

## Phong Model/Specular Reflection

When we look at an illuminated shiny surface, such as polished metal, an apple etc we see a highlight or bright spot, at certain viewing direction this phenomenon is called “specular reflection” and is the result of total or near total reflection of the incident light in a concentrated region around the “specular reflection angle”.

This angle is equal to the angle of incidence.

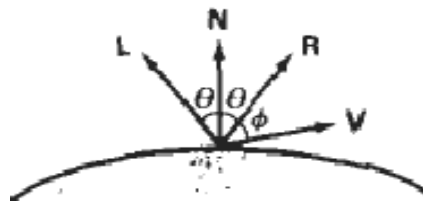
**N** – unit normal surface vector

**R** – unit vector in the direction of ideal specular reflection

**L** – unit vector directed towards point light source

**V** – unit vector pointing to viewer from the surface position

$\phi$  – viewing angle relative to specular reflection direction **R**



For ideal reflector (perfect mirror) incident light is reflected only in the specular reflection direction i.e. **V** and **R** coincide ( $\phi = 0$ ).

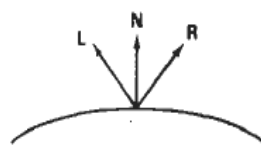
Shiny surfaces have narrow  $\phi$  and dull surfaces have wider  $\phi$

An empirical model for calculating specular reflection range was developed by Phong Bui Tuong called “Phong specular reflection” model and it sets the intensity of specular reflection directly proportional to  $\cos^n \phi$   $\phi \rightarrow 0$  to  $90$

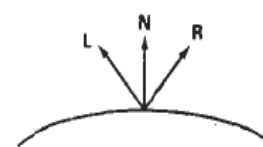
Specular reflection parameter  $n_s$  is determined by type of surface

Very shiny surface has large  $n_s$  value

Very dull surface has smaller  $n_s$  value (down to 1)



Shiny Surface  
(Large  $n_s$ )

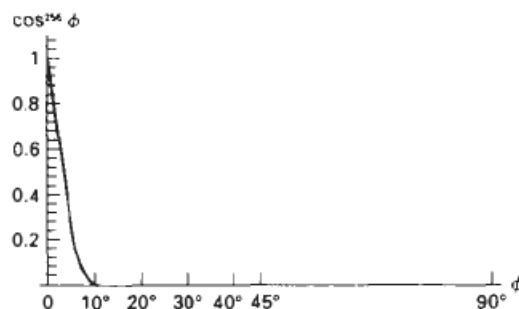
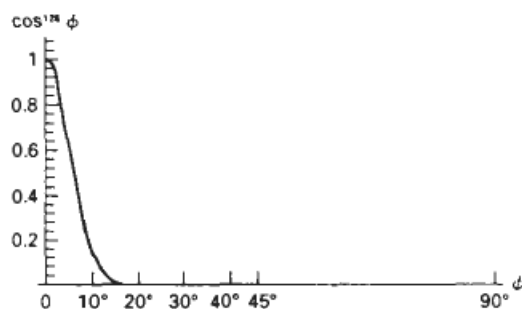
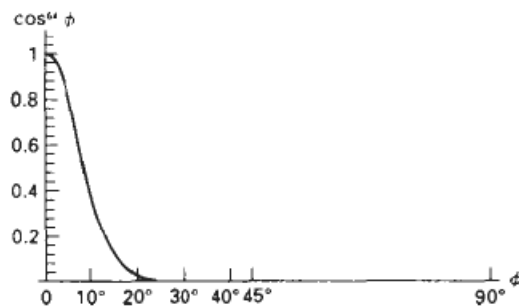
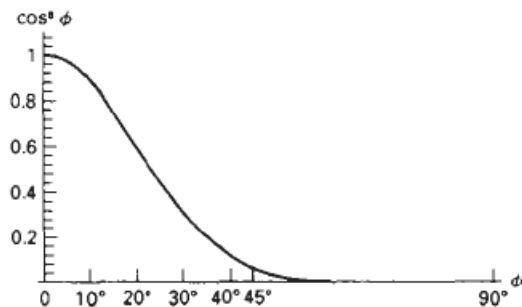
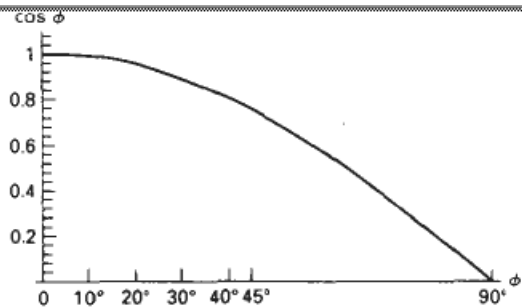


Dull Surface  
(Small  $n_s$ )

Rough surface, e.g. chalk has  $n_s = 1$

Intensity of specular reflection depends on material properties of surface, other factors such as polarization, color of incident light.

For monochromatic specular reflections intensity variations can be approximated by SR coefficient  $W(\phi)$



$W(\theta)$  tends to increase as  $\theta$  increases, at  $\theta = 90$   $W(\theta) = 1$  and all incident light is reflected.

Fresnel's law of reflection describes specular reflection intensity with  $\theta$  and using  $W(\theta)$ , Phong specular reflection model as

$$I_{\text{spec}} = W(\theta) I_L \cos^{ns} \theta$$

where  $I_L$  is intensity of light source

$\theta$  is viewing angle relative to the specular reflection direction  $R$ .

So transparent materials like glass exhibit specular reflection as  $\theta$  approaches 90. At  $\theta = 0$  about 4 percent of the incident light on a glass surface is reflected.

Now also 
$$I_{\text{spec}} = W(\theta) I_L (V \cdot R) \quad \text{as } V \cdot R = \cos^{ns} \theta$$

$R$  can be calculated in term of  $N$  and  $L$

$$R + L = (2N \cdot L)N \quad \text{or} \quad R = (2N \cdot L)N - L$$

Simplified Phong model is obtained by half way vector  $H$  between  $L$  and  $V$  to calculate the range of SRs

Replacing  $V \cdot R$  in equation with  $N \cdot H \rightarrow \cos \theta$  replaced by  $\cos \alpha$  Half way vector  $H$

$$H = \frac{L+V}{2}$$

$$|\mathbf{L} + \mathbf{V}|$$

If both viewer and light source are sufficiently far from surface both  $\mathbf{V}$  and  $\mathbf{L}$  are constant over the surfaces. Hence  $\mathbf{H}$  is constant.

For non Planar surfaces  $\mathbf{N} \cdot \mathbf{H}$  requires less computation than  $\mathbf{V} \cdot \mathbf{R}$

If  $\mathbf{V}$  is coplanar with  $\mathbf{l}$  and  $\mathbf{R}$  (also  $\mathbf{N}$ ) then  $\alpha = \phi / 2$

If  $\mathbf{V}, \mathbf{L}, \mathbf{N}$  are non coplanar then  $\alpha > \phi / 2$

Combined diffuse and specular reflections with multiple light sources

For single point light source

$$\mathbf{I} = \mathbf{I}_{\text{diffuse}} + \mathbf{I}_{\text{spec}} = \mathbf{K}_a \mathbf{I}_a + \mathbf{K}_d \mathbf{I}_L (\mathbf{N} \cdot \mathbf{L}) + \mathbf{K}_s \mathbf{I}_L (\mathbf{N} \cdot \mathbf{H})^n$$

For multiple light sources

$$\mathbf{I} = \mathbf{K}_a \mathbf{I}_a + \sum_{i=1}^n \mathbf{I}_{Li} [ (\mathbf{K}_d (\mathbf{N} \cdot \mathbf{L}_i) + \mathbf{K}_s (\mathbf{N} \cdot \mathbf{H}_i)^n ) ]$$