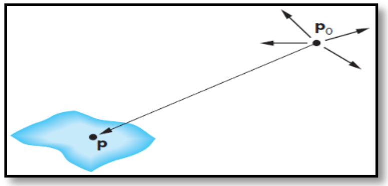
Categories:

1. Global ambient light
   - Independent of light source
   - Lights entire scene
   - Example: reflection of sunlight from several surfaces
2. Local ambient light
   - Contributed by additional light sources
   - Can be different for each light and primary color
   - Example: Reflection of fluorescent lamps from several surfaces

Diffuse Light

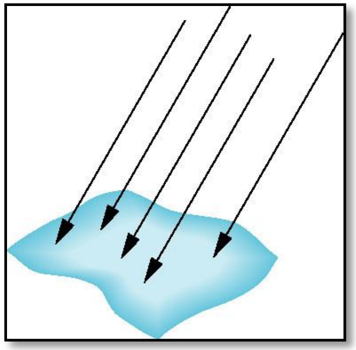
- **Point Source**
  - Given by a point
  - Light emitted equally in all directions
  - Intensity decreases with square of distance
  - Point source $[x\ y\ z\ 1]^T$
  - At point p, intensity received



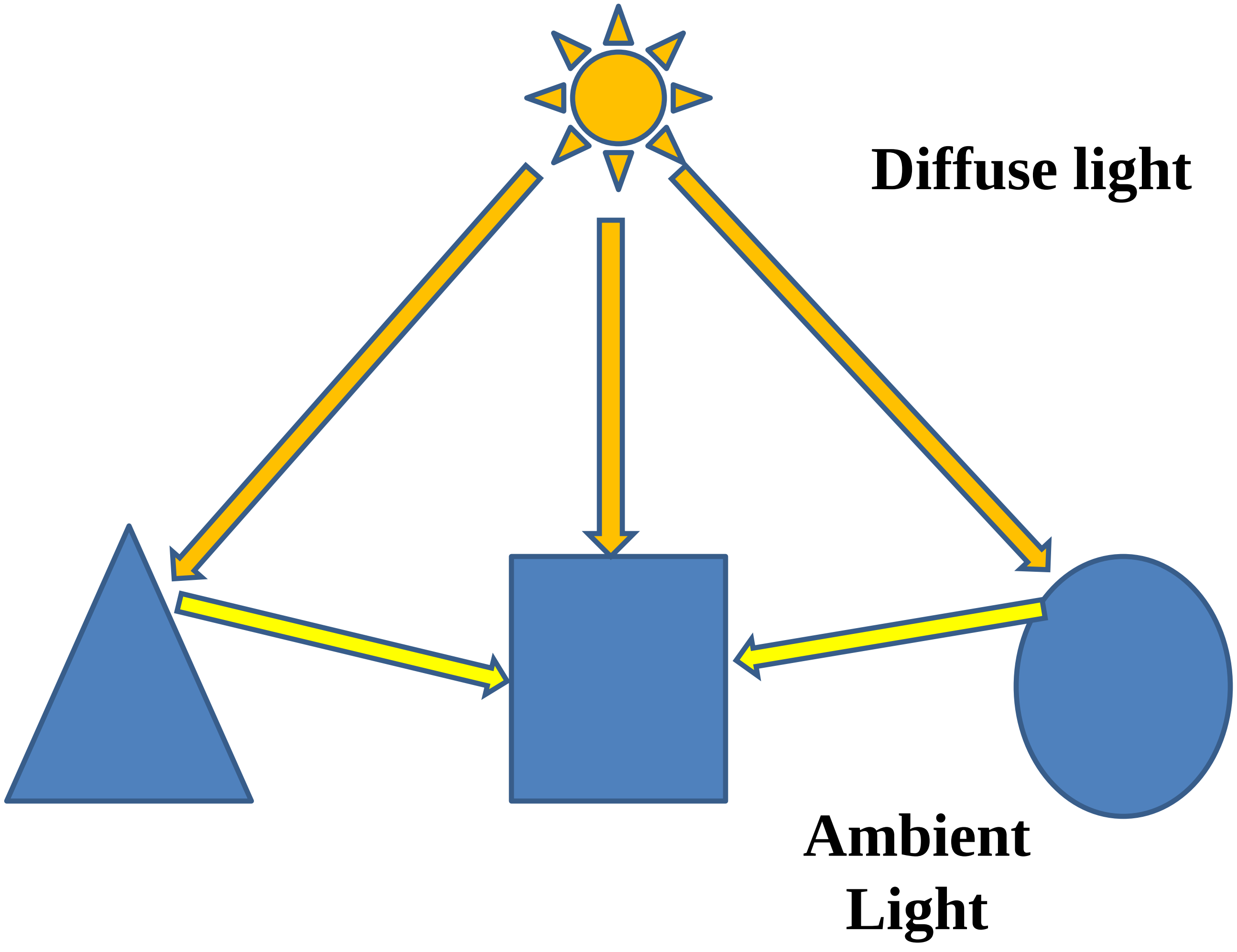


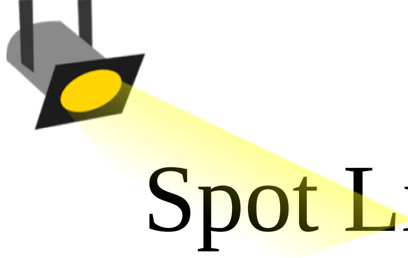
$$i(p, p_0) = \frac{1}{|p - p_0|^2} I(p_0).$$

- **Directional Source**
  - Given by a direction
  - Simplifies some calculations
  - Intensity dependents on angle between surface normal and direction of light
  - Distant source $[x\ y\ z\ 0]^T$



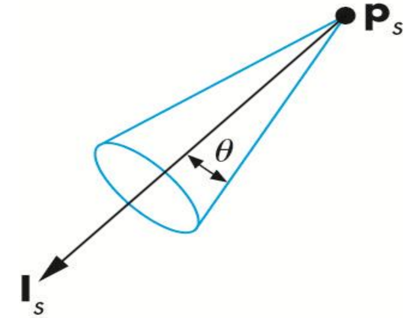
Ambient light vs Diffuse light





Spot Light

- *Spotlight* is a point source that emits light in restricted set of directions,
  - Requires color, point, direction, falloff parameter
  - usually direction boundary forms a cone shape.
  - Here θ is Cutoff Cone. No light is seen at points lying outside Cutoff angle.

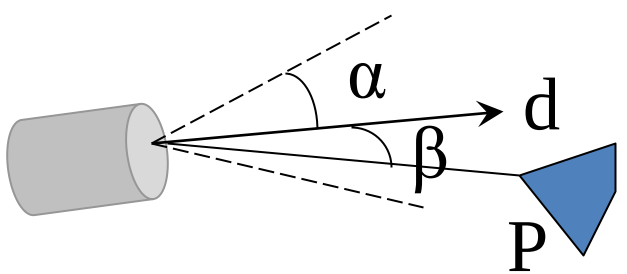


- Intensity falls off directionally

Spot Light

- Consider, a spot light aimed at direction d.
  - ***β*** is the angle between aimed direction ***d*** and a line from source to object ***P***
  - Source has cut off angle ***α*** and intensity ***I***
  - Intensity of spot light received at ***P*** is

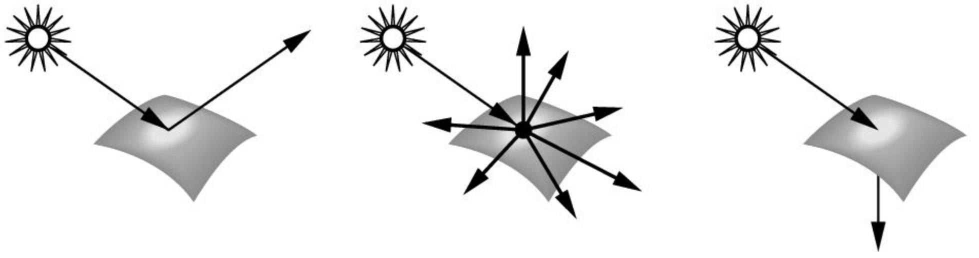
$$\boxed{\text{Intensity at P} = I \cos^{\varepsilon}(\beta)}$$



Types of surface

Interaction between light and material can be classified as

- **Specular surfaces** – Ideal mirror
- **Diffuse surfaces** – Reflected light is ideally reflected to all directions uniformly
- **Translucent surfaces** – allow some lights to penetrate the surface – refraction – glass, water



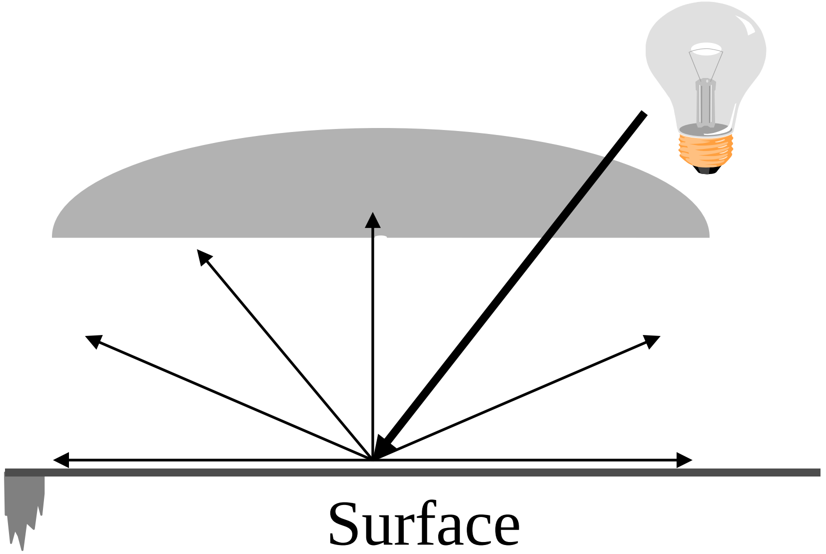
(a) (b) (c)

Reflection

Defuse Reflectance, Specular Reflectance

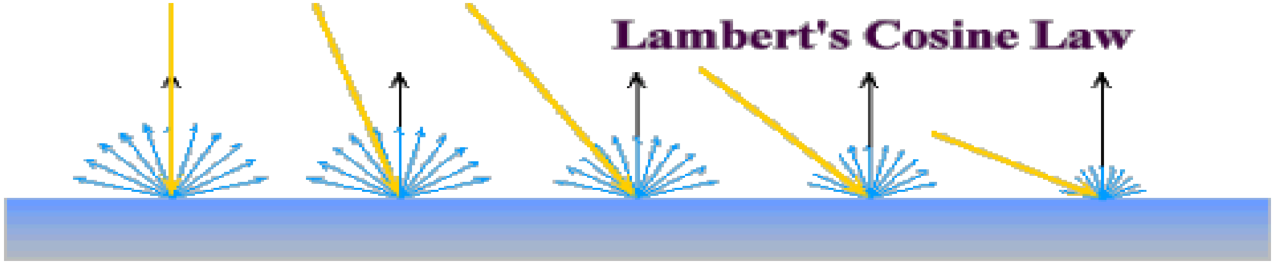
Ideal Diffuse Reflectance

- Assumes surface reflects equally in all directions.
- An ideal diffuse surface is, at the microscopic level, a very rough surface.
  - Example: chalk, clay, some paints



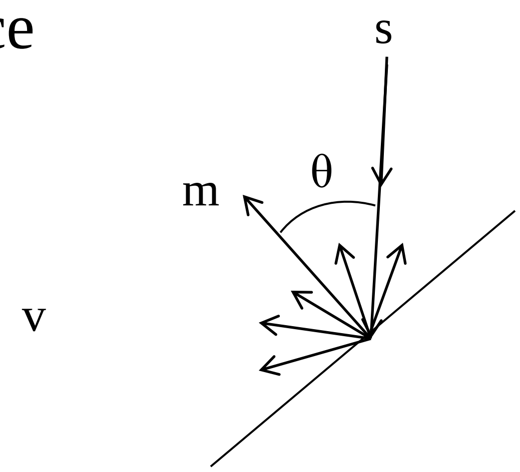
Ideal Diffuse Reflectance

- Ideal diffuse reflectors reflect light according to Lambert's cosine law.
- Lambert's law determines how much of the incoming light energy is reflected. The reflected intensity is independent of the viewing direction.
- But reflected light intensity depends on incident angle of light.



Ideal Diffuse Reflectance

- Suppose light is incident on diffuse surface S.
  - m = direction of Normal of the surface
  - v = viewer’s direction
  - s = direction of incident light
  - θ = incident angle
  - I_s = Intensity of Light Source
  - Intensity of reflected light, I_d

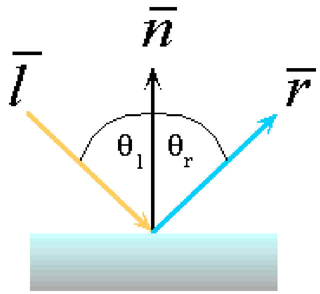


– $I_d = I_s$ Þ$_d$ (s.m/|s||m|) , where Þ$_d$ is *the diffuse reflectance coefficient*.

– If θ is negative, then I_d= max(I_s Þ$_d$ (s.m/|s||m|) ,0)

Ideal Specular Reflection

- Reflection is only at mirror angle. An ideal mirror is a purely specular reflector.
  - View dependent reflection. That is, reflected light's intensity varies with viewr's position.
  - Intensity of refelcted light is strong near mirror angle and strongest at mirror angle.
  - An Ideal specular reflection follows Snell's Law.

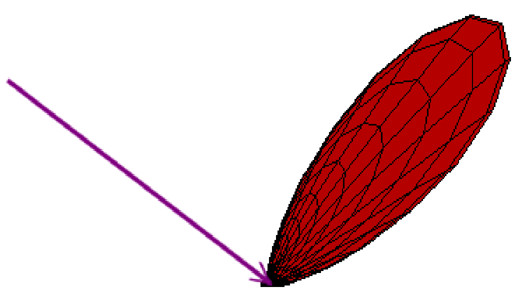


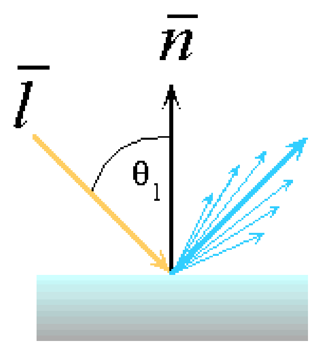
Snell's Laws:

- The incoming ray and reflected ray lie in a plane with the surface normal
- The angle that the reflected ray forms with the surface normal equals the angle formed by the incoming ray and the surface normal.

Non-ideal Reflectors

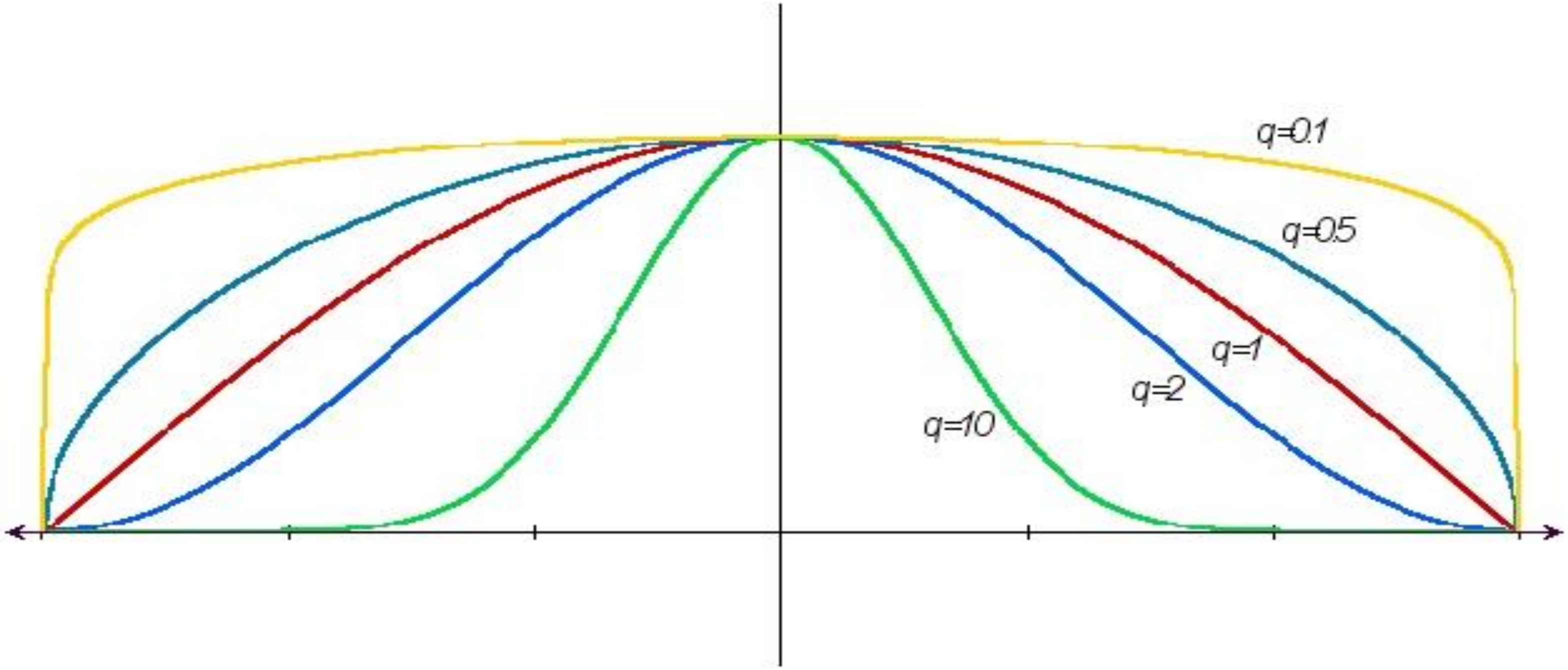
- Simple Empirical Model:
  - We expect most of the reflected light to travel in the direction of the ideal ray.
  - However, because of microscopic surface variations we might expect some of the light to be reflected just slightly offset from the ideal reflected ray.
  - As we move farther and farther, in the angular sense, from the reflected ray we expect to see less light reflected.





Non-ideal Reflectors

- Phong model approximates the fall off of specular reflection.
- The cosine term is maximum when the surface is viewed from the mirror direction and falls off to 0 when viewed at 90 degrees away from it.
- The scalar $\boldsymbol{n}_{\text{shiny}}$ controls the rate of this fall off

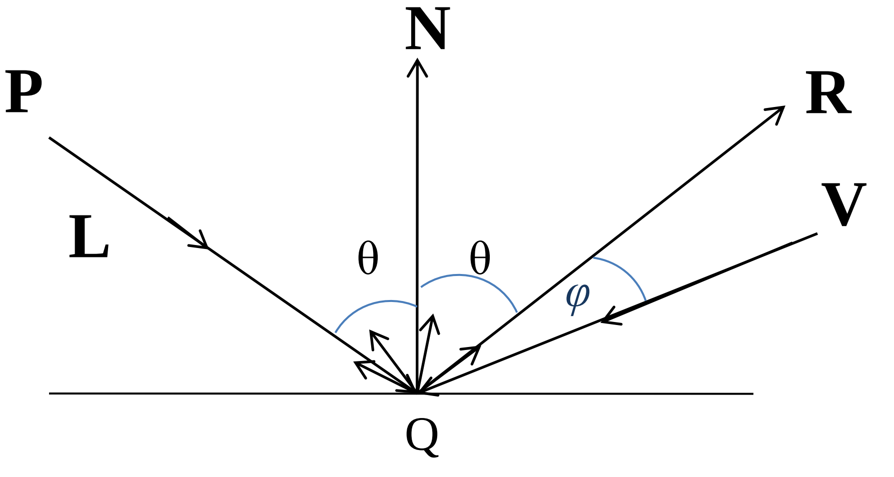


Phong Model

- Compute the combined impact of ambient, diffuse and specular reflectance at a point on surface
- Also called Local Illumination model as its main focus is on the direct impact of light coming from a source.
- This model has no physical basis, yet it is one of the most commonly used illumination models in computer graphics.

Phong Model

- Also models secondary effect of light.
- *Consider a point light source p and viewpoint v. What should be color of light reflected into viewer's eye from point Q of the surface?*
  - *Consider* ***diffuse*** *component,* ***specular*** *component of the incident light and* ***ambient*** *light present in the environment*



Mathematical Calculation of Phong Model

- First we consider, 2 extreme cases of light reflection.
  - Diffuse Reflection :

    $I_d \propto \cos\theta$

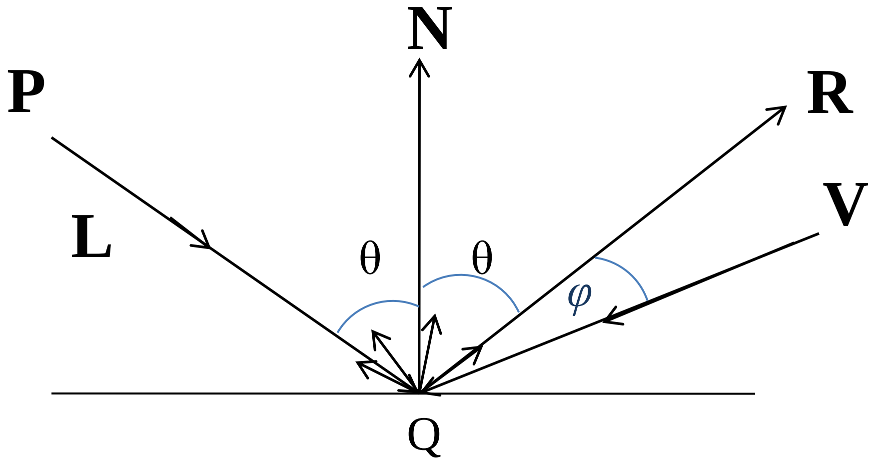
    $= I_p\, k_d \cos\theta$

    $= I_p\, k_d\, (\mathbf{L}.\mathbf{N})$

  - Specular Reflection:
  - $I_s \propto (\cos\varphi)^k$

    $= I_p\, k_s\, (\cos\varphi)^k$

    $= I_p\, k_s\, (\mathbf{R}.\mathbf{V})^k$



Mathematical Calculation of Phong Model

- We need to ircorporate the effect light present in environment. Thus total refelcted light also includes ambient component.
  - Ambient Component = $I_a k_a$
- Total reflected light intensity from Q,

$$I = \text{Ambient Component} + \text{Diffuse Component} + \text{Specular Component}$$

$$= I_a k_a + I_p k_d (\mathbf{L}.\mathbf{N}) + I_p k_s (\mathbf{R}.\mathbf{V})^k$$

$$= I_a k_a + I_p [k_d \max \{(\mathbf{L}.\mathbf{N}),0\} + k_s \max\{(\mathbf{R}.\mathbf{V})^k ,0\}]$$

Additional Issues

- When there are n light sources in the scene, their effects are cumulative: Intensity at Q,

  $I = I_a k_a + \sum_{(i=1 \text{ to } n)} I_{pi} \{k_d (\mathbf{L}.\mathbf{N}) + k_s (\mathbf{R}.\mathbf{V})^k \}$

- The intesnsity of red, green and blue component of reflected light,

  $I_r = I_a k_{ar} + I_p k_{dr} (\mathbf{L}.\mathbf{N}) + I_p k_s (\mathbf{R}.\mathbf{V})^k$

  $I_g = I_a k_{ag} + I_p k_{dg} (\mathbf{L}.\mathbf{N}) + I_p k_s (\mathbf{R}.\mathbf{V})^k$

  $I_b = I_a k_{ab} + I_p k_{db} (\mathbf{L}.\mathbf{N}) + I_p k_s (\mathbf{R}.\mathbf{V})^k$

  – k_s is same as color of specular component is same as color of light source, not affected by surface color.

How to get vector **R** ?

- Find a formula to compute R, the reflection of vector L with respect to normal vector?

$\mathbf{R} = 2\,(\mathbf{L}.\mathbf{N})\mathbf{N} - \mathbf{L}$

(see Solved Problem 11.10 in Schaum(2nd edition))

Blinn and Torrence Variation

- Calculation of **R** is computaionally expensive. So in phong model the term **R**.**V** is somtimes replaced by **N**. **H** , where **H** is a unit vector that bisect the angle between **L** and **V**.
  - angle between **N** and **H** measures the falloff of intensity.
  - Though calculation of N.H is is computaionally inexpensive relative to R.V, but N.H is not always equal to R.V . In that case calculation of specular component will be approximate. (see Solved Problem 11.11 in Schaum(2nd edition)))

Effect of the reflection coefficients

Diffuse Reflection Coefficient

- $I_d = \max \{I_s \rho_d \cos \Theta, 0\}$
- Source intensity is 1.0
- Background intensity is 0.4
- Sphere reflecting diffuse light, for six reflection coefficients: 0, 0.2, 0.4, 0.6, 0.8, and 1.

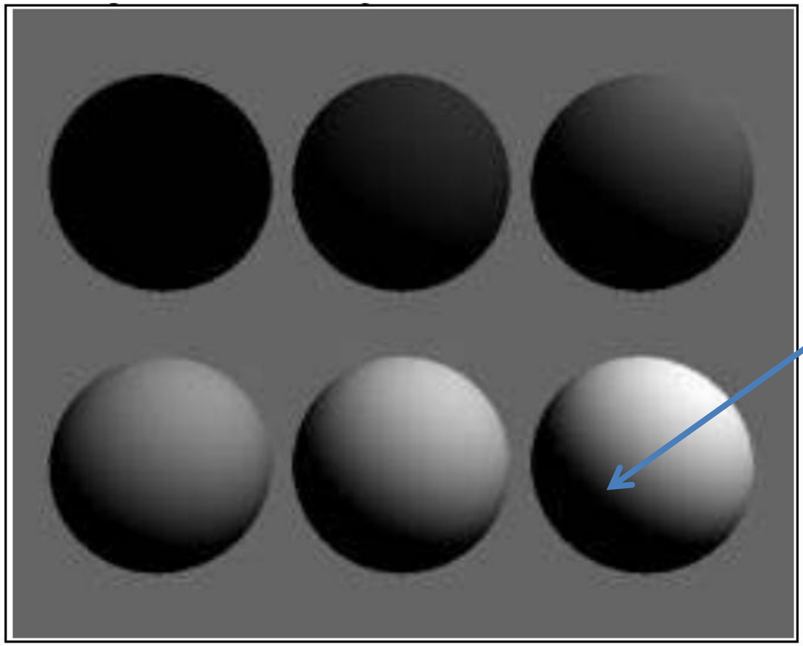


Figure 8.11. Spheres with various reflection coefficients shaded with diffuse light. (file: fig8.11.bmp)

Angle Θ between surface normal and incident light is > 90^o

Ambient Reflection Coefficient

- Effect of adding ambient light to the diffuse light reflected by a sphere
- Diffuse source intensity is 1.0
  Diffuse reflection coefficient is 0.4
  Ambient source intensity is 1.0
- Moving from left to right the ambient reflection coefficient takes on values: 0.0, 0.1, 0.3, 0.5, and 0.7
  - Too little ambient light makes shadows appear too deep and harsh
  - Too much makes the picture look washed out and bland

Figure 8.16. On the effect of ambient light.

Specular Reflection Coefficient

- The ambient and diffuse reflection coefficients are 0.1 and 0.4 for all spheres.
- $I_d = Is\, \rho_s \cos(\varphi)^f$

More shiny and more highly concentrated along the direction r

Exponent f

3 6 9 25 200

More mirror like, more focused reflection with increasing exponent

reflection coefficient ρ_s

0.25

0.5

0.75

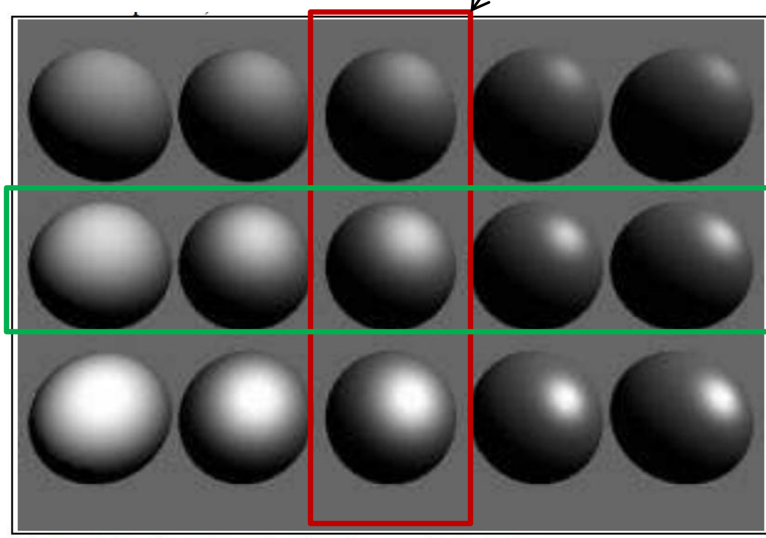


Figure 8.15. Specular reflection from a shiny surface.

Color

Adding Color

- Color is constructed by adding certain amounts of red, green, and blue light
- light sources have three “types” of color:

$$\text{ambient} = (I_{ar}, I_{ag}, I_{ab}), \text{ diffuse} = (I_{dr}, I_{dg}, I_{db}), \text{ and specular} = (I_{spr}, I_{spg}, I_{spb})$$

Adding Color

- Surface has two sets of reflection co-efficient

ambient reflection coefficients: ρ_{ar}, ρ_{ag}, and ρ_{ab},
diffuse reflection coefficients: , ρ_{dr}, ρ_{dg}, and ρ_{db}

- Color of the specular component is often the same as that of the light source – mirror like:

  ρ_{sr} , ρ_{sg} , $\rho_{sb} = \rho_s$

  – Glossy red apple when illuminated by a yellow light is yellow rather than red

What makes an apple red?

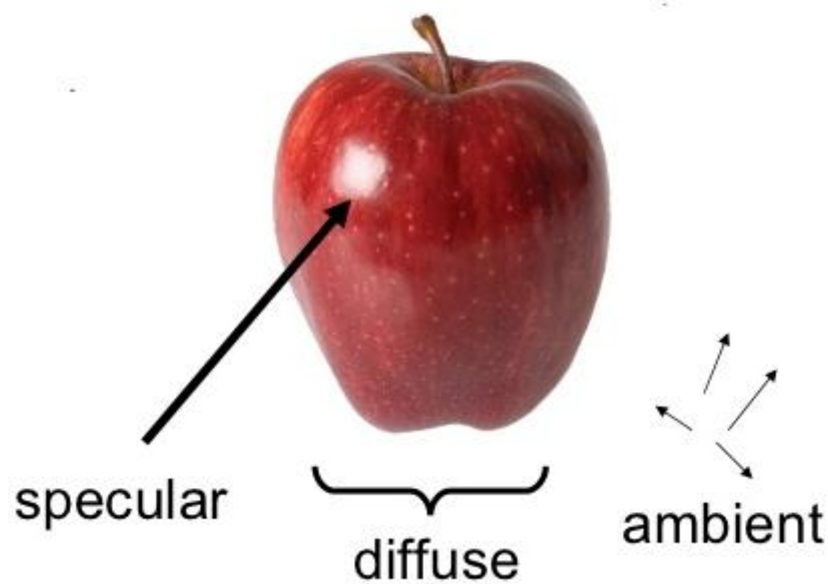


Image synthesis view:

"light, surface, and material interact to reflect light perceived as color, modeled via simplifying assumptions"

Adding Color

- By “color” of a surface we mean the color that is reflected from it when the illumination is white light
- The ambient and diffuse reflection coefficients are based on the color of the surface itself.

Color of an object

- Color of a sphere is 30% red, 45% green, and 25% blue
- Ambient light in environment:
  White light (Isr= Isg= Isb = I)
- Sphere's ambient and diffuse reflection coefficients:
  $I_{ar}=I_{dr}=0.3K$
  $I_{ag}=I_{dg}=0.45K$
  $I_{ab}=I_{db}=0.25K$
- The individual diffuse components have intensities
  $I_{dr}= 0.3\ K\ I$
  $I_{dg}= 0.45\ K\ I$
  $I_{db}= 0.25\ K\ I$

- Reddish Object in Greenish Light ?

  Think!

Reference

- Hill: 8.2.1 - 8.2.6