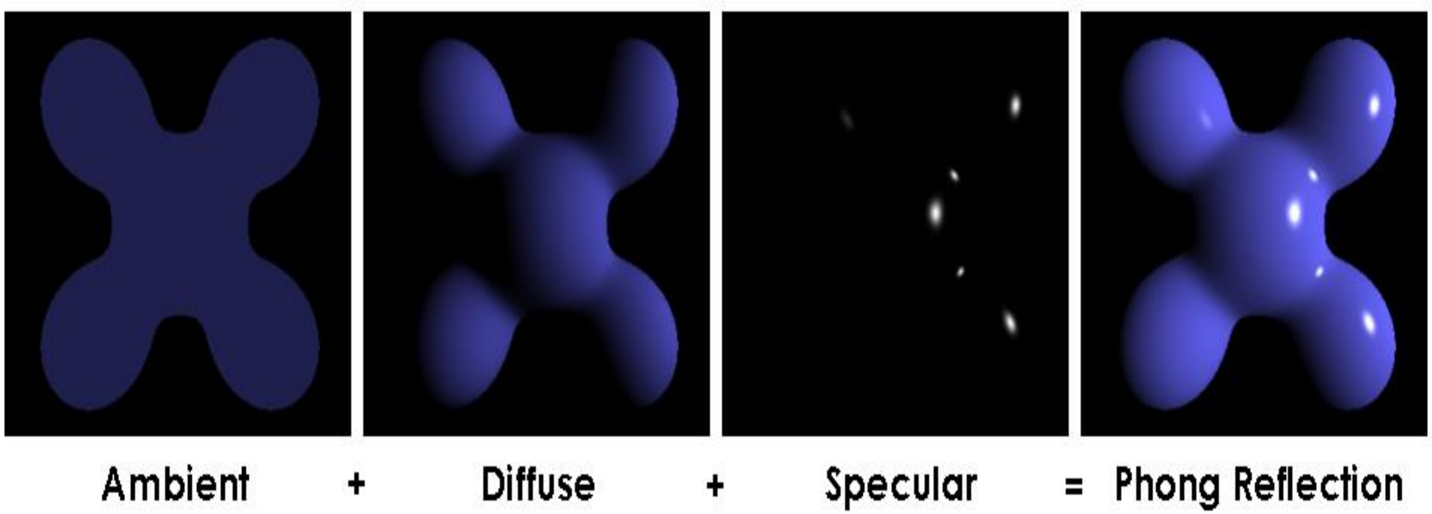
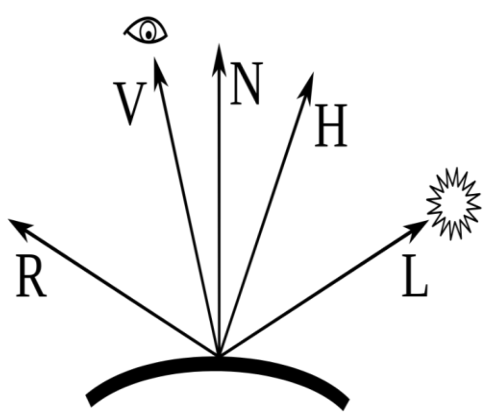
CGP 2

Dr Wojciech Palubicki

Phong model of lighting





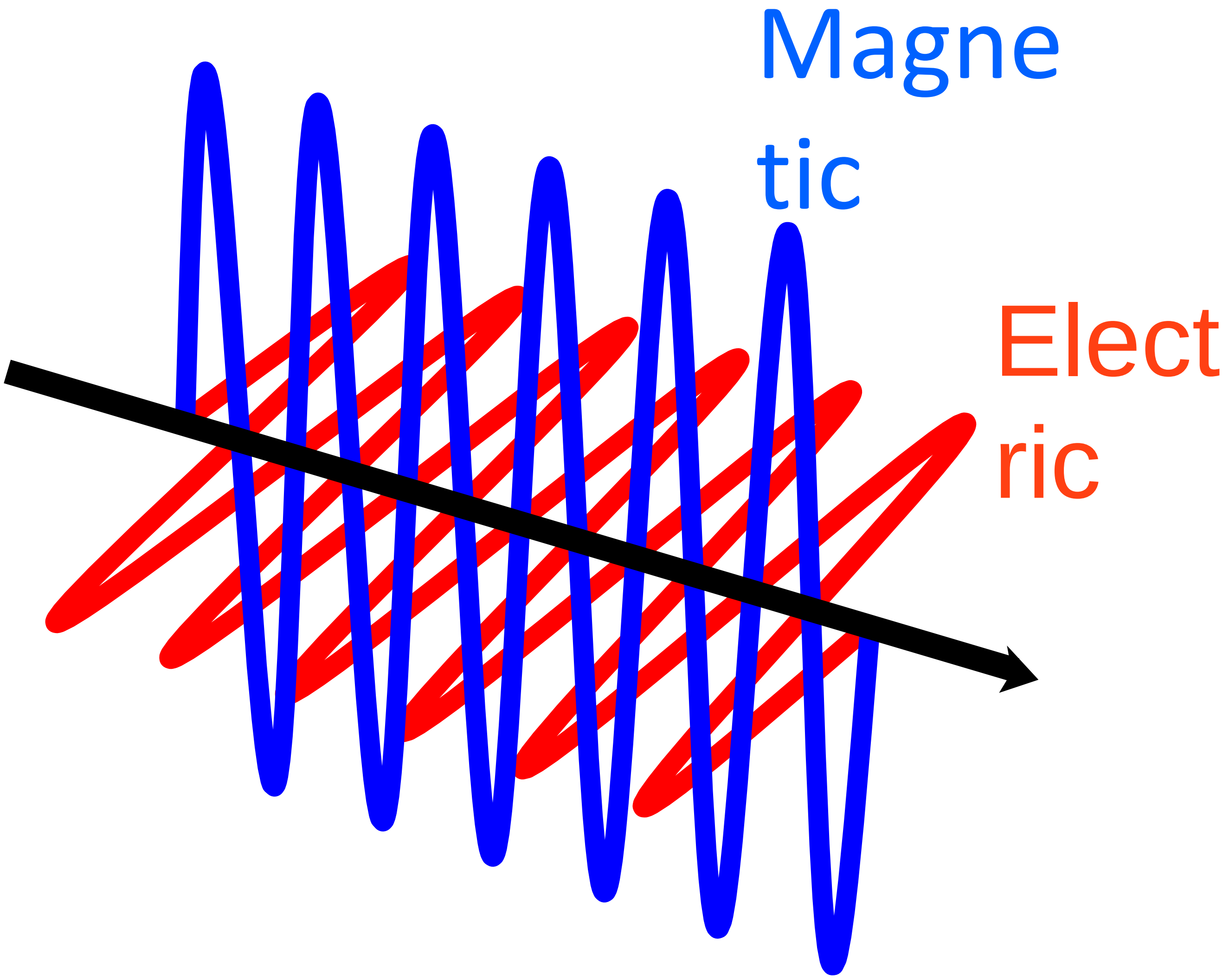

PHONG


PHONG
PBR

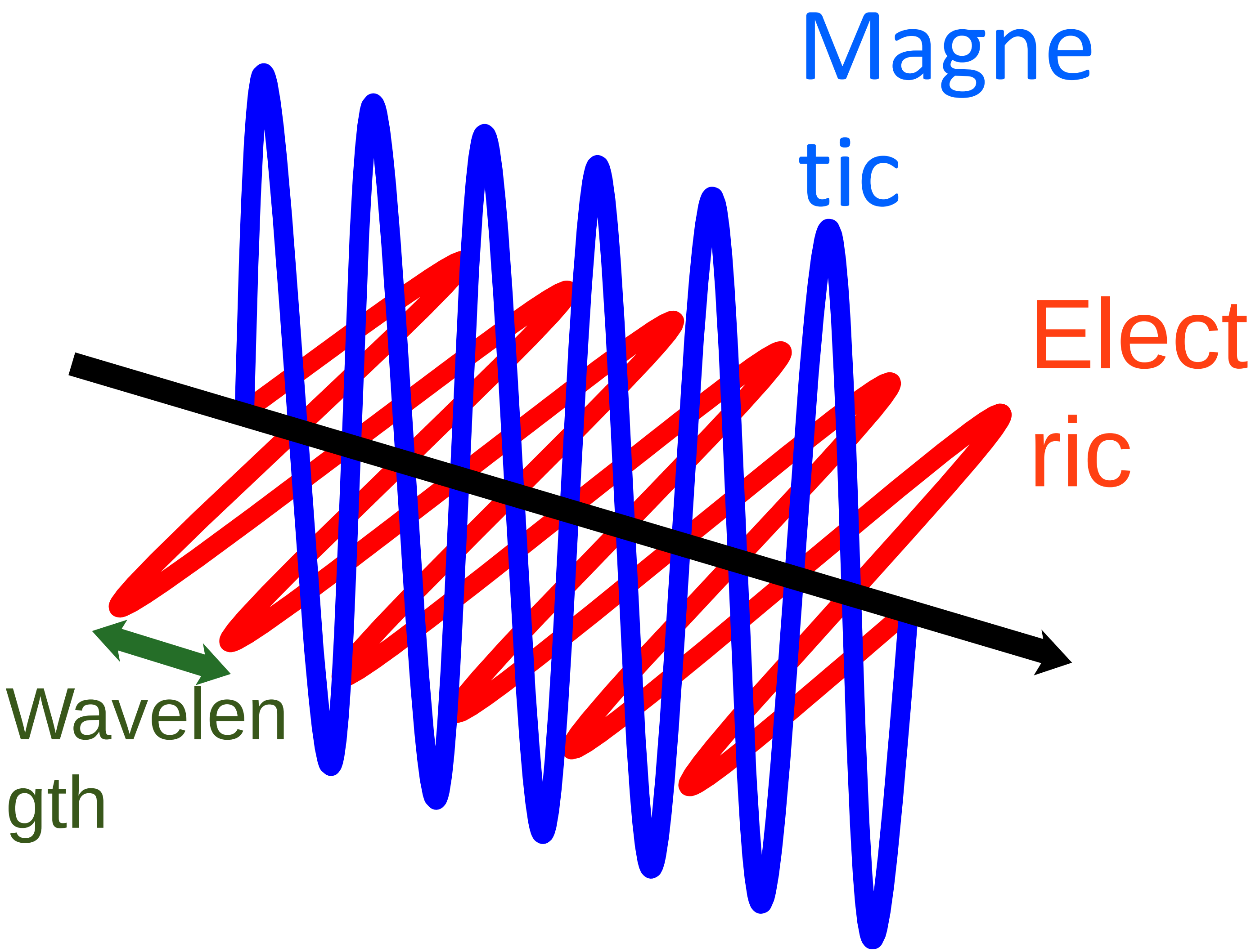
Physically based rendering (PBR)

- “Real-Time Rendering, 3rd Edition”, A K Peters 2008
- Physics of Light
- Geometric Optics
- Mathematical description for real-time lighting (micro-facet BRDF)

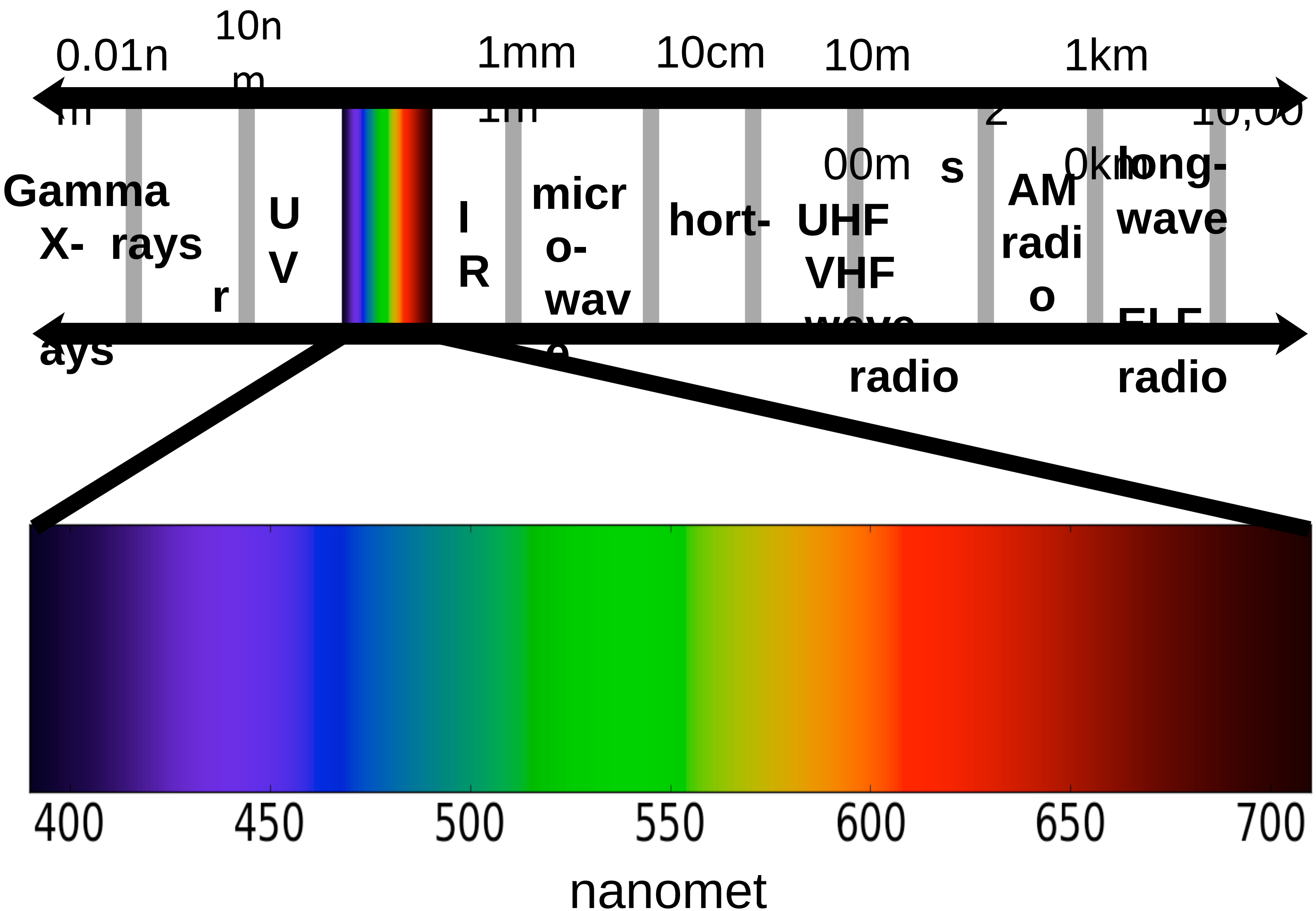
Light – physical point of view

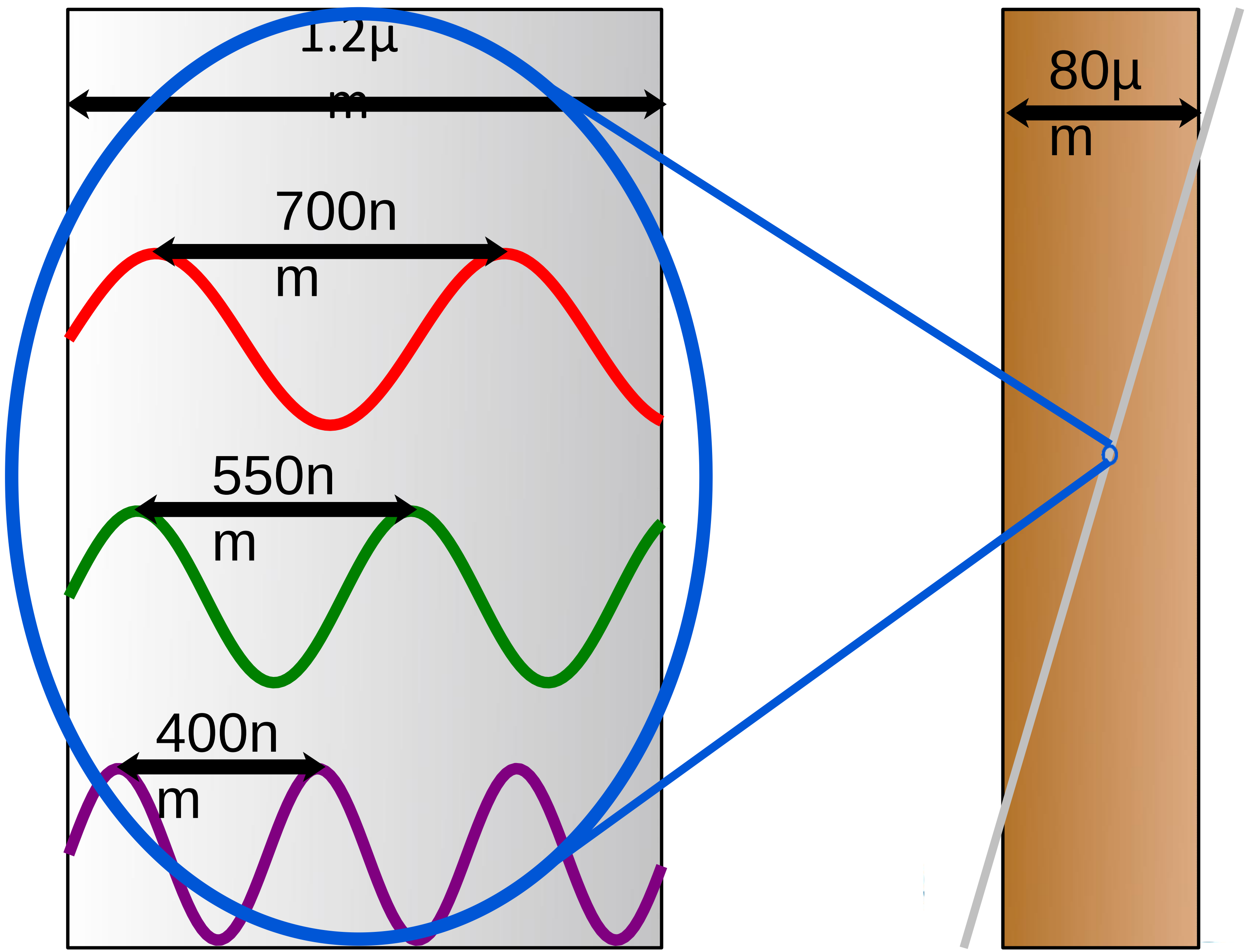


Light – physical point of view



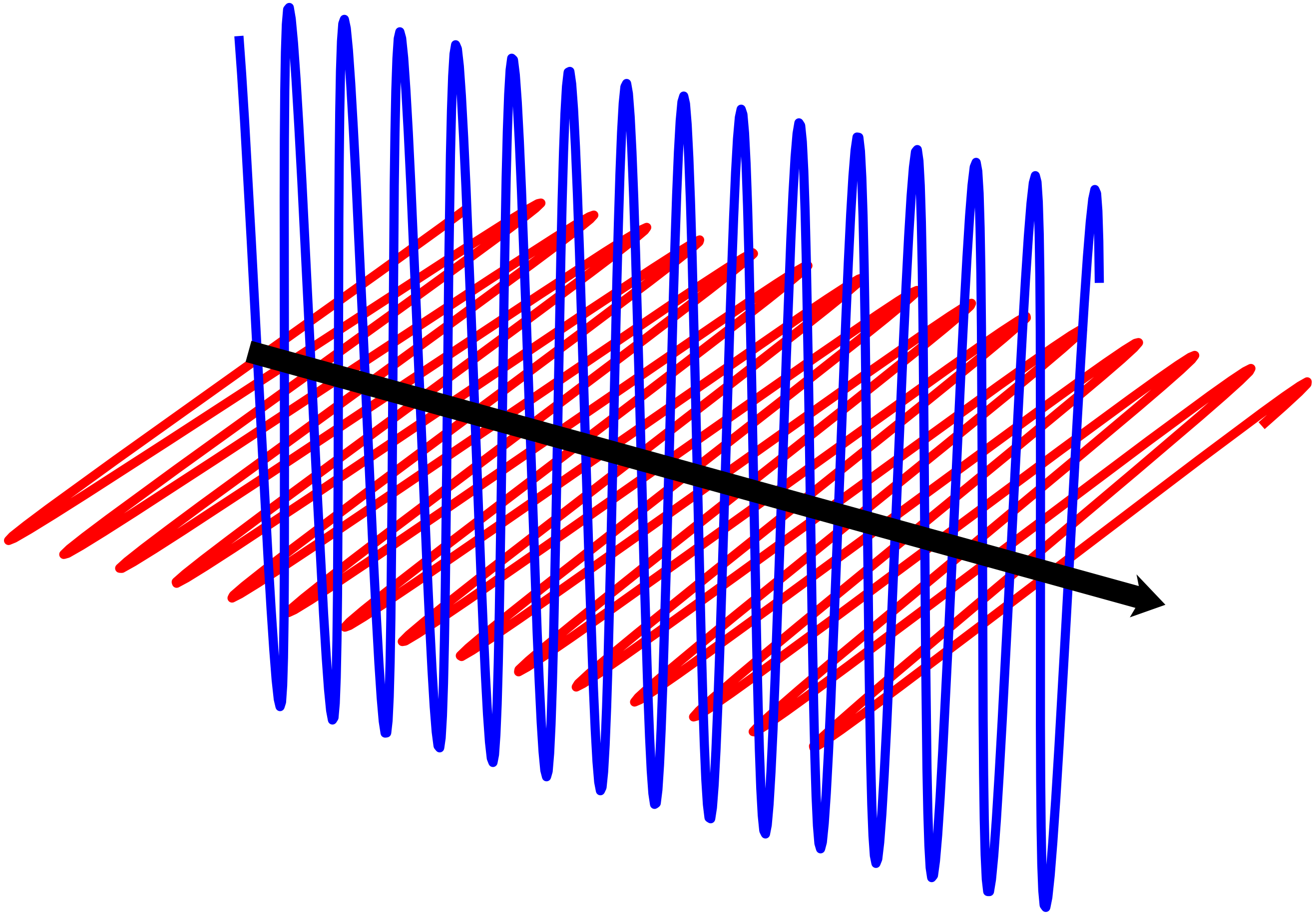
Electromagnetic wavelengths



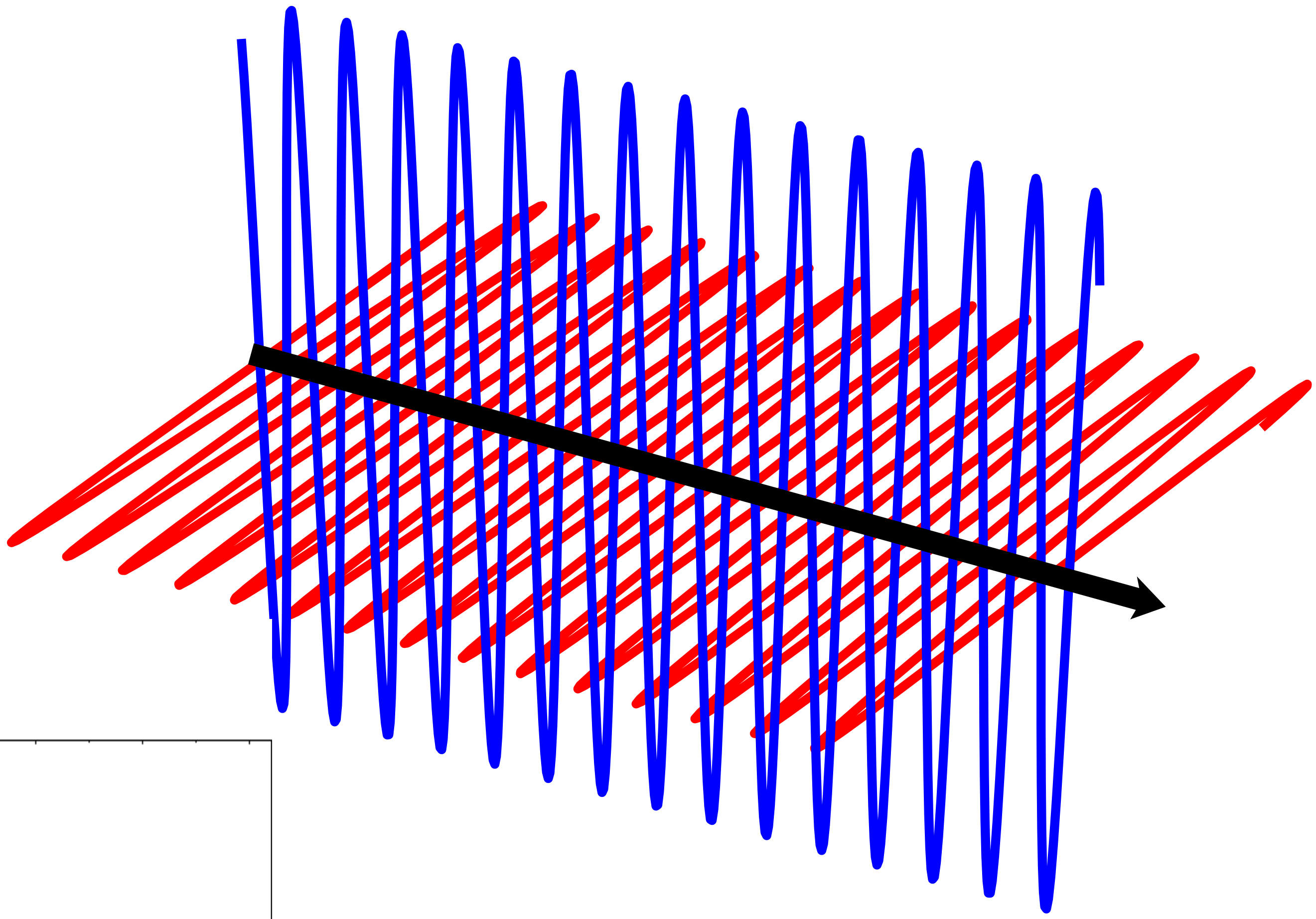


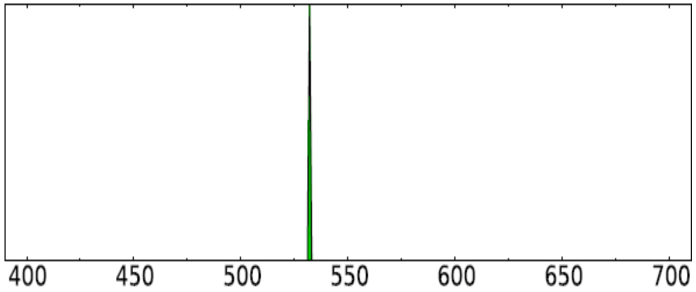
1.2μ
m
700n
m
550n
m
400n
m
80μ
m

Wavelengths

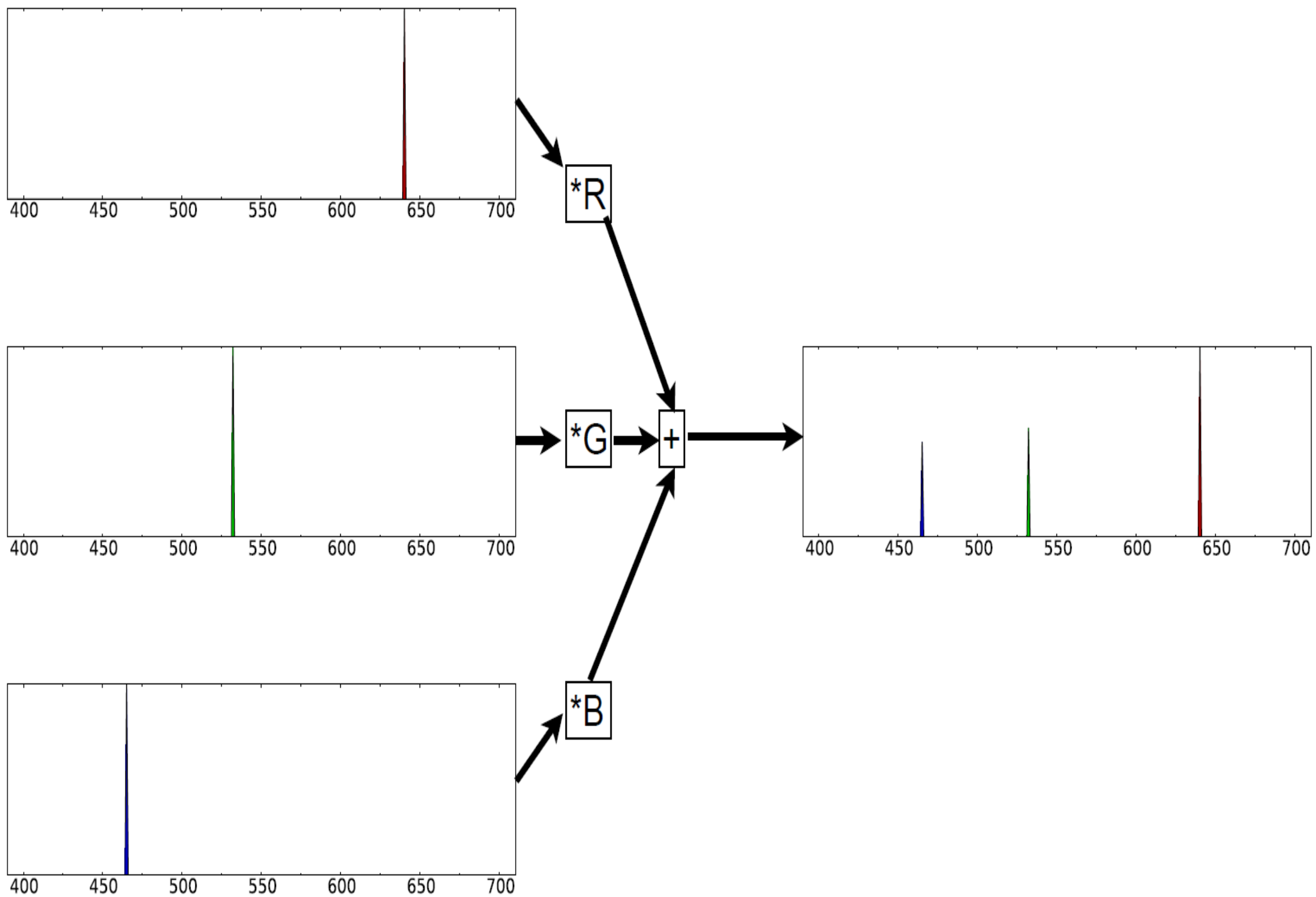


Spectral Power Distribution (SPD)

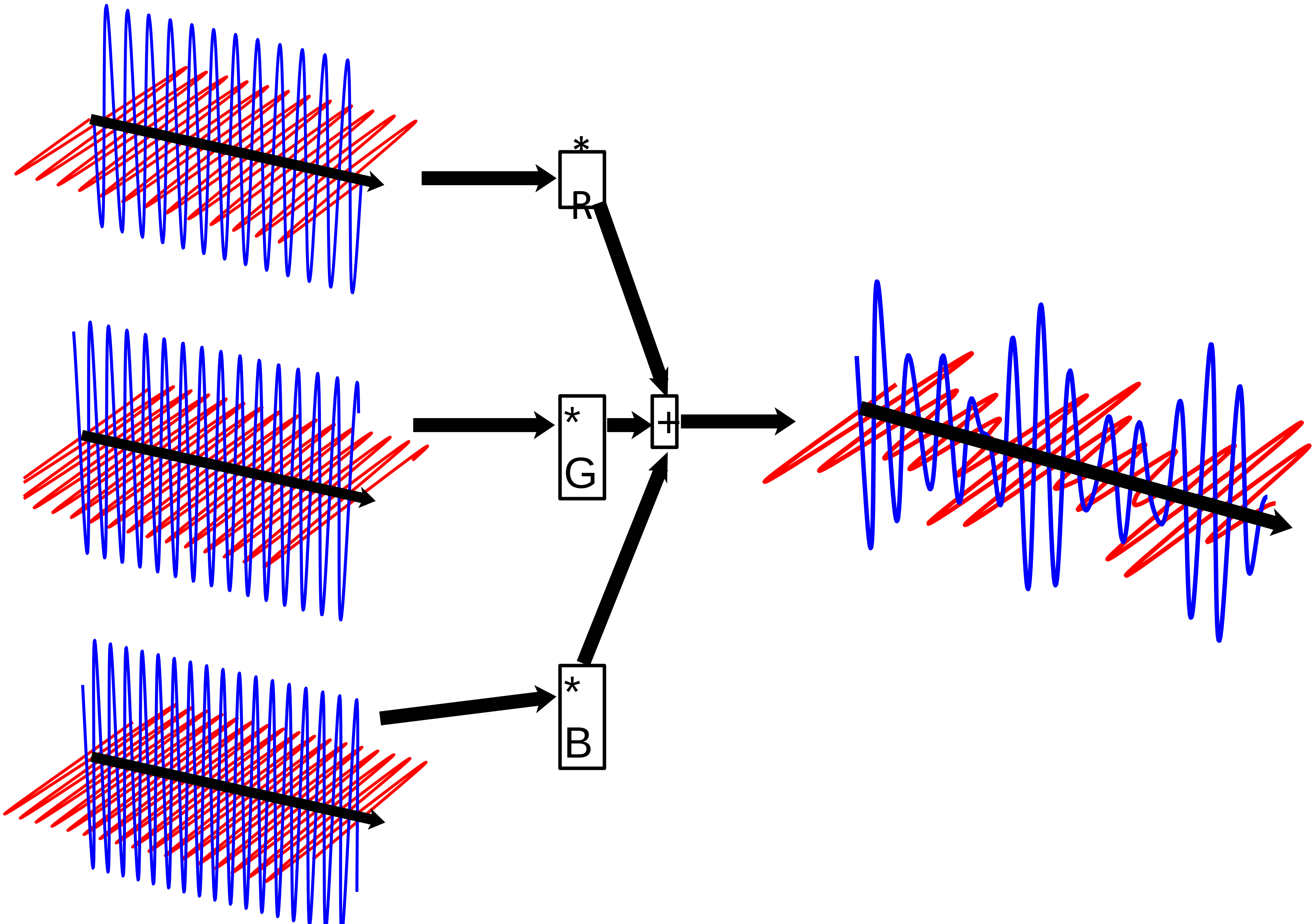




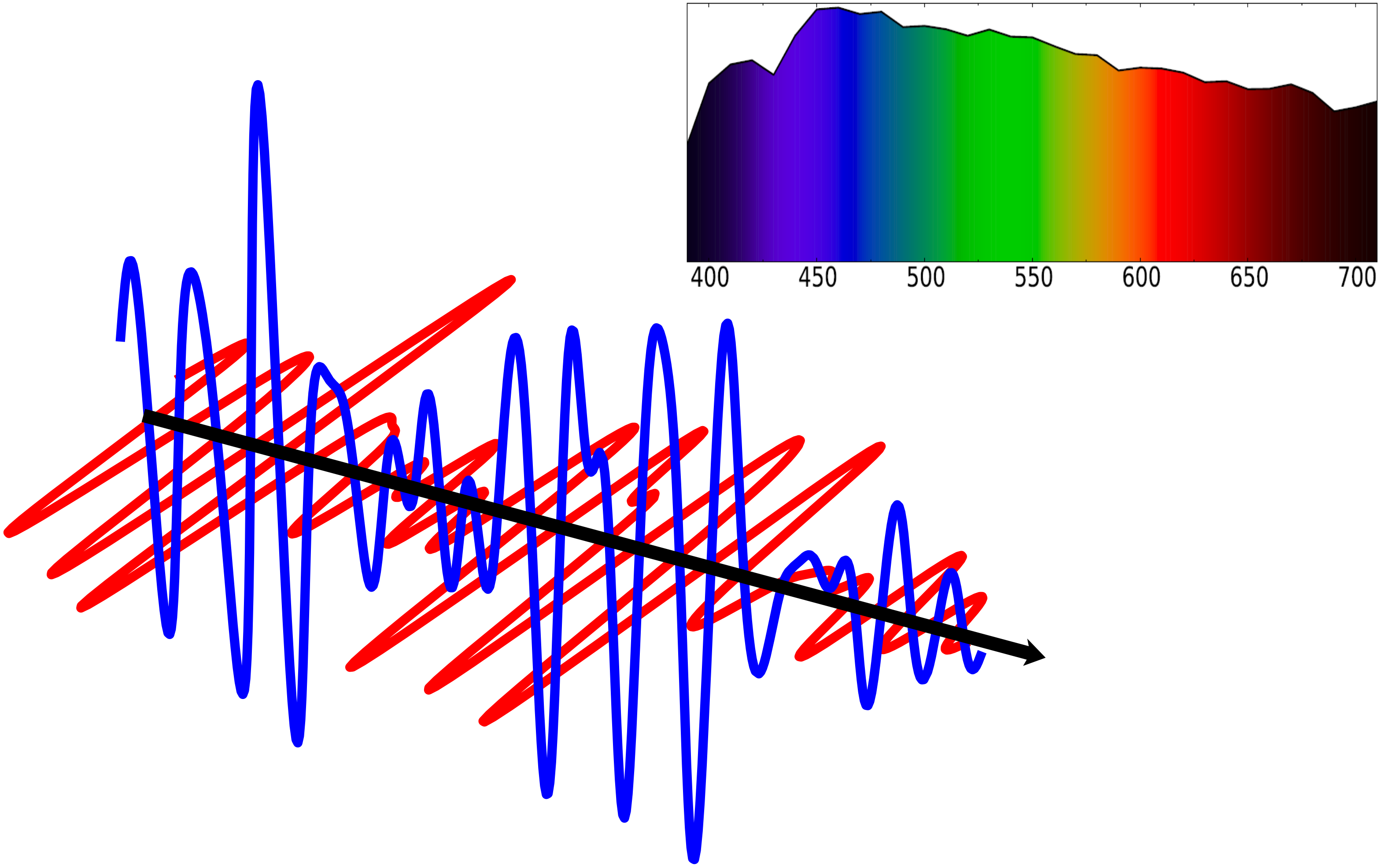
Example: RGB Laser Projector



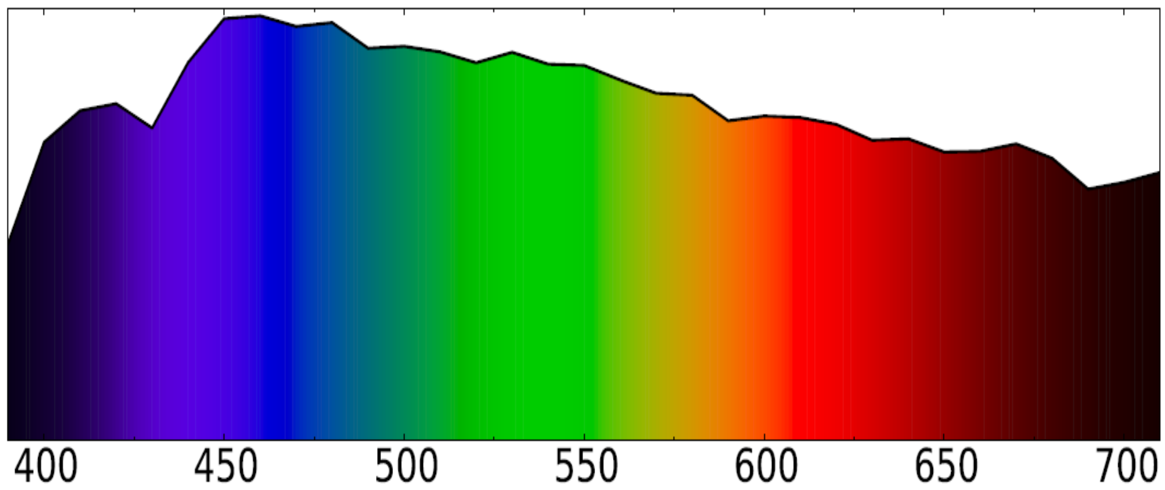
Resulting wave form

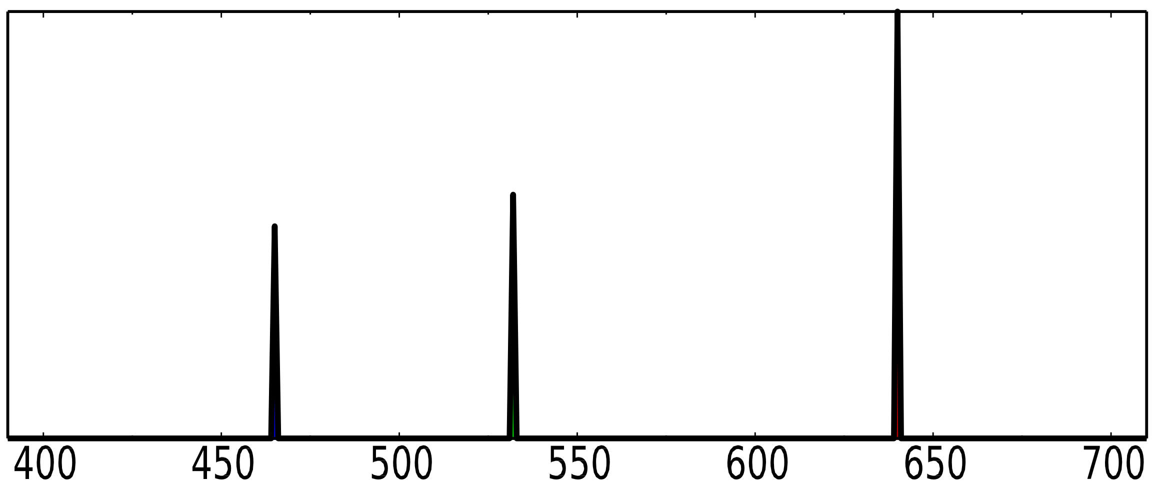


White light wave form

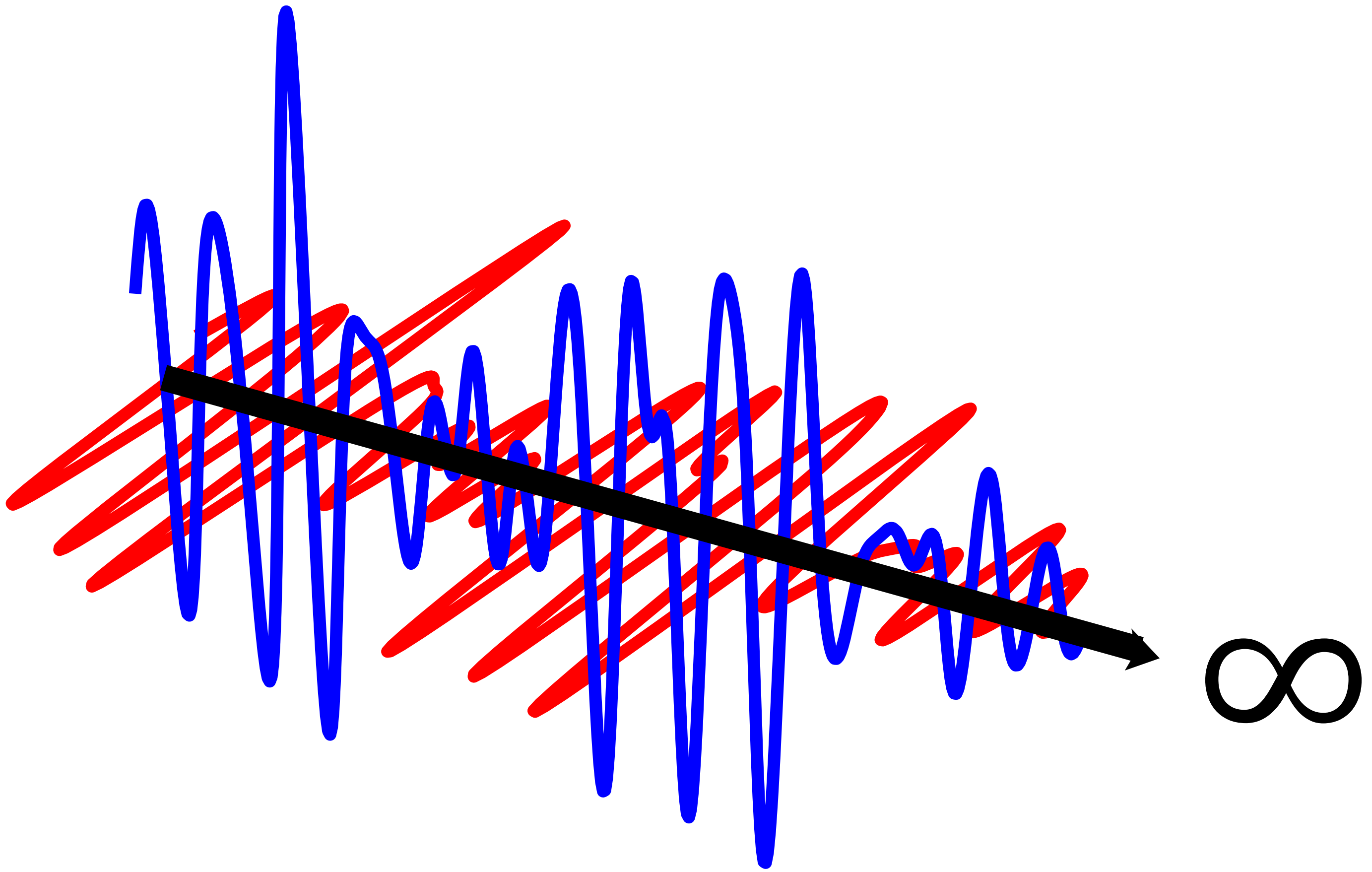


White light and laser projector light comparison

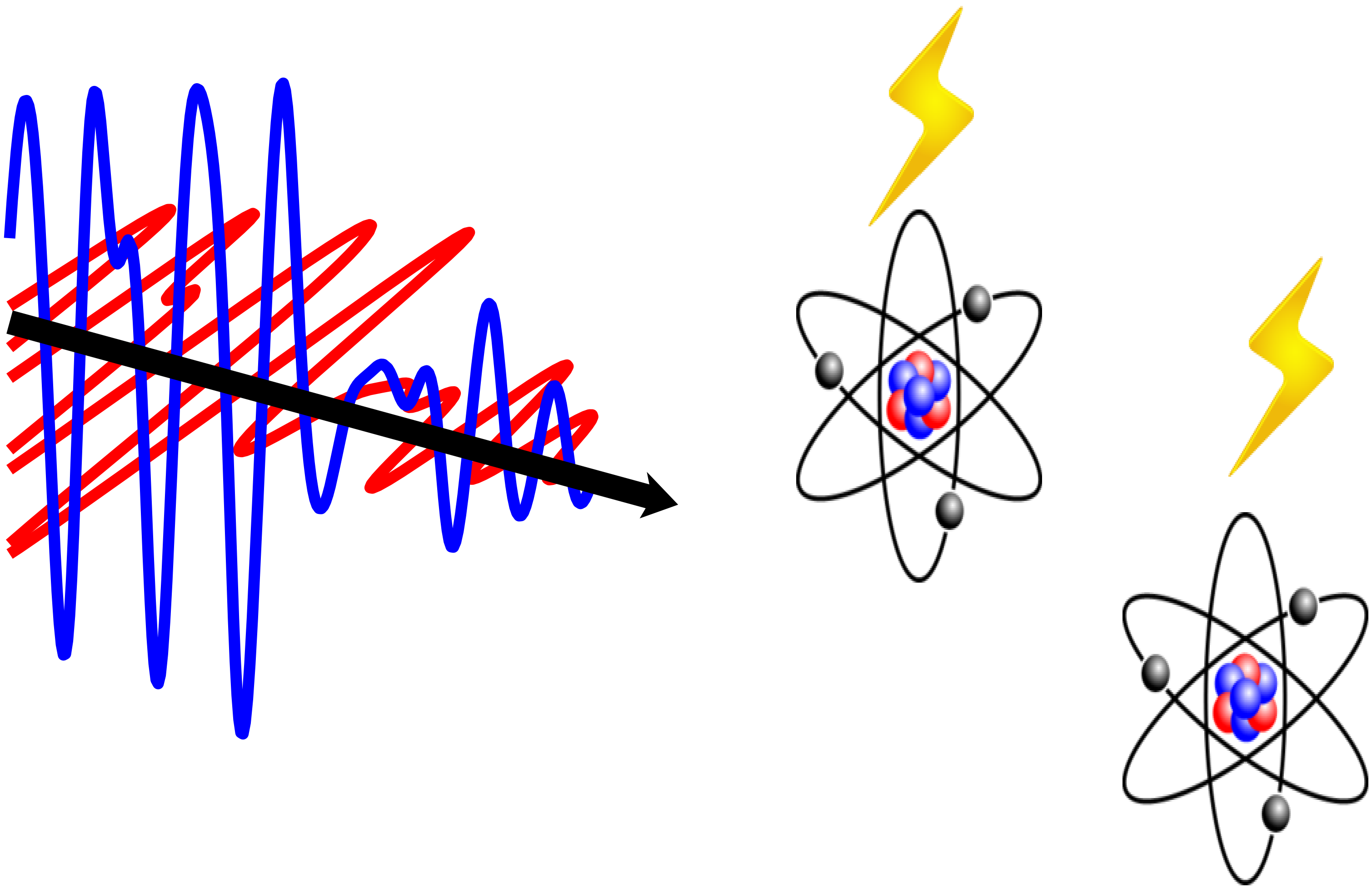




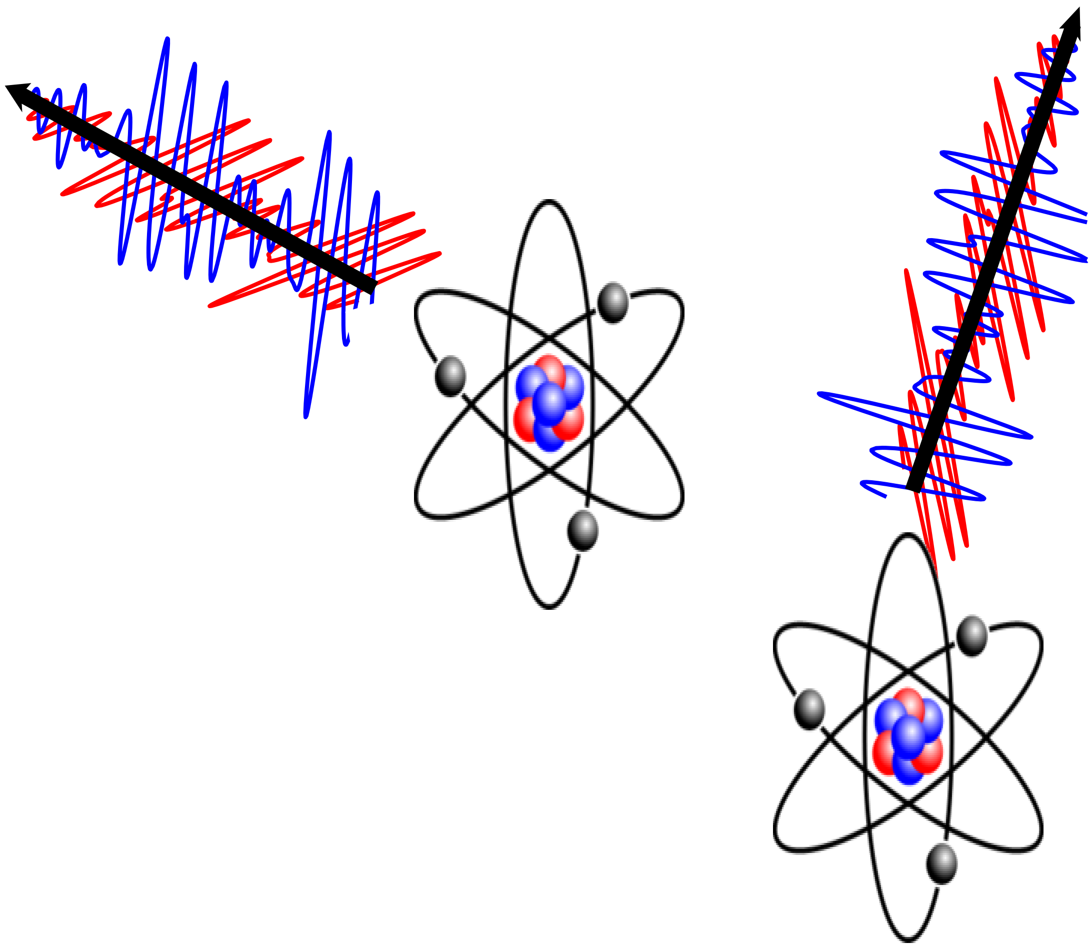
In a vacuum light propagates to infinity



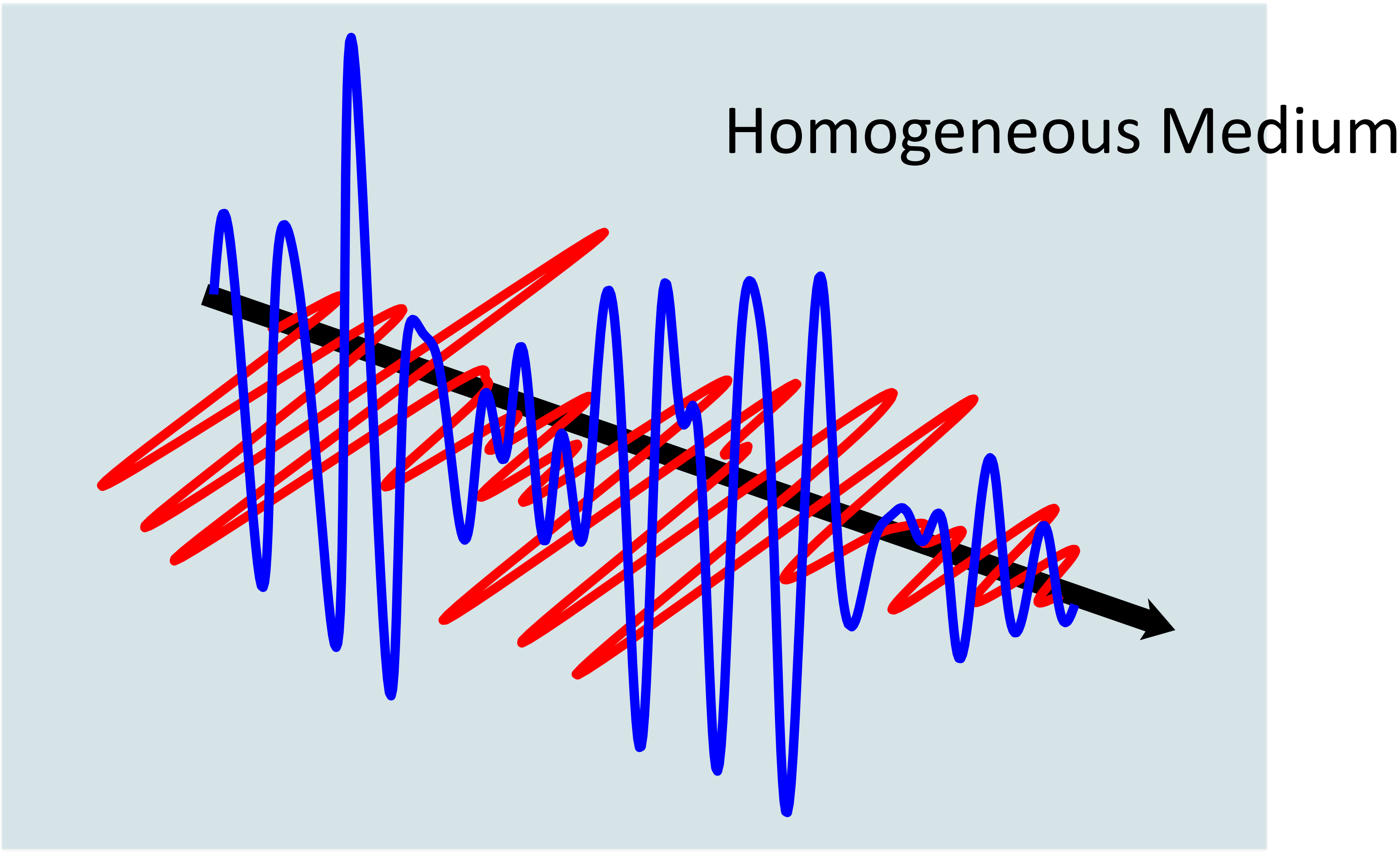
When interacting with atoms it energizes them



This energy is absorbed and re-radiated as light

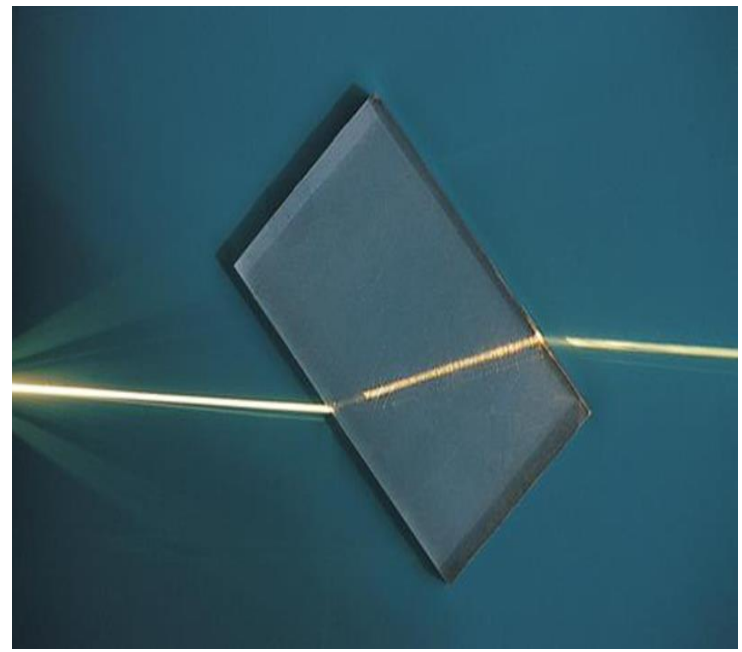


Simplification

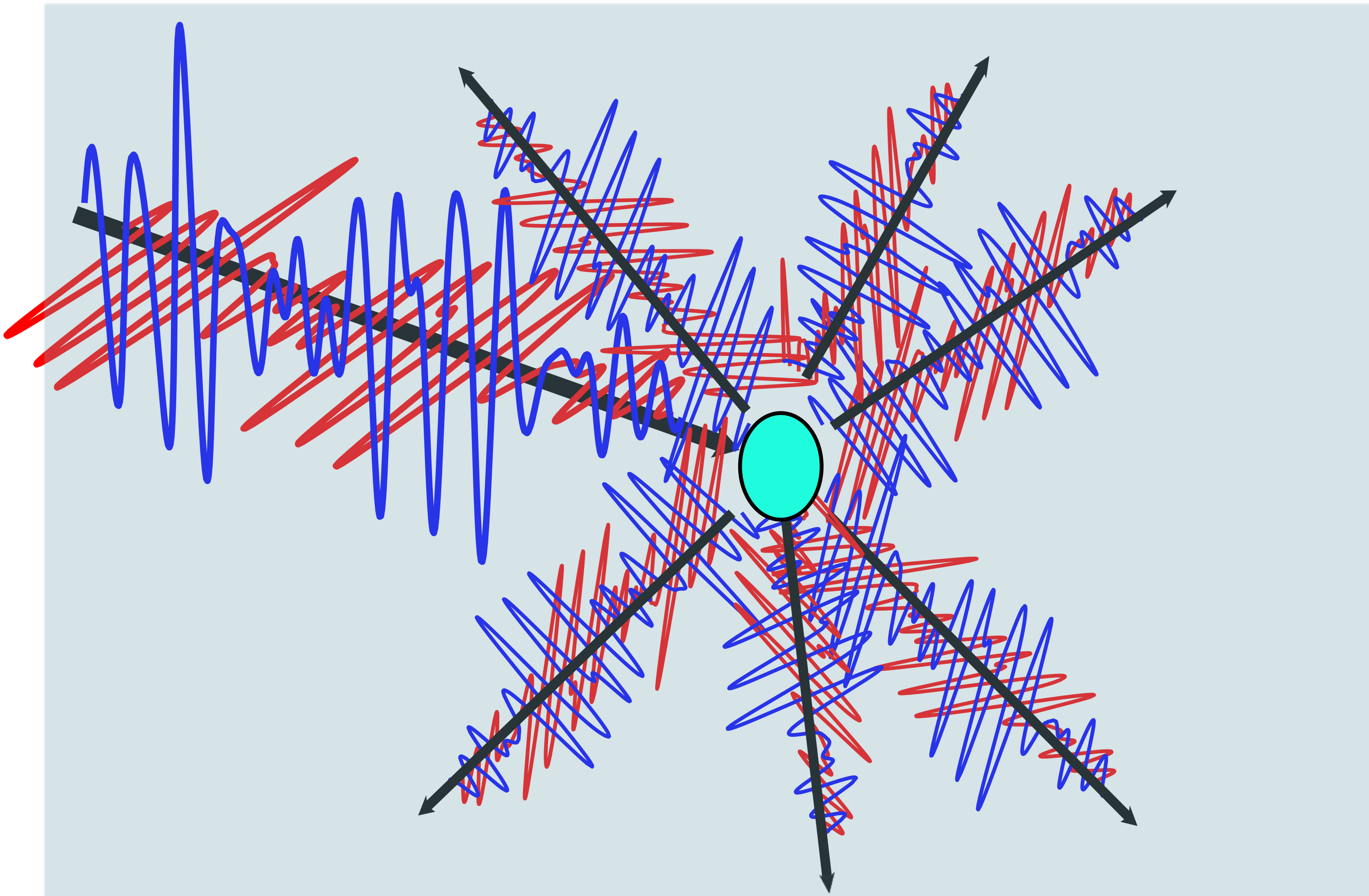


Refractive Index (dimensionless)

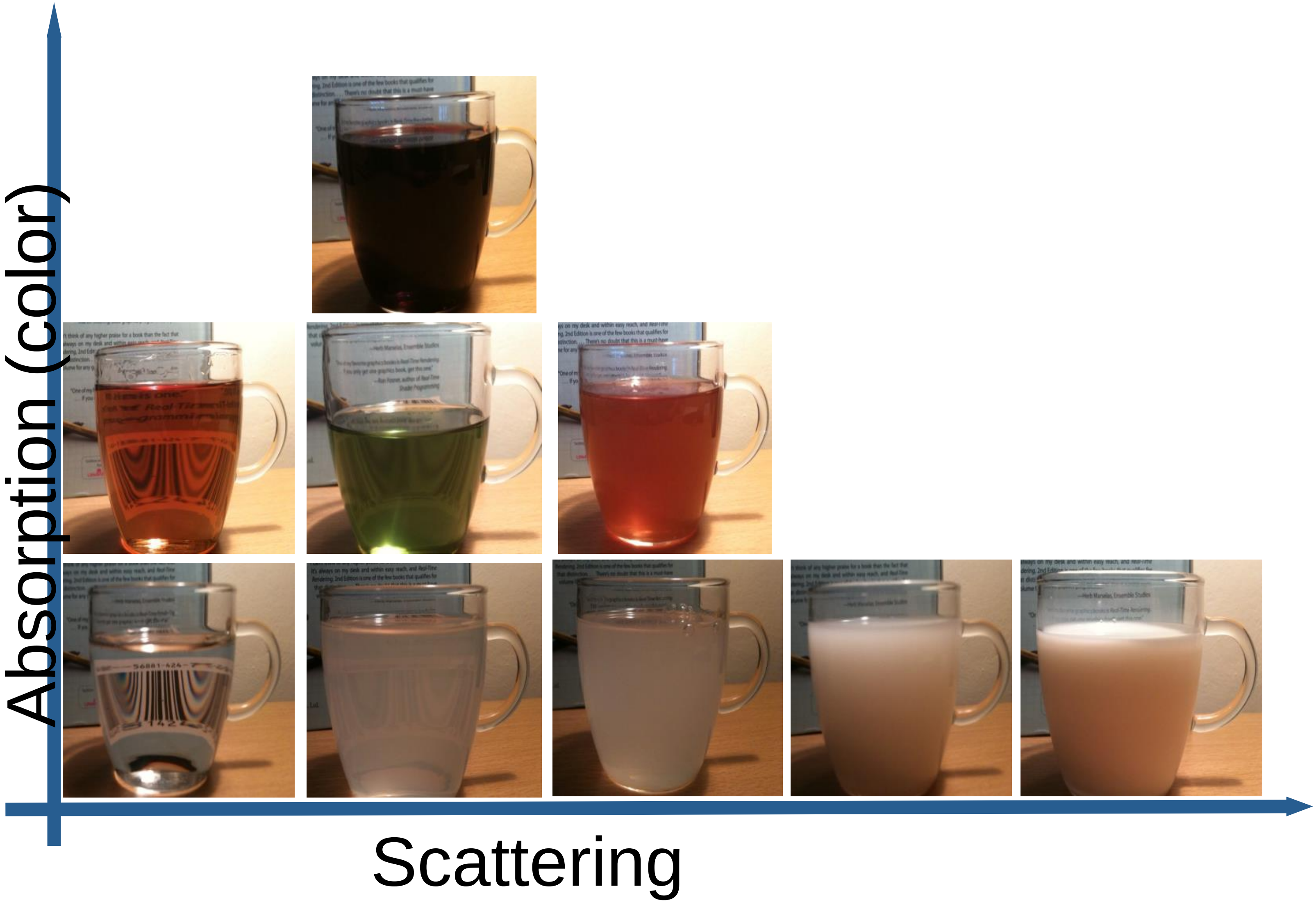
- $n = \frac{c}{v}$
- c is the speed of light in vacuum
- v is the phase velocity of light in the medium
- Measures the **absorption** of light by a medium



Scattering particle

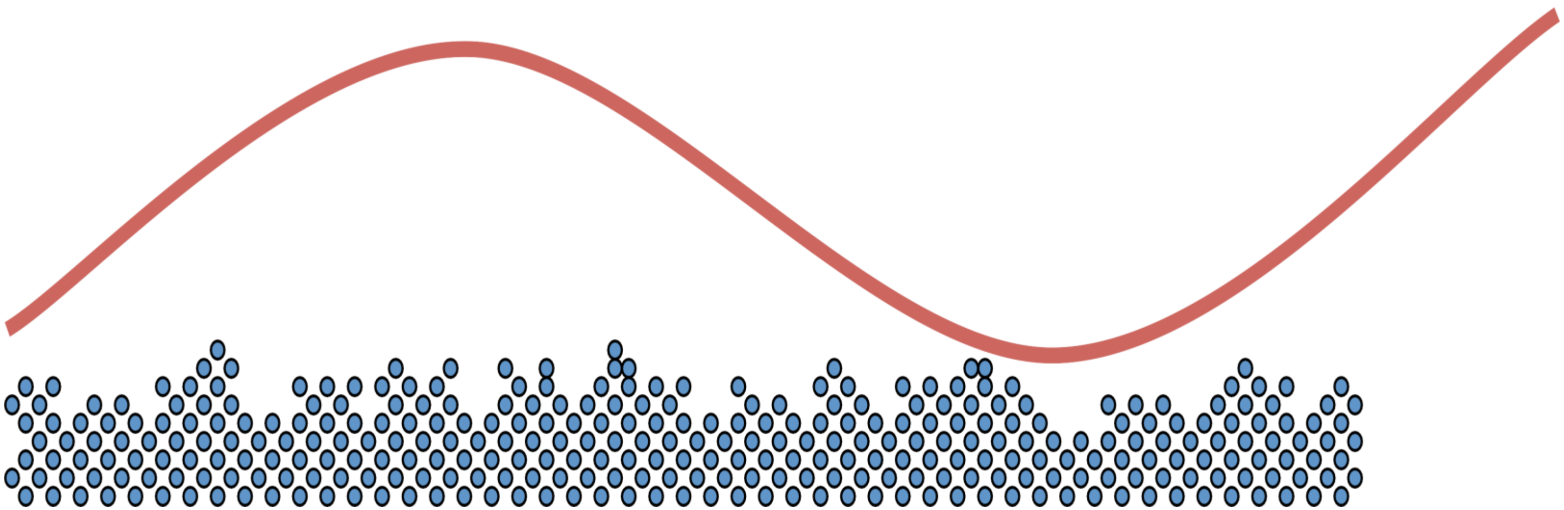


Appearance of a medium

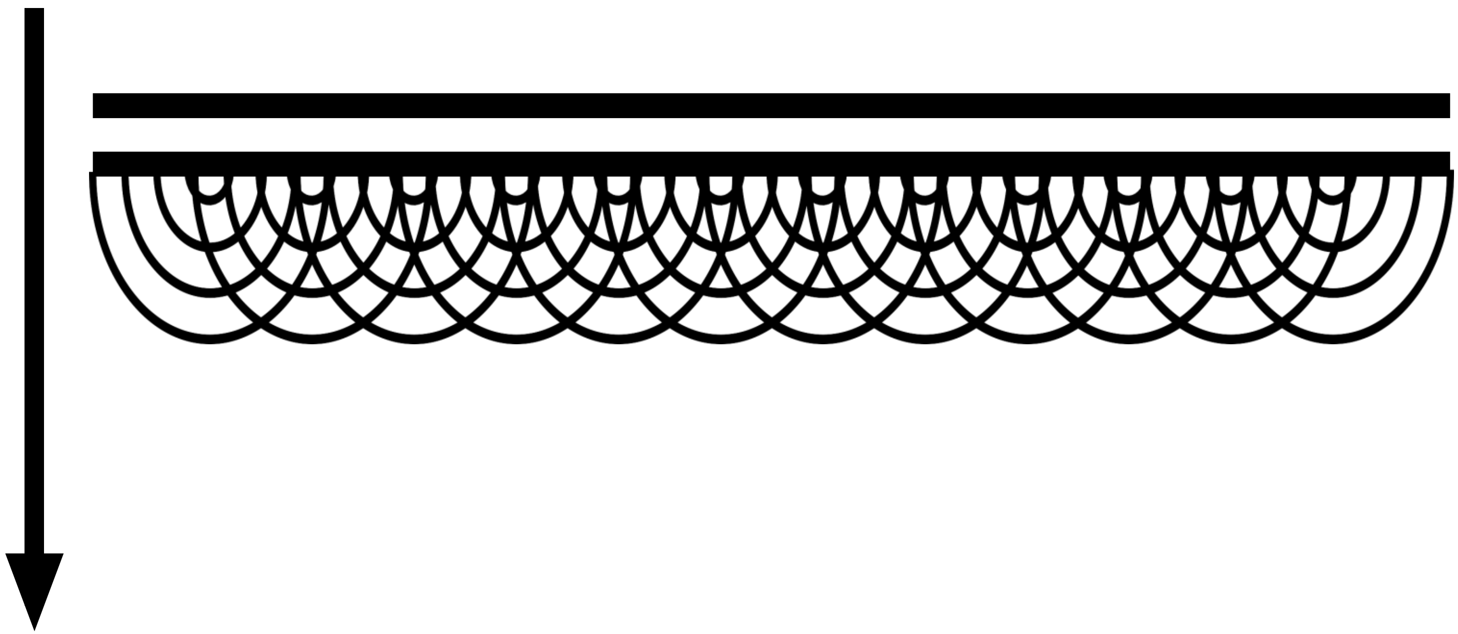


Object surfaces

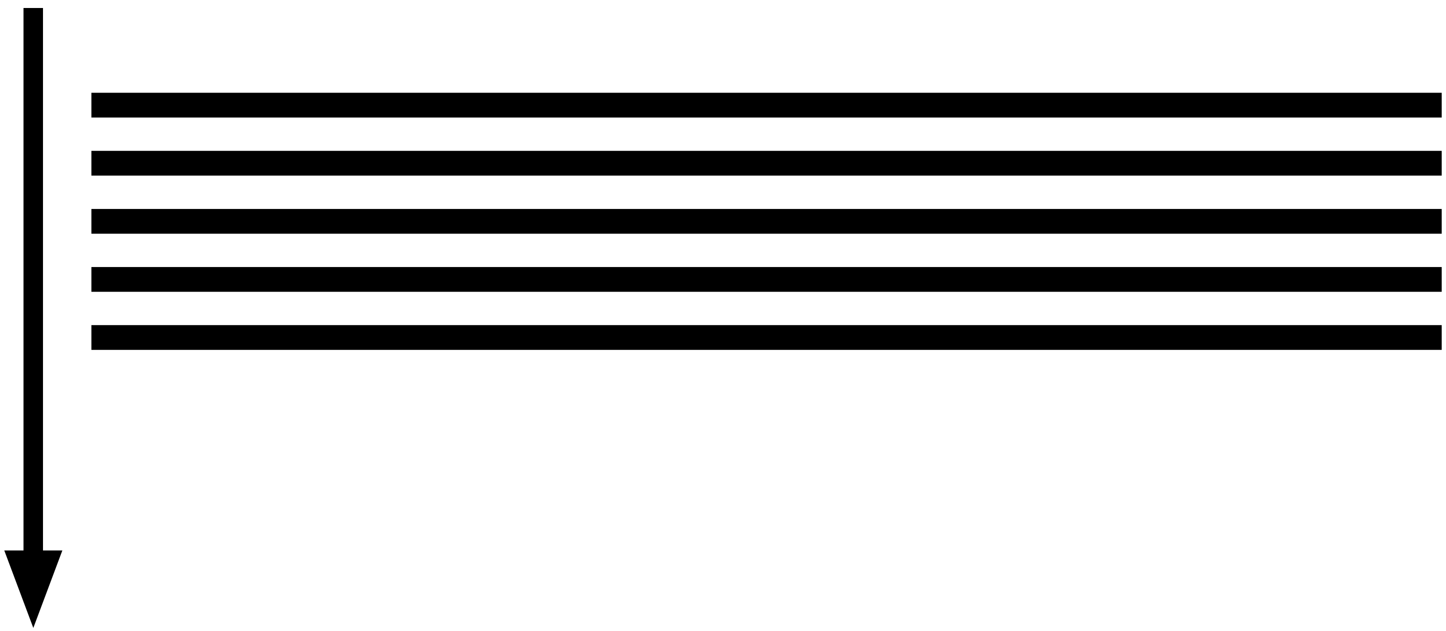
Nanogeom etry



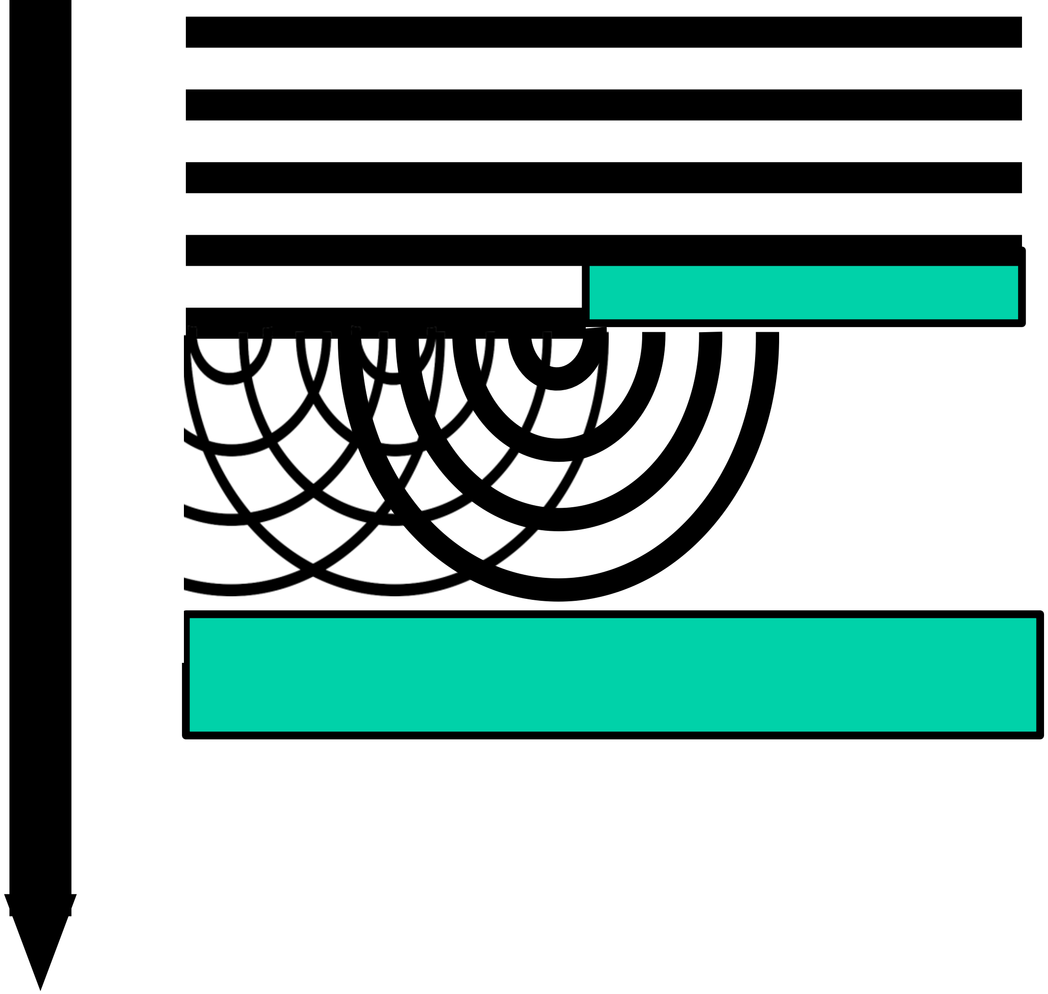
Huygens-Fresnel Principle



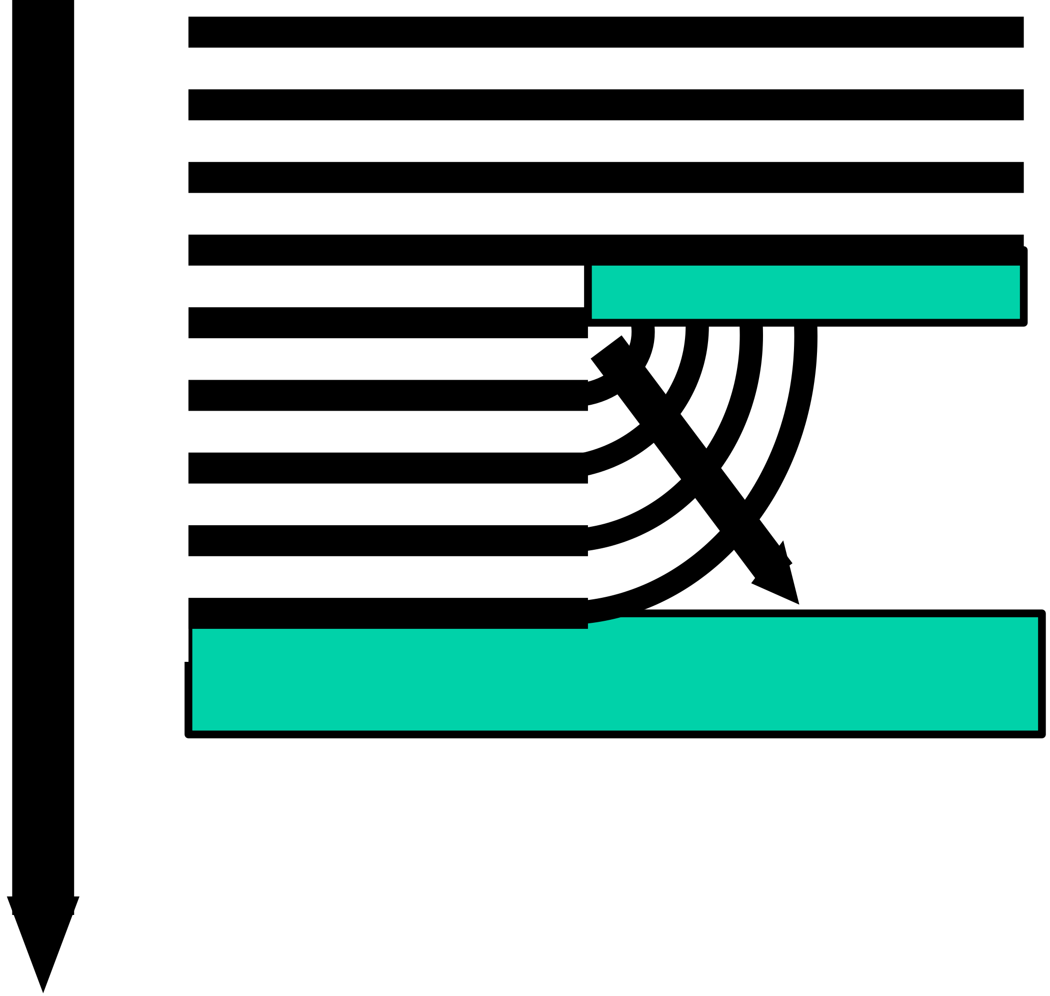
Huygens-Fresnel Principle



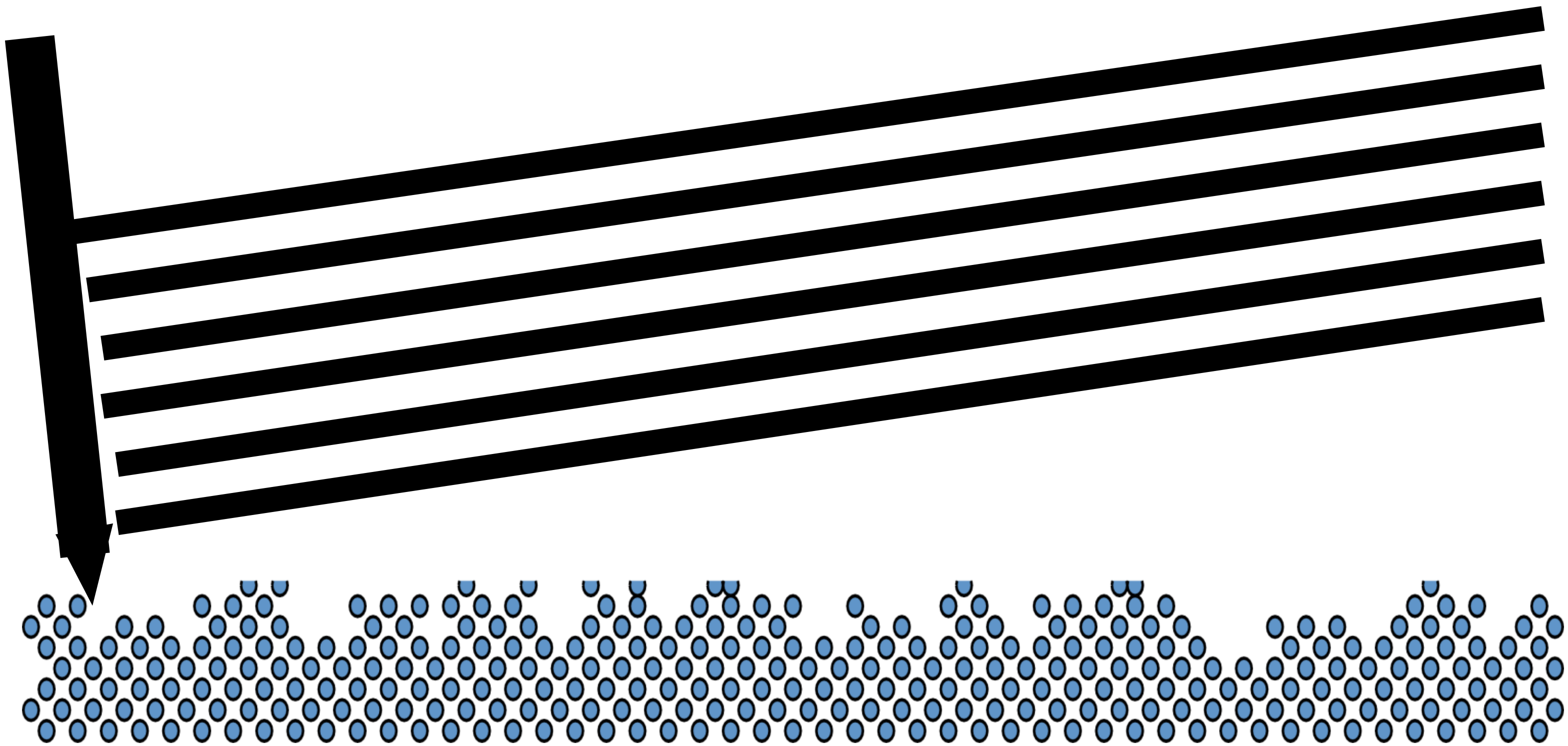
Diffract ion



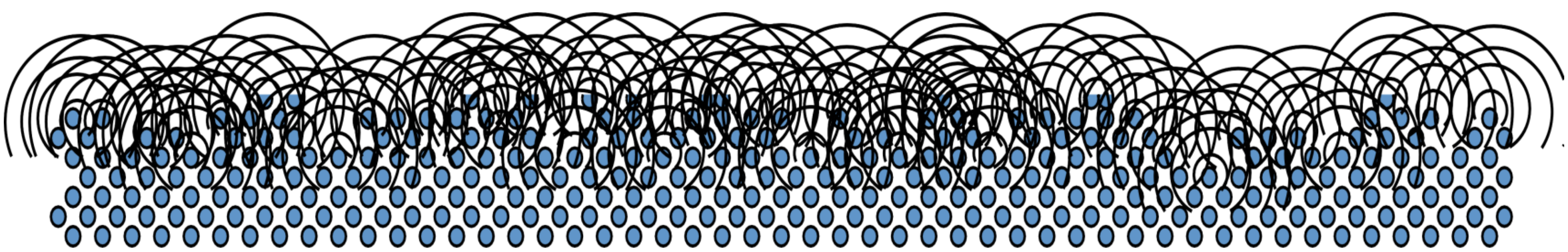
Diffract ion



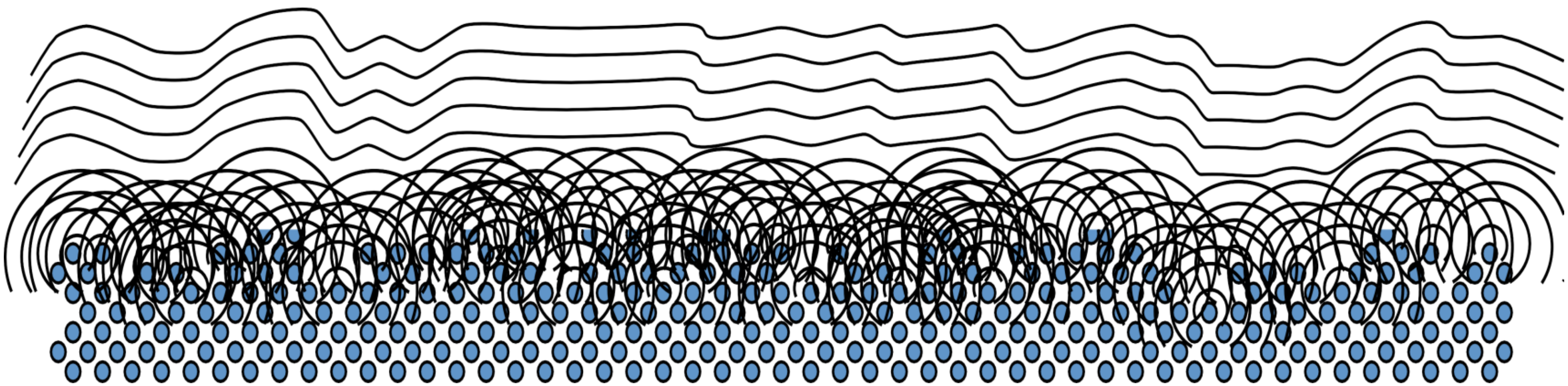
Diffraction from Optically-Smooth Surface



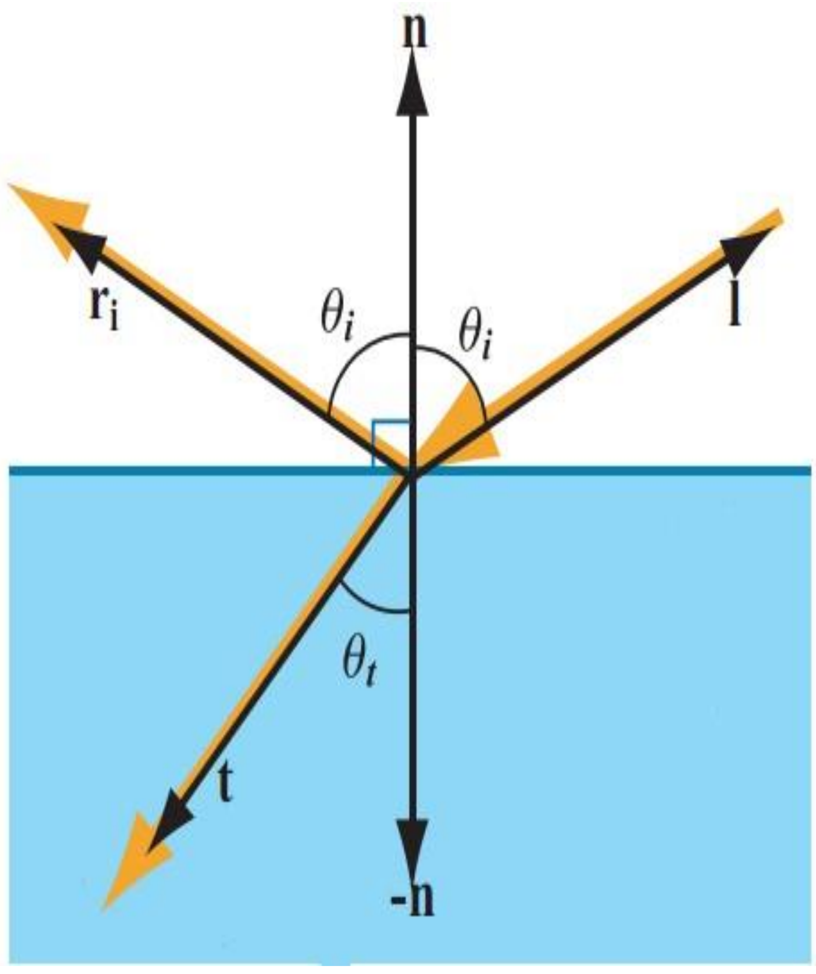
Diffraction from Optically-Smooth Surface



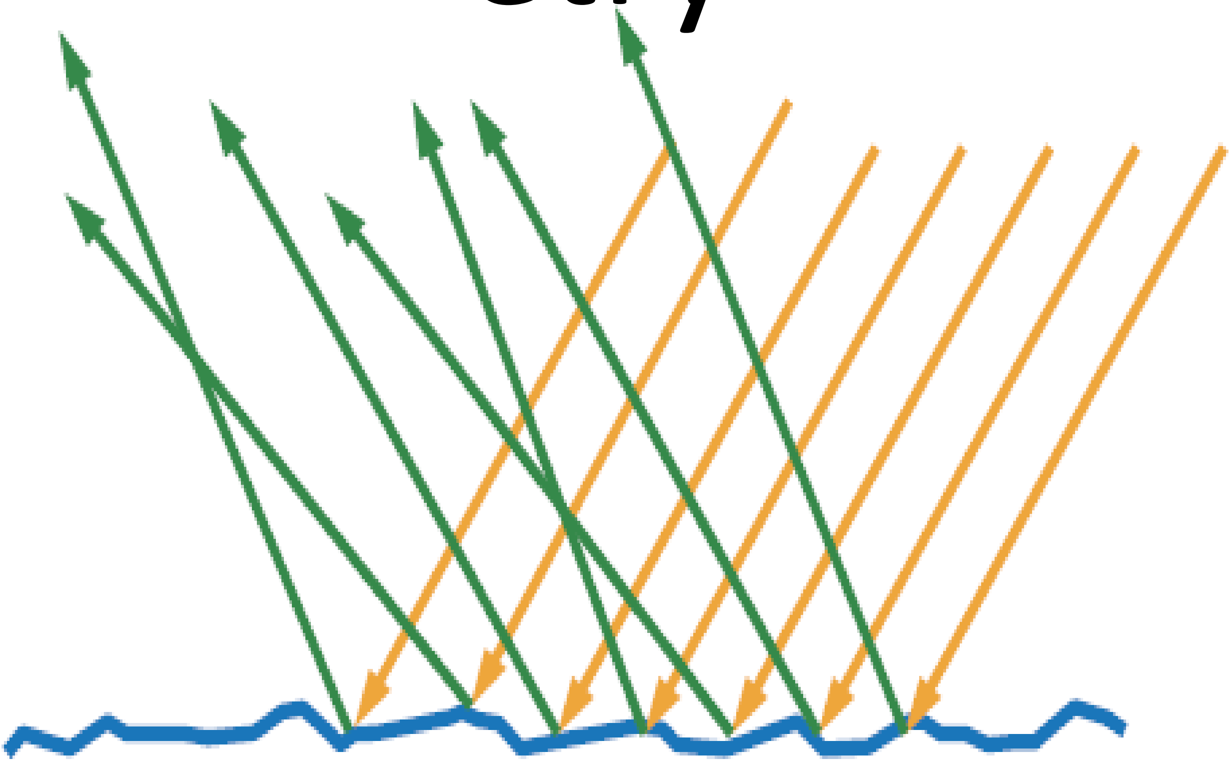
Diffraction from Optically-Smooth Surface



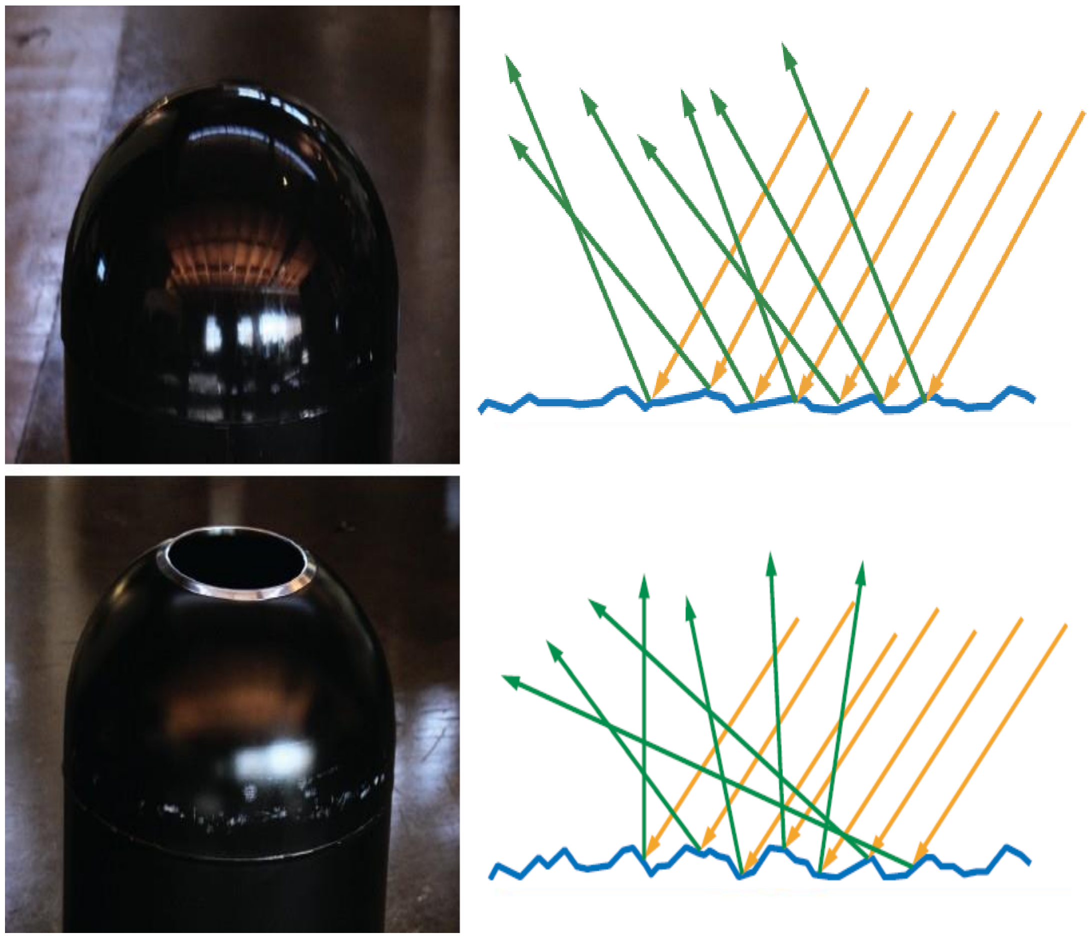
Geometric Optics



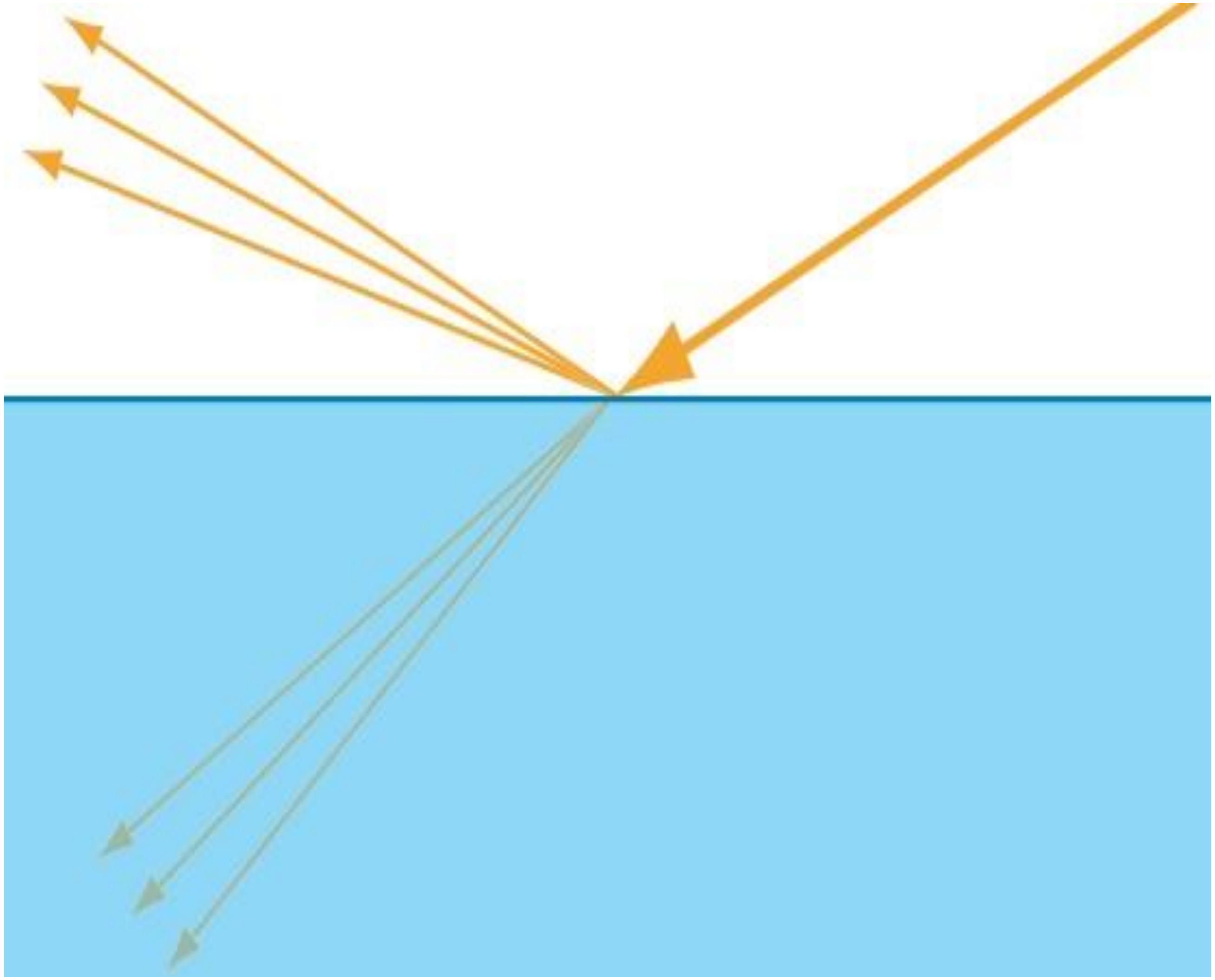
Microgeom etry



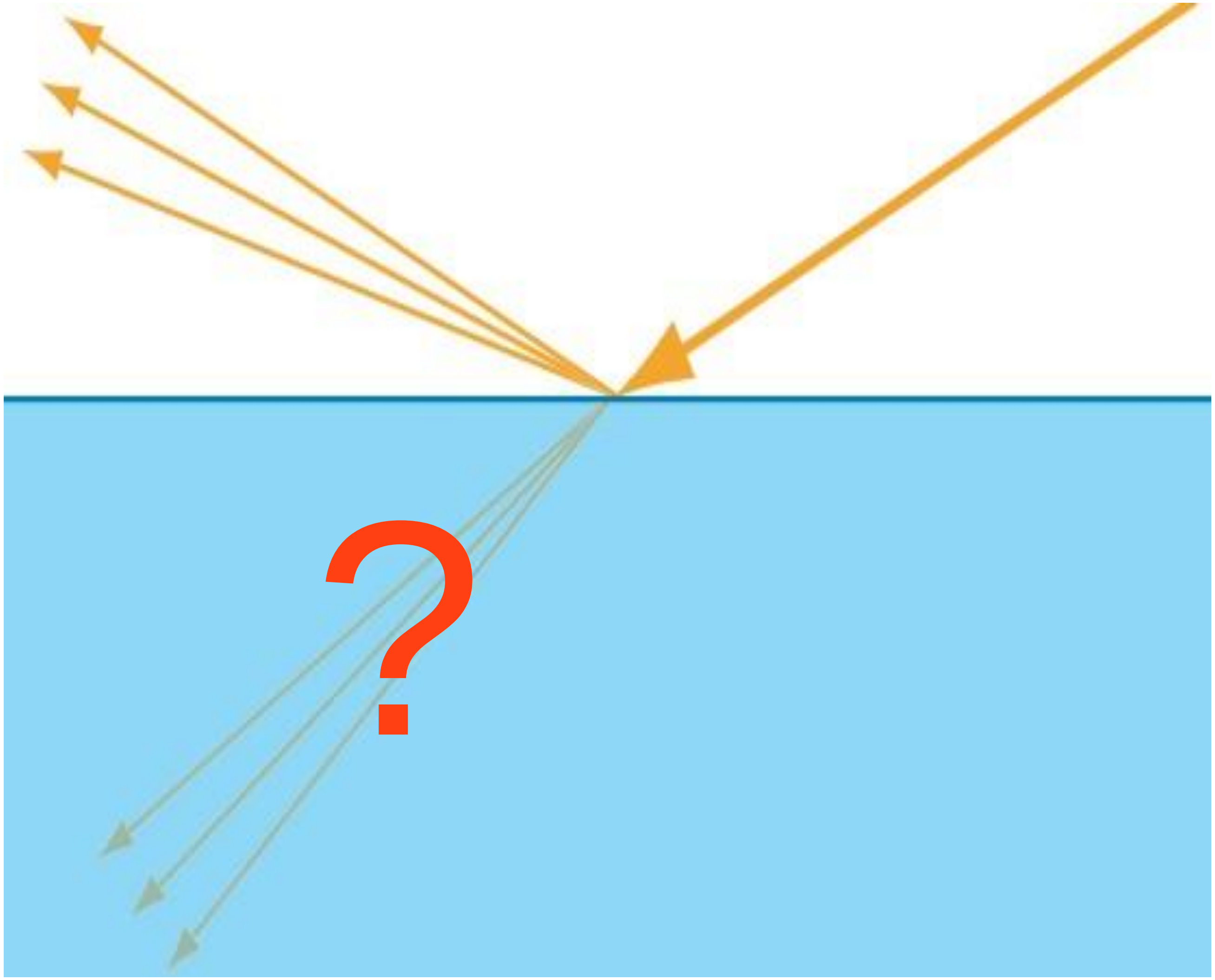
Rougher = Blurrier Reflections



Statistical macroscopic view



What happens to the refracted light?



Metals
(Conductors)

Dielectrics
(Insulators)

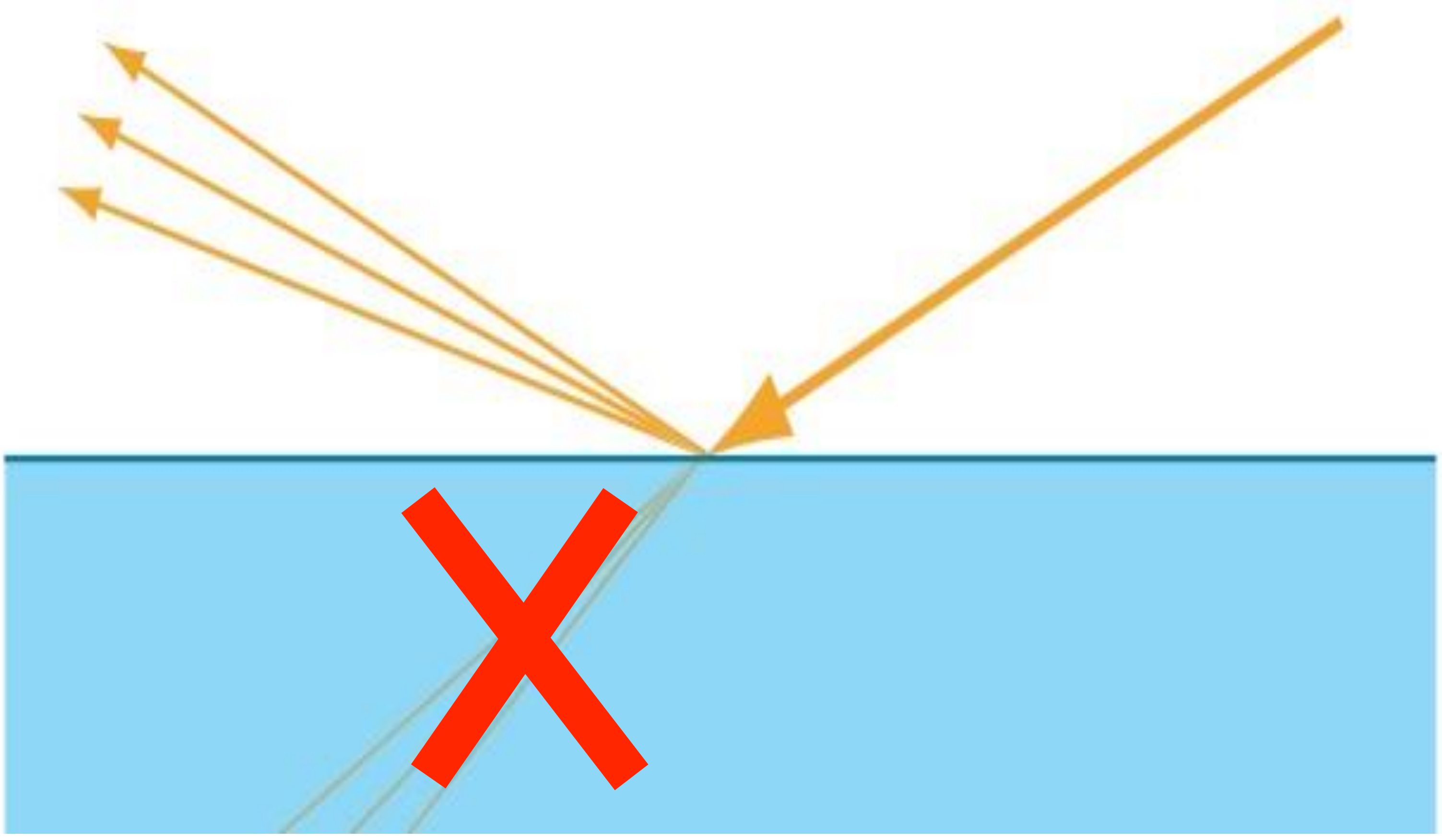
Semiconductors

Metals

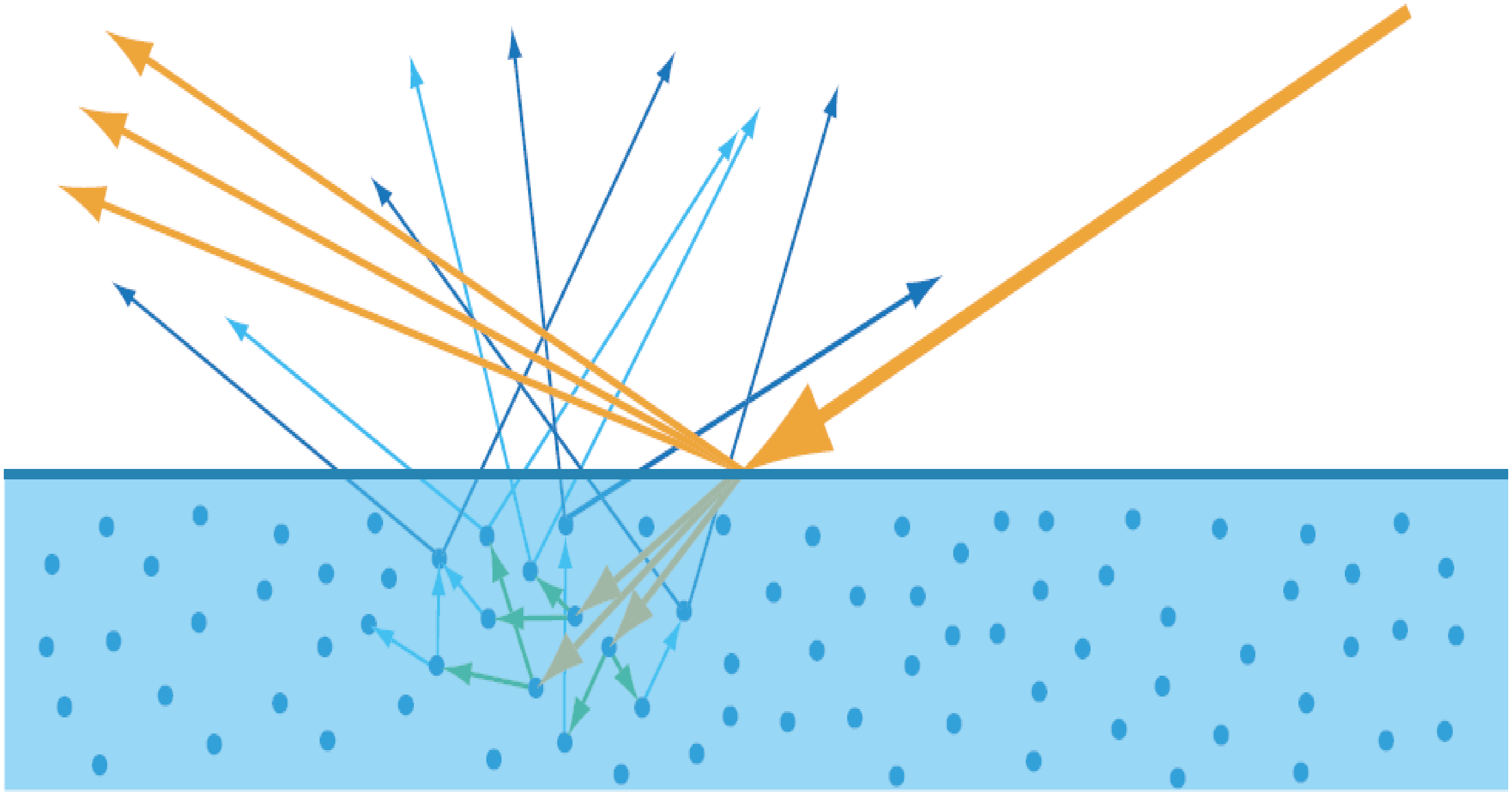
Non-Metals

~~Semiconductors~~

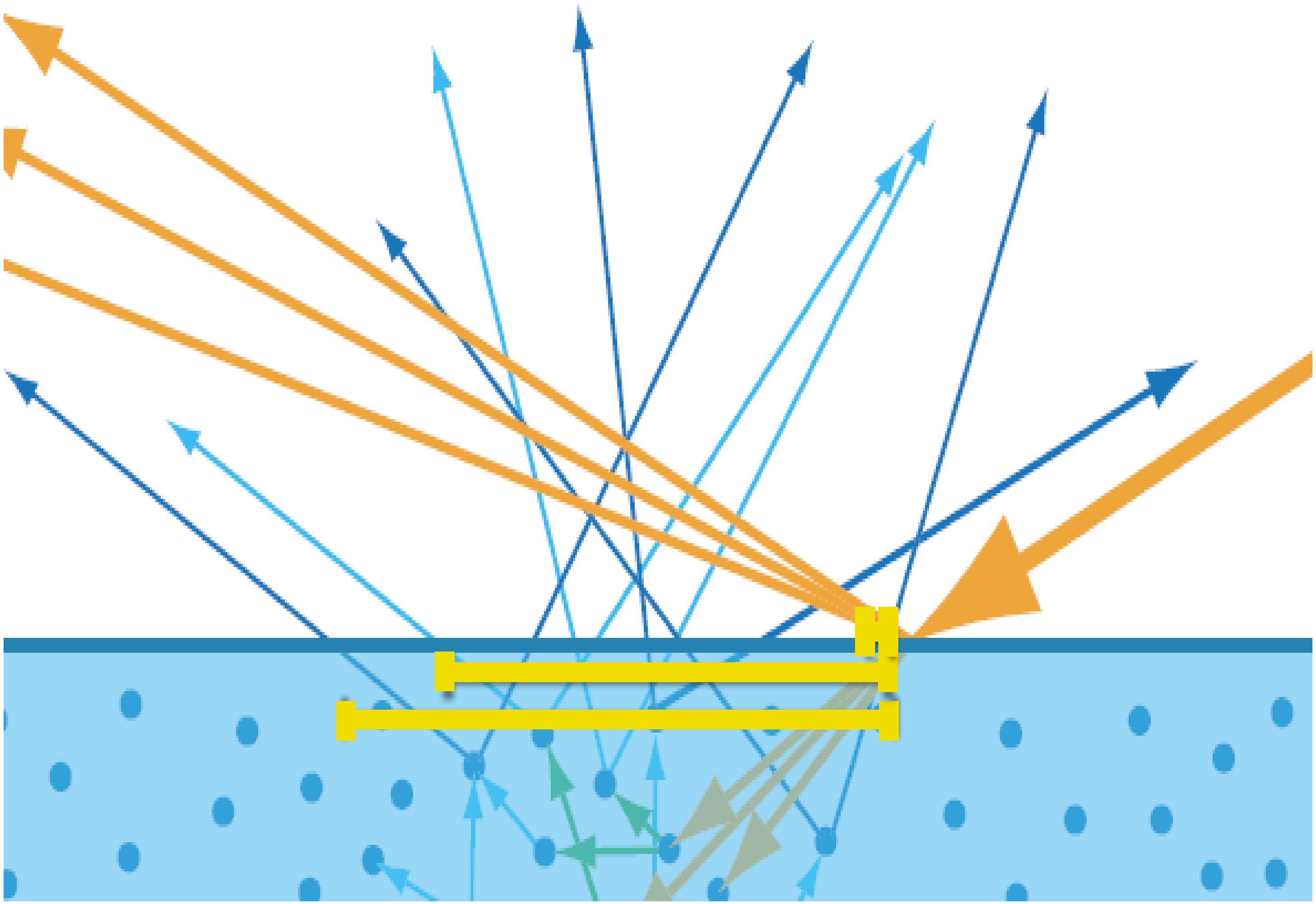
Meta
ls



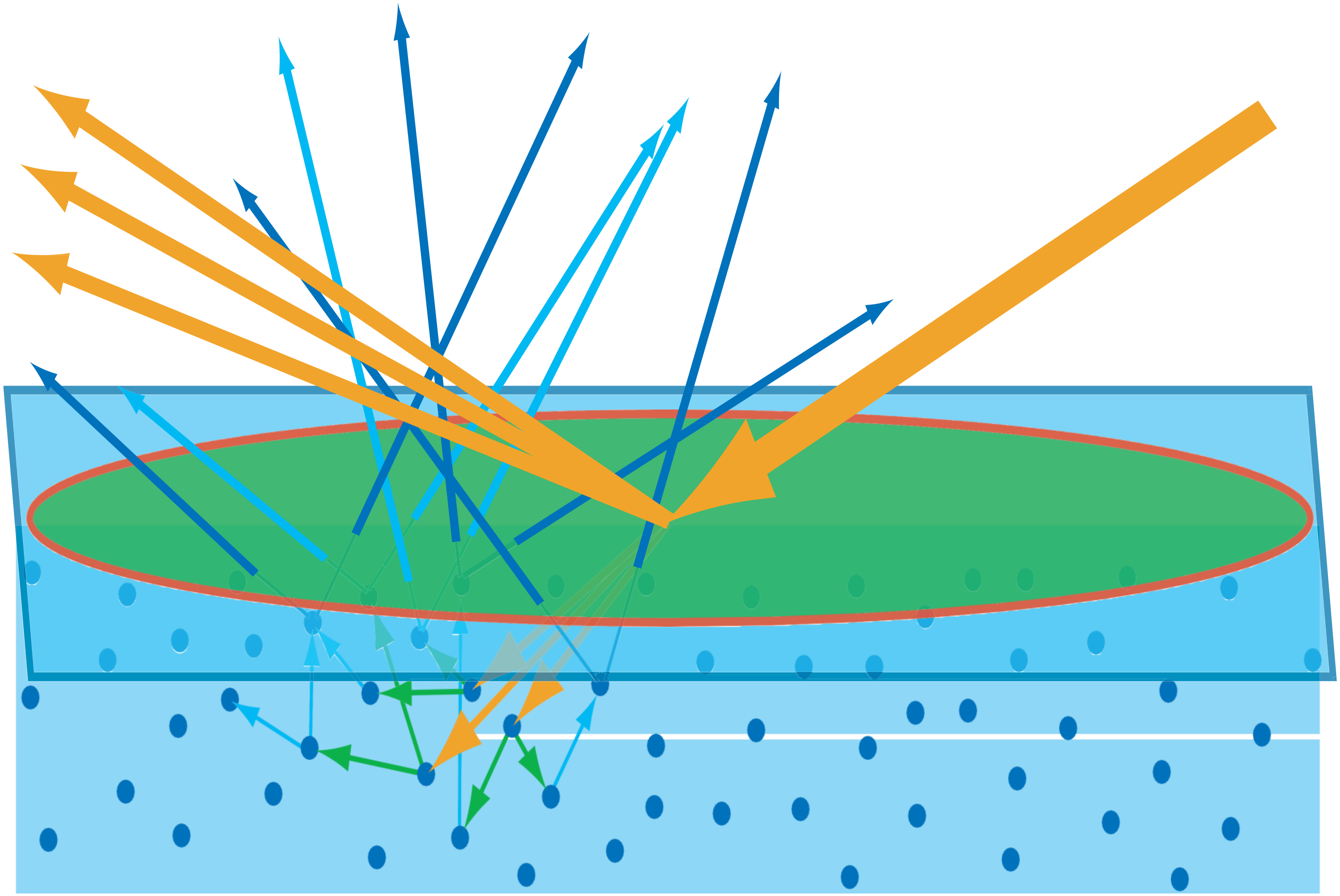
Non-Metals



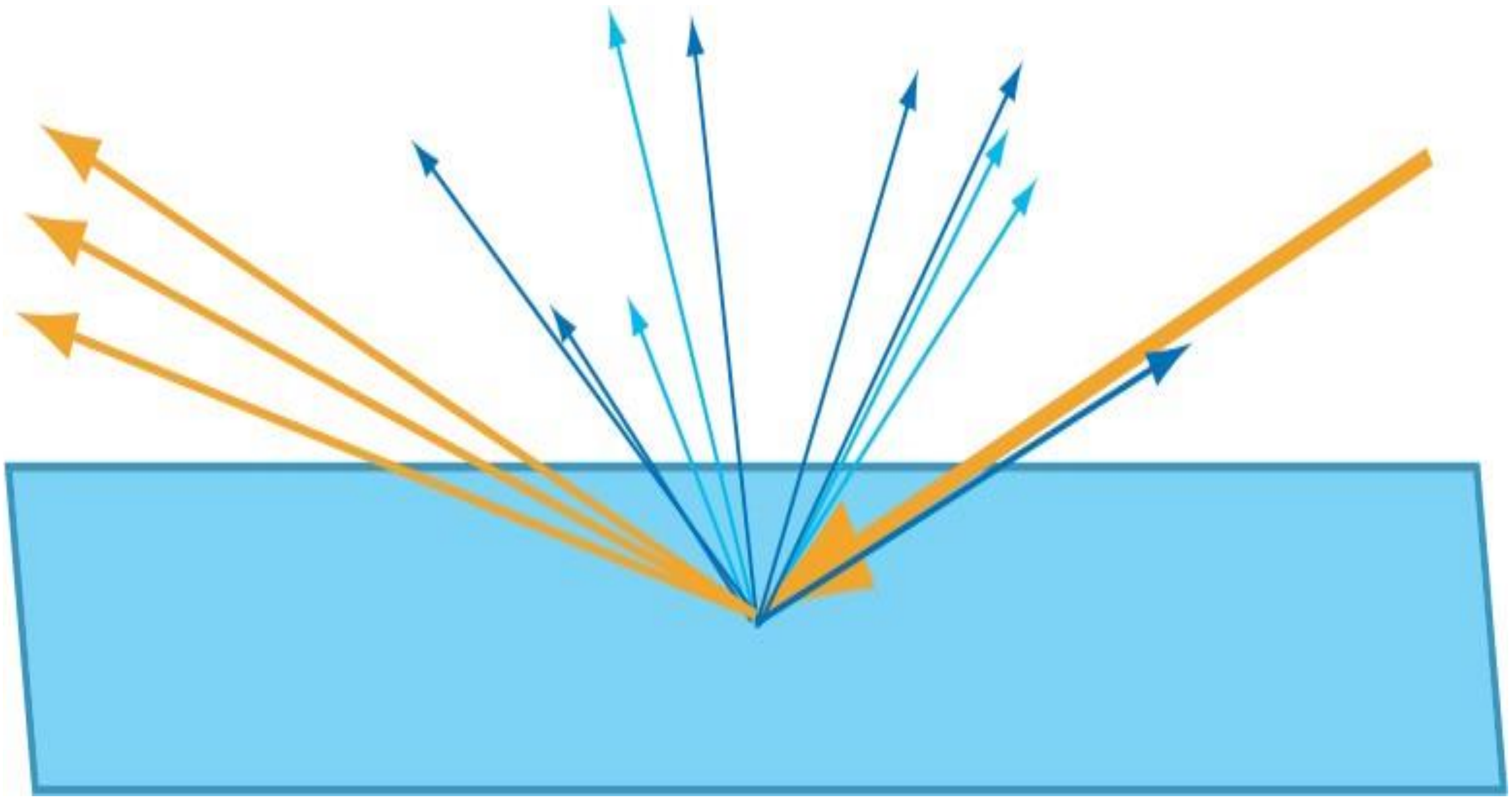
Refracted light



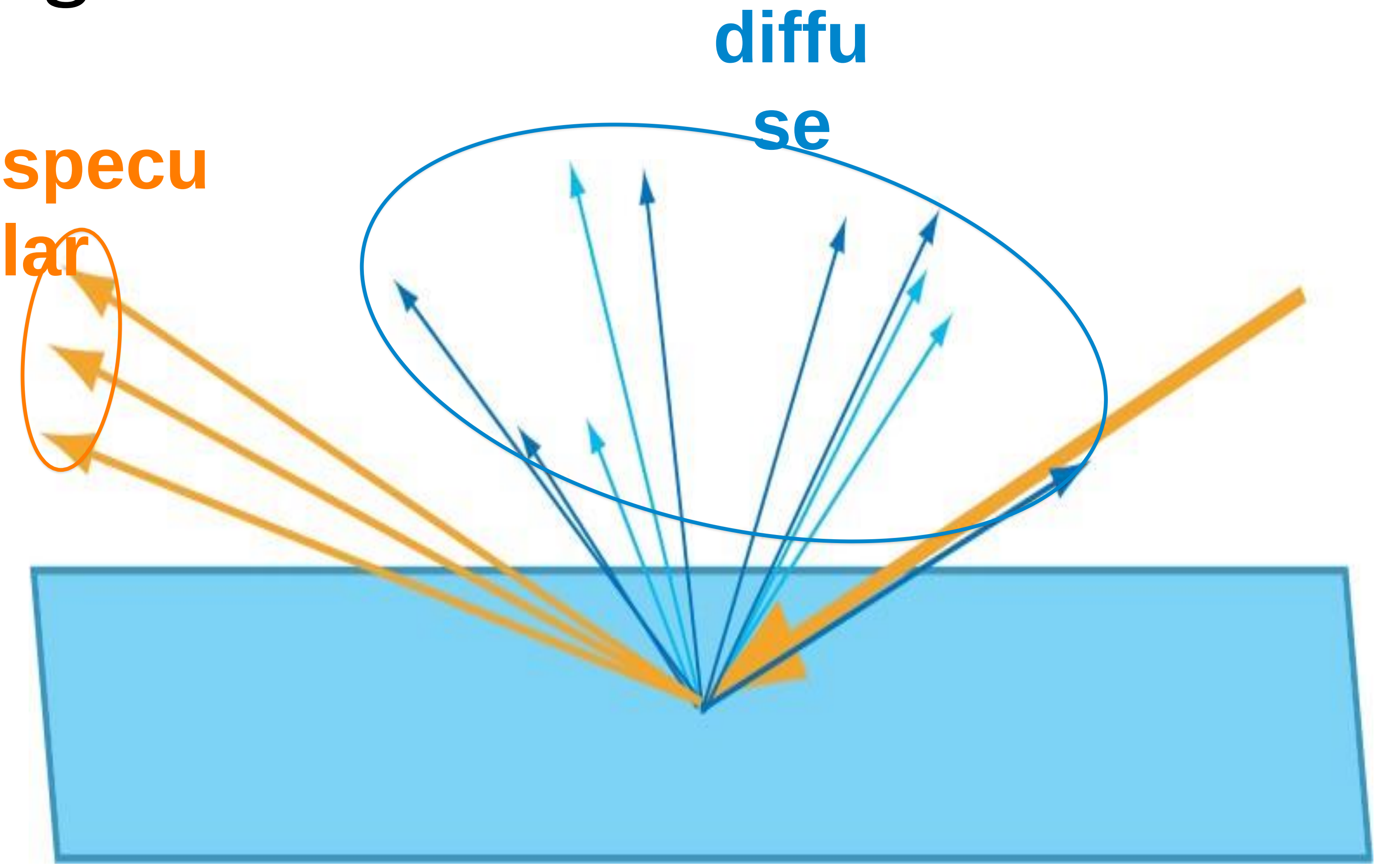
Large sub-Surface scattering area



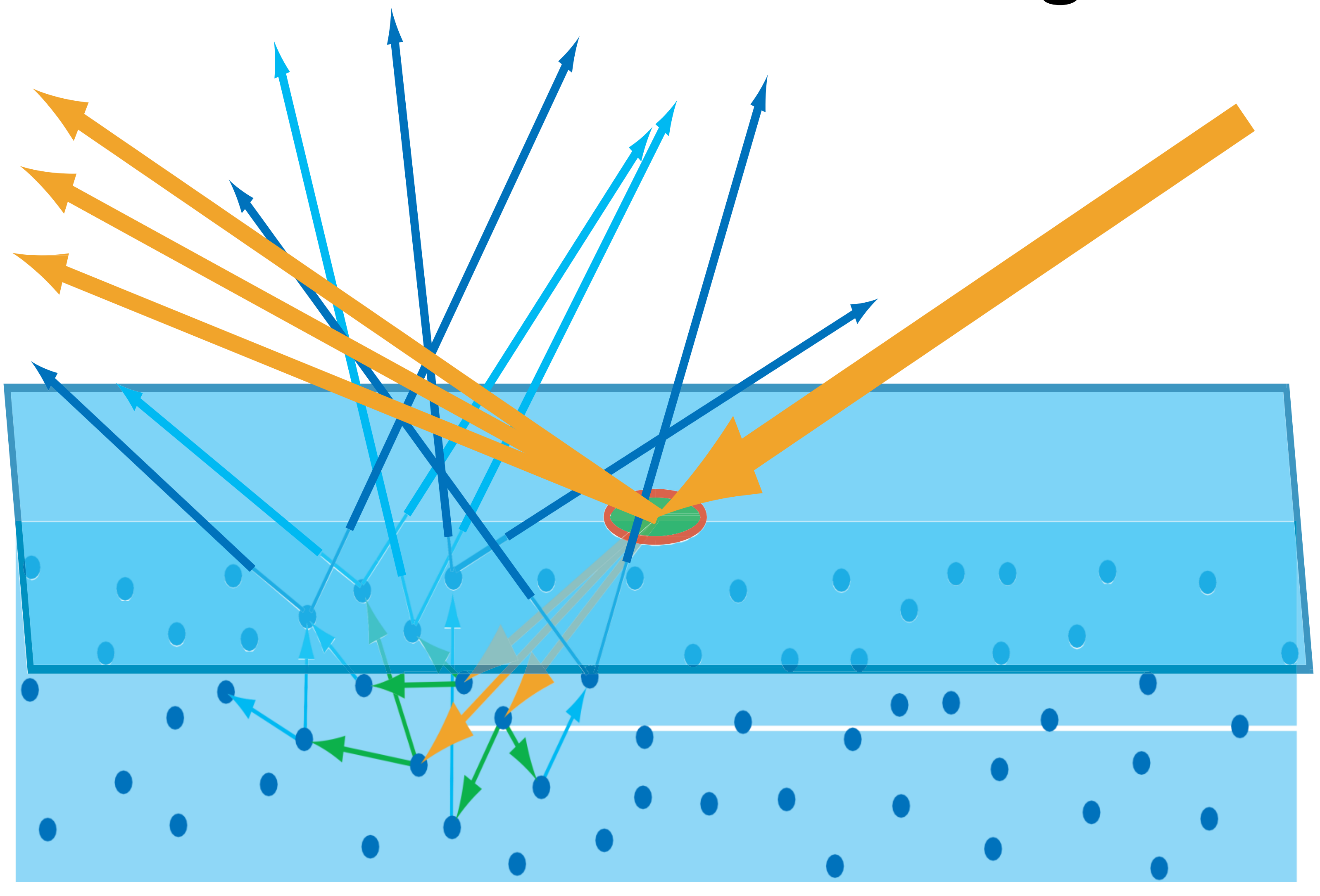
Ignoring sub-surface scattering



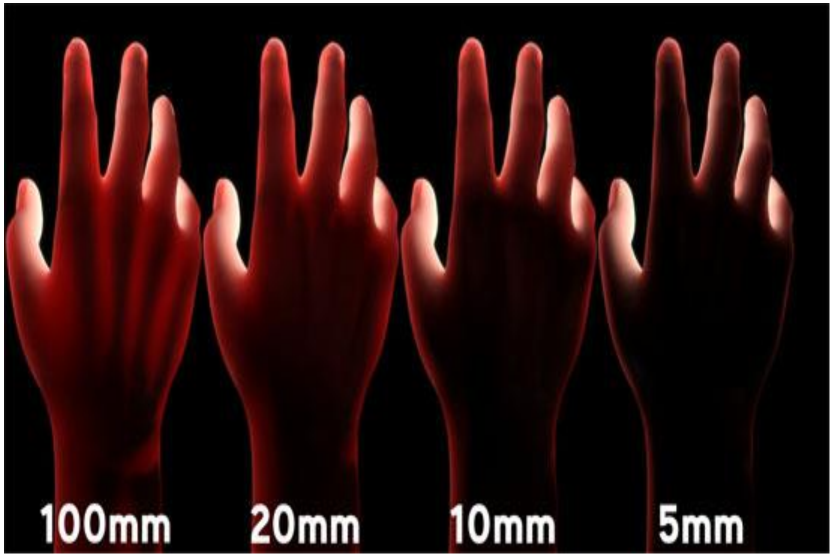
Divide into specular and diffuse light



Small sub-surface scattering area




SSS OFF
SSS ON


100mm
20mm
10mm
5mm

Mathematical model

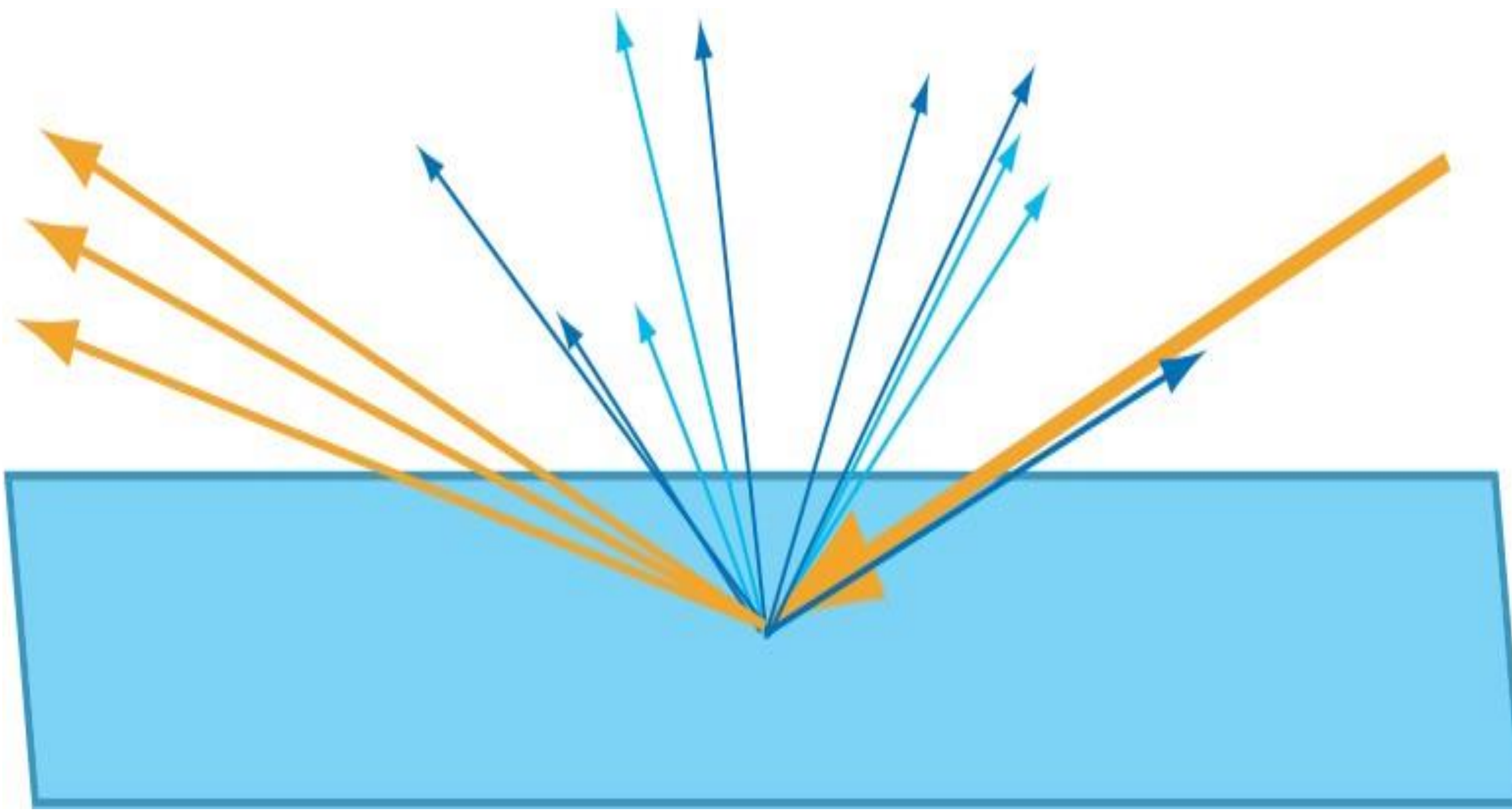
Radiance

Single Ray

Spectral/RG

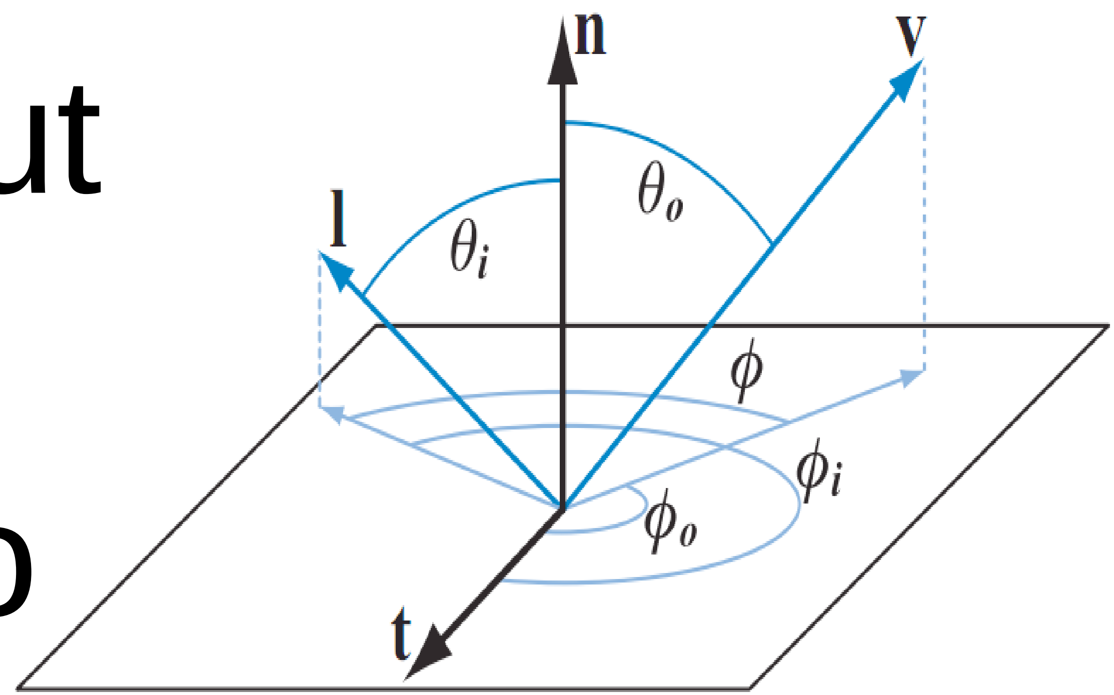
B

Depends only on light and view directions



Bidirectional **R**eflectance **D**istribution **F**unction

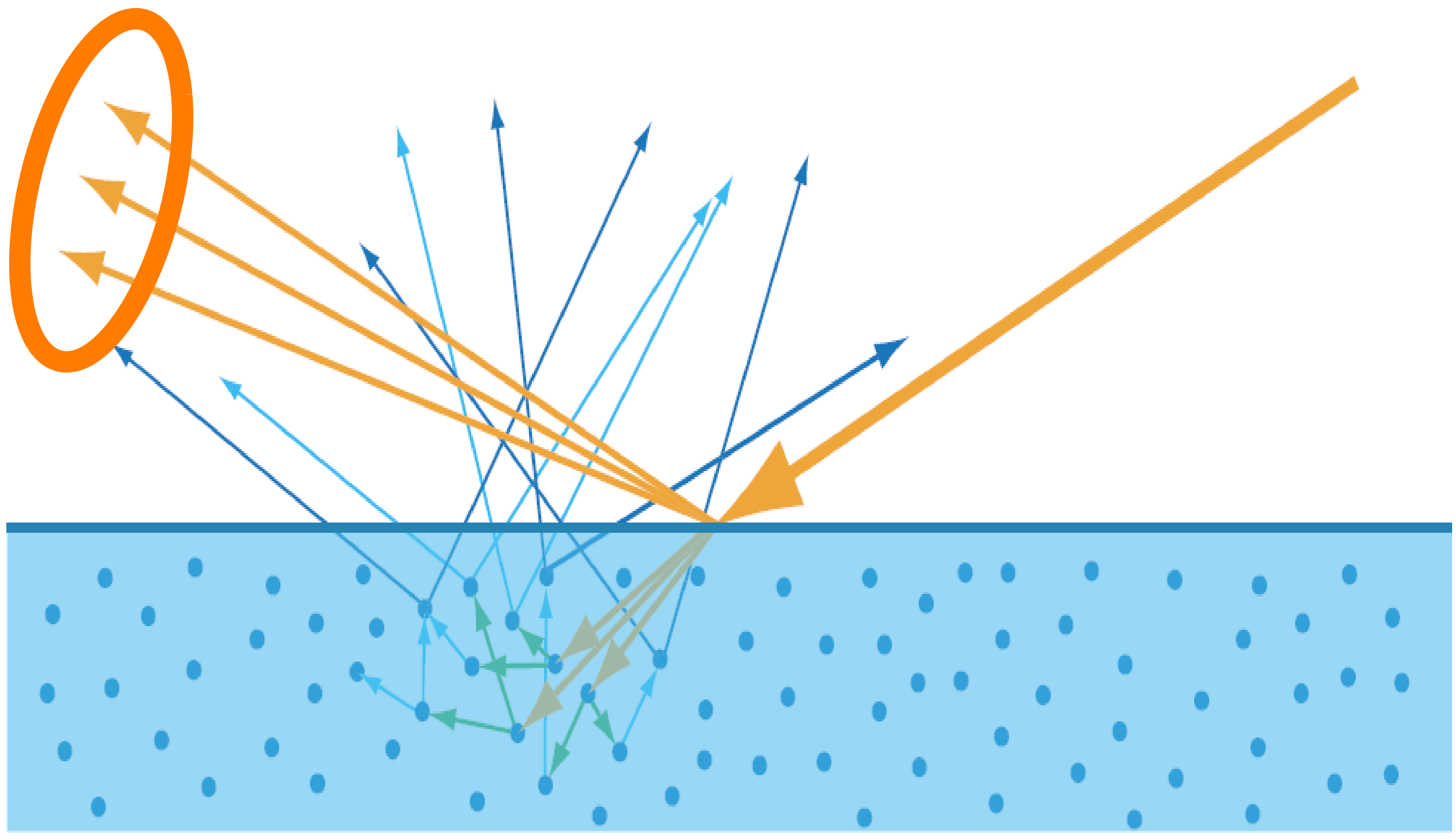
$$f(\mathbf{l}, \mathbf{v})$$



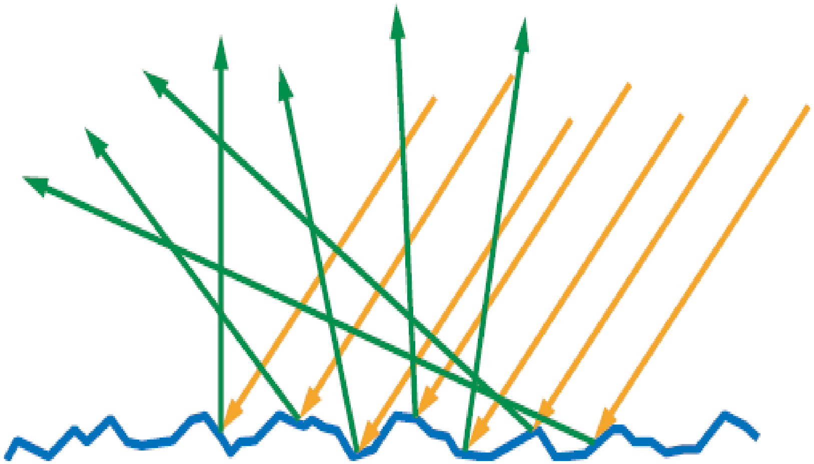
The Reflectance Equation

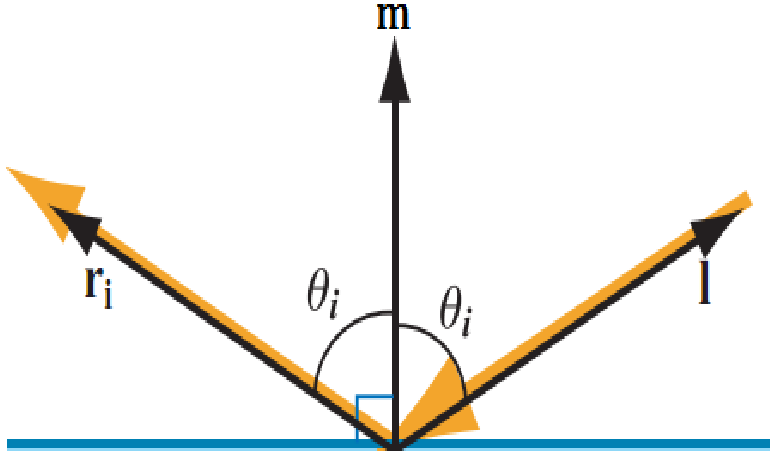
$$L_o(\mathbf{v}) = \int_\Omega f(\mathbf{l}, \mathbf{v}) \otimes L_i(\mathbf{l})(\mathbf{n} \cdot \mathbf{l})\, d\omega_i$$

Surface Reflection
(Specular Term)

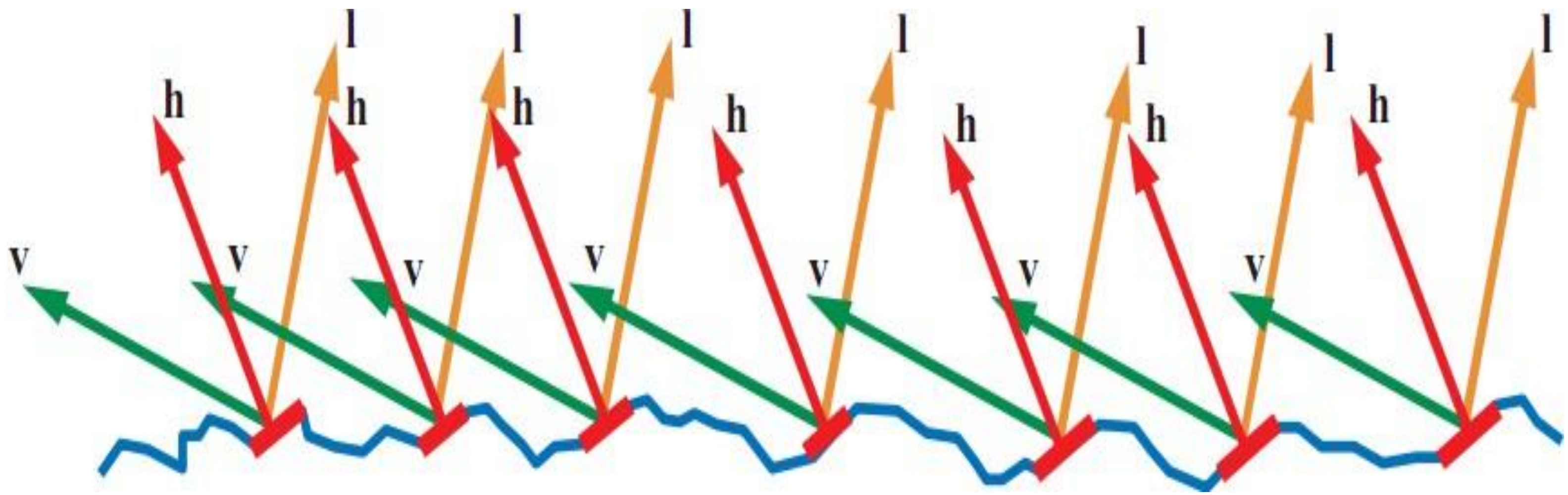


Microfacet Theory

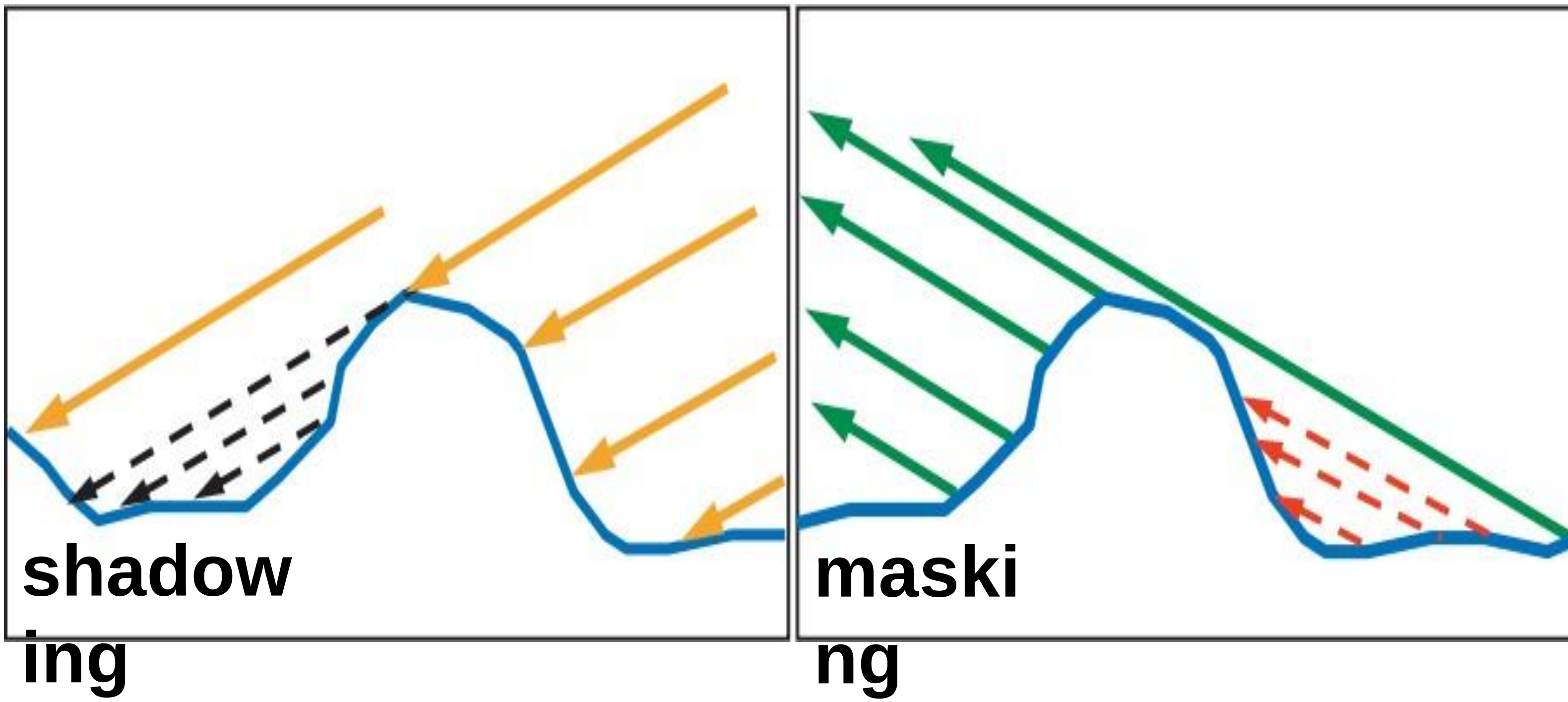




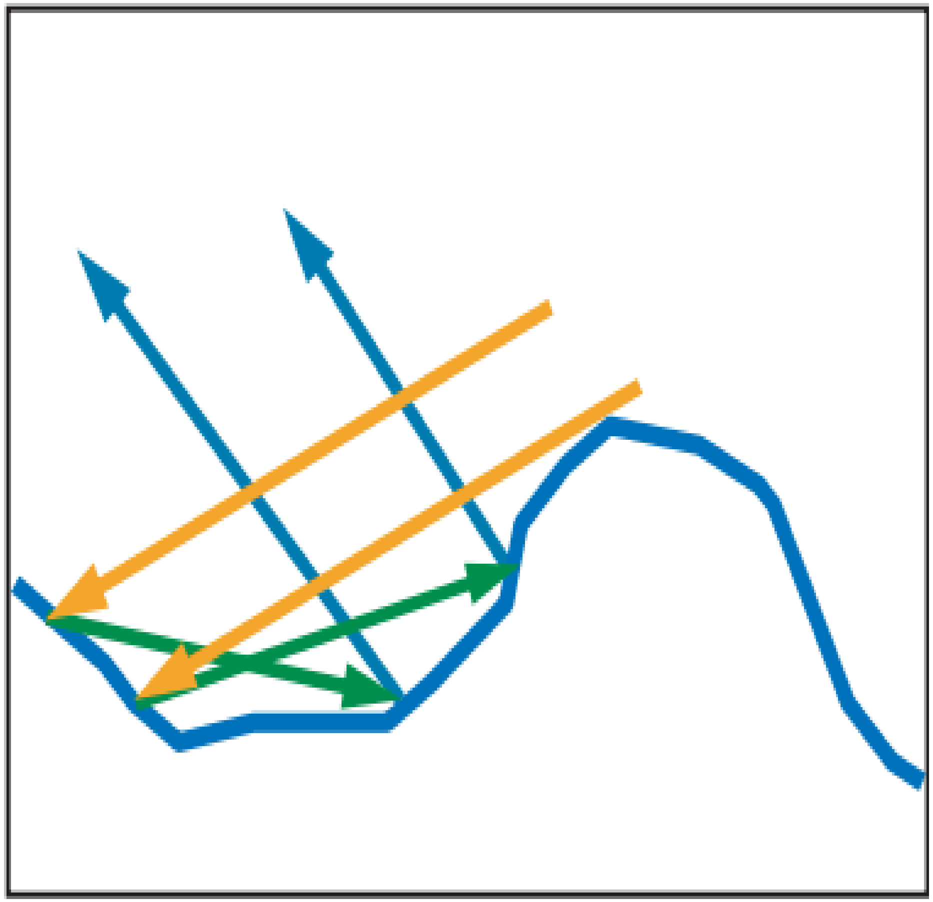
The Half Vector



Shadowing and Masking



Multiple Surface Bounces



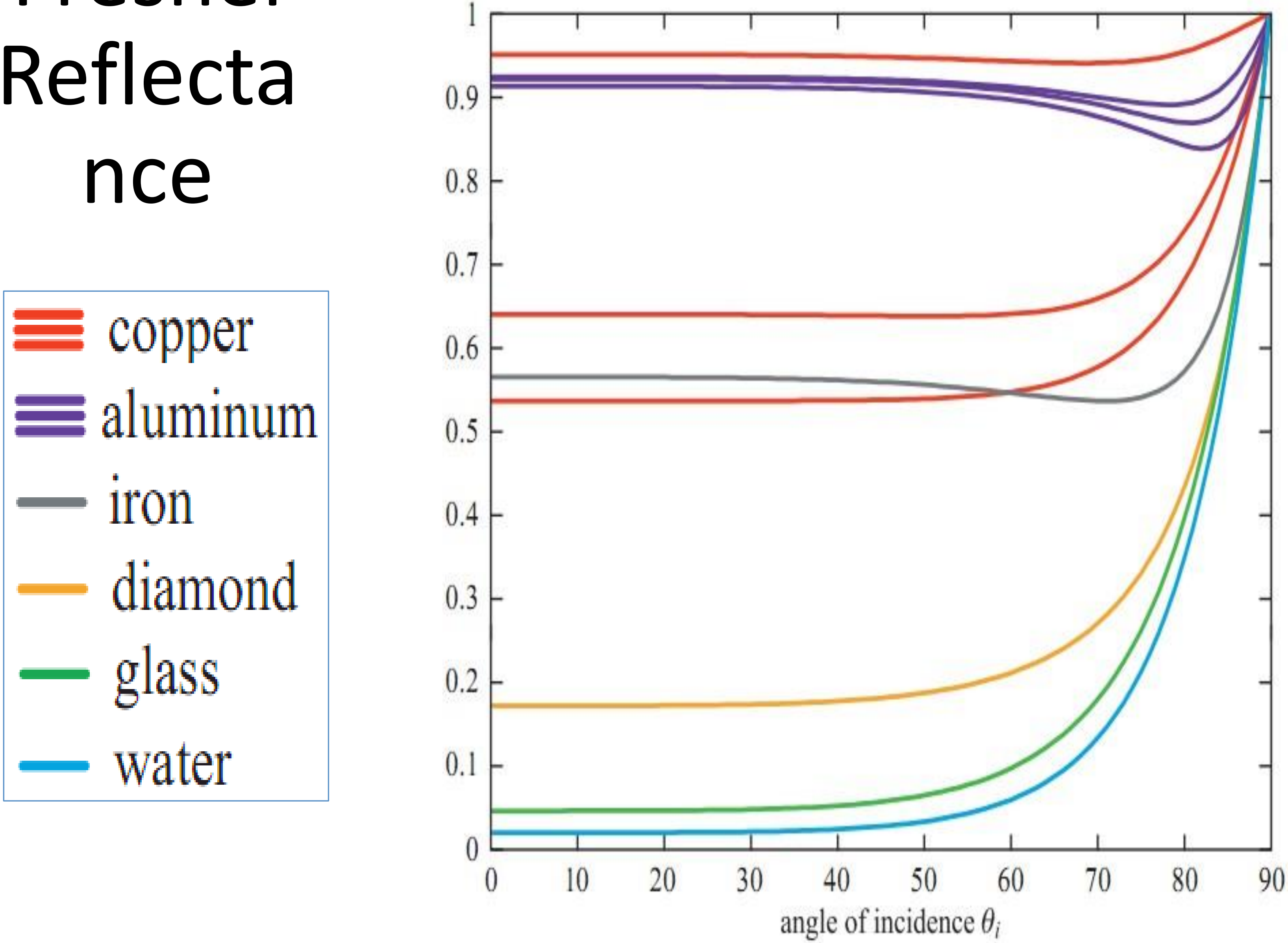
Microfacet Specular BRDF

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

Fresnel Reflectance

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

Fresnel Reflectance

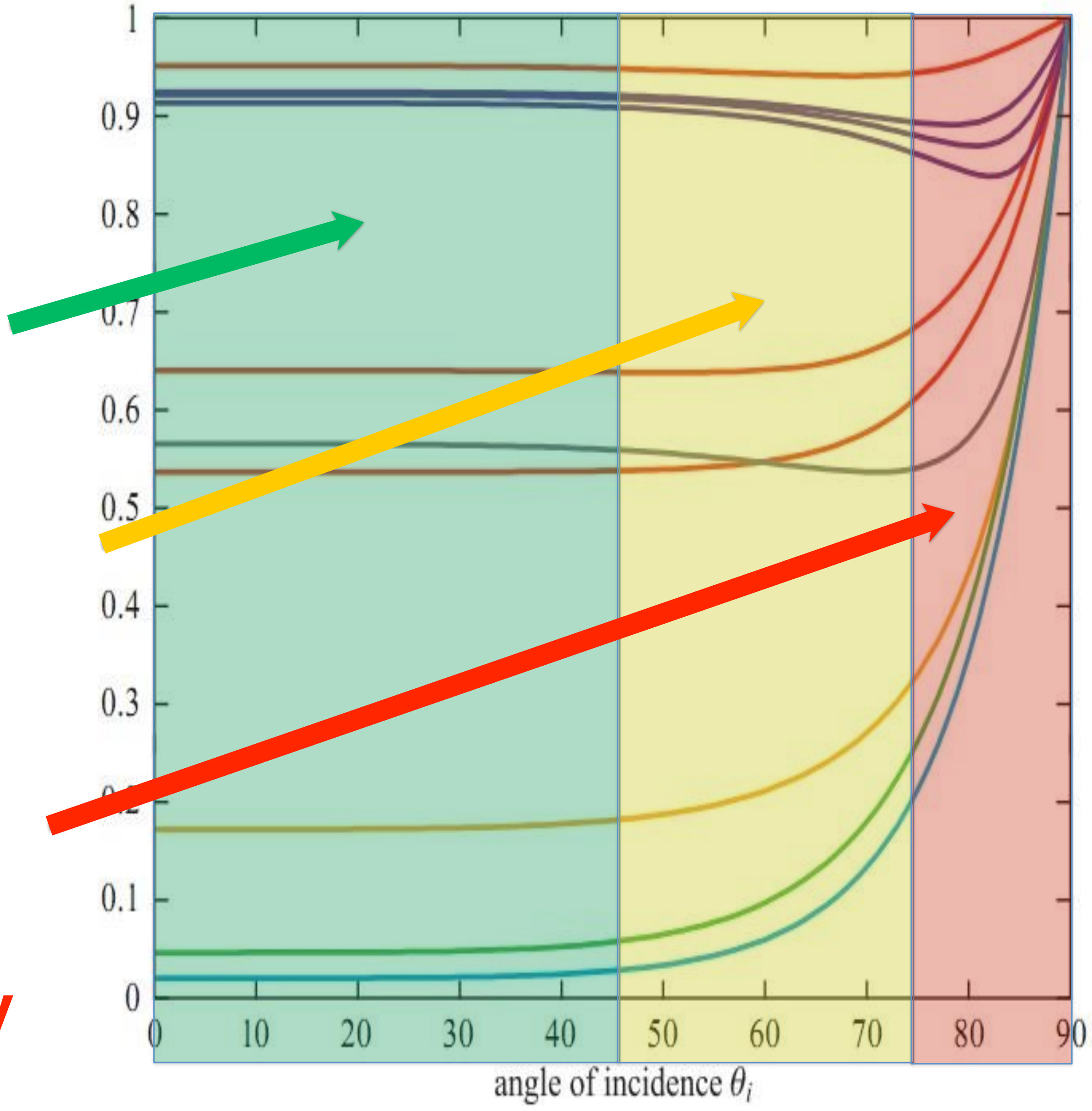


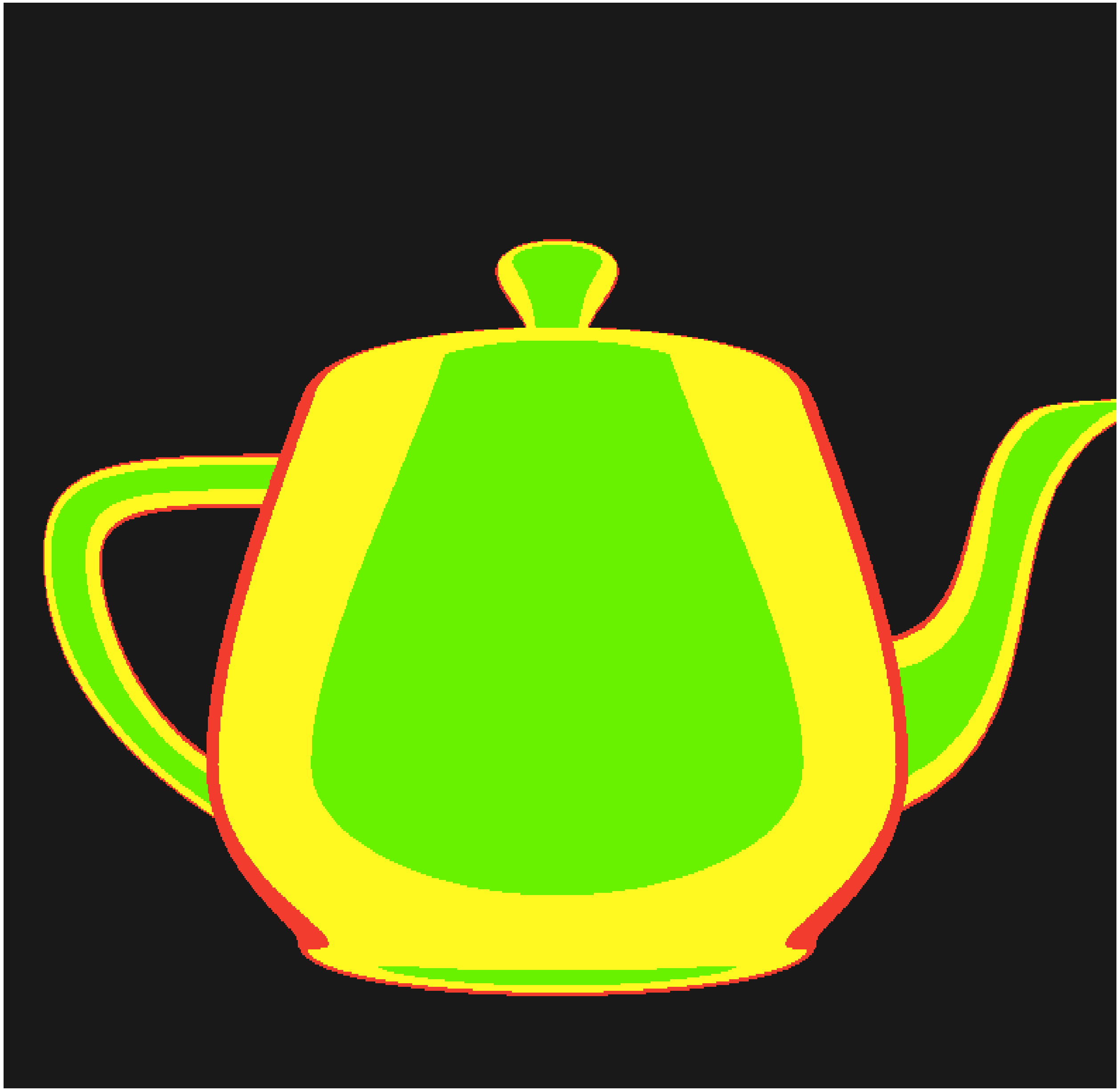
Fresnel Reflectance

barely changes

changes somewhat

goes rapidly to 1

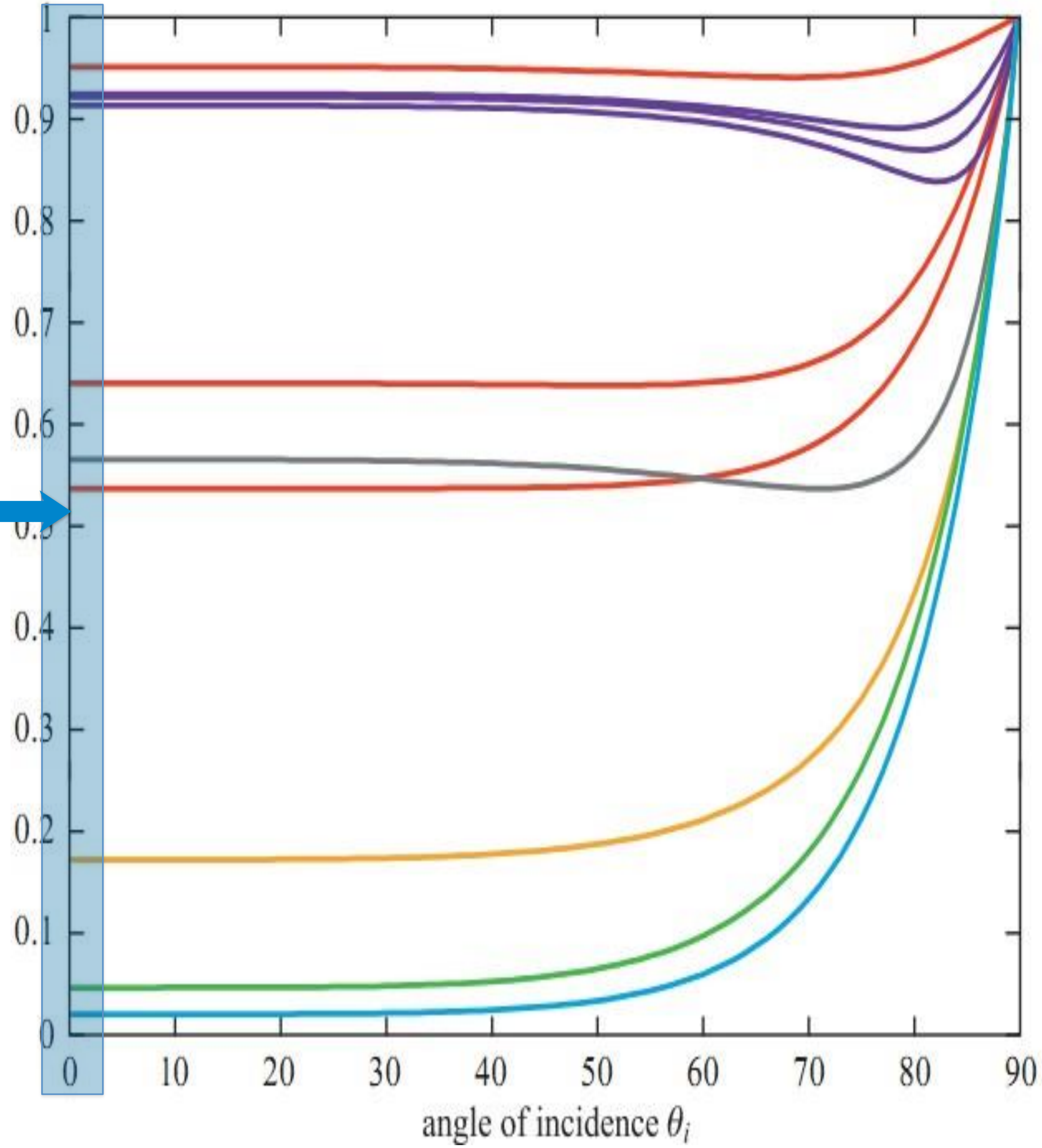




Fresnel Reflectance

$$F_0 = F(0^\circ)$$

Is the surface's characteristic specular color



Metal	F_0 (Linear, Float)	F_0 (sRGB, U8)	Color
Titanium	0.542,0.497,0.449	194,187,179	
Chromium	0.549,0.556,0.554	196,197,196	
Iron	0.562,0.565,0.578	198,198,200	
Nickel	0.660,0.609,0.526	212,205,192	
Platinum	0.673,0.637,0.585	214,209,201	
Copper	0.955,0.638,0.538	250,209,194	
[illegible]	[illegible]	[illegible]	

Metal	F_0 (Linear, Float)	F_0 (sRGB, U8)	Color
Titanium	0.542,0.497,0.449	194,187,179	
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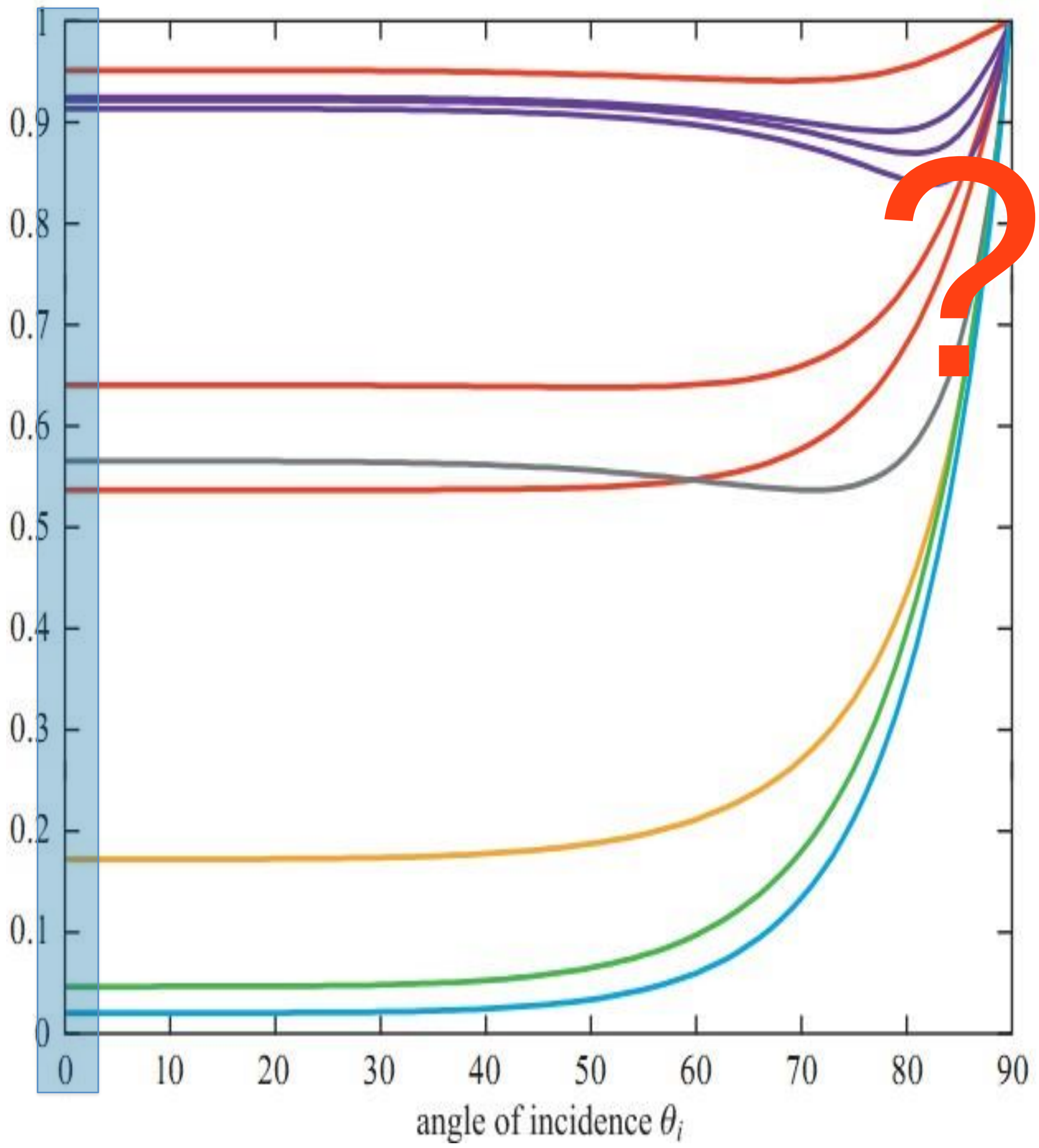
Nickel	0.660,0.609,0.526	212,205,192	
Platinum	0.673,0.637,0.585	214,209,201	
Copper	0.955,0.638,0.538	250,209,194	
Palladi	0.733,0.697,0.	222,217,211	

F_0 Values for Dielectrics

Dielectric	F_0 (Linear, Float)	F_0 (sRGB, U8)	Color
Water	0.020	39	
Plastic, Glass	0.040 – 0.045	56 – 60	
Crystalware, Gems	0.050 – 0.080	63 – 80	
Diamond-like	0.100 – 0.200	90 – 124	

Fresnel Reflectance



The Schlick Approximation to Fresnel

- Fairly accurate, cheap, parameterized by F_0

$$F_{\text{Schlick}}(F_0, \mathbf{l}, \mathbf{n}) = F_0 + (1 - F_0)(1 - (\mathbf{l} \cdot \mathbf{n}))^5$$

- For microfacet BRDFs $(\mathbf{n} = \mathbf{h})$:

$$F_{\text{Schlick}}(F_0, \mathbf{l}, \mathbf{h}) = F_0 + (1 - F_0)(1 - (\mathbf{l} \cdot \mathbf{h}))^5$$

Normal Distribution Function

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

Different Normal Distribution Functions

$$D_p(\mathbf{m}) = \frac{\alpha_p + 2}{2\pi}(\mathbf{n} \cdot \mathbf{m})^{\alpha_p}$$

$$D_{uabc}(\mathbf{m}) = \frac{1}{\left(1 + \alpha_{abc1}\left(1 - (\mathbf{n} \cdot \mathbf{m})\right)\right)^{\alpha_{abc2}}}$$

$$D_{tr}(\mathbf{m}) = \frac{\alpha_{tr}^2}{\pi\left((\mathbf{n} \cdot \mathbf{m})^2\left(\alpha_{tr}^2 - 1\right) + 1\right)^2}$$

$$D_b(\mathbf{m}) = \frac{1}{\pi\alpha_b^2(\mathbf{n} \cdot \mathbf{m})^4} e^{-\left(\frac{1 - (\mathbf{n} \cdot \mathbf{m})^2}{\alpha_b^2(\mathbf{n} \cdot \mathbf{m})^2}\right)}$$

Let $D_{BlinnPhong}(h) = K(\underline{n.h})^{\alpha}$

$$\int_{\Theta} D_{BlinnPhong}(h)(n.h)\,dh = 1$$

$$\int_{\Theta} K(\underline{n.h})^{\alpha}(n.h)\,dh = 1$$

$$K\int_{0}^{2\pi}\int_{0}^{\pi}(\underline{n.h})^{\alpha}(n.h)\,sin\theta\ d\theta d\varphi = 1$$

$$K\int_{0}^{2\pi}\left(\int_{0}^{\pi/2}(\underline{n.h})^{\alpha}(n.h)\,sin\theta\ d\theta + \int_{\pi/2}^{\pi}(\underline{n.h})^{\alpha}(n.h)\,sin\theta\ d\theta\right)\,d\varphi = 1$$

$$K\int_{0}^{2\pi}\left(\int_{0}^{\pi/2}(n.h)^{\alpha+1}\,sin\theta\ d\theta + \int_{\pi/2}^{\pi}0\,(n.h)\,sin\theta\ d\theta\right)\,d\varphi = 1$$

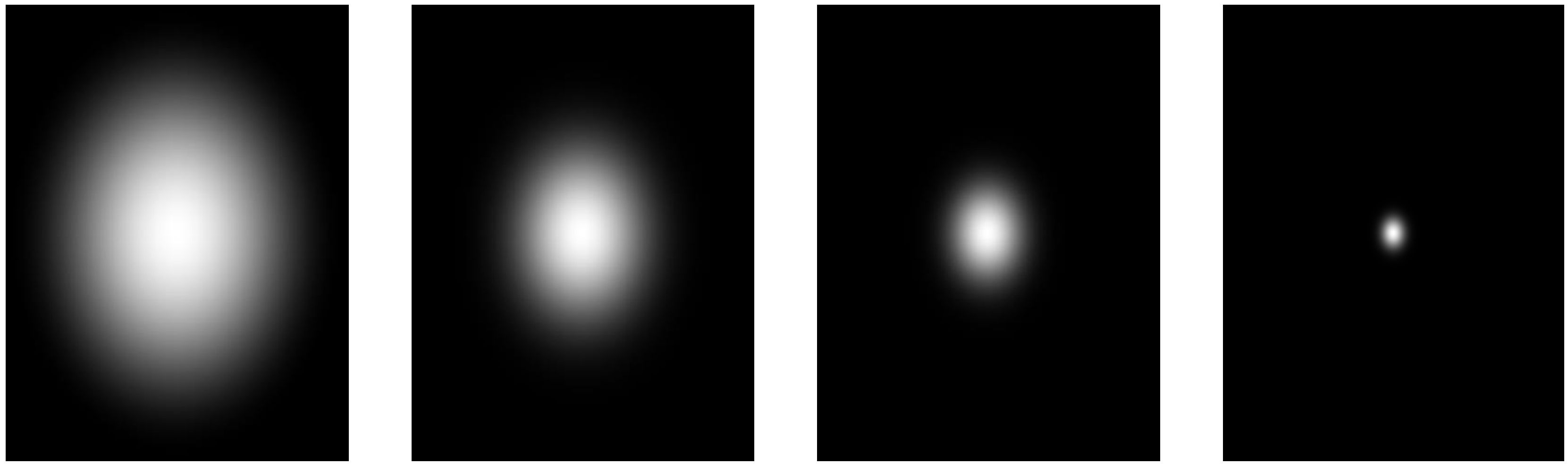
$$K\,2\pi\int_{0}^{\pi/2}(cos\theta)^{\alpha+1}\,d(-cos\theta) = 1$$

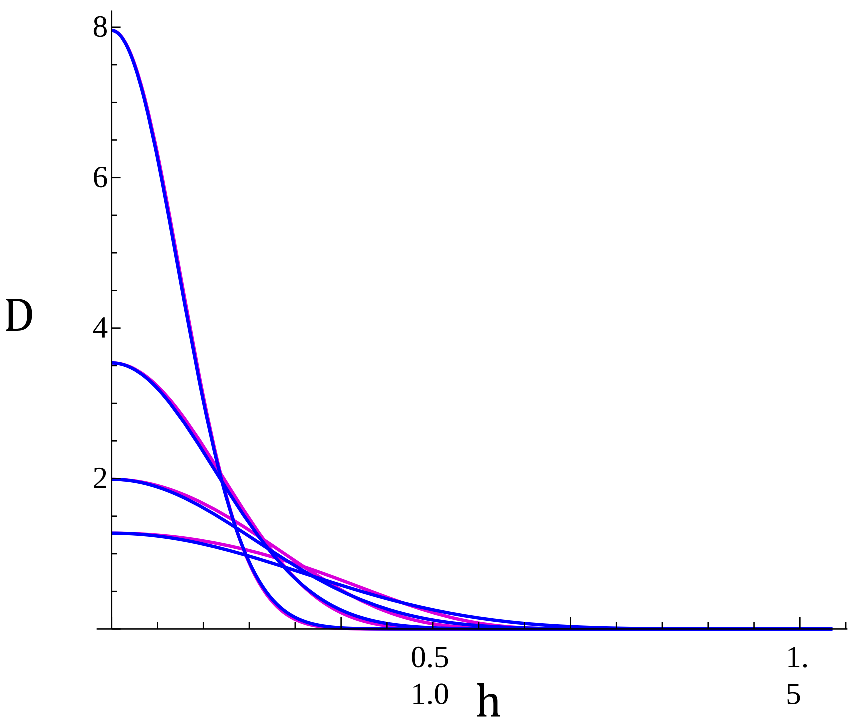
$$-K\,2\pi\left[\frac{\cos^{\alpha+2}\theta}{\alpha+2}\right]_{0}^{\pi/2} = 1$$

$$-K\,2\pi\frac{-1}{\alpha+2} = 1$$

$$K = \frac{\alpha+2}{2\pi}$$

$$\therefore\ D_{BlinnPhong}(h) = \frac{\alpha+2}{2\pi}(\underline{n.h})^{\alpha}$$




8
6
D
4
2
0.5
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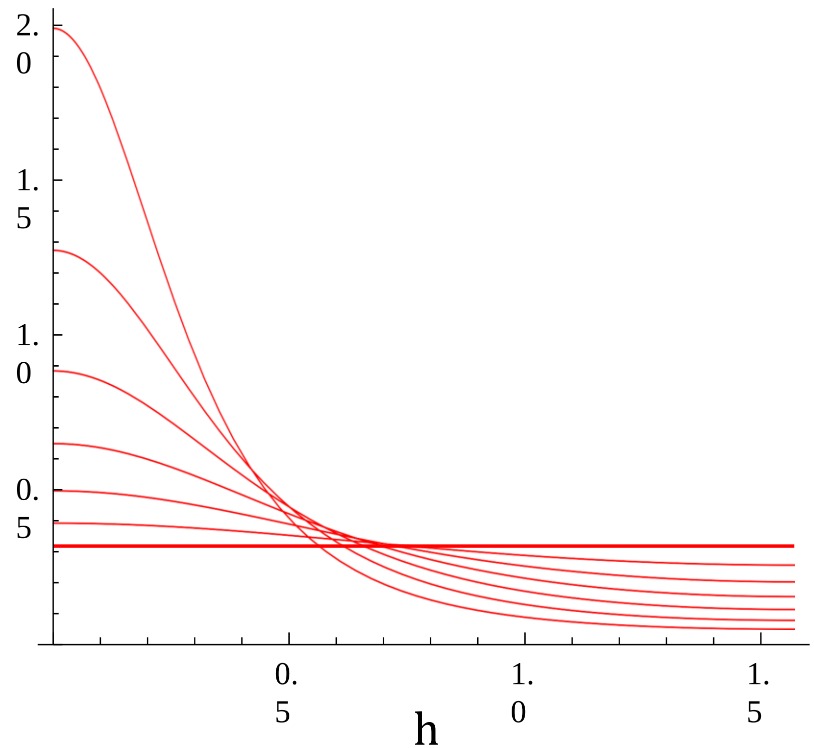
1.
5


2.
0
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0
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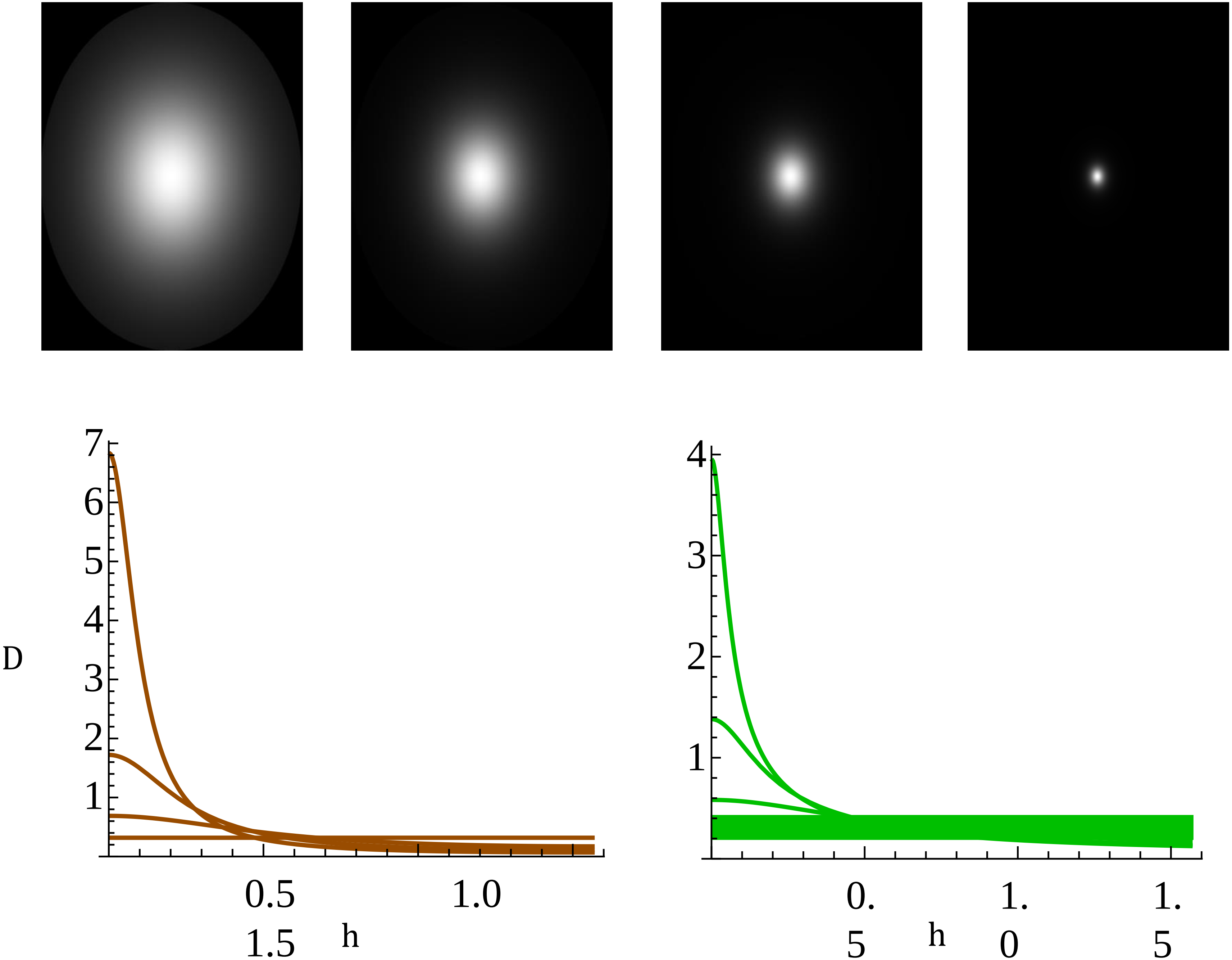
5
h

.



7
6
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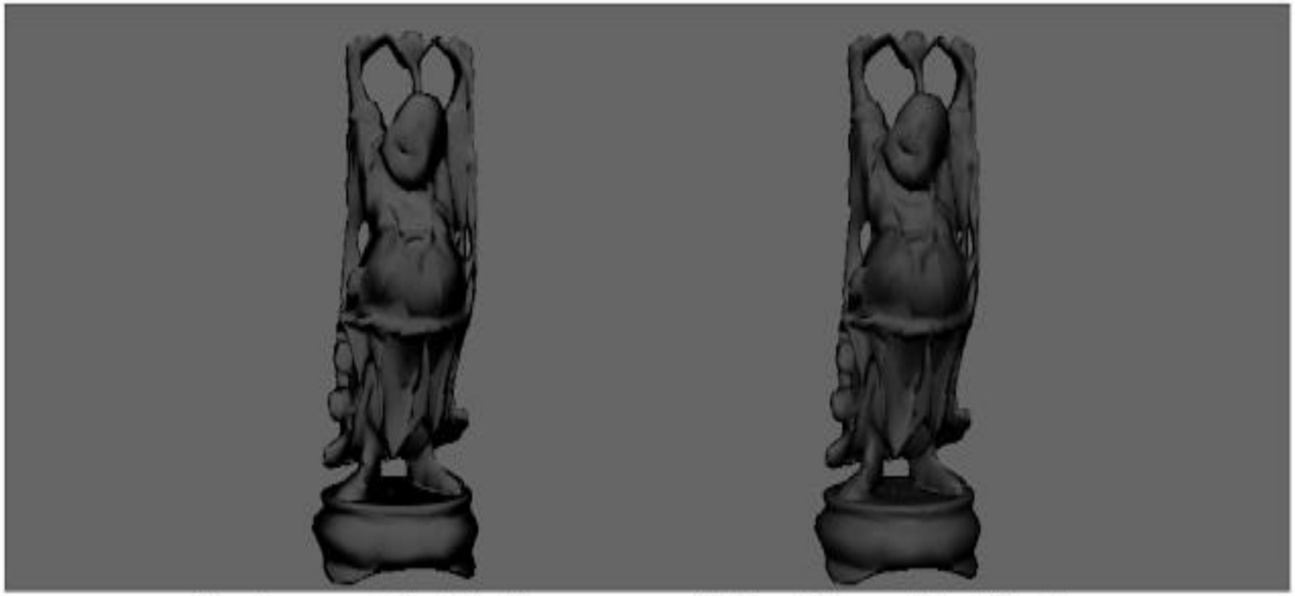


Beckmann Distribution Blinn-Phong Distribution

Both rendered with Schlick Geometry term, n=10.67, m=0.748, showing only the specular term
The 2 distributions start to diverge only with large m and n.

Geometry Function

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

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

$$\frac{G_{\mathrm{ct}}(\mathbf{l},\mathbf{v},\mathbf{h})}{(\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})} \approx \frac{1}{(\mathbf{l}\cdot\mathbf{h})^2} \qquad G_{\mathrm{implicit}}(\mathbf{l},\mathbf{v},\mathbf{m}) = (\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})$$

$$G_{\mathrm{s}}(\mathbf{l},\mathbf{v},\mathbf{h}) = G_{\mathrm{s1}}(\mathbf{l},\mathbf{h})G_{\mathrm{s1}}(\mathbf{v},\mathbf{h})$$

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

$$\frac{G_{\mathrm{ct}}(\mathbf{l},\mathbf{v},\mathbf{h})}{(\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})} \approx \frac{1}{(\mathbf{l}\cdot\mathbf{h})^2} \qquad G_{\mathrm{implicit}}(\mathbf{l},\mathbf{v},\mathbf{m}) = (\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})$$

$$G_{\mathrm{s}}(\mathbf{l},\mathbf{v},\mathbf{h}) = G_{\mathrm{s1}}(\mathbf{l},\mathbf{h})G_{\mathrm{s1}}(\mathbf{v},\mathbf{h})$$

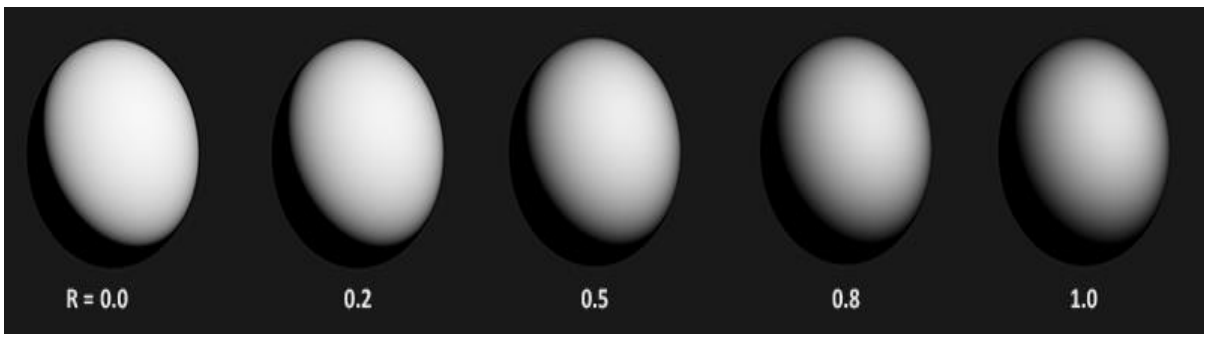
Heitz 2014, Journal of Computer Graphics Techniques Vol. 3, No. 2, 2014

G_{s1}

$$G_{1-Schlick}(v,h)=\frac{(n.v)}{(n.v)(1-k)+k}$$

$$\text{, where } k=m\sqrt{\frac{2}{\pi}}\text{, } m \text{ is the rms roughness}$$

Schlick method results



Varying roughness parameter values R

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

Concentration of active microfacets

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

Visibility of microfacets

Concentration of active microfacets

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

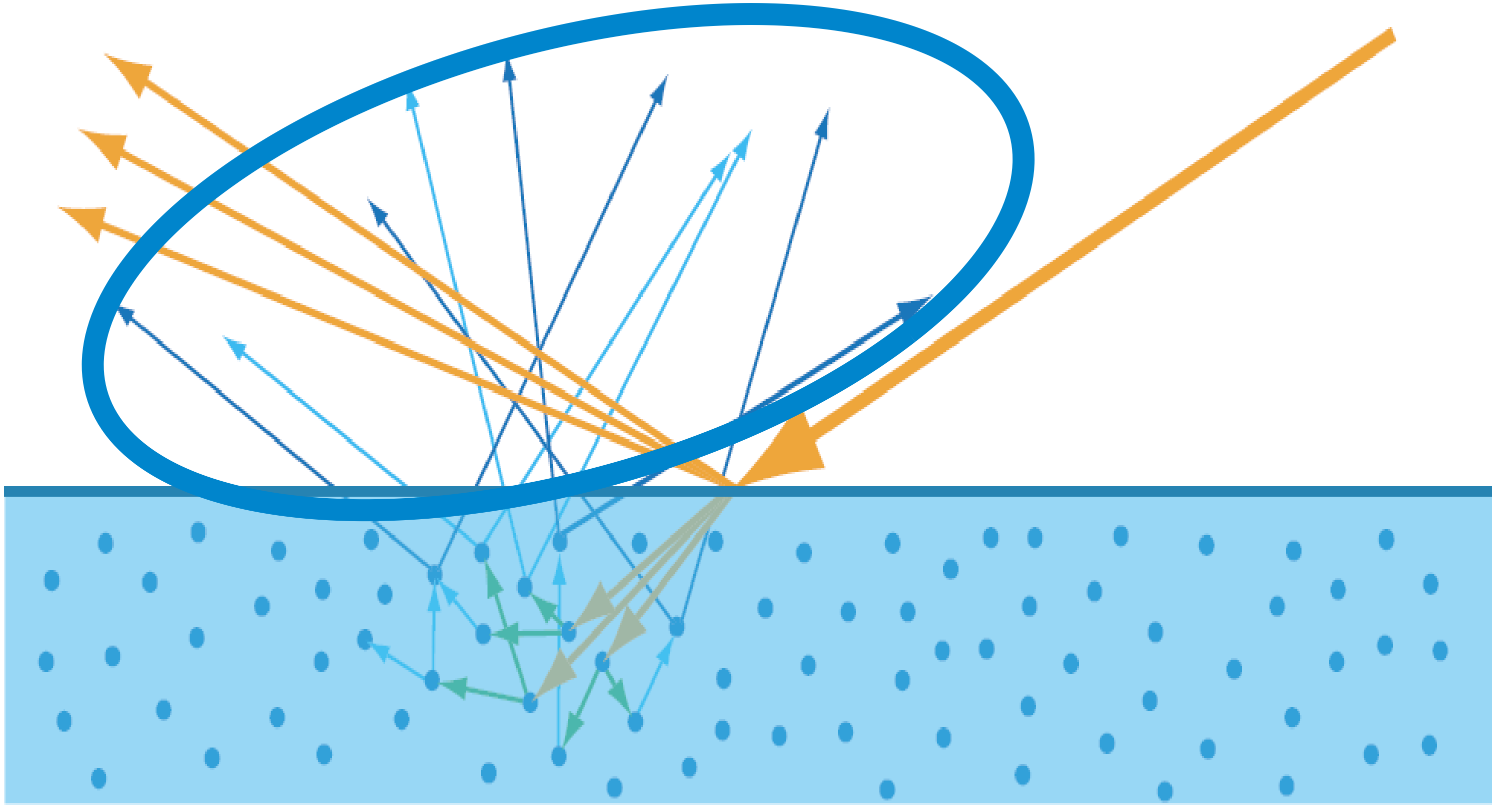
Fresnel reflectance

Visibility of microfacets

Concentration of active microfacets

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

Subsurface Reflection (Diffuse Term)



Lambe
rt

- Constant value ($\mathbf{n}\cdot\mathbf{l}$ is part of reflectance equation):

$$f_{Lambert}(\boldsymbol{l},\boldsymbol{v}) = \frac{\mathbf{c}_{diff}}{\pi}$$

- $\mathbf{c}_{diff}$: fraction of light reflected, or diffuse color, also called **albedo**

Example microfacet BRDF

- http://simonstechblog.blogspot.com/2011/12/microfacet-brdf.html

Exercise

- Render 25 different spheres with varying metallic and roughness parameter values using a BRDF of your choice.
- How is F0 calculated?
- How would you add a texture? What information would be necessary?