ILLUMINATION MODEL AND SURFACE-RENDERING METHODS

- ***Illumination model*** or a ***lighting model*** or a ***shading model*** is the model for calculating light intensity at a single surface point.
- ***Surface rendering*** is a procedure for applying a lighting model to obtain pixel intensities for all the projected surface positions in a scene.

Photorealism involves two elements

- Accurate representations of surface properties or objects, and
- Good physical descriptions of the lighting effects in a scene.

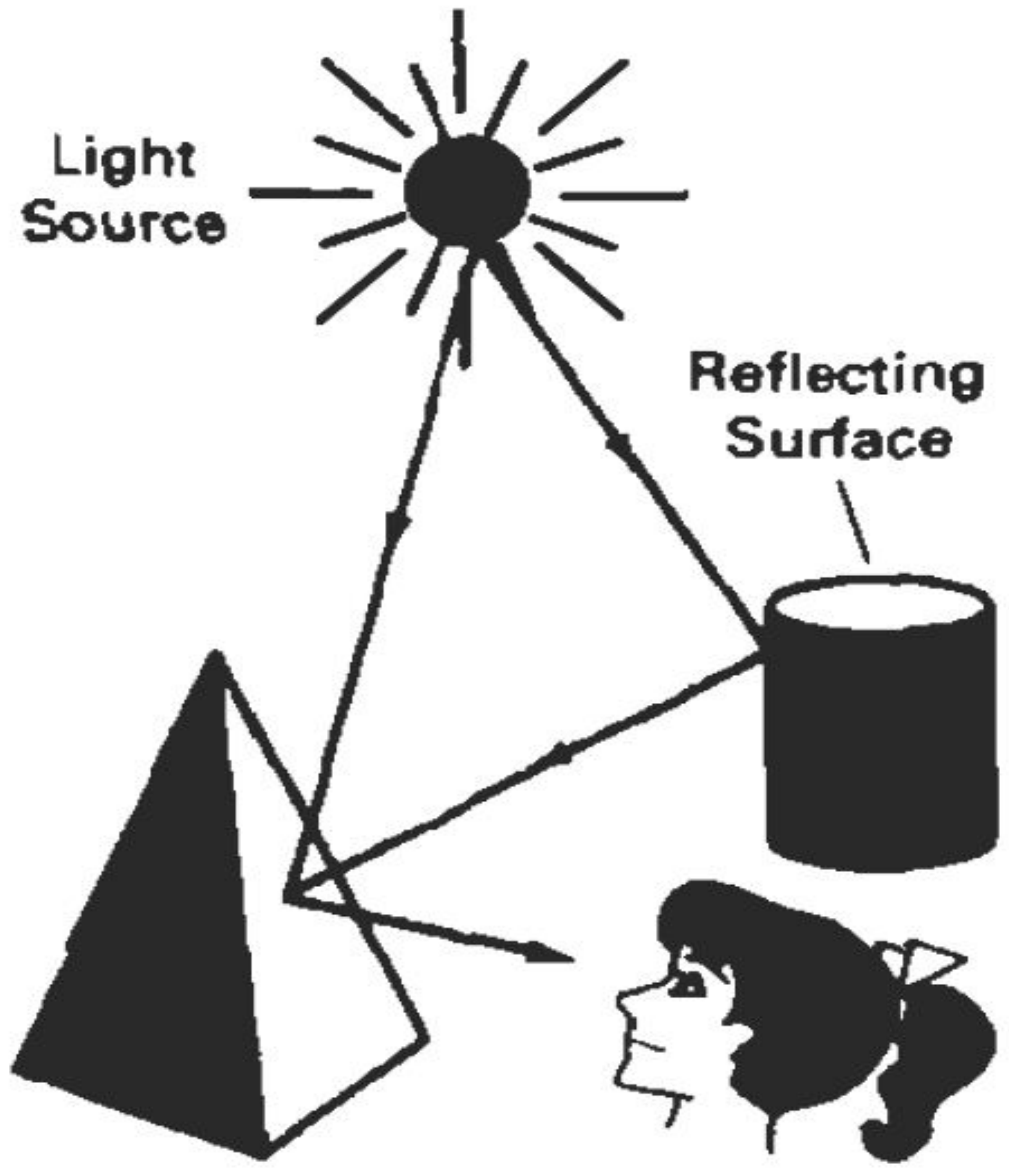
***lighting effect** include

light reflections, transparency, surface texture and shadows.

14.1 <u>LIGHT SOURCES</u>

The total reflected light is the sum of the contributions from

1. Light sources,
2. Other reflecting surfaces in a scene.



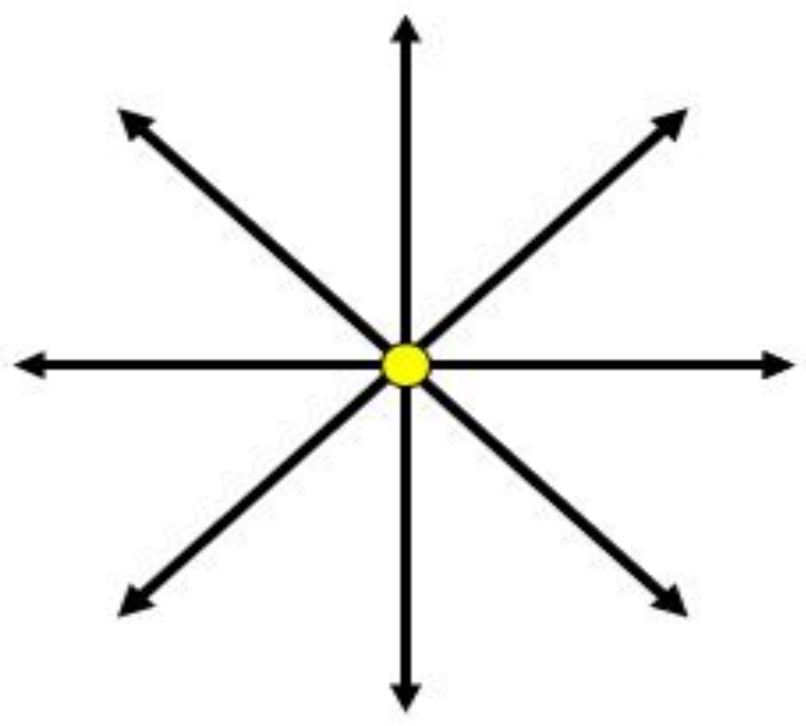
So, a surface that is not directly exposed to a light source may be still visible if nearby objects are illuminated.

- Light sources => light emitting sources
- Reflecting surface=> light reflecting sources
- A luminous object can be both
  - Light source
  - Light reflector

Example:- plastic globe with a light bulb inside, both emits and reflects lights from the surface of the globe.

Emitted light from the globe may then illuminate other objects in the vicinity.

- The simplest model for a light emitter in a point source rays from the source follows radial diverging paths from the source position.

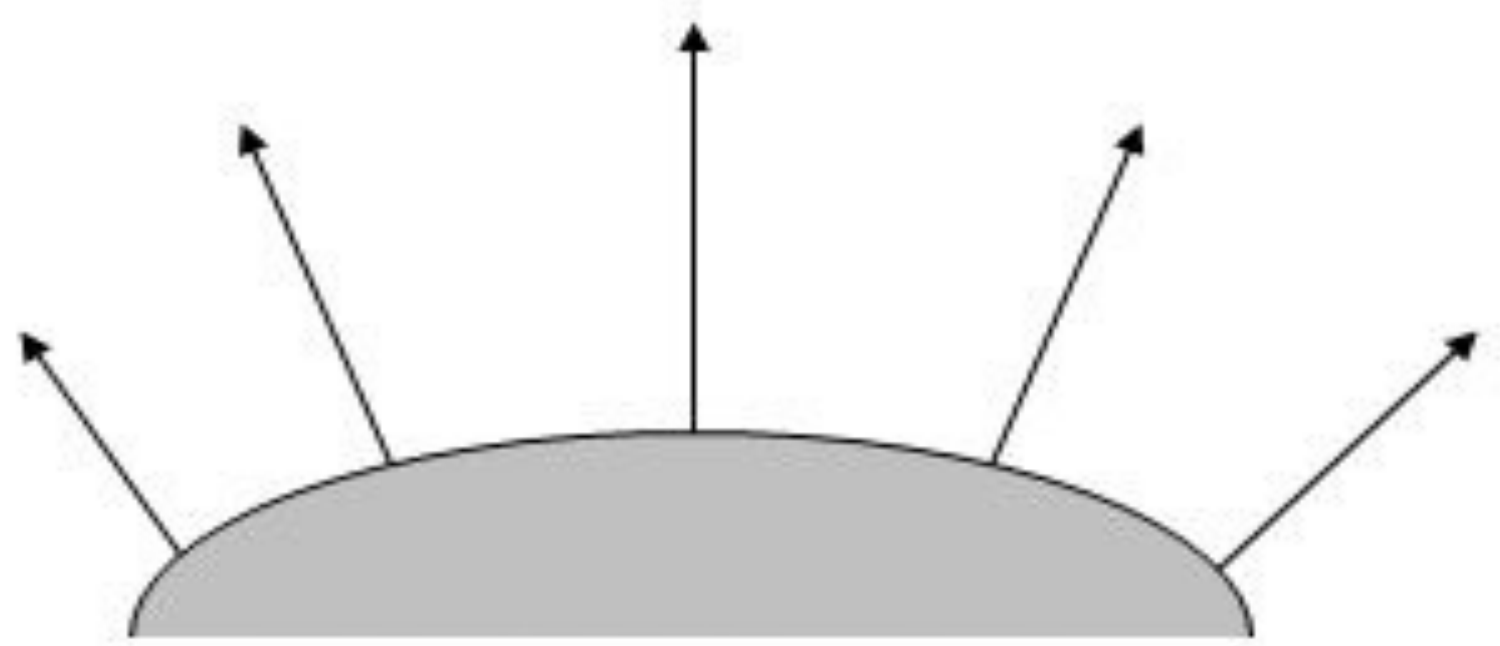


- When light is incident on an opaque surface, part of it is reflected and some part is absorbed.
- The amount of incident light reflected by a surface depends on the type of material.

TYPES OF MATERIAL

1. SHINY- reflects more of the incident light.
2. DULL - absorb more of the incident light.

- Surfaces which are rough, tend to scatter the reflected light in all directions. This scatter light is called **Diffuse Reflection.**



Diffuse reflection from a surface.

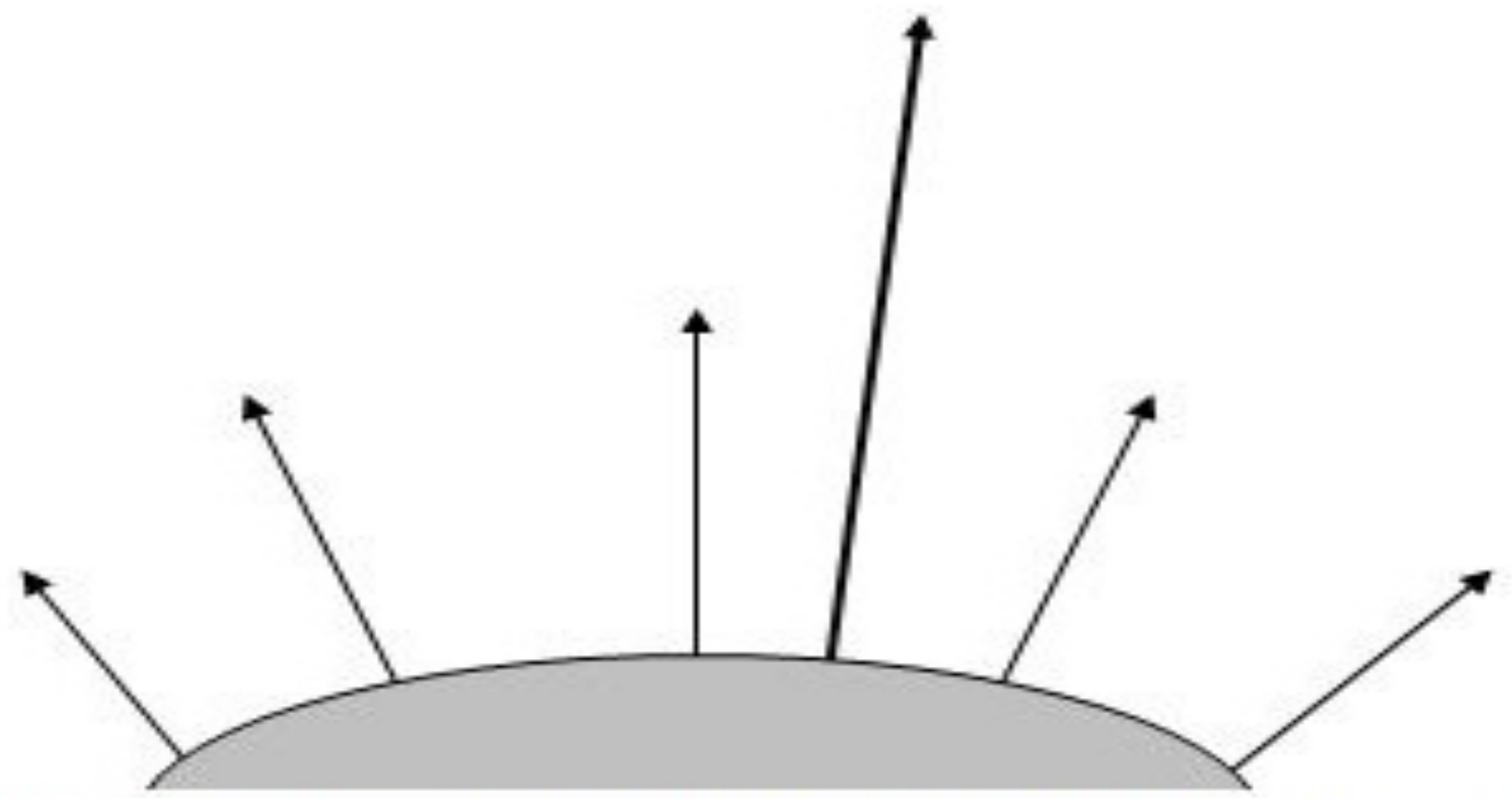
What we call the color of an object is the color of the incident light.

Example:- A blue object illuminated by a white light source reflects the blue component of the white light and totally absorb all other components.

Example:- If a blue object is viewed under a red light, it appears black since all the incident light is absorbed.

In addition to diffuse reflection, light sources create highlights or bright spots called specular reflection.

This highlighting effect is seen more on shiny surfaces than dull surfaces.



Speculiar reflection superimposed on diffuse reflection vectors.

14.2 Basic Illumination Models

Lighting calculations are based on:

- ✦ Optical properties of surfaces, such as glossy, matte, opaque, and transparent. This controls the amount of reflection and absorption of incident light.
- ✦ The background lighting conditions.
- ✦ The light-source specifications. All light sources are considered to be point sources, specified with a coordinate position and intensity value (colour).

Ambient Light

- The combination of light reflections from various surfaces produce a uniform illumination called ambient light.
- Ambient light has no spatial or directional characteristics.
- The amount of ambient light incident on each object is a constant for all surfaces and over all directions.
- We can set the level for the ambient light in a scene with parameter I_a. So, each is the illuminated with this constant value.
- The intensity of the reflected light for each surface depends on the optical properties of the surface; that is, how much of the incident energy is to be reflected and how much absorbed.

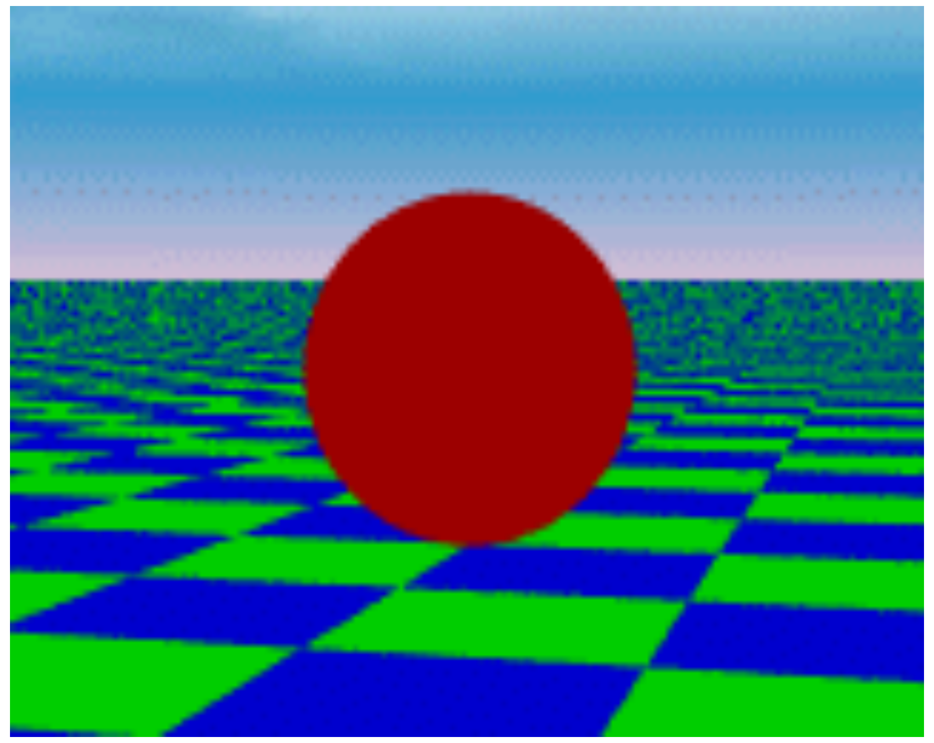


Fig. 6
Ambient light shading.

Ambient Light - Example

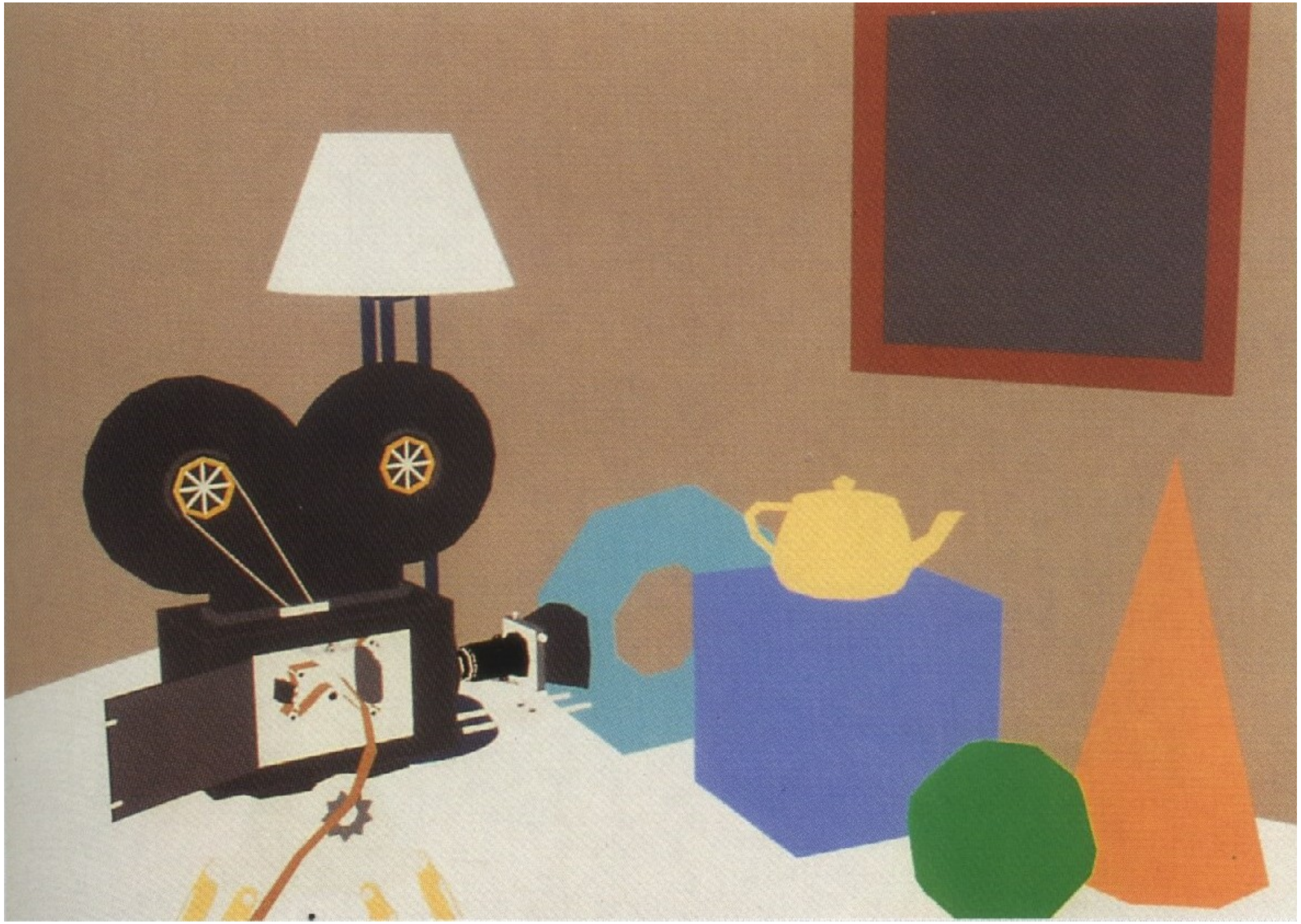


Fig. 7
An ambient illumination only.

Diffuse Reflection

- Diffuse reflections are constant over each surface in a scene, independent of the viewing direction.

- 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***.

  $0 <= k_d <= 1$;

  k_d near 1 – highly reflective surface; (This produces a bright surface with the intensity of the reflected light near that of the incident light)

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

  k_d is a function of surface color;

- If a surface is exposed only to a ambient light, we can express the intensity of the diffuse reflection at any point on the surface as,

$$I_{ambdiff} = k_d I_a$$

Diffuse Reflection

Ideal Diffuse Reflectors or Lambertian Reflectors

- If we assume that the diffuse reflections from the surface are scattered with equal intensity in all directions, independent of viewing directions, then such surfaces are called ideal diffuse reflectors or Lambertian reflectors, since radiated light energy from any point on the surface is governed by Lambert's cosine law.

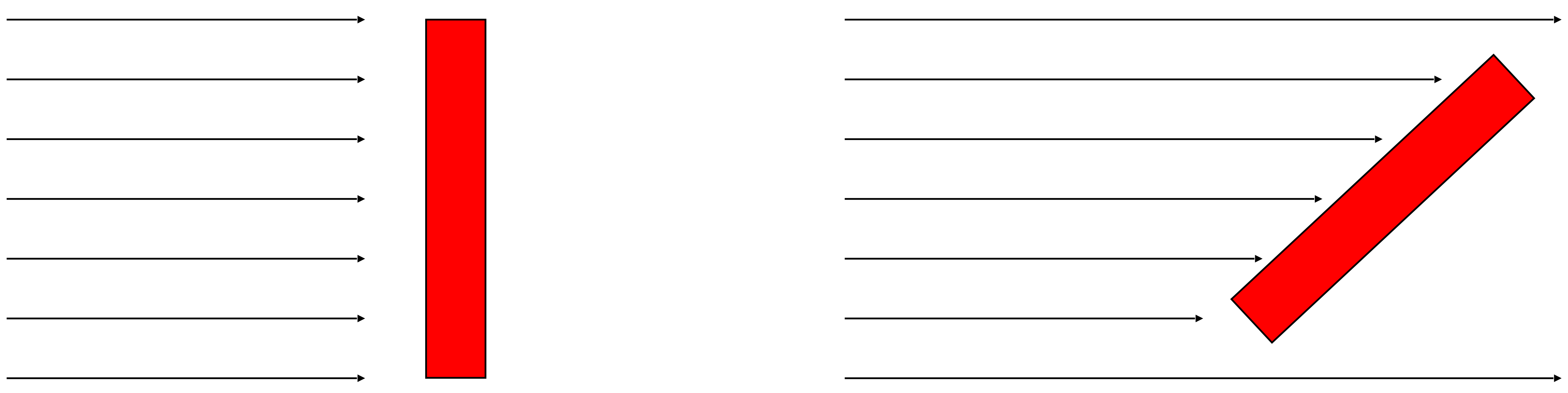
- Lambert's Cosine Law: The radiated light energy from any small surface area dA in any direction ϕN relative to the surface normal is proportional to $\cos \phi N$.

  Light Intensity $\propto \cos \phi N$

  Light Intensity $= dA \cos \phi N$

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)

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

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

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

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.

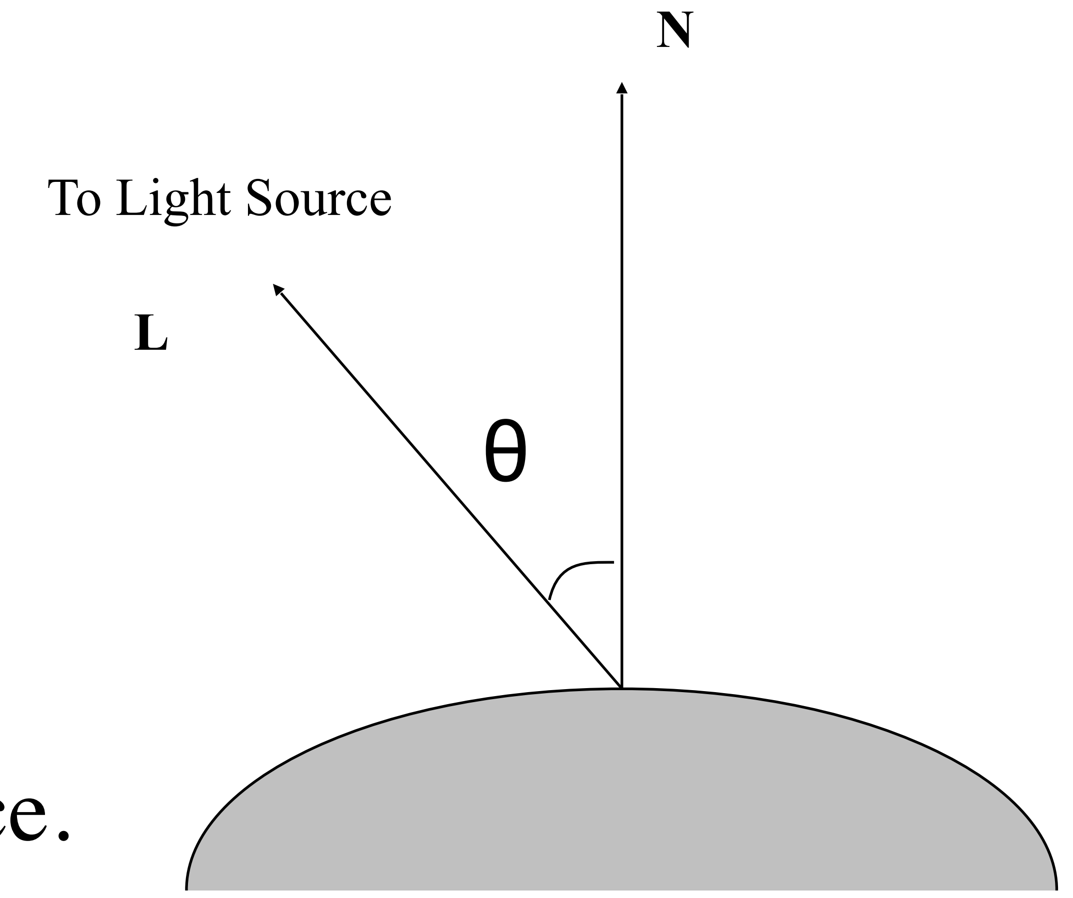


Fig. 9
Angle of incidence θ between the unit light-source direction vector **L** and the unit surface normal **N**.

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

Diffuse Reflection

Figure illustrates the illumination with diffuse reflection, using various values of parameter k_d between 0 and1.

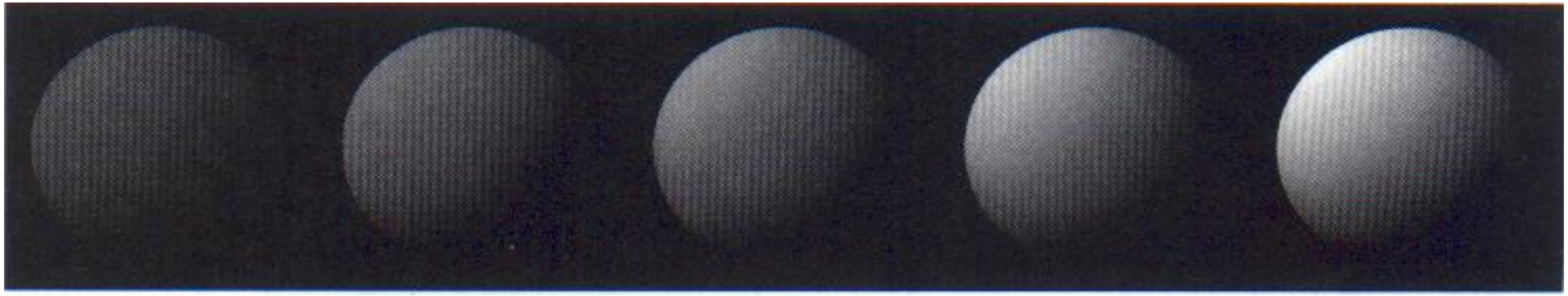


Fig. 10

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.

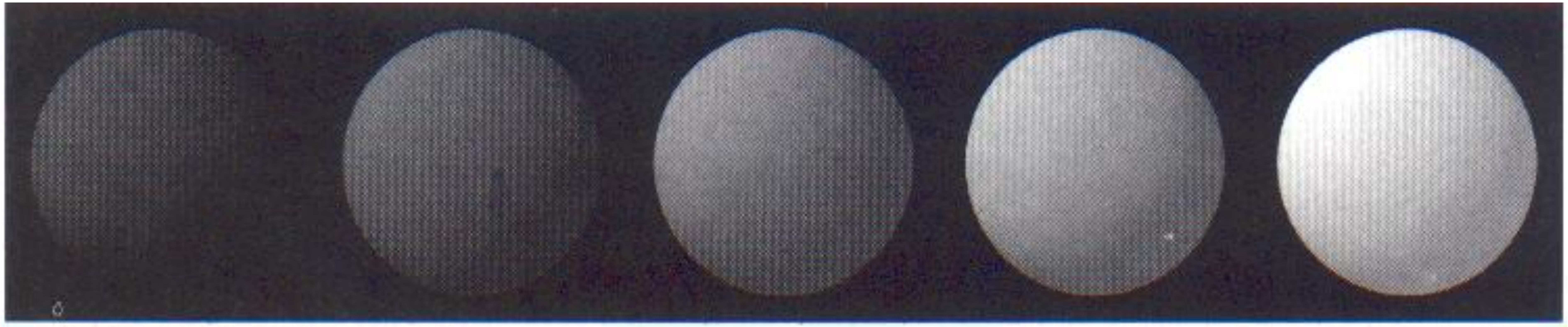


Fig. 11

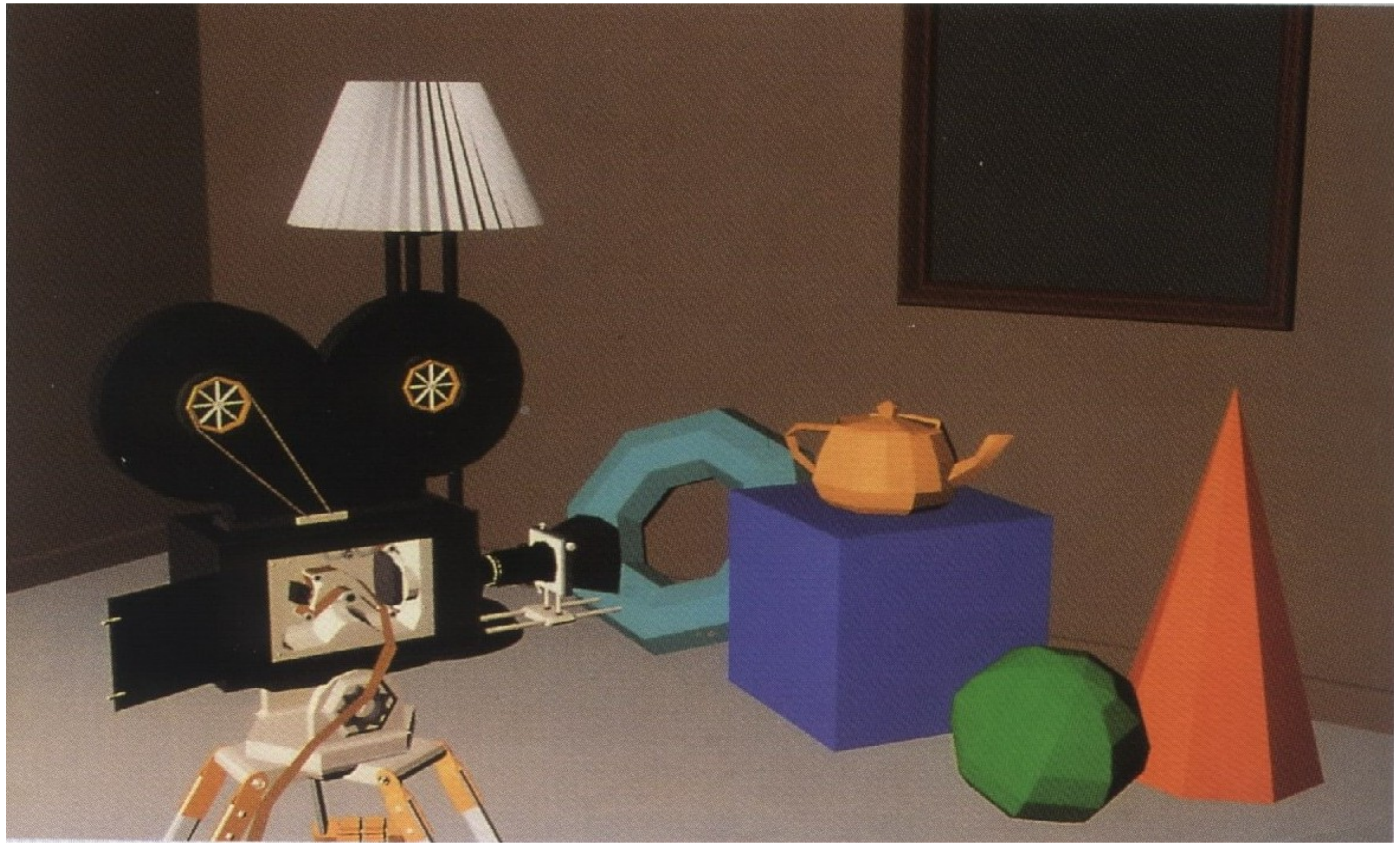
Series of pictures of sphere illuminated by ambient and diffuse reflection model.

$I_a = I_l = 1.0$, $k_d = 0.4$ and k_a values (0.0, 0.15, 0.30, 0.45, 0.60).

- In many graphics packages, k_a (ambient-reflection coefficient) is used to modify the ambient light intensity I_a for each surface

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

Diffuse Reflection - Example



Individually shaded polygons with diffuse reflection.

Specular Reflection

When we **look** at an illuminated **shiny** surface, such as polished metal, an apple, or a person's forehead, **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.

- **R**- 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 **θ** is the viewing angle relative to the specular-reflection direction **R**.
- Angle ***Φ*** is the viewing angle relative to the specular-reflection direction R.

For an ideal reflector (perfect mirror), incident light is reflected only in the specular-reflection direction. In this case, we would only see reflected light when vectors V and R coincide (Φ = 0)

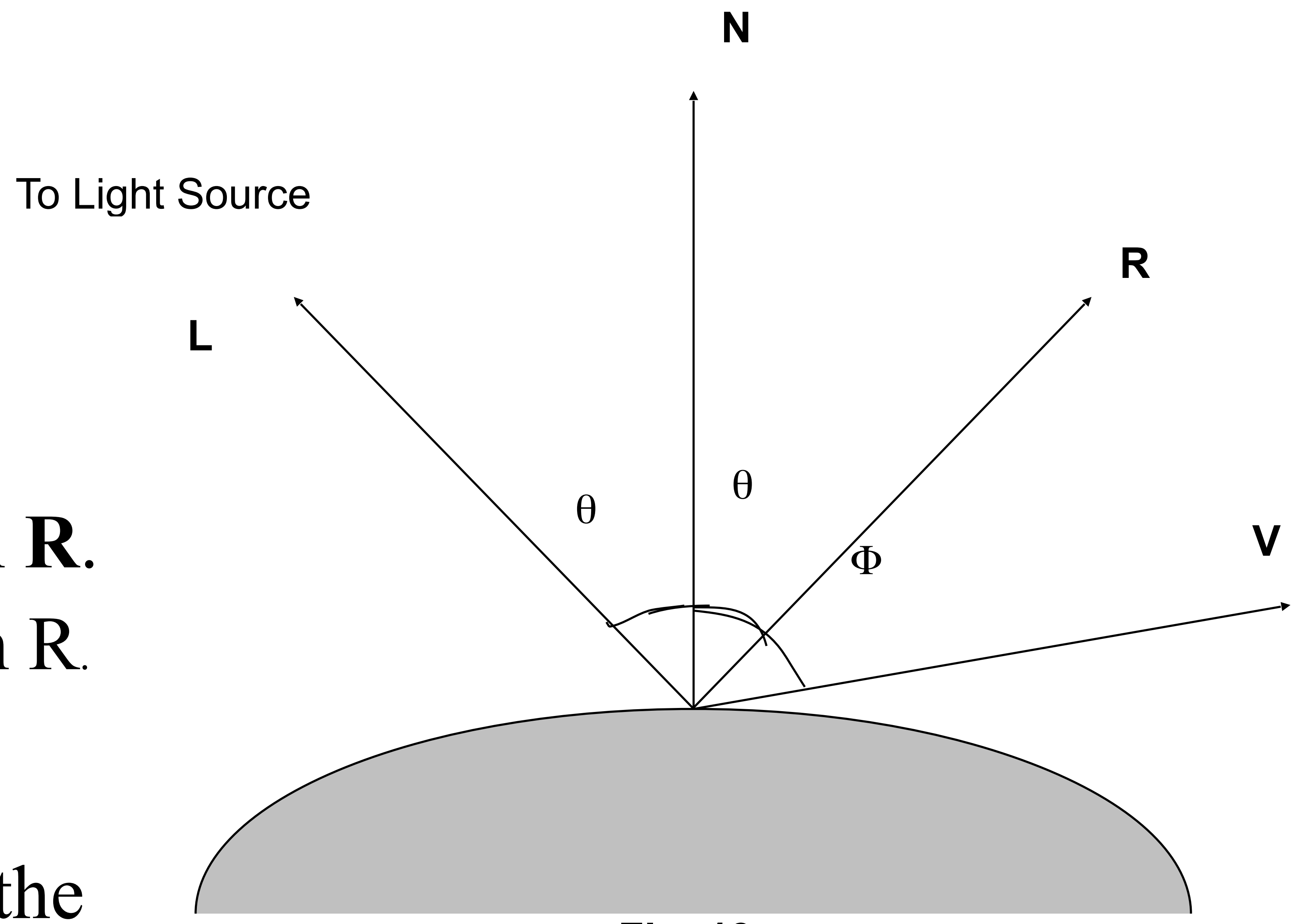


Fig. 13
Modelling specular reflection.

Phong Model

Objects other than ideal reflectors exhibit specular reflections over a finite range of viewing positions around vector R. Shiny surfaces have a narrow specular-reflection range, and dull surfaces have a wider reflection range.

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

- Sets the intensity of specular reflection proportional to $\cos^{n_s} \Phi$;
- 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.

- Very shiny surface has a large value for n_s (say, 100 or more);
- Dull surface has a small value for n_s (down to 1)
- For perfect reflector (perfect mirror), n_s is infinite
- We can approximately model monochromatic specular intensity variations using a specular-reflection function, W(θ), for each surface. In general, **W(θ) tends to increase as the angle of incidence increases**. At **θ** = ***90º***, W(**θ**) = 1 and all of the incident light is reflected. The variation of specular intensity with angle of incidence is described by ***Fresnel's Laws* of *Reflection.*** Using the spectral-reflection function *W(***θ***)*, we can write the Phong specular-reflection model as

$$I_{spec} = W(\theta) I_l \cos^{ns}\Phi$$

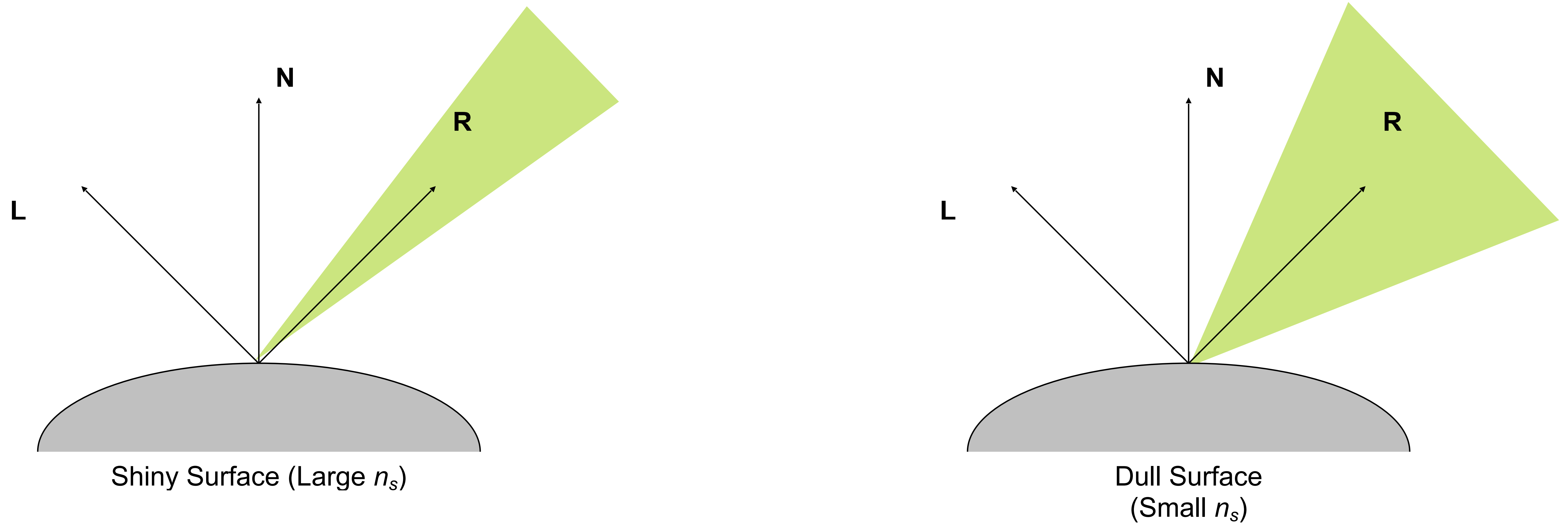


Fig. 14

Phong Model

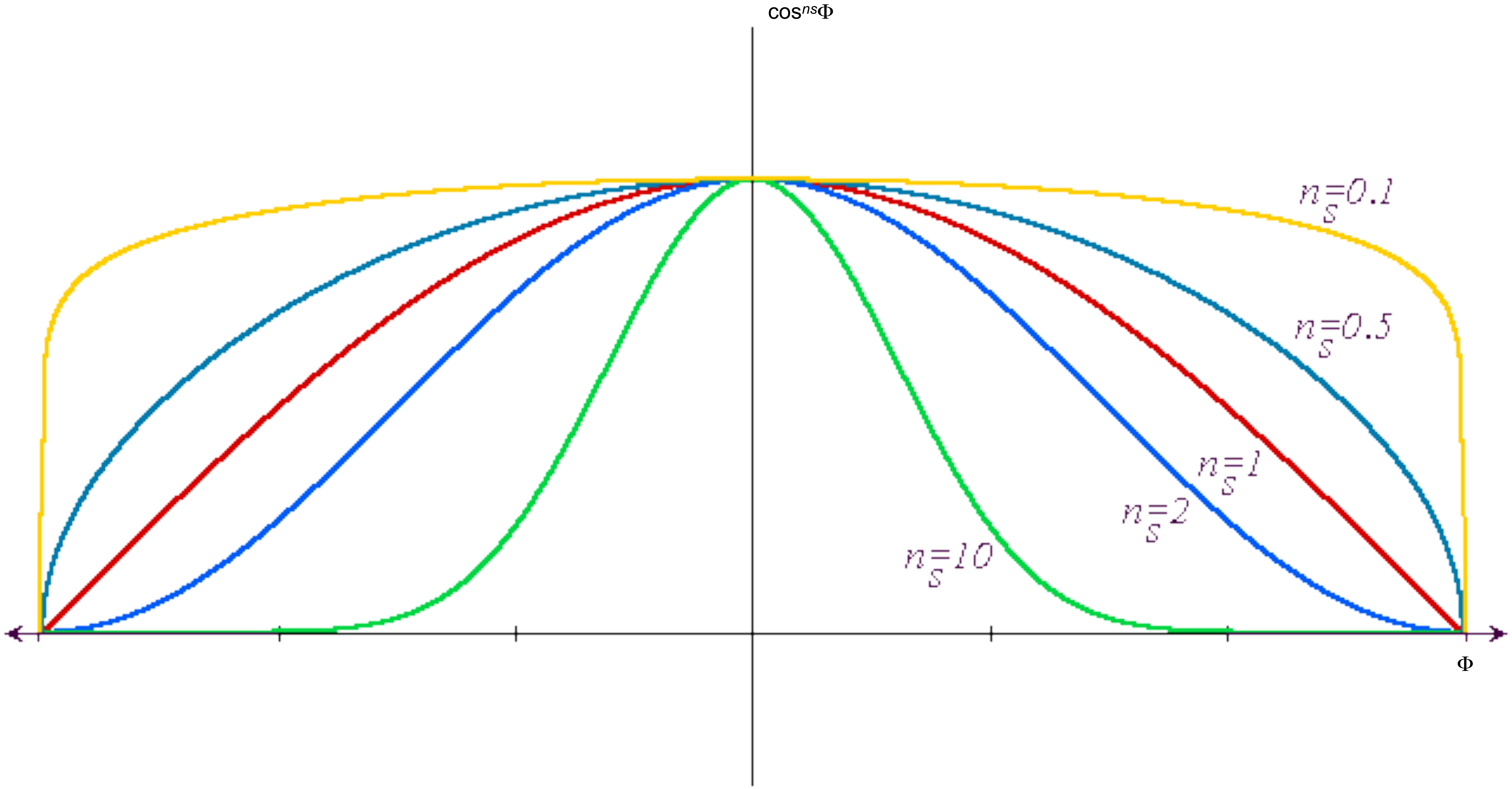


Fig. 15
Plots of $\cos^{ns}\Phi$ for several values of specular parameter n_s.

Phong Model

- Transparent materials, such as glass, only exhibit appreciable specular reflections as θ approaches 90^o. At $\theta = 0^o$, about 4 percent of the incident light on a glass surface is reflected. And for most of the range of θ the reflected intensity is less than 10 percent of the incident intensity.
- But for many opaque materials, specular reflection is nearly constant for all incidence angles. In this case, we can model the reflected light effects by replacing $W(\theta)$ with a constant specular-reflection coefficient k_s,

  Phong specular-reflection model:

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

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

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

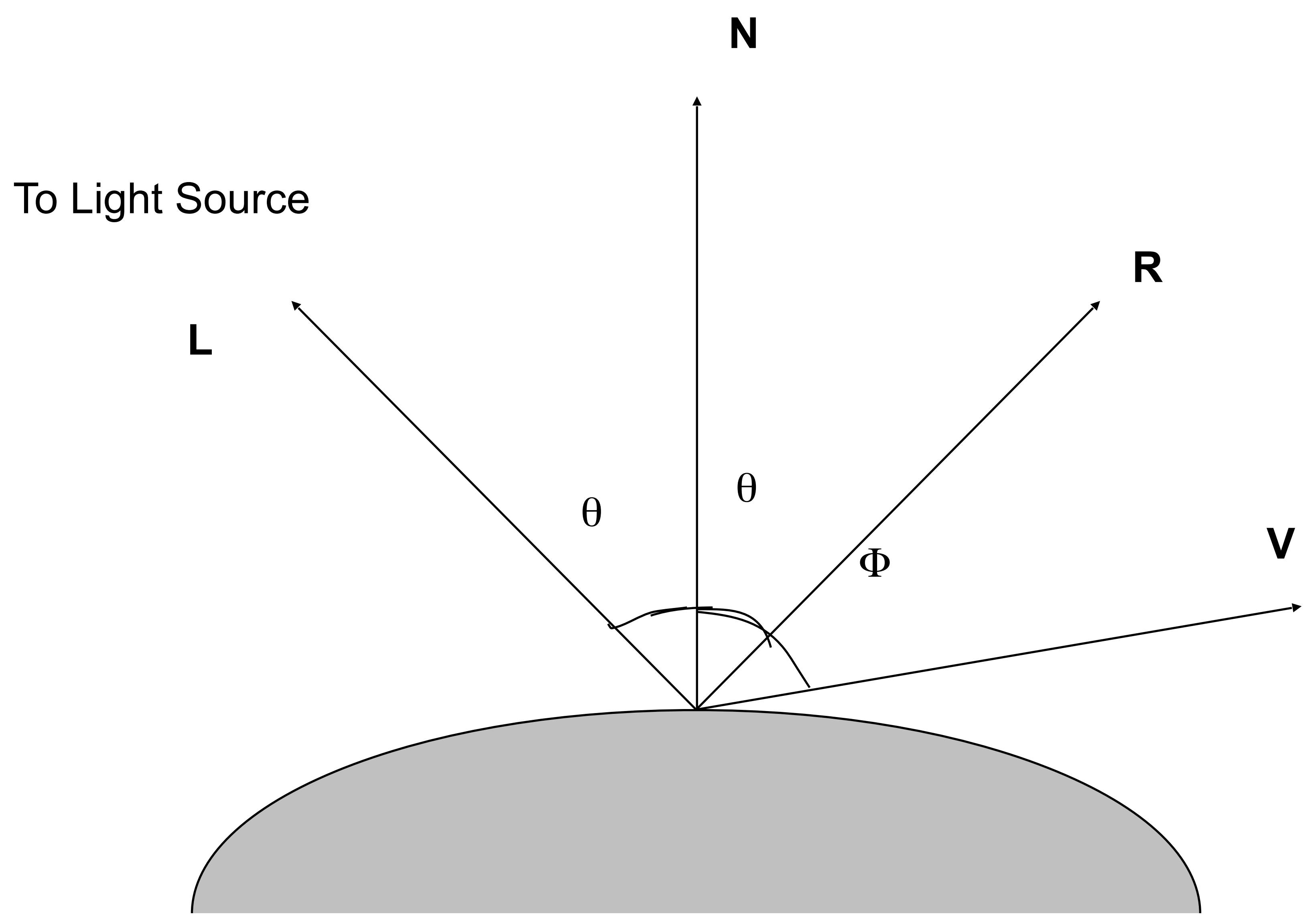


Fig. 13
Modelling specular reflection.

Specular Reflection - Example

Fig. 18
Phong shading polygons with specular reflection.

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

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

$$I = k_a I_a + k_d I_l (\mathrm{N}\cdot\mathrm{L}) + k_s I_l \cos^{n_s}\Phi$$

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 summing the contributions from the individual sources:

$$I = k_a I_a + \Sigma^{n}_{i=1} I_{li} \left[k_d (\mathrm{N}\cdot\mathrm{L_i}) + k_s(\cos^{n_s}\Phi)\right]$$