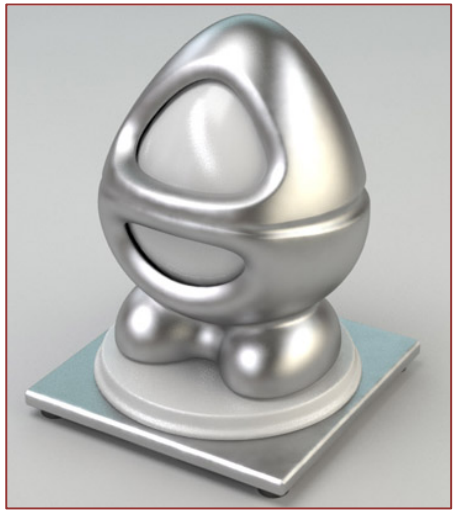
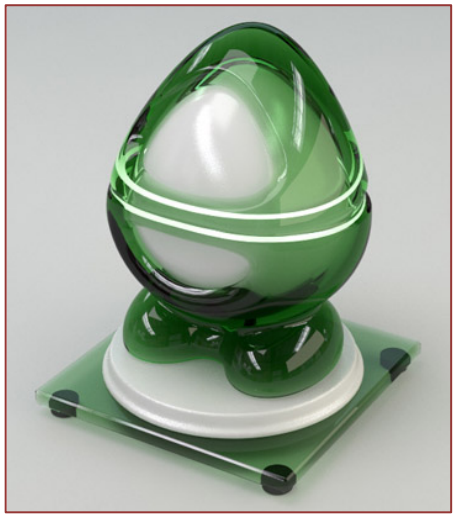
Materials and Appearance: An Introduction

Georgios Papaioannou - 2014

Visual Appearance

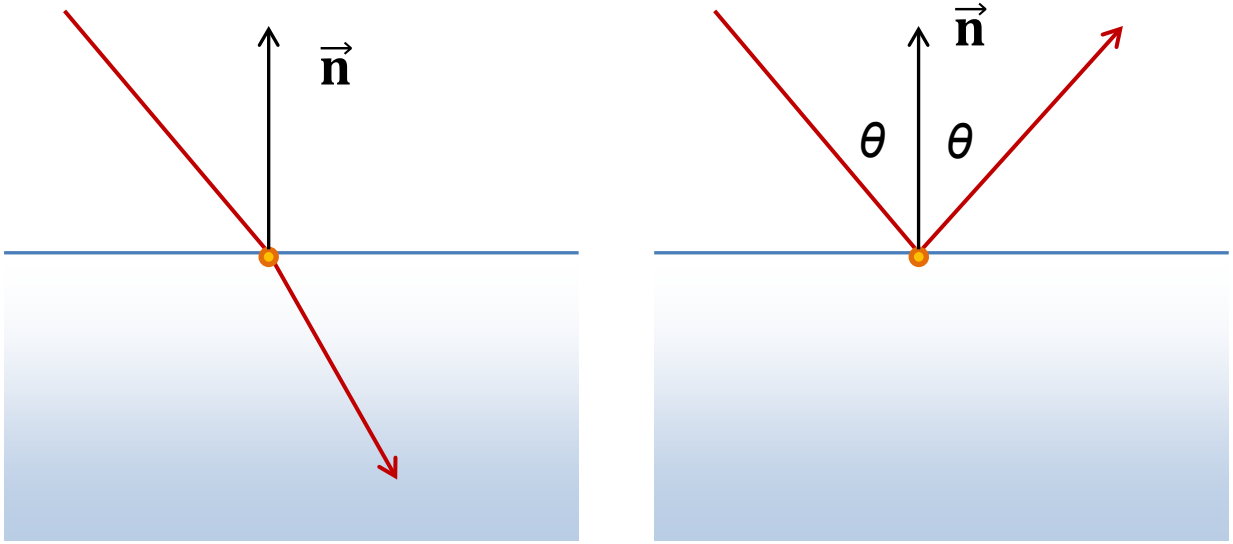




- What makes an object appear in a certain manner?
- Its ability to:
  - Reflect light on its surface (radiation in general)
  - Absorb light
  - Allow light to be transmitted inside it
- The phaenomena that deflect the light inside its body (in/out-scattering)
- The spatio-temporal variation of the above (texture)

Basic Light Transport (1)

- When light encounters the interface of a surface, 2 things occur:
  - Light is reflected off the surface
  - Light is transmitted inside the volume of the object



Transmission Reflection

Basic Light Transport (2)

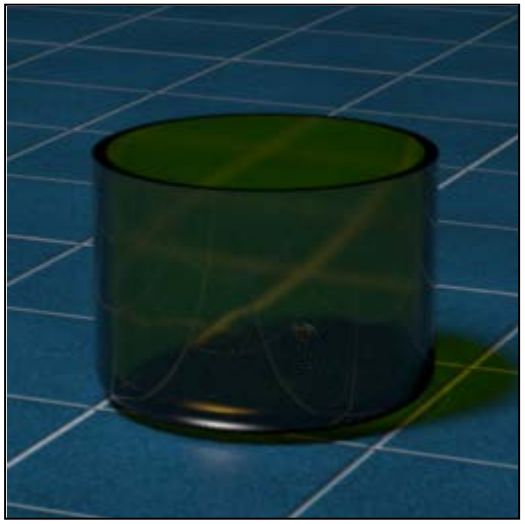
- Light is an electromagnetic wave and the ratio of reflected vs transmitted energy is determined by
  - The angle of incidence (θ)
  - The index of refraction of the object (material property)
  - The mode of polarization of the incident light
- We will use particular properties for the above in the Shading Models slides

Reflected Light

- Materials reflect light differently
- Surface reflection is also called specular reflection
  - Non-metals in general do not change the wavelength of the reflected light
  - Metals allow particular wavelengths to be reflected and absorb the rest (depending also on the angle of incidence)

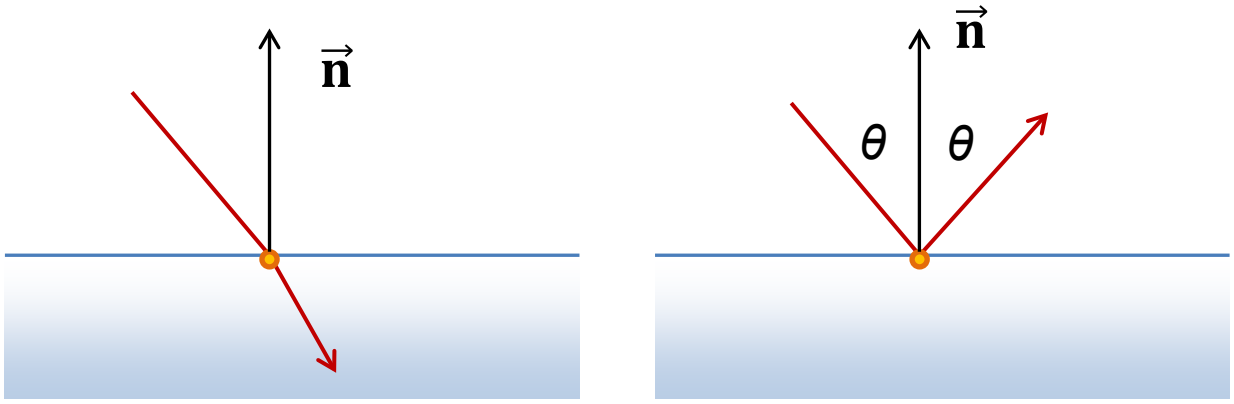
Transmitted Light

- Light that penetrates the surface of an object is refracted and transmitted through the object's body
- Transmitted light gets scattered and absorbed as it interacts with inhomogeneous matter (such as the body's particles)



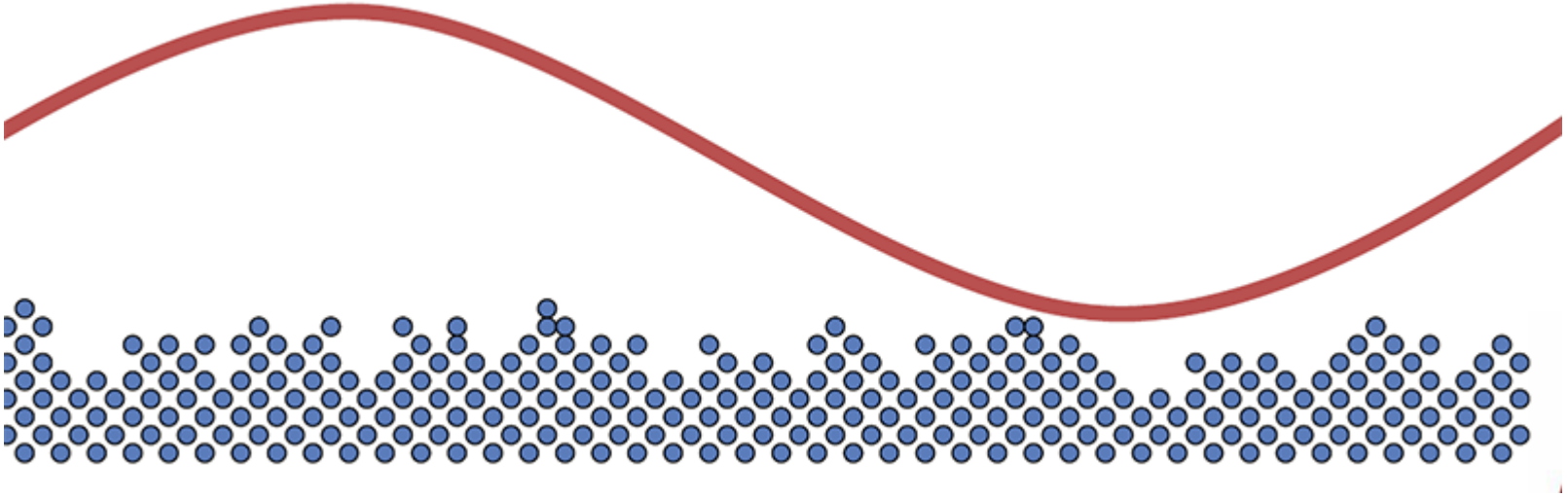
Ideal vs Non-Ideal Surfaces (1)

- In a micro-scale level, all surfaces are considered ideal, i.e. “perfectly flat”
- As a consequence:
  - Light is reflected in a single “ideal” direction
  - Light is refracted in a single “ideal” direction (Snell’s law of optics)



Ideal vs Non-Ideal Surfaces (2)

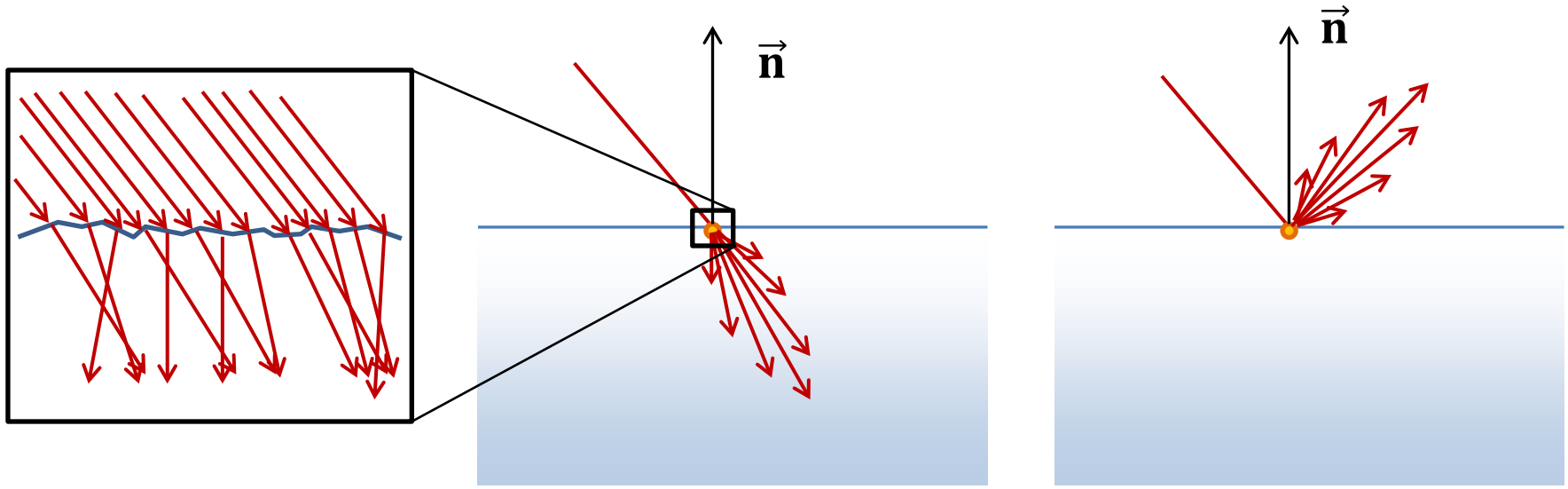
- Perfectly flat? What about atoms?
- We compare the scale relative to the wavelength of the light
  - For visible light, wavelength is considerably larger than the atomic scale level



Source: [PBSM]

Ideal vs Non-Ideal Surfaces (3)

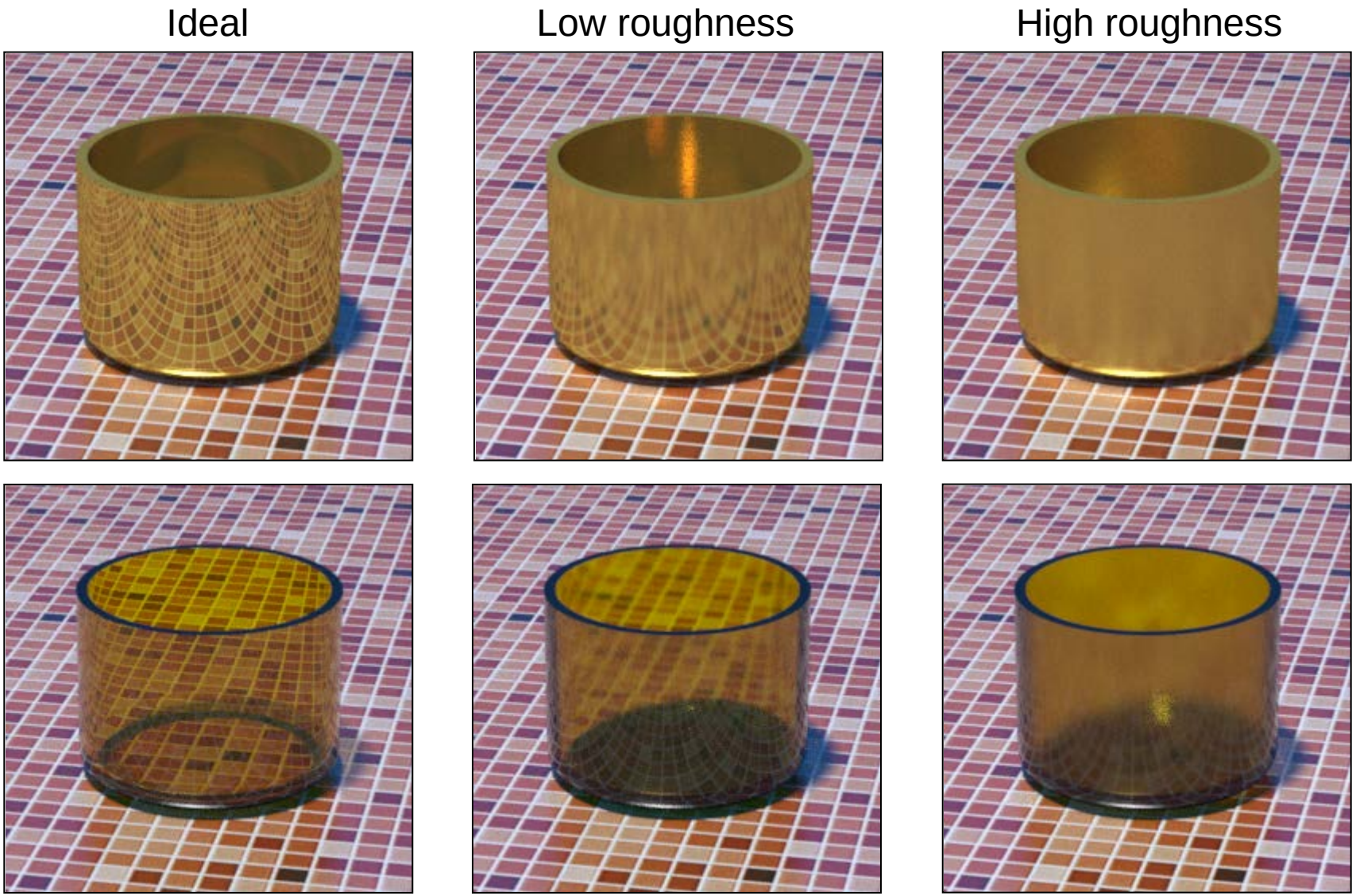
- This however seldom happens in reality
- At a meso-/macro-scopic level all surfaces are imperfect and therefore reflect and refract the light in slightly different directions:



Ideal vs Non-Ideal Surfaces (4)

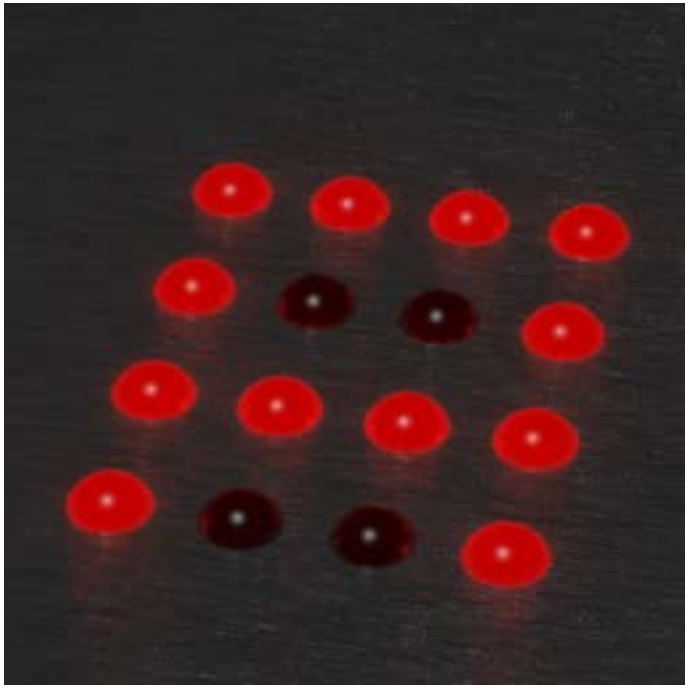
- Few surfaces (mostly high-quality optical mirrors and lenses) are *optically flat* (all irregularities are much smaller than visible light wavelengths)
- Most surfaces have irregularities, which are larger than light wavelengths but smaller than the *scale of observation* (e.g. subpixel size)

Ideal vs Non-Ideal Surfaces (5)



Emission

- Bodies can emit light
- Intrinsic light emission is added to the reflected or scattered light of a surface or medium



Scattering & Absorption (1)

What happens inside the object?

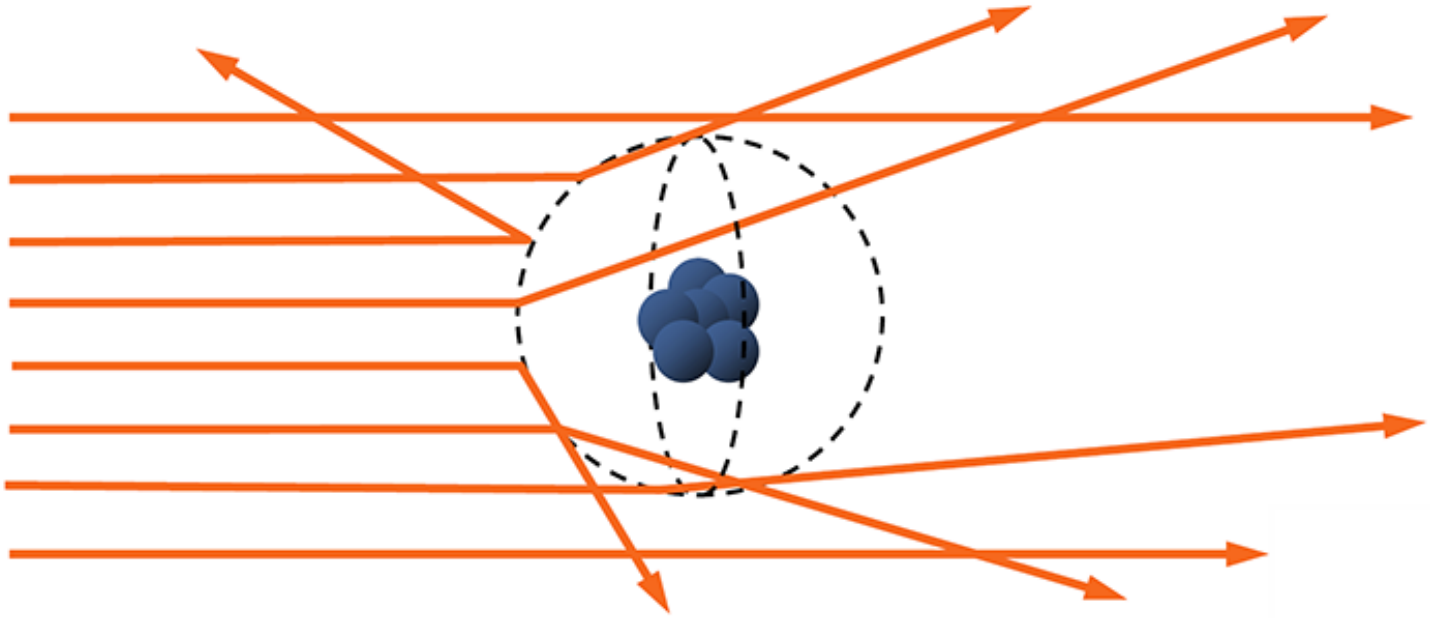
- Photons collide with particles and lose energy (converted to heat) → absorption
- Photons are deflected → scattering

Scattering & Absorption (2)

- Light propagating through a homogeneous medium is affected by medium's refractive index
  - Refractive index may vary with wavelength
- For inhomogeneous media, index of refraction changes:
- If it changes slowly and continuously, light bends
- If it changes abruptly, over a small distance (compared to the wavelength), then light scatters
  - Direction of light changes abruptly; amount of light stays the same

Scattering & Absorption (3)

– Collision with body particles results in potentially abrupt change of light transport direction



Source: [PBSM]

Scattering & Absorption (4)

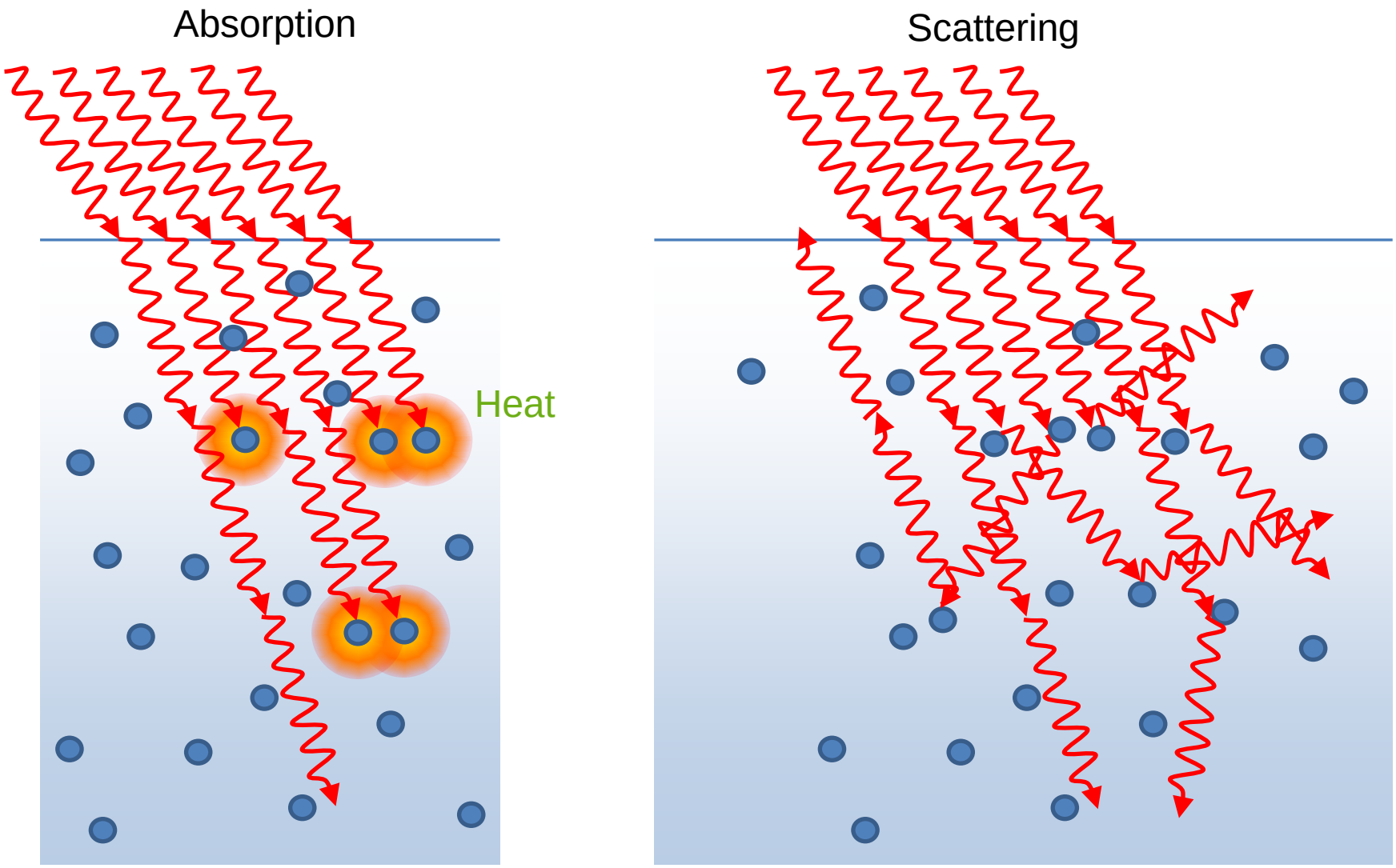
- Absorption occurs over all or part of the visible spectrum

Clear medium – low absorption

Denser medium – medium absorption

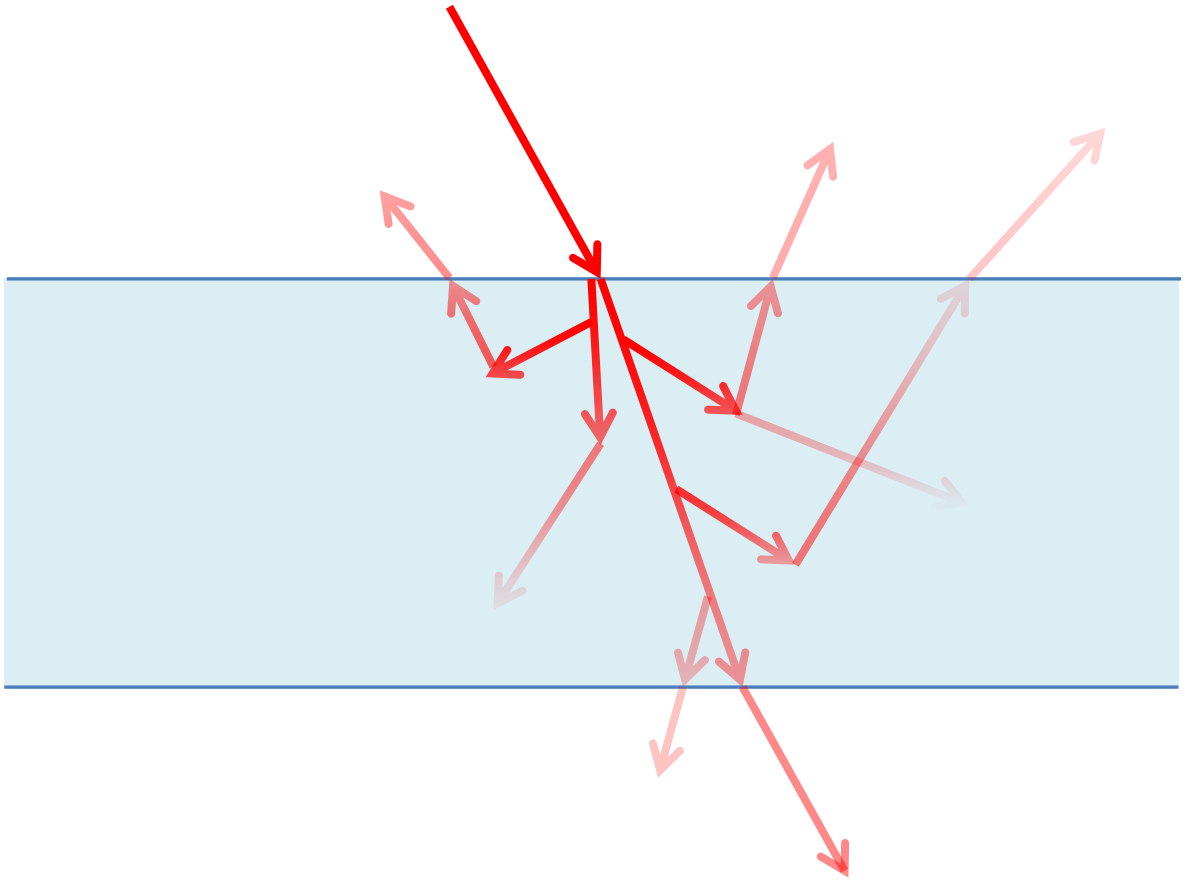
Source: [PBSM]

Scattering & Absorption (4)



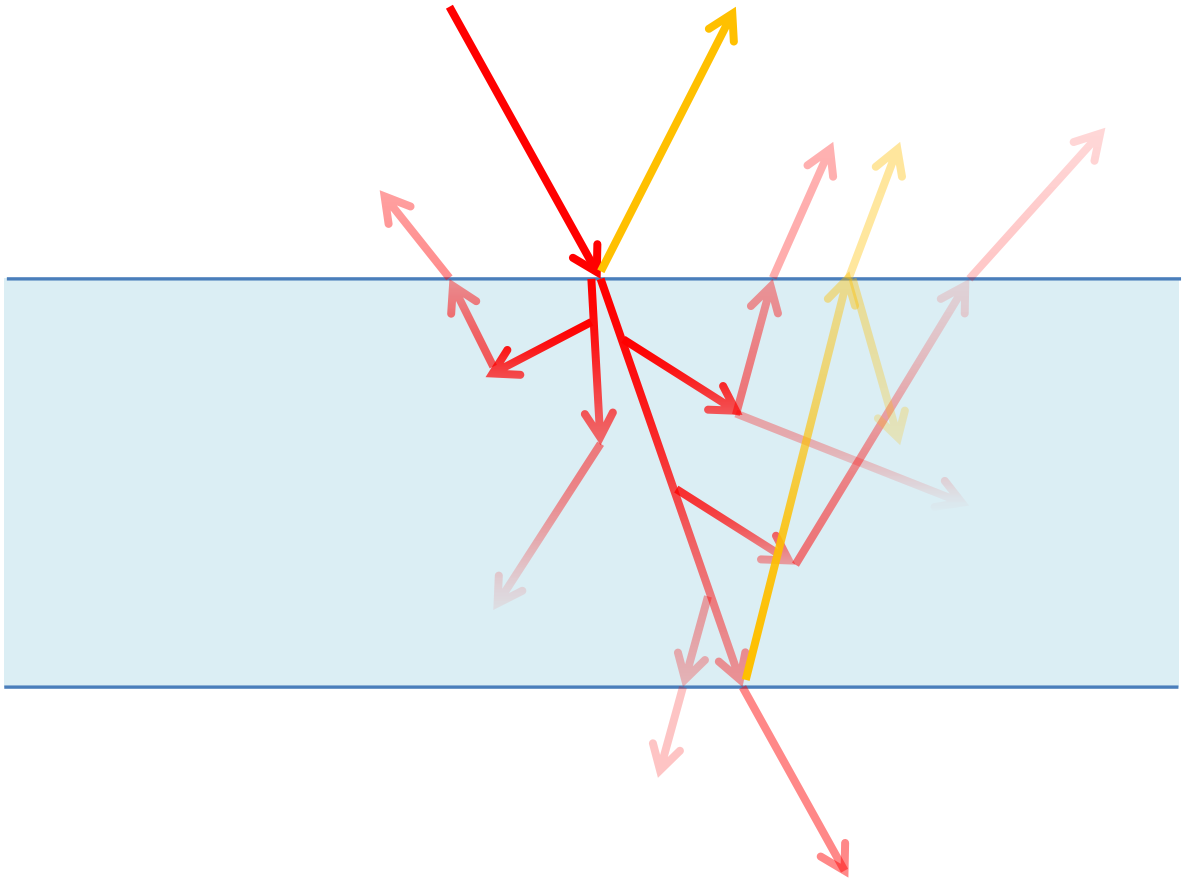
Scattering & Absorption (5)

The combined phaenomena contribute to the appearance of the material



Scattering & Absorption (6)

… and are also combined with the reflected part of the energy



Scattering & Absorption (7)

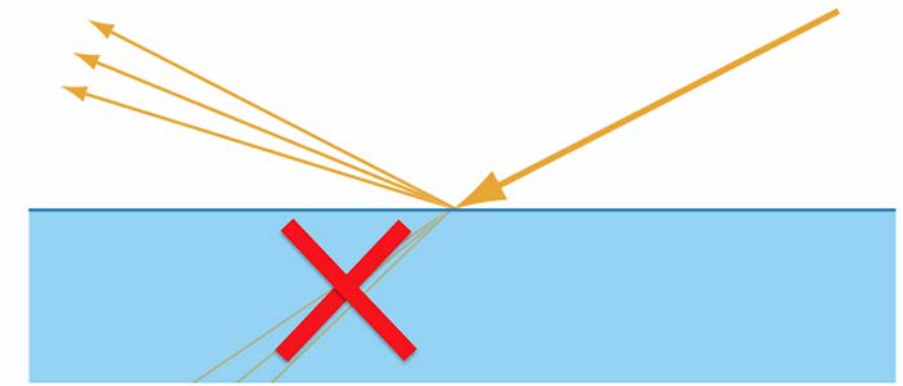
Cloudy medium – medium scattering

Translucent medium – heavy scattering

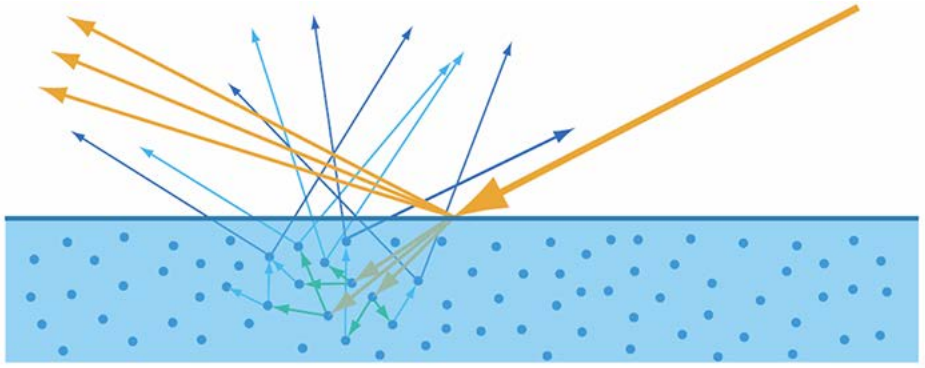
Source: [PBSM]

Metals and Dielectrics

- Metals: All refracted light is immediately absorbed



- Dielectrics: Refracted light undergoes scattering and/or absorption, often re-emerging from the surface



The Appearance of Scattering (1)

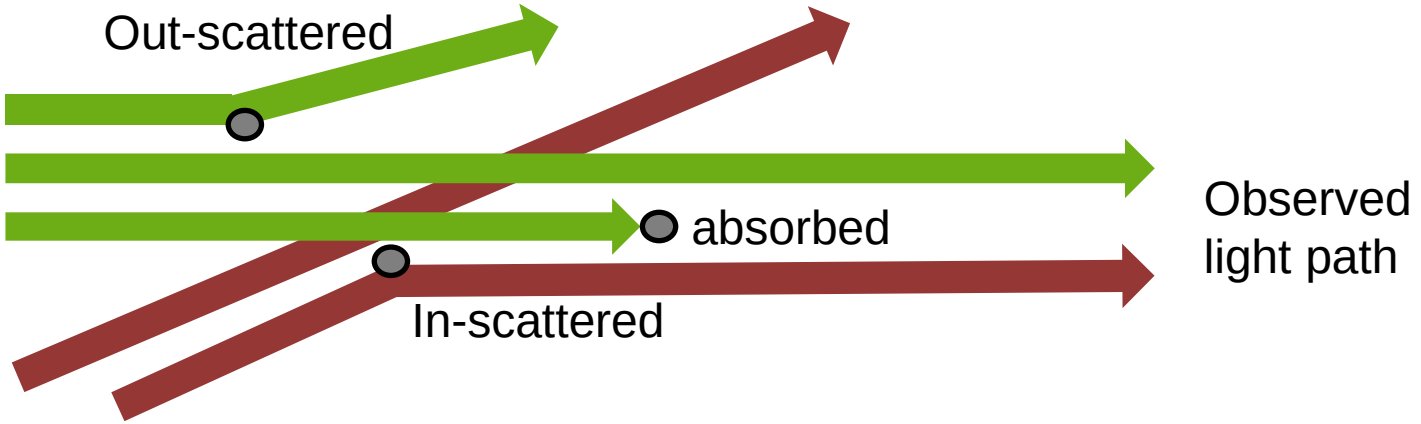
- Scattering is in general responsible for the intrinsic color of a body
- What light energy is not absorbed, is returned back to the environment
  - Each wavelength is scattered and absorbed differently, resulting to a perceived “color”

The Appearance of Scattering (2)

- For dense objects, light scattered back through the surface of incidence near the point of entry is namely diffusely reflected or diffused
  - The scattered color is the albedo of the surface (objective color)

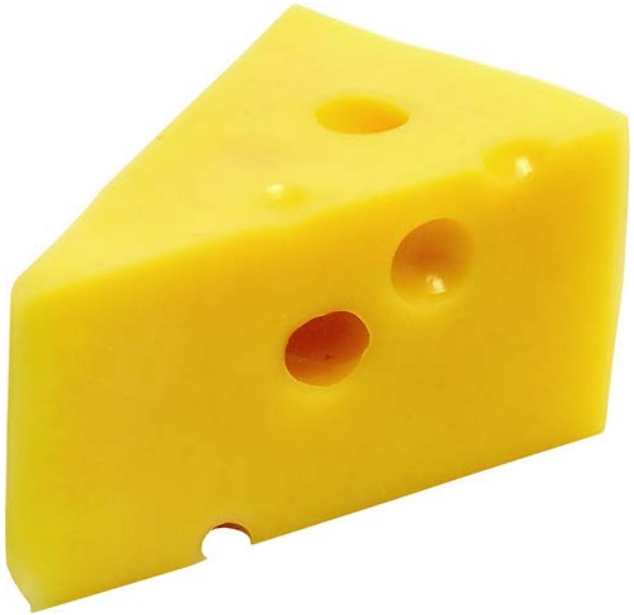
In-Scattering vs Out-Scattering

- The contribution of light on a single direction, consists of:
  - Light traveling on this path that is deflected off it or absorbed (out-scattering)
  - Light traveling on different paths that is deflected towards this direction (in-scattering)



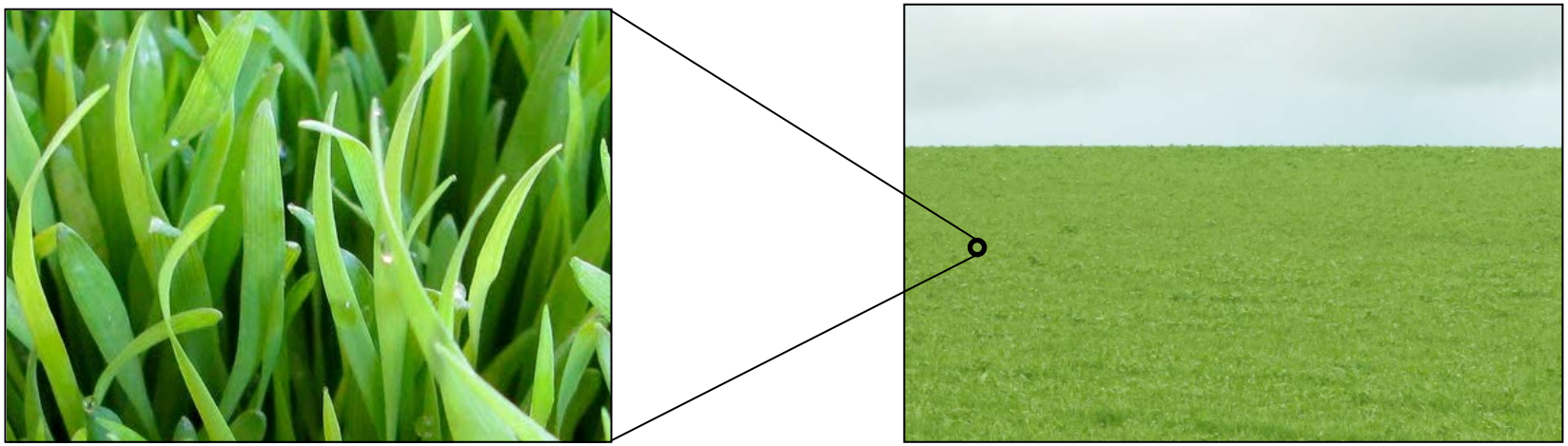
Subsurface Scattering (1)

- Scattered light that exits at a “relatively” different point than the point of entry to the surface creates the subsurface scattering effect → translucency



Yes, Size Does Matter! (1)

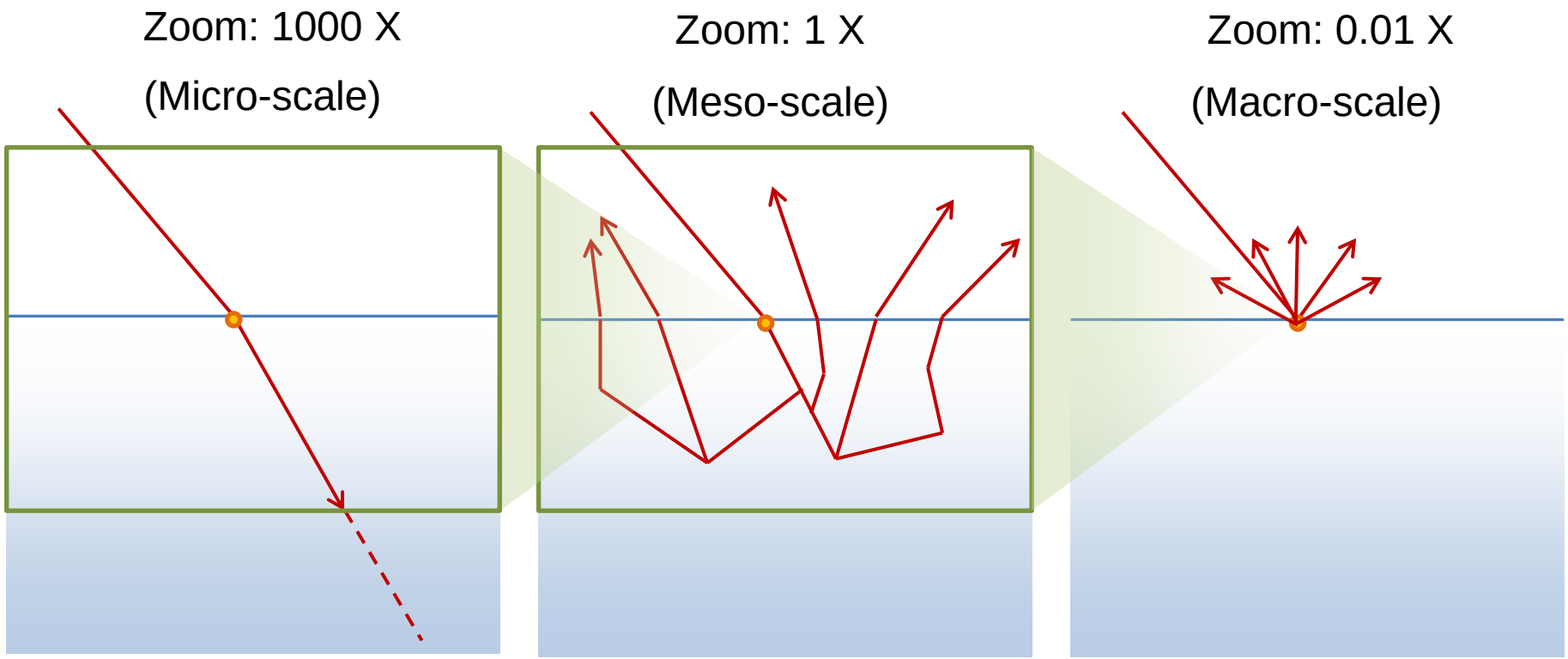
- The scale of observation makes a lot of difference
  - It alters the appearance of surfaces (perceived through each pixel)
  - So, it dictates the use of different algorithms to handle the light transport



Glossy, translucent, directional lighting

Highly uniform in/out-scattering

Yes, Size Does Matter! (2)



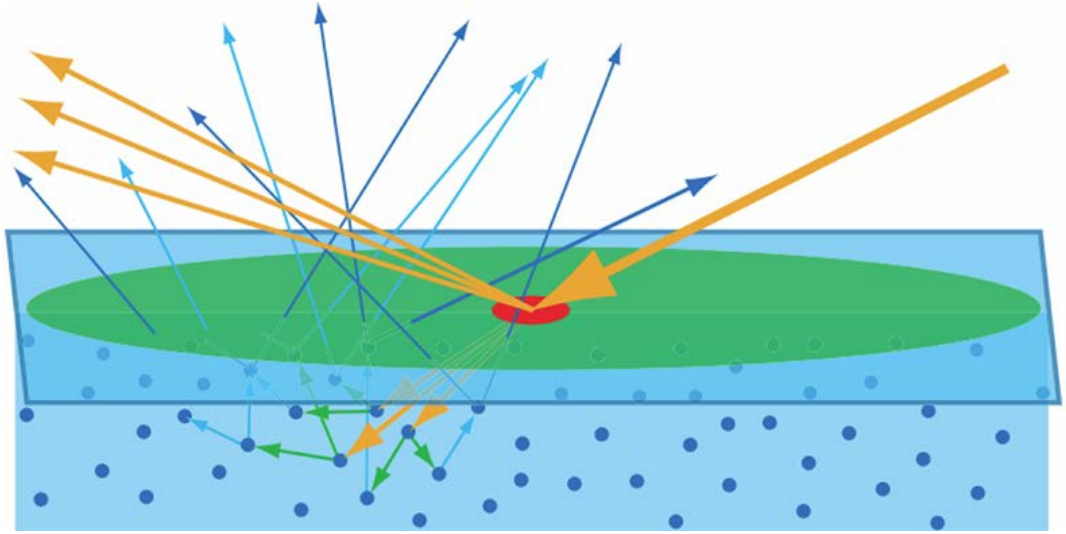
Refraction (transmission)

Sub-surface scattering

Diffuse “reflection”

Scale and Subsurface Scattering (1)

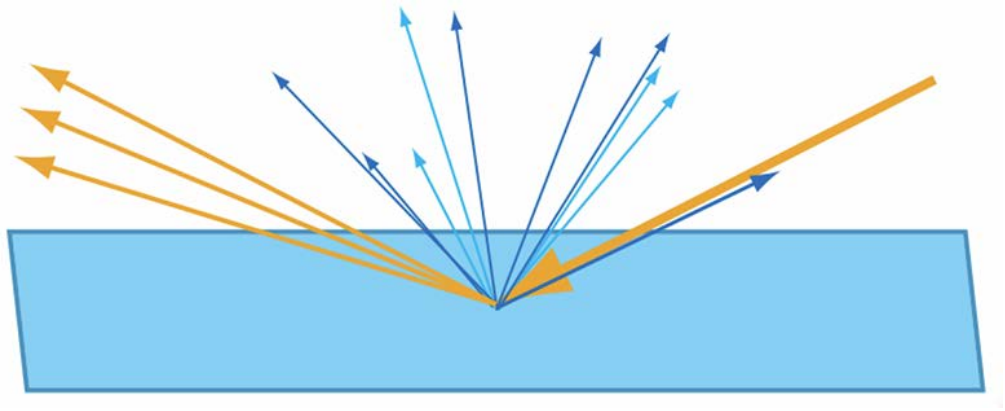
- Distribution of entry-exit distances depends on density and properties of scattering particles
- If pixel is large (green circle) compared to entry-exit distances, can assume distances are zero



Source: [PBSM]

Scale and Subsurface Scattering (2)

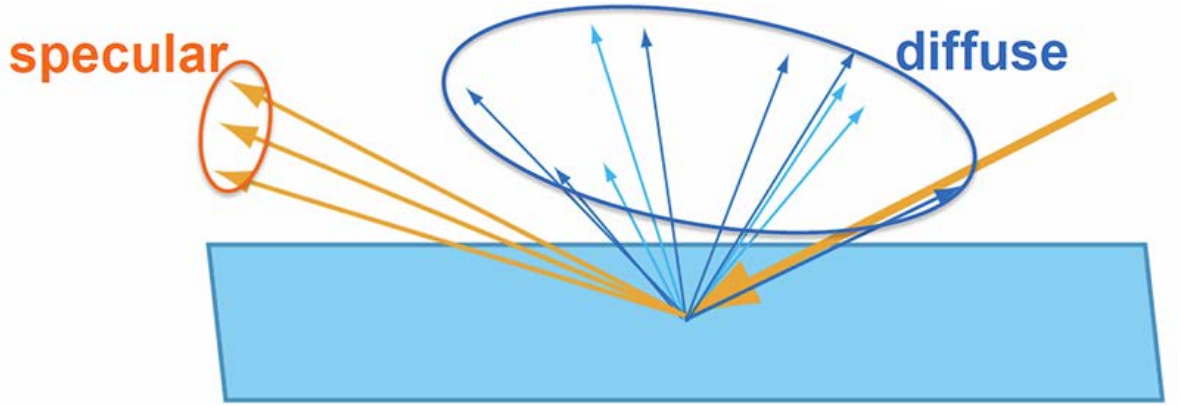
- By ignoring entry-exit distance, all shading can be computed locally, at a single point



Source: [PBSM]

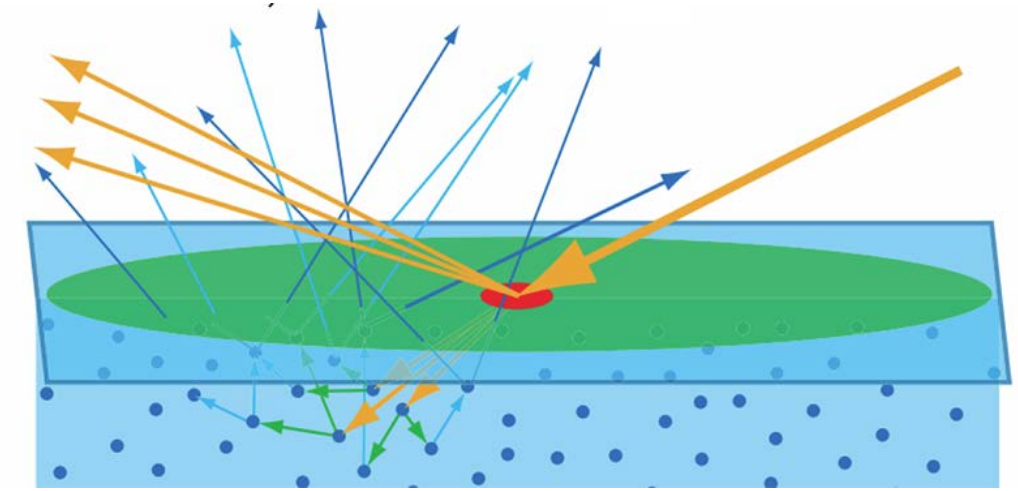
Scale and Subsurface Scattering (3)

- Surface reflection is typically modeled as specular and refraction with subsurface scattering as diffuse



Scale and Subsurface Scattering (4)

- If pixel is small (red circle) compared to entry-exit distances, local shading does not suffice and scattering must be computed otherwise



Source: [PBSM]

Reflection and Scattering Combined

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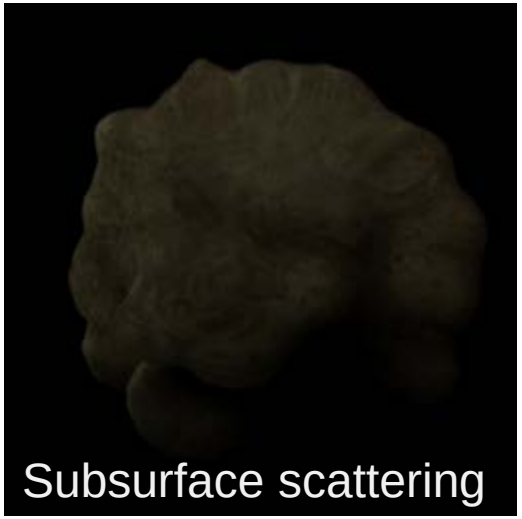

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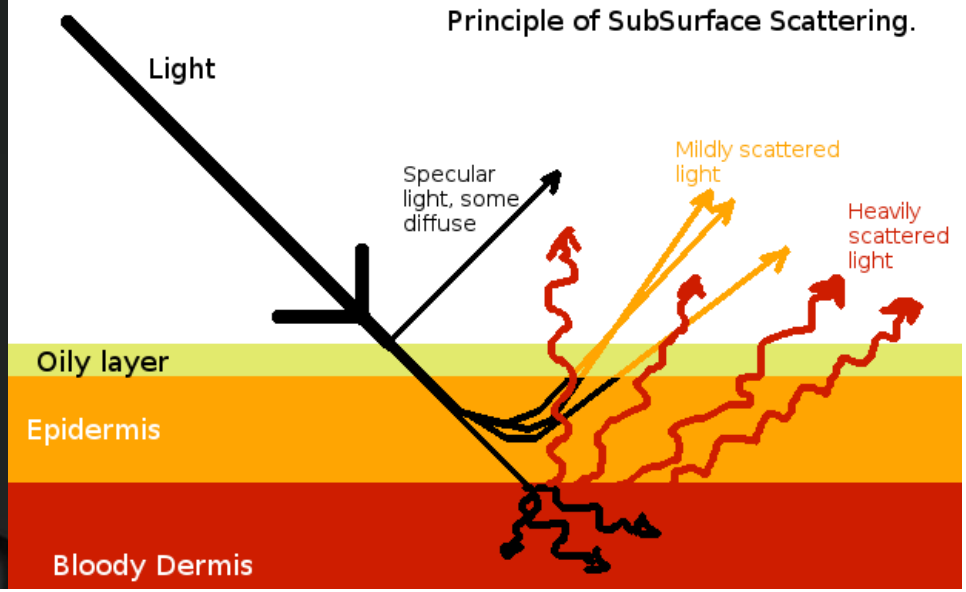
Scattering in Thin Media

- Smoke, clouds, haze etc. consist of small particles that deflect the light in various directions
- We call these bodies, whose surface cannot be defined or is not involved in the lighting estimation, participating media

Layered Materials

- Many real world materials consist of multiple layers with different properties each
- Typical examples:
  - Skin
  - Paint
  - Leaves



Spatial Material Variation (1)

- Spatial material attribute variations are determined by a process called texturing (more on the respective chapter)

Image source: http://www.cgsociety.org/index.php/CGSFeatures/CGSFeatureSpecial/shades_of_davy_jones

Spatial Material Variation (2)

- Texture patterns (procedural, bitmaps), called textures, are mapped to the 3D coordinates of surfaces and volumes
  - They determine any attribute of the material (e.g. albedo, index of refraction, reflectivity etc.) as a function of position and direction

Computer Graphics Taxonomy of Events

- An “event” is a state change to light as it travels through a medium or intercepts a surface
- In CG algorithms, typically used events on surfaces are:
  - Specular reflection (ideal/non-ideal)
  - Specular transmission (ideal/non-ideal)
  - Diffuse reflection
  - Diffuse transmission
  - Absorption (due to extinction near the surface)

AUEB COMPUTER GRAPHICS GROUP

Contributors

- Georgios Papaioannou

- Sources:
  - [PBSM] SIGGRAPH 2010 Course: Physically Based Shading Models in Film and Game Production