

CT5202: Photorealistic Rendering

Light

BOCHANG MOON



Light

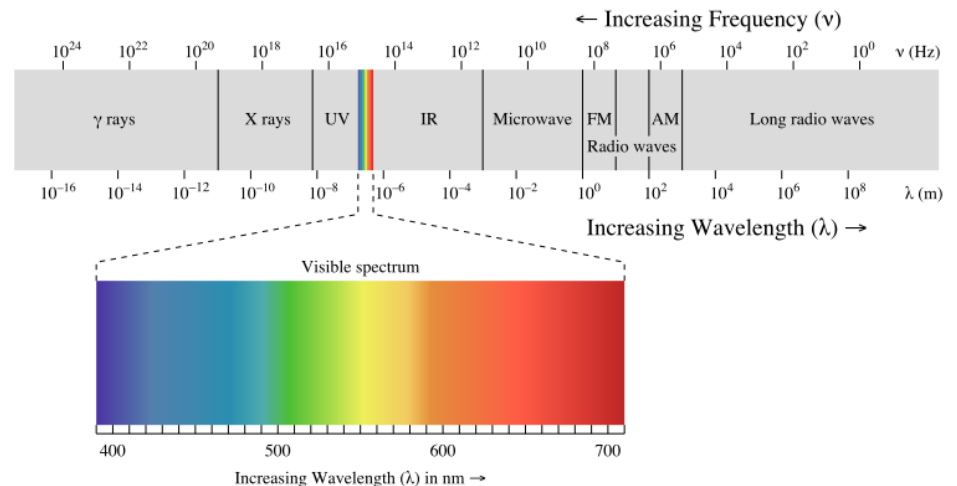
- A form of energy
- Q. How do we measure the light?
- Radiometry is a set of techniques for measuring light
- International System of Units (SI)
 - e.g., meter (m), gram (g), joule (J)

Photons

- Described as collections of a large number of photons
- Photons
 - A photon is a quantum of light
 - Position, direction of propagation, a wavelength λ
 - c.f., SI unit for λ is nm ($1\text{nm} = 10^{-9}\text{m}$)
 - Amount of energy carried by a photon
 - $q = hf = \frac{hc}{\lambda}$
 - $h = 6.63 \times 10^{-34}\text{Js}$ (Plank's Constant)
 - Frequency $f = \frac{c}{\lambda}$
 - c is a speed of a photon

Spectral Energy

- The total energy can be measured by summing the energy q_i of each photon
 - i = index of a photon
- Spectral Energy (Q_λ)
 - Measure the amount of light energy across wavelengths
 - *e. g.*, $Q_\lambda[500,600] = \frac{10.2}{100} = 0.12 J(nm)^{-1}$



Power

- Power
 - Rate of energy produced by light sources
 - Watts (W) = joules / second
 - e.g., 100-watt light bulb
 - Generate 100J per second
 - Q. Can we calculate the energy carried by a photon in this example?
 - Assume the average photon produces the energy of a $\lambda = 500nm$ photon
 - Frequency $f = \frac{c}{\lambda} = \frac{3 \times 10^8 ms^{-1}}{500 \times 10^{-9} m} = 6 \times 10^{14} s^{-1}$
 - Energy $hf = 6.63 \times 10^{-34} Js \times 6 \times 10^{14} s^{-1} \approx 4 \times 10^{-19} J$
 - Q. How many photons are emitted per second from the bulb?
 - Approximately 10^{20} photons

Power

- Power
 - Rate of energy produced by light sources
 - Watts (W) = joules / second
 - e.g., 100-watt light bulb
 - Generate 100J per second
 - Spectral power ($W(nm)^{-1}$)
 - Assume: a light emits a 100W power evenly across wavelengths 400nm to 800nm
 - Spectral power $\Phi_\lambda \equiv \Phi = \frac{100W}{400nm} = 0.25W(nm)^{-1}$
 - Can we calculate the spectral power for the case that a shutter of a measurement device opens for a time interval Δt centered at time t ?
 - Spectral power $\Phi = \frac{\Delta q}{\Delta t \Delta \lambda}$

Irradiance

- Spectral irradiance H
 - Intuitively, it describes how much light arrives at a point
 - $\Delta\Phi/\Delta A$ (Power per unit area)
 - $H = \frac{\Delta q}{\Delta A \Delta t \Delta \lambda}$
 - Note that we use a finite area ΔA instead of a point
 - Units for the irradiance are $Jm^{-2}s^{-1}(nm)^{-1}$
- Radiant exitance (emittance), E
 - Describe how much light leaves from a point

Radiance

- It describes how much light with a specific direction arrives at a point

- $response = \frac{\Delta H}{\Delta \sigma} = \frac{\Delta q}{\Delta A \Delta \sigma \Delta t \Delta \lambda}$



- $response = \frac{\Delta H}{\Delta \sigma \cos \theta} = \frac{\Delta q}{\Delta A \cos \theta \Delta \sigma \Delta t \Delta \lambda}$

- Radiance that hits a surface

- **Surface radiance**

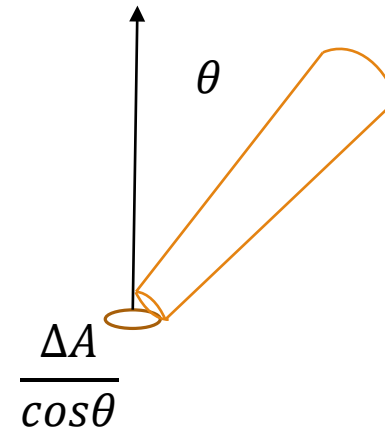
- Radiance that leaves a surface

- $L_s = \frac{\Delta E}{\Delta \sigma \cos \theta}$

- **Field radiance**

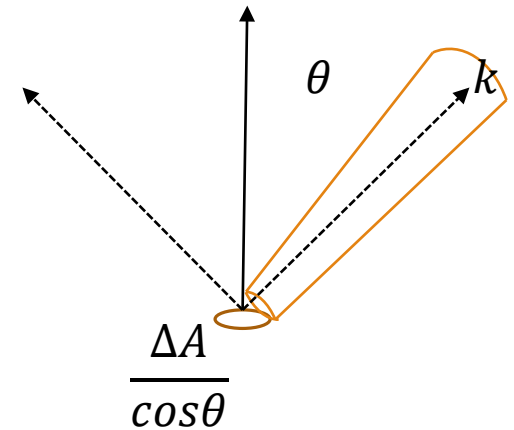
- Radiance incident at a surface

- $L_f = \frac{\Delta H}{\Delta \sigma \cos \theta}$



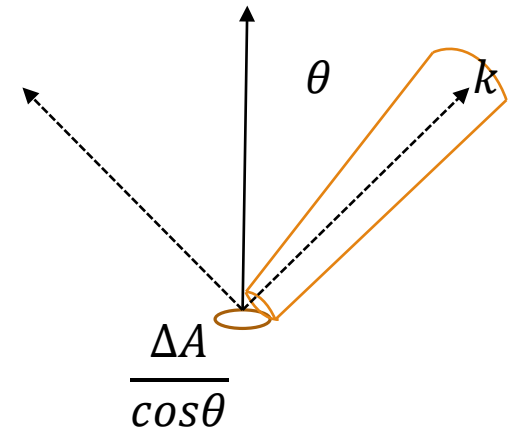
Radiance

- Irradiance can be expressed by summing radiance terms
- $H = \int_{all\ k} L_f(k) \cos\theta d\sigma$
- k is a unit vector
 - Incident direction
- (θ, ϕ) is a spherical coordinates w.r.t. the surface normal
- Differential solid angle has the following relation:
 - $d\sigma \equiv \sin\theta d\theta d\phi$
- As a result,
 - $H = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\frac{\pi}{2}} L_f \cos\theta \sin\theta d\theta d\phi = \pi L_f$
 - Q. What's the assumption for the equation above?



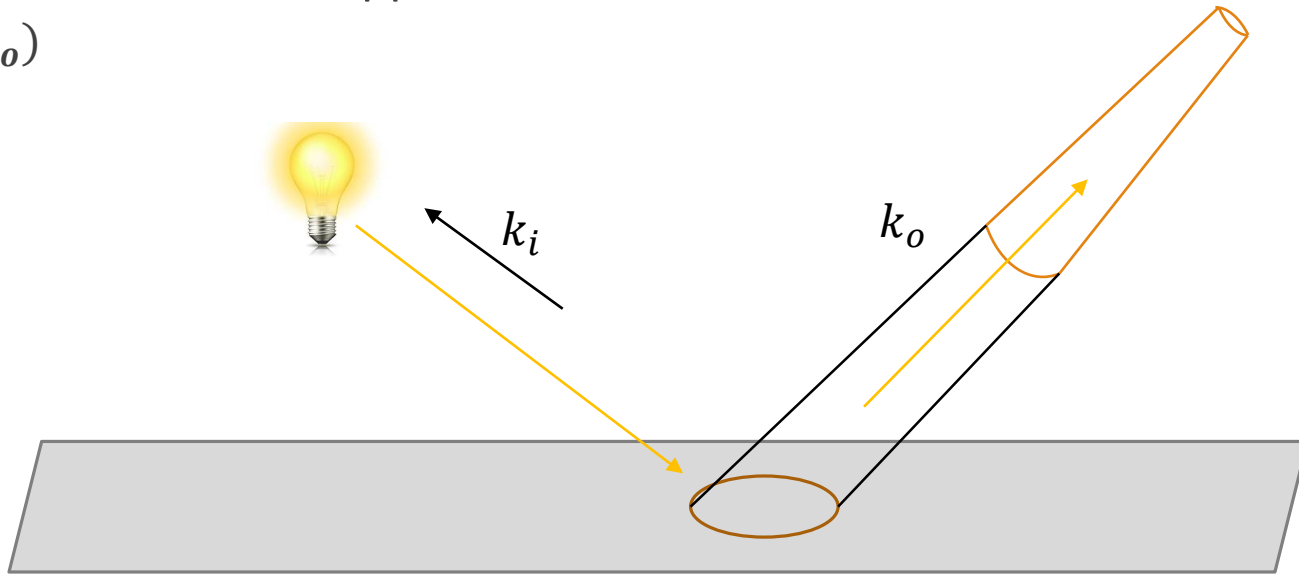
Radiance

- Can we compute power of hitting a surface?
 - $\Phi = \int_{all\ x} H(\mathbf{x})dA$
 - Indicate that the power can be computed by integrating the irradiance across the surface area
 - \mathbf{x} : a point on the surface



BRDF

- Bidirectional reflectance distribution function (BRDF) that defines how light is reflected at a surface
- BRDF controls surface appearance
 - $\rho(k_i, k_o)$



BRDF

- Directional Hemispherical Reflectance
 - $R(\mathbf{k}_i) = \frac{\text{power in all outgoing directions } k_o}{\text{power in a beam from direction } k_i}$
 - $R(\mathbf{k}_i)$ should be between 0 to 1. Why?
- Radiance can be also expressed as the following:
 - $L(\mathbf{k}_o) = H\rho(\mathbf{k}_i, \mathbf{k}_o) = \frac{\Delta E}{\Delta\sigma_o \cos\theta_o}$
- The reflectance can be represented with summing BRDF:
 - $R(k_i) = \int_{\text{all } \mathbf{k}_o} \rho(\mathbf{k}_i, \mathbf{k}_o) \cos\theta_o d\sigma_o$

Example: Ideal Diffuse Surface

- Let's assume an ideal diffuse surface (Lambertian)
 - Lambertian has a constant $\rho = C$, i.e., reflect light equally with all directions

- $$R(k_i) = \int_{all\ k_o} C \cos\theta_o d\sigma_o = \int_{\phi_o=0}^{2\pi} \int_{\theta_o}^{\frac{\pi}{2}} C \cos\theta_o \sin\theta_o d\theta_o d\phi_o = \pi C$$

- When $R(k_i) = 1$

- $\rho = C = \frac{1}{\pi}$

- When $R(k_i) = r$

- $\rho(\mathbf{k}_i, \mathbf{k}_o) = C = \frac{r}{\pi}$

Next Course?

- Light Transport Equation