The Light Field

Electromagnetic waves; photons

Frequency spectra

    and color

Frequency (Hertz)

| 1 | 10^2 | 10^4 | 10^6 | 10^8 | 10^{10} | 10^{12} | 10^{14} | 10^{16} | 10^{18} | 10^{20} | 10^{22} | 10^{24} | 10^{26} |

| Power | Heat | Radio | Infra-Red | | Ultra-Violet | X-Rays | Gamma Rays | Cosmic Rays |

| 10^{16} | 10^{14} | 10^{12} | 10^{10} | 10^8 | 10^6 | 10^4 | 10^2 | 1 | 10^{-2} | 10^{-4} | 10^{-6} | 10^{-8} |

Wavelength (NM)

| IR | R | G | B | IR |
| 700 | 600 | 500 | 400 |
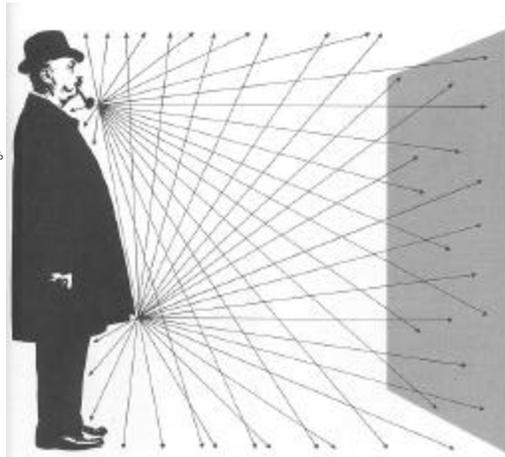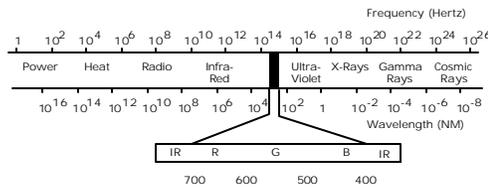
Polarization

Spatial distribution

From London and Upton

Questions

1. **How is light measured?**

2. **How is the spatial distribution of light energy described?**

3. **How is reflection from a surface characterized?**

4. **What are the conditions for equilibrium flow of light in an environment?**

Transport Theory

Transport theory is concerned with calculating how stuff Q flows in the environment.

- ■ Mass m
- ■ Charge q
- ■ Radiant energy $\mathbf{F}$

Transport quantities are built around a core of basic geometric ideas. These are tricky!

The easiest way to learn transport theory is to think in terms of particles (photons).

Particle Density

Phase Space

Particle characterized by position and velocity
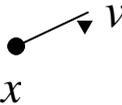
Particle densities

Ratio of number of particles to volumes (phase space)

$$\boxed{d^3x} \times \boxed{d^3v} \qquad n(x,v,t) = \lim_{\Delta^3 x \Delta^3 v \to 0} \frac{N(t)}{\Delta^3 x \Delta^3 v}$$

$$\Re^3 \times \Re^3$$

Flows

Count particles crossing a surface
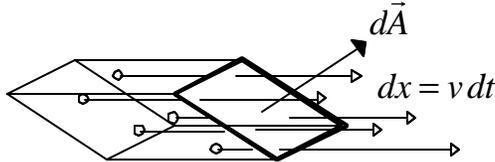
$$d^3 x = v \cos q \, dA = (\vec{v} \, dt) \bullet d\vec{A}$$

$$Q(x,v) = n(x,v) \, d^3 x = n(x,v)(\vec{v} \, dt) \bullet d\vec{A}$$

■ **Flux [Stuff/Time] (or Rate or Flow)**

$$\Phi = \frac{dQ}{dt} = n(x,v) \vec{v} \bullet d\vec{A}$$

■ **Flux density [Stuff/(Time•Area)]**

$$\Phi = \frac{d^2 Q}{dt \, dA} = n(x,v) \vec{v} \bullet d\hat{A} = n(x,v) \, v \cos q$$

Angles and Solid Angles

■ **Angle** $\quad q = \dfrac{length}{radius}$

$\mathbb{P}$ circle has 2p radians

■ **Solid angle** $\quad \Omega = \dfrac{area}{radius^2}$

$\mathbb{P}$ sphere has 4p steradians
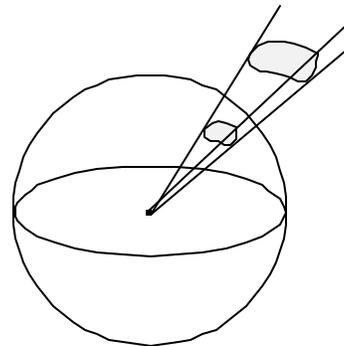
If the area is not on the sphere, then the solid angle subtended by the area is equal to the area projected onto the unit sphere.

Differential Solid Angles
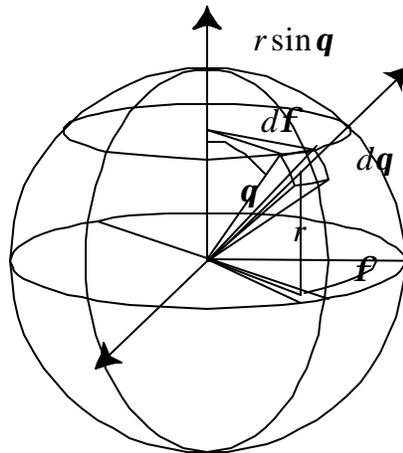
$r \sin \boldsymbol{q}$

$d\boldsymbol{f}$

$d\boldsymbol{q}$

$\boldsymbol{q}$

r

P

$$dA = (r\,d\boldsymbol{q})(r\sin\boldsymbol{q}\,d\boldsymbol{f})$$

$$= r^2 \sin\boldsymbol{q}\,d\boldsymbol{q}\,d\boldsymbol{f}$$

$$d\boldsymbol{w} = \frac{dA}{r^2} = \sin\boldsymbol{q}\,d\boldsymbol{q}\,d\boldsymbol{f}$$

$$S = \int_{0}^{\boldsymbol{p}}\int_{0}^{2\boldsymbol{p}} \sin\boldsymbol{q}\,d\boldsymbol{q}\,d\boldsymbol{f} = 4\boldsymbol{p}$$

Radiance and Luminance

Definition: The *radiance* (*luminance*) is the power per unit projected area perpendicular to the ray per unit solid angle in the direction of the ray.

$d\boldsymbol{w}$

dA

$d\bar{\boldsymbol{w}}$

$d\vec{A}$

$$L(x,\boldsymbol{w}) = \frac{d^2\Phi}{d\vec{\boldsymbol{w}} \bullet d\vec{A}}$$

$$d^2\Phi = L(x,\boldsymbol{w})\,d\vec{\boldsymbol{w}} \bullet d\vec{A}$$

$$= L(x,\boldsymbol{w})\cos\boldsymbol{q}\,d\boldsymbol{w}\,dA$$

Page 4
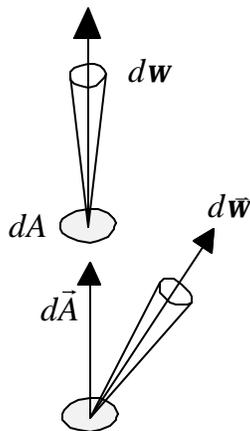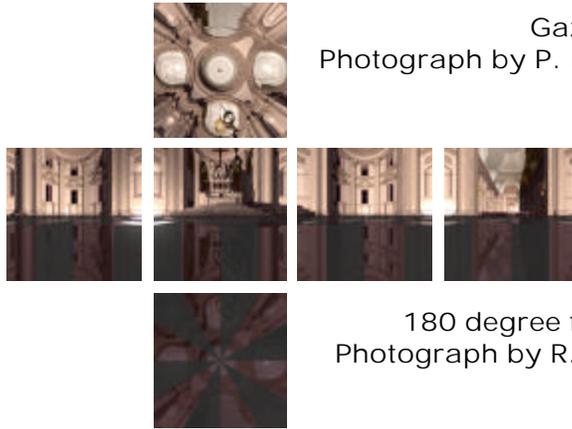
Environment Maps

Gazing Ball
Photograph by P. Haeberli

180 degree fisheye
Photograph by R. Packo
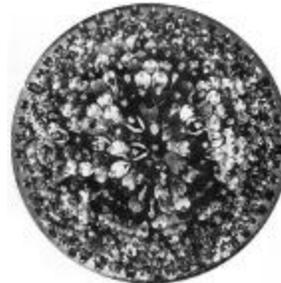
Cubical Environment Map

Spherical Light Field
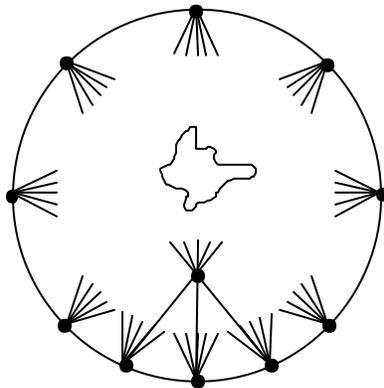
**Capture all the light leaving
an object - like a hologram**

4 degree-of-freedom gantry

Two-Plane Light Field
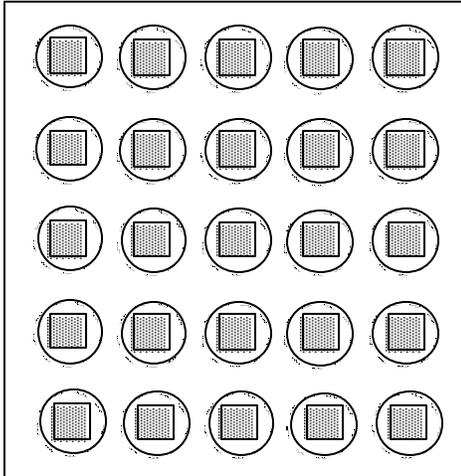
2D Array of Cameras
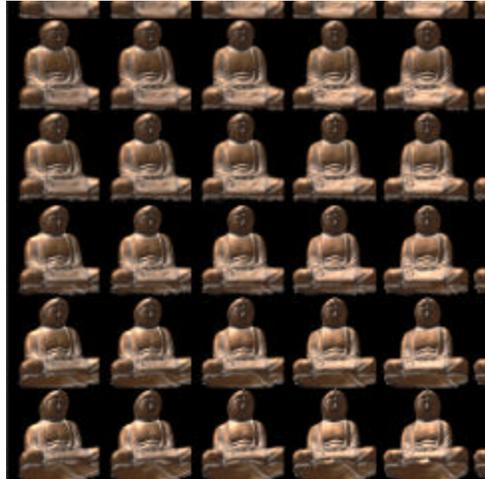
2D Array of Images

Radiant Energy and Power

Power: Watts vs. Lumen

- ■ **Energy efficiency**
- ■ **Spectral efficacy**
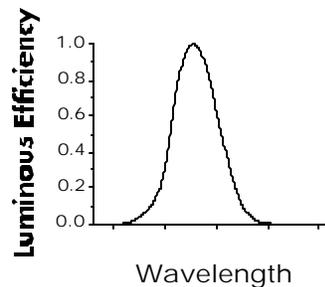
Energy: Joules vs. Talbot

- ■ **Since the velocity of light is so fast, may typically ignore distinction between power and energy**
- ■ **Exposure - Reaction rates**
  - ■ **Film response**
  - ■ **Skin - sunburn**

Radiometry vs. Photometry

■ **Radiance and Radiometry [Units = Watts]**

   Physical measurement of electromagnetic energy.

■ **Luminance and Photometry [Units = Lumen]**

   Perceptual measurement of relative subjective sensation due to light of different wavelengths.

■ **Brightness [Units = Brils]**

   Perceptual measurement of the relative perceived sensation of light of different intensities.


Properties of Radiance

1. **Fundamental field quantity that characterizes the distribution of light in an environment.**

   - All other quantities are derived from it.

2. **Radiance invariant along a ray.**

   - Energy and throughput conserved implies radiance conserved.

3. **Response of a sensor proportional to radiance.**

Radiance: 1st Law

The radiance in the direction of a light ray remains constant as the ray propagates.

$$d\Phi_1 = L_1 dw_1 dA_1 = L_2 dw_2 dA_2 = d\Phi_2$$

$$dw_1 = dA_2/r^2$$
$$dw_2 = dA_1/r^2$$

$$dw_1 dA_1 = \frac{dA_1 dA_2}{r^2} = dw_2 dA_2$$

$$\therefore L_1 = L_2$$
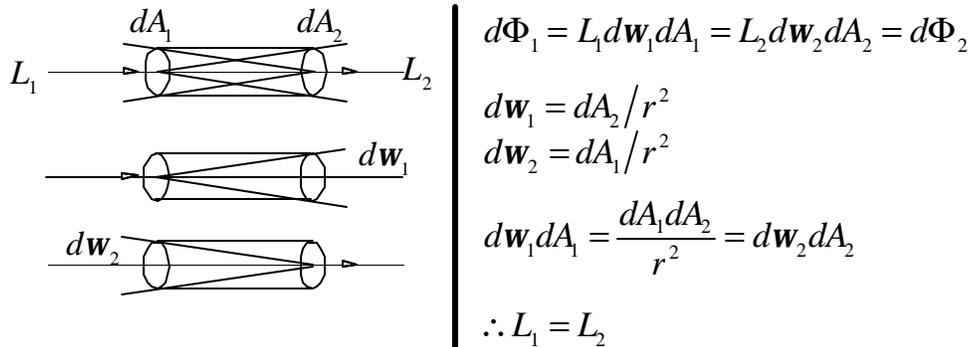
L is the numeric quantity that should be associated with rays in ray tracers.

Radiance: 2nd Law

The response of a sensor is proportional to the radiance of the surface visible to the sensor.

L is what should be computed and displayed.
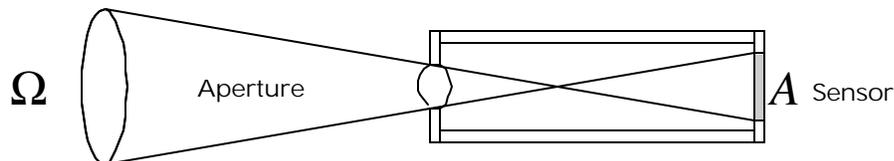
Ω **Aperture** A **Sensor**

$$R = \iint_{A\,\Omega} L\cos q \; dw\, dA = L\iint_{A\,\Omega} \cos q \; dw\, dA = LT$$

Throughput $\quad T = \iint_{A\,\Omega} \cos q \; dw\, dA$

Quiz 1

Does radiance increase under a magnifying glass?

NO!!
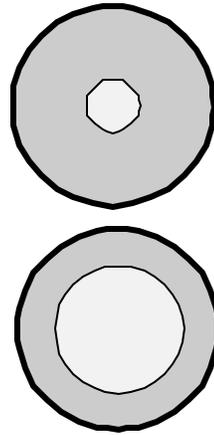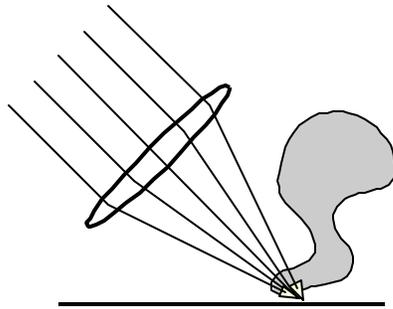
Quiz 2

Does the brightness that a wall appears to the eye depend on the distance of the viewer to the wall?

NO!!