Intensity Attenuation

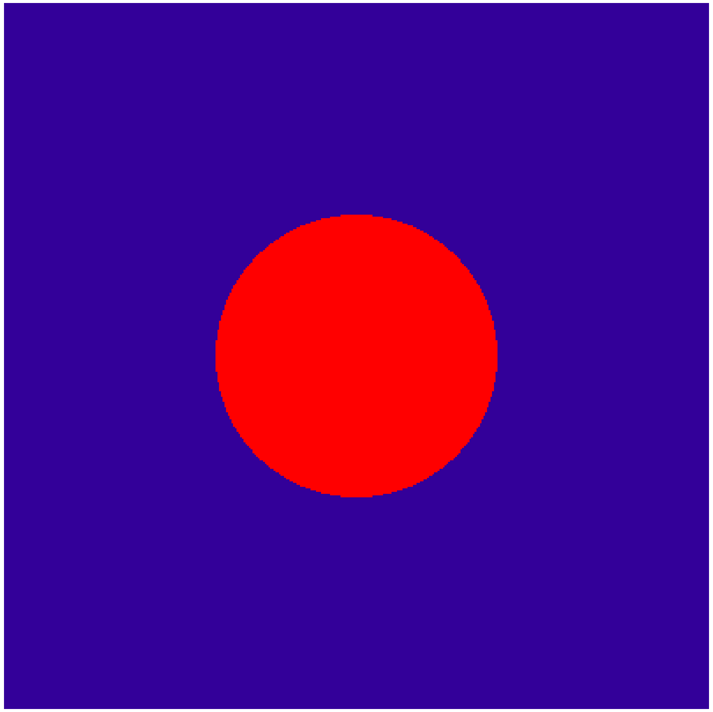
Contents

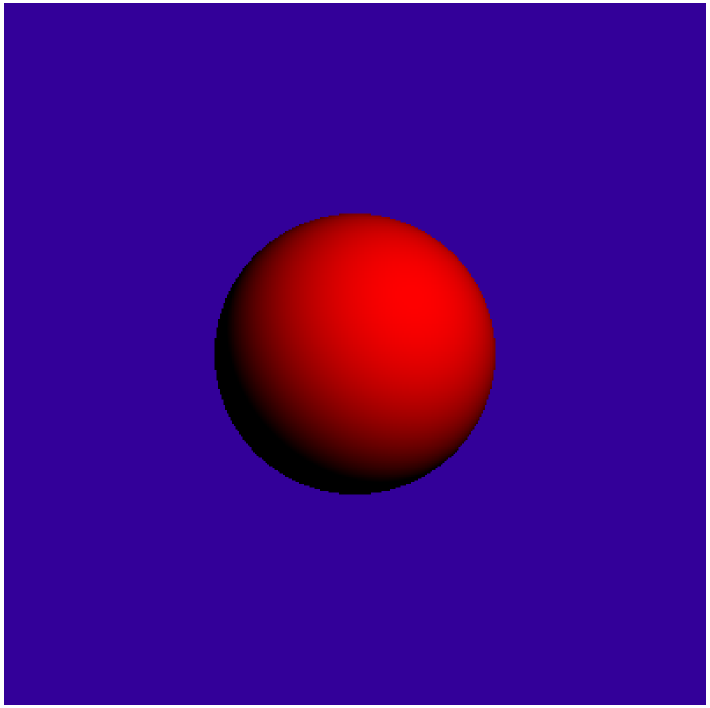
Today we will start to look at illumination models in computer graphics

– Why do we need illumination models?
– Different kinds of lights
– Different kinds of reflections
– Basic lighting model

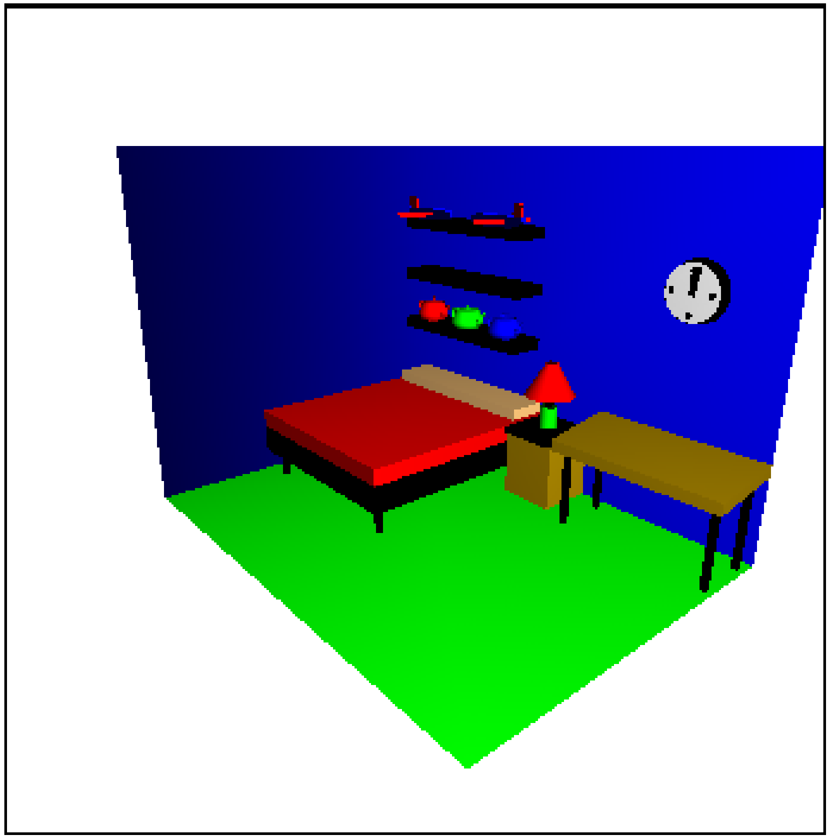
Why Lighting?

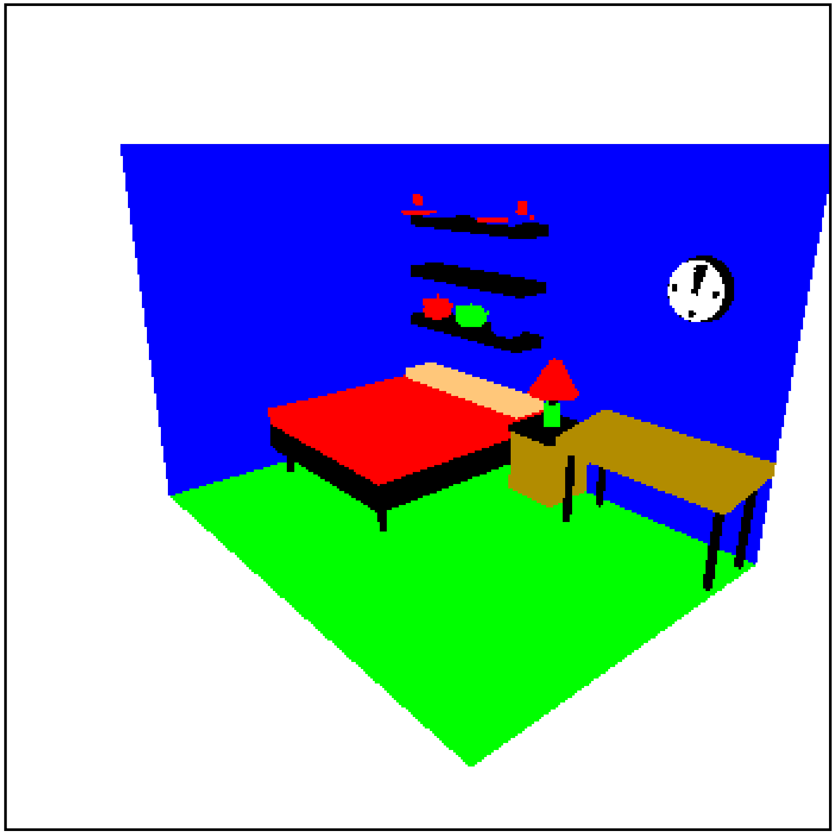
If we don't have lighting effects nothing looks three dimensional!



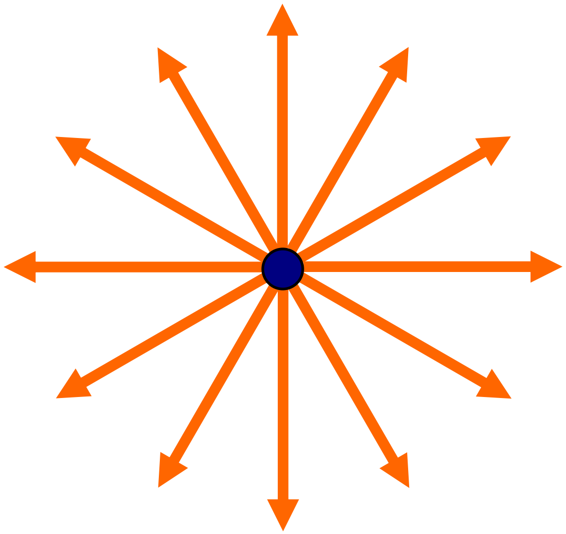


Why Lighting? (cont…)





Point Light Sources



A point source is the simplest model we can use for a light source

We simply define:

- The position of the light
- The RGB values for the colour of the light

Light is emitted in all directions

Useful for small light sources

Radial Intensity Attenuation

As light moves from a light source its intensity diminished

At any distance d_l away from the light source the intensity diminishes by a factor of $1/d_l^2$

However, using the factor $1/d_l^2$ does not produce very good results so we use something different

Radial Intensity Attenuation (cont…)

We use instead in inverse quadratic function of the form:

$$f_{radatten}(d_l) = \frac{1}{a_0 + a_1 d_l + a_2 d_l^{\,2}}$$

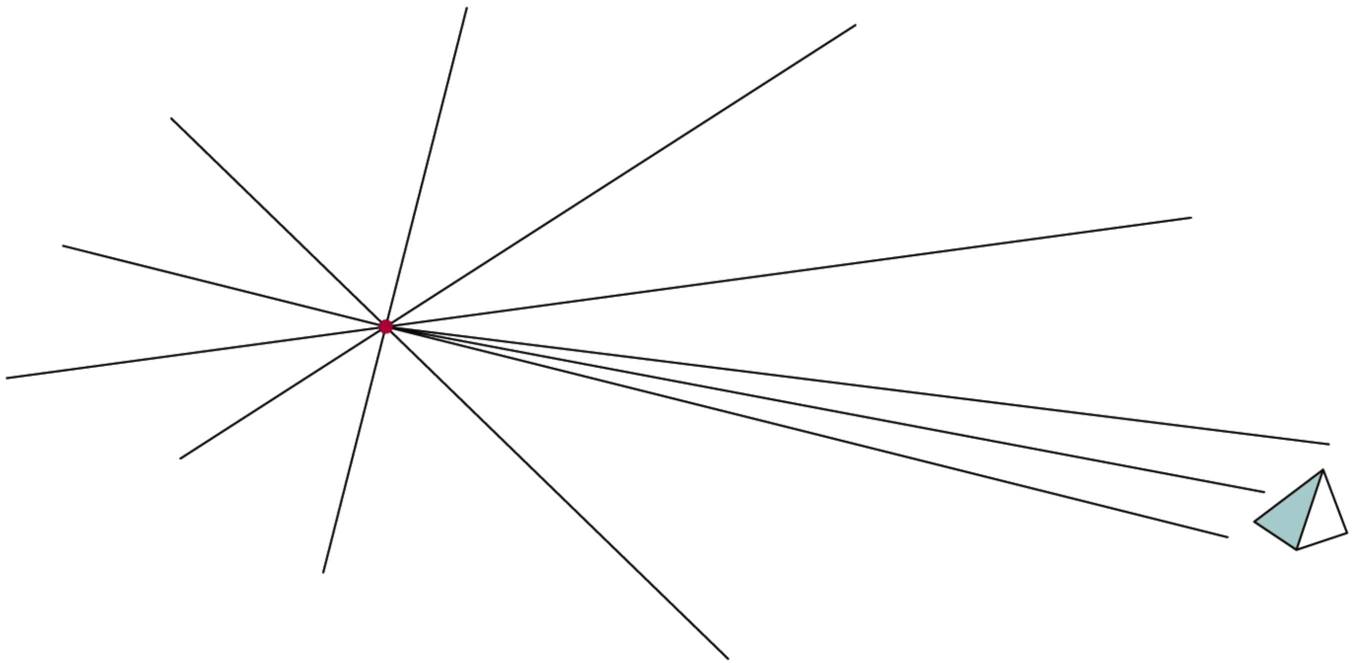
where the coefficients a_0, a_1, and a_2 can be varied to produce optimal results

Infinitely Distant Light Sources

A large light source, like the sun, can be modelled as a point light source

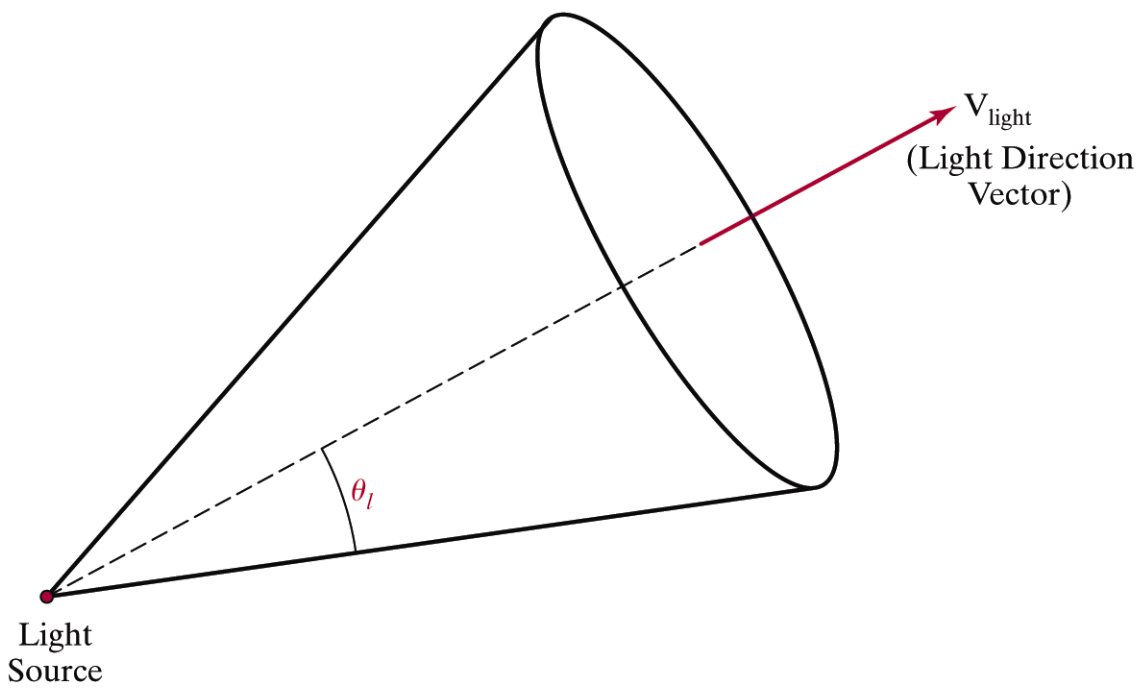
However, it will have very little directional effect

Radial intensity attenuation is not used



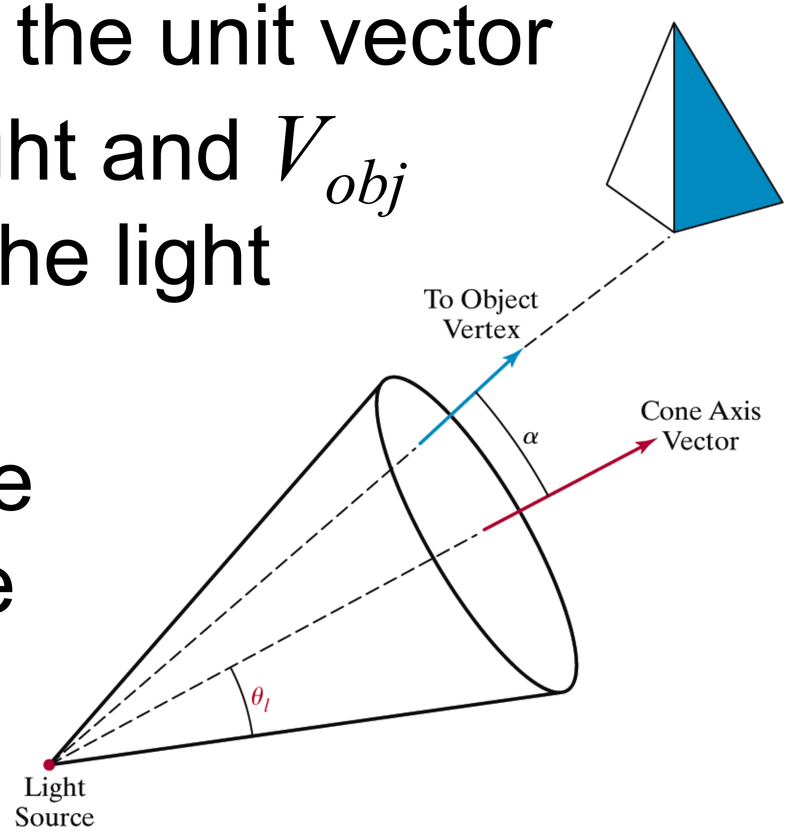
Directional Light Sources & Spotlights

To turn a point light source into a spotlight we simply add a vector direction and an angular limit θ_l



Directional Light Sources & Spotlights (cont…)

We can denote V_{light} as the unit vector in the direction of the light and V_{obj} as the unit vector from the light source to an object



The dot-product of these two vectors gives us the angle between them

$$V_{obj} \cdot V_{light} = \cos\alpha$$

If this angle is inside the light's angular limit then the object is within the spotlight

Angular Intensity Attenuation

As well as light intensity decreasing as we move away from a light source, it also decreases angularly

A commonly used function for calculating angular attenuation is:

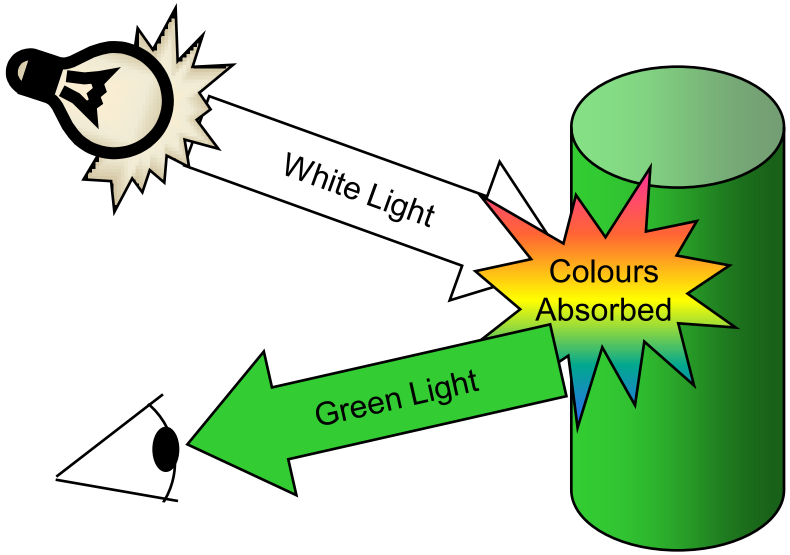
$$f_{angatten}(\phi) = \cos^{a_l} \phi \qquad\qquad 0^\circ \leq \phi \leq \theta$$

where the attenuation exponent a_l is assigned some positive value and angle ϕ is measured from the cone axis

Reflected Light

The colours that we perceive are determined by the nature of the light reflected from an object

For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object



Surface Lighting Effects

The amount of incident light reflected by a surface depends on the type of material

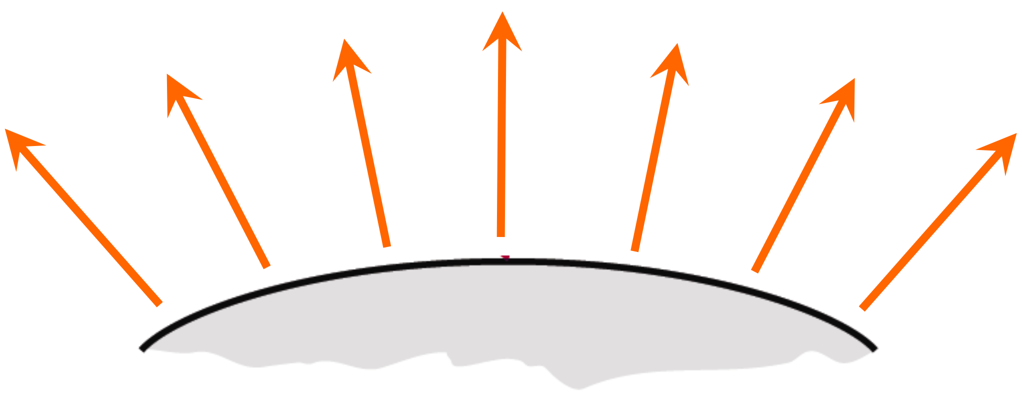
Shiny materials reflect more of the incident light and dull surfaces absorb more of the incident light

For transparent surfaces some of the light is also transmitted through the material

Diffuse Reflection

Surfaces that are rough or grainy tend to reflect light in all directions

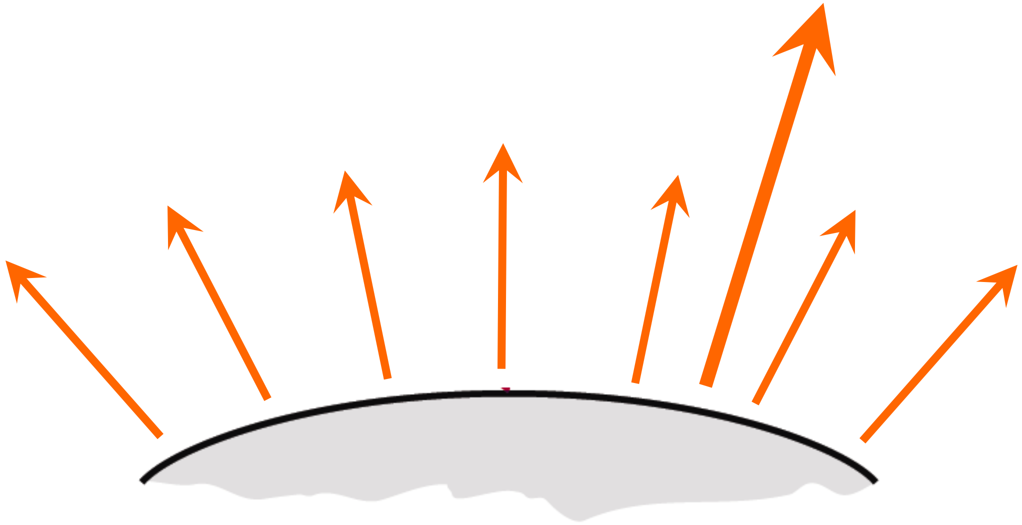
This scattered light is called **diffuse reflection**



Specular Reflection

Additionally to diffuse reflection some of the reflected light is concentrated into a highlight or bright spot

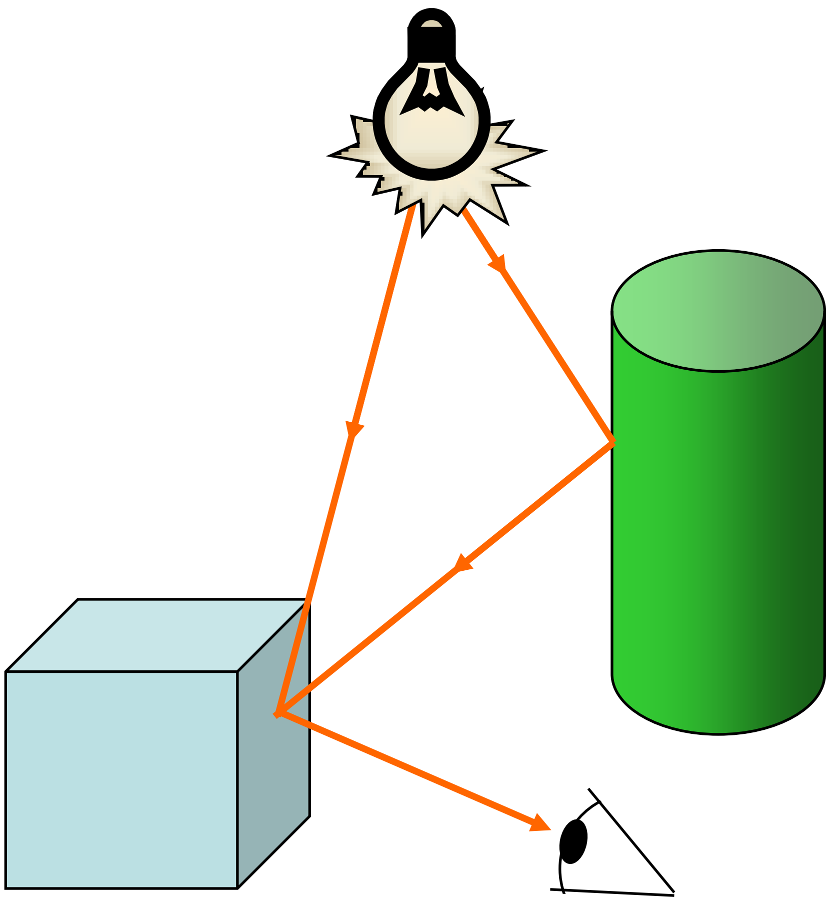
This is called **specular reflection**



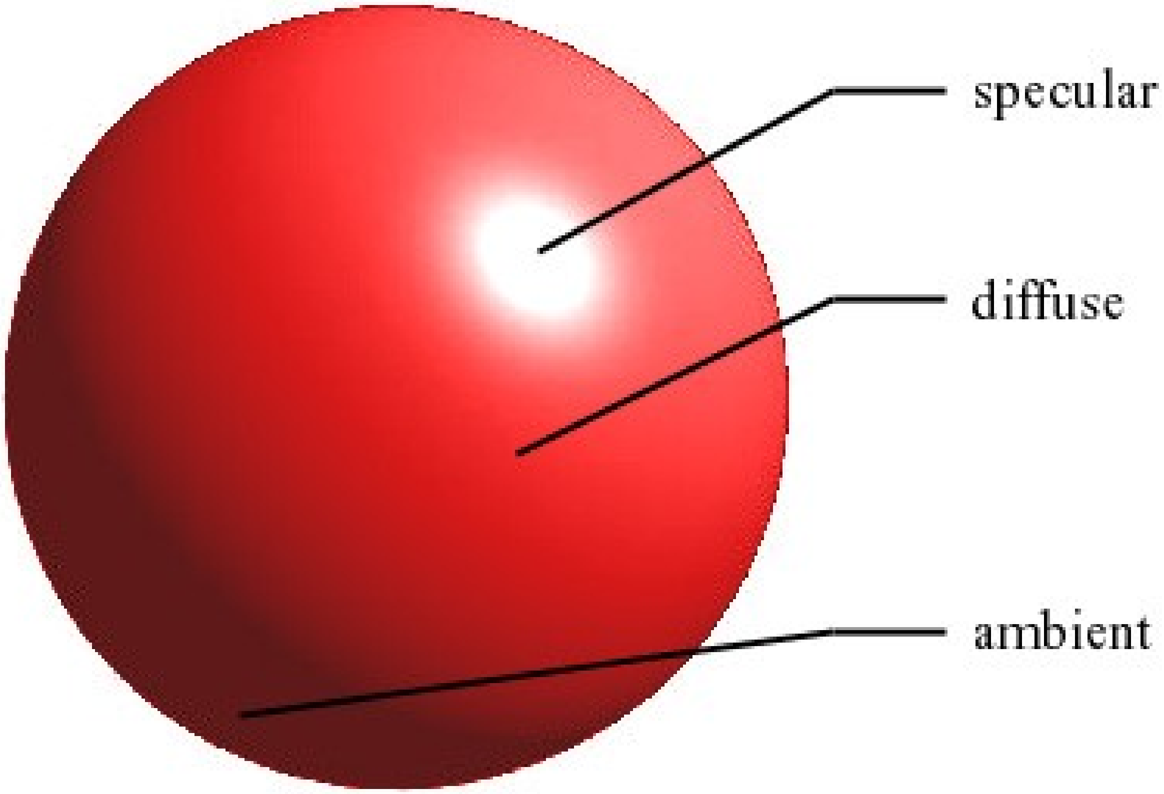
Ambient Light

A surface that is not exposed to direct light may still be lit up by reflections from other nearby objects – **ambient light**

The total reflected light from a surface is the sum of the contributions from light
sources and reflected light



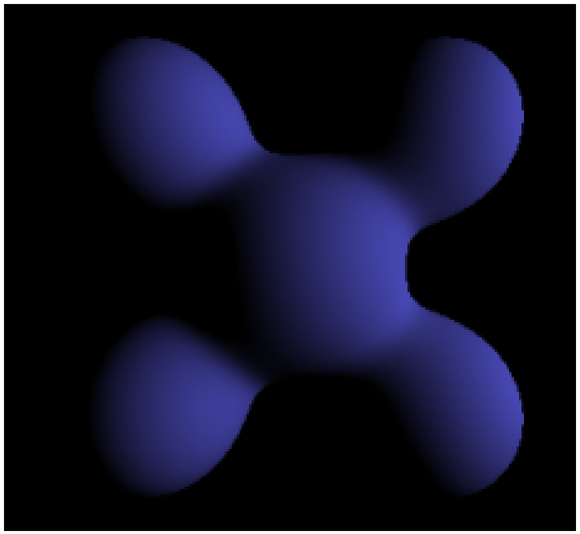
Example



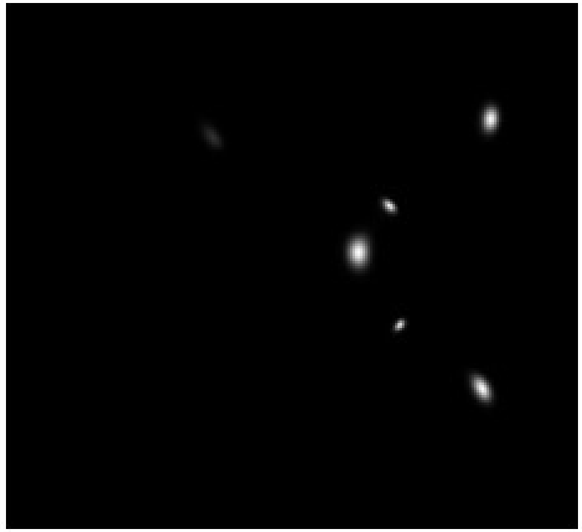
Example

Ambient

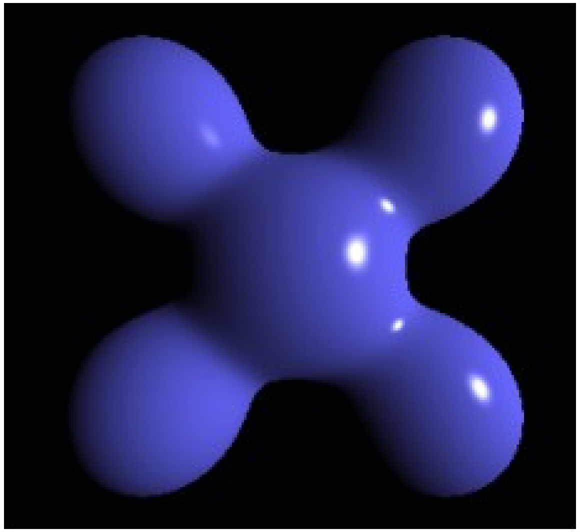
Diffuse



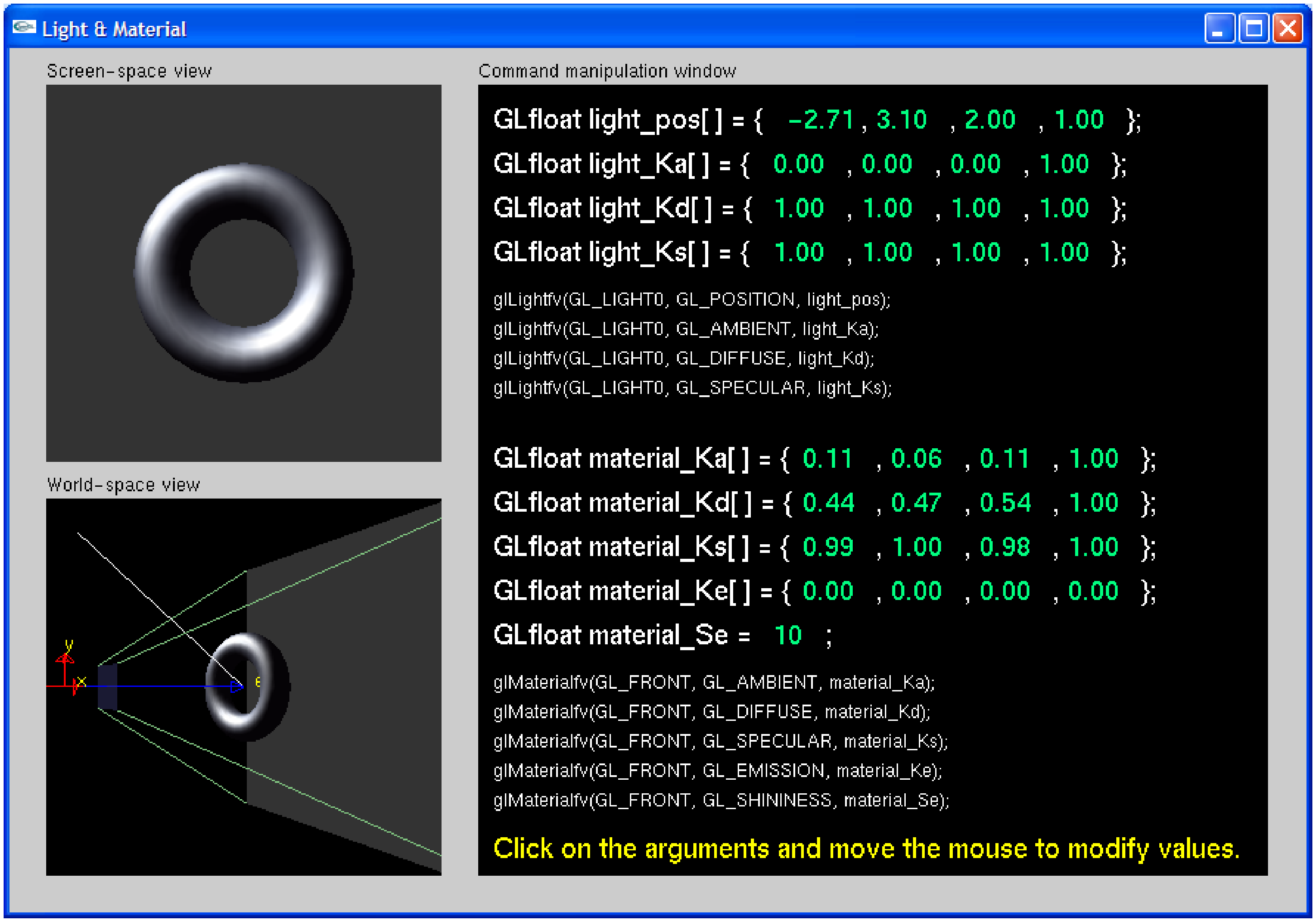
Specular



Final Image



Nate Robin’s Tutorial



Nate Robin’s OpenGL Tutorials available at: http://www.xmission.com/~nate/tutors.html

Basic Illumination Model

We will consider a basic illumination model which gives reasonably good results and is used in most graphics systems

The important components are:

- Ambient light
- Diffuse reflection
- Specular reflection

For the most part we will consider only monochromatic light

Ambient Light

To incorporate background light we simply set a general brightness level for a scene

This approximates the global diffuse reflections from various surfaces within the scene

We will denote this value as I_a

Diffuse Reflection

First we assume that surfaces reflect incident light with equal intensity in all directions

Such surfaces are referred to as **ideal diffuse reflectors** or **Lambertian reflectors**

Diffuse Reflection (cont…)

A parameter k_d is set for each surface that determines the fraction of incident light that is to be scattered as diffuse reflections from that surface

This parameter is known as the **diffuse-reflection coefficient** or the **diffuse reflectivity**

k_d is assigned a value between 0.0 and 1.0

- 0.0: dull surface that absorbs almost all light
- 1.0: shiny surface that reflects almost all light

Diffuse Reflection – Ambient Light

For background lighting effects we can assume that every surface is fully illuminated by the scene's ambient light I_a

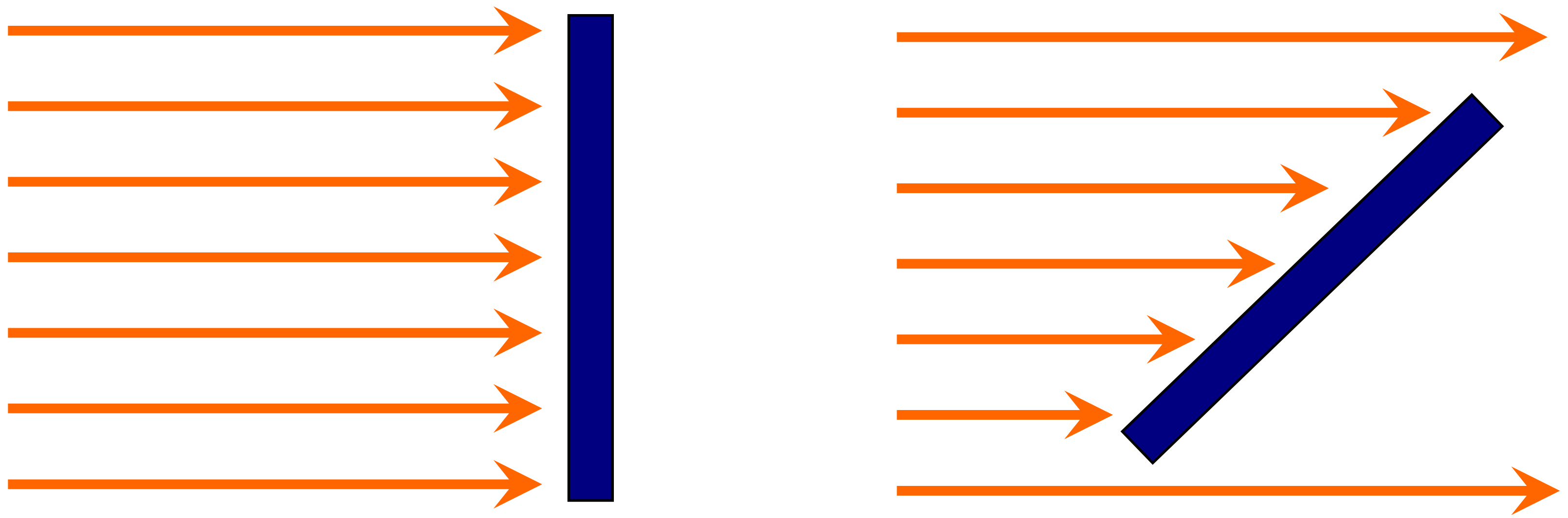
Therefore the ambient contribution to the diffuse reflection is given as:

$$I_{ambdiff} = k_d I_a$$

Ambient light alone is very uninteresting so we need some other lights in a scene as well

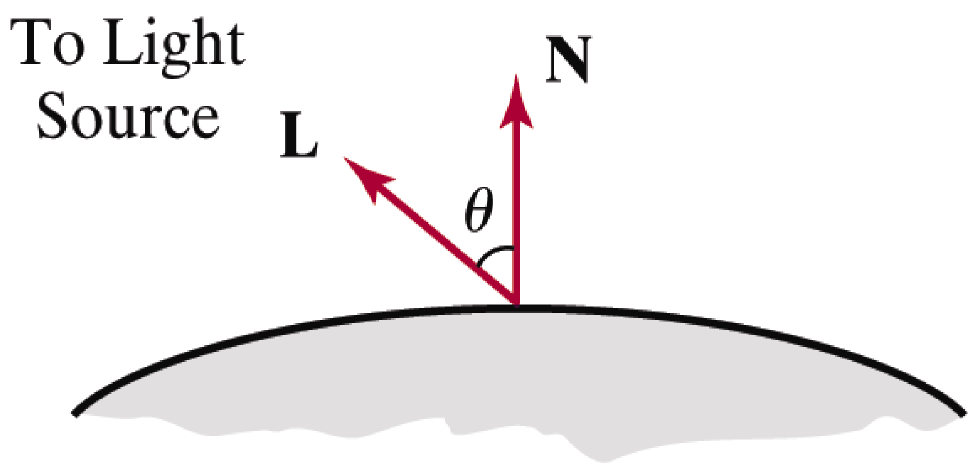
Diffuse Reflection (cont…)

When a surface is illuminated by a light source, the amount of incident light depends on the orientation of the surface relative to the light source direction



Diffuse Reflection

The angle between the incoming light direction and a surface normal is referred to as the **angle of incidence** given as θ



Diffuse Reflection (cont…)

So the amount of incident light on a surface is given as:

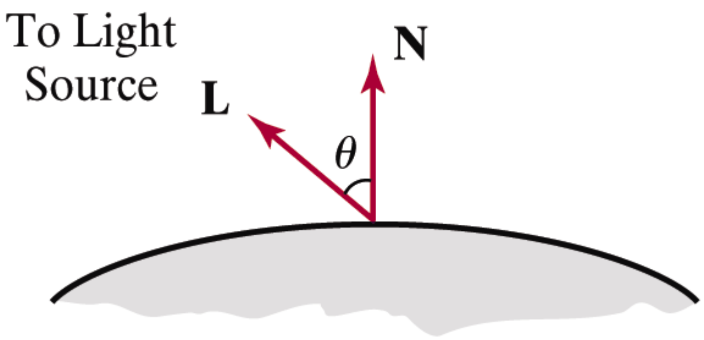
$$I_{l,incident} = I_l \cos\theta$$

So we can model the diffuse reflections as:

$$\begin{aligned} I_{l,diff} &= k_d I_{l,incident} \\ &= k_d I_l \cos\theta \end{aligned}$$

Diffuse Reflection (cont…)

Assuming we denote the normal for a surface as N and the unit direction vector to the light source as L then:



$$N \cdot L = \cos\theta$$

So:

$$I_{l,diff} = \begin{cases} k_d I_l (N \cdot L) & \text{if } N \cdot L > 0 \\ 0 & \text{if } N \cdot L \leq 0 \end{cases}$$

Combining Ambient And Incident Diffuse Reflections

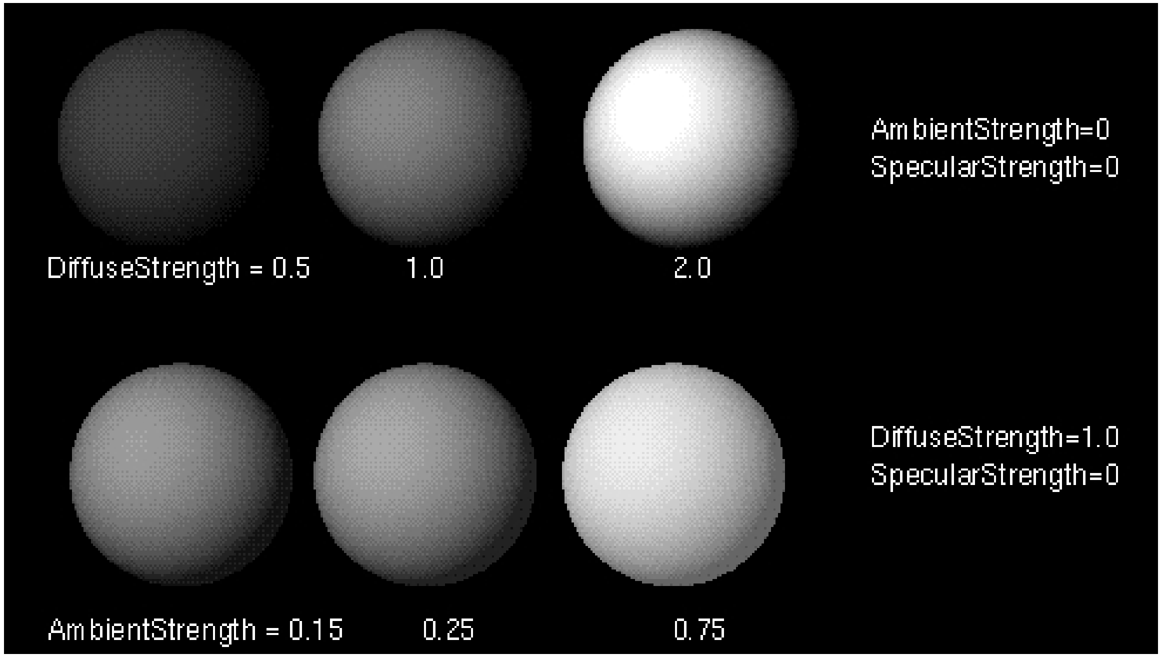
To combine the diffuse reflections arising from ambient and incident light most graphics packages use two separate diffuse-reflection coefficients:

- k_a for ambient light
- k_d for incident light

The total diffuse reflection equation for a single point source can then be given as:

$$I_{diff} = \begin{cases} k_a I_a + k_d I_l (N \cdot L) & \text{if } N \cdot L > 0 \\ k_a I_a & \text{if } N \cdot L \le 0 \end{cases}$$

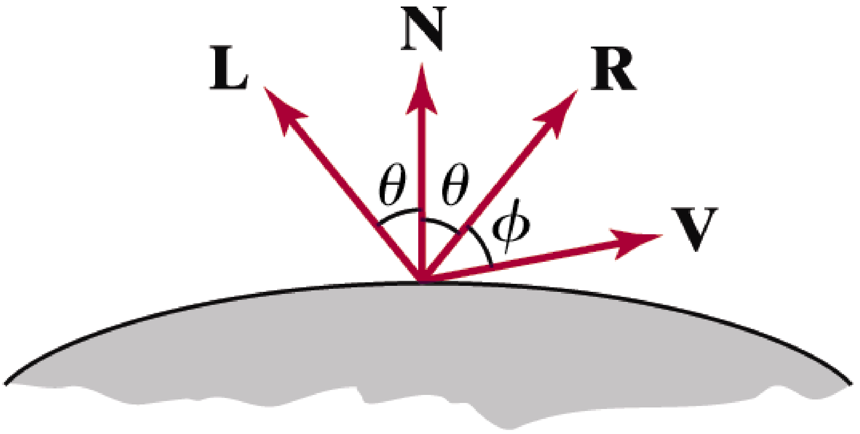
Examples


AmbientStrength=0
SpecularStrength=0
DiffuseStrength = 0.5
1.0
2.0
DiffuseStrength=1.0
SpecularStrength=0
AmbientStrength = 0.15
0.25
0.75

Specular Reflection

The bright spot that we see on a shiny surface is the result of near total of the incident light in a concentrated region around the **specular reflection angle**

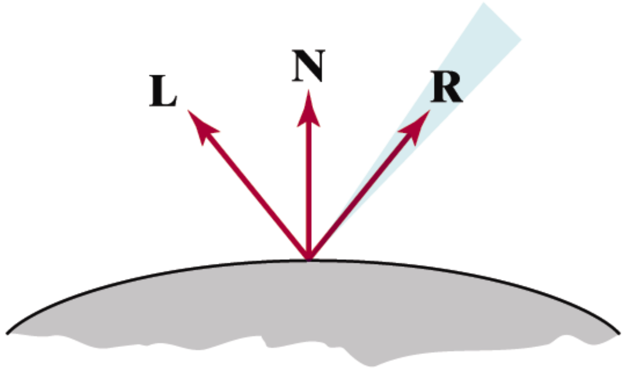
The specular reflection angle equals the angle of the incident light



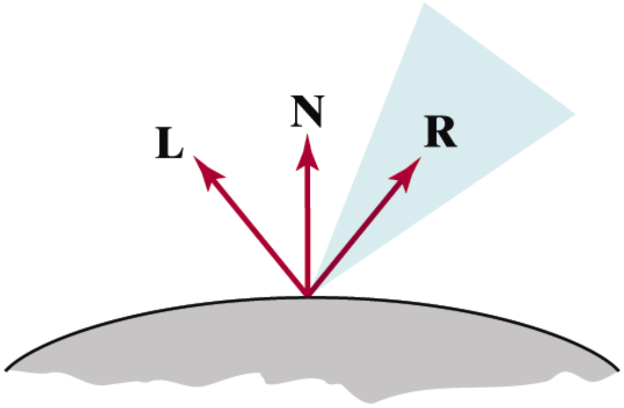
Specular Reflection (cont…)

A perfect mirror reflects light only in the specular-reflection direction

Other objects exhibit specular reflections over a finite range of viewing positions around vector *R*



Shiny Surface
(Large n_s)

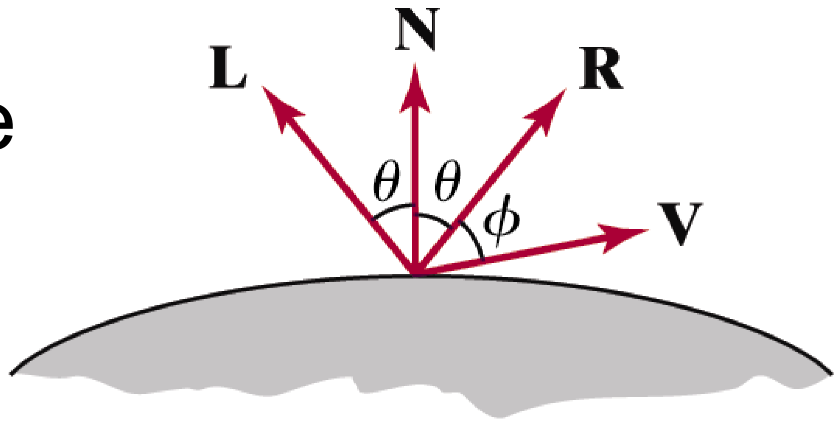


Dull Surface
(Small n_s)

The Phong Specular Reflection Model

The **Phong specular reflection** model or **Phong model** is an empirical model for calculating specular reflection range developed in 1973 by Phong Bui Tuong

The Phong model sets the intensity of specular reflection as proportional to the angle between the viewing vector and the specular reflection vector



The Phong Specular Reflection Model (cont…)

So, the specular reflection intensity is proportional to $\cos^{n_s} \phi$

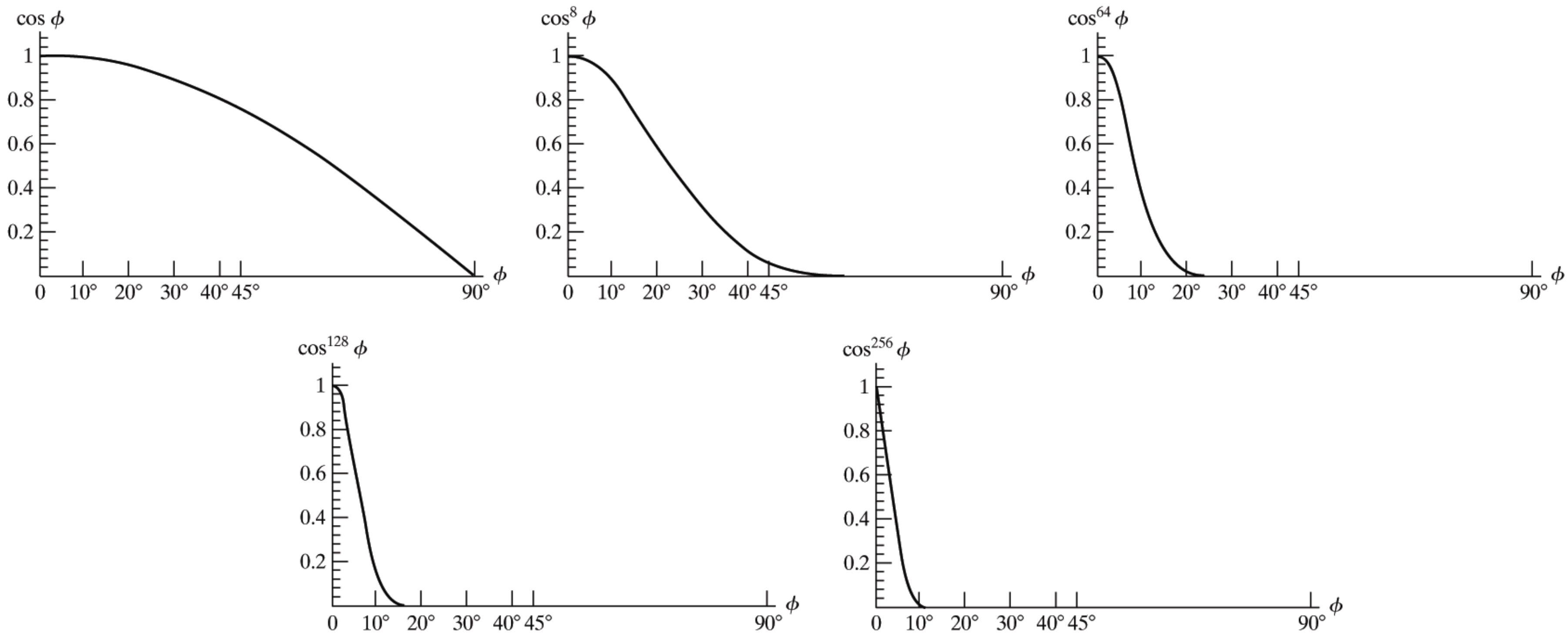
The angle *Φ* can be varied between 0° and 90° so that cos*Φ* varies from 1.0 to 0.0

The **specular-reflection exponent**, n_s is determined by the type of surface we want to display

- Shiny surfaces have a very large value (>100)
- Rough surfaces would have a value near 1

The Phong Specular Reflection Model (cont…)

The graphs below show the effect of n_s on the angular range in which we can expect to see specular reflections



The Phong Specular Reflection Model (cont…)

For some materials the amount of specular reflection depends heavily on the angle of the incident light

Fresnel's Laws of Reflection describe in great detail how specular reflections behave

However, we don't need to worry about this and instead approximate the specular effects with a constant specular reflection coefficient k_s

The Phong Specular Reflection Model (cont…)

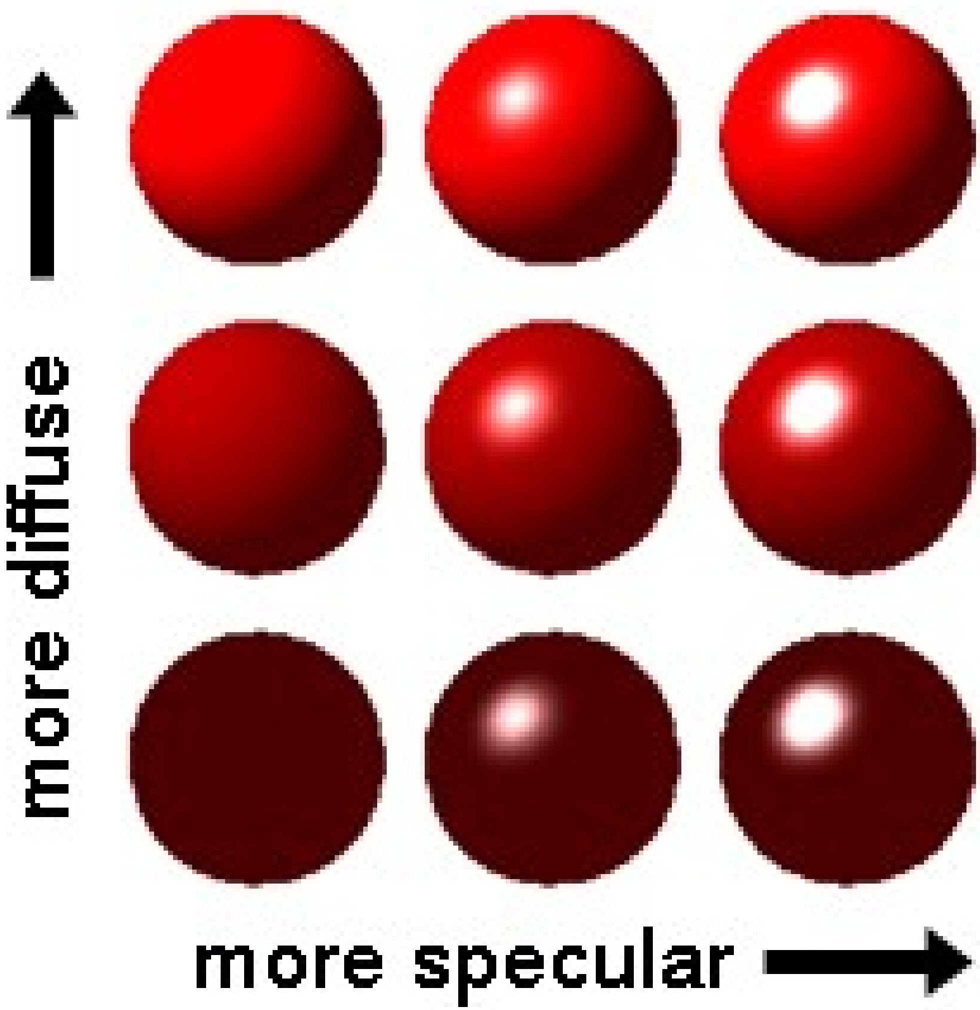
So the specular reflection intensity is given as:

$$I_{l,spec} = k_s I_l \cos^{n_s} \phi$$

Remembering that $V \cdot R = \cos \phi$ we can say:

$$I_{l,spec} = \begin{cases} k_s I_l (V \cdot R)^{n_s} & \text{if } V \cdot R > 0 \text{ and } N \cdot L > 0 \\ 0.0 & \text{if } V \cdot R < 0 \text{ or } N \cdot L \leq 0 \end{cases}$$

Example



Combining Diffuse & Specular Reflections

For a single light source we can combine the effects of diffuse and specular reflections simply as follows:

$$I = I_{diff} + I_{spec}$$

$$= k_a I_a + k_d I_l (N \cdot L) + k_s I_l (V \cdot R)^{n_s}$$

Diffuse & Specular Reflections From Multiple Light Sources

We can place any number of light sources in a scene

We compute the diffuse and specular reflections as sums of the contributions from the various sources

$$I = I_{ambdiff} + \sum_{l=1}^{n} \left[I_{l,diff} + I_{l,spec} \right]$$

$$= k_a I_a + \sum_{l=1}^{n} I_l \left[k_d (N \cdot L) + k_s (V \cdot R)^{n_s} \right]$$

Common Exam Question

Adding Intensity Attenuation

To incorporate radial and angular intensity attenuation into our model we simply adjust our equation to take these into account

So, light intensity is now given as:

$$I = I_{ambdiff} + \sum_{l=1}^{n} \left[f_{l,radatten} f_{l,angatten} \left(I_{l,diff} + I_{l,spec} \right) \right]$$

where $f_{radatten}$ and $f_{angatten}$ are as discussed previously

RGB Colour Considerations

For an RGB colour description each intensity specification is a three element vector

So, for each light source:

$$I_l = (I_{lR}, I_{lG}, I_{lB})$$

Similarly all parameters are given as vectors:

$$k_a = (k_{aR}, k_{aG}, k_{aB}) \qquad k_d = (k_{dR}, k_{dG}, k_{dB})$$

$$k_s = (k_{sR}, k_{sG}, k_{sB})$$

RGB Colour Considerations (cont…)

Each component of the surface colour is then calculated with a separate expression

For example:

$$I_{lR,diff} = k_{dR} I_{lR} (N \cdot L)$$

$$I_{lG,diff} = k_{dG} I_{lG} (N \cdot L)$$

$$I_{lB,diff} = k_{dB} I_{lB} (N \cdot L)$$

Summary

T create realistic (or even semi-realistic) looking scenes we must model light correctly

To successfully model lighting effects we need to consider:

- Ambient light
- Diffuse reflections
- Specular reflections