# Biomedical Optics I

Introduction

E. Göran Salerud

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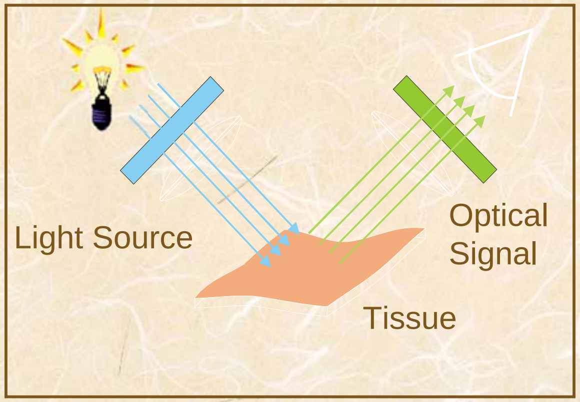
# Course Content

- Introduction, general optics
- Optical definitions and calculations
- Tissue optical properties
- Optical transport
- Monte Carlo simulation
- Measurement of optical parameters
- Applications
  - PPG
  - Spectroscopy
  - OCT
  - LDF

# Why use optical methods?

- Probes structures as well as molecules associated with disease progression already present in tissue
- Non-invasive
- Fast
- Automated

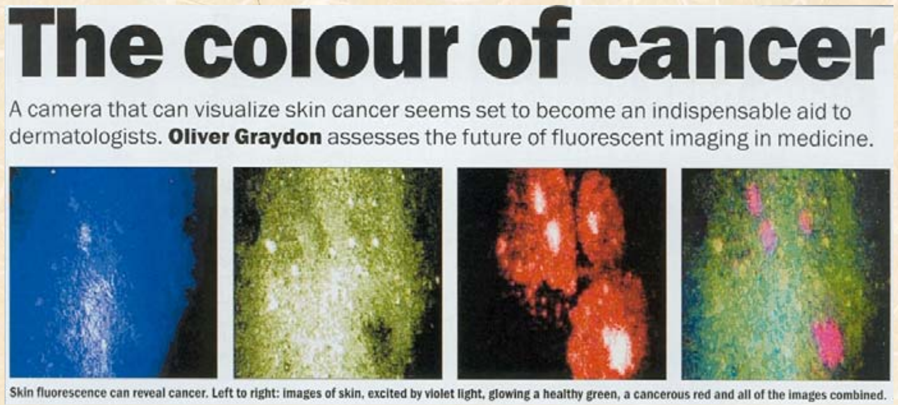



# Why should you learn about Biomedical Optics?

- Working understanding of absorption, fluorescence and scattering spectroscopies
- To understand how these interactions can be modeled in tissue
- How they can be implemented in diagnostic tools

# What could be regarded as Biomedical Optics?

# Skin flourescence

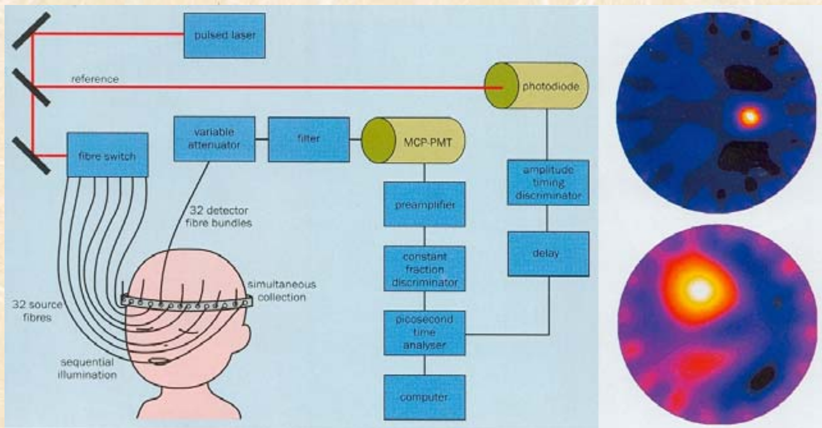


The colour of cancer

A camera that can visualize skin cancer seems set to become an indispensable aid to dermatologists. **Oliver Graydon** assesses the future of fluorescent imaging in medicine.

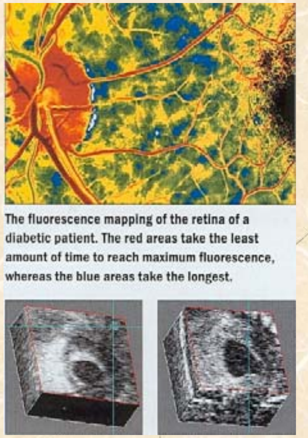
Skin fluorescence can reveal cancer. Left to right: images of skin, excited by violet light, glowing a healthy green, a cancerous red and all of the images combined.

# Picosecond laser for oxygen measurements

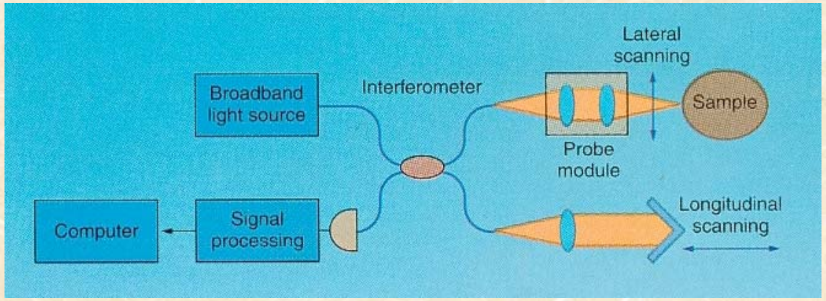



# Lasertracking of the eye

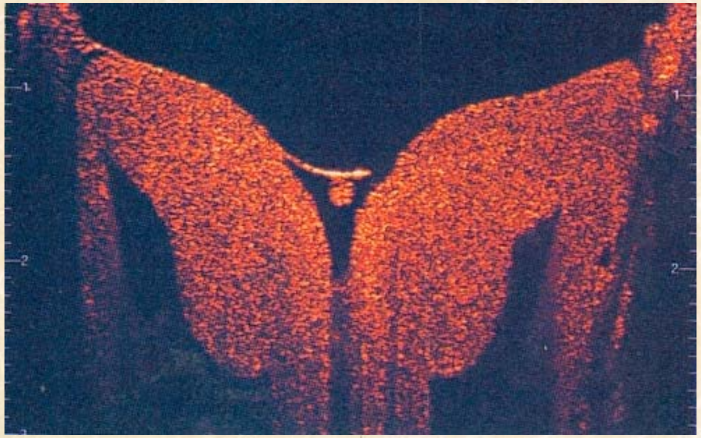
# Flourescense of retina, Diabetic patient



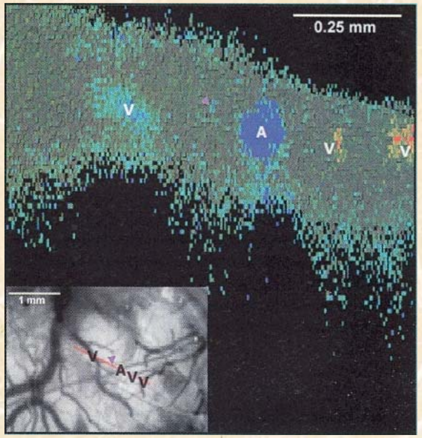

# OCT




# Brain tissue of frog

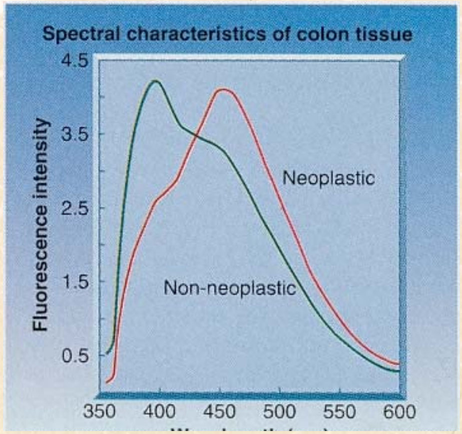


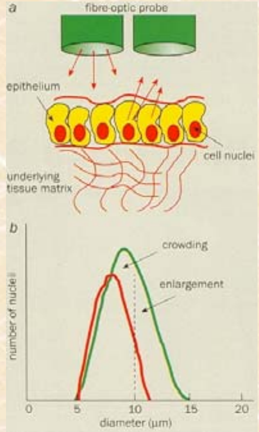

# OCT radar



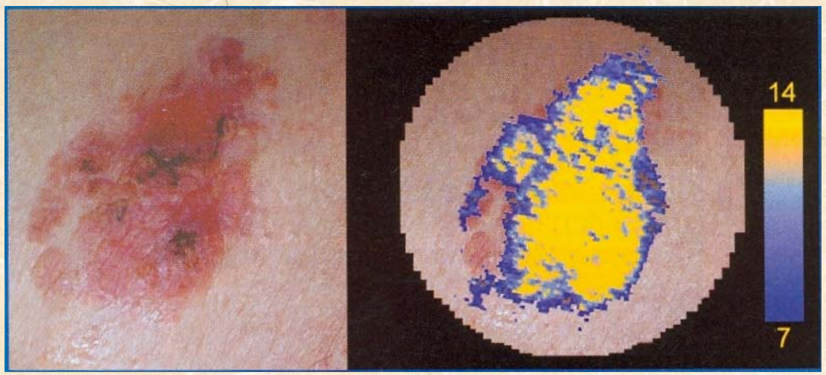
# PDT


# Spectroscopy

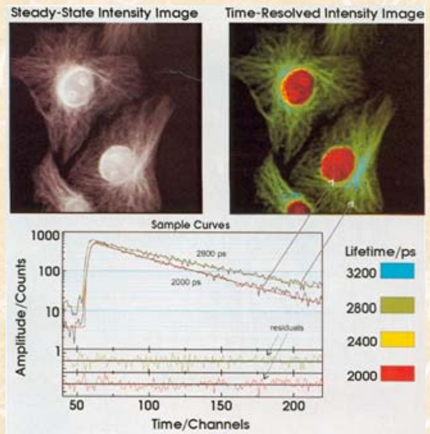


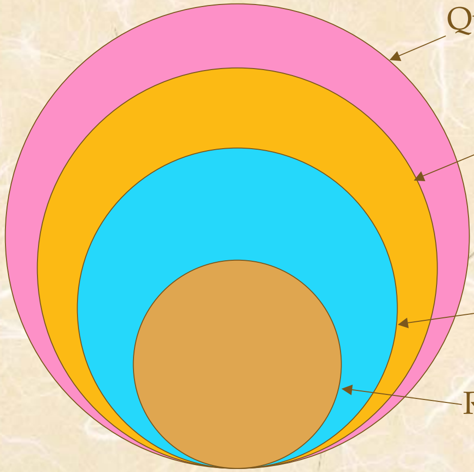

# Basal cell carcinoma




# Time resolved microscopy



# Fundamentals of Optics




# Ray Optics

- Light travels in the form of rays. They are emitted by light sources and can be observed when they reach an optical detector.
- An optical medium is characterized by a quantity n>1, the refractive index. It is the ratio of the speed of light in free space $c_0$ to that in the medium.
- In a inhomogenous medium the refractive index n(**r**) is a function of the position.

$$\text{Optical pathlength} = \int_A^B n(r)\,ds$$

# Wave Optics

- **Definition:** That branch of optics concerned with radiant energy and related phenomena, as defined by wave characteristics.
- Thomas Young discovered the interference of light from adjacent pinholes and established the wave theory of light.
- The polarization of light by reflection had been discovered in 1808 by Malus and the polarizing angle discovered by Brewster in 1811.
- Fresnel was able to explain polarization using Young's suggestion that light was a transverse vibration and his analyses of diffraction effects were convincing, but the final proof of the wave theory depended on the experimental proof that light traveled more slowly in denser media

# EM Optics

- **Definition:** Wave of radiation identified by individual fluctuations of electric and magnetic fields.
- Maxwells equations in free space

$$\nabla^2 \vec{E} = \frac{1}{c^2}\frac{\partial^2 \vec{E}}{\partial t^2}$$

$$\nabla^2 \vec{\mathbf{B}} = \frac{1}{c^2}\frac{\partial^2 \vec{\mathbf{B}}}{\partial t^2}$$

$$\textit{where,}$$

$$c - \textit{speed of light}$$

Describes propagation of light in free space.

# Quantum Optics

- Historical perspective
  - Max Planck (1858-1947) - Introduced concept of light energy or "quanta" (blackbody radiation) and the "Planck" constant
  - Albert Einstein (1879-1955) - Proof for particle behavior of light came from the experiment of the photoelectric effect
- Quantum-mechanical properties of light.
- The electric and magnetic fields E and H are mathematically treated as operators in a vector space

# Quantum Description of Light

- *Energy of a photon:*

$$E_{photon} = h\nu = hc/\lambda$$

*Momentum of a photon:*

$$p_{photon} = E_{photon}/c = h/\lambda$$

$$m_{photon} = 0$$

# Wave / Particle Duality

Photons versus EM waves

- Light is composed of small parcels called photons.
- Depending on their interactions with other matter, light either has particle or wavelike behavior.
- This duality in the nature of photons is a key aspect of Quantum theory

# Wave / Particle Duality

Photons versus EM waves (continued)

- Light is a particle and has wave like behavior
- The photon concept and the wave theory of light complement each other
- Depends on the specific phenomenon being observed

# Overview of Spectroscopy

Definition: Interaction of EM Radiation with Matter

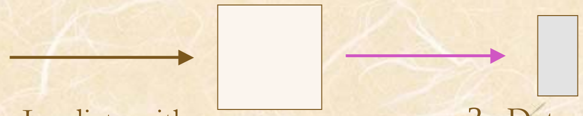
We see objects because they remit some part of the light falling on them from a source.
We function as reflection/ transmission spectrometers.

Normally, we see only reflection and transmission of light, but there are other types of interactions.

# Overview of Spectroscopy

Spectroscopic Measurements

1. Sample



2. Irradiate with EM radiation

3. Detector to measure

Absorption
Emission
Scattering
($\theta$, $\lambda$, t)

4. Interpret results. Requires some understanding of the physical basis of the interaction.

# Overview of Spectroscopy

Information available from spectroscopy

- Analytical – concentrations of molecules
- Structural – shape, size, conformation, etc
- Dynamic – molecular motion, movement of cells and molecules, etc
- Energetics – pH, binding, etc

# Classical Description of Light

EM spectrum