

Iluminação

Hughes et al. Caps. 26 e 27

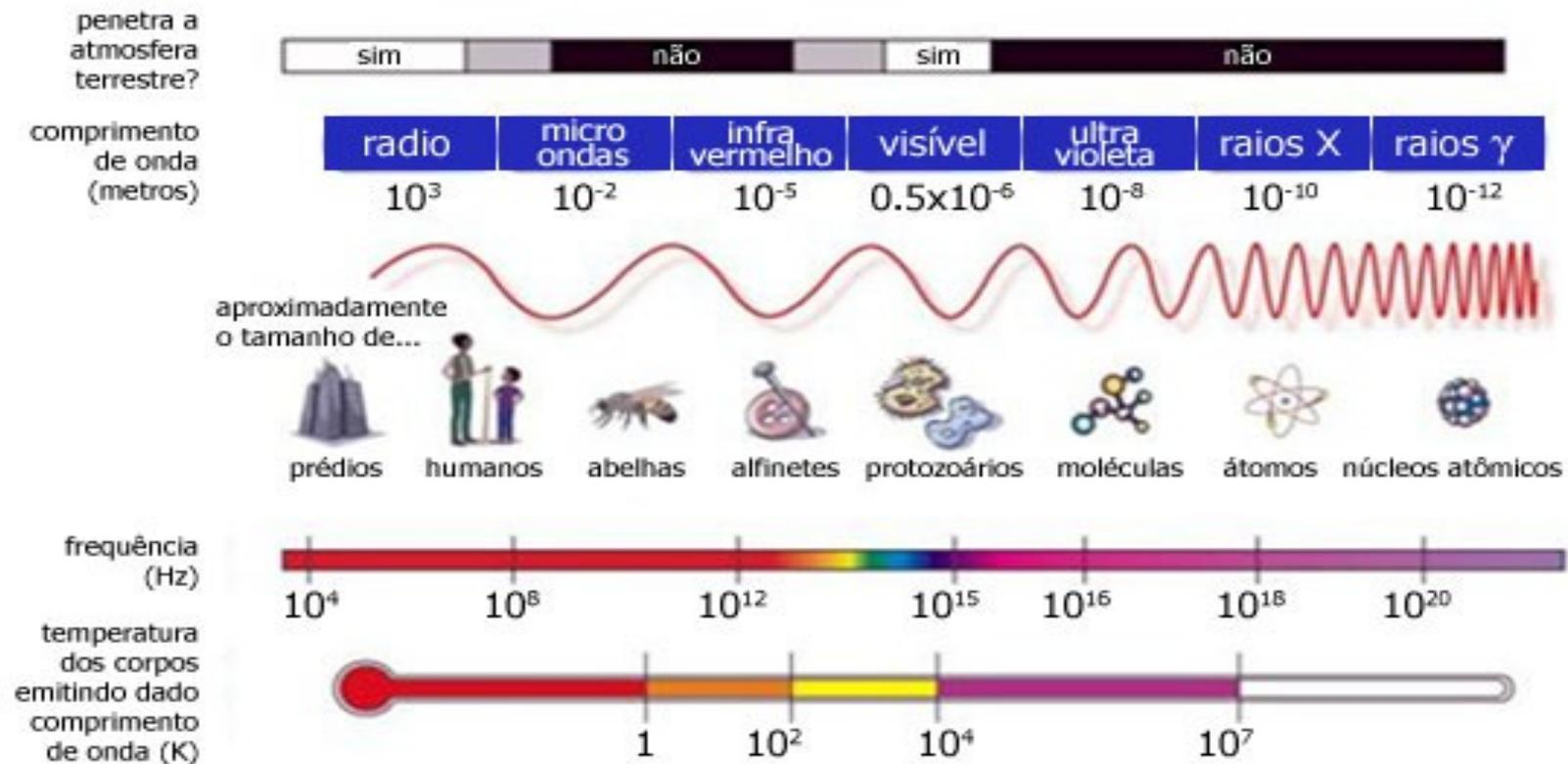
IA725 – Primeiro Semestre de 2016

PE - 22

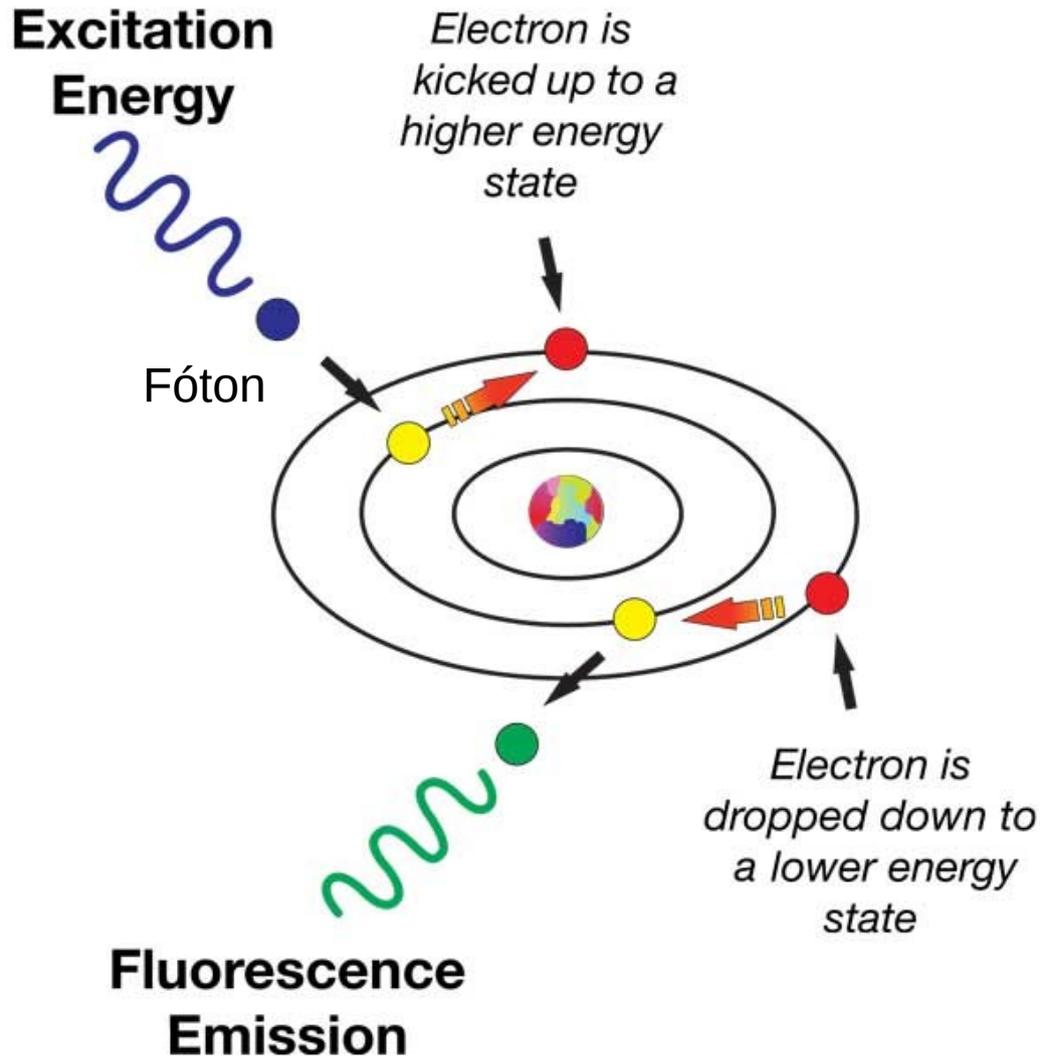
Profa. Ting

Espectro Eletromagnético

O Espectro Eletromagnético

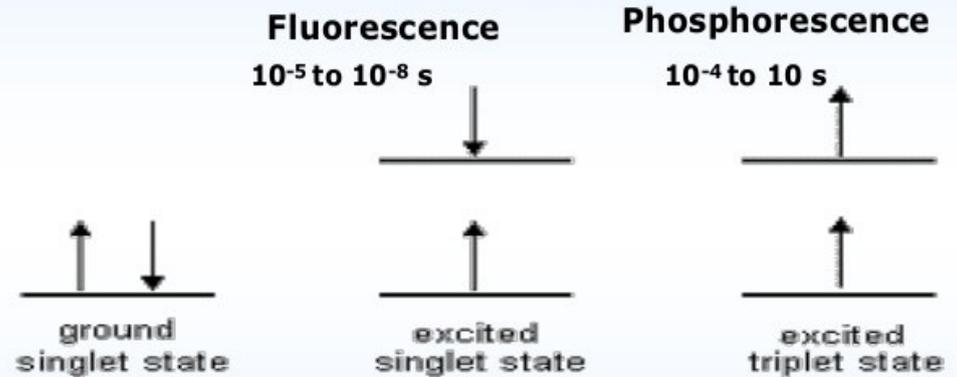


Emissão e Absorção de Fótons



Fluorescence – ground state to *singlet* state & back

Phosphorescence – ground state to *triplet* state & back



Example of Phosphorescence

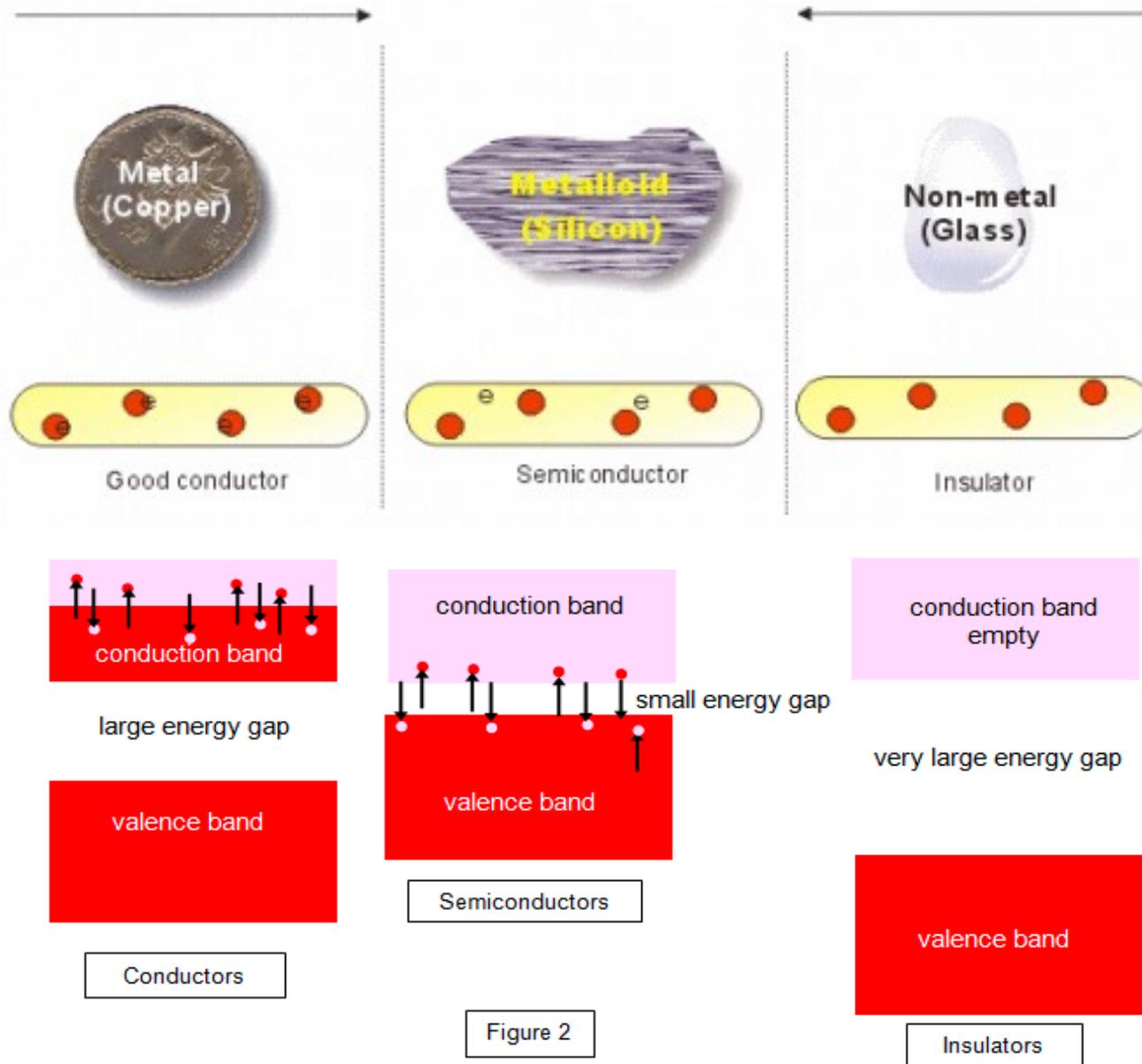


0 sec

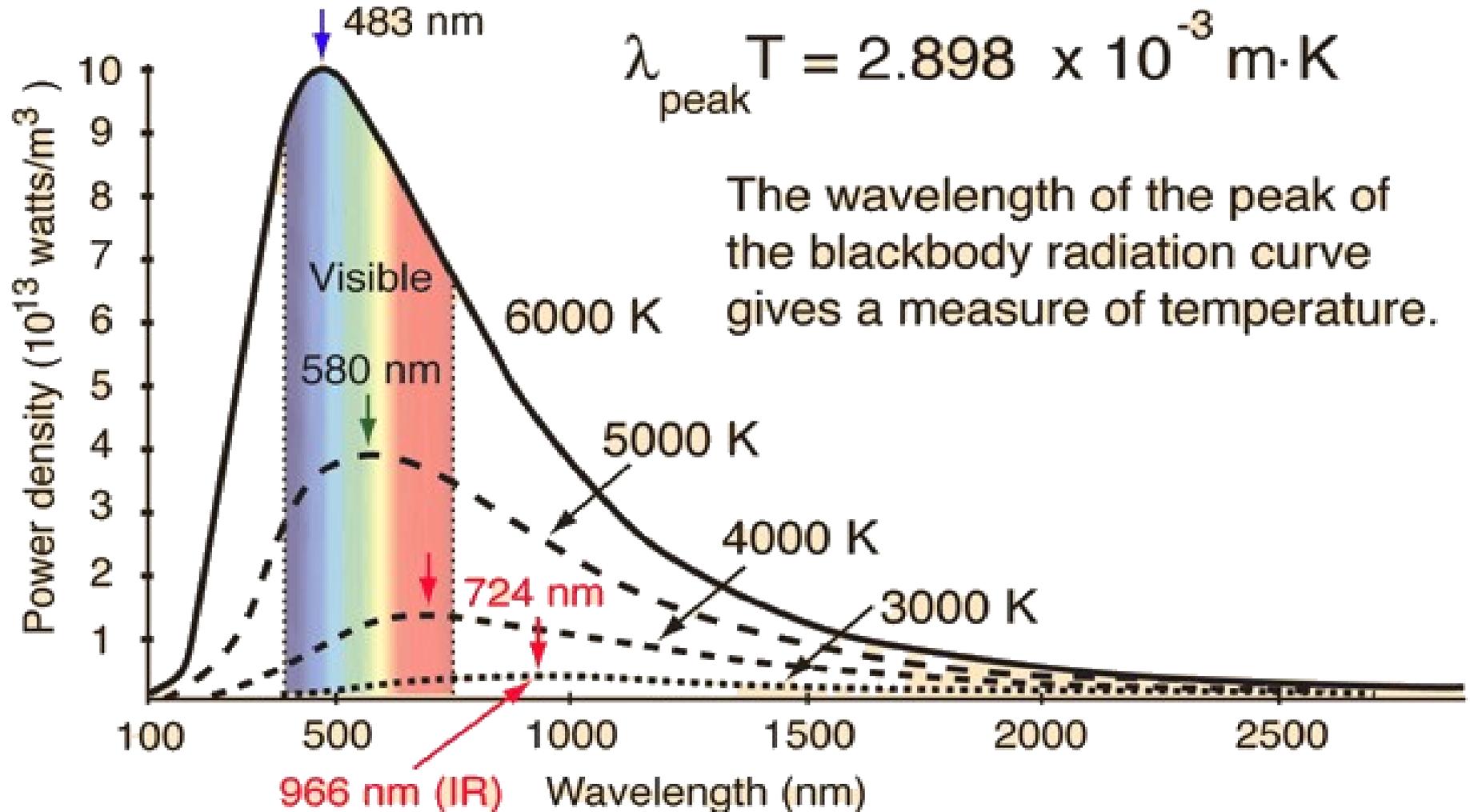


1 sec

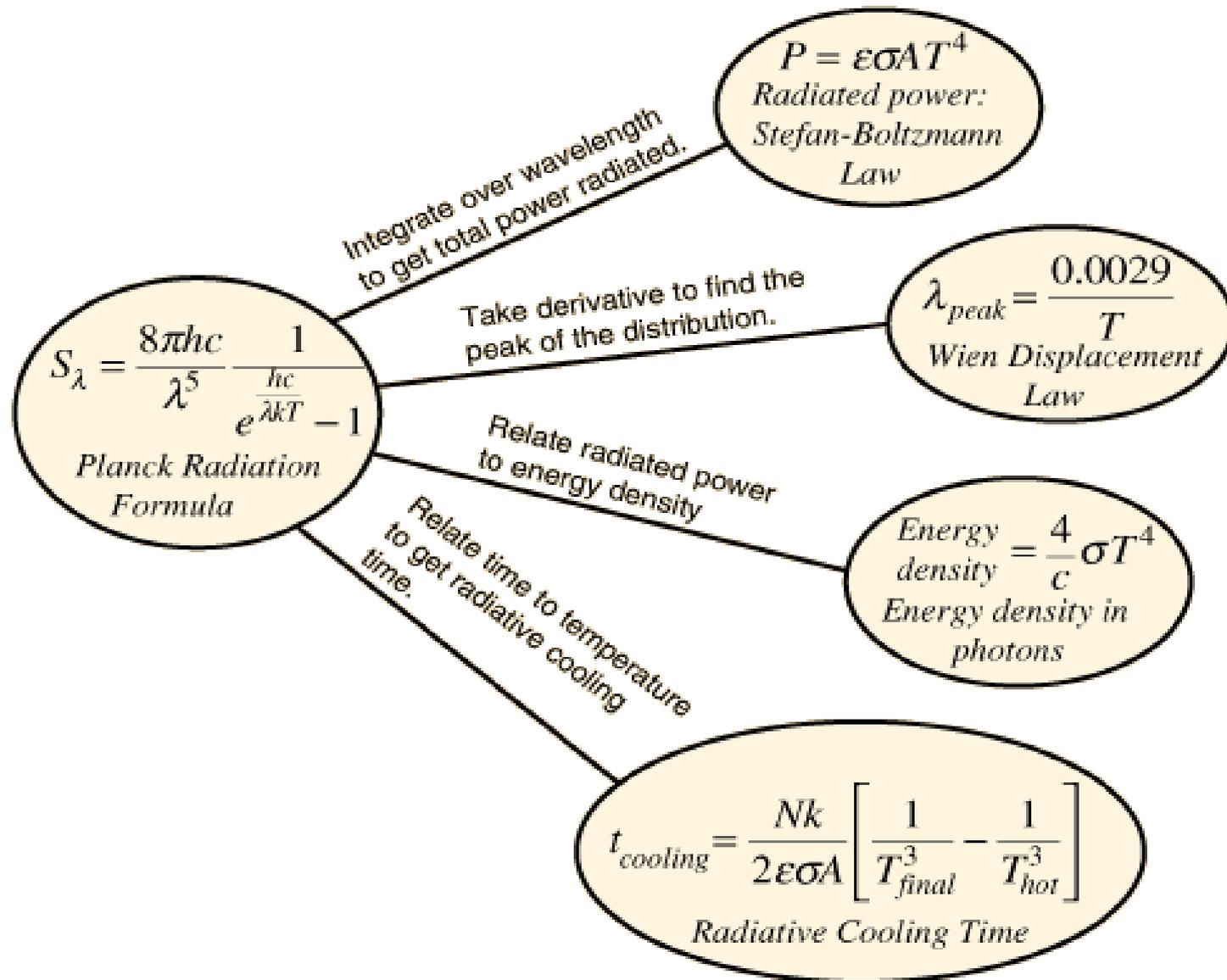
Metais, Semi-condutores e Isolantes



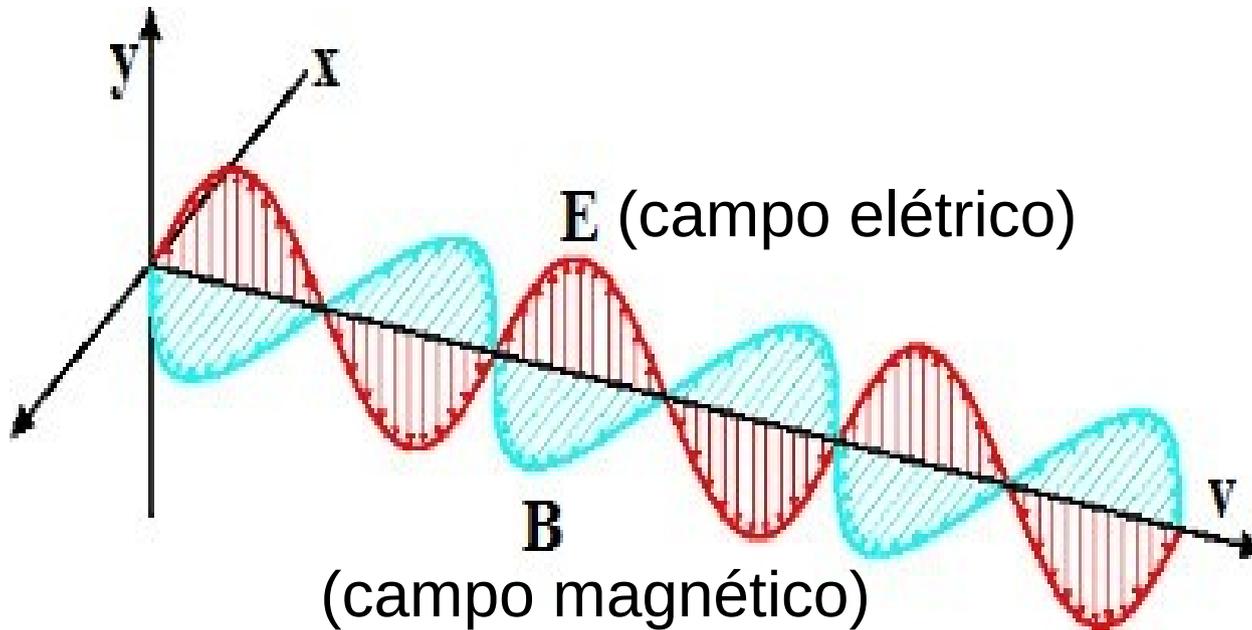
Lei de Deslocamento de Wien



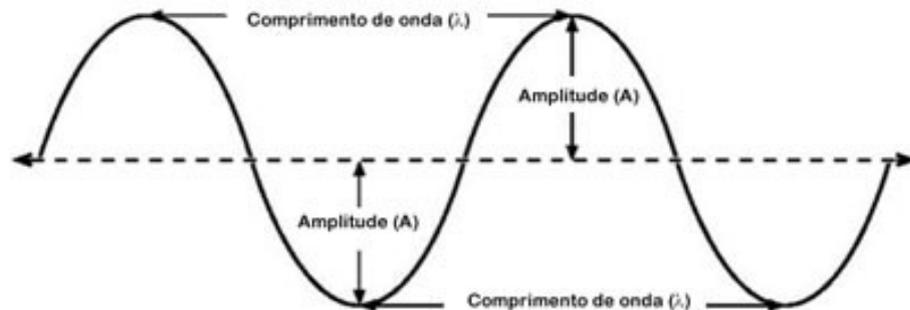
Fórmula de Radiação de Planck



Ondas Eletromagnéticas



$$E = h\nu = h \frac{c}{\lambda}$$



E = energia

h=constante de Planck ($6.626 \cdot 10^{-34}$ Js)

ν =frequência

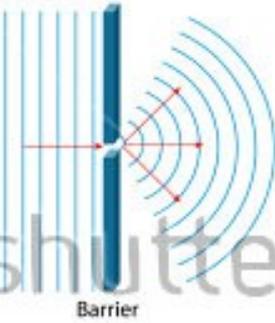
c=velocidade da luz ($2.996 \cdot 10^8$ ms⁻¹)

λ =comprimento de onda

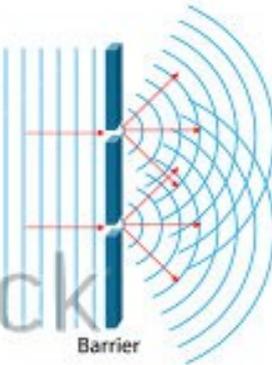
Difrações

DIFFRACTION OF WAVES

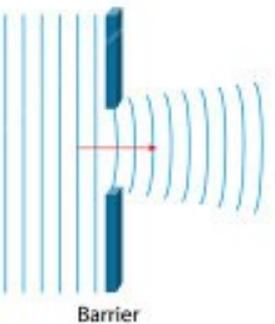
Wave impinges on a narrow slit



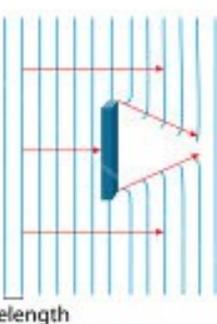
Wave interference



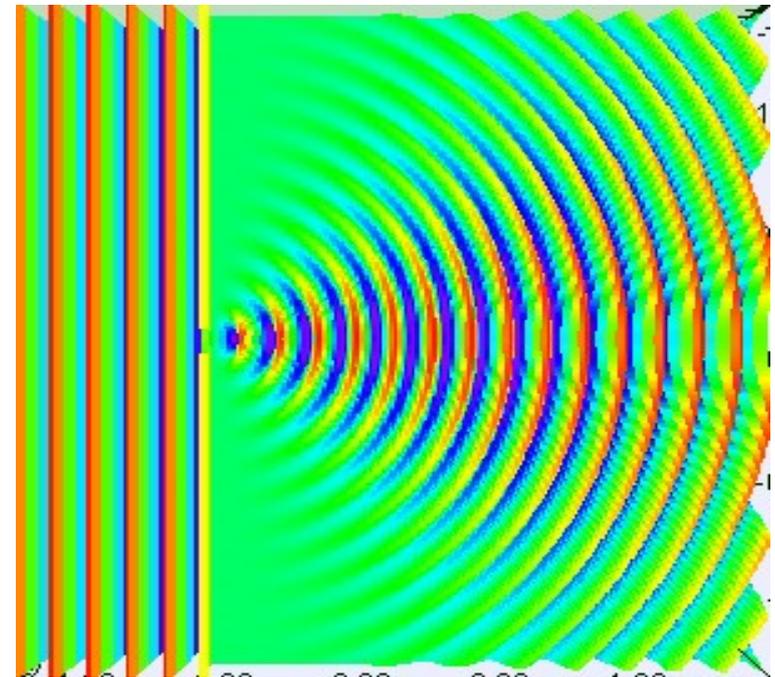
Wave impinges on a broad slit



Barrier is longer than the wavelength

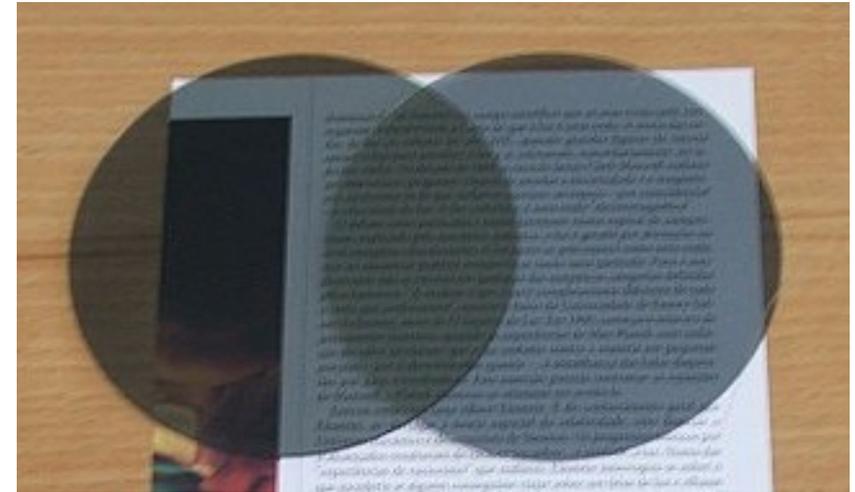
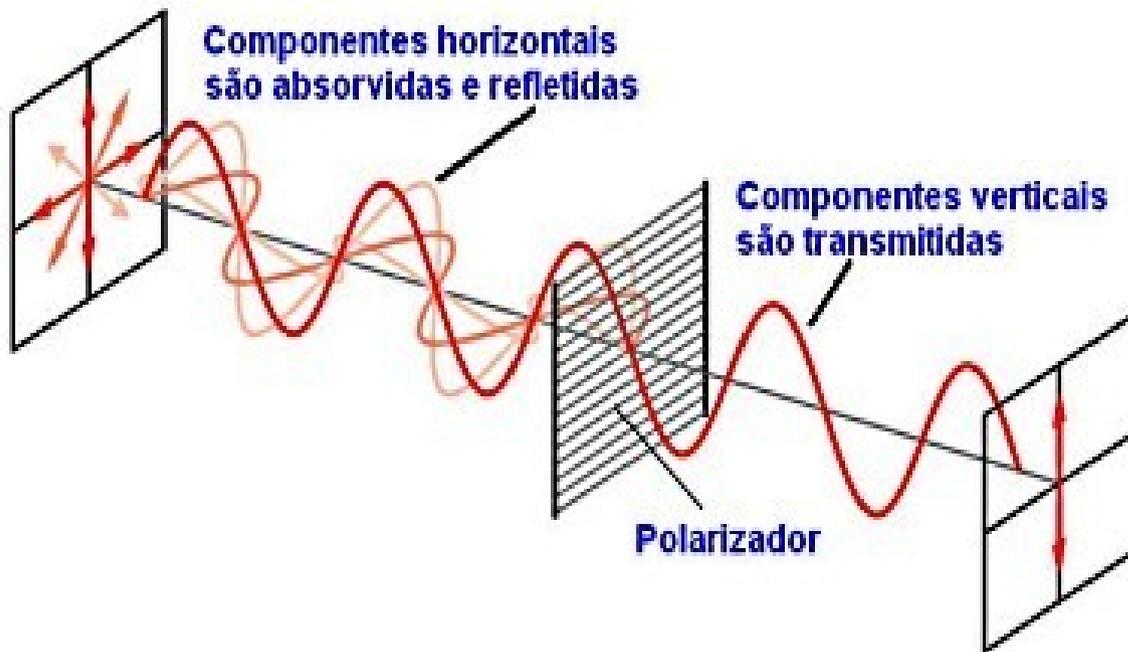


www.shutterstock.com · 369964910



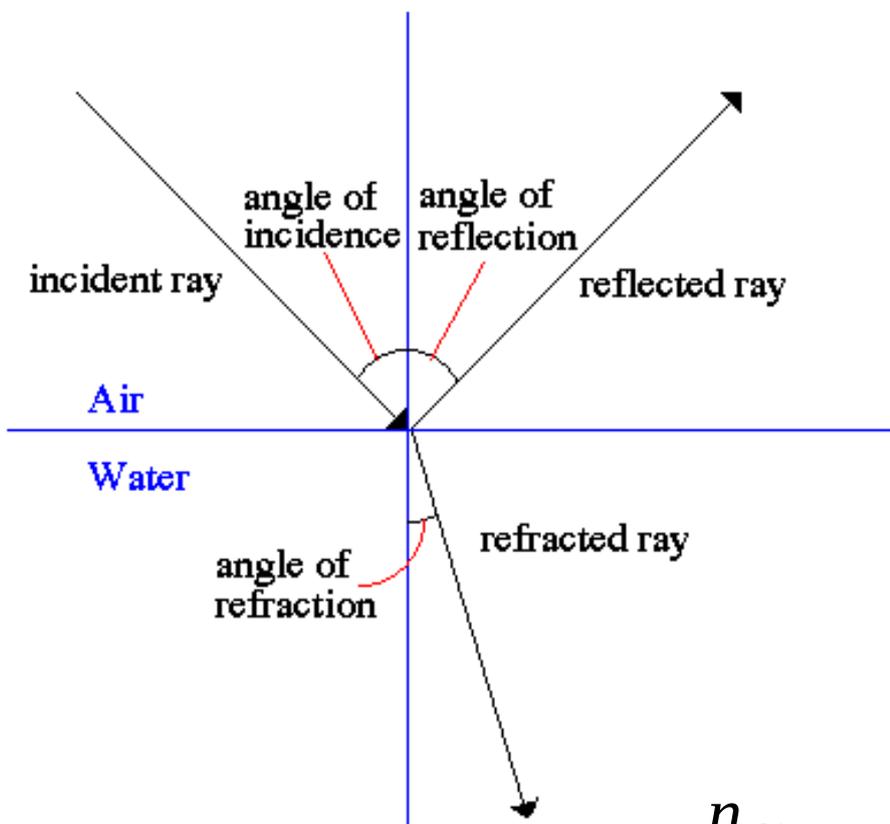
<https://glofx.com/what-are-diffraction-kaleidoscope-glasses/>

Polarização



Refrações

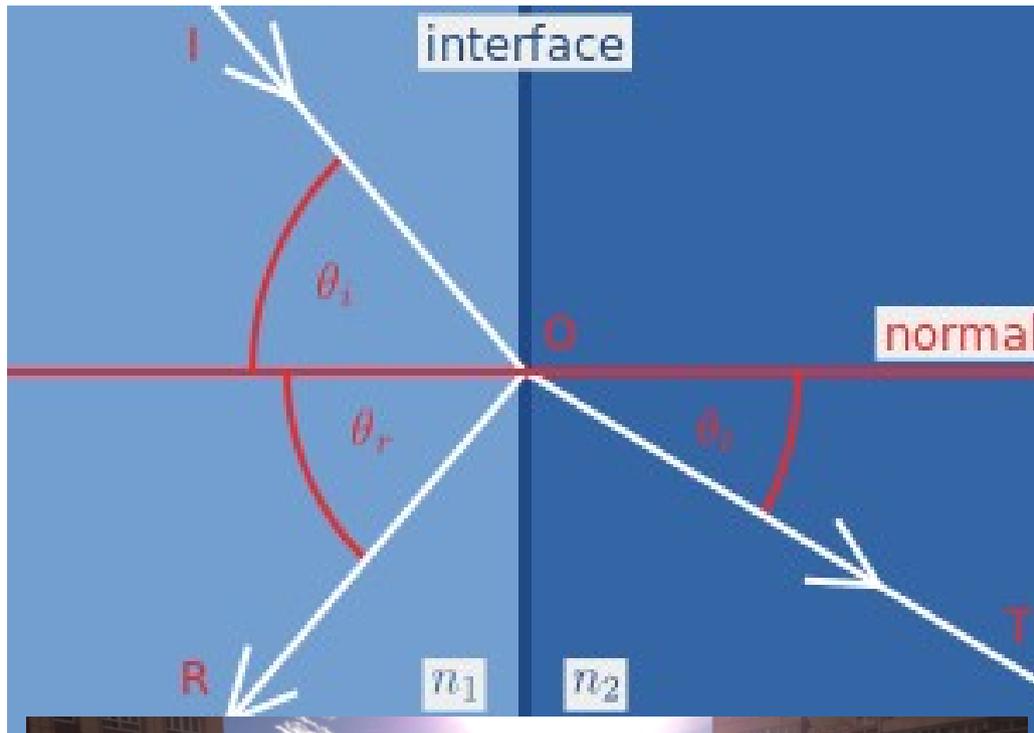
Reflection and Refraction



$$\frac{n_{Air}}{n_{Water}} = \frac{\text{sen } \theta_r}{\text{sen } \theta_i}$$



Reflectância de Fresnel



Fórmula de Cook-Torrance

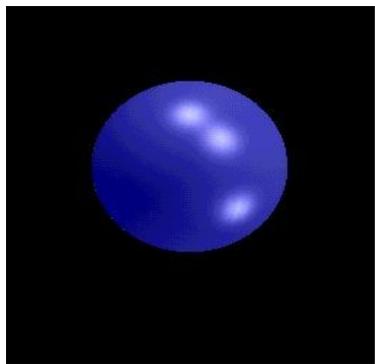
$$F_{\lambda}(\theta_i) = \frac{1}{2} \frac{(g - c)^2}{(g + c)^2} \left(1 + \frac{(c(g + c) - 1)^2}{(c(g - c) + 1)^2} \right)$$

$$c = \cos \theta_i = \bar{l} \cdot \bar{h}$$

$$g = \sqrt{\left(\frac{n_i}{n_t}\right)^2 + c^2} - 1$$

$$T = \left(1 - F_{\lambda}(\theta_i) \right) \frac{n_2^2}{n_1^2} L$$





Reflectância de Fresnel



Fresnel Reflectance

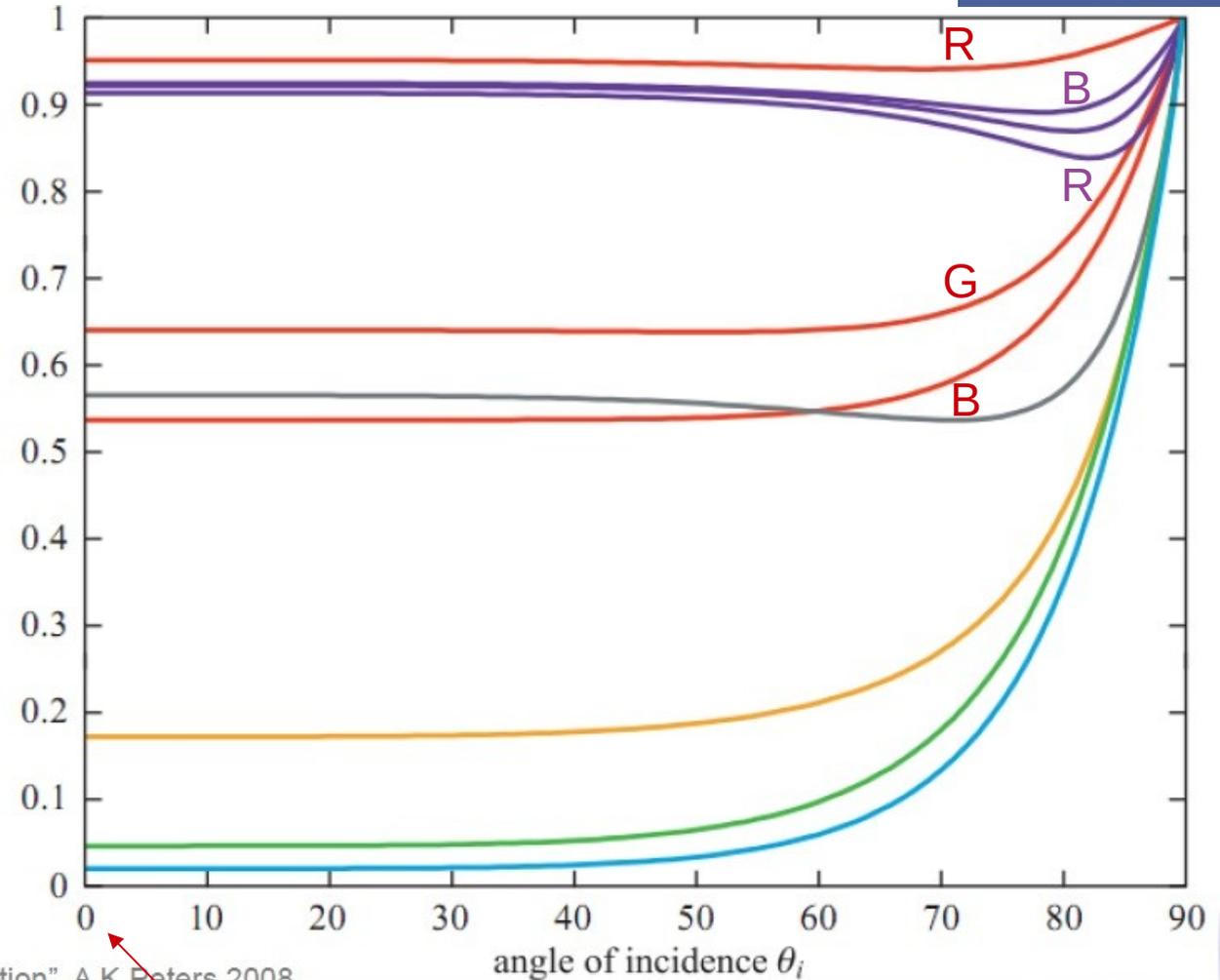


Image from "Real-Time Rendering, 3rd Edition", A.K Peters 2008

Incidência normal →
característica especular
da superfície

Aproximação de Schlick

$$F(f_0) = f_0 + (1 - f_0)(1 - L \cdot h)^5$$

, where f_0 is reflectance at normal incident

$F(f_0)$ is fresnel reflectance term,

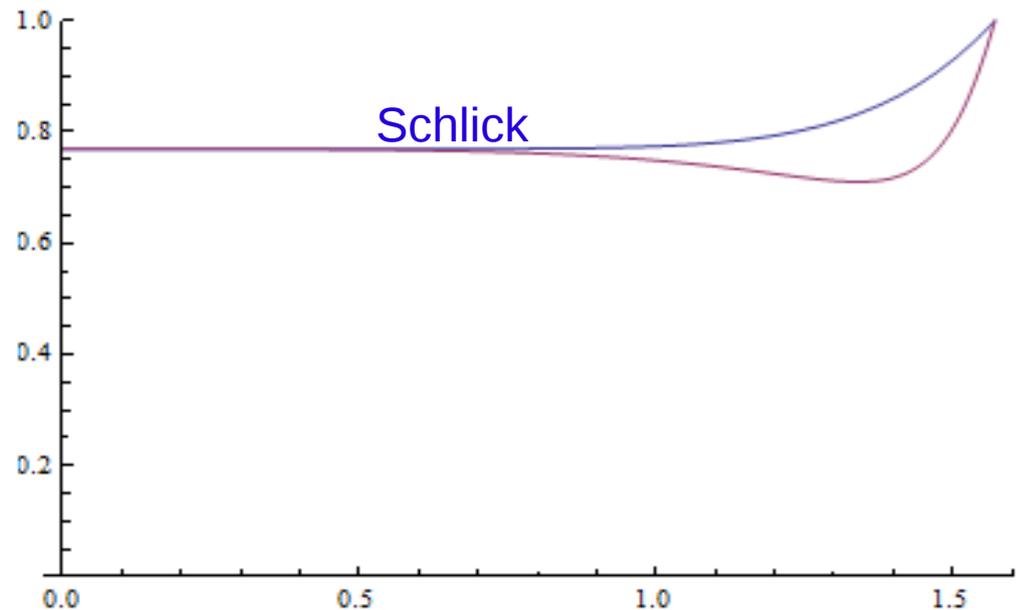
l is the light direction,

v is the view direction,

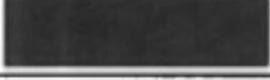
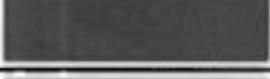
h is the half vector between l and v

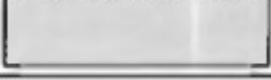
$$f_0 = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 = \left(\frac{n - 1}{n + 1} \right)^2$$

$$n = \frac{n_1}{n_2} \rightarrow \frac{1}{n_2}$$

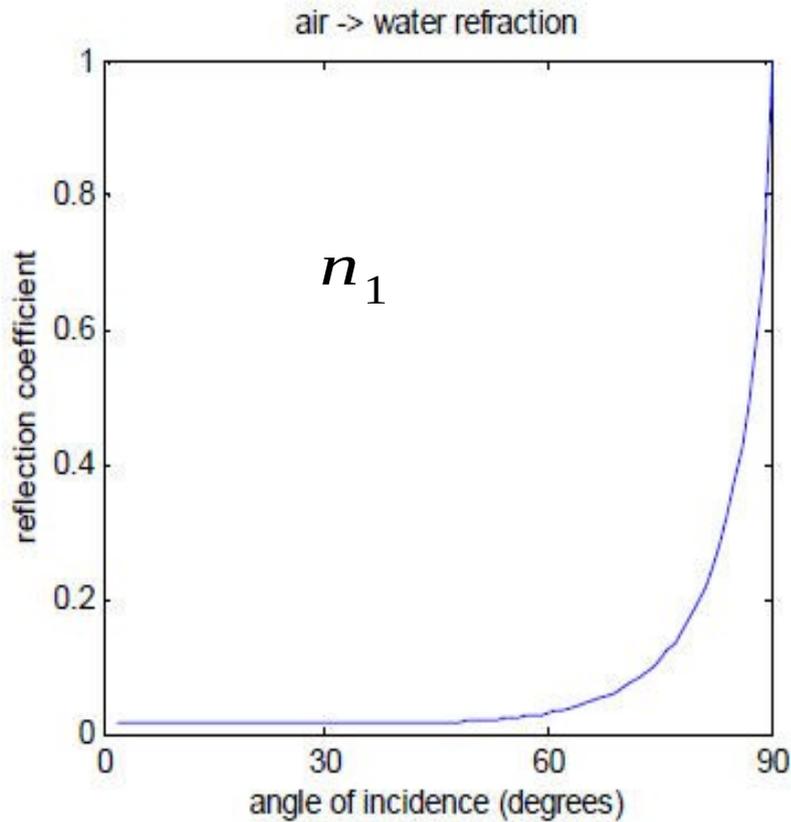


Valores Típicos de Fresnel

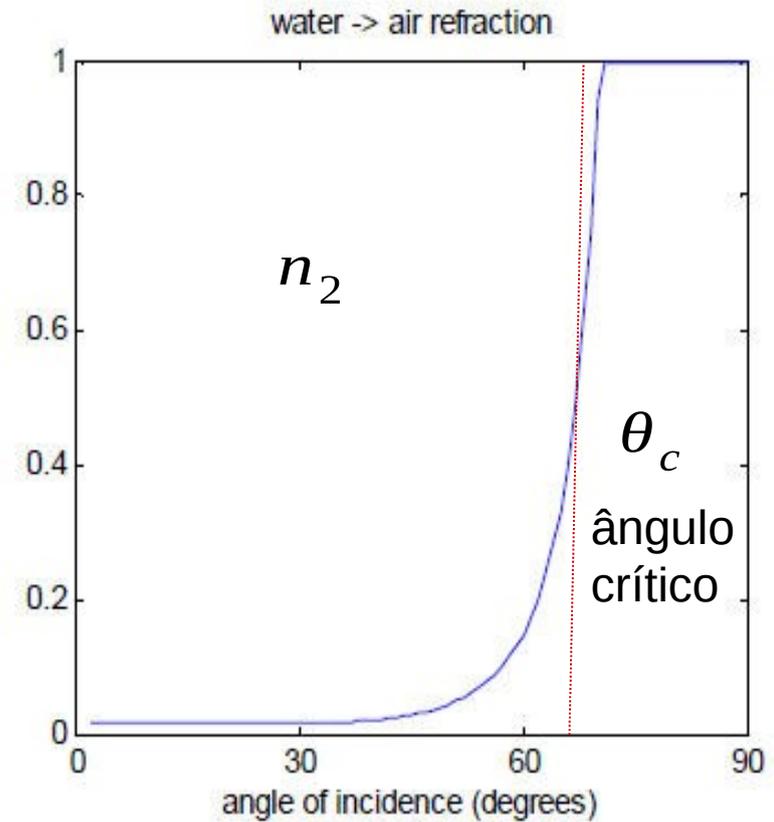
Insulator	$R_F(0^\circ)$ (Linear)	$R_F(0^\circ)$ (sRGB)	Color
Water	0.02,0.02,0.02	0.15,0.15,0.15	
Plastic / Glass (Low)	0.03,0.03,0.03	0.21,0.21,0.21	
Plastic High	0.05,0.05,0.05	0.24,0.24,0.24	
Glass (High) / Ruby	0.08,0.08,0.08	0.31,0.31,0.31	
Diamond	0.17,0.17,0.17	0.45,0.45,0.45	

Metal	$R_F(0^\circ)$ (Linear)	$R_F(0^\circ)$ (sRGB)	Color
Gold	1.00,0.71,0.29	1.00,0.86,0.57	
Silver	0.95,0.93,0.88	0.98,0.97,0.95	
Copper	0.95,0.64,0.54	0.98,0.82,0.76	
Iron	0.56,0.57,0.58	0.77,0.78,0.78	
Aluminum	0.91,0.92,0.92	0.96,0.96,0.97	

Reflectâncias Externa e Interna



Reflectância externa

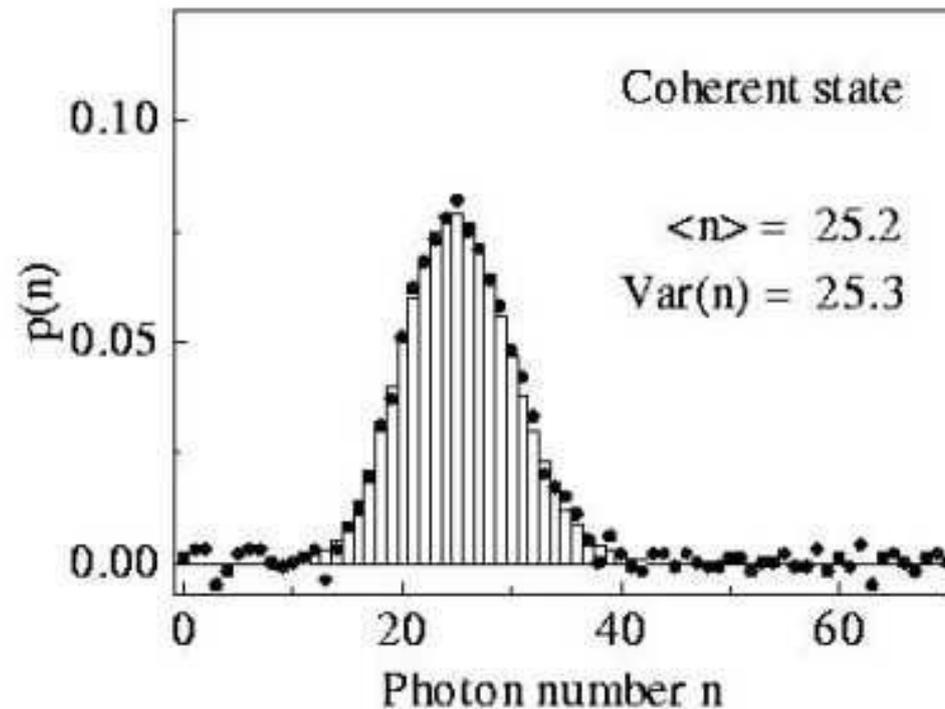


Reflectância interna

Índice de refração maior \rightarrow ângulo crítico

$$\sin \theta_c = \frac{n_1}{n_2}$$

Modelamento de Energia Luminosa

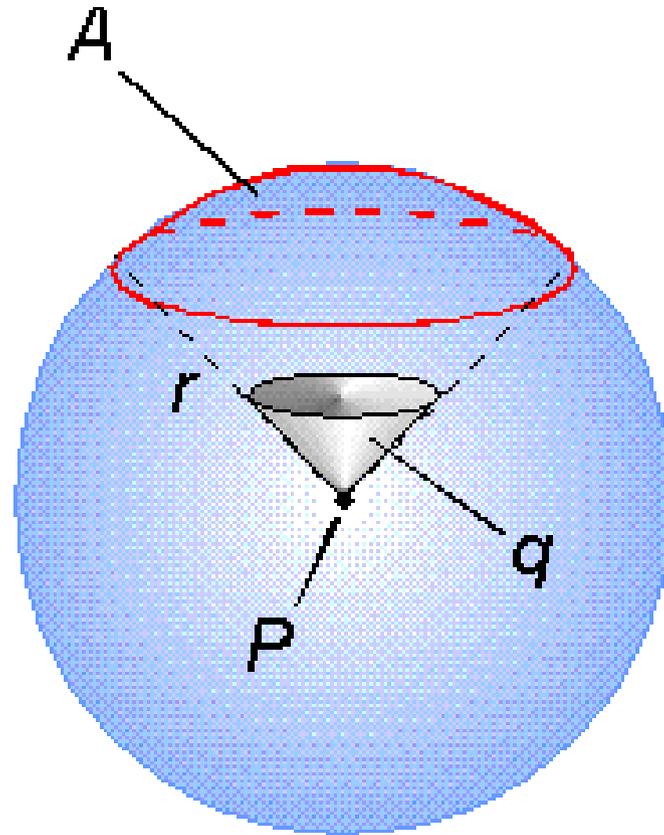


Função de Distribuição de probabilidade de Fótons

$$\square Pr = \int_a^b p(n) dn$$

Ângulo Sólido

Unidade de medida de ângulo sólido (sr), tal que uma esfera completa de área $4\pi r^2$ tem sempre 4π esterradianos.



Computação de Ângulos Sólidos

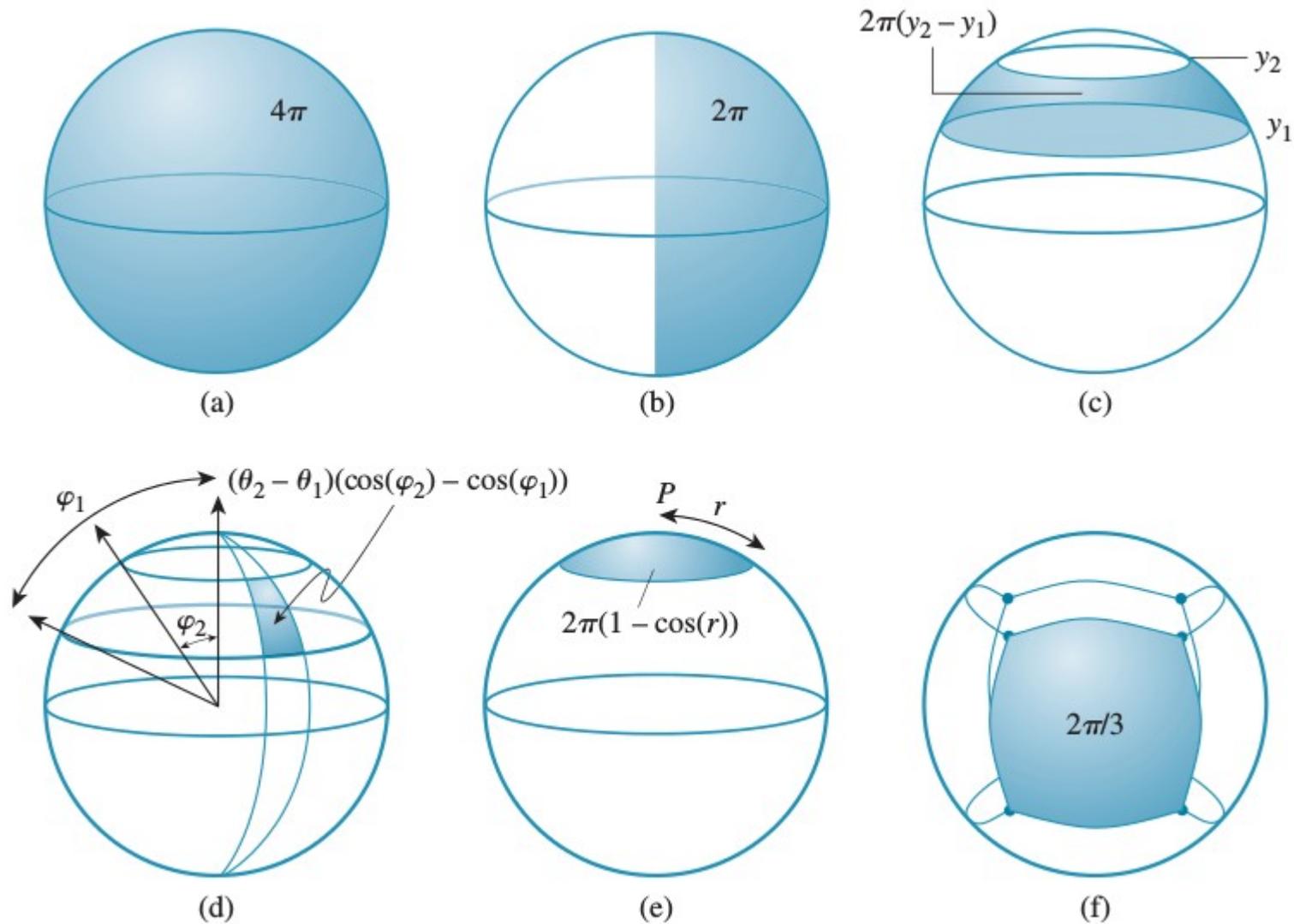
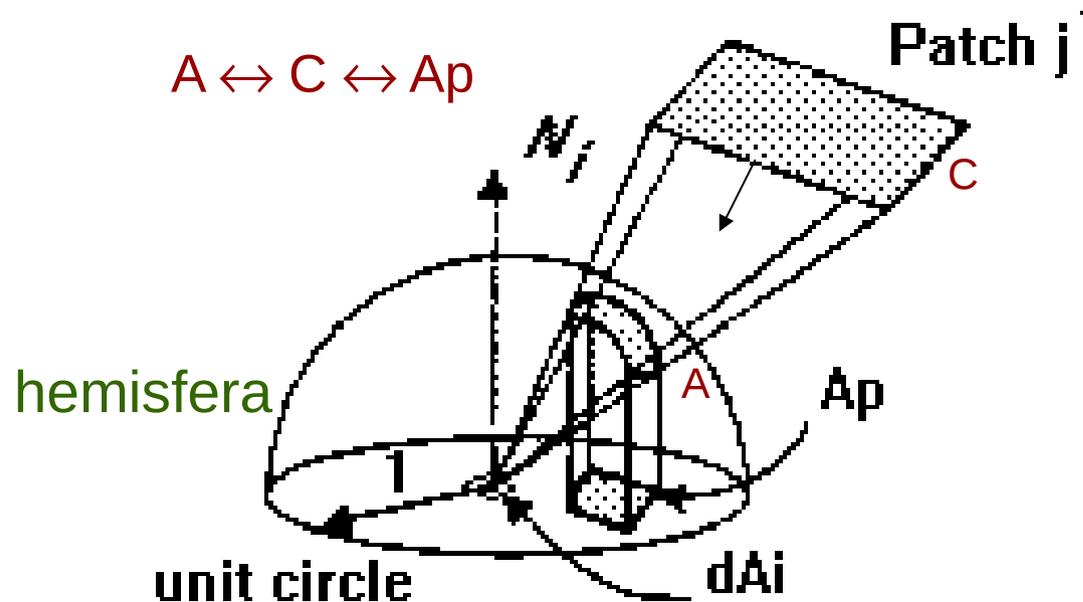


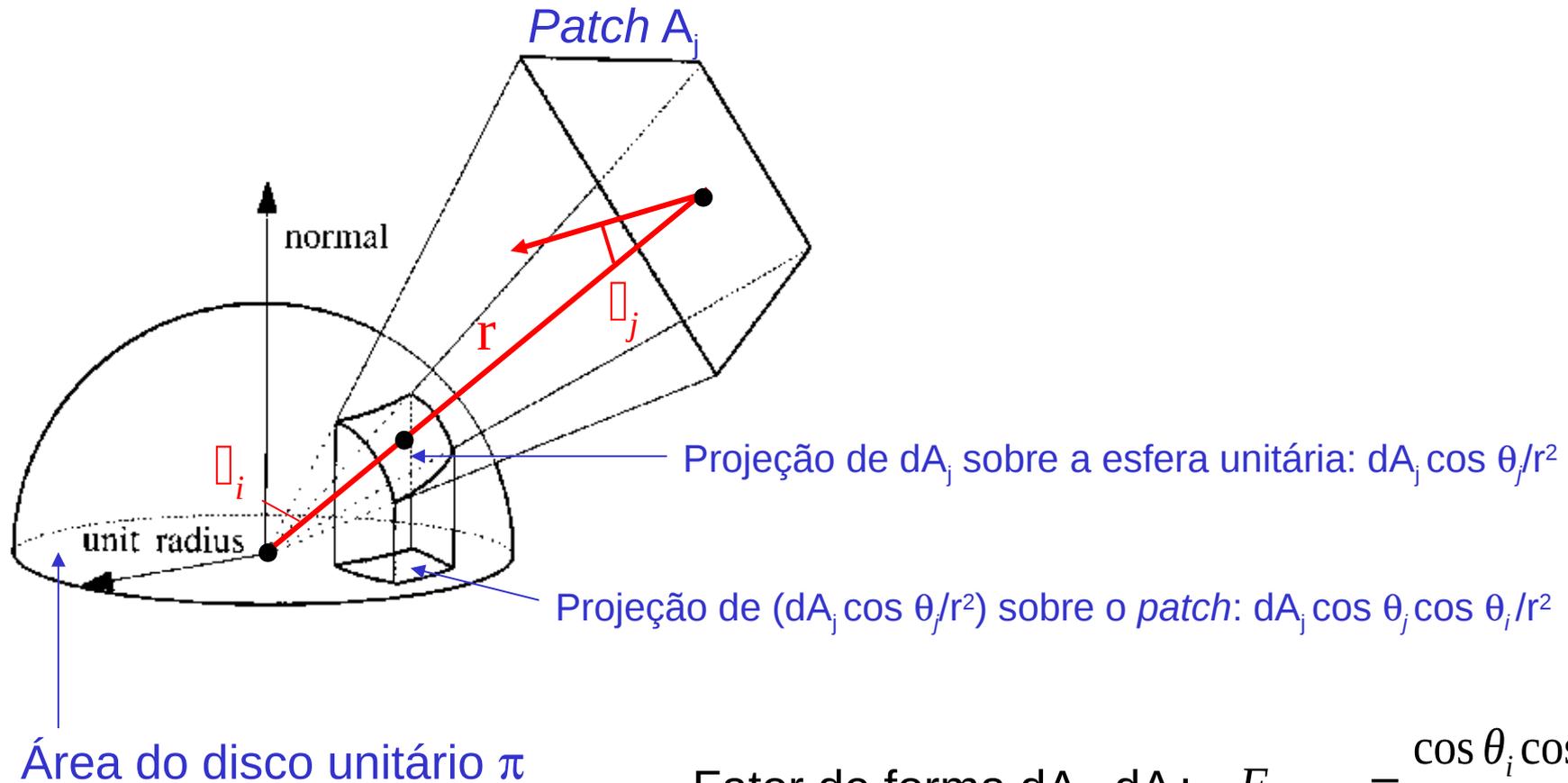
Figure 26.21: Various solid angles on the unit sphere.

Fatores de Forma

Analogia de Nusselt (1928): fatores de forma de projeções de um patch são equivalentes ao do próprio patch.



Analogia de Nusselt



Fator de forma $dA_j - dA_i$:
$$F_{dA_i dA_j} = \frac{\cos \theta_i \cos \theta_j}{\pi r^2} dA_j$$

Fator de forma $A_j - dA_i$:
$$F_{dA_i A_j} = \int_{A_j} \frac{\cos \theta_i \cos \theta_j}{\pi r^2} dA_j$$

Grandezas Radiométricas

- **Fluxo Radiante:** taxa de energia radiante Q transferida de uma região a outra através de um campo.

$$\phi = \frac{dQ}{dt}$$

$$Q = h\nu = \frac{hc}{\lambda}$$

$$c \rightarrow 2.998 \times 10^8 \text{ m/s}$$

$$h \text{ (Constante de Planck)} \rightarrow 6.62620 \times 10^{-34} \text{ Js}$$

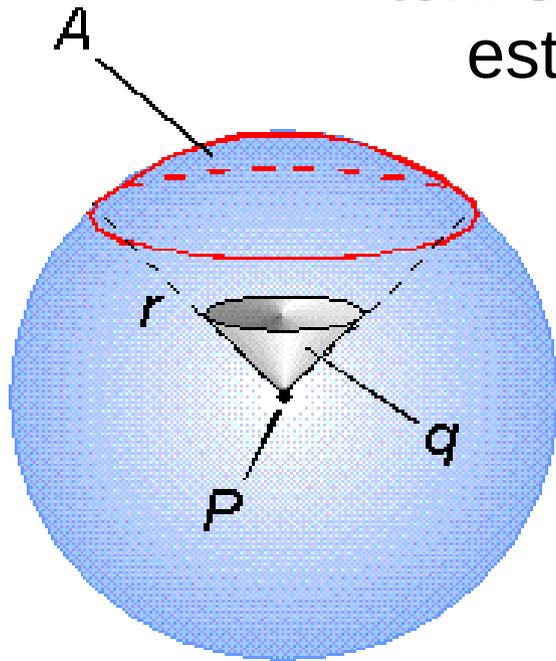
- **Densidade do fluxo radiante:** taxa do fluxo radiante por área da superfície.

$$u = \frac{d\phi}{dA}$$

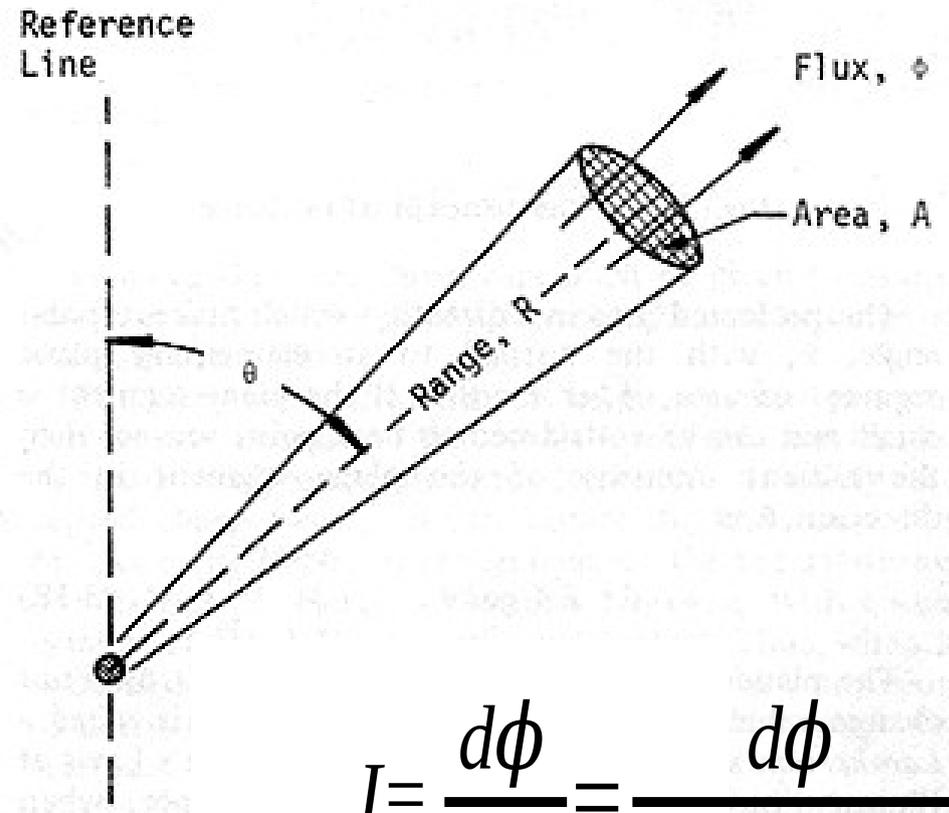
- **Irradiância (E):** sentido do fluxo para dentro da superfície
- **Saída radiante (M) ou Radiosidade (B):** sentido do fluxo para fora da superfície.

Grandezas Radiométricas

Esterradiano (sr) é uma unidade de medida de ângulo sólido, tal que uma esfera completa de área $4\pi r^2$ tem sempre 4π esterradianos.



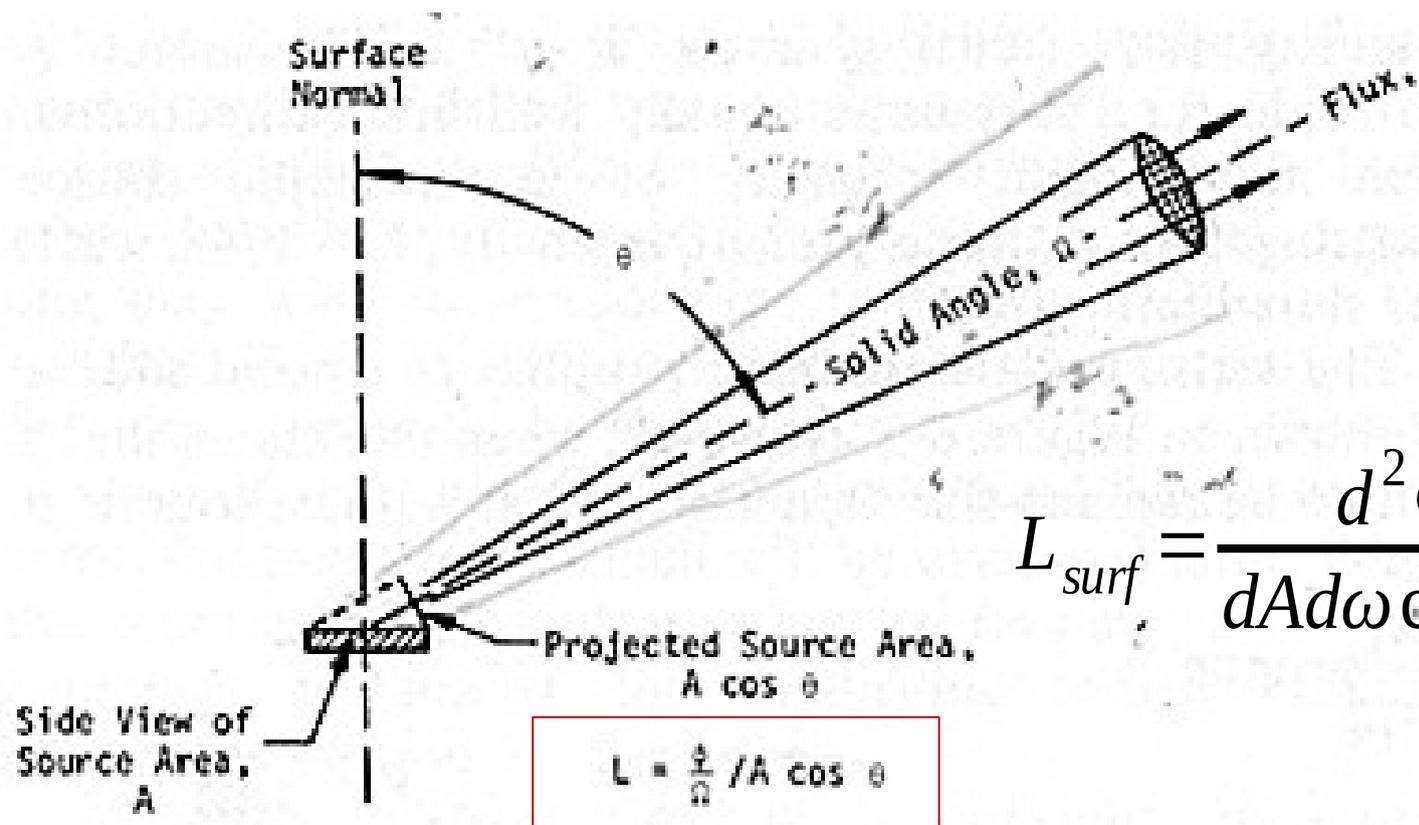
- Intensidade Radiante:** fluxo radiante por unidade de ângulo sólido



$$I = \frac{d\phi}{d\Omega} = \frac{d\phi}{(dA/R^2) sr}$$

Grandezas Radiométricas

- **Radiância**: fluxo radiante por unidade de área e por unidade de ângulo sólido.

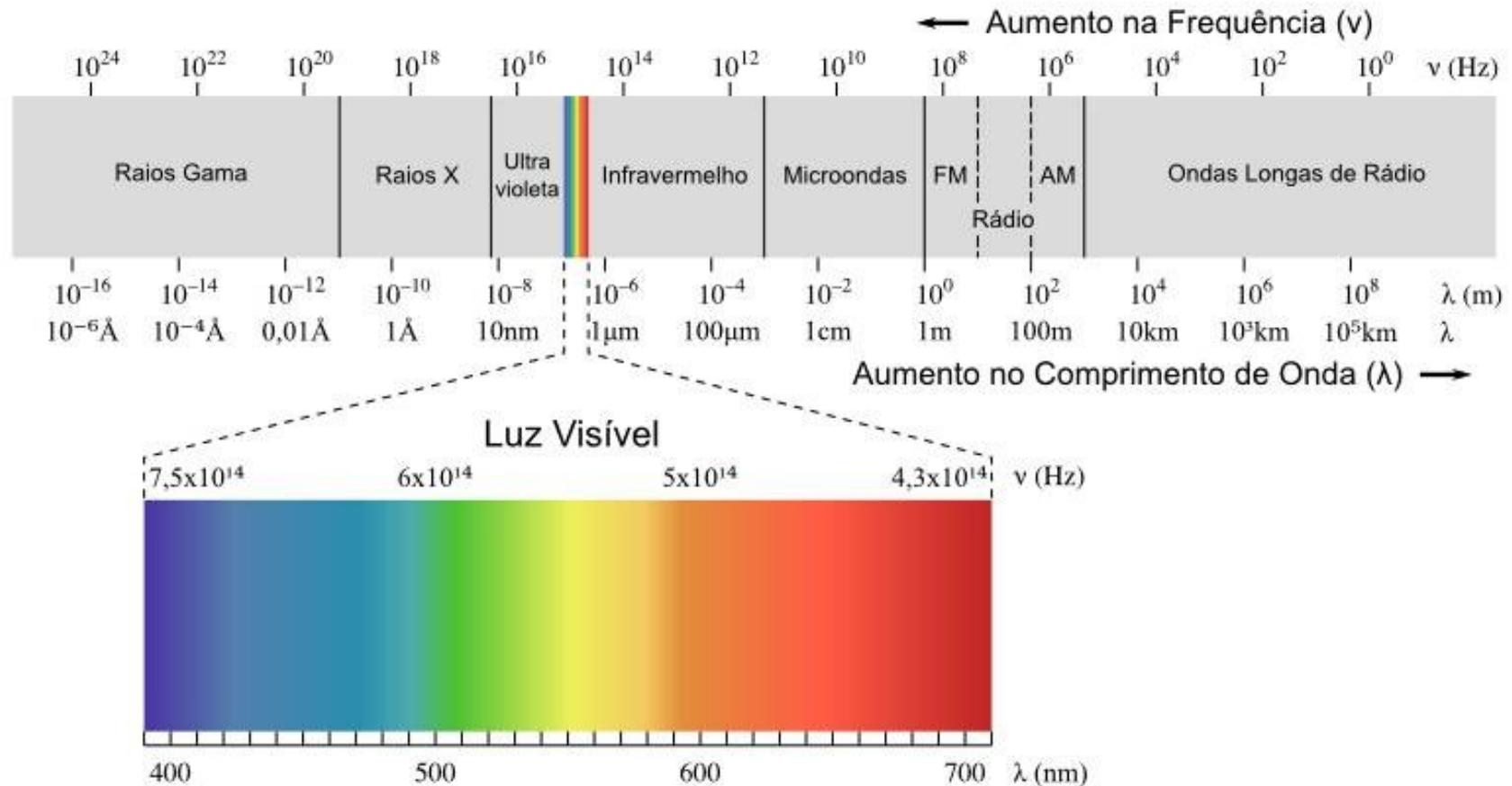


$$L_{surf} = \frac{d^2 \Phi}{dA d\omega \cos(\theta)} \sim \frac{d^2 \Phi}{dA d\omega}$$

Grandezas Radiométricas

- Energia Radiante (Q) em Joule (J)
- Fluxo radiante (Φ) em Watt (W)
- Irradiância (E) em Watt/m² (W/m²)
- Intensidade Radiante (I) em Watt/sr (W/sr)
- Radiância (L) em Watt/m².sr

Luz: Faixa Espectral Visível

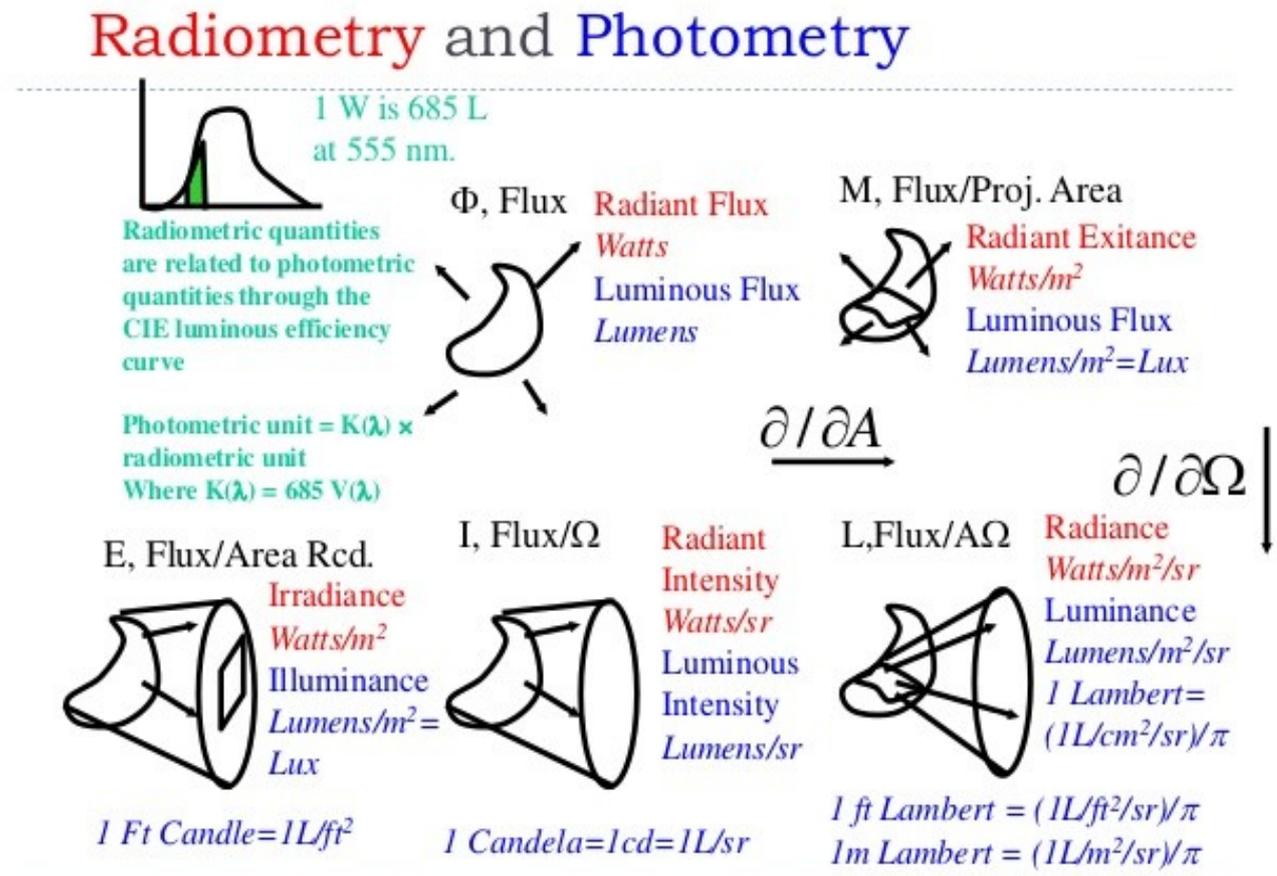


Conceitos

- Radiometria
 - Técnicas de medição de radiação eletromagnética, incluindo a faixa espectral visível.
- Fotometria
 - Técnicas de medição da luz, em termos de como o seu brilho é percebido pela **visão humana**.
- Colorimetria
 - Técnicas de quantificação e “aferição” da percepção de cores pela **visão humana**.

Fotometria e Radiometria

- **Radiometria**: medidas sobre a luz (radiações) em termos do espectro eletromagnético
- **Fotometria**: medidas sobre a luz em termos da percepção da visão humana.



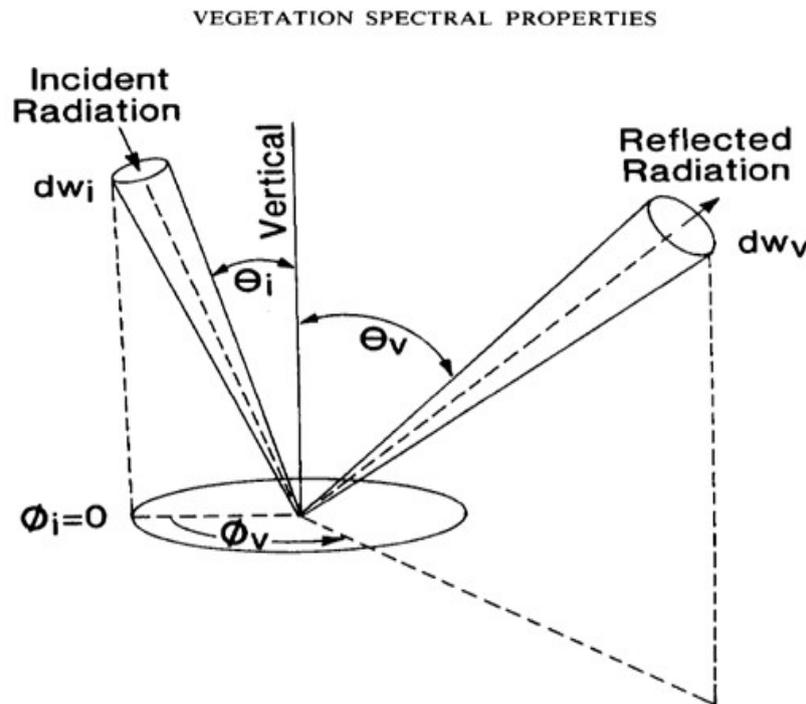
Unidades em Português

UNIDADES USADAS EM FOTOMETRIA E RADIOMETRIA

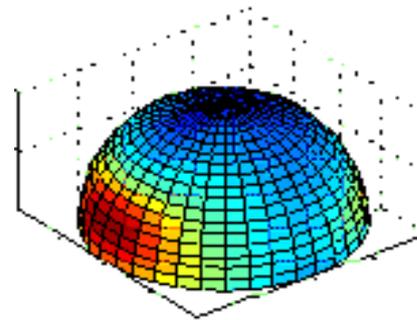
Medida	Radiométrica	Fotométrica	Uso
emissão total	potência: watts	lumens	luz de lâmpadas
emissão num ângulo sólido de uma fonte puntual	intensidade: watts/estéreo-radiano	intensidade luminosa: candela = lumen/estéreo-radiano	estrelas
emissão total recebida	potência: watts	lumens	detectores
emissão por unidade de área	irradiância: W/m ²	iluminância: lumen/m ² = metro-candela	detectores

Grandezas Radiométricas

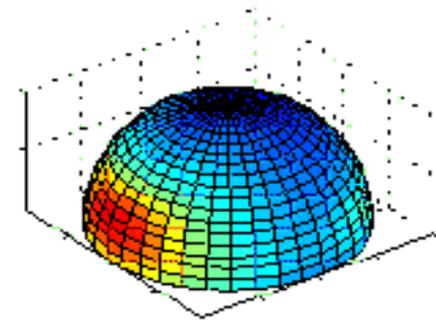
- Distribuição de Radiância:** descreve fluxos de radiação de um dado comprimento de onda que chegam a um ponto em todas as direções.



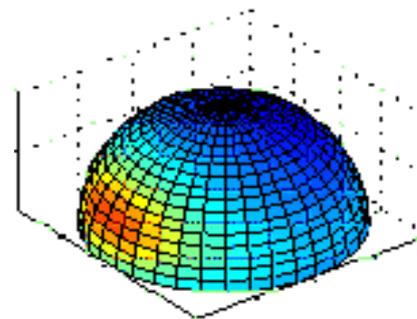
Solar height 10 deg.



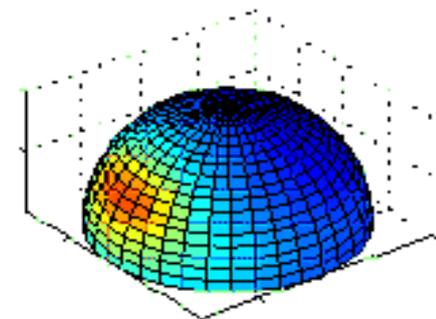
Solar height 20 deg.



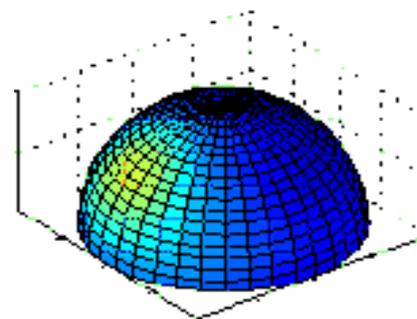
Solar height 30 deg.



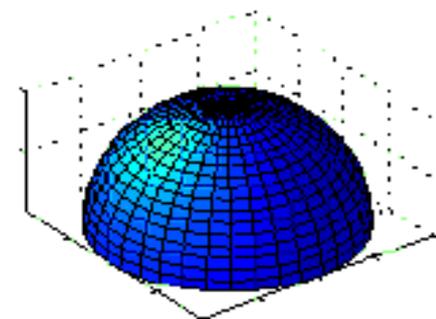
Solar height 40 deg.



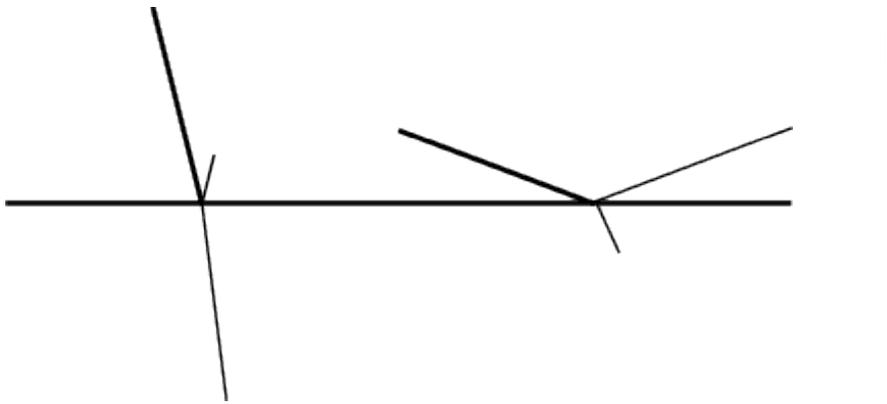
Solar height 50 deg.



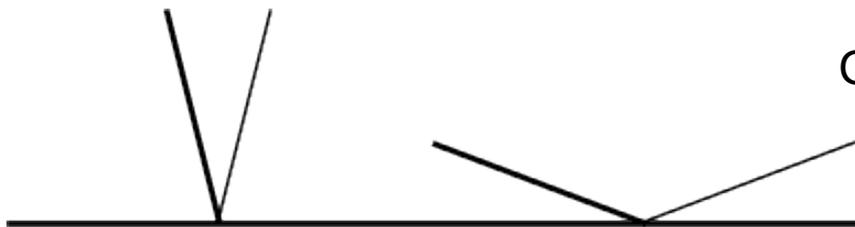
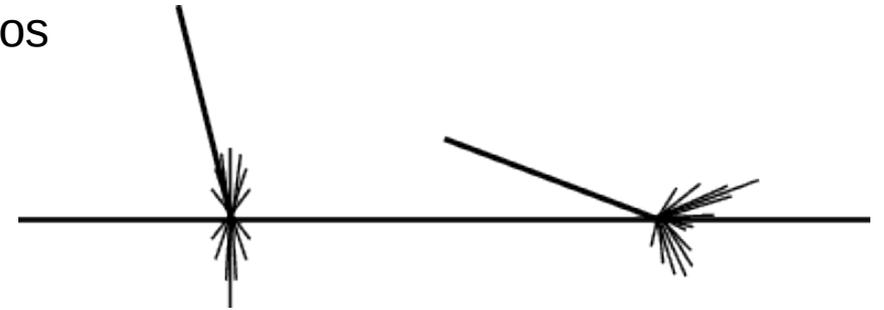
Solar height 60 deg.



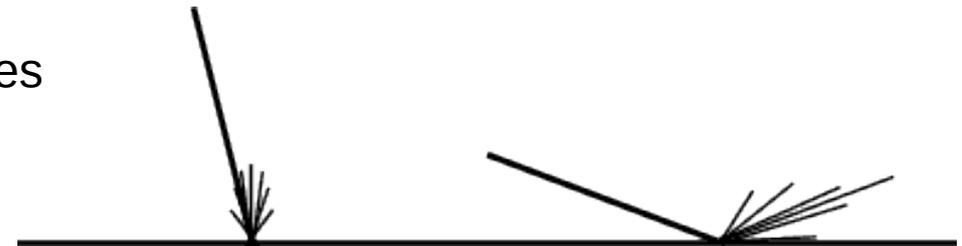
Classes de Superfícies



Dielétricos

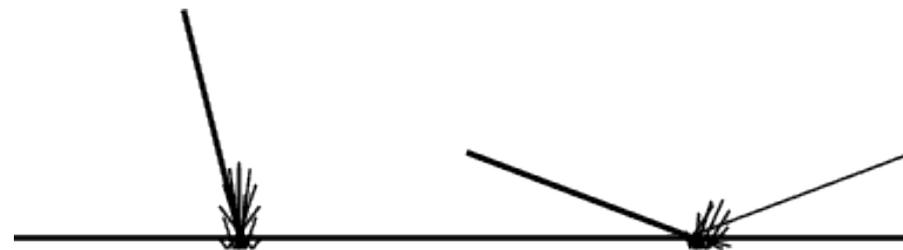


Condutores



Polidas

Rugosas

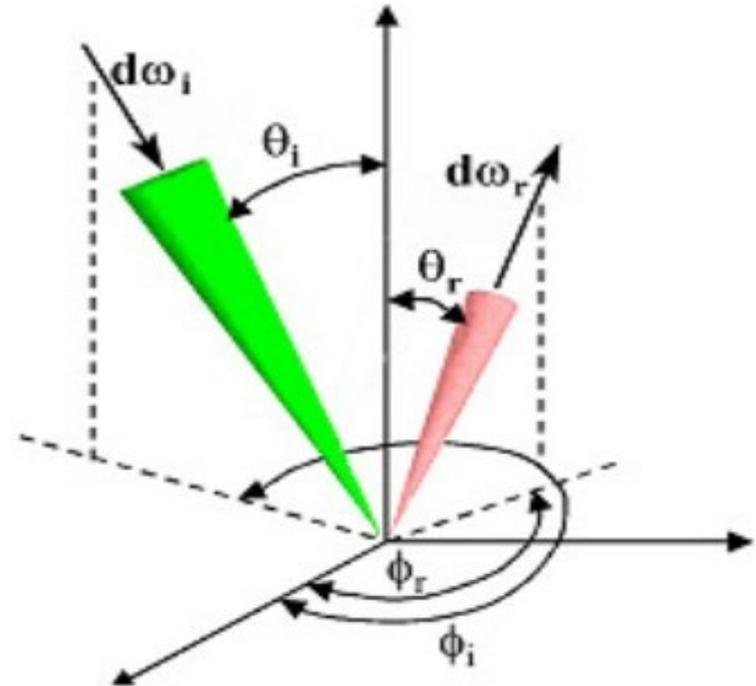


Compostos (plástico)

BRDF

Bidirecional Reflectance Distribution Function

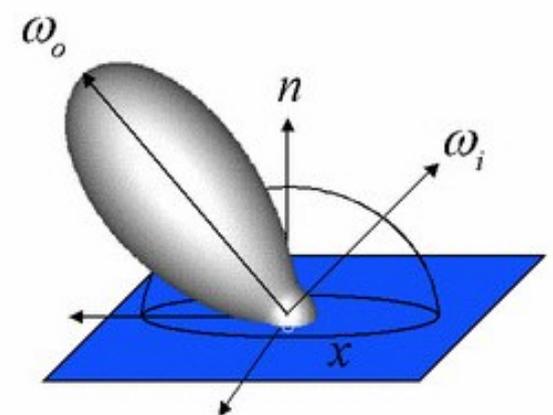
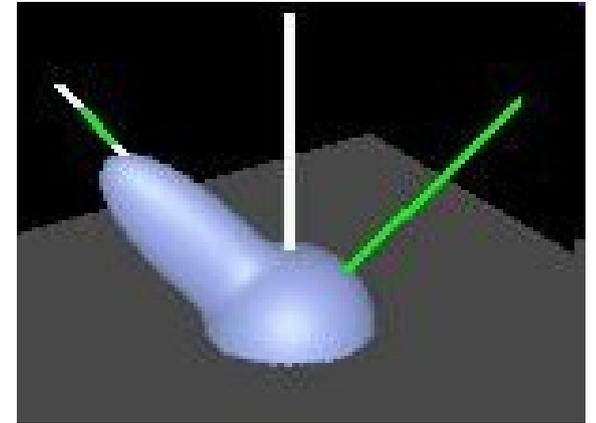
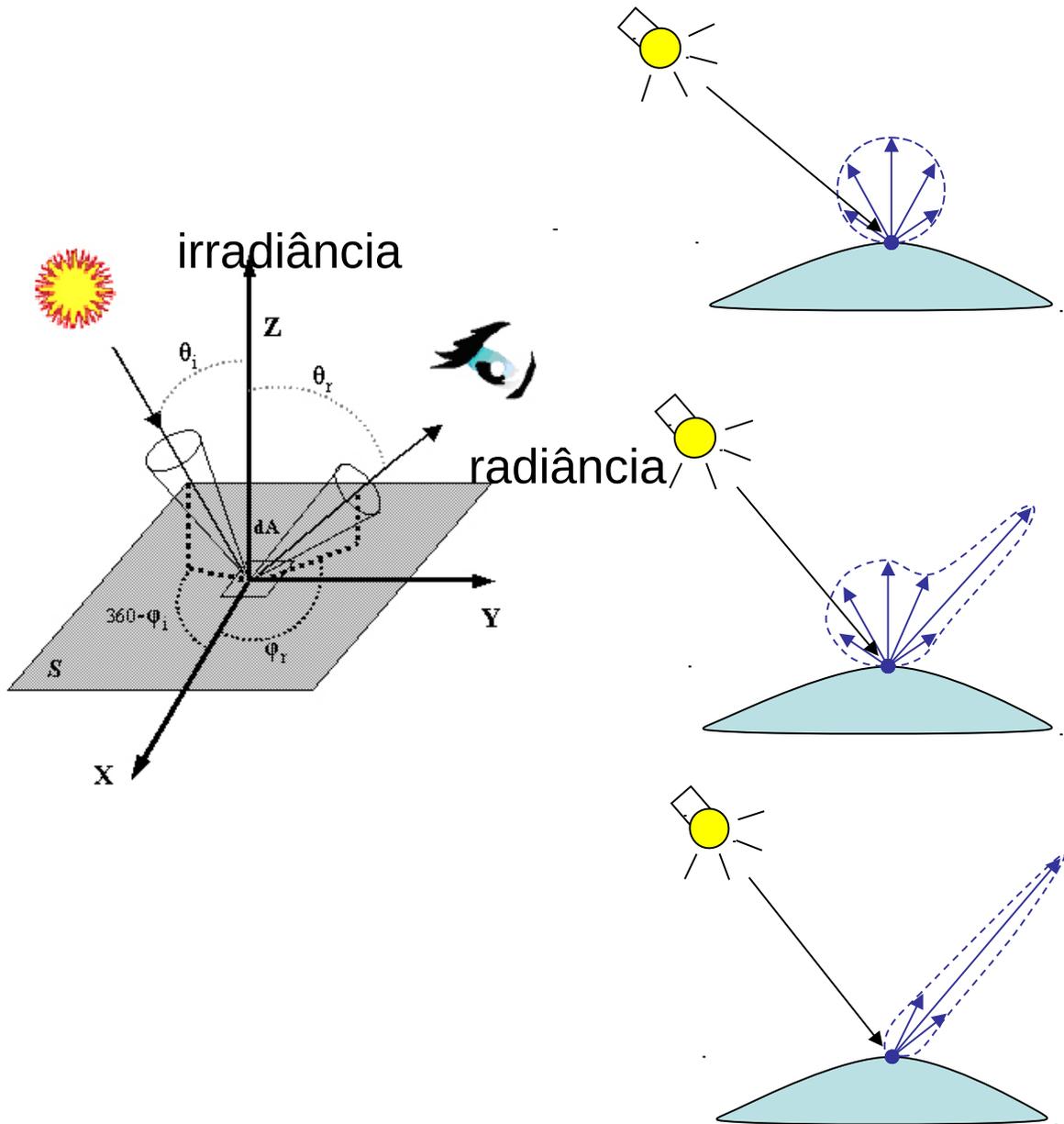
- Função de Distribuição de Reflectância Bidirecional
 - Descreve a razão entre radiações luminosas incidentes e refletidas num ponto de uma superfície
 - Satisfaz reciprocidade de Helmholtz
 - Satisfaz conservação de energia



Bidirectional reflectance distribution function (BRDF)

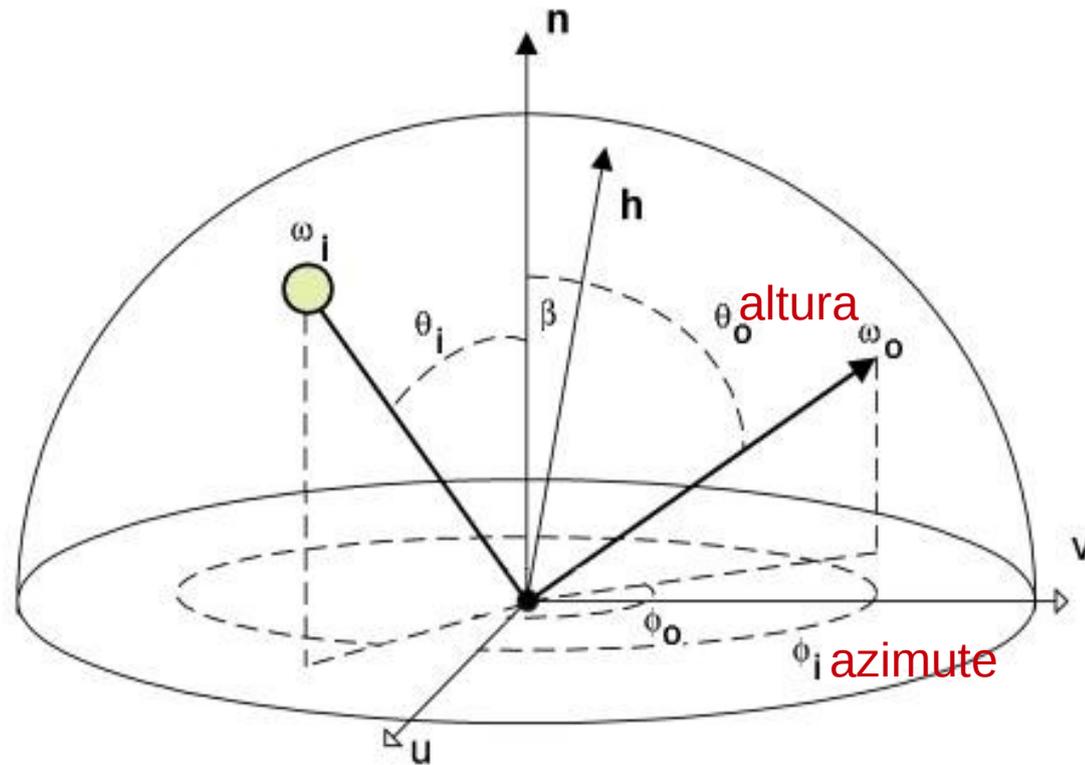
$$f(\theta_i, \phi_i, \theta_r, \phi_r) = \frac{dL_r(\theta_r, \phi_r)}{dE_i(\theta_i, \phi_i)}$$

BRDF



Para uma superfície Lambertiana (perfeitamente difusa), BRDF é constante:

Equação de Reflectância



$$L(\theta_o, \phi_o) = f(\theta_o, \phi_o, \theta_i, \phi_i) L(\theta_i, \phi_i) \cos(\theta_i)$$

$$L(\omega_o) = f(\omega_o, \omega_i) L(\omega_i) (\vec{n} \cdot \omega_i)$$

$$L(\theta_o, \phi_o) = \iint f(\theta_o, \phi_o, \theta_i, \phi_i) L(\theta_i, \phi_i) \cos(\theta_i) d\sigma(\theta_i, \phi_i)$$

BRDF: fonte pontual/direcional

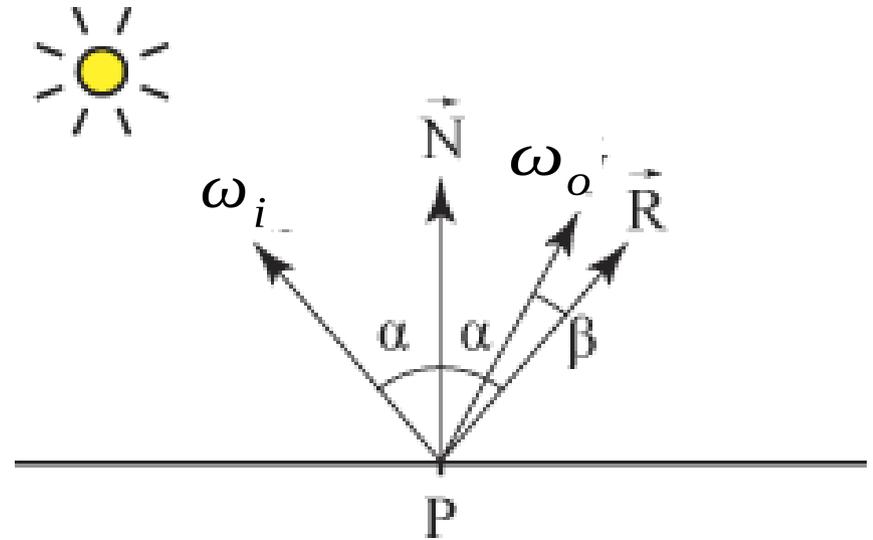
$$L(\omega_o) = f(\omega_o, \omega_i) L(\omega_i) (\vec{n} \cdot \omega_i)$$

- Termo especular de Phong

$$f_{Phong}(\omega_o, \omega_i) = \frac{k_s (\vec{r} \cdot \omega_o)^{m_{shi}}}{\vec{n} \cdot \omega_i}$$

- Termo especular de Blinn

$$f_{Blinn}(\omega_o, \omega_i) = \frac{k_s (\vec{n} \cdot \vec{h})^{m_{shi}}}{\vec{n} \cdot \omega_i}$$



BRDF anisotrópica

- Efeito anisotrópico: efeito em que a aparência visual de uma superfície altera quando ela gira em torno de um eixo.



Modelo de Ward para reflectância especular

$$k_{\text{spec}} = \frac{1}{\sqrt{(N \cdot L)(N \cdot R)}} \frac{N \cdot L}{4\pi\alpha_x\alpha_y} \exp \left[-2 \frac{\left(\frac{H \cdot X}{\alpha_x}\right)^2 + \left(\frac{H \cdot Y}{\alpha_y}\right)^2}{1 + (H \cdot N)} \right]$$

http://en.wikipedia.org/wiki/Specular_highlight#Ward_anisotropic_distribution

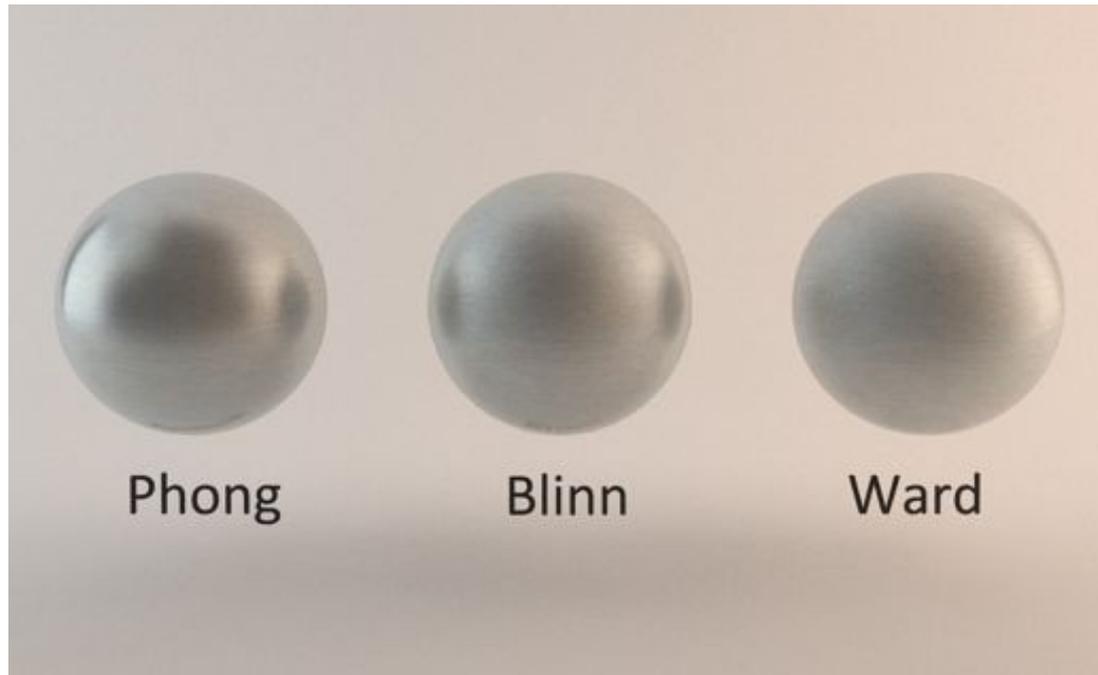
<http://www.graphics.cornell.edu/~bjw/wardnotes.pdf>

– Outro modelo

$$f(\omega_o, \omega_i) = m_{\text{spec}} \left(\sqrt{1 - (\vec{l} \cdot \vec{t})^2} \sqrt{1 - (\vec{v} \cdot \vec{t})^2} - (\vec{l} \cdot \vec{t}) \cdot (\vec{v} \cdot \vec{t}) \right)^{m_{\text{shi}}}$$

Comparações Visuais

“The BRDF types determine the type of the highlights and glossy reflections for a material. You would use Ward for metals such as stainless steel. Blinn and Phong for plastics and none metals and Blinn for chrome materials. Calculation speeds do vary for each type. Phong is fastest, followed by Blinn, and then Ward.”



Reflectância Difusa

- Modelo de Oren-Nayar

$$L_r = \frac{\rho}{\pi} \cdot \cos \theta_i \cdot (A + (B \cdot \max[0, \cos(\phi_i - \phi_r)] \cdot \sin \alpha \cdot \tan \beta)) \cdot E_0$$

$$A = 1 - 0.5 \frac{\sigma^2}{\sigma^2 + 0.33}$$

$$B = 0.45 \frac{\sigma^2}{\sigma^2 + 0.09}$$

$$\alpha = \max(\theta_i, \theta_r)$$

$$\beta = \min(\theta_i, \theta_r)$$



Real Image



Lambertian Model



Oren-Nayar Model

Microgeometria

- Modifica as direções das reflexões.
- Bloqueia reflexões.
- Altera a distribuição dos vetores normais das micro-estruturas
- Gera efeito de retro-reflexões.

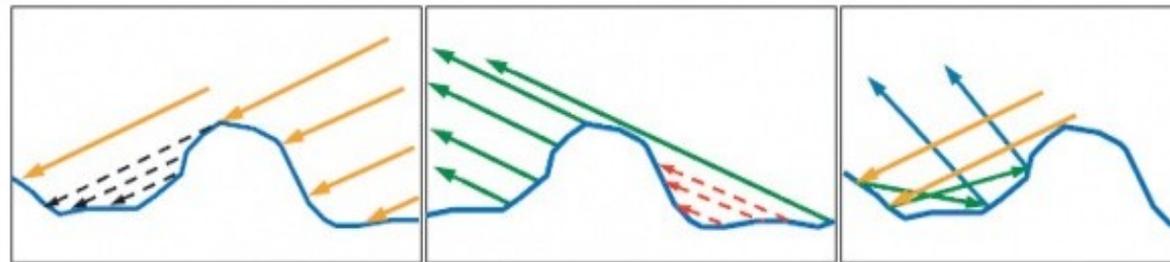
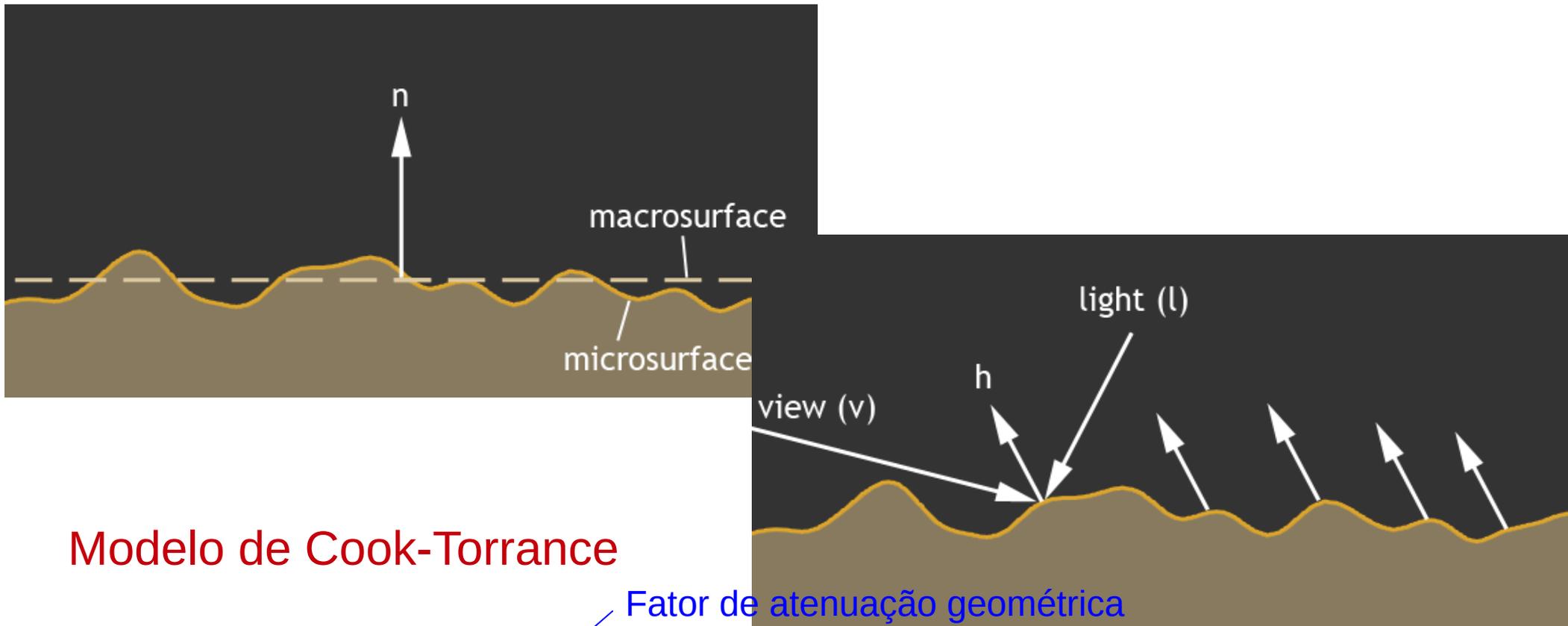


Figure 23: On the left, we see that some microfacets are occluded from the direction of l , so they are shadowed and do not receive light (so they cannot reflect any). In the center, we see that some microfacets are not visible from the view direction v , so of course any light reflected from them will not be seen. In both cases these microfacets do not contribute to the BRDF. In reality, shadowed light does not simply vanish; it continues to bounce from the microfacets and some of it does make its way into the view direction (as seen on the right). These *interreflections* are ignored by microfacet theory. (Image from “Real-Time Rendering, 3rd edition”)

Microfacetetas



Modelo de Cook-Torrance

$$f(\vec{l}, \vec{v}) = \frac{F(\vec{l}, \vec{h}) G(\vec{l}, \vec{v}, \vec{h}) D(\vec{h})}{4(\vec{n} \cdot \vec{l})(\vec{n} \cdot \vec{v})}$$

Fator de atenuação geométrica (pointing to $G(\vec{l}, \vec{v}, \vec{h})$)
Distribuição de Beckmann: função de distribuição de vetores normais (pointing to $D(\vec{h})$)

<http://kevin-george-2n3x.squarespace.com/blog/2014/5/25/the-brdf-and-microfacet-theory>

Termos do Modelo Cook-Torrance

$$F(f_0) = f_0 + (1 - f_0)(1 - l \cdot h)^5$$

, where f_0 is reflectance at normal incident
 $F()$ is fresnel reflectance term,
 l is the light direction,
 v is the view direction,
 h is the half vector between l and v

$$f_0 = \left(\frac{1 - n}{1 + n} \right)^2$$

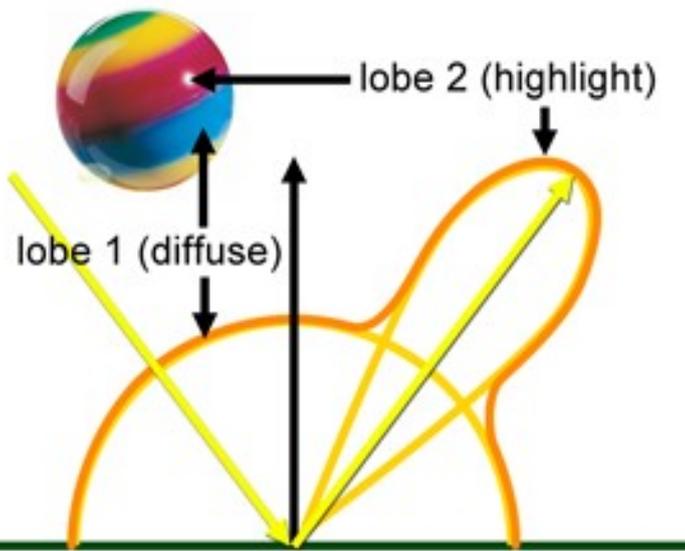
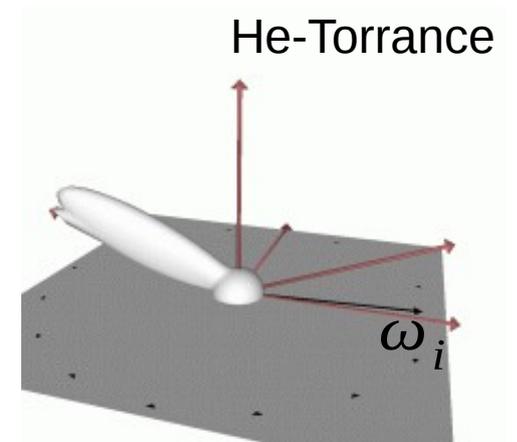
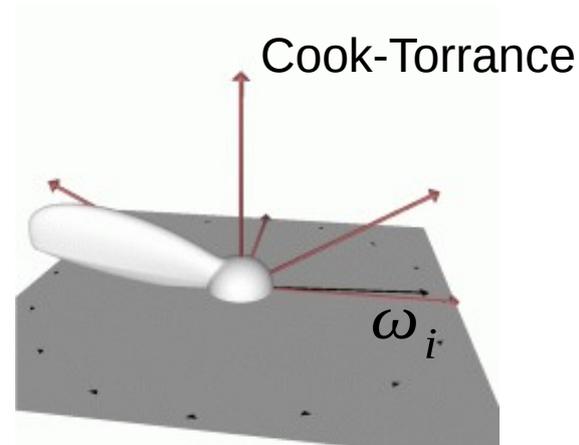
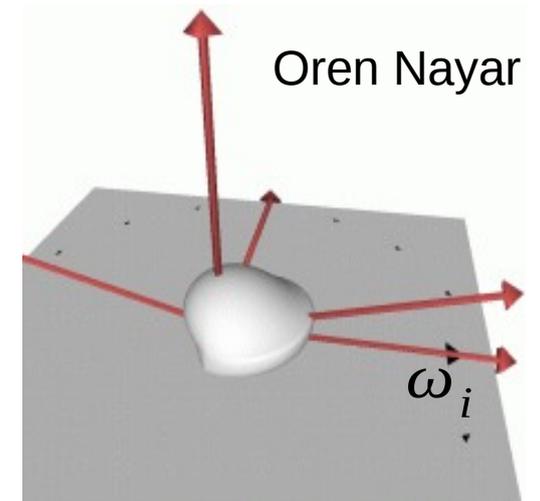
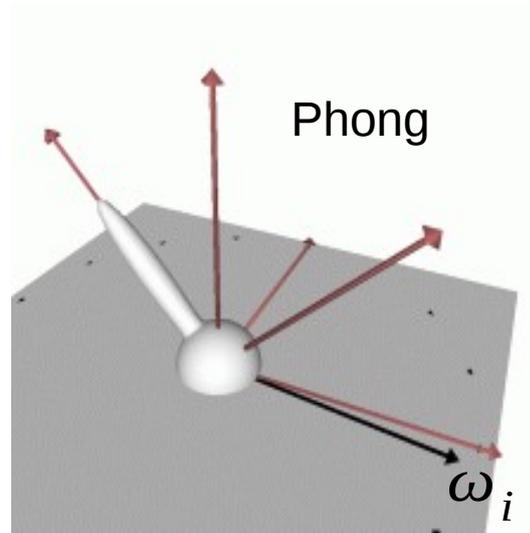
, where f_0 is reflectance at normal incident
 n is the refractive index

$$G_{implicit}(n, h, v, l) = (\underline{n \cdot l})(\underline{n \cdot v}) D_{Beckmann}(h, n, m) = \frac{e^{\frac{(\underline{n \cdot h})^2 - 1}{m^2 (\underline{n \cdot h})^2}}}{\pi m^2 (\underline{n \cdot h})^4}$$

, where h is the microfacet normal,
 n is the macro surface normal,
 m is the root mean square slope of the microfacet surface (i.e. roughness), with range $m \in [0, \infty)$, but usually within $m \in [0, 1]$
 underline denotes clamping to zero

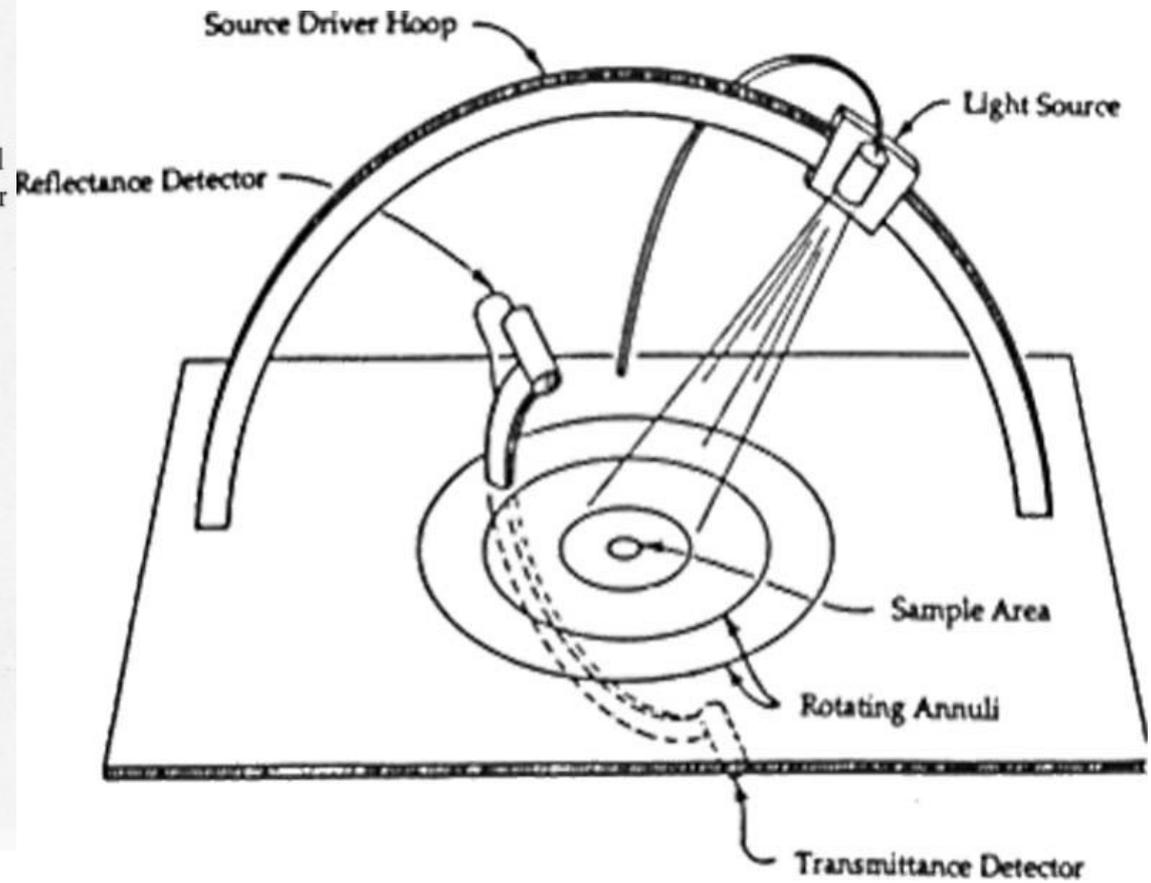
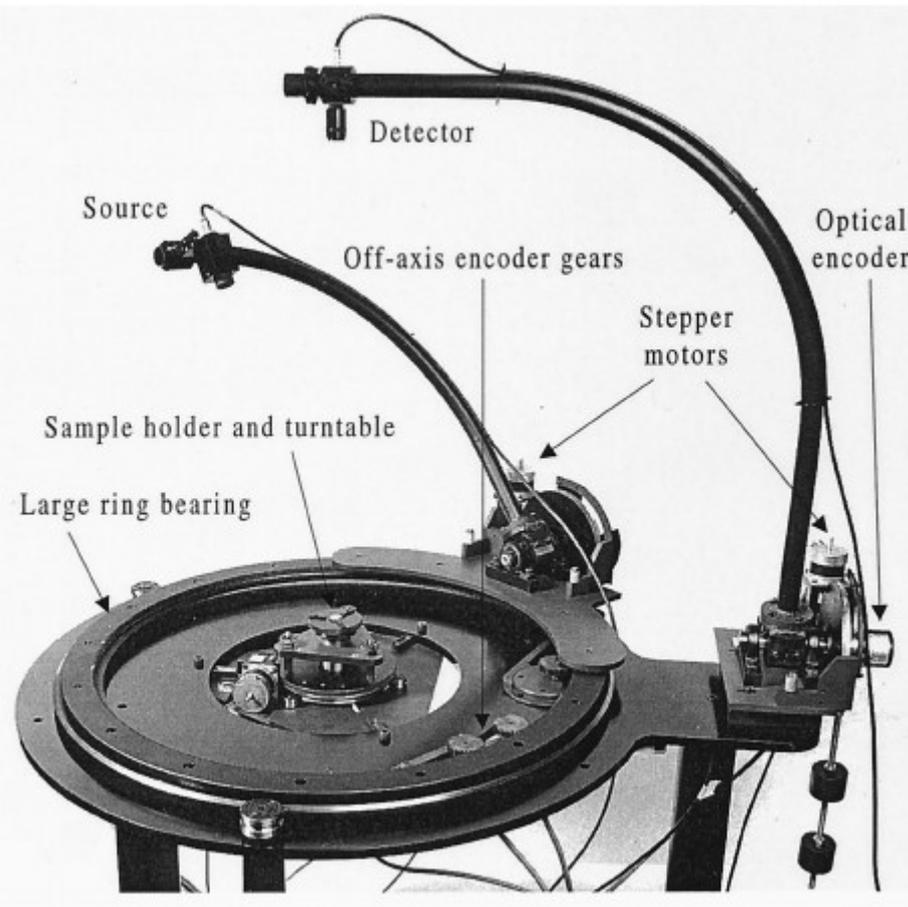
$$G_{Cook\ Torrance}(n, h, v, l) = \min\left(1, \frac{2(n \cdot h)(n \cdot v)}{v \cdot h}, \frac{2(n \cdot h)(n \cdot l)}{v \cdot h}\right)$$

BRDF: lóbulos difusos e especulares



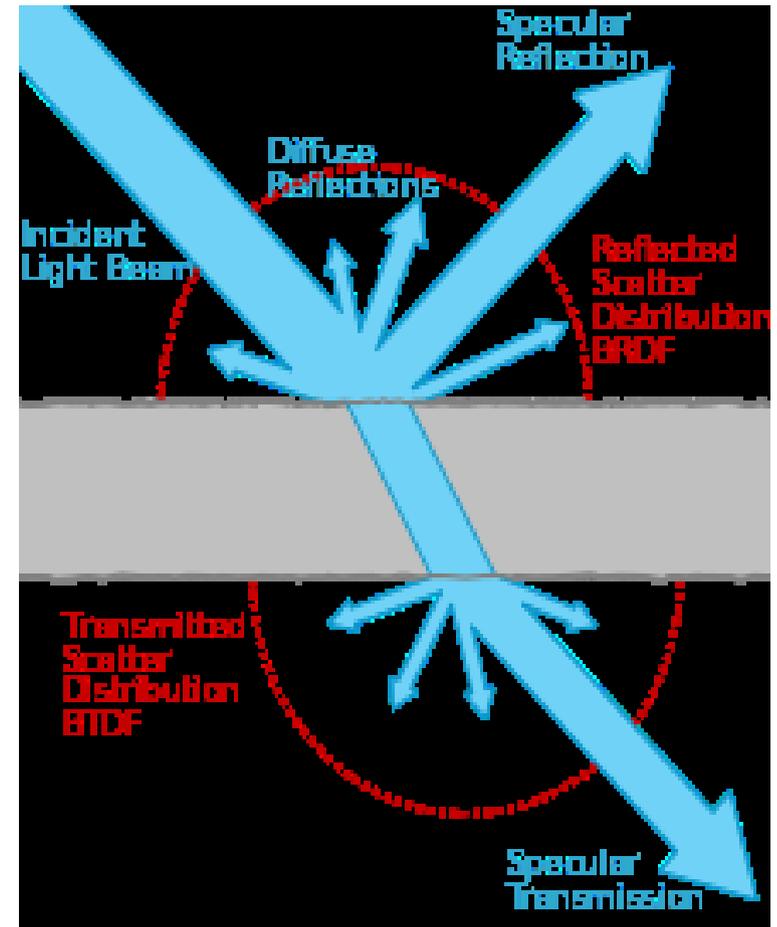
© www.scratchapixel.com

Gonioreflectometer

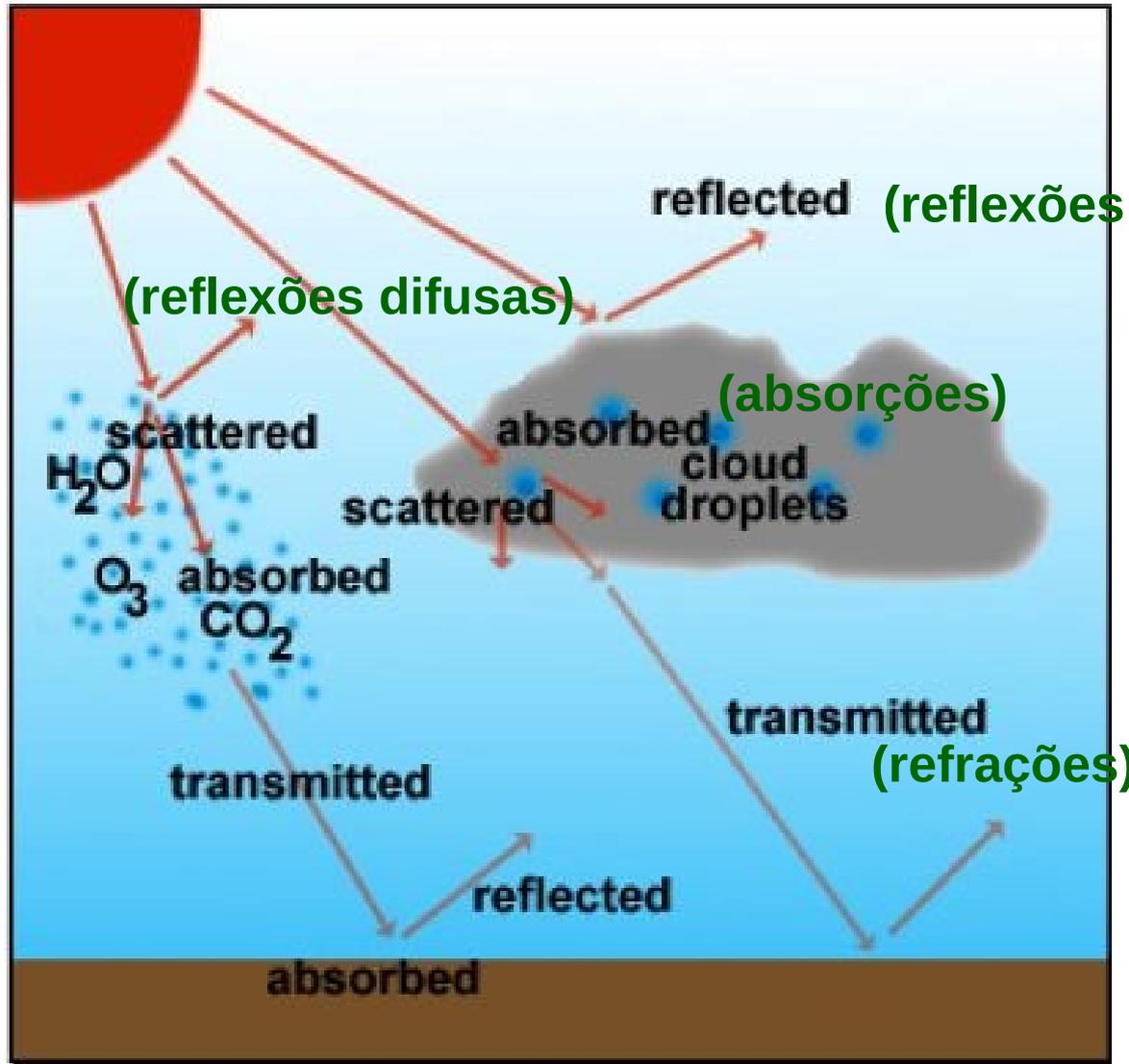


BSDF

- Função de Distribuição de Espalhamento (*Scattering*) Bidirecional
 - 2 BRDFs
 - 2 BTDFs



Espalhamento

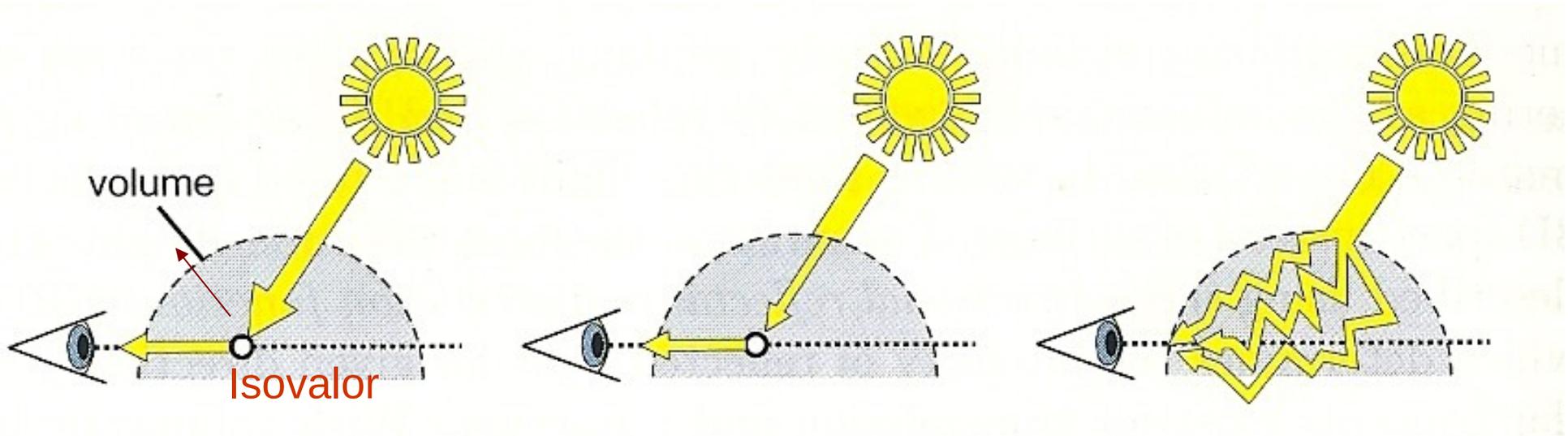


**Modelos físicos
apresentam custo
computacional muito
alto!!!**



**Métodos heurísticos
baseados em
observações.**

Reflexões Difusas no Volume



simples

simples
com
atenuações

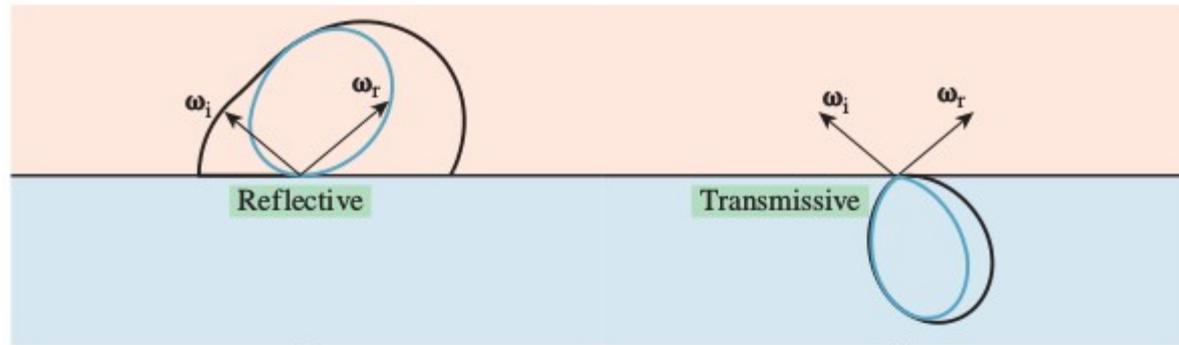
difusas/
múltiplas

Iluminação Local

Iluminação Global

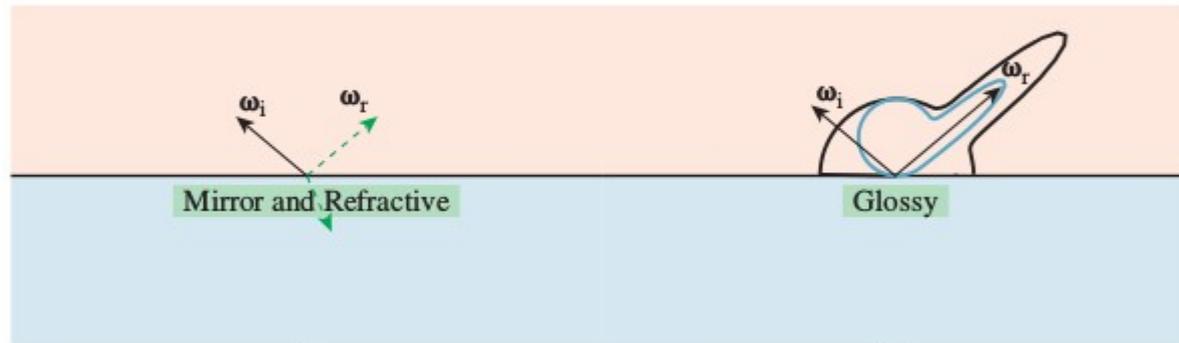
Scattering = reflexões + refrações

Bidirectional Scattering Distribution Function



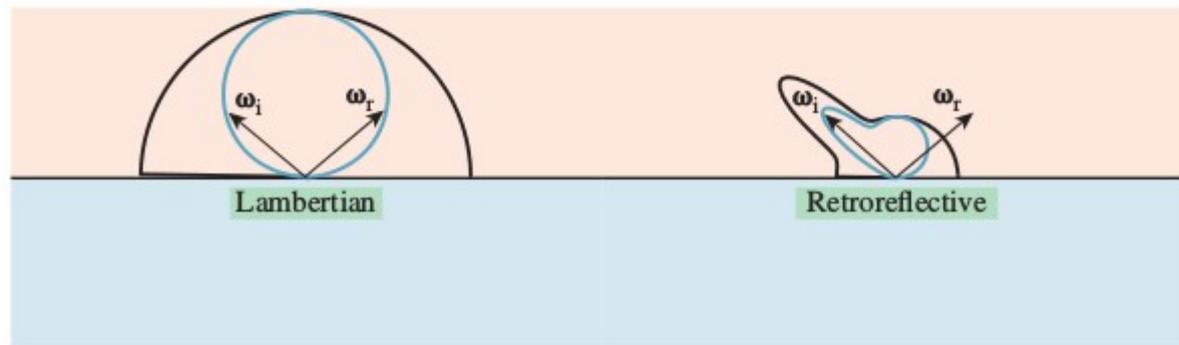
(a)

(b)



(c)

(d)



(e)

(f)

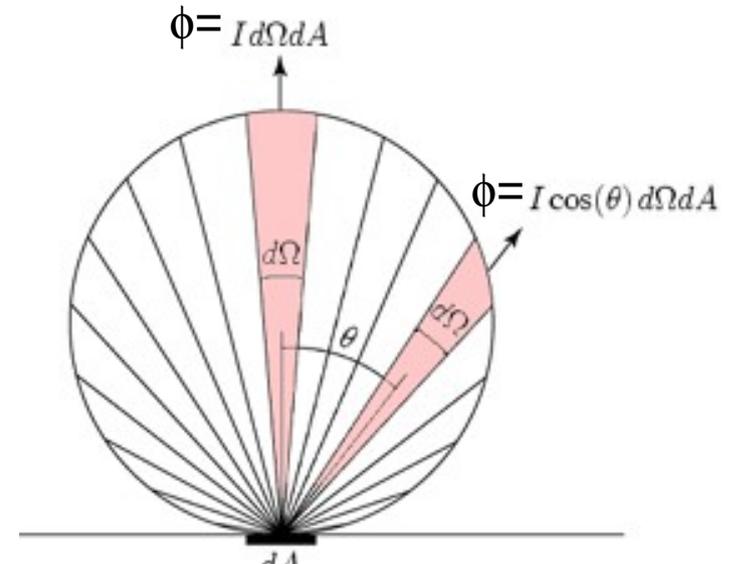
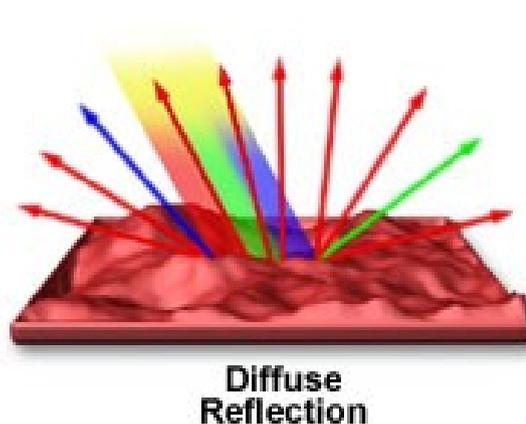
BSDF



Modelo de Iluminação Phong

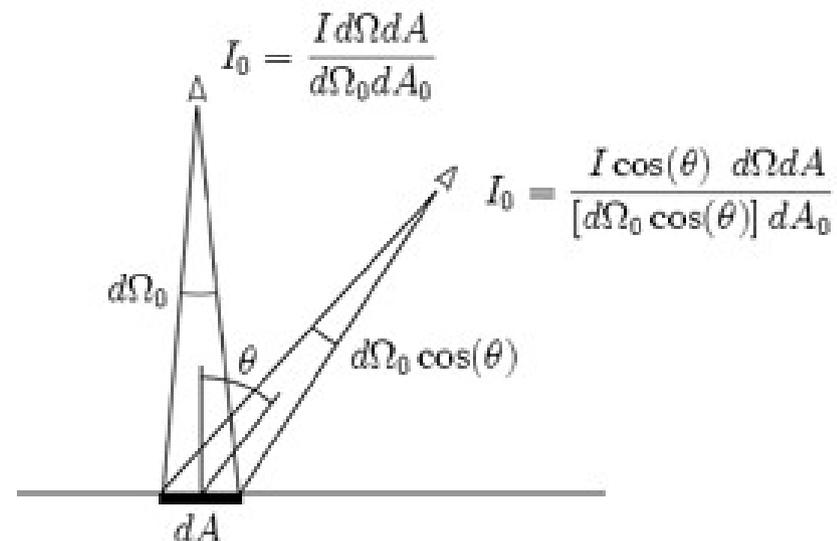
Reflexões Difusas

Intensidade luminosa refletida é diretamente proporcional ao cosseno do ângulo θ



Intensidade percebida pelo observador independe da sua posição

$$I_d = k_d I_d \cos \theta$$



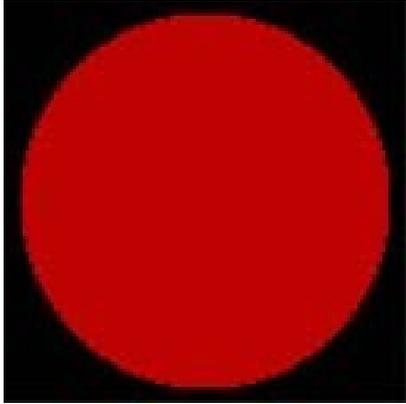
Modelo de Iluminação Phong

Multireflexões



Intensidade luminosa comum para todos os pontos do ambiente

$$I_a = k_a I_a$$

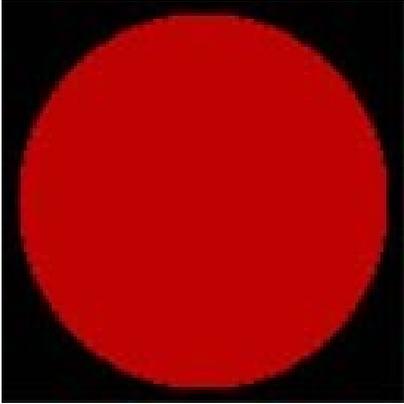


ambiente

Modelo de Phong

$$I_p = k_a I_a + k_d I_d \cos\theta + k_s I_s (\cos\beta)^\alpha$$

Modelo de Iluminação Phong

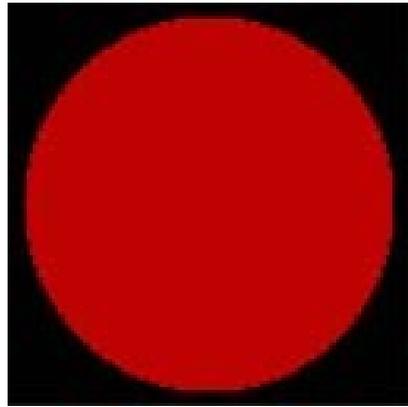


ambiente

Modelo de Phong

$$I_p = k_a I_a + k_d I_d \cos\theta + k_s I_s (\cos\beta)^\alpha$$

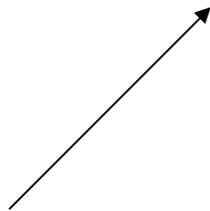
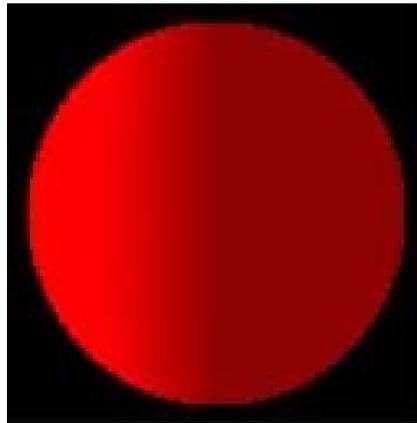
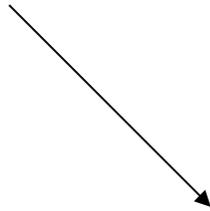
Modelo de Iluminação Phong



ambiente

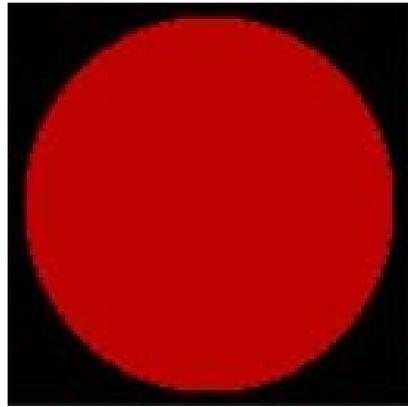
Modelo de Phong

$$I_p = k_a I_a + k_d I_d \cos\theta + k_s I_s (\cos\beta)^\alpha$$



difusa

Modelo de Iluminação Phong



ambiente

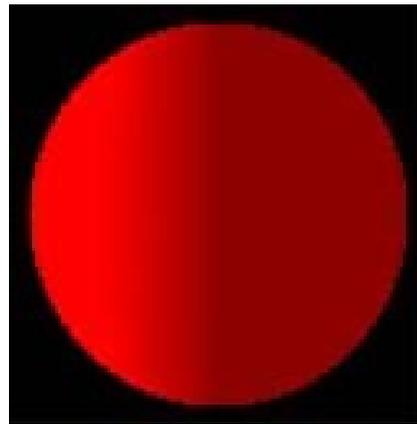
Modelo de Phong

$$I_p = k_a I_a + k_d I_d \cos\theta + k_s I_s (\cos\beta)^\alpha$$

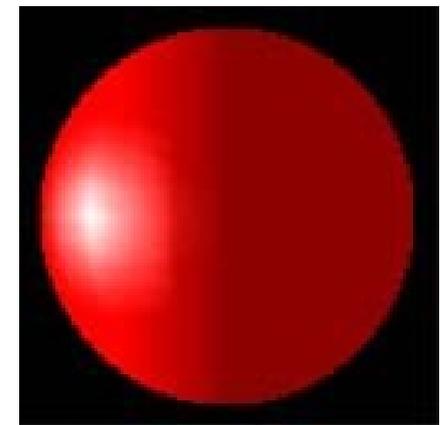
$$k_a + k_d + k_s = 1$$



difusa

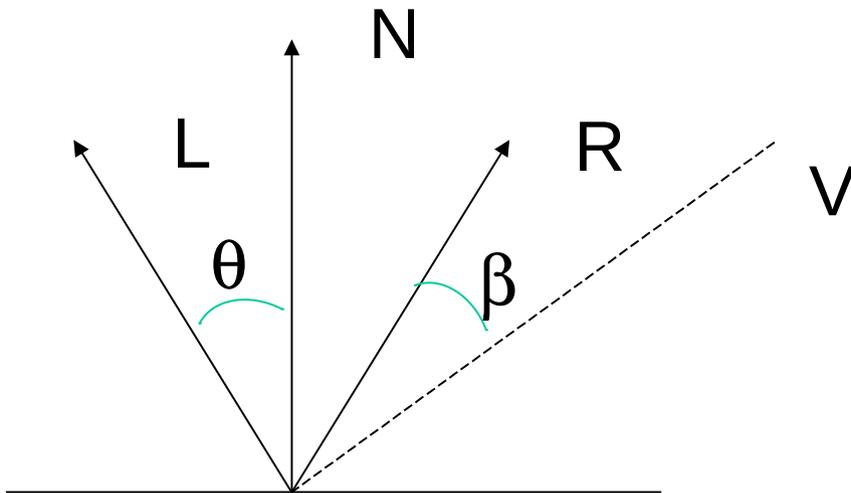


especular



Modelo de Iluminação Phong

$$I_p = k_a I_a + k_d I_d \cos\theta + k_s I_s (\cos\beta)^\alpha$$



$$\cos\theta = \frac{N \cdot L}{(|N||L|)}$$
$$\cos\beta = \frac{R \cdot V}{(|R||V|)}$$

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

Vetor Normal no cálculo da componente especular!!

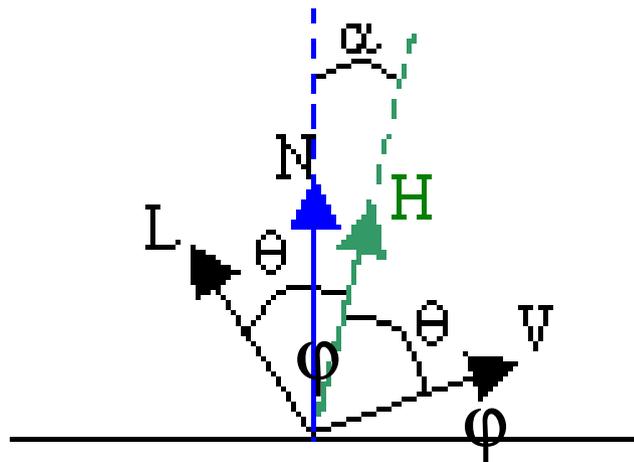
Modelo de Iluminação Blinn

$$I_p = k_a I_a + k_d I_d \cos\theta + k_s I_s (\cos\phi)^{\alpha'}$$

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

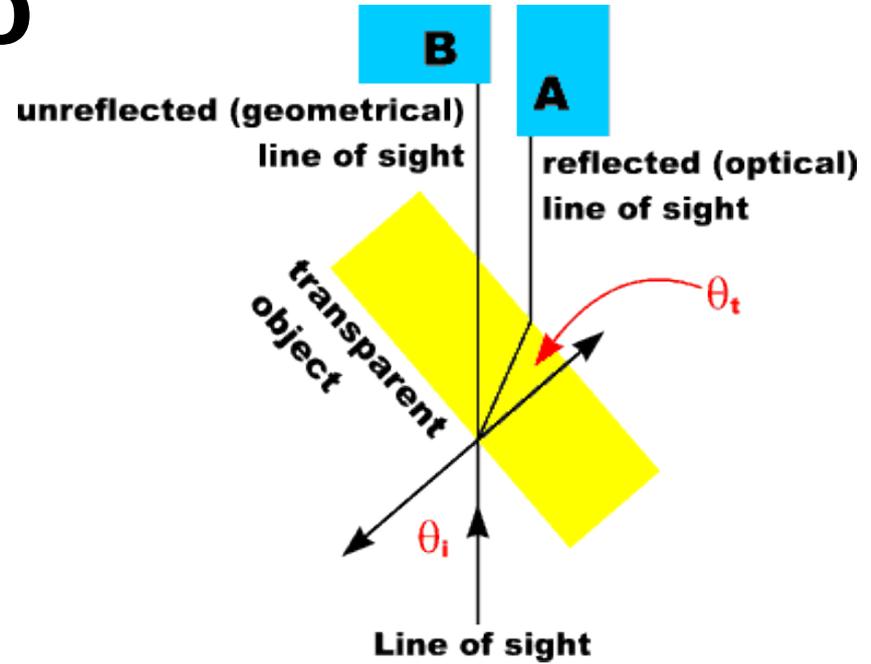
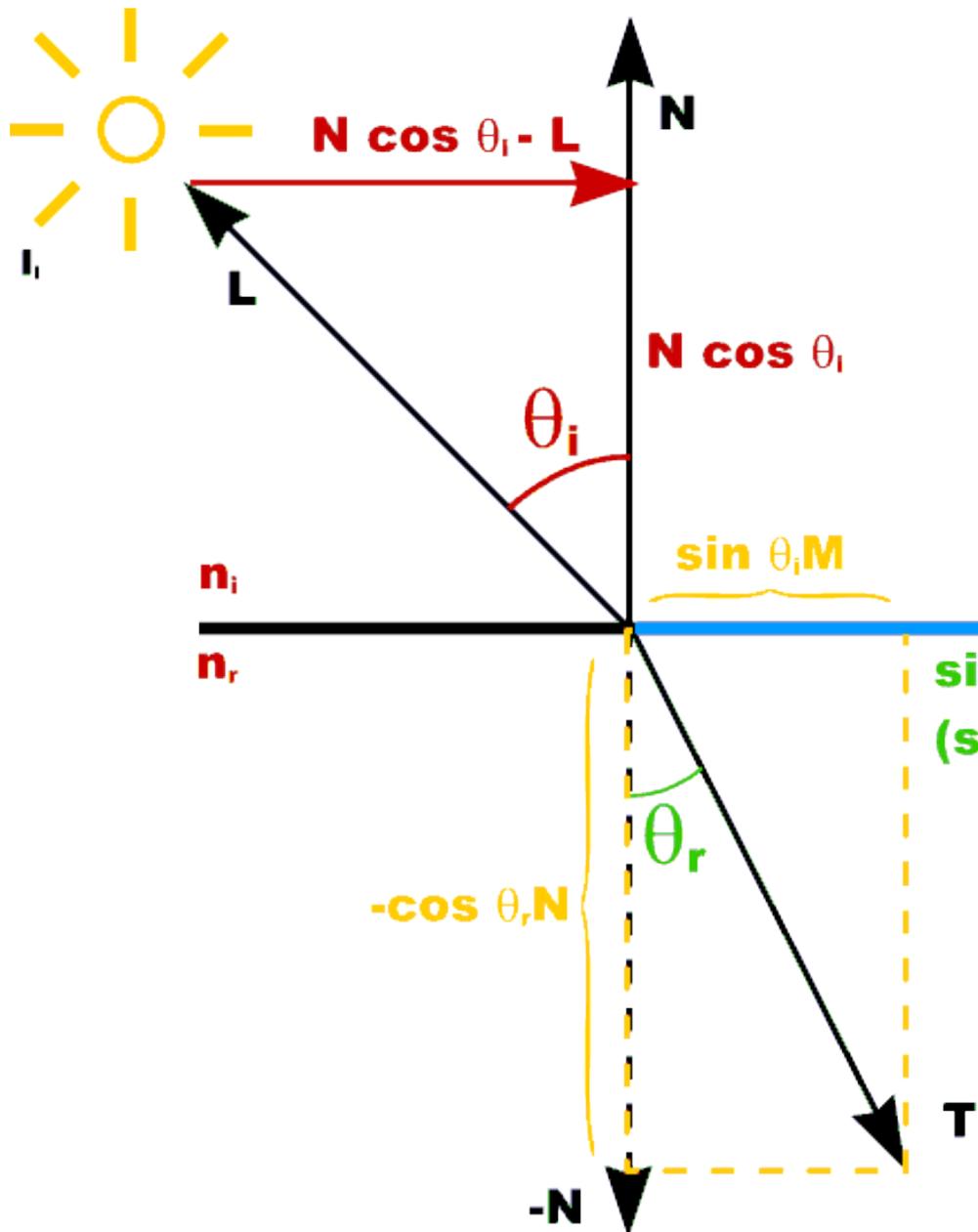
Intensidade luminosa refletida é diretamente proporcional à potência α' do coseno do ângulo θ

$$I_s = k_s I_s (\cos\phi)^{\alpha'}$$



Vantagem: Quando a fonte luminosa e o observador forem distantes, H é constante.

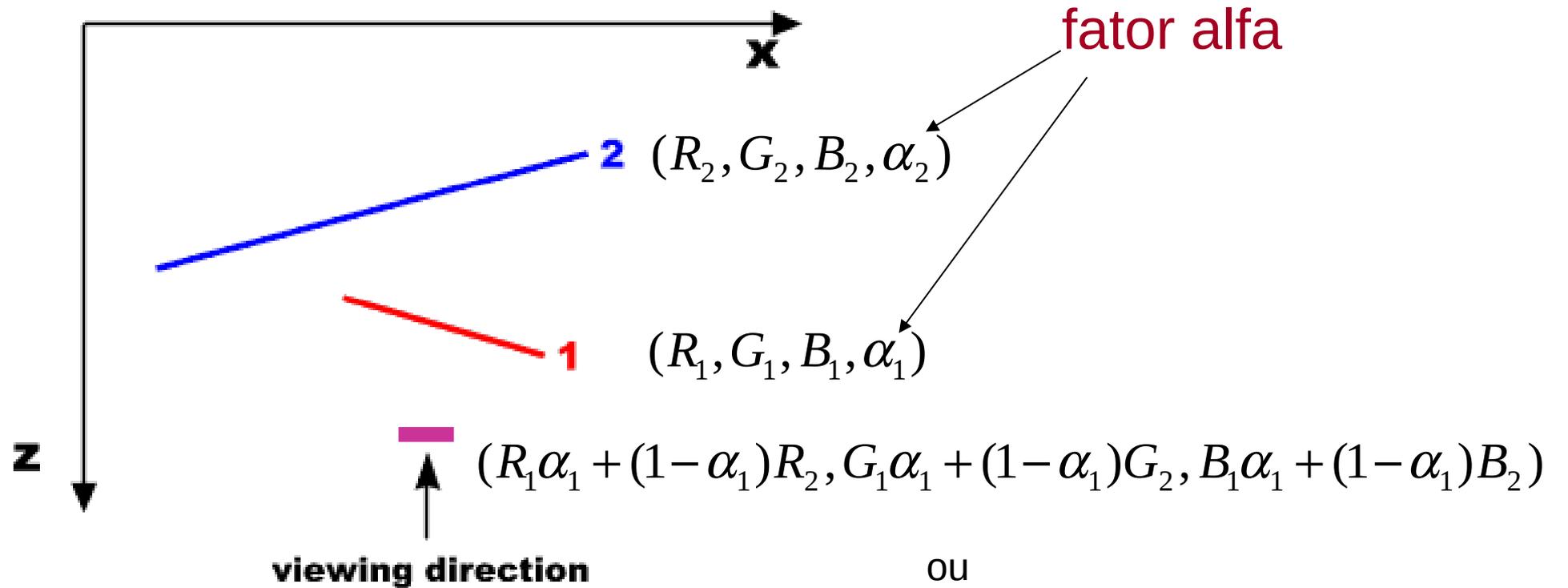
Refração



$\sin \theta_r = n_i / n_r \sin \theta_i$
(snell's law)

$$\vec{T} = \left(\frac{n_i}{n_r} (\vec{N} \cdot \vec{L}) - \sqrt{1 - \left(\frac{n_i}{n_r} \right)^2 (\vec{N} \cdot \vec{L})^2} \right) \vec{N} - \frac{n_i}{n_r} \vec{L}$$

Uma Aproximação

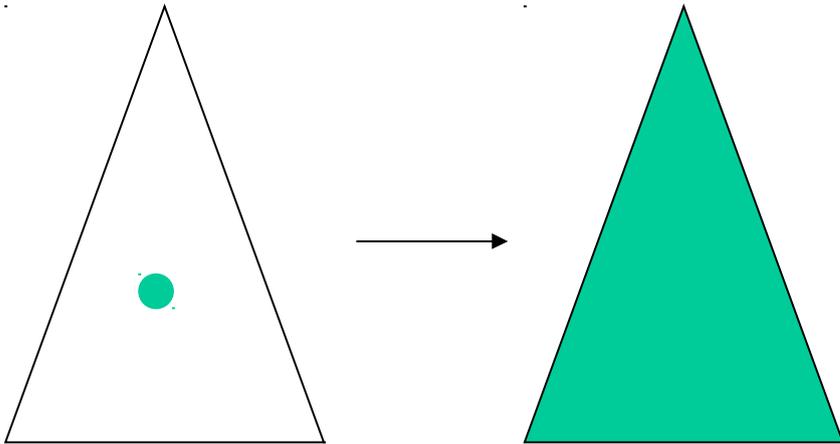


$$(R_2\alpha_2 + (1-\alpha_2)R_1, G_2\alpha_2 + (1-\alpha_2)G_1, B_2\alpha_2 + (1-\alpha_2)B_1)$$

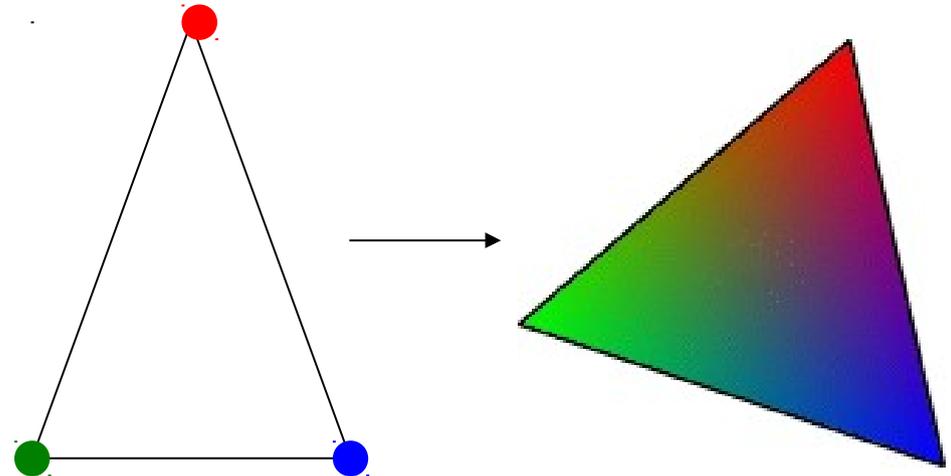
Tonalização (*Shading*)

Calcular as propriedades gráficas ou geométricas em algumas amostras e **propagá-las** para o restante dos pontos

Cópia (*Flat shading*)

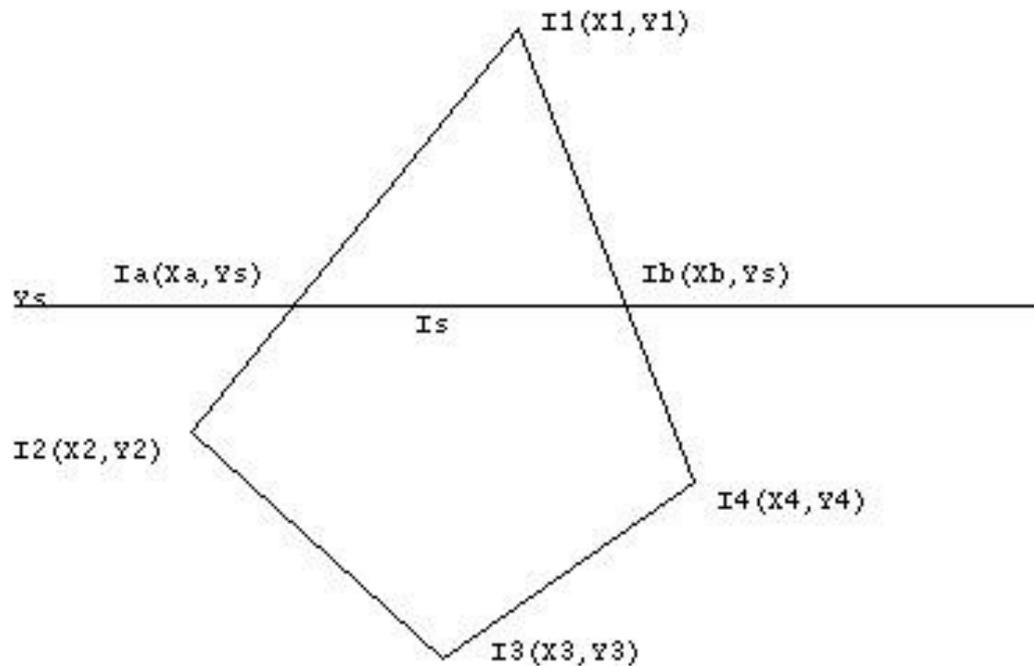


Interpolação (*Gouraud shading*)



Tonalização

Interpolação Linear de Intensidades



Gouraud Shading

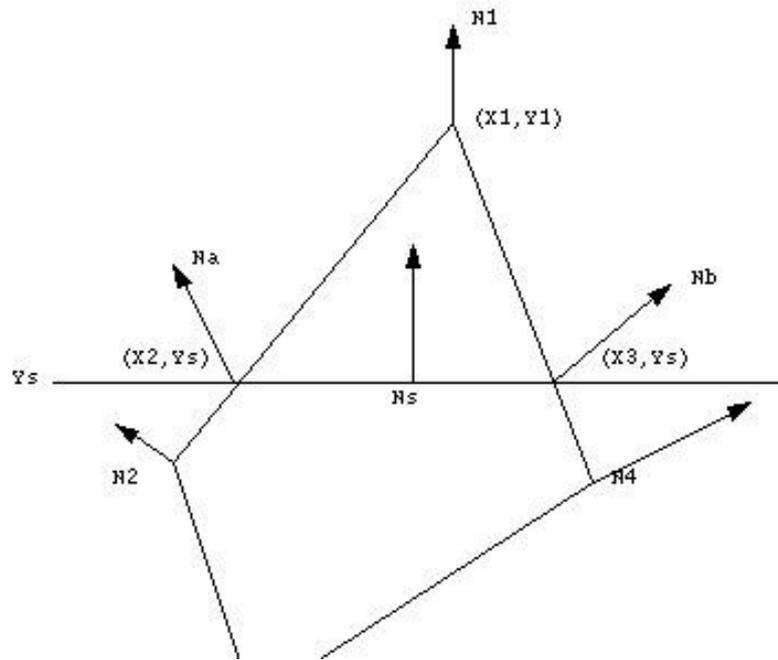
Interpolação linear de intensidades

$$I_a(t) = t I_1 + (1-t) I_2$$

$$I_b(t) = t I_1 + (1-t) I_4$$

Tonalização

Interpolação Linear de Intensidades



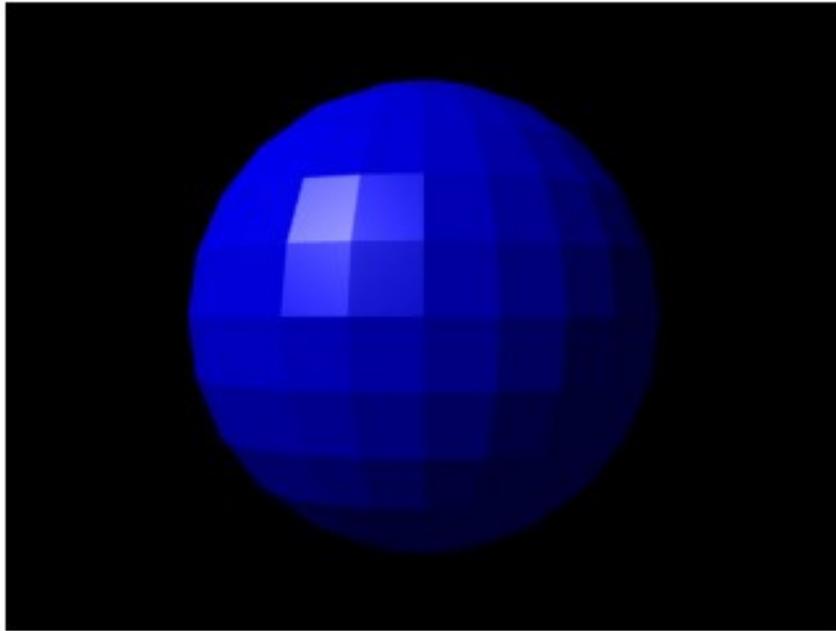
Phong Shading

Interpolação linear de vetores normais

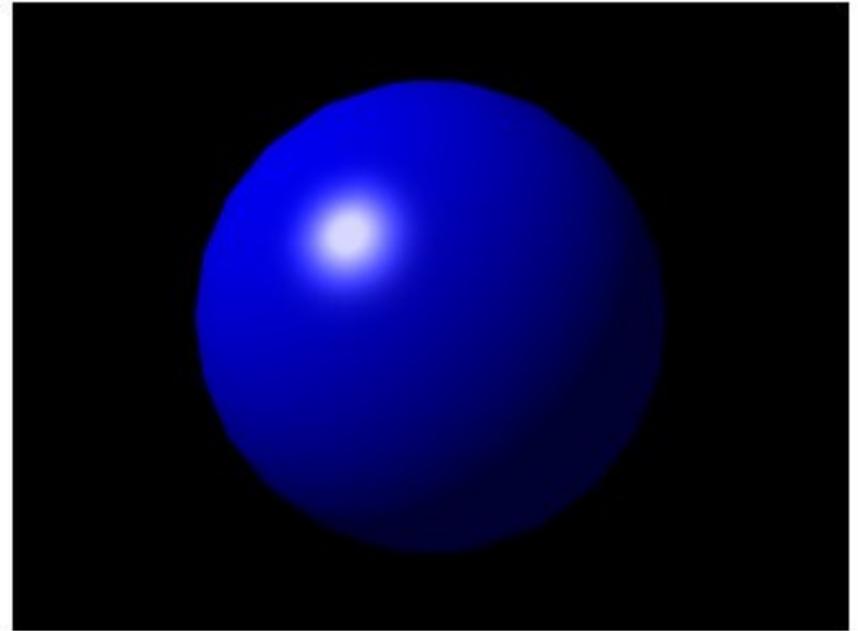
$$N_a(t) = t N_1 + (1-t) N_2$$

$$N_b(t) = t N_1 + (1-t) N_4$$

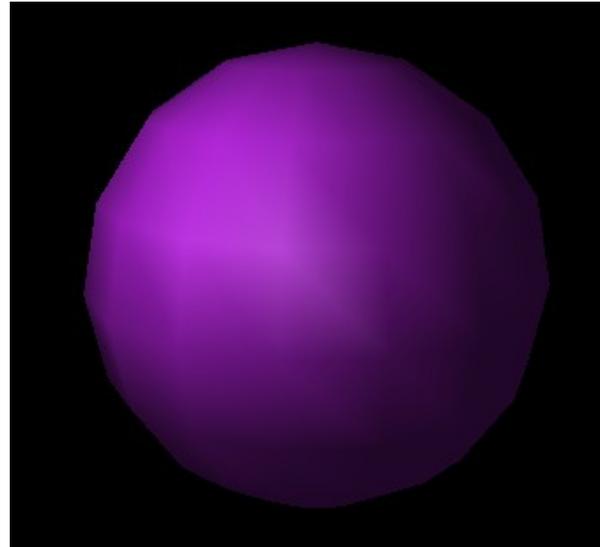
Tonalização



FLAT SHADING



PHONG SHADING



GOURAUD SHADING