Universidad de los Andes

Departamento de Física

Medical Physics (Elective Course) 2019-II

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There will be some guest lectures by Prof. Luz Stella Veloza Salcedo, Universidad Nacional de Colombia, Bogotá, who is working in the field of medical physics.

I Introduction

It is often that most people including even the physics students do not realize the importance of fundamental sciences in everyday life. Medical physics is indeed a branch of physics which has grown on the basis of several basic science discoveries. Many of the tools on which modern medicine is based were invented by physicists with one of the best example being that of the discovery of X-rays by Roentgen which earned him the first Nobel prize in physics. Technologies such as nuclear magnetic resonance and positron emission tomography would not have been possible without the fundamental research in nuclear and particle physics. We have a come long way in medical physics starting from the days of the use of X rays in medicine. The present course aims at bringing the knowledge and understanding of the recent developments in medical physics to students of physics while bridging the gap between fundamental science and technological applications at the same time. The course in principle is also of interest to students of biomedical engineering, who, while being exposed to the modern developments in the diagnostic and therapeutic tools in medicine can also appreciate the roots of these developments in basic science.

The course begins with an introduction to the basics of interaction of radiation with matter and the discussion of the biological effects of radiation on the human body and other living organisms. Next, after describing the basic principles of the radiation detection, a functioning of advanced medical imaging modalities and their applications in medical diagnostics is described. In particular we will present examples of clinical applications and explain in detail methods of operation of: Computed Tomography, Mammography, Magnetic Resonance Imaging, Ultrasonograph Imaging, Single Photon Emission Computed Tomography and Positron Emission Tomography. An introduction to nuclear medicine therapy techiques such as Radiotherapy, Brachyteraphy, Hadron Therapy and Boron Neutron Capture Therapy will be given.

II Objectives

The main objectives of the course are:

- to give a background for understanding the physics and bio-medical principles of the most advanced methods used in cancer diagnosis and therapy and
- to broaden scientific horizons of participants by showing examples of applications of the basic physics and biological phenomena in daily life medicine and health care.

III Skills developed

On completion of the course, the student is expected:

- to develop a background on the different available techniques in the field of medical physics
- to develop an understanding of the physical principles and functioning of the methods used in diagnosis and therapy
- to have an overview of the most advanced methods used in the field with the knowledge of applications.

IV Scheduled topics and approximate duration

First 5 weeks (Prof. Paweł Moskal)

- Dosimetry in medical physics
  - Basics of interaction of radiation with matter
  - Biological effects of radiation
- Detection of radiation in medical physics
  - Detection of photons, X-rays and gamma quanta
  - Detection of electrons, protons and heavy ions
  - Detection of electromagnetic and acoustic waves
- Diagnostics: Computed Tomograhy (CT) and Mammography
  - Basic principles and applications of CT and Mammography
  - Future applications of Cone Beam Computed Tomography (if time permits)
- Diagnostics: Magnetic Resonance Imaging (MRI)
  - Basic principles and applications of MRI
  - Functional MRI
- Diagnostic: Ultrasound Imaging (US) (if time permits)
  - Basic principles and applications of ultrasound and acoustic imaging

Next 2 weeks

- Basics of Nuclear Medicine
  - Stability of the nucleus (alpha, beta and gamma decay)
  - Radioactivity: exponential decay, equilibrium in the parent and daughter nucleus
  - Radionuclide production by nuclear reactors and cyclotrons
  - Positron emission
- Dosimetry in Nuclear Medicine
  - radioactive tracers, calculation of absorbed dose, natural radioactivity and radiation exposure
  - radiation exposure in nuclear disasters
  - Steps in dose calculations
  - Teaching examples

Next 5 weeks

- Radiotherapy and Brachytherapy
  - Physics and radiobiology basics of radiotherapy
  - Dosimetry in radiotherapy
  - Patient motion compensation in radiotherapy
  - Basic principles and applications of Brachytherapy
- Hadron therapy
  - physical and biological phenomena constituting basis of hadron therapy
  - principles of operation of patients treatment with proton and carbon ions
  - newest directions for hadron therapy monitoring
- Boron Neutron Capture Therapy (BNCT)
  - physical and biological phenomena constituting basis of BNCT
  - future directions in BNCT
- Diagnostics and therapy in Nuclear Medicine
  - Radiopharmaceuticals in diagnostics and therapy
  - Basic principles of Single Photon Emission Computed Tomography (SPECT)

Next 3 weeks (Prof. Paweł Moskal)

- Positron Emission Tomography (PET)
  - Principle of operation of state of the art PET detectors
  - Principle of PET image reconstruction
  – radiation attenuation corrections
  – motion corrections

- Future directions in PET imaging:
  – Total-body PET (low dose and simultaneous multi-organ imaging)
  – Functional brain imaging with PET
- Computer simulations in medical physics
  - Very basics of Monte-Carlo simulations
  - Examples of application of Monte Carlo simulations:
  – for design of medical diagnostics devices
  – for personalized treatment in hadron and radio therapy.

Last week
Project presentations

V Methodology

Since the course is focussed on teaching the basic principles used in medical physics, the classes will involve black board teaching accompanied by presentations. The physics and theory involved will be taught during the lectures. Examples with applications will be shown with the help of presentations.

VI Grades

2 Partial exams: August 28, 2019, 15 % and September 24, 2019, 15 %

Term Paper: 40 % (20 % for presentation and 20 % for write-up)

Final Exam 30 %

There will be one partial exam and one final exam during the semester. The students also have to present a term paper. The term paper consists of an article written by the student on a topic closely connected with the syllabus of this course. The student is expected to choose a topic and then find relevant information in books and literature and some research articles (can also be from journals with pedagogic articles) which discuss the issue. The topic cannot be one which already exists in the above program. Having chosen the topic, the student can discuss the topic outside lecture hours with the lecturer if he/she finds it necessary. Based on this, he/she should be able to make a write-up on the topic and do the presentation. Students can work in groups of 2 or 3 persons.

VII References

The following books contain the basic principles required for this course.

F. H. Attix, "Introduction to Radiation Physics and Radiation Dosimetry", Wiley-VCH (1991).

H. E. Johns and J. R. Cunningham, "The Physics of Radiology", 4^{th} edition, C C Thomas Pub Ltd. (1983).

Michael G. Stabin, "Fundamentals of Nuclear Medicine Dosimetry", Springer (2008).

Additional references:

A. Fenster and J. C. Lacefield, "Ultrasound Imaging and Therapy", CRC Press (2018).

Mia K. Markey, "Physics of Mammographic Imaging", CRC Press (2012).

Q. Li and R. M. Nishikawa, "Computer-Aided Detection and Diagnosis in Medical Imaging", CRC Press (2015).

P. M. Devlin, R. A. Cormack, C. L. Holloway, A. J. Stewart, "Brachytherapy: Applications and Techniques", Demos Medical, Second Edition (2015).

I. J. Das and H. Paganetti, "Principles and Practice of Proton Beam Therapy", Medical Physics Pub corp (2015).

N. S. Hosmane, J. A. Maguire, Y. Zhu and M. Takagaki, " Boron and Gadolinium Neutron Capture Therapy for Cancer Treatment", World Scientific (2012).

R. L. Wahl and Robert S. B. Beanlands, "Principles and Practice of PET and PET/CT", LWW, Second Edition (2008).

R. W. Brown et al., "Magnetic Resonance Imaging", Wiley-Blackwell, Second Edition (2014).