Photomedicine

CH-448: 3 credits
Molecular & Biological Chemistry; Master
Chemistry and Chemical Engineering; Master
Microengineering; Master
EDOC + Minor in Photonics

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(please make an appointment)
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Photomedicine

- CLASS LOCATION AND MEETING TIMES

  Monday from 12:15 - 14:00 in room GC D0 386.

- MOODLE ACCESS FOR STUDENTS

  https://moodle.epfl.ch/course/view.php?id=15073

Photomedicine

Students list from IS-Academia

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Ducruet Lou-Anne Juliette	330238	Féminin	CGC_CHIM
Guillosson Coline	325754	Féminin	CGC_CHIM
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Micaleff Arthur Baptiste	378105	Masculin	MX
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Tancredi Lisa	346899	Féminin	CGC_CHIM
Tang Vidale Marc	389495	Masculin	CGC_CHIM
Von Doderer Edward Richard	313250	Masculin	CGC_CHIM
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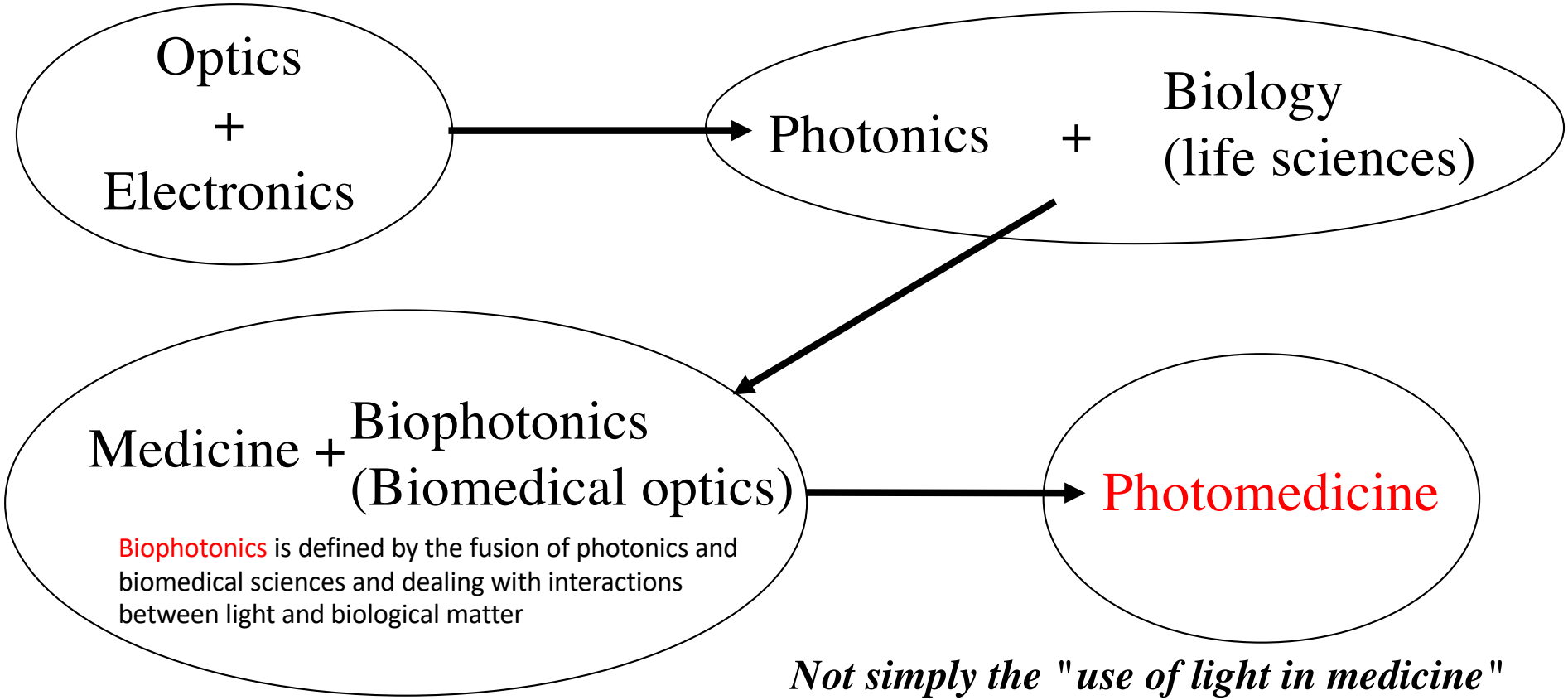
Wiprächtiger Liam	339370	Masculin	CGC_CHIM
Zhang Michael	395179	Masculin	CGC_CHIM

What is Photomedicine ?

Photomedicine includes:

- ***The study and treatment of diseases caused by exposure to (sun)light.***
- ***The diagnostic and therapeutic applications of light for detecting, characterizing and treating diseases.***

Scientific fields and technologies supporting photomedicine ?



Not simply the "use of light in medicine" for diagnostic or therapeutic purposes !

!! Near infrared and near UV are also considered in photomedicine!!

Main applications in the field of photomedicine

- Optical **diagnosis** (non-invasive/minimally invasive, high resolution)
- Light-based **therapies** (minimally invasive, novel treatments possible; e.g. photodynamic therapy, plastic surgery with lasers)
- Bioimaging / **biosensing** (non-invasive, highly sensitive/selective, remote sensing)
- …

Course Description and Objectives

- This course will provide students with an overview of current status and research in photomedicine.

- We will also briefly address the study and treatment of diseases caused by the exposure of tissues to light.

Course Description and Objectives *cont.*

Through ***lectures***, ***exercises***, recent ***literature*** review papers, classroom ***discussion + oral presentations***, students should gain an understanding of the present status and major research directions in photomedicine and develop the ability to critically evaluate works and technologies in this field.

This course will briefly review selected basic principles of radiometry, optics, tissue optical spectroscopy as well as the most important applications of these techniques in photomedicine.

Medical interest of light

• Non-invasive, real-time **detection** and **measurements** of structure and function in living systems *in situ*

• "Novel", minimally- or non-invasive **therapeutics**

• Enhanced sensing and spatial resolution **in the clinic** (optical resolution, …)

• Compatibility with other methods/technologies:
  • multi-modal: electrical, chemical, mechanical
  • fiber optics for minimally invasive therapy

Why photomedicine !

Health care costs in 2019 in USA was 3.8 trillion $US, in Germany 390.6 billion €. Advanced photonic technology enables early detection of diseases and the development of minimal-invasive treatment leading to shorter hospitalization time. Patient specific drugs will be more effective and treat the origin of the diseases. These changes will reduce health care cost considerably. Some estimates expect a reduction of up to 20%. This would result in an overall reduction of up to **1 trillion $US per annum worldwide**.

The market of **photonics** in **medtech** applications is growing fast: From US$ 5.95 billion in 2005 to US$ 20,4 billion in 2010 to US$ 38,3 billion in 2015.

Medical imaging is contributing to a $ 710 million growth between 2015 and 2020

Source: Statistisches Bundesamt; "Towards a Bright Future for Europe Strategic Research Agenda in Photonics", Published by: European Technology Platform Photonics, www.forbes.com.; Photonics Spectra, 09/2017.

Importance of Photomedicine

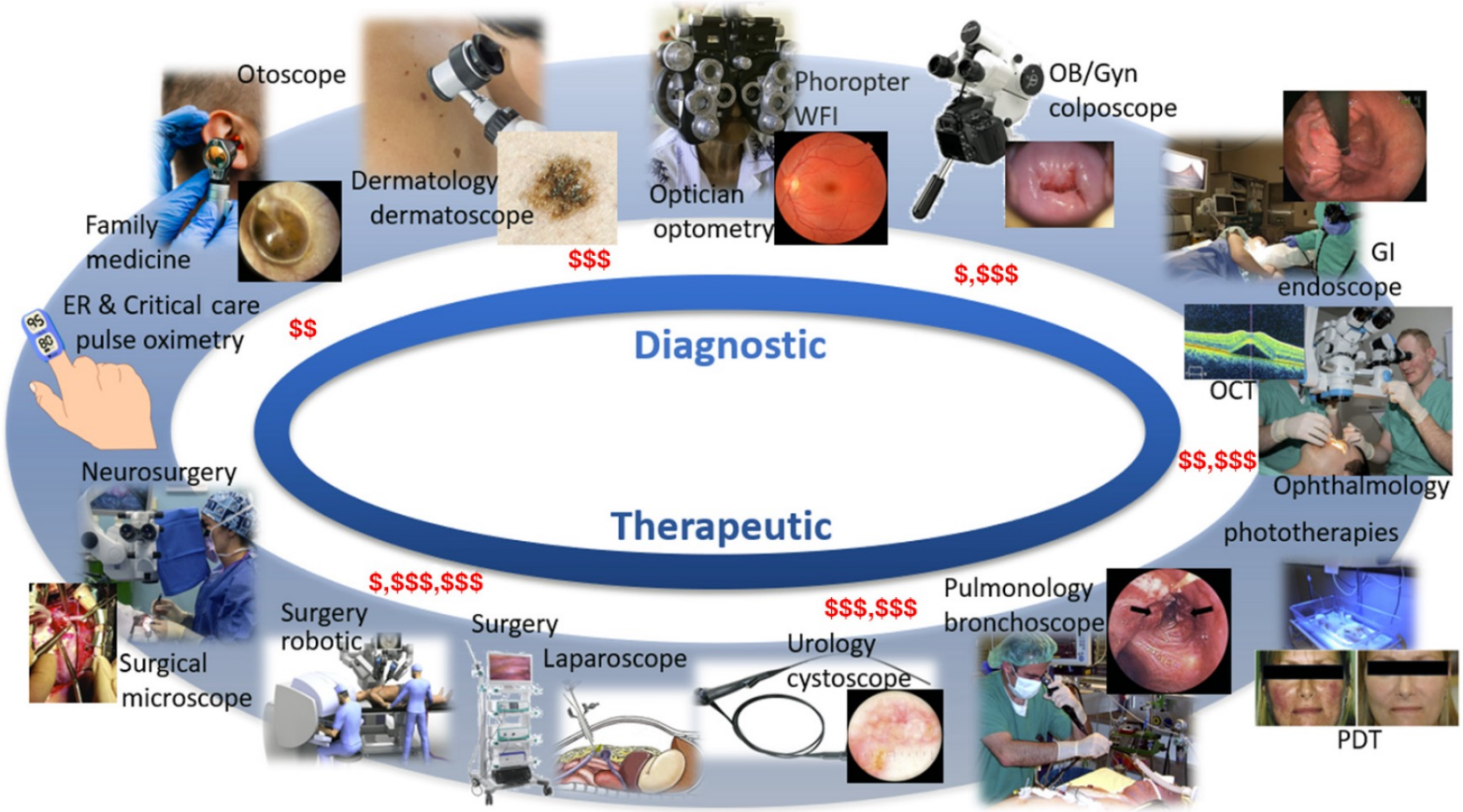


Fig. 2 Visual display of a range of many commonly adopted optical technologies used in medicine, broadly classified as diagnostic (top) and therapeutic (bottom), and roughly organized clockwise from lower system cost (top left) to higher system cost (bottom left), as noted by red dollar signs.

Source: B. Pogue, JBO, 2023

Importance of Photomedicine

Market of medical imaging

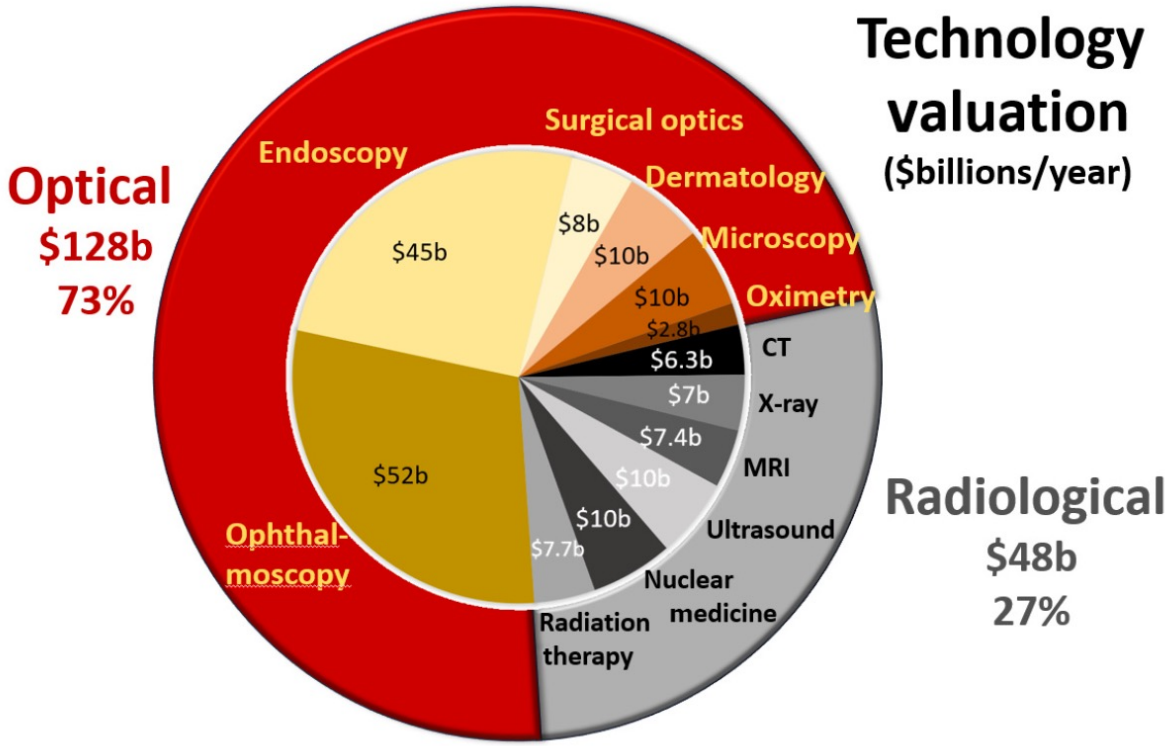


Fig. 3 Global market valuation of six radiological areas (CT, x-ray, MRI, ultrasound, nuclear medicine, and radiotherapy) is summarized above totaling $48 billion for 27% of the global device market. The optical technology areas that were largest are also summarized (ophthalmology, endoscopy, surgery, dermatology, microscopy, and pulse oximetry) totaling $128 billion/year for 73% market share.

Source: B. Pogue, JBO, 2023

SWOT of Photomedicine

Table 3 Strengths, weaknesses, opportunities & threats (SWOT) of the technology sector of medical optical imaging.

Strengths	Weaknesses
• Highly efficient economical imaging due to invention and advancement of CMOS cameras	• Largely limited to surface and cavity imaging, vision imaging, or near sub-surface sensing/imaging
• Enormous economy of scale with consumer optical devices, a $2.8 trillion industry	• Tissue imaging deeper than a few mm has never been commercially successful due to limited spatial resolution
• Large engineering workforce, largest technology sector in medicine	• Each application has specialized system, diffusing the overall view of optical imaging systems
• Primary tool for point-of-care and interventional vision	• Slow introduction of contrast agents
• Optical devices are core to many highly sensitive radiation detection systems	
• Synergy with advances in display technologies	
Opportunities	**Threats**
• Continuing explosion of consumer technologies that advance optical imaging capabilities	• Dearth of communication between academic and industrial biomedical optics research directions
• Advanced surgical, laparoscopic, endoscopic technologies that augment vision beyond just color imaging	• Limited NIH investment in optical tech despite being widely adopted in point-of-care exams
• Microscopic to macroscopic imaging in the same instruments	• Funding structures limit the ability to work with industry on collaborative development
• Scattering makes the signal more sensitive to the entire tissue volume, beyond vessels	• Lack of technical domain experts within the medical center to assist physician groups when deploying advanced medical optical systems
• Highest potential for molecular sensing of all imaging modalities due to numerous optical molecular probes	• Physician work overload minimizing use of advanced instruments
• Shifting healthcare toward wellness instead of healthcare, requiring monitoring technologies	
• Screening requires low-cost, low-risk systems	

Source: B. Pogue, JBO, 2023

Photomedicine: motivation / interest

- It is multidisciplinary !
  (major technology breakthroughs frequently occur at the interfaces of disciplines)

- **Opportunities for engineers:**
  - Optical engineering for noninvasive diagnostic technologies (imaging, spectral or "point" measurements).
  - Device miniaturization (endoscopy), integration, automation, and robotic control.

Photomedicine: motivation / interest

- **Opportunities for engineers** (continued):
  - New chemicals: photosensitizers or probes for analyte detection, biosensing and treatments.
  - Real time monitoring of drug delivery, biodistribution and action (tissue response).

…

Photomedicine: motivation / interest

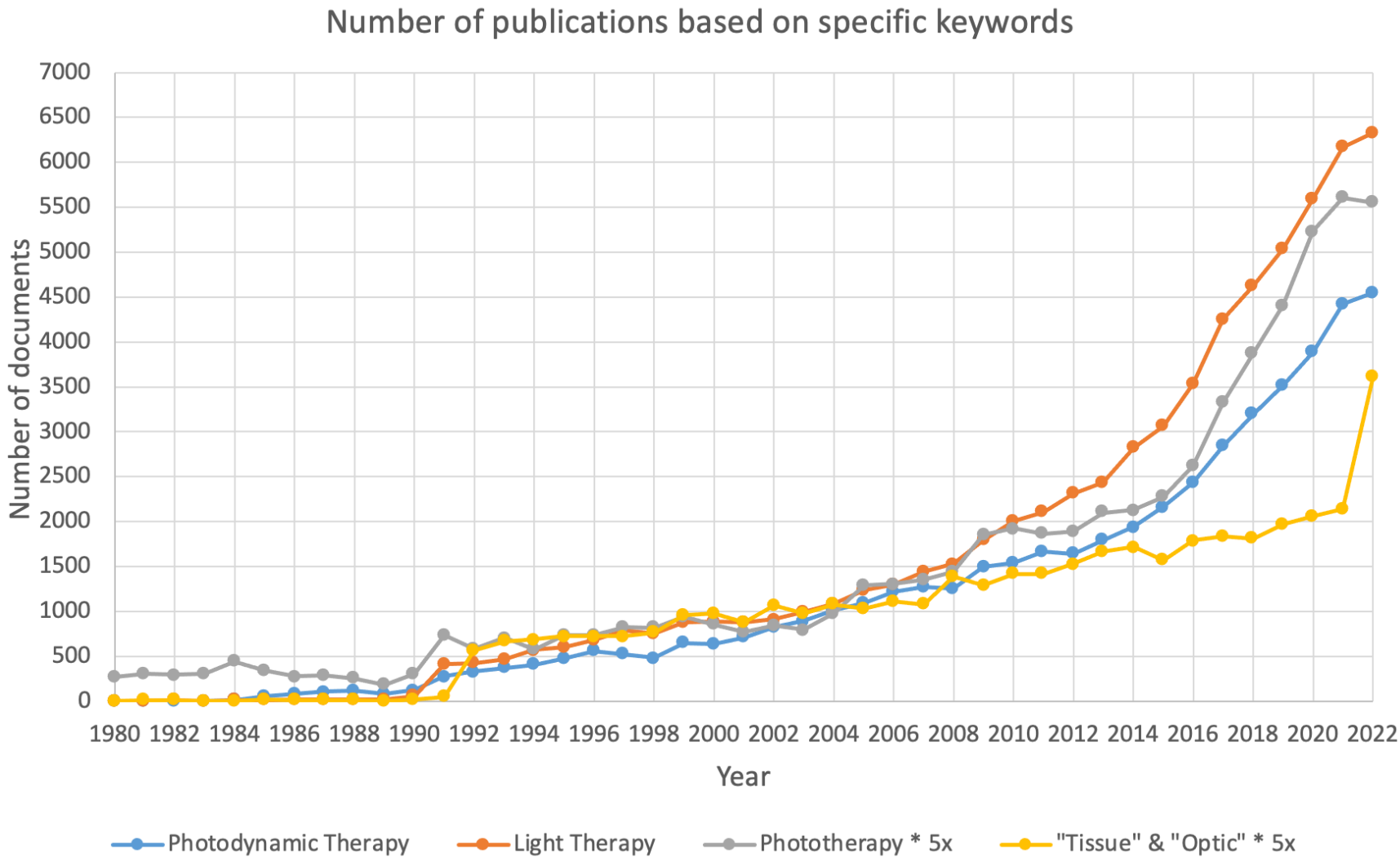
Developments of enabling technologies in optical science!

- laser sources
- optoelectronic devices (LEDs)
- fiber optics
- physical and chemical sensors
- spectroscopy and imaging
- …

…are being applied to photomedicine

Many of them are versatile, robust and inexpensive, and are being developed at an increasing rate!

Web of Science records for specific topics
(1980 to 2022)



Tentative Syllabus

1. **Introduction**
2. **History**
3. **Radiometry / photometry**
4. **Optics review**
   - Ray optics
   - Electromagnetic / wave optics
   - Quantum description of light
   - Wave-particle duality

Tentative Syllabus *cont.*

5. **Tissue optics**
   - Tissue optical parameters
   - The radiative transport equation (RTE)
   - Approximation of the RTE
   - Measurement methods
6. **Light dosimetry in tissues**
7. **Applications of Absorption, fluorescence and Raman spectroscopies and imaging in photomedicine**
8. **Dyes, luminophores and photosensitizers**

Tentative Syllabus *cont.*

9. Intruments

Light sources

Dispersive devices

Detectors for optical spectroscopy and imaging

10. Selected applications (in part students' presentations)

Oxymetry

Angiography

Laser-tissue interactions

Phototherapy and Photodynamic therapy

Photodetection of early cancers

Optical coherence tomography

…

Class presentations

- On a topic of major interest to you, you will review relevant literature.

- This could be a general review paper, or a critical evaluation/description of a particular phenomenon, study, method, or technology.

- In order to benefit the entire class and provide you with valuable feedback, you will give an oral, in-class presentation (?about 15 + 5 minutes?) on your topic.

Class presentations

Examples of topics

Final selections of the topics must be approved by the instructor.
I encourage you to discuss your ideas with me as soon as possible.

- Molecular probes/markers/contrast agents used in photomedicine.
- Photosensitizers used in photodynamic therapy.
- Optical Instrumentation: light (laser) sources; optical waveguides; detectors; time-domain vs. frequency-domain methods; safety considerations; …
- Tissue Optics.
- Computational approaches to model the light propagation in tissues.

Class presentations

Examples of topics *cont*.

Final selections of the topics must be approved by the instructor.
I encourage you to discuss your ideas with me as soon as possible.

- Optical Diagnostics: Clinical Spectroscopy and Imaging: elastic scattering; diffuse reflectance; laser-induced fluorescence; Raman; endogenous and exogenous contrast agents; optical coherence tomography; low coherence interferometry; …

- Biomedical Microscopy: fluorescence wide-field; fluorescence lifetime; confocal sectioning; multi-photon excitation; second-harmonic generation; near-field ...

Class presentations

Examples of topics *cont*.

Final selections of the topics must be approved by the instructor.
I encourage you to discuss your ideas with me as soon as possible.

- Light/laser-based Therapy: photothermal; photomechanical; photochemical; photodynamic therapy; tissue engineering ...

- Biophotonic Technology: optical biosensors; microarray technology; flow cytometry; laser tweezers; laser scissors; laser capture microdissection; bionanophotonics; biomaterials for photonics ...

Class presentations

Examples of topics *cont*.

Final selections of the topics must be approved by the instructor.
I encourage you to discuss your ideas with me as soon as possible.

- Why do sub-dermal blood vessels look blue ?
  Tissue optics is complex. One particular observation that is not completely obvious is why sub-dermal blood vessels look blue and not red, as one might have suspected. An understanding of this problem is of interest for laser treatments of hyper-vascularised lesions, such as port wine stains.

Class presentations

- This is a personal work !

  (Please read the polylex **Honor Code** and **the Code of Ethics for Citing Information Sources**).

Exams

Grading

Your grade will be determined as follows:

- Oral exam 2/3
- Oral presentation 1/3

Recommended readings

General Reference Texts:

- *Quantitative Biomedical Optics*

  I. Bigio and S. Fantini (Cambridge Uni. Press, 2016)

- *Fundamentals of Biomedical Optics*

  C. Boudoux (Pollux, 2016)

- *Handbook of Photomedicine*

  M. Hamblin, Y-Y. Huang (CRC Press, 2014)

  http://www.crcnetbase.com/doi/book/10.1201/b15582

- *Optics*

  E. Hecht (Addison Wesley, 2000)

Recommended readings *cont.*

Specialized Texts:

- *Handbook of Biomedical Fluorescence*
  M.-A. Mycek & B.W. Pogue (Dekker, 2003)
  http://www.crcnetbase.com/isbn/9780824709556

- *Optical-Thermal Response of Laser Irradiated Tissue*
  A.J. Welch & M.J.C. van Gemert (Plenum, 1995)

- *Principles of Fluorescence Spectroscopy*
  J.R. Lakowicz (Kluwer, 1999)

Recommended readings *cont.*

(Other useful resources)

- ***Biophotonics***
  - free subscription at: https://www.photonics.com/BioPhotonics/p1
- ***The Virtual Journal for Biomedical Optics***
  - http://www.opticsinfobase.org/vjbo/virtual_issue.cfm
- **Newport** has very good optics tutorials
  - https://www.newport.com/resourceListing/tutorials
- **http://www.photobiology.info** is a very good site in the field of photobiological sciences

Glossaries

Optics https://www.plasticoptics.com/glossary.pdf

Optical fibers https://focenter.com/foc-glossary

Medicine http://alexabe.pbworks.com/f/Dictionary+of+Medical+Terms+4th+Ed.-+(Malestrom).pdf

Available on Moodle !

Photochemistry

GLOSSARY OF TERMS USED IN PHOTOCHEMISTRY
INTERNATIONAL UNION OF PURE
AND APPLIED CHEMISTRY
ORGANIC CHEMISTRY DIVISION
COMMISSION ON PHOTOCHEMISTRY
S.E. Braslavsky Pure and Applied Chemistry Vol. 79, No. 3, pp. 293-465, 2007

Available on Moodle !

Thanks !

I would like to acknowledge and heartily thank the people who helped me to create this course.

In particular, I am deeply indebted to:

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- Prof. Bruce Tromberg, University of California, Irvine
- Prof. Urs Utzinger, University of Arizona
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For sending me their lecture materials