

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

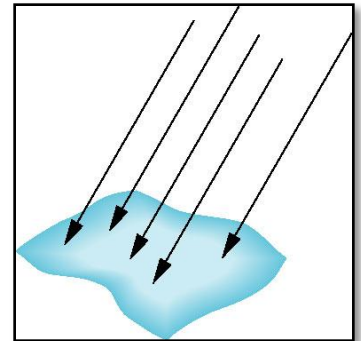
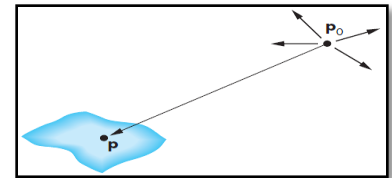
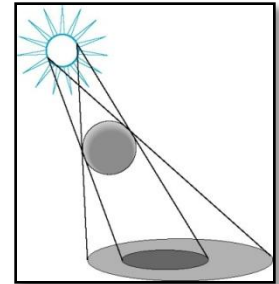
- **Point Source**

- 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

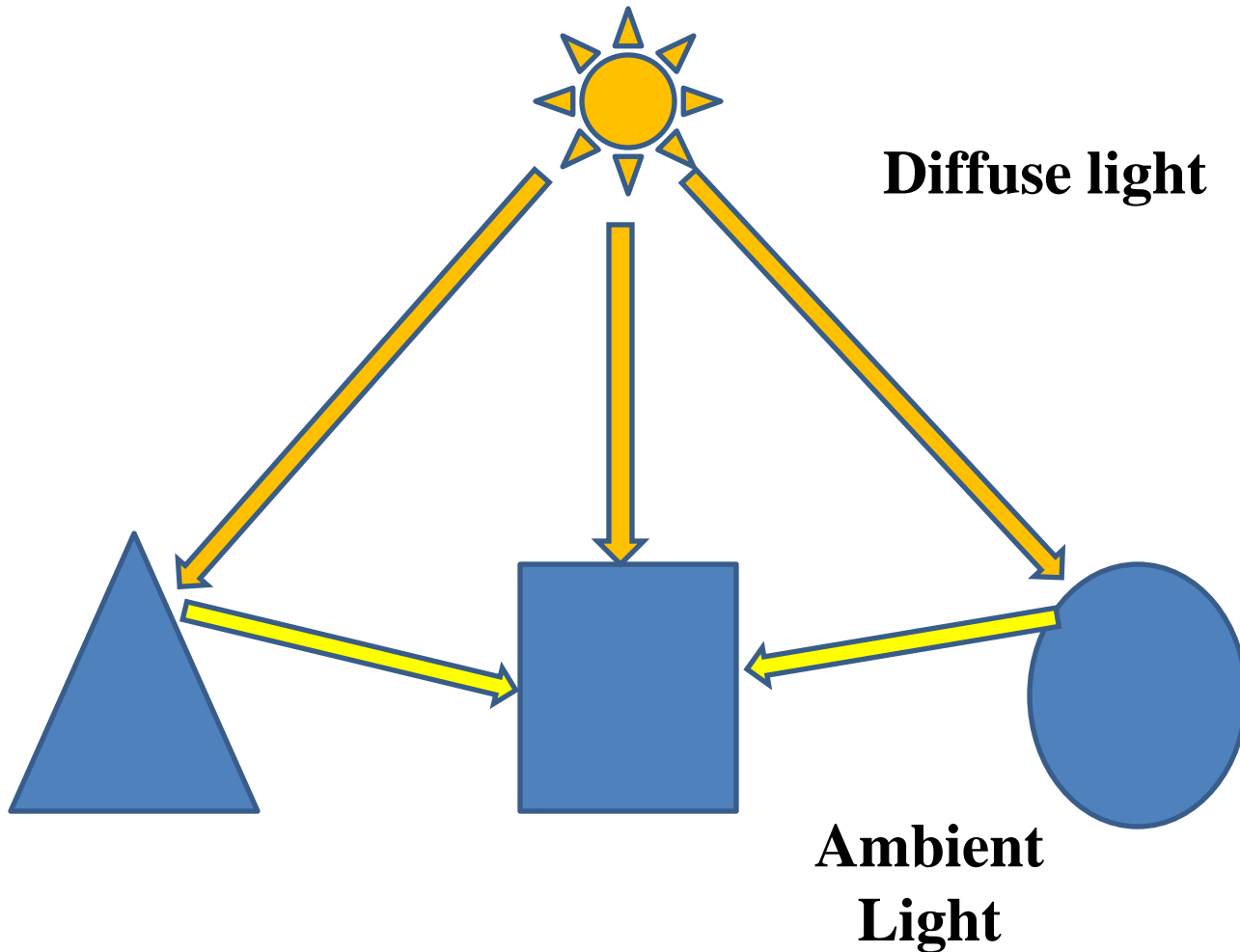
$$i(p, p_0) = \frac{1}{|p - p_0|^2} I(p_0).$$

- **Directional Source**

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



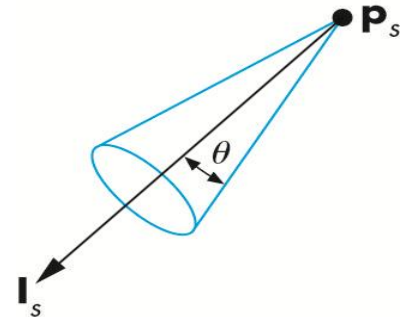
Ambient light vs Diffuse light





Spot Light

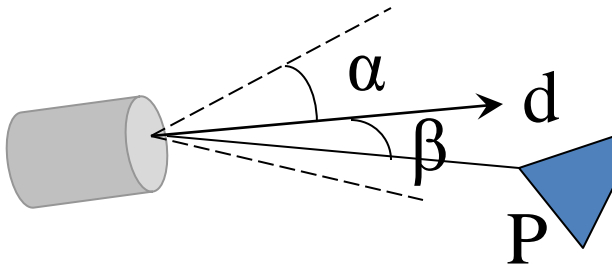
- *Spotlight* is a point source that emits light in restricted set of directions,
 - Requires color, point, direction, falloff parameter
 - usually direction boundary forms a cone shape.
 - Here θ is Cutoff Cone. No light is seen at points lying outside Cutoff angle.
- Intensity falls off directionally



Spot Light

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

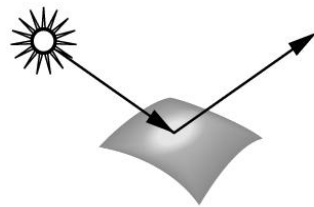
$$\text{Intensity at P} = I \cos^{\epsilon}(\beta)$$



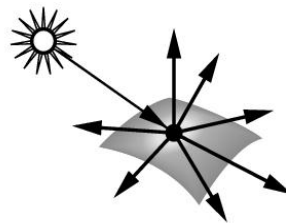
Types of surface

Interaction between light and material can be classified as

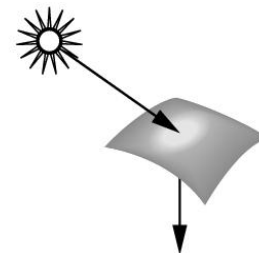
- **Specular surfaces** – Ideal mirror
- **Diffuse surfaces** – Reflected light is ideally reflected to all directions uniformly
- **Translucent surfaces** – allow some lights to penetrate the surface – refraction – glass, water



(a)



(b)



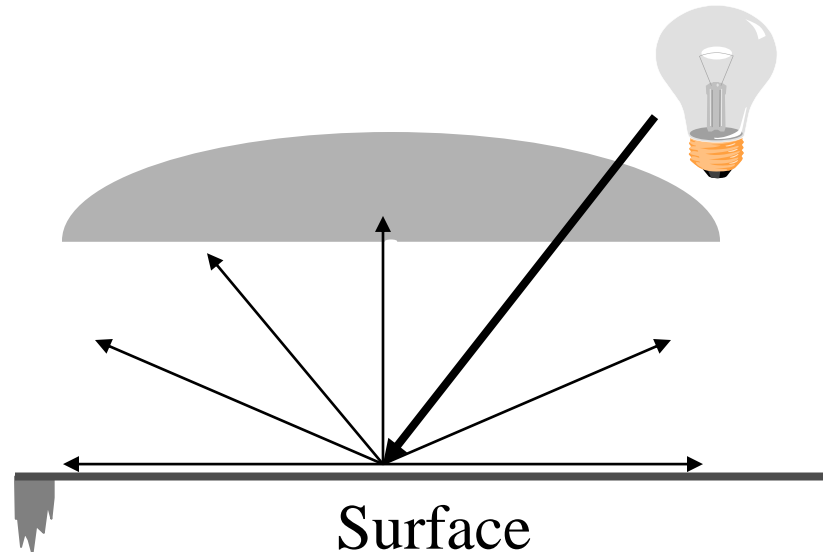
(c)

Reflection

Diffuse Reflectance, Specular
Reflectance

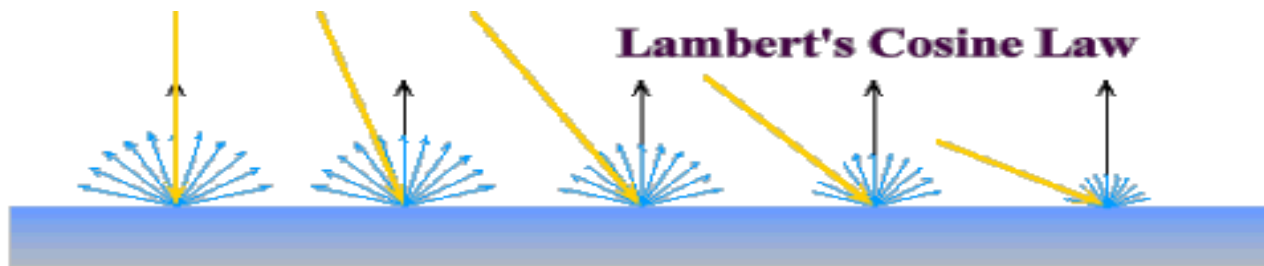
Ideal Diffuse Reflectance

- 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



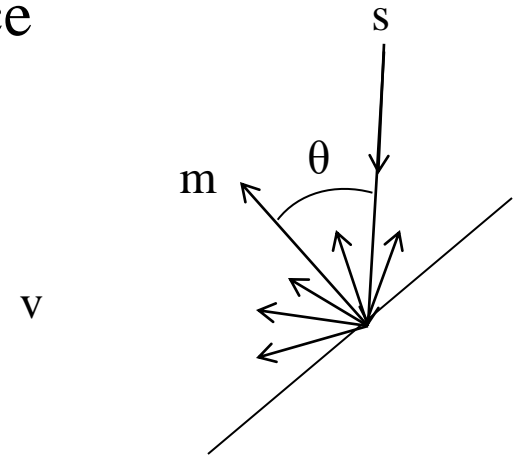
Ideal Diffuse Reflectance

- 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.



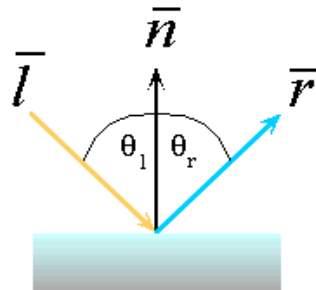
Ideal Diffuse Reflectance

- 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
- $I_d = I_s P_d (s \cdot m / |s| |m|)$, where P_d is *the diffuse reflectance coefficient*.
- If θ is negative, then $I_d = \max(I_s P_d (s \cdot m / |s| |m|), 0)$



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 viewer's position.
 - Intensity of reflected light is strong near mirror angle and strongest at mirror angle.
 - An Ideal specular reflection follows Snell's Law.

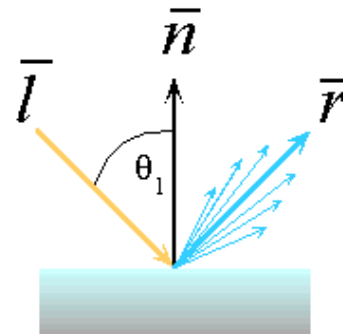
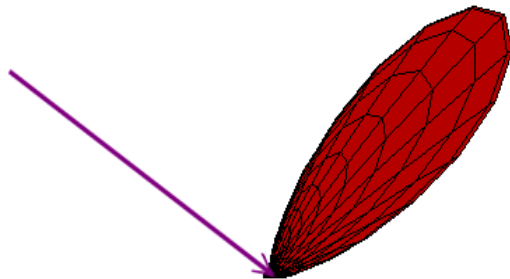


Snell's Laws:

- 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.

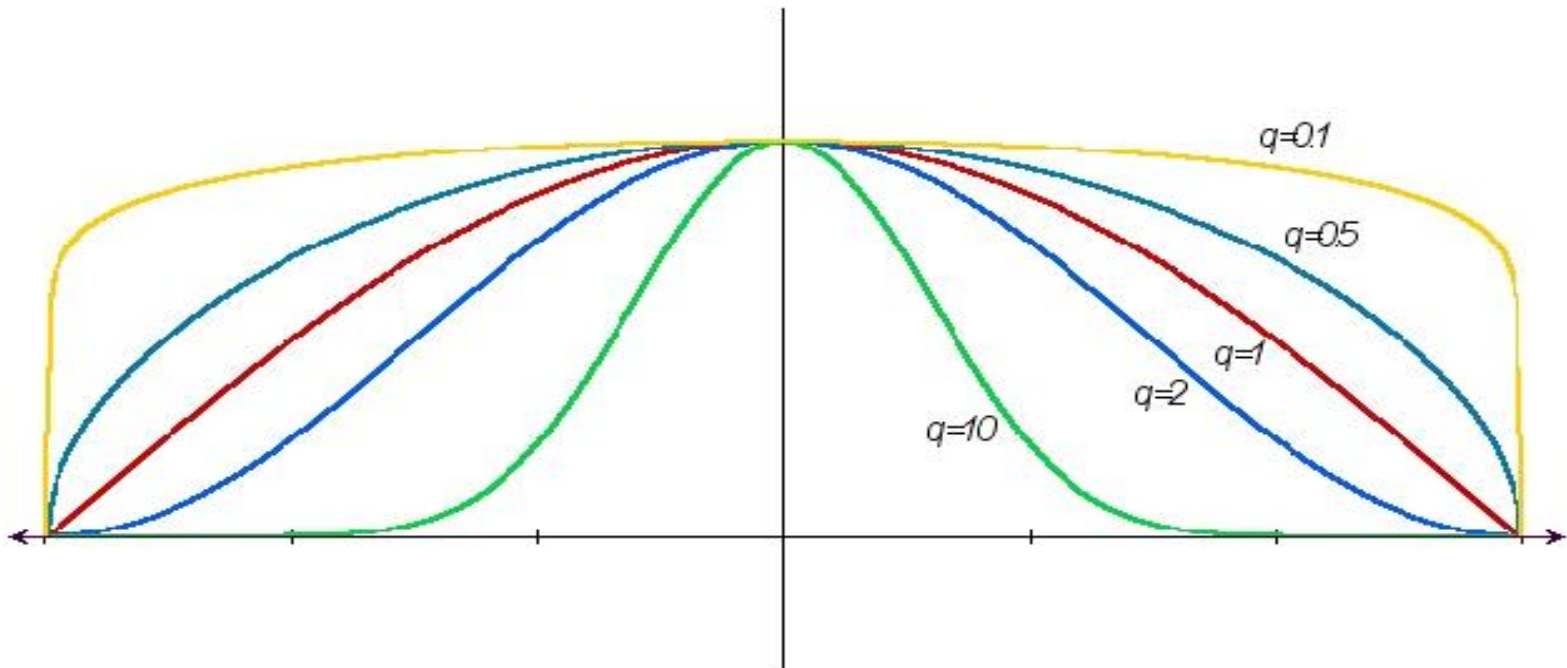
Non-ideal Reflectors

- 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 n_{shiny} controls the rate of this fall off

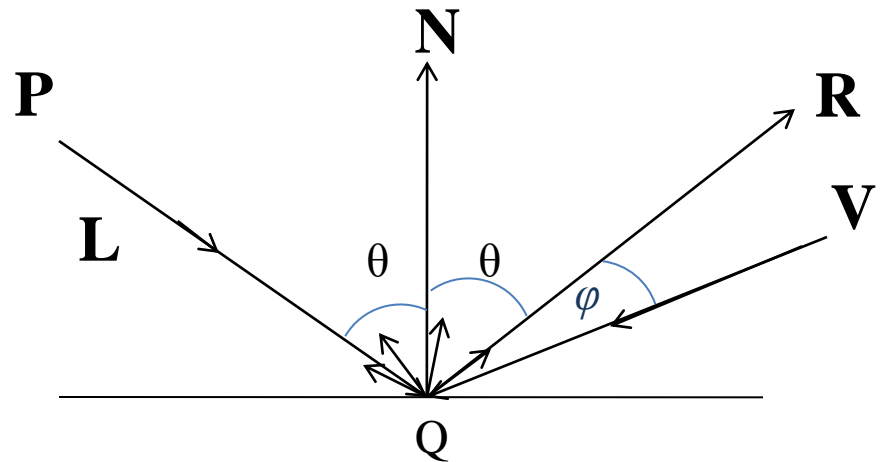


Phong Model

- 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

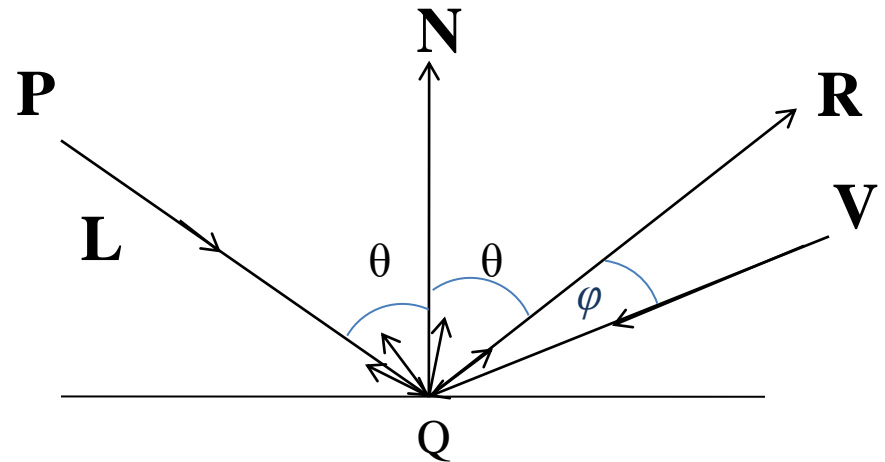
- First we consider, 2 extreme cases of light reflection.

- Diffuse Reflection :

$$\begin{aligned} I_d &\propto \cos\theta \\ &= I_p k_d \cos\theta \\ &= I_p k_d (\mathbf{L} \cdot \mathbf{N}) \end{aligned}$$

- Specular Reflection:

$$\begin{aligned} I_s &\propto (\cos\phi)^k \\ &= I_p k_s (\cos\phi)^k \\ &= I_p k_s (\mathbf{R} \cdot \mathbf{V})^k \end{aligned}$$



Mathematical Calculation of Phong Model

- We need to incorporate the effect light present in environment. Thus total reflected light also includes ambient component.

- Ambient Component = $I_a k_a$

- Total reflected light intensity from Q,

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

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

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

Additional Issues

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

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

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

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

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

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

- 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?

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

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

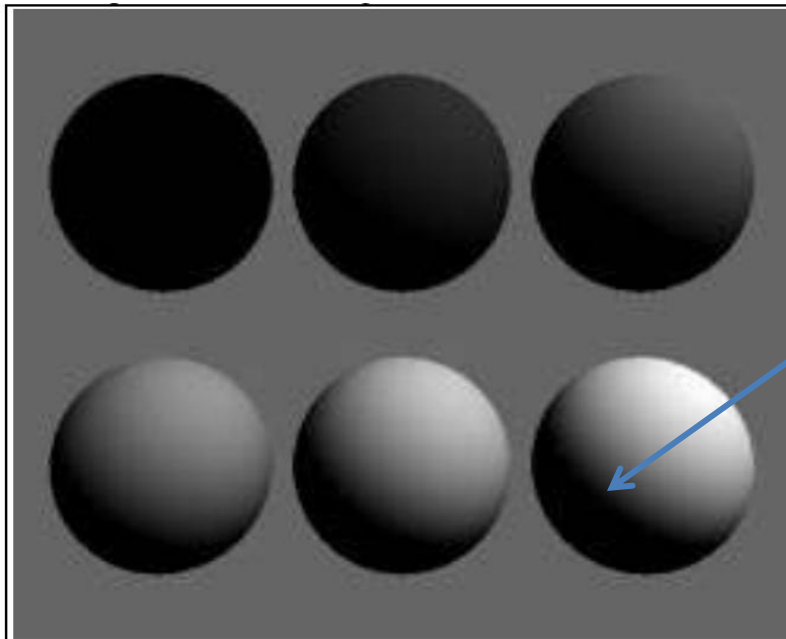
Blinn and Torrence Variation

- Calculation of \mathbf{R} is computationally expensive. So in phong model the term $\mathbf{R.V}$ is sometimes replaced by $\mathbf{N.H}$, where \mathbf{H} is a unit vector that bisect the angle between \mathbf{L} and \mathbf{V} .
 - angle between \mathbf{N} and \mathbf{H} measures the falloff of intensity.
 - Though calculation of $\mathbf{N.H}$ is computationally inexpensive relative to $\mathbf{R.V}$, but $\mathbf{N.H}$ is not always equal to $\mathbf{R.V}$. 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.



Angle Θ between
surface normal and
incident light is $> 90^\circ$

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

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

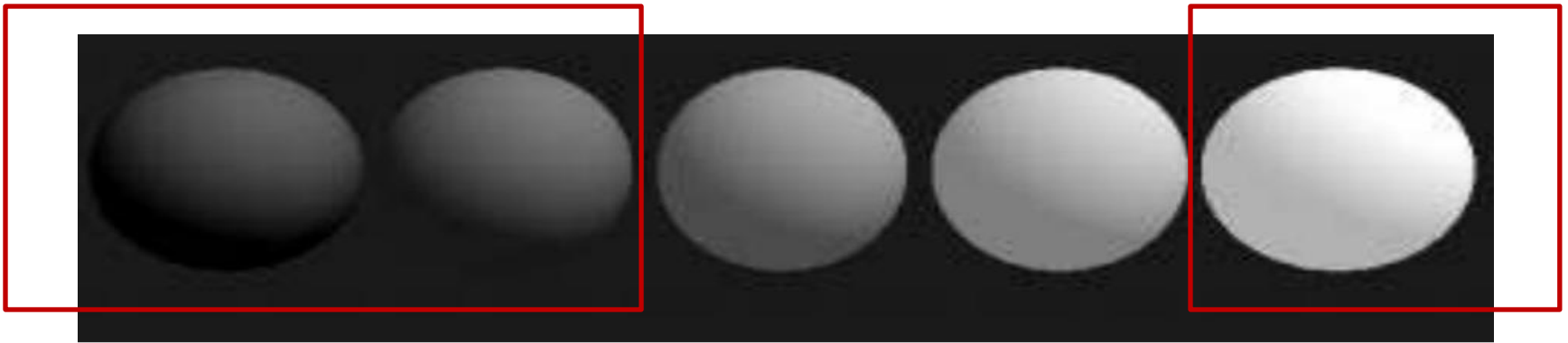
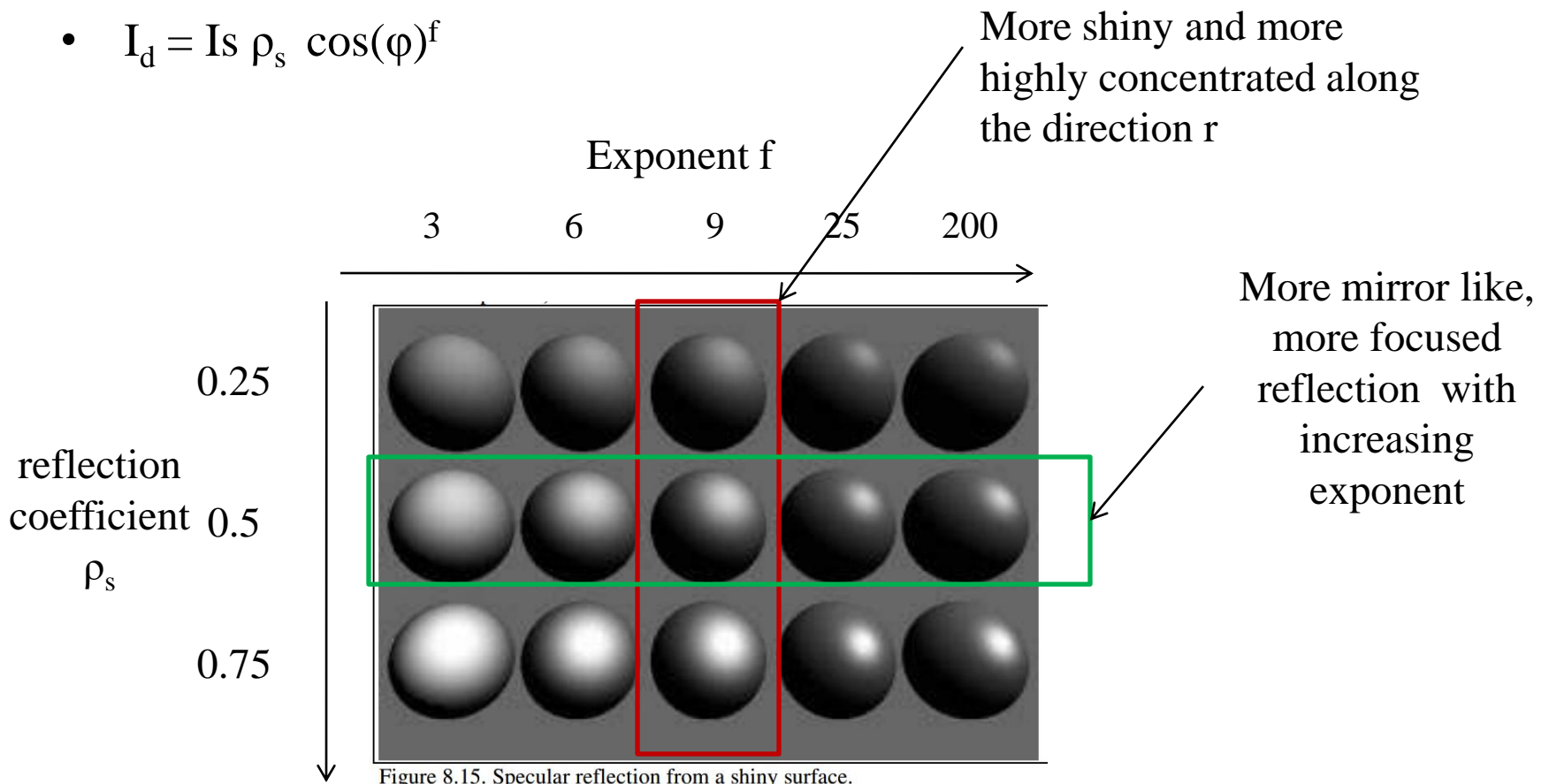


Figure 8.16. On the effect of ambient light.

Specular Reflection Coefficient

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



Color

Adding Color

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

ambient = (I_{ar}, I_{ag}, I_{ab}) , diffuse = (I_{dr}, I_{dg}, I_{db}) , 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:
 $\rho_{sr}, \rho_{sg}, \rho_{sb} = \rho_s$
 - Glossy red apple when illuminated by a yellow light is yellow rather than red

What makes an apple red?

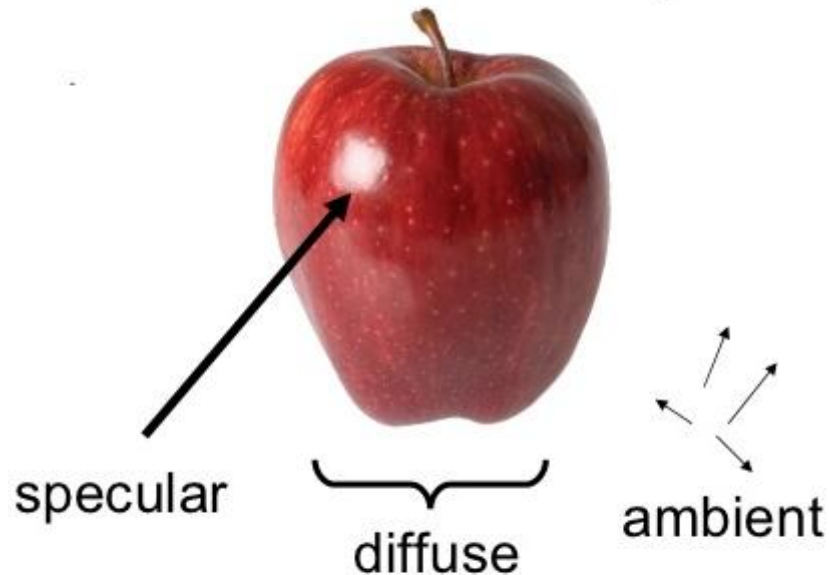


Image synthesis view:

“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 ($I_{sr} = I_{sg} = I_{sb} = I$)
- 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