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Module 4

Color and Illumination Models

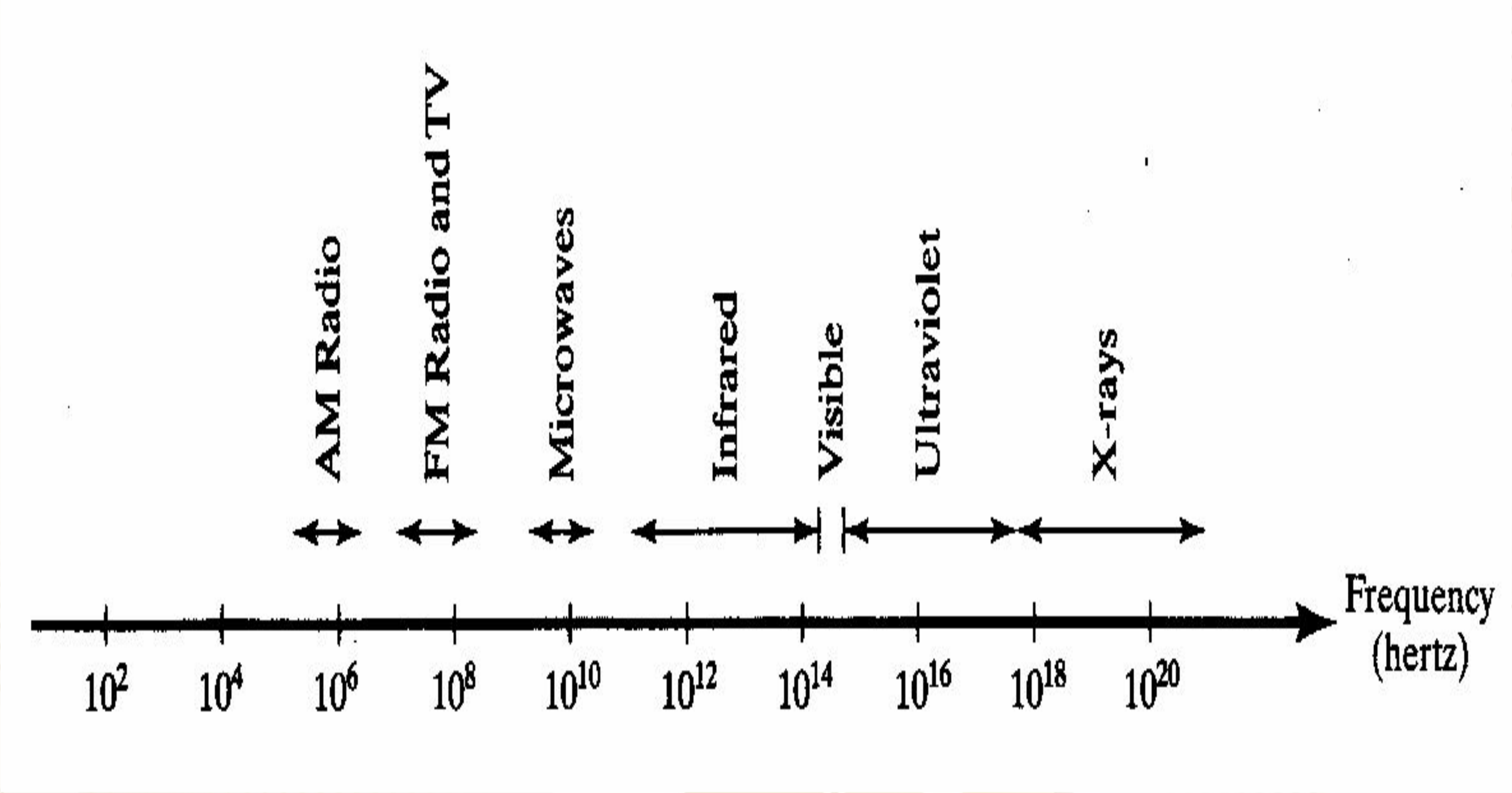
Color Models –properties of Light

- Light is radiant energy
- Color is electromagnetic radiation within a narrow frequency band.
- Other frequency groups in the electromagnetic spectrum are referred to as radio waves,microwaves, infrared waves and x-rays.

Spectral color

- Each frequency value within the **visible region** of spectrum corresponds to a distinct spectral color
- Low frequency end(3.8×10^{14} hertz) –red colors (780 nm)
- High frequency end (7.9×10^{14} hertz- violet colors (380 nm)

Physical properties of light



Visible light is part of the electromagnetic radiation (380-780 nm)

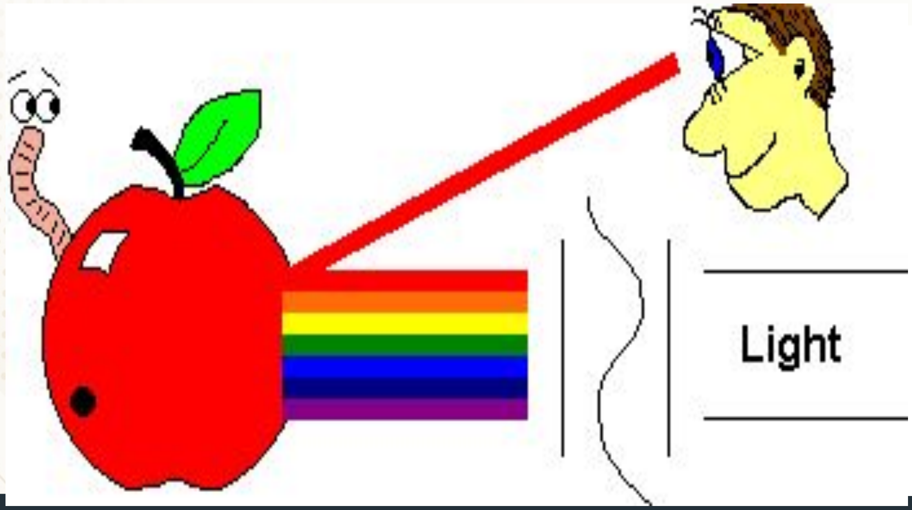
1 nm (nanometer) = 10^{-10} m (=10^{-7} cm)

1 Å (angstrom) = 10 nm

Radiation can be expressed in wavelength (λ) or frequency (f), $c=\lambda f$, where $c=3 \times 10^{10}$ cm/sec

Properties of Light

- When white light is incident on an opaque object , some frequencies are reflected and some are absorbed.
- The combination of frequencies present in the reflected light determines the color of the object that we see.(**Dominant frequency or Hue)**



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Characteristics of Color

1. **Dominant Frequency (Hue)or(color)**The color we see (red, green, purple).

2. **Brightness or luminance of the light**

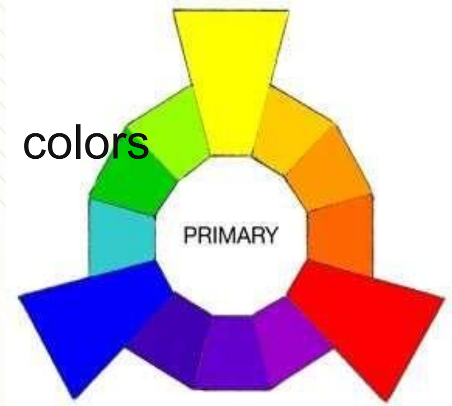
The total light energy, how bright is the color (How bright are the lights illuminating the object?)

3. **Purity (Saturation)**

Purity describes how close a light appears to be to a pure spectral color, such as pink is less saturated than red.

Chromaticity refers to the two properties (purity & hue) together.

Color Model



Primary Colors
Sets of colors that can be combined to make a useful range of colors

Color Gamut
Set of all colors that we can produce from the primary colors.

Complementary Colors
Two primaries that produce white.

Example, in the RGB model: red & cyan , green & magenta , blue & yellow.

- No finite set of real primary colors can be combined to produce all possible visible colors.

- However, given a set of three primary colors, we can characterize any fourth color using color-mixing processes.

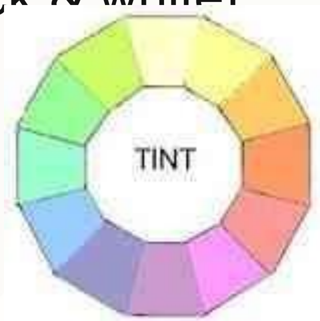
Intuitive color concepts

Shades , Tints & Tones

•A shade is produced by “dimming ” a hue.[Adding black].
Dark Blue = pure blue + black

•A tint is produced by "lightening" a hue. [Adding white].
Pastel red = pure red + white

•Tone refers to the effects of reducing the "colorfulness" of a hue.
[adding gray] or [adding black & white]



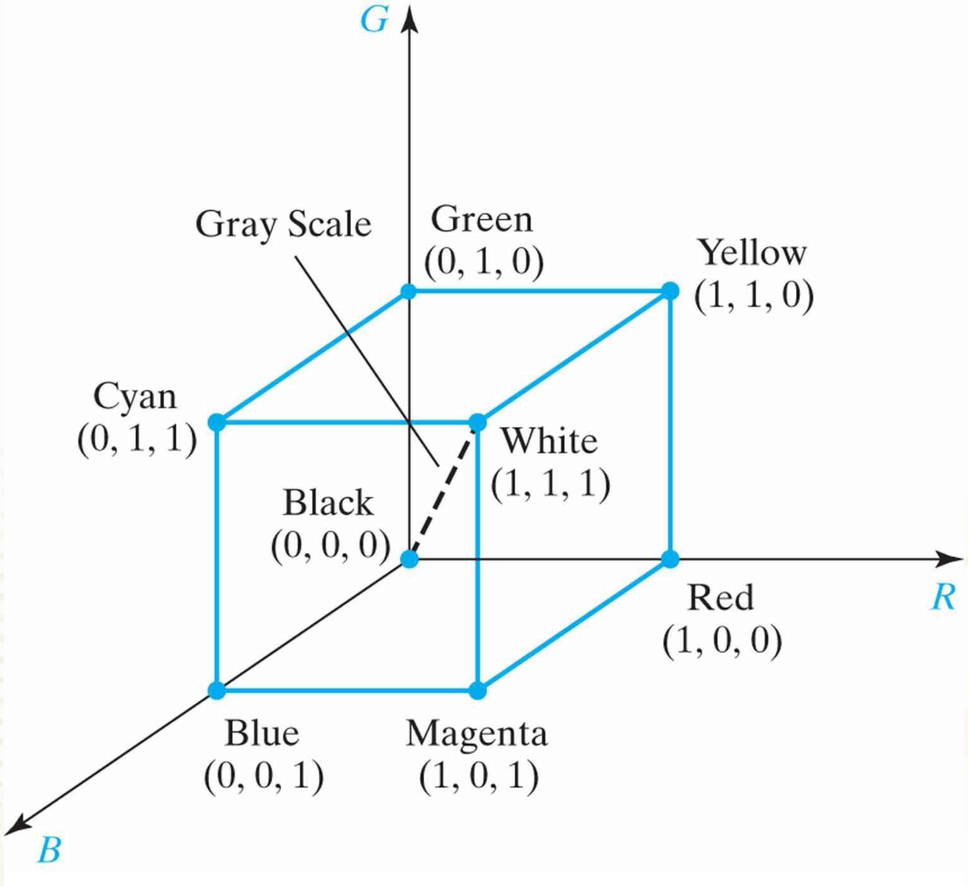
Thus, shading takes a hue toward black, tinting takes a hue towards white, and tones cover the range in between.

RGB Model

Tristimulus theory or Theory of vision

- The red, green, and blue (RGB) color space is widely used throughout computer graphics.
- Additive Color Model.
- Unit Cube defined on R, G & B axes.
- The Origin (0,0,0) represents black and the diagonally opposite vertex (1,1,1) is White.
- Vertices of the cube on the axes represent primary colors, and the remaining vertices are the complementary color points for each of the primary colors.
- Shades of gray are represented along the main diagonal.

Figure 19-11 The RGB color model. Any color within the unit cube can be described as an additive combination of the three primary colors.



RGB Model

Each color point within the unit cube can be represented as w weighted vector sum of the primary colors, using unit vectors **R**,**G** and **B**.

$C(\lambda) = (R,G,B) = R\mathbf{R} + G\mathbf{G} + B\mathbf{B}$

Where R,G, and B are assigned values in the range from 0 to 1.0.

For example , the magenta vertex is obtained by adding the maximum red and blue values to produce : (1,0,1)

CMY(cyan-magenta-yellow) and CMYK Model

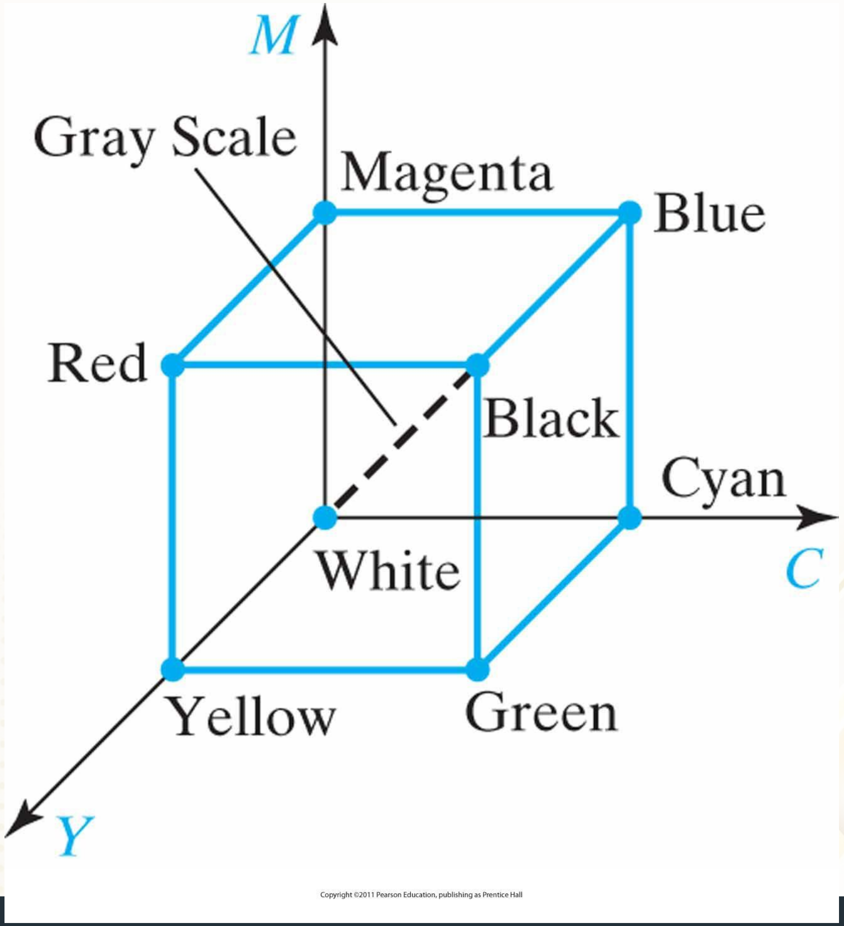
- Subtractive Color Model.

- Used for hardcopy devices (ex. Printers).
- Cyan contains green and blue components, red is subtracted.
- Magenta subtracts green component, yellow subtracts blue component

- A printed color that looks red absorbs the other two components G and B and reflects R.

- Thus the C-M-Y coordinates are just the complements of the R-G-B coordinates.

Figure 19-13 The CMY color model. Positions within the unit cube are described by subtracting the specified amounts of the primary colors from white.



(1,1,1)- black. All components of incident light are subtracted.

Origin represents white.

Shades of gray along the diagonal

Combination of cyan and magenta ink produces blue light, because red and green components of the incident light are absorbed

Cyan+ yellow=green

Magenta+yellow=red

Transformation between CMY and RGB color spaces

In additive color models such as RGB, white is the "additive" combination of all primary colored lights, while black is the absence of light.

In the CMYK model, it is the opposite: white is the natural color of the paper or other background, while black results from a full combination of colored inks.

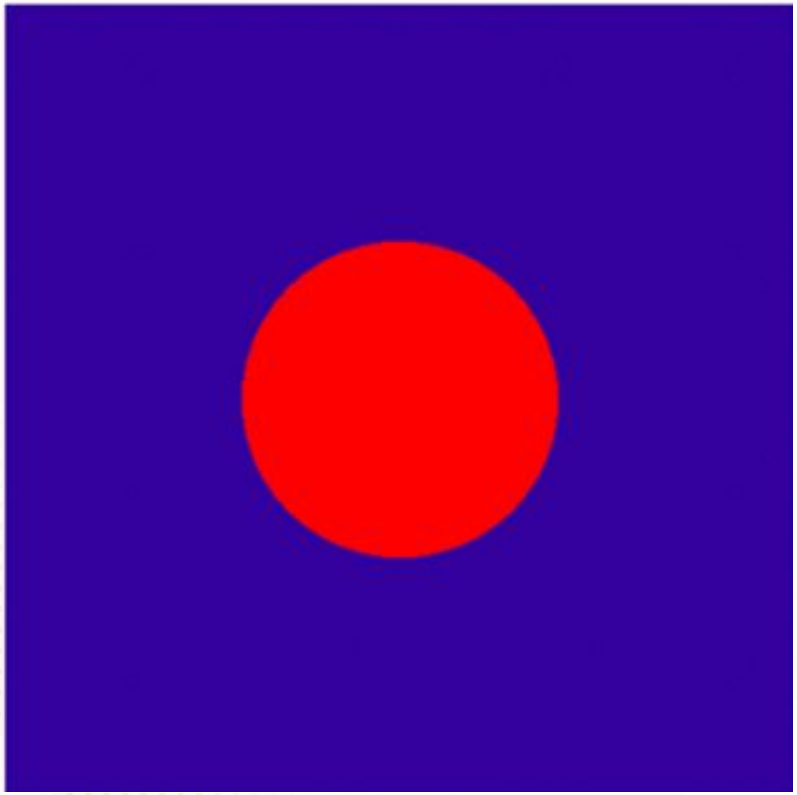
RGB To CMY

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

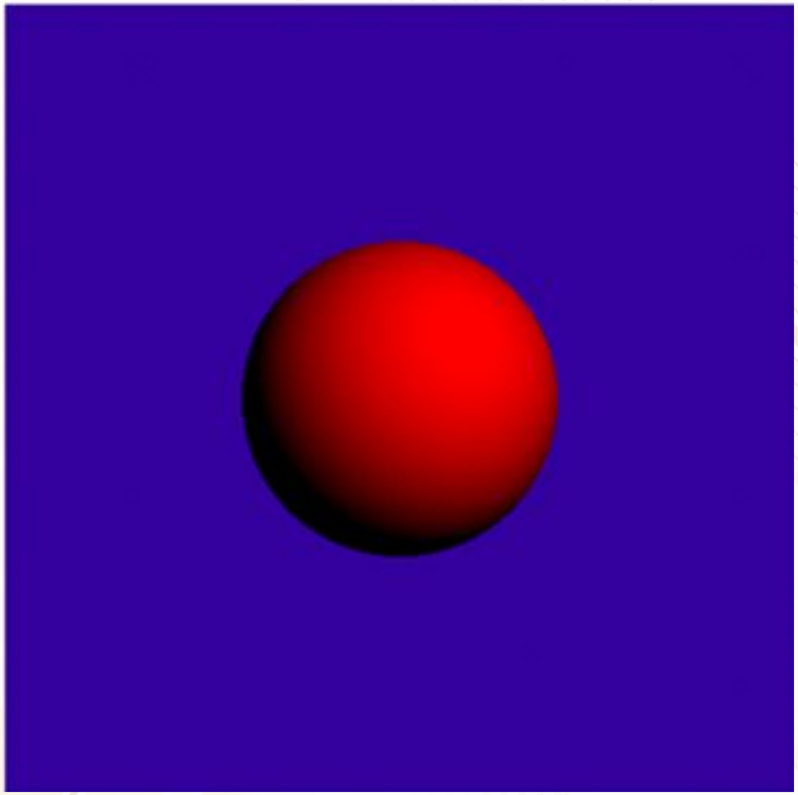
CMY To RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

Lighting

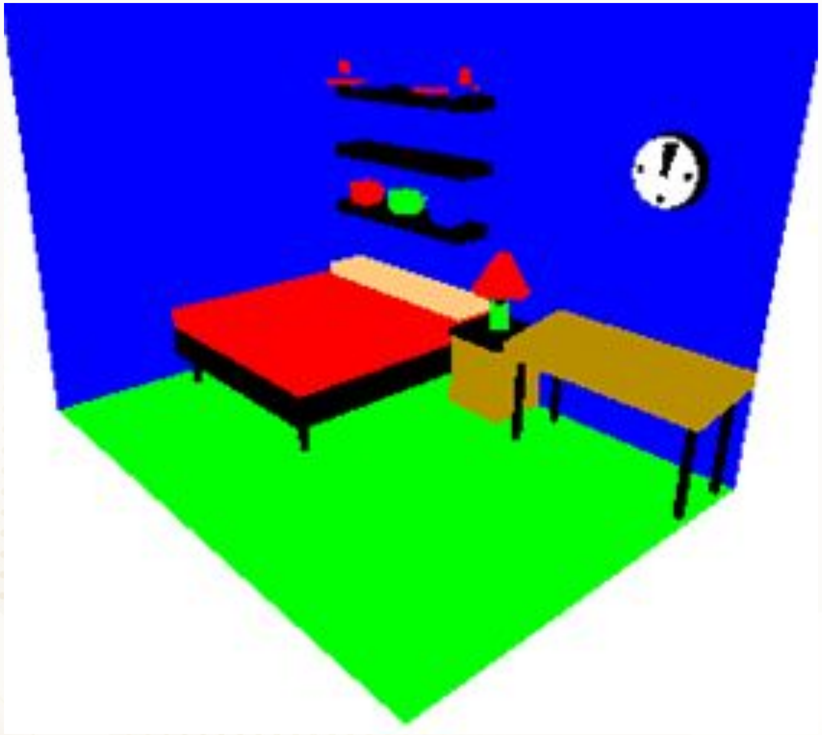


3D without lighting

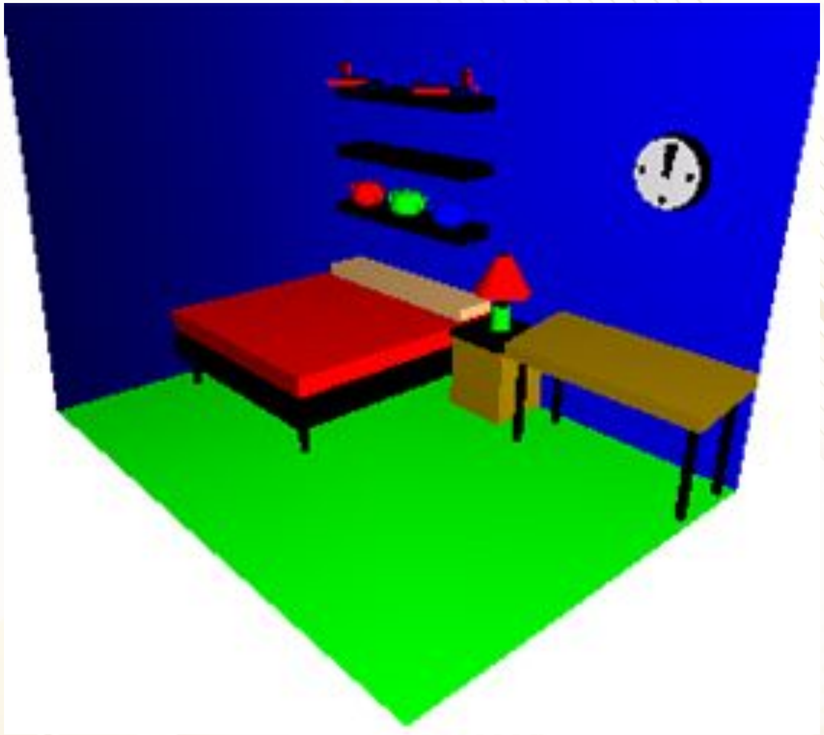


3D with lighting

3D without lighting



3D with lighting



Light sources

Point light sources

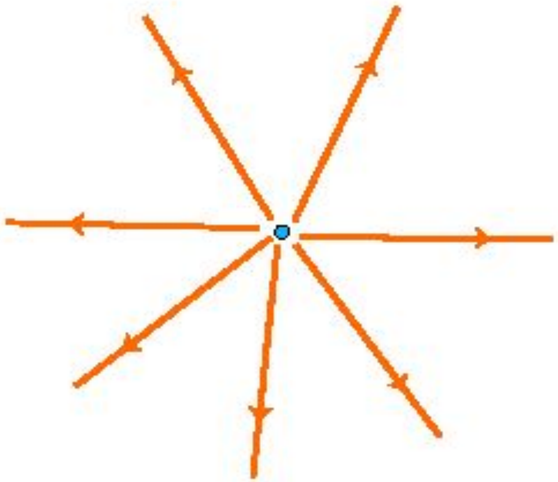
Infinitely Distant Light sources

Directional light sources and spotlight effects

Any object that is emitting radiant energy is a light source

Point Light Sources

- Described by a position and a light color
- Light rays are emitted from the point light source in all directions

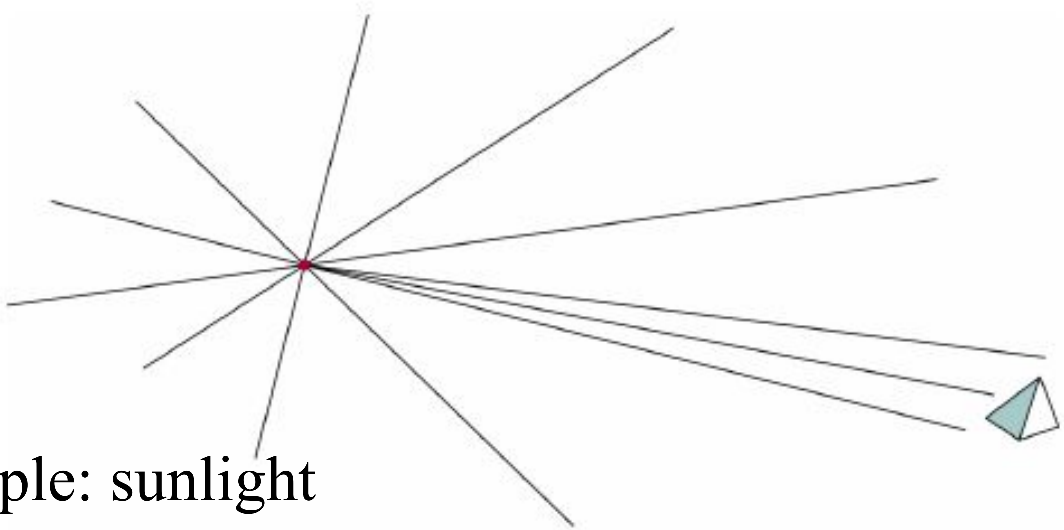


- The position information is used to identify the objects illuminated by the point source.

Infinitely Distant Light Sources

Large light source sun, very far from scene

- They can be simulated by a single emission direction vector. This direction is used to calculate the amount of light received at a position.



-Example: sunlight

The light from a distant light source to any position in the scene is nearly constant

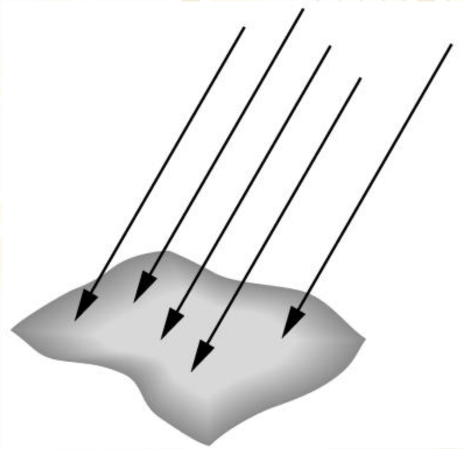
Distant light sources

we replace location of light sources with their directions.

The location of a point light source at p_o is represented internally as 4 dimensional column matrix $p_0 = [\ x\ ,\ y\ ,\ z\ ,\ 1\ ]^T$.

The distant light source

$p_o = [\ x, y, z\ ,0]^T$



Directional Light Sources and Spotlight Effects

- A directional light source can be defined by a light direction (V_{light}) and an angular limit (θ_l)

Objects outside the light cone will not be illuminated.

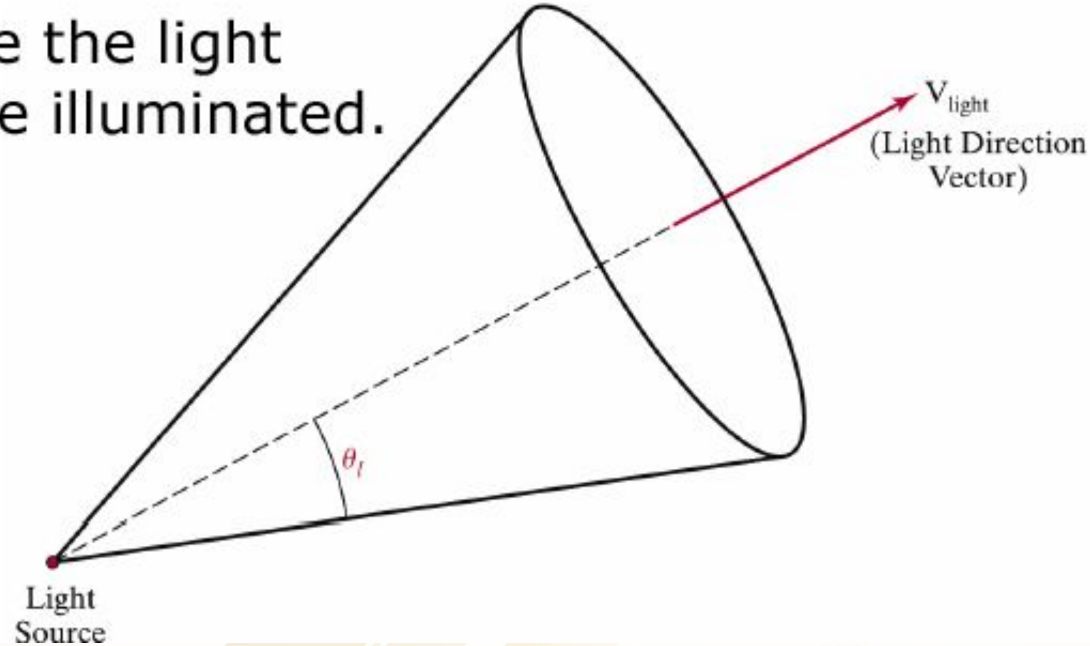


Figure 17-3 A directional point light source. The unit light-direction vector defines the axis of a light cone, and angle θ_l defines the angular extent of the circular cone.

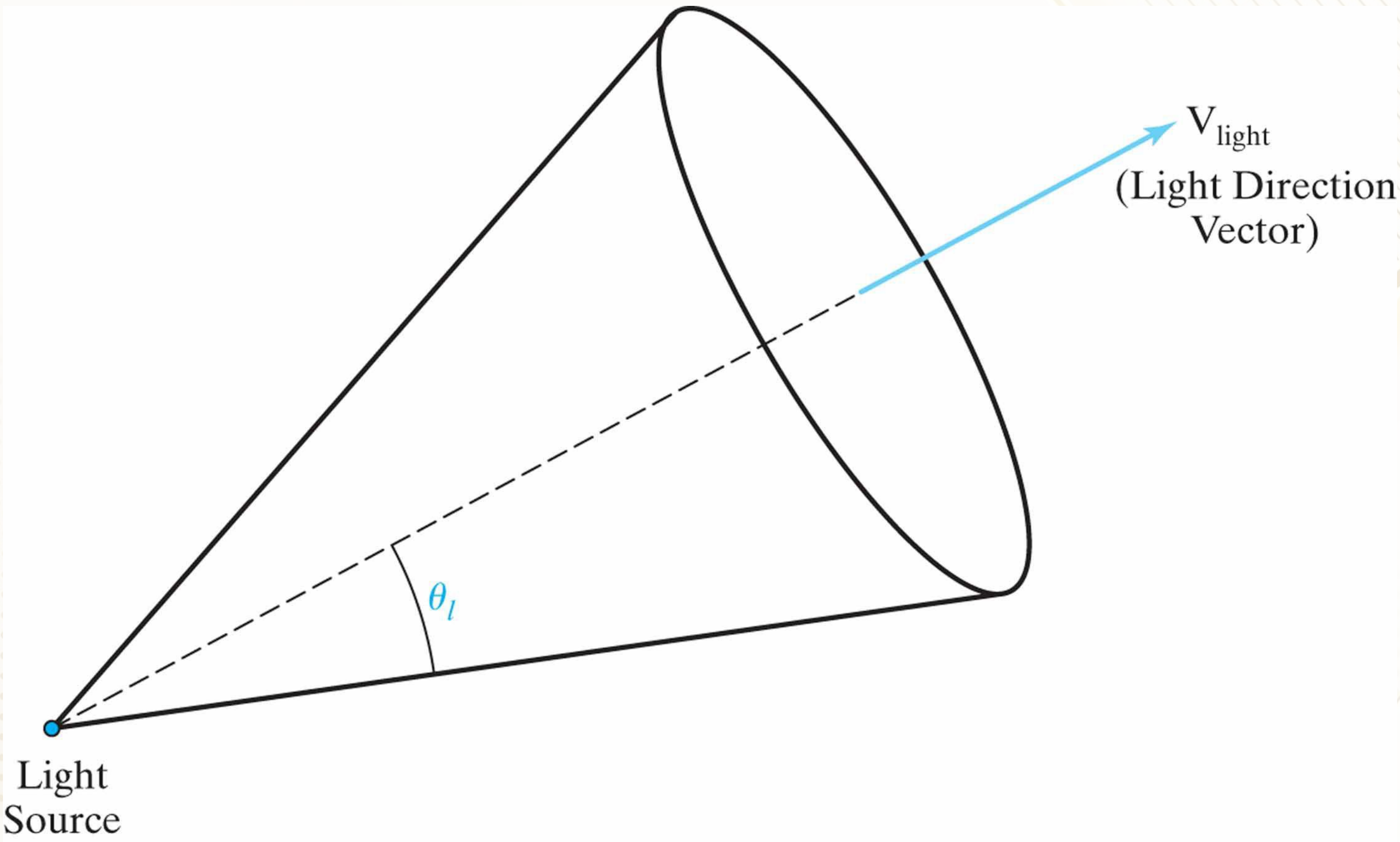
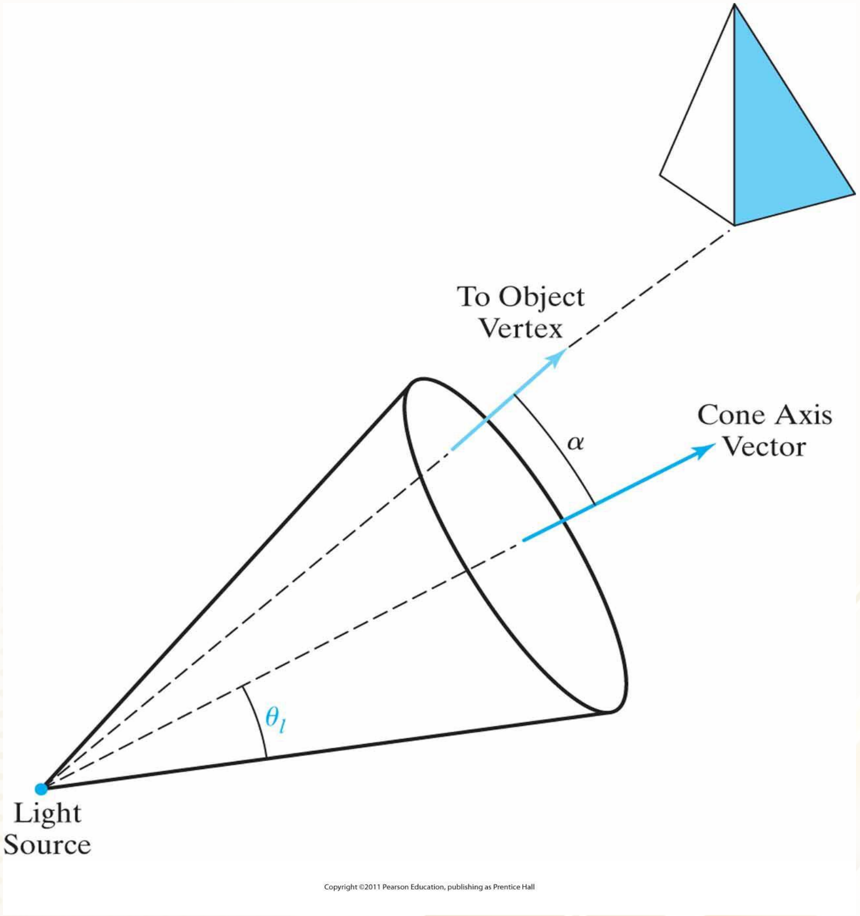


Figure 17-4 An object illuminated by a directional point light source.

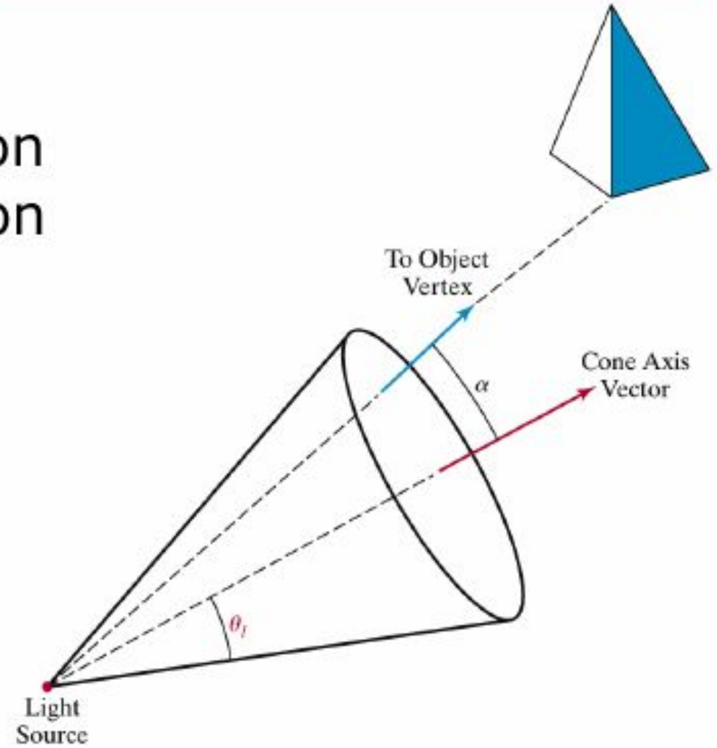


Determination of objects inside the light cone

- The cosine of the angle between the light direction vector and object direction is given by:

$$\cos\alpha = \mathbf{V}_{\mathbf{obj}} \cdot \mathbf{V}_{\mathbf{light}}$$

- If $\cos\alpha \geq \cos\theta_l$ then the object is within the light cone (assuming θ_l is between 0 and 90 degrees)



We can also apply attenuation based on the angular distance α

Surface Lighting effects

Diffuse reflections

Specular reflections

ambient

Surface Lighting effects

- When light is incident on an opaque surface, part of it is reflected and part is absorbed.
- 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 an illuminated transparent surface, some of the incident light will be reflected and some will be transmitted through the material

Diffuse reflection

Rough or Grainy surfaces scatter the reflected light in all directions. This scattered light is called ***diffuse reflection***.

The surface appears equally bright from all viewing directions.

What we call the color of an object is the color of the diffuse reflection of the incident light.

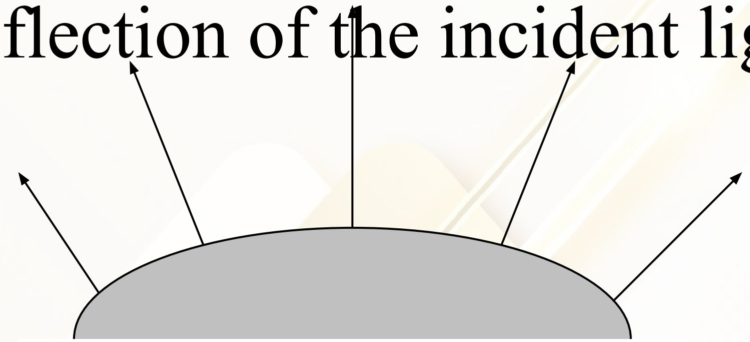


Fig. 4
Diffuse reflection from a surface.

Specular reflection

Light sources create highlights, bright spots, called ***specular reflection***. More pronounced on shiny surfaces than on dull. Reflected light is concentrated into highlight.

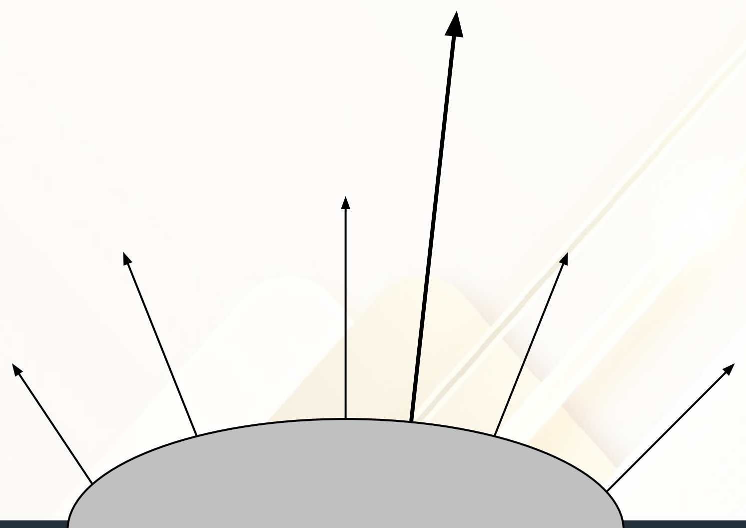


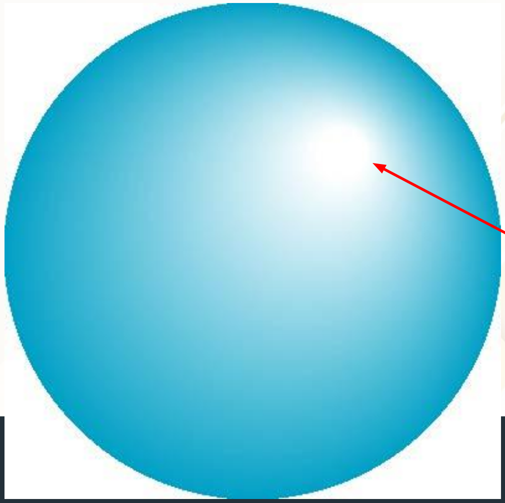
Fig. 5

Specular reflection superimposed on diffuse reflection vectors.

Specular Surfaces

Smooth surfaces show specular highlights.

Reflection of some of the light from the source in the direction of viewer.

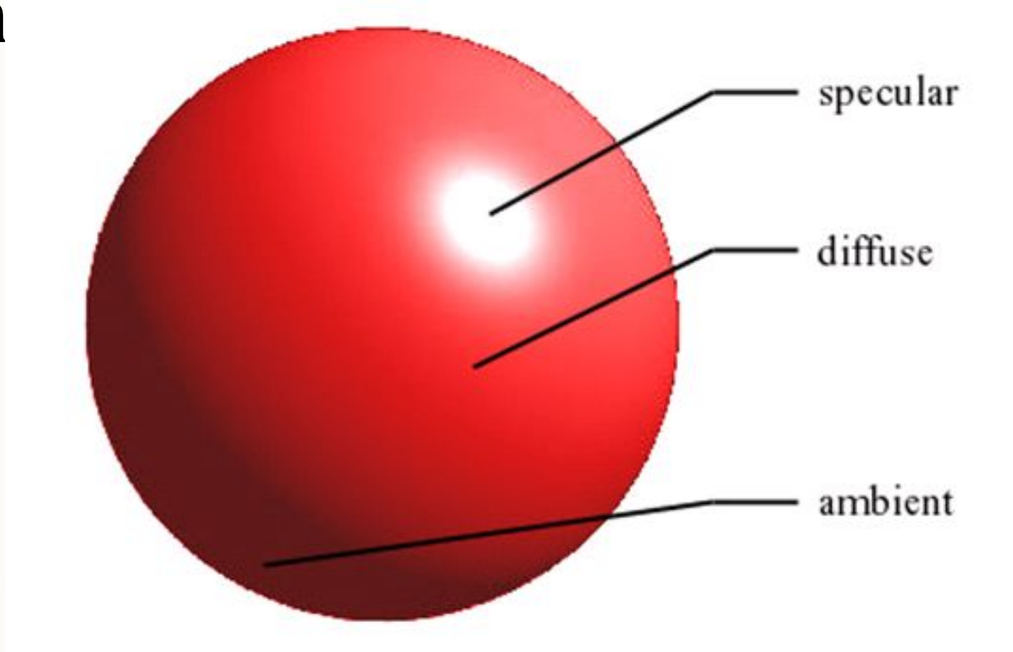


specular highlight

Ambient or background light

Surface is not directly exposed to a light source may still be visible due to the reflected light from near by object that are illuminated

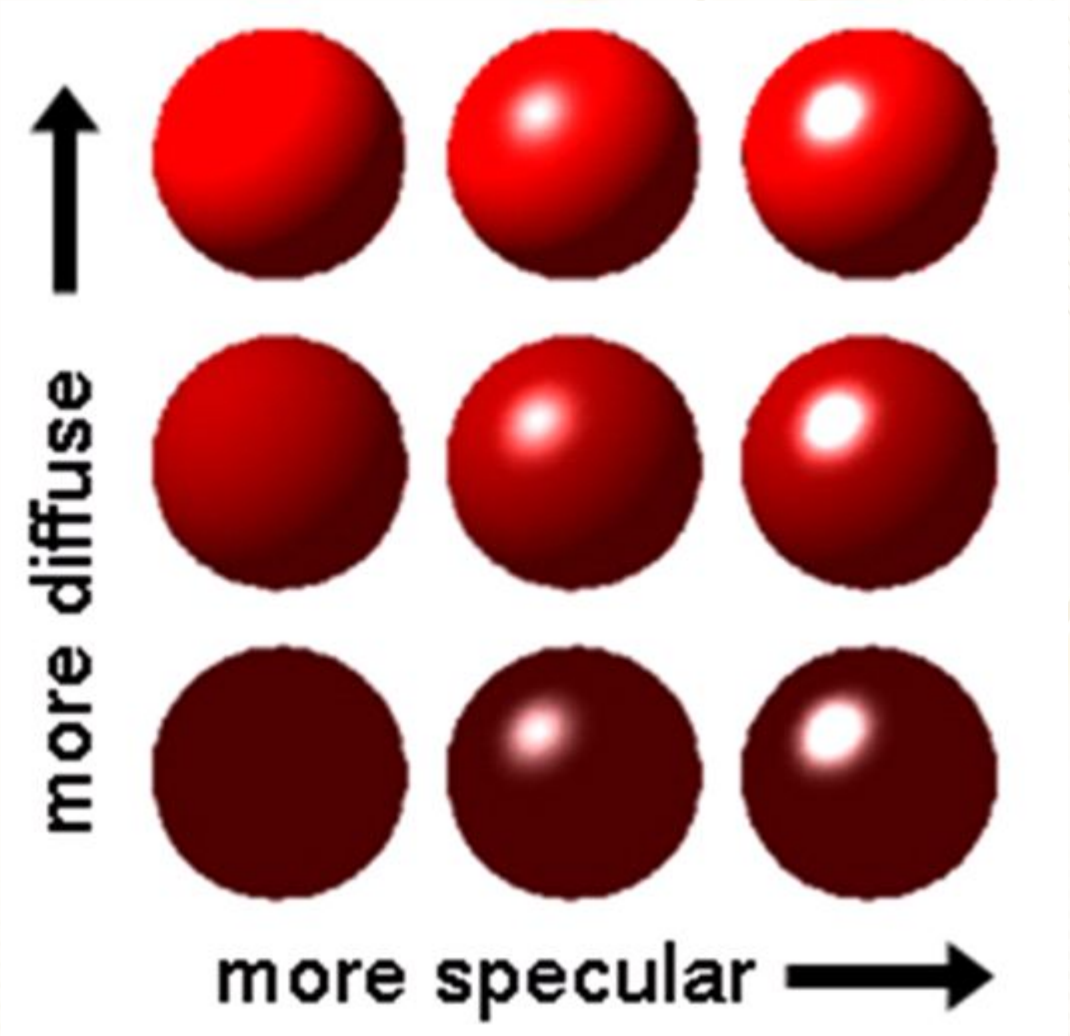
Componen



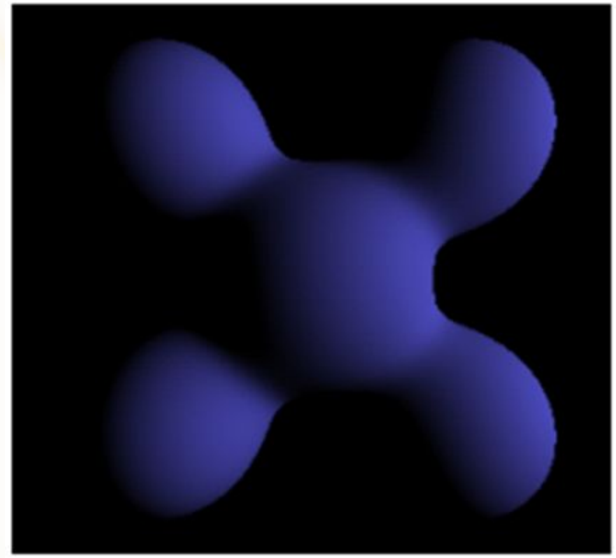
Ambient – surface exposed to **indirect light** reflected from nearby objects.

Diffuse – reflection from **incident** light with equal intensity in all directions. Depends on surface properties.

Specular – near **total** of the incident light around reflection angle.

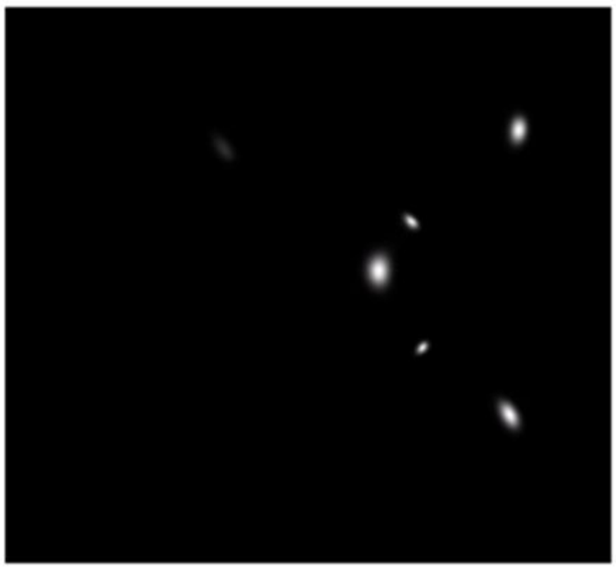

more diffuse
more specular

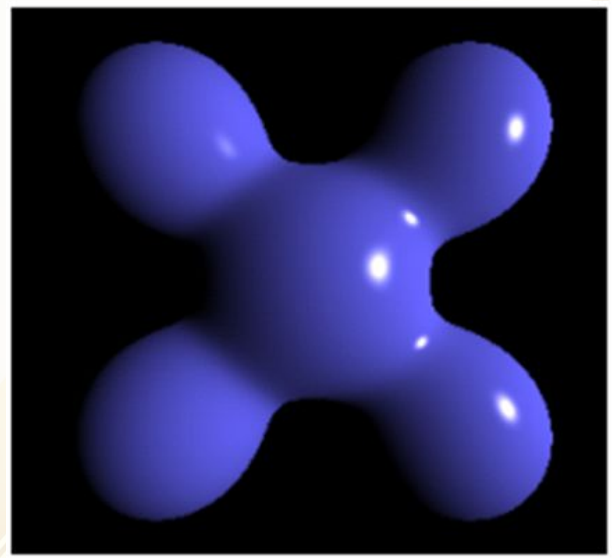
ambient



diffuse

specular





final

Basic Illumination model

An illumination model (or) lighting model

- used to calculate the **intensity of light** that we should see at a given point on the surface of an object.

Ambient Light

Incorporate background lighting

Produces a uniform lighting that is same for all objects

The amount of ambient light incident on each object is a constant for all surfaces and over all directions.

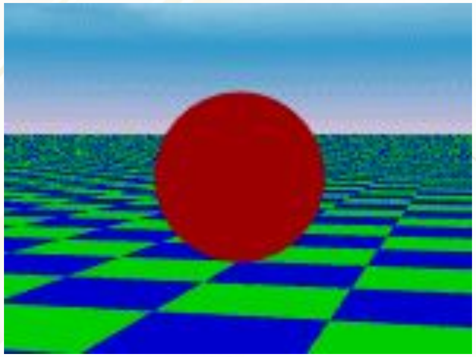


Fig. 6

Ambient light shading.

Ambient Light

The level of ambient light in a scene is a parameter I_a, and each surface illuminated with this constant value.

Illumination equation for ambient light is

$$I = k_a I_a$$

where

I is the resulting intensity

I_a is the incident ambient light intensity

k_a is the object's basic intensity, ***ambient-reflection coefficient***.

Diffuse Reflection

- Incident light is scattered with equal intensities in all directions, independent of the viewing direction- called **ideal diffuse reflectors or Lambertian reflectors.**

Lambert' cosine law

Amount of radiant energy relative to surface normal is proportional to cosθ

The amount of the incident light that is diffusely reflected can be set for each surface with parameter k_d, the ***diffuse-reflection coefficient***, or ***diffuse reflectivity***.

$0 \le k_d \le 1$;

k_d near 1 – highly reflective surface;

k_d near 0 – surface that absorbs most of the incident light;

k_d is a function of surface color;

Diffuse Reflection

Even though there is equal light scattering in all direction from a surface, the brightness of the surface does depend on the orientation of the surface relative to the light source:

(a) (b)

Fig. 8

A surface perpendicular to the direction of the incident light (a) is more illuminated than an equal-sized surface at an oblique angle (b) to the incoming light direction.

Diffuse Reflection

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As the angle between the surface normal and the incoming light direction increases, less of the incident light falls on the surface.

We denote the ***angle of incidence*** between the incoming light direction and the surface normal as θ. Thus, the amount of illumination depends on $\cos\theta$.

If the incoming light from the source is perpendicular to the surface at a particular point, that point is fully illuminated.

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Diffuse Reflection

If I_l is the intensity of the point Light source, then the diffuse reflection equation for a point on the surface can be written as

$$I_{l,diff} = k_d I_l \cos\theta$$

or

$$I_{l,diff} = k_d I_l (N \cdot L)$$

where

N is the unit normal vector to a surface and **L** is the unit direction vector to the point light source from a position on the surface.

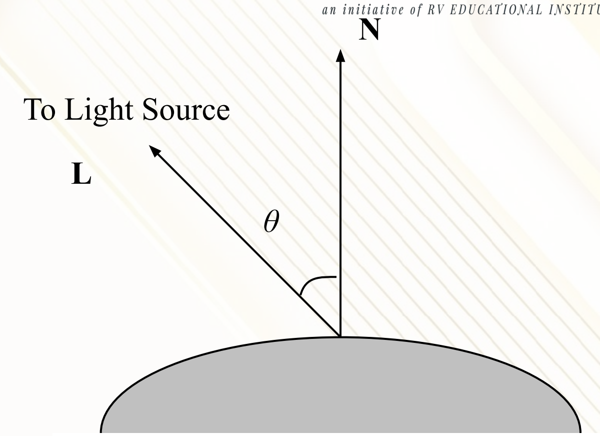


Fig. 9
Angle of incidence θ between the unit light-source direction vector **L** and the unit surface normal **N**.

- A surface is illuminated by a point source only if the angle of incidence is in the range 0° to *90 ° (cos 0 is in the interval from 0 to 1)*.
- *When* cos **ϴ** *is negative, the* light source
- is "behind" the surface.

Diffuse Reflection

Figure 10 illustrates the illumination with diffuse reflection, using various values of parameter k_d between 0 and1, k_a=0.0

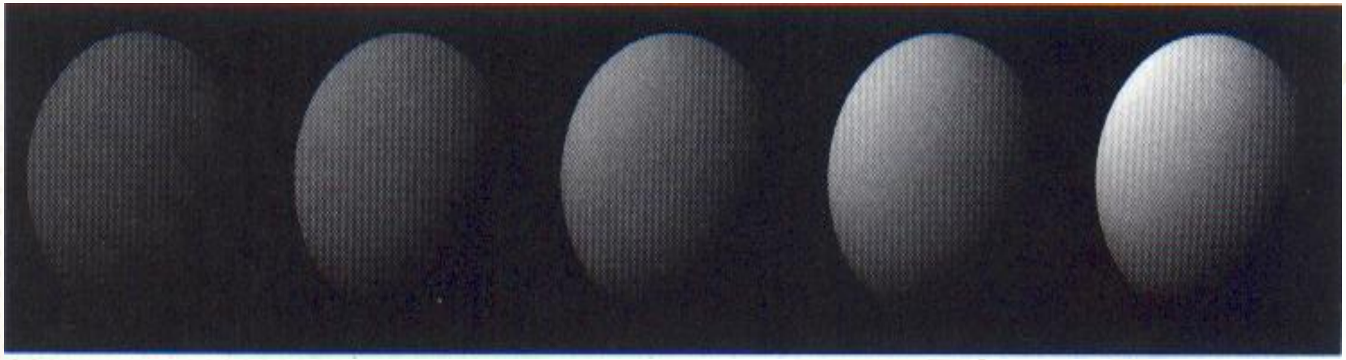


Fig. 10
Series of pictures of sphere illuminated by diffuse reflection model only using different k_d values (0.4, 0.55, 0.7, 0.85,1.0).

Diffuse Reflection

We can combine the ambient and point-source intensity calculations to obtain an expression for the total diffuse reflection.

$$I_{diff} = k_a I_a + k_d I_l (\mathbf{N} \cdot \mathbf{L})$$

where both k_a and k_d depend on surface material properties and are assigned values in the range from 0 to 1.

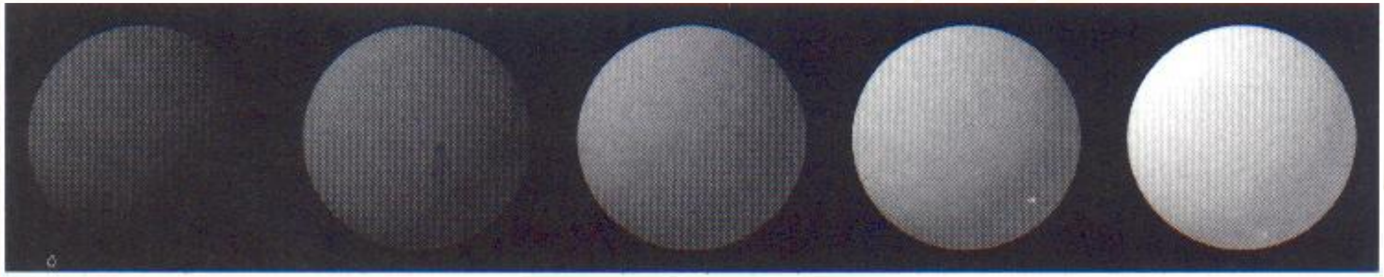


Fig. 11
Series of pictures of sphere illuminated by ambient and diffuse reflection model.
$I_a = I_l = 1.0$, $k_d = 0.4$ and k_a values (0.0, 0.15, 0.30, 0.45, 0.60).

Specular Reflection and *the Phong Model*

- **we see a highlight, or bright spot, at certain viewing directions.** This phenomenon, called ***specular reflection***, ***is the result of total***, ***or near*** total reflection 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

Figure 13 shows the specular reflection direction at a point on the illuminated surface. In this figure,

- **R** represents the unit vector in the direction of specular reflection;
- **L** – unit vector directed toward the point light source;
- **V** – unit vector pointing to the viewer from the surface position;
- Angle *Φ* is the viewing angle relative to the specular-reflection direction **R**.

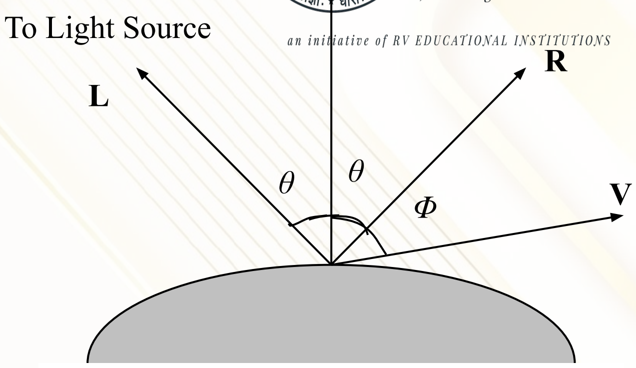


Fig. 13
Modeling specular reflection.

Phong Model

Phong model is an empirical model for calculating the specular-reflection range:

- Sets the intensity of specular reflection proportional to $\cos^{ns}\Phi$;
- Angle Φ assigned values in the range 0^o to 90^o, so that $\cos\Phi$ values from 0 to 1;
- ***Specular-reflection parameter*** n_s is determined by the type of surface,
- ***Specular-reflection coefficient*** k_s equal to some value in the range 0 to 1 for each surface.

Shiny surface

a large value for n_s-100

Dull surface or rough

N_s= 1 (chalk)

Perfect reflector

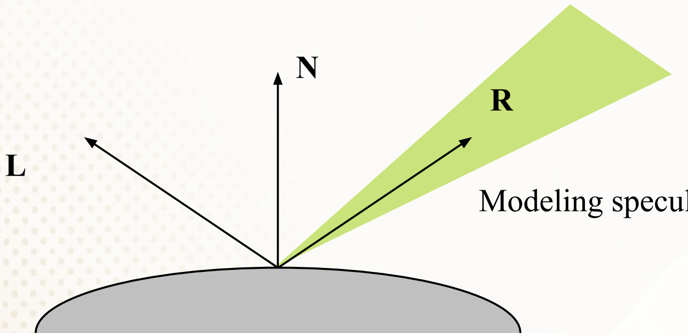
ns- infinity

Phong Model

Very shiny surface is modeled with a large value for n_s (say, 100 or more);

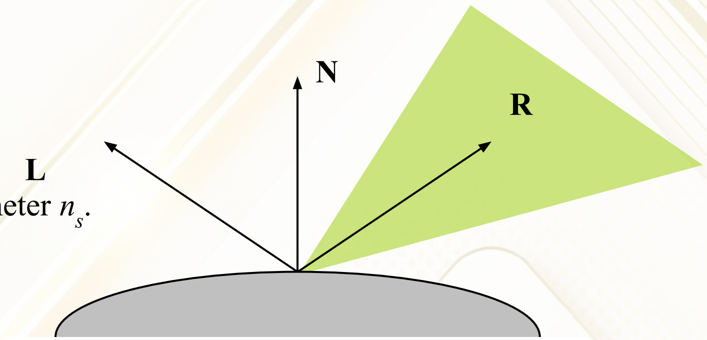
Small values are used for duller surfaces.

For perfect reflector (perfect mirror), n_s is infinite;



Shiny Surface (Large n_s)

Fig. 14
Modeling specular reflection with parameter n_s.



Dull Surface
(Small n_s)

Phong Model

Phong specular-reflection model:

$$I_{spec} = k_s I_l \cos^{ns}\Phi$$

Since **V** and **R** are unit vectors in the viewing and specular-reflection directions, we can calculate the value of $\cos^{ns}\Phi$ with the dot product **V·R**.

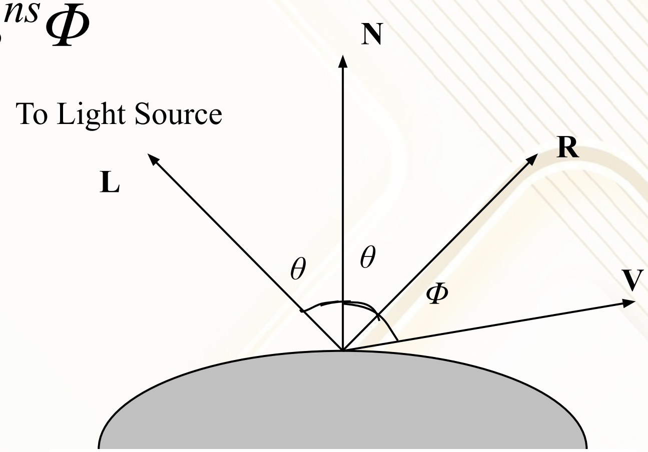


Fig. 13
Modeling specular reflection.

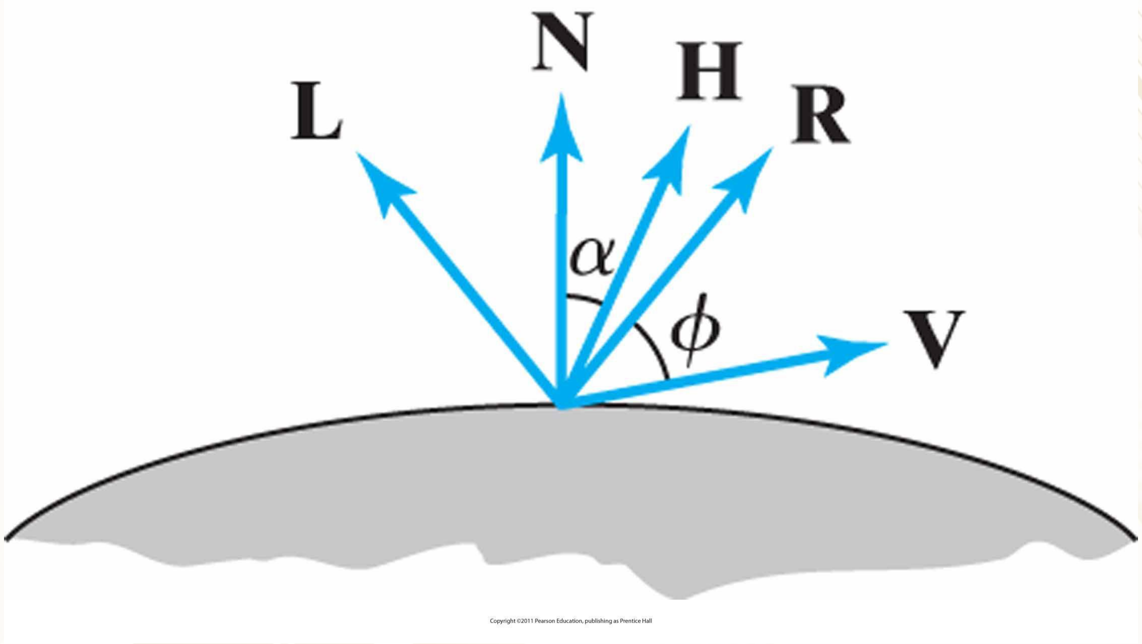
$$I_{spec} = k_s I_l (\mathbf{V} \cdot \mathbf{R})^{ns}$$

Figure 17-18 Halfway vector **H** along the bisector of the angle between **L** and **V**.

$$\alpha = \Phi/2$$

$$H = (L + V)/|(L + V)|$$

Avoid calculation of r



Combine Diffuse & Specular Reflections

For a single point light source, we can model

the combined diffuse and specular reflections from a point on an illuminated surface as

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

$$= k_a I_a + k_d I_l (\mathbf{N} \cdot \mathbf{L}) + k_s I_l (\mathbf{N} \cdot \mathbf{H})^{ns}$$

Combine Diffuse & Specular Reflections with Multiple Light Sources

If we place more than one point source in a scene, we obtain the light reflection at any surface point by summering the contributions

from the individual sources:

$$I = k_a I_a + \Sigma^{n}_{i=1} I_{li} \, [k_d (\mathbf{N} \cdot \mathbf{L_i}) + k_s (\mathbf{N} \cdot \mathbf{H_i})^{ns}]$$

Light Sources in OpenGL

Enabling Lighting and Lights

Lighting in general must be enabled

Each individual light must be enabled

OpenGL supports at least 8 light sources

```
glEnable(GL_LIGHTING);
glEnable(lightname);
Lightname- GL_LIGHT0,GL_LIGHT1,..GL_LIGHT7
glEnable(GL_LIGHT0);
```

glLightfv(GLenum source, GLenum parameter, GLfloat *pointer_to_array)

glLightf(GLenum source, GLenum parameter, GLfloat value)

There are four values we need to set:

the position(direction) of light source, the amount of ambient,diffuse and specular light associated with the source.

Suppose we wish to specify the first source GL_LIGHT0 at(1.0,2.0,3.0)

GLfloat light0_pos[]= {1.0,2.0,3.0,1.0}- point source

GLfloat light0_pos[]= {1.0,2.0,3.0,0.0} – distant source

Light Sources in OpenGL

For a single light source , if we want a white specular component and red ambient and diffuse components, we can use following code:

```
GLfloat ambient[] = {1.0, 0.0, 0.0, 1.0};
GLfloat diffuse[] = {1.0, 0.0, 0.0, 1.0};
GLfloat specular[] = {1.0, 1.0, 1.0, 1.0};
GLfloat light0_pos[]= {1.0,2.0,3.0,1.0}
glLightfv(GL_LIGHT0, GL_POSITION, light0_pos);
glLightfv(GL_LIGHT0, GL_AMBIENT, ambient);
glLightfv(GL_LIGHT0, GL_DIFFUSE, diffuse);
glLightfv(GL_LIGHT0, GL_SPECULAR, specular);
```

Light sources in openGL

Global Ambient Light

if we want a small amount of white light, even when all light sources are turned off or disabled

```
GLfloat al[] = {0.1, 0.1, 0.1, 1.0};
glLightModelfv(GL_LIGHT_MODEL_AMBIENT, al);
```

default value is { 0.2, 0.2 ,0.2,1.0}

Light source in openGL

Spotlights

Create point source as before

Specify additional properties to create spotlight.

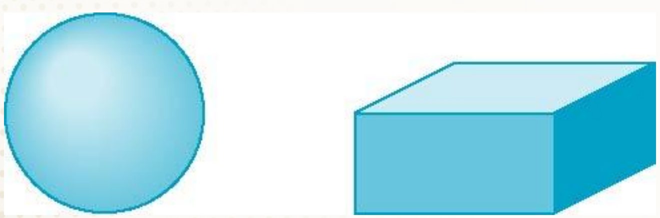
```
GLfloat sd[] = {-1.0, -1.0, 0.0};
glLightfv(GL_LIGHT0, GL_SPOT_DIRECTION, sd);
glLightf(GL_LIGHT0, GL_SPOT_CUTOFF, 45.0);
glLightf(GL_LIGHT0, GL_SPOT_EXPONENT, 2.0);
```

Front and Back Faces

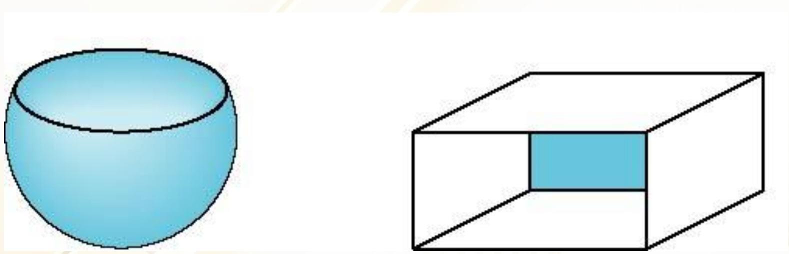
By default - shade only front faces which works correctly for convex objects

Each side can have its own properties which are set by using **GL_FRONT**, **GL_BACK**, or

glLightModeli(GL_LIGHT_MODEL_TWO_SIDED,GL_TRUE);



back faces not visible



back faces visible

Specification of Materials in OpenGL

Material properties are also part of the OpenGL state

Set by **glMaterialfv()**

glMaterialfv(GLenum face, GLenum type,GLfloat
***pointer_to_array)**

glMaterialf(GLenum face, GLenum type, GLfloat value)

```
GLfloat ambient[] = {0.2, 0.2, 0.2, 1.0};
GLfloat diffuse[] = {1.0, 0.8, 0.0, 1.0};
GLfloat specular[] = {1.0, 1.0, 1.0, 1.0};
GLfloat shine = 100.0
glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, ambient);
glMaterialfv(GL_FRONT_AND_BACK, GL_DIFFUSE, diffuse);
glMaterialfv(GL_FRONT_AND_BACK, GL_SPECULAR, specular);
glMaterialfV(GL_FRONT_AND_BACK, GL_SHININESS, shine);
```