CT5202: Photorealistic Rendering

# Light

Lecturer: 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

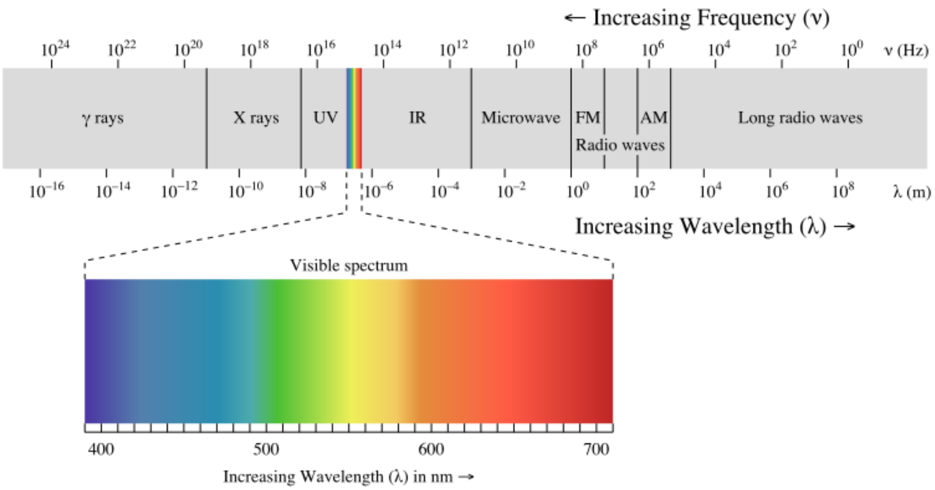
- Described as collections of a large number of photons
- Photons
  - A photon is a quantum of light
  - Position, direction of propagation, a wavelength $\lambda$
  - c.f., SI unit for $\lambda$ is nm ($1nm = 10^{-9}m$)

  - Amount of energy carried by a photon
    - $q = hf = \frac{hc}{\lambda}$
    - $h = 6.63 \times 10^{-34} Js$ (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 ($Q_\lambda$)
    - Measure the amount of light energy across wavelengths
    - $e.g., Q_\lambda[500{,}600] = \frac{10.2}{100} = 0.12\,J(nm)^{-1}$




wikipedia.org

# 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 $f = \frac{c}{\lambda} = \frac{3\times10^8 ms^{-1}}{500\times10^{-9} m} = 6 \times 10^{14} s^{-1}$
    - 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 $\Delta t$ centered at time t?
      - Spectral power $\Phi = \frac{\Delta q}{\Delta t \Delta \lambda}$

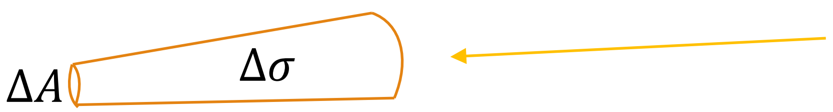
# Irradiance

- 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 $\Delta A$ 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

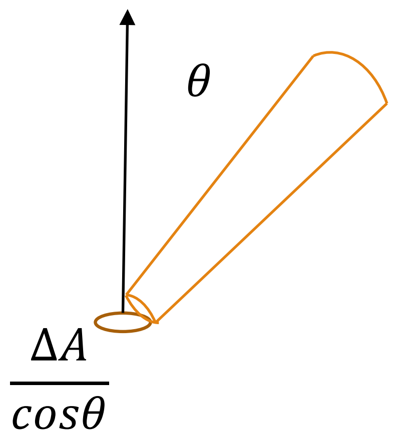
# Radiance

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

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



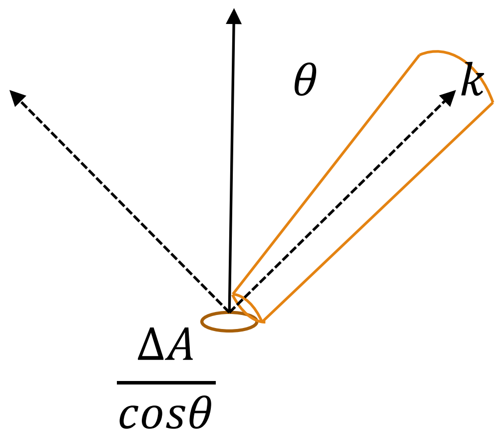

- $response = \frac{\Delta H}{\Delta \sigma cos\theta} = \frac{\Delta \mathrm{q}}{\Delta A cos\theta \Delta \sigma \Delta t \Delta \lambda}$
  - Radiance that hits a surface




- Surface radiance
  - Radiance that leaves a surface
  - $L_s = \frac{\Delta E}{\Delta \sigma cos\theta}$
- Field radiance
  - Radiance incident at a surface
  - $L_f = \frac{\Delta H}{\Delta \sigma cos\theta}$

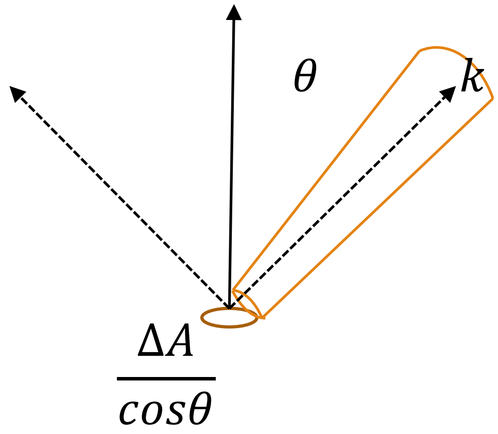
# Radiance

- Irradiance can be expressed by summing radiance terms
- $H = \int_{all\ \boldsymbol{k}} L_f(k) cos\theta d\sigma$
- k is a unit vector
  - Incident direction
- $(\theta, \phi)$ 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?



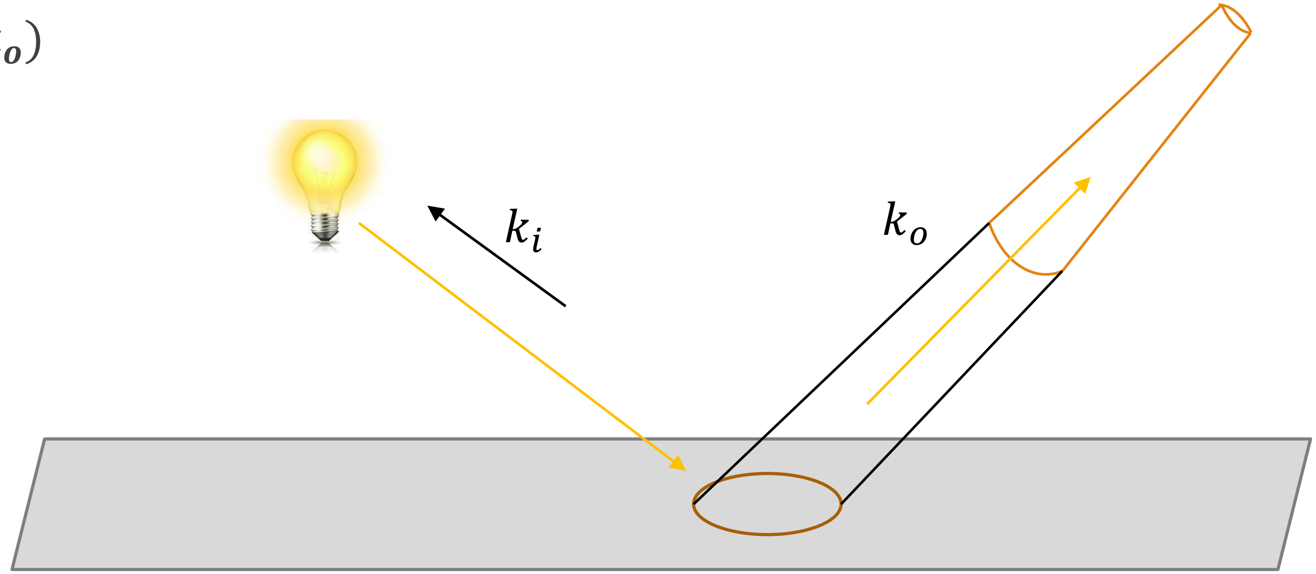
# Radiance

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



# BRDF

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



# BRDF

- Directional Hemispherical Reflectance
  - $R(\boldsymbol{k_i}) = \frac{power\ in\ all\ outgoing\ directions\ k_o}{power\ in\ a\ beam\ from\ direction\ k_i}$
  - $R(\boldsymbol{k_i})$ should be between 0 to 1. Why?

- Radiance can be also expressed as the following:
  - $L(\boldsymbol{k_o}) = H\rho(\boldsymbol{k_i}, \boldsymbol{k_o}) = \frac{\Delta E}{\Delta\sigma_o cos\theta_o}$

- The reflectance can be represented with summing BRDF:
  - $R(k_i) = \int_{all\ \boldsymbol{k_o}} \rho(\boldsymbol{k_i}, \boldsymbol{k_o}) cos\theta_o d\sigma_o$

# 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 $R(k_i) = r$
  - $\rho(\boldsymbol{k_i}, \boldsymbol{k_o}) = C = \frac{r}{\pi}$

# Next Course?

- Light Transport Equation