Biomedical Optics IV

Optical transport in tissues

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Optical transport in tissues

- Primary unscattered light
  - Coherence, polarization
- Secondary multiply scattered light
  - Transition to diffusion
  - Diffusion of light

Primary unscattered light

Coherence, polarization

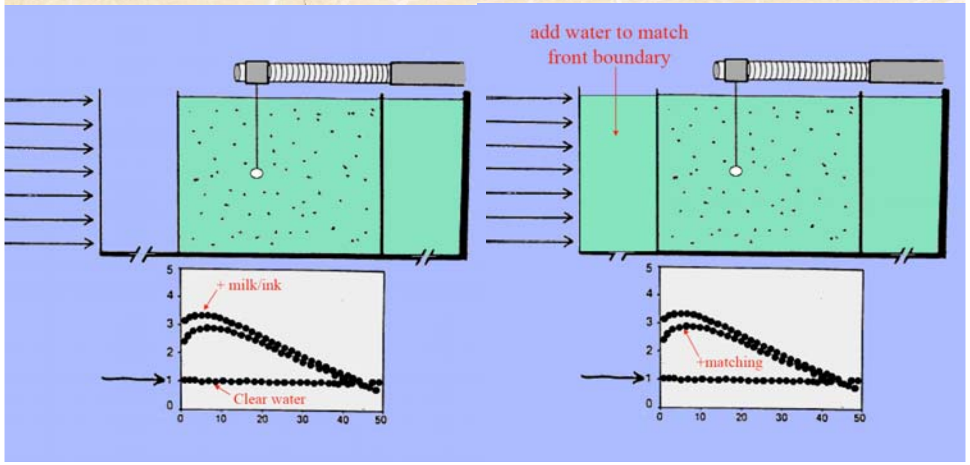
$$T = \exp(-\mu_t r)$$

$$\mu_t = \mu_a + \mu_s$$

Clip2

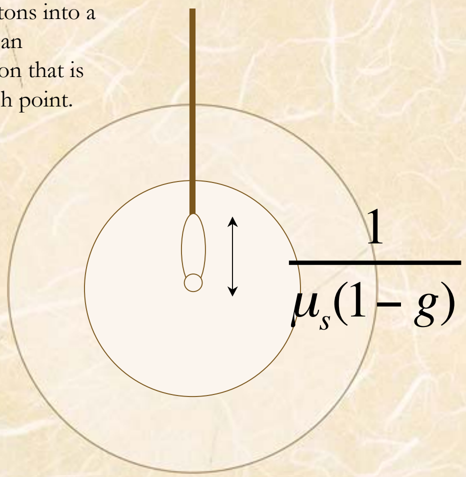
Demonstration of light entering a fishtank with scattering media

Clip 3



Optical fiber in scattering medium

Launching collimated photons into a scattering medium creates an apparent center for diffusion that is $1/\mu_s'$ in front of the launch point.



Clip 4

Irradiance E

- At a point of a surface, the radiant energy flux (or power) incident on an element of the surface, divided by the area of the surface [W/cm^2]
- E = P/A
  - Fluence rate
  - Radiant exittance
    - *radiant dose rate*
    - *radiant emittance*

Radiant exposure H

- At a point of a surface, the radiant energy incident on an element of the surface, divided by the area of the surface [J/cm^2]
- H = Q/A = P ∗ t/A = E ∗ t

1D model

A simple expression approximates the penetration of light into a scattering tissue illuminated with a broad collimated beam. This is a 1-dimensional solution, only a function of depth z. The solution is not correct near the surface, but is correct within the tissue.

$$F(z) = E_0 k \exp(-z/\delta)$$

$$\delta = \sqrt{\mu_a / D} \text{ and } D = \frac{1}{3}\frac{1}{\mu_a + \mu_s'}$$

Fluence rate

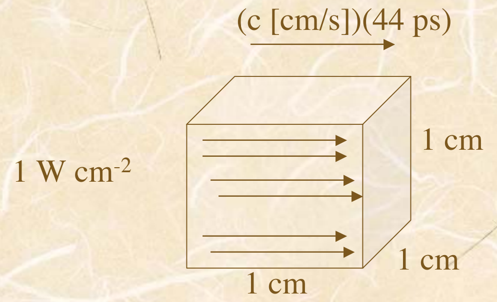
Fluencerate is a parameter that is proportional to the concentration of photons

$$F = c * C[Wcm^{-2}]$$

$$C = \text{concentration}[Jcm^{-3}]$$

$$c = \text{speed of light}[cm/s]$$

Conentration of photons



$$C_{ph} = \frac{En}{c}\frac{\lambda}{hc}$$

(1 W/cm^2)(1/c)(λ/hc)
=1.45x10^8 photons/cm^2
=2.41x10^{-13} moles/liter

Time-resolved diffusion

$$\text{Diffusivity, } \chi = cD \; [\text{cm}^2/s]$$

$$C(\mathbf{r},t) = U_0 \frac{\exp(-\frac{\mathbf{r}^2}{4\chi t})}{(4\pi\chi t)^{3/2}}$$

[Jcm^{-3}] [J] [cm^{-3}]

Time-resolved diffusion of photons simply describes the diffusion of photon concentration (or photon energy concentration) as a function of distance (r) from a point sourceand time (t) after the impulse of optical energy deposition.

Radiant exposure

$$H(\mathbf{r}) = \int_0^\infty cC(\mathbf{r},t)\exp(-\mu_a ct)dt$$

$$= U_0 \frac{\exp(-\mathbf{r}\sqrt{\mu_a/D})}{4\pi D\mathbf{r}}$$

Integration of F over time yields the time-independent overall exposure H. The H in response to a sequence of impulses of value U_o and frequency f, which present an average power P = fU_o, yields the time-independent steady-state expression for fluence rate in response to a steady-state point-source of power.

Time-resolved fluence rate

$$F(\mathbf{r},t) = c\underbrace{U_0 \frac{\exp(-\frac{\mathbf{r}^2}{4\chi t})}{(4\pi\chi t)^{3/2}}}_{C(\mathbf{r},t)} \exp(-\mu_a c t)$$

$[\mathrm{Wcm}^{-2}]$ [cm/s][J] $[\mathrm{cm}^{-3}]$ absorption

$$P_0 = U_0 f \quad \text{in the limit}$$

$$f \to \infty$$

$$U_0 \to 0$$

Steady-state fluence rate

$$F(\mathbf{r}) = P_0 \frac{\exp(-\mathbf{r}/\delta)}{4\pi D\mathbf{r}}$$

$$\delta = \sqrt{D/\mu_a}$$

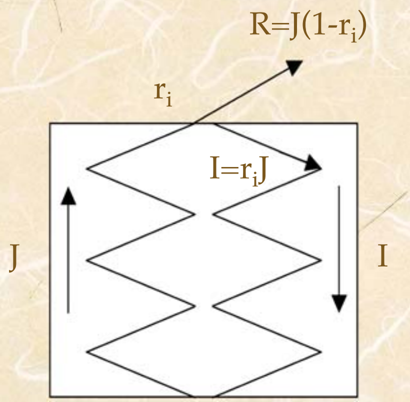
$$D = \frac{1}{3}\frac{1}{\mu_a + \mu_s'}$$

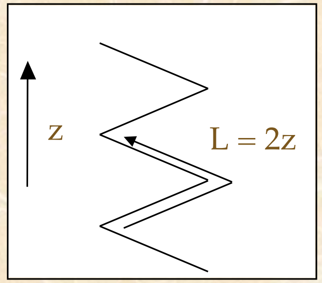
$$F(\mathbf{r}) = P_0 \frac{\exp(-\mu_{eff}\mathbf{r})}{4\pi D\mathbf{r}}$$

$$D = \frac{1}{3\mu_s(1-g)}$$

$$\mu_{eff} = \sqrt{\mu_a/D} = \sqrt{3\mu_a\mu_s(1-g)}$$

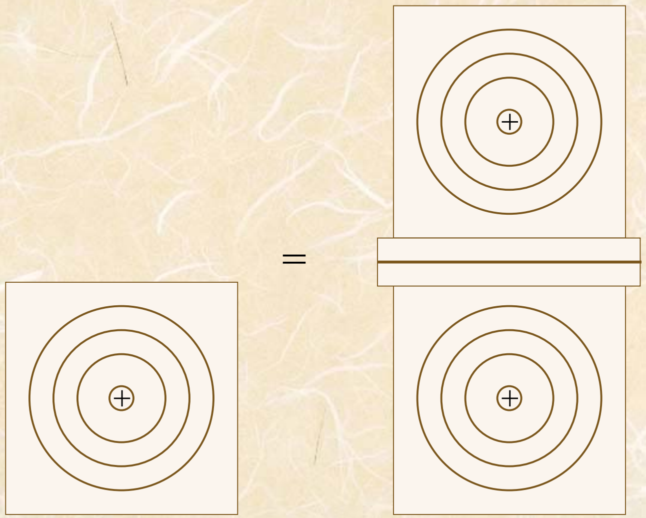
Air/tissue surface interface



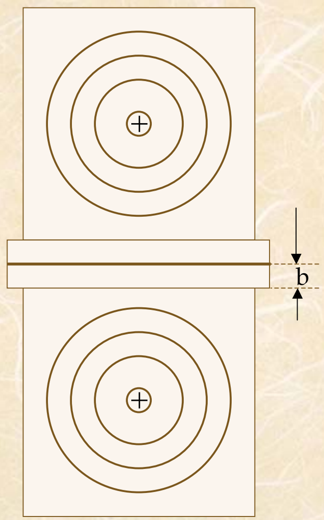


$$
\begin{aligned}
F &= 2(I + J) \\
&= 2(r_i J + J) \\
&= 2(r_i + 1)\frac{R}{(1 - r_i)} \\
&= 2\frac{(1 + r_i)}{(1 - r_i)}R
\end{aligned}
$$

Internal source and virtual source



Surface and virtual boundary



$$R = -D\frac{dF}{dz} = D\frac{F(0)}{b}$$

$$b = 2\frac{(1 + r_i)}{(1 - r_i)}D$$