Chapter 5.
Lighting and Shading

Photorealism in Computer Graphics

- Photorealism in computer graphics involves
  - Accurate representations of surface properties, and
  - Good physical descriptions of the lighting effects

- Modeling the lighting effects that we see on an object is a complex process, involving principles of both physics and psychology

- Physical illumination models involve
  - Material properties, object position relative to light sources and other objects, the features of the light sources, and so on

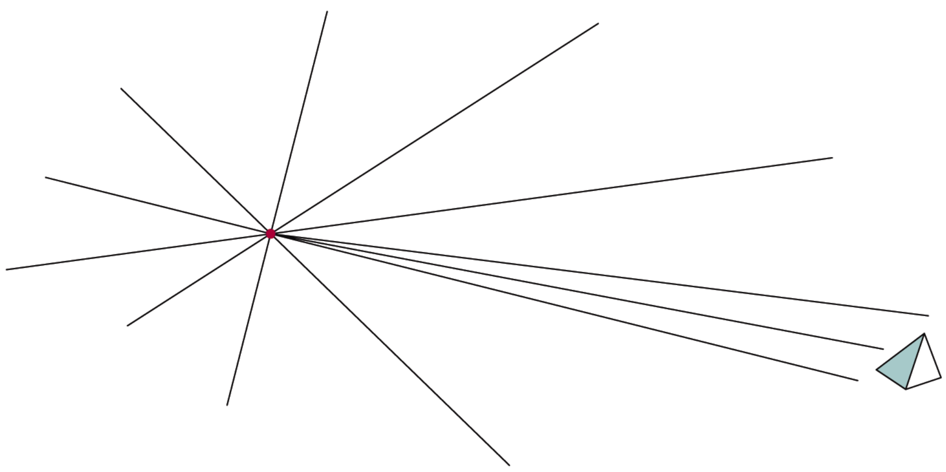
Illumination and Rendering

- An ***illumination model*** in computer graphics
  - also called a ***lighting model*** or a ***shading model***
  - used to calculate the color of an illuminated position on the surface of an object
  - Approximations of the physical laws

- A ***surface-rendering method*** determine the pixel colors for all projected positions in a scene

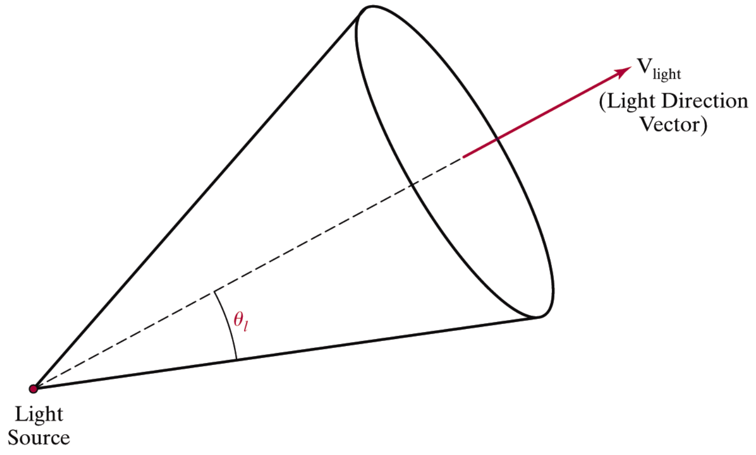
Light Sources

- Point light sources
  - Emitting radiant energy at a single point
  - Specified with its position and the color of the emitted light
- Infinitely distant light sources
  - A large light source, such as sun, that is very far from a scene
  - Little variation in its directional effects
  - Specified with its color value and a fixed direction for the light rays

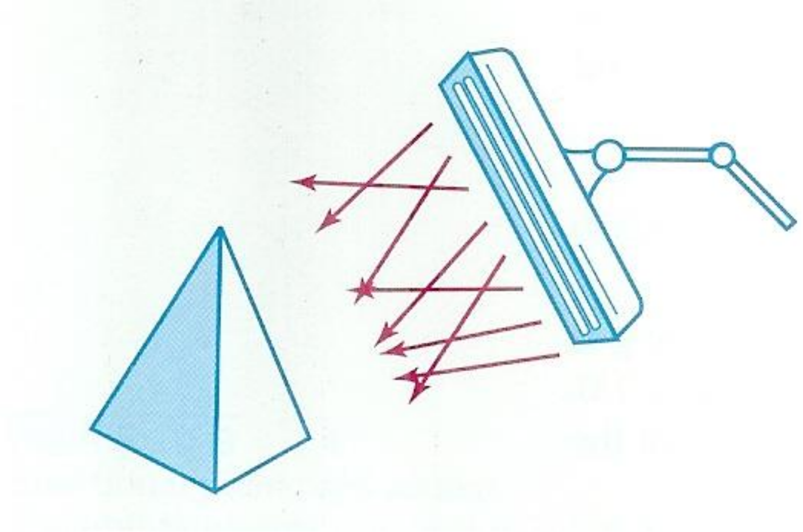


Light Sources

- Directional light sources
  - Produces a directional beam of light
  - Spotlight effects



- Area light sources



Light Sources

- Radial intensity attenuation
  - As radiant energy travels, its amplitude is attenuated by the factor $1/d^2$
  - Sometimes, more realistic attenuation effects can be obtained with an inverse quadratic function of distance

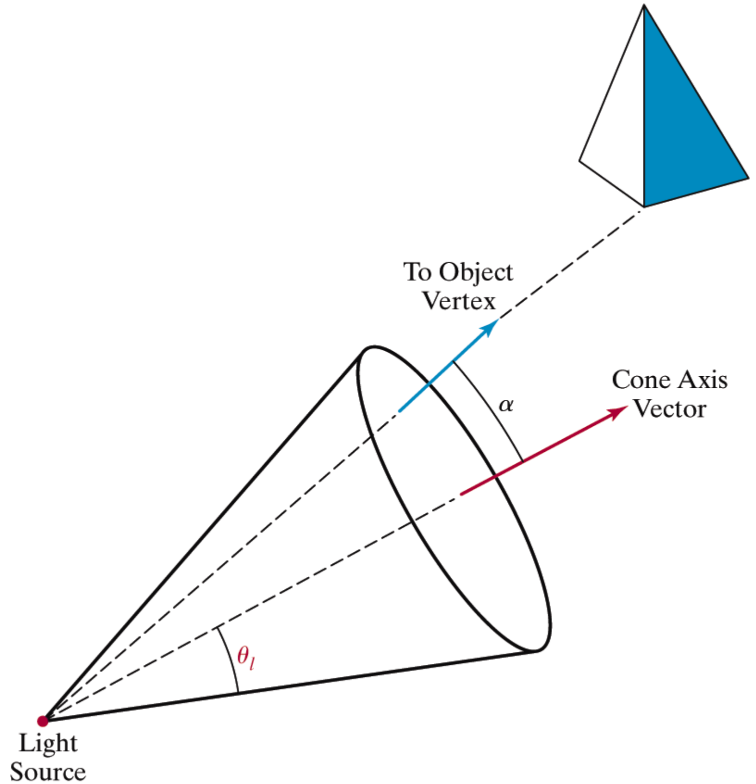
$$f = \begin{cases} 1.0 & \text{if source is at infinity} \\ \dfrac{1}{a_0 + a_1 d + a_2 d^2} & \text{if source is local} \end{cases}$$

  - The intensity attenuation is not applied to light sources at infinity because all points in the scene are at a nearly equal distance from a far-off source

Light Sources

- Angular intensity attenuation
  - For a directional light, we can attenuate the light intensity angularly as well as radially

$$f(\alpha) = \cos^n \alpha$$

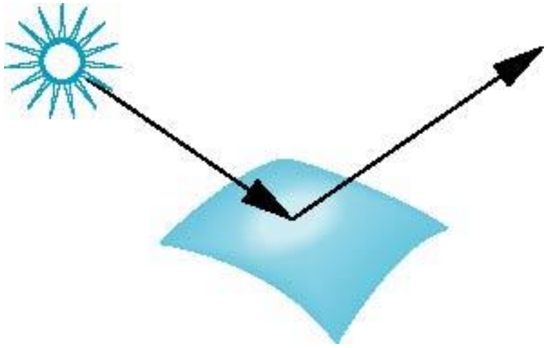


Surface Lighting Effects

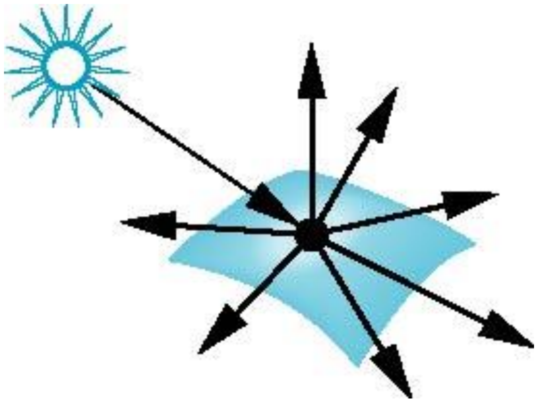
- An illumination model computes the lighting effects for a surface using the various optical properties
  - Degree of transparency, color reflectance, surface texture
- The reflection (***phong illumination***) model describes the way incident light reflects from an opaque surface
  - Diffuse, ambient, specular reflections
  - Simple approximation of actual physical models

Surface Types

- The smoother a surface, the more reflected light is concentrated in the direction a perfect mirror would reflected the light
- A very rough surface scatters light in all directions



smooth surface



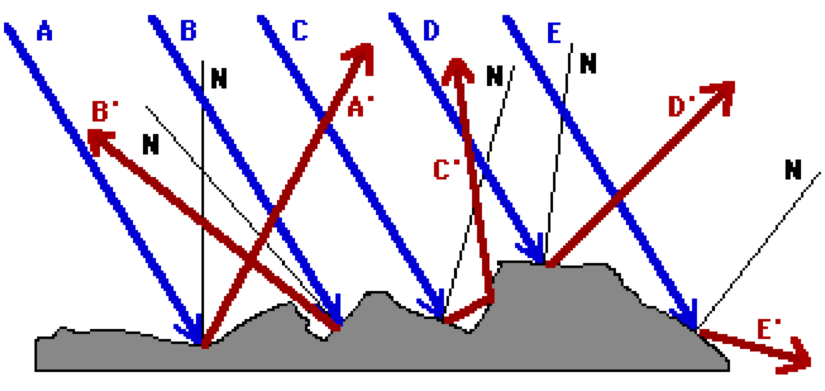
rough surface

Phong Model

- A simple model that can be computed rapidly
- Has three components
  - Diffuse
  - Specular
  - Ambient

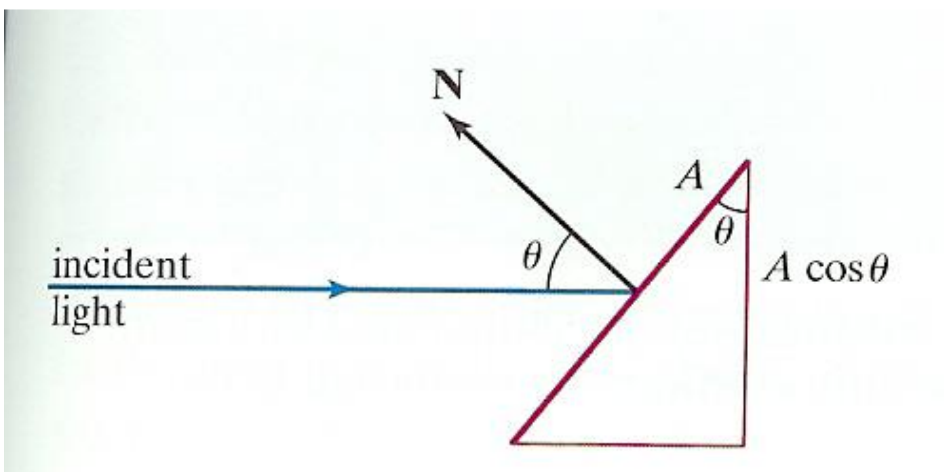
Diffuse Reflection

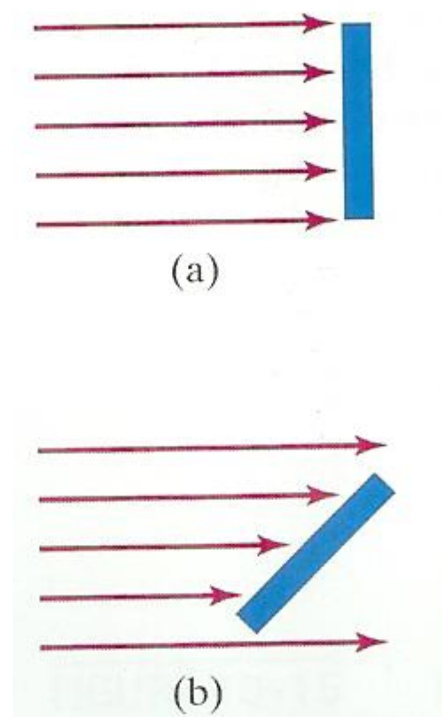
- Incident light is scattered with equal intensity in all directions
- Such surfaces are called ***ideal diffuse reflectors***
  (also referred to as ***Lambertian reflectors***)



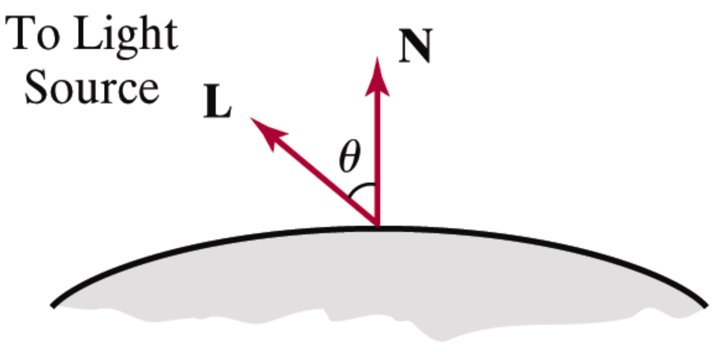
Diffuse Reflection

- Light intensity is independent of angle of reflection
- Light intensity depends on angle of incidence





Diffuse Reflection



$$I = k_d I_l \cos\theta = k_d I_l (N \cdot L)$$

I_l : the intensity of the light source

k_d : diffuse reflection coefficient,

N : the surface normal (unit vector)

L : the direction of light source, (unit vector)

Ambient Light

- Multiple reflection of nearby (light-reflecting) objects yields a uniform illumination
- A form of diffuse reflection independent of he viewing direction and the spatial orientation of a surface
- Ambient illumination is constant for an object

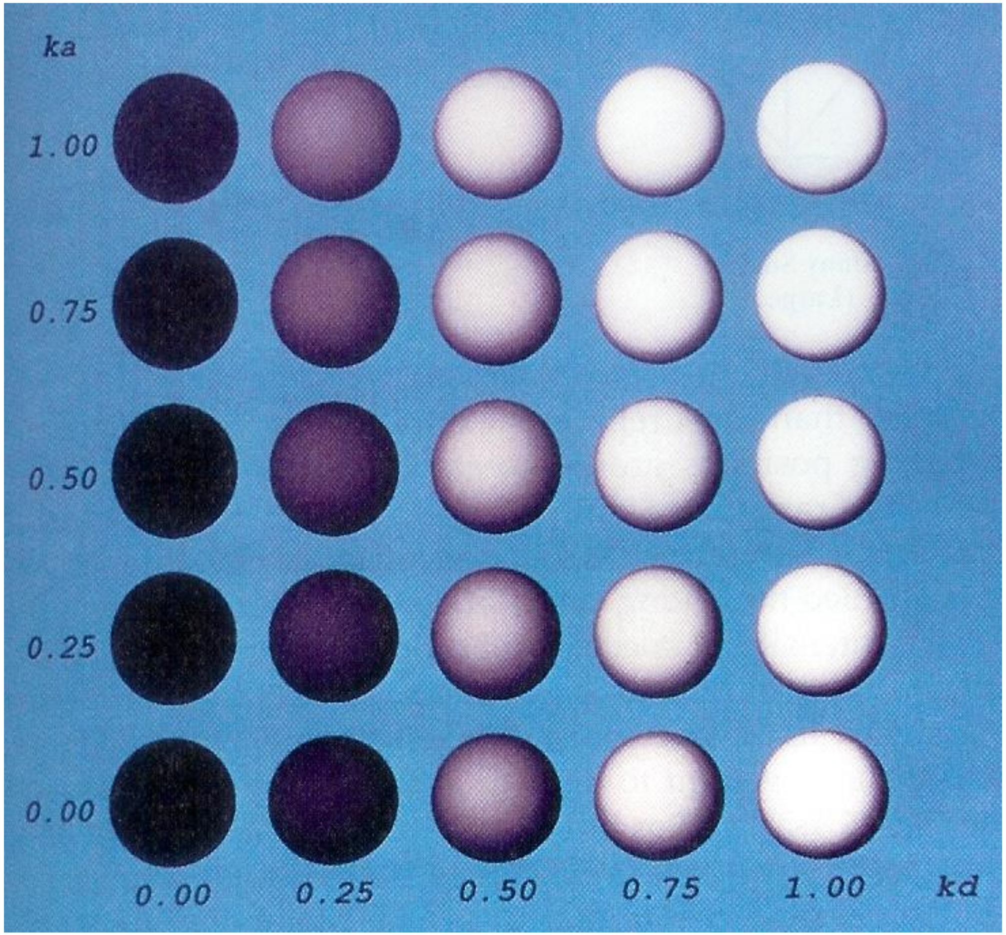
$$I = k_a I_a$$

I_a: the incident ambient intensity

k_a: ambient reflection coefficient, the proportion reflected away from the surface

Ambient + Diffuse

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



Specular Reflection

- Perfect reflector (mirror) reflects all lights to the direction where angle of reflection is identical to the angle of incidence
- It accounts for the ***highlight***
- Near total reflector reflects most of light over a range of positions close to the direction

Specular Reflection

- Phong specular-reflection model
  - Note that N, L, and R are coplanar, but V may not be coplanar to the others

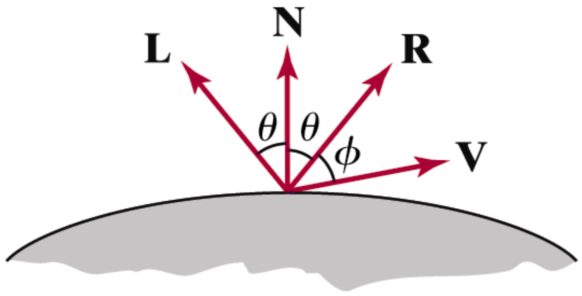


Figure 10-16

Specular reflection angle equals angle of incidence θ.

$$I = k_s I_l \cos^n \phi = k_s I_l (R \cdot V)^n$$

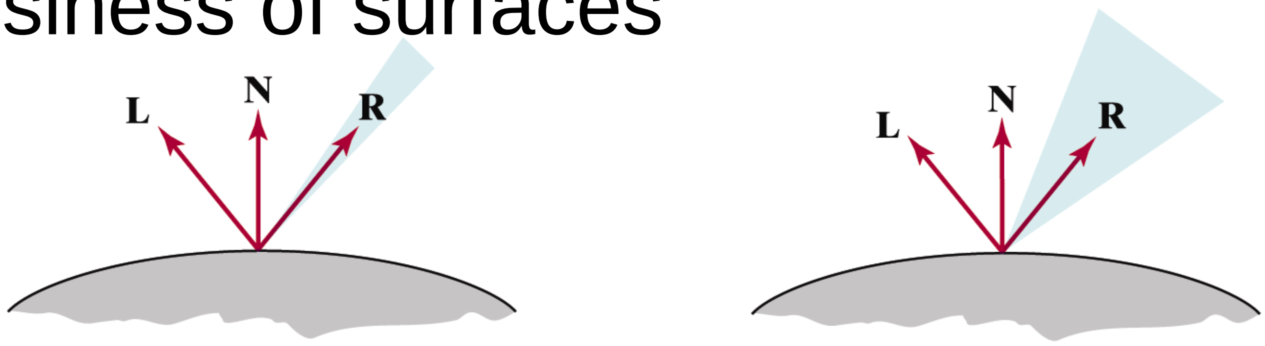
I_l : intensity of the incident light

k_s : color-independent specular coefficient

n : the gloss of the surface

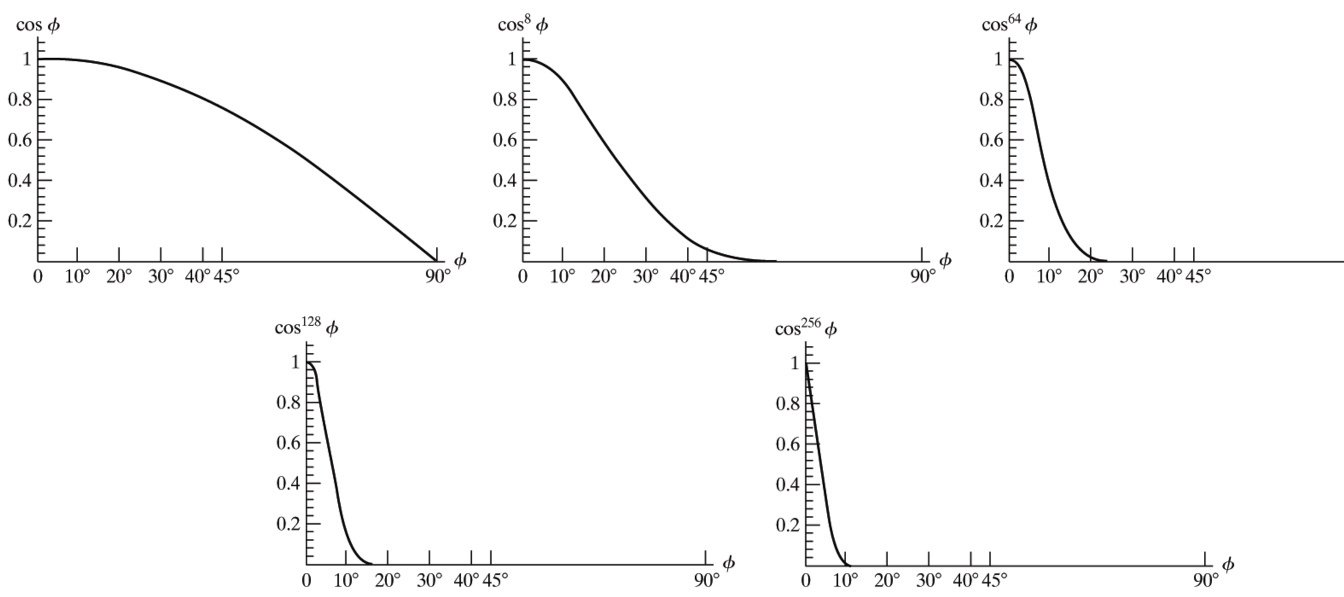
Specular Reflection

- Glossiness of surfaces



Shiny Surface
(Large n_s)

Dull Surface
(Small n_s)



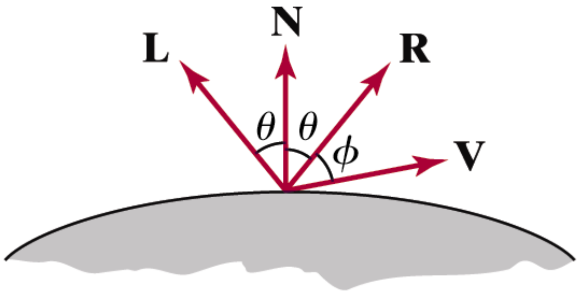
Specular Reflection

- Specular-reflection coefficient k_s is a material property
  - For some material, k_s varies depending on θ
  - $k_s = 1$ if $\theta = 90^\circ$

- Calculating the reflection vector R

$$R + L = (2L \cdot N)N$$

$$R = (2L \cdot N)N - L$$



Specular Reflection

- Simplified Phong model using halfway vector
  - H is constant if both viewer and the light source are sufficiently far from the surface

$$H = \frac{V + L}{|V + L|}$$

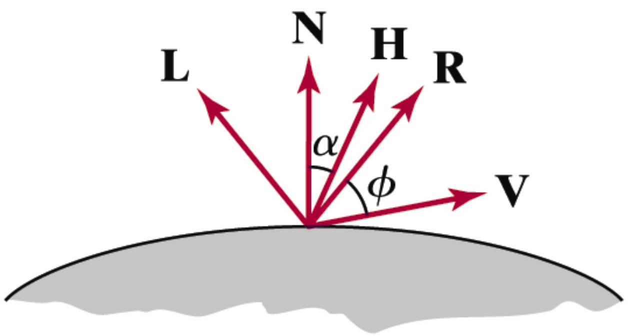


Figure 10-22

Halfway vector **H** along the bisector of the angle between **L** and **V**.

$$I = I_p k_s \cos^n \phi = I_p k_s (R \cdot V)^n$$

$$\approx I_p k_s \cos^n \alpha = I_p k_s (N \cdot H)^n$$

Ambient+Diffuse+Specular Reflections

- Single light source

$$I = k_a I_a + k_d I_l (N \cdot L) + k_s I_l (R \cdot V)^n$$

- Multiple light source

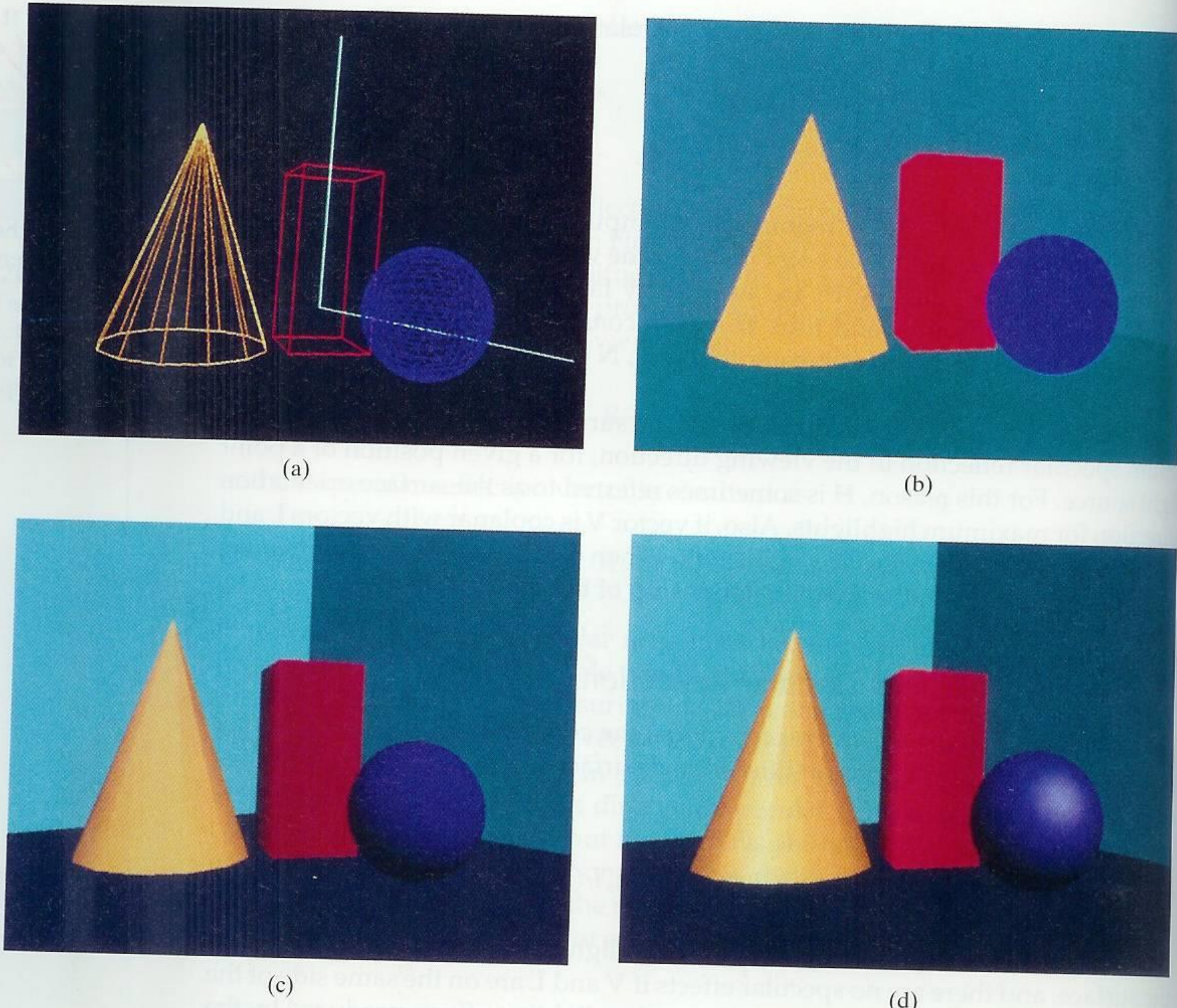
$$I = k_a I_a + \sum_l k_d I_l (N \cdot L) + k_s I_l (R \cdot V)^n$$

- Emission and attenuation

$$I = I_{emit} + k_a I_a$$
$$+ \sum_l f_{l,rad\_atten} f_{l,ang\_atten} \left(k_d I_l (N \cdot L) + k_s I_l (R \cdot V)^n \right)$$

Parameter Choosing Tips

- For a RGB color description, each intensity and reflectance specification is a three-element vector
- The sum of reflectance coefficients is usually smaller than one $k_a + k_d + k_s \leq 1$
- Try *n* in the range [0, 100]
- Use a small k_a (~0.1)
- Example
  - Metal: n=90, k_a=0.1, k_d=0.2, k_s=0.5



(a)
(b)
(c)
(d)