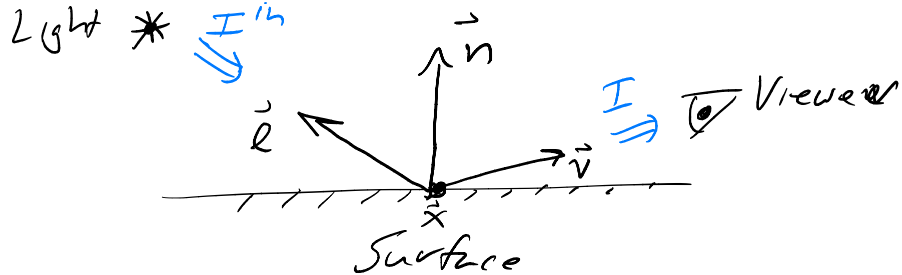
Phong lighting   Local lighting model.   (No shadows)

Take into account



$\vec{l}, \vec{n}, \vec{v}$ - unit vectors

I_a^{in} - incoming ambient light

I_d^{in} - " diffuse "

I_s^{in} - " specular "

ρ_a - ambient reflectivity

ρ_d - diffuse "

ρ_s - specular "

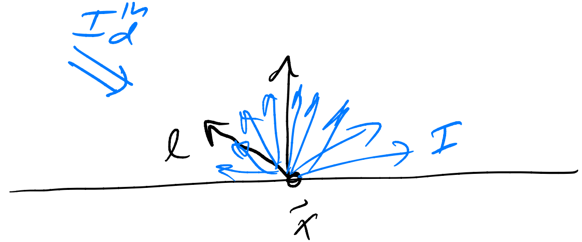
I_e - emissive outgoing light.

f - specular exponent (scalar - controls sharpness of specular highlights)

I_a, I_d, I_s - outgoing light components

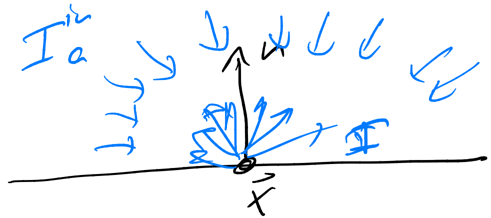
These all depend on color (R, G, B) except: $\vec{l}, \vec{n}, \vec{v}, f$ do not

Diffuse

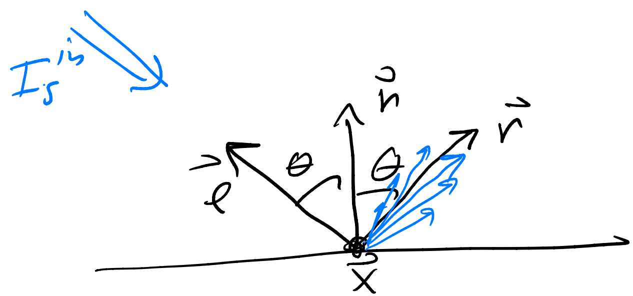


Reflects equally in all directions

Ambient



Specular



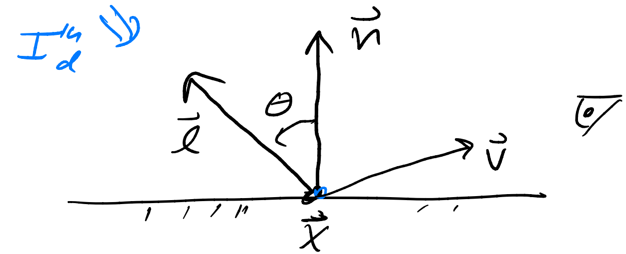
Reflecting mostly around direction of perfect reflection
"mostly" controlled by the specular exponent f

Total Outgoing light $\quad I = I_e + I_a + I_d + I_s$

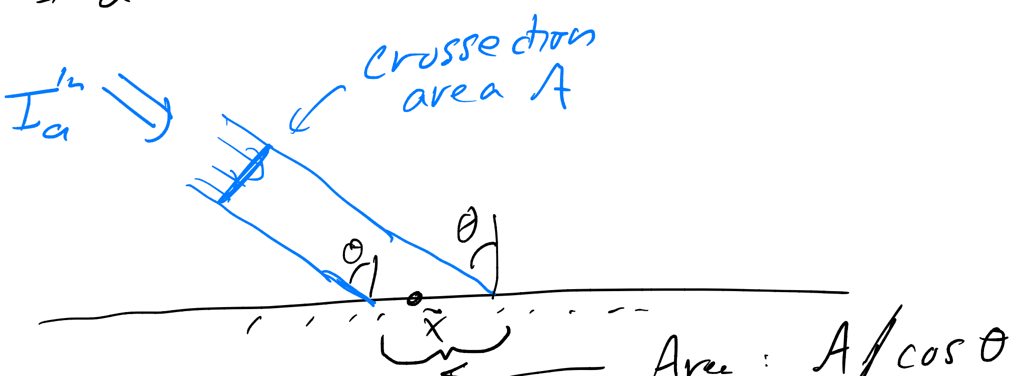
Ambient : $\quad I_a = \rho_a I_a^{in}$ $\qquad \rho_a$ - ambient reflectivity coefficient.

Diffuse

$$I_d = \rho_d I_d^{in} \cos\theta$$
$$= \rho_d I_d^{in} (\vec{n} \cdot \vec{\ell})$$



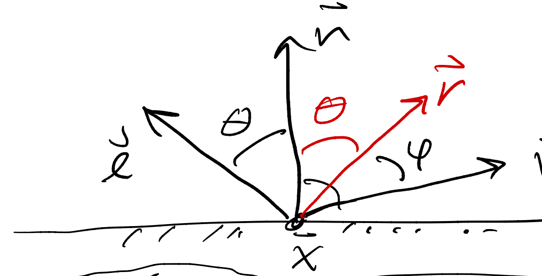
$I_d^{in} \cos\theta$ - illumination per unit surface area.



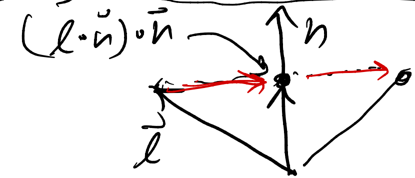
"Lambertian" surface

Specular

$\vec{r}$ - direction of perfect reflection



$$\vec{r} = 2(\vec{\ell}\cdot\vec{n})\vec{n} - \vec{\ell}$$



$$(\vec{\ell}\cdot\vec{n})\vec{n} - \ell = \vec{r} - (\vec{\ell}\cdot\vec{n})\vec{n}$$

So $\vec{r} = 2(\vec{\ell}\cdot\vec{n})\vec{n} - \vec{\ell}$

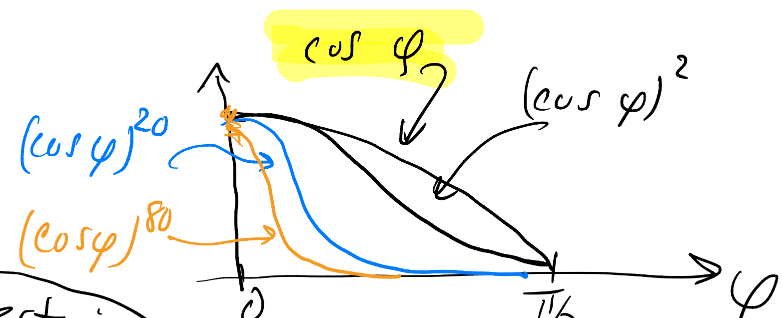
$$I_s = \rho_s I_s^{in} (\cos\varphi)^f$$

$$= \rho_s I_s^{in} (\vec{r}\cdot\vec{v})^f$$

if $\vec{r}\cdot\vec{v} \geq 0$, i.e. $\varphi \leq \pi/2$

$I_s = 0$ if $(\vec{r}\cdot\vec{v}) < 0$.

$$I_s = \rho_s I_s^{in} \left(\max\{0, \vec{r}\cdot\vec{v}\}\right)^f$$



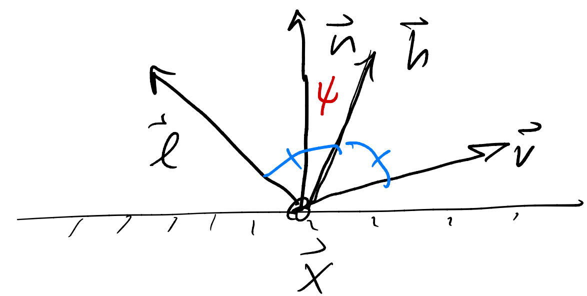
Intuition If $\varphi \approx 0$, get a strong specular reflection. Otherwise, very little specular reflection

Alternate calculation for specular, that does not use the $\vec{r}$ vector

Uses halfway vector $\vec{h} = \dfrac{\vec{l}+\vec{v}}{\|\vec{l}+\vec{v}\|}$ - midway between l and $\vec{v}$

$\cos\psi = \vec{h}\cdot\vec{n}$

ψ - angle between $\vec{h}$ and $\vec{n}$



If $\vec{l}, \vec{v}, \vec{n}$ are coplanar, then $\psi = \frac{1}{2}\varphi$. ($\varphi$ - angle between $\vec{r}$ and v)

Alternative calculation: $I_s = \rho_s \cdot I_s^{in} (\vec{h}\cdot\vec{n})^f$ (Replaced $\max\{0, \vec{r}\cdot\vec{v}\}$ with $\vec{h}\cdot\vec{n}$).

Note if $\vec{v} = \vec{r}$, $\vec{h} = \vec{n}$. So result is "similar"

Advantages to using $\vec{h}$:

Advantages to using the halfway vector

- $\vec{h} \cdot \vec{n}$ is always ≥ 0 (Unlike $\vec{r} \cdot \vec{v}$)
- Sometimes $\vec{l}$ and $\vec{v}$ are constant independent of the position $\vec{x}$ on the surface

- If the light directional – $\vec{l}$ is constant

For a positional light at position $\vec{w}$,

$$\vec{l} = \frac{\vec{w} - \vec{x}}{\|\vec{w} - \vec{x}\|}$$

- If the viewer is directional, $\vec{v}$ is fixed

Usually, use $\vec{v} = -\vec{k}$ (looking down the negative z-axis)

Otherwise, if viewer is positional at position $\vec{w}'$

$$\vec{v} = \frac{\vec{w}' - \vec{x}}{\|\vec{w}' - \vec{x}\|}$$

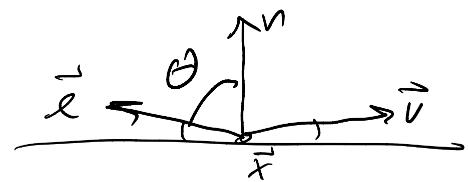
A viewer is called non-local or local.

→ In this case: $\vec{h} = \frac{\vec{l} + \vec{v}}{\|\vec{l} + \vec{v}\|}$ is constant

- Using h is advantageous if $f = 1$.

Fresnel adjustment to specular light.

Physical principle More specular reflectivity at "grazing" angles for the light & view directions than the above formulas give.



Schlick approximation to Fresnel Specularity

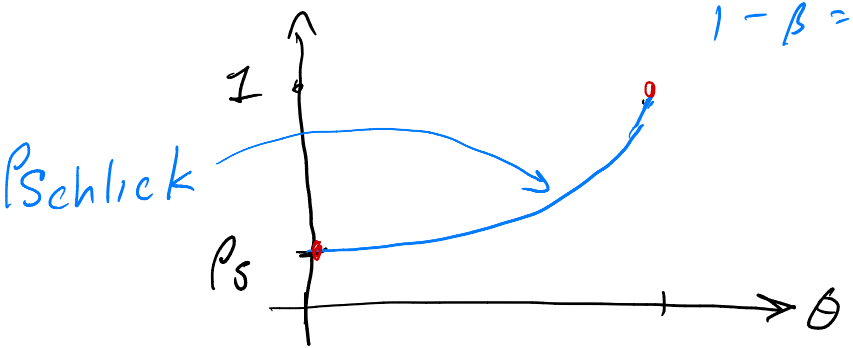
Idea $I_s = \rho_{Schlick} \cdot I_s^{in} \max\{0, \vec{v}\cdot\vec{r}\}^f$ $\quad \rho_s$ is replaced $\rho_{Schlick}$

$\rho_{Schlick}$ will be ≈ 1 when $\vec{\ell}\cdot\vec{n} \approx 0$

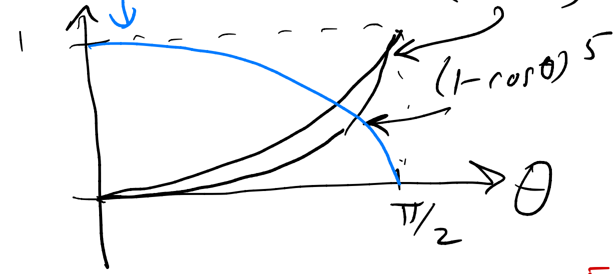
Formula Let $\beta = (1-\cos\theta)^5 = (1-\vec{\ell}\cdot\vec{n})^5$

Let $\rho_{Schlick} = (1-\beta)\rho_s + \beta \cdot 1 = (1-\beta)\rho_s + \beta = \rho_s + \beta(1-\rho_s)$

$= \mathrm{lerp}(\rho_s, 1, \beta) = \mathrm{mix}(\rho_s, 1, \beta)$



$1 - \beta = 1 - (1 - \cos\theta)^5$



$\beta = (1 - \cos\theta)^5$

ρ_s - specular reflectivity when $\theta = 0$

1 " " when $\theta = 1$

Putting it all together

$$I = I_a + I_d + I_s + I_e$$

$$= I_e + \rho_a I_a^{in,global}$$

for i-th light

$$+ \sum_{\text{lights } i} \rho_a I_a^{in,i}$$

$$+ \sum_{\text{lights } i} \rho_d I_d^{in,i} (\vec{l}_i \cdot \vec{n})^f$$

$\vec{l}_i$ - direction for light i

$$+ \sum_{\text{lights } i} \rho_s I_s^{in,i} (\vec{r}_i \cdot \vec{v})^f$$

$\vec{r}_i$ - reflection direction for light i

Do separately for red, green, blue.