

# Biomedical Optics VII

Optical properties measurements

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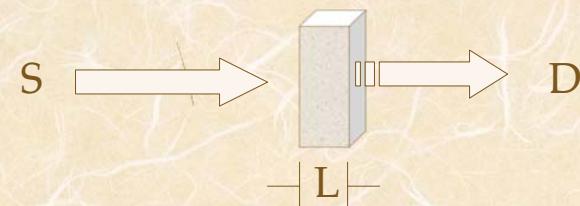
## Collimated transmission calculations

$$T = \exp(-\varepsilon^* CL) = 0.980 \quad \text{at } \lambda = 632.8 \text{ nm}$$

$$\begin{aligned} \varepsilon^* &= -\ln(T)/CL \\ &= \frac{-\ln(0.980)}{\left(\frac{2 \text{ \%lipid}}{4000}\right)(1 \text{ cm})} = 40 \left[ \frac{\text{cm}^{-1}}{\text{\%lipid}} \right] \end{aligned}$$

$$\mu_s = (40)(2 \text{ \%lipid}) = 80 \text{ cm}^{-1}$$

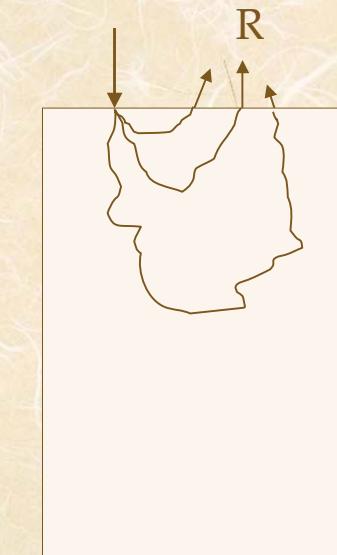
## Attenuation of collimated beam



$$\mu_a + \mu_s = \varepsilon C = \frac{-\ln(T)}{L}$$

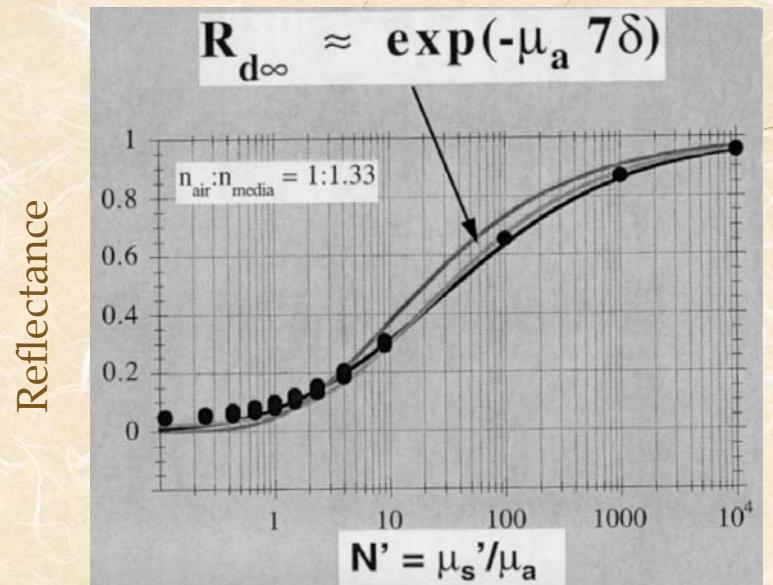
$\left[ \frac{\text{cm}^{-1}}{\text{\%lipid}} \right] \left[ \text{\%lipid} \right]$

## Total diffuse reflectance, R



$$R = \exp(-\mu_a L_{eff})$$

$$R = \exp(-\mu_a 7\delta)$$



Reduced scattering/absorption

Optical penetration depth,  $\delta$

$$T = k * \exp(-r/\delta)$$

$$\delta = \sqrt{\frac{D}{\mu_a}} = \frac{1}{\sqrt{3\mu_a(\mu_a + \mu_s)}}$$

$$= \frac{1}{\mu_{eff}}$$

## Calculations

$$R_\infty = \frac{P_{detected}}{P_0} R_{std}$$

$$= \frac{0.605 \mu W}{0.700 \mu W} (1.00) = 0.855$$

With added ink:

$$= \frac{0.351 \mu W}{0.700 \mu W} (1.00) = 0.496$$

## Calculations

$$R = 0.855$$



milk  
(2% lipid)

$$R = 0.496$$



milk +  
0.100 ml of ink  
into 400 ml milk  
( $\mu_a$  ink stock =  $2480 \text{ cm}^{-1}$ )

$$\mu_a \text{ ink} = 2480 / 4000 = 0.62 \text{ cm}^{-1}$$

## Calculations

$$R_\infty \approx \exp(-\mu_a 7\delta) = \exp\left(-\frac{7}{\sqrt{3(1 + \frac{\mu_s}{\mu_a})}}\right)$$

$$\frac{\mu_s}{\mu_a} = \frac{49}{3(-\ln(R_\infty))^2} - 1 = 665$$

$$\frac{\mu_s}{\mu_a + \mu_{a ink}} = \frac{49}{3(-\ln(R_\infty))^2} - 1 = 32$$

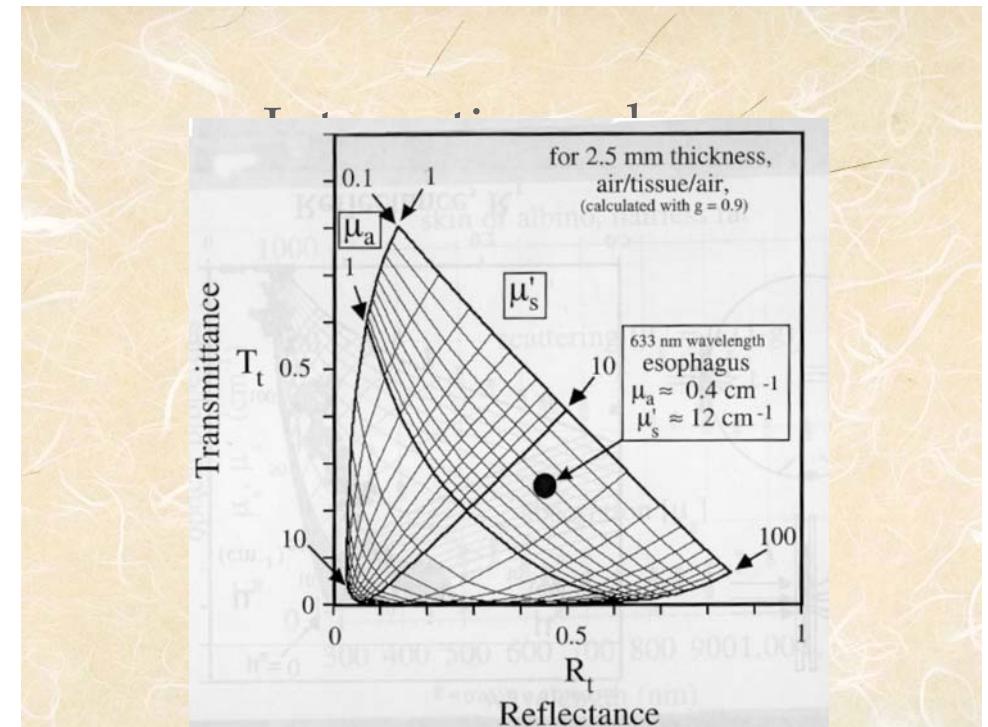
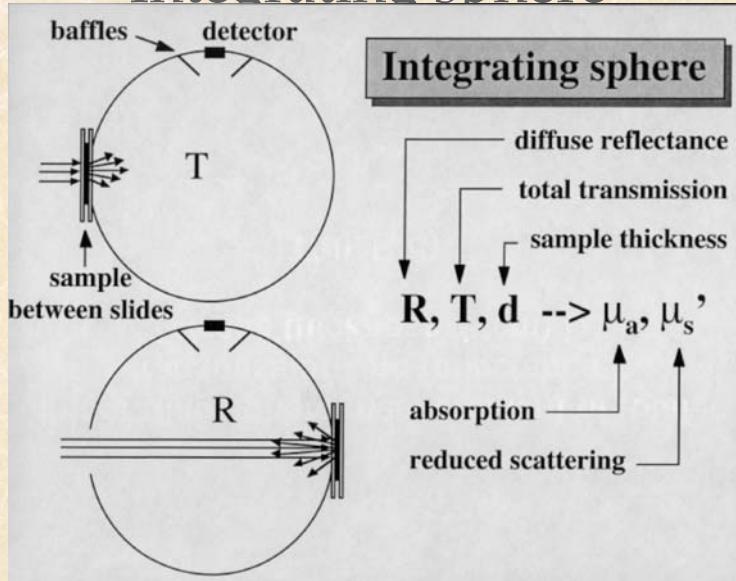
cont

$$\mu_a * 665 = (\mu_a + \mu_{a ink}) * 32$$

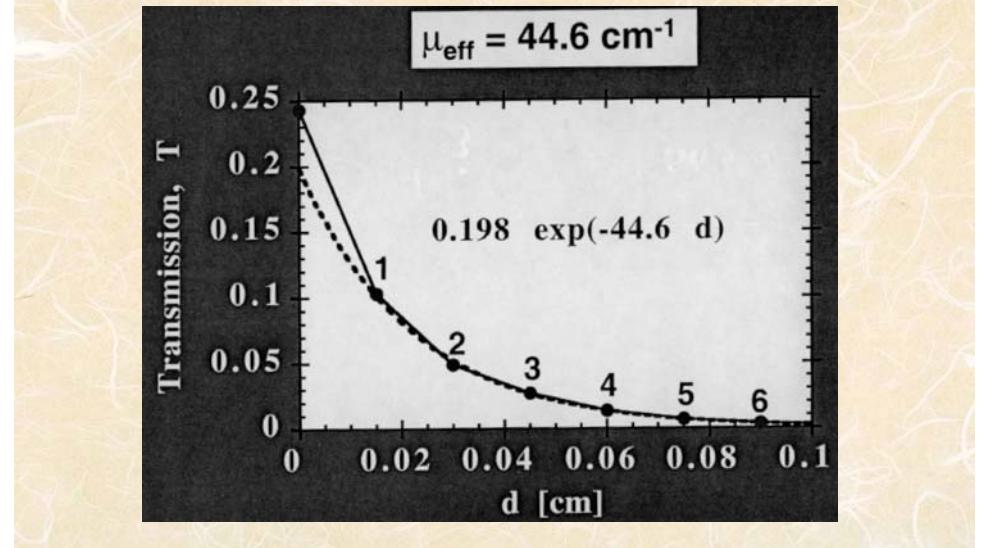
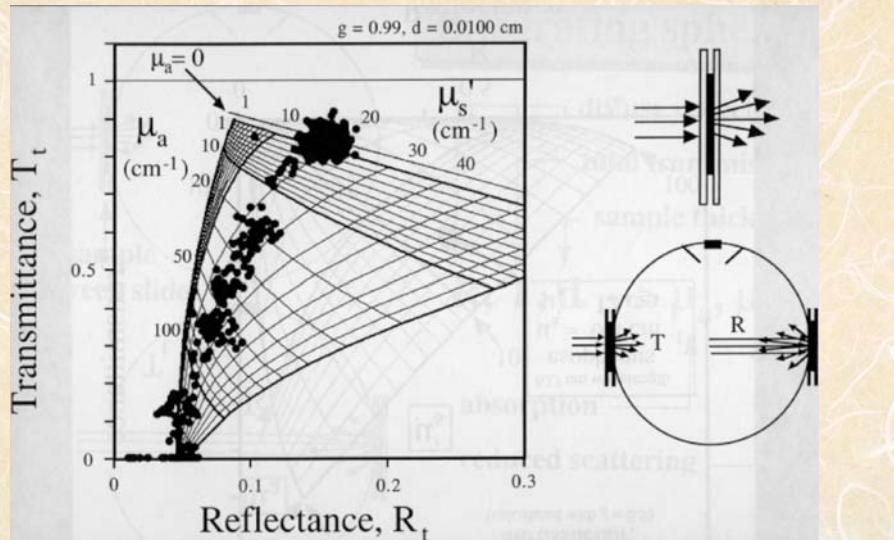
$$\mu_a = \frac{665 \mu_{a ink}}{1 - \frac{32}{665}} = 0.031 \text{ cm}^{-1} \frac{\text{for milk (2% lipid)}}{\text{at 633nm}}$$

$$\mu_{a ink} = 0.62 \text{ cm}^{-1}$$

## Integrating sphere



## Integrating sphere



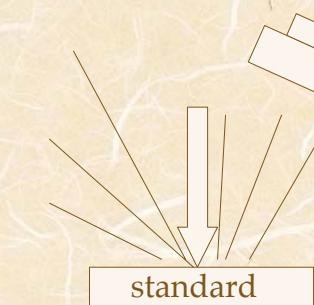
## Transmission calculations

$$\mu_{eff} = \sqrt{3\mu_a(\mu_a + \mu_s')} \approx \sqrt{3\mu_a\mu_s'} = 44.6 \text{ cm}^{-1}$$

$$\mu_a\mu_s' = \frac{44.6^2}{3} = 663 \text{ cm}^{-2}$$

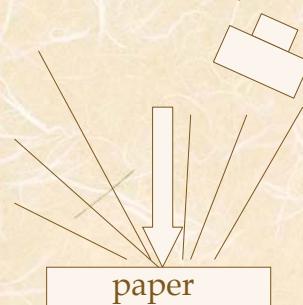
## Reflection calculations

Reflected power  
= 2  $\mu W$



100% reflectance standard

Reflected power  
= 1.58  $\mu W$



$$R_\infty = \frac{1.58}{2.00}(1.00) = 0.792$$

$$R_\infty \approx \exp(-\mu_a 7\delta) = \exp\left(-\frac{7}{\sqrt{3(1 + \frac{\mu_s}{\mu_a})}}\right)$$

$$\frac{\mu_s}{\mu_a} = \frac{49}{3(-\ln(R_\infty))^2} - 1 = 300$$

$$\mu_s' = \frac{633 \text{ cm}^{-2}}{\mu_a} \quad \text{from integrating sphere}$$

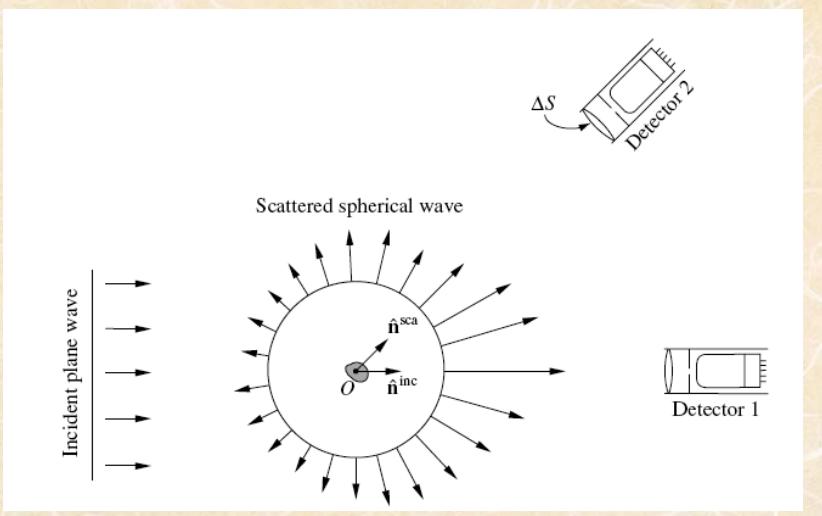
$$\mu_s' = 300\mu_a \quad \text{from paper reflectance}$$

$$\mu_a^2 = \frac{633}{300} = 2,21 \text{ cm}^{-2}$$

$$\mu_a = 1.48 \text{ cm}^{-1}$$

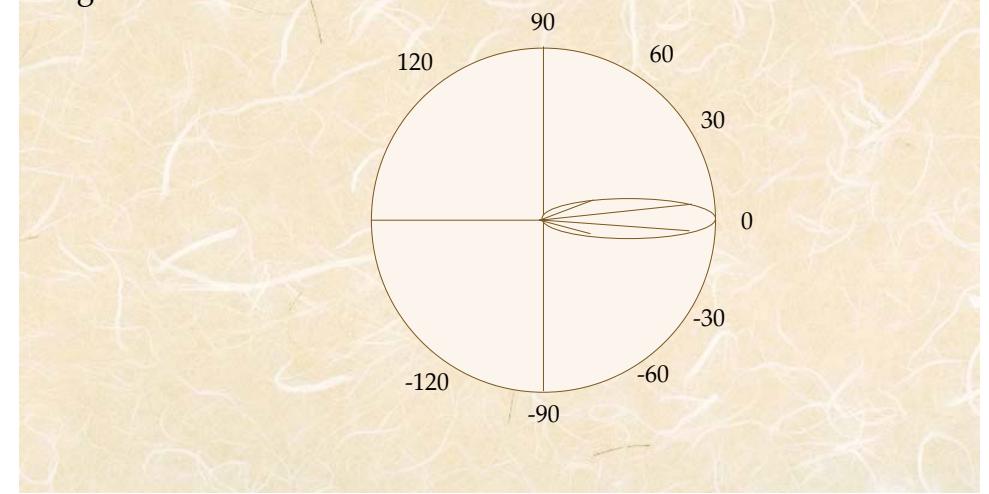
$$\mu_s' = 446 \text{ cm}^{-1}$$

## Goniometer principle



## Scattering pattern $p(\theta)$

$g=0.78$  at 633 nm



## Alternative calculations

$$\mu_s' = \mu_s(1 - g)$$

$$g = 1 - \frac{\mu_s'}{\mu_s}$$

$$g = 1 - \frac{20}{80} = 0.75$$

## CCD camera with tilted source

