Centre for the Clinical Application of Particles

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Nuclear diagnostics and Magnetic Resonance Imaging

Week 1; Lecture 1; Section 1: Introduction

K. Long (k.long@imperial.ac.uk)
Department of Physics, Imperial College London/STFC
R. McLauchlan (ruth.mclauchlan@nhs.net)
Radiation Physics & Radiobiology Department, Imperial College Healthcare NHS Trust

Section 1

Introduction

Aims

With the course we aim to:

- Provide students with a general overview of the physical principles that underlie nuclear diagnostics (ND) and magnetic resonance imaging (MRI);
- Allow students to appreciate the factors that influence the development of contrast in ND and MRI; and
- Give students the means to estimate the resolution, speed, and sensitivity of ND and MRI imaging modalities.

Objectives 1: radionuclides and gamma camera

At the end of the course students will be able to:

- Explain the principal methods used for the production of radionuclides;
- Explain and apply the definitions of activity, half-life and decay constant;
- Calculate the energies of the particles involved in radioactive decay in a given situation;
- Explain the principal radioactive decay pathways and the application of the radiation produced to medical imaging;
- Explain how a gamma camera operates and discuss the main parameters that affect its performance;
- Calculate the resolution and efficiency of a gamma camera in a particular situation; and
- Explain the different types of event that can be recorded by using a gamma camera and discuss how these affect the image.

Objectives 2: SPECT and PET

At the end of the course students will be able to:

- Explain how Single Photon Emission Computed Tomography (SPECT) is performed;
- Explain the methods typically used in the reconstruction of a SPECT images;
- Explain how a Positron Emission Tomography (PET) image is produced and discuss the principal limitations of PET;
- Discuss the different types of detection events recorded by a PET system and how they affect the image;
- Calculate the resolution, detection efficiency, detection rate, and coincidence rate for a particular PET scanner;
- Explain how to compensate for attenuation and unwanted random and scatter events in PET; and
- Describe and discuss the main differences between 2D and 3D PET image acquisition

Objectives 3: Magnetic resonance imaging

At the end of the course students will be able to:

- Describe the principles of nuclear magnetic resonance (NMR);
- Discuss how relaxation mechanisms contribute to the generation of contrast in magnetic resonance imaging (MRI);
- Describe techniques for spatial localisation of the NMR signals in MRI;
- Distinguish between phase and frequency encoding is used in MRI to enable the spatial localisation of the NMR signal;
- Use the Fourier-transform technique to exploit ‘k-space’ to describe MRI images in this space;
- Connect the receiver bandwidth, acquisition time, and sampling frequency to the field of view and resolution;
- Identify the causes of the most common image artefacts;
- Show how the signal-to-noise ratio (SNR) is affected by the choice of data acquisition parameters;
- Recall the major hardware components necessary for MRI;
- Recall, devise, and interpret typical MRI pulse sequences and discuss the changes in image contrast induced by changes in the pulse sequences; and
- Calculate the optimal ‘TR’ and ‘TE’ to maximise image contrast for ‘proton density’, ‘T1’, and ‘T2’ weighted imaging.

Recommended books

Nuclear Medicine

- **Physics in Nuclear Medicine**
  S. Cherry, J.A. Sorenson, M.E. Phelps
  Central Library: 616.075 CHE also available as an e-book
- **The Essential Physics of Medical Imaging**
  J. Bushberg, J. Seibert, E. Leidholdt, J. Boone
  Central Library: 616.075 BUS and as an e-book
- **Practical Nuclear Medicine**
  P.F. Sharp, H.G. Gemmell, A.D Murray (Eds.)
  Central Library: 615.849 BUS and as an e-book
- **Essentials of Nuclear Medicine Physics and Instrumentation**
  R.A. Powsner, M.R. Palmer, E,R. Powsner
  Available at Hammersmith Library Main floor (WN440 POW) and as an e-book

Recommended books

Magnetic resonance imaging

- **MRI: the basics**
  R. Hasgemi, W. Bradley, C. Lisanti
  Central Library: 616.075 HAS
- **MRI: from picture to proton**
  D.W. McRobbie, M.J. Graves, E.A. Moore, M.R. Prince
  Central Library: 616.075 HAS and available online at:
  https://doi.org/10.1017/9781107706958
- **Electromagnetics in Magnetic Resonance Imaging**
  C.M. Collins
  Available as an e-book and online at:
  https://iopscience-iop-org.iclibezp1.cc.ic.ac.uk/book/978-1-6817-4083-6

Taught sections

The course material is broken down into:

- "Weeks"; each week will contain roughly 2 "lectures"
- "Lectures"; each lecture is broken down into a number of "sections"
- "Sections" will usually contain the material related to a particular (sub-)topic
  - Each section will be presented as a set of slides and a Panopto presentation
- "Active-learning" exercises will be interspersed with the sections

In a non-Covid year:

- The material presented in a "lecture" would correspond to that contained in a single 50-minute lecture

Discussion sessions

The course is intended as an introduction to the clinical application of NM and MRI techniques:

- Both the physical principles; and
- Aspects of the practical clinical application

So, after the presentation of a particular technique there will be:

- "Questions and applications" (Q&A) sessions led by a medical physicist
  - . . . your opportunity to ask questions!

Q&A sessions have dual purpose:

- Presentation of practical aspects of the technique
- Student-led question-and-answer session ($\approx$ "office hour")

Problem sheets

There will be two problem sheets:

1. Towards the end of the presentation of the nuclear diagnostics
2. Towards the end of the presentation of MRI

The problem sheets are not assessed

Communication: Blackboard and Piazza

Blackboard will be used for the distibution of course materials

Piazza will be used as a discussion forum:

- You should have received an invitation to the Piazza discussion group;
- Please do use it to raise issues, discuss course materials etc.

Overview of schedule in weeks, lectures, and sections

Week	Lecture	Section
1. 15Feb21	1. Introduction, nuclear medicine o/v, nuclear decay theory	1. Introduction
		2. Nuclear medicine
		3. Nuclear decay, revision
	2. Radionuclides, production methods, gamma-camera intro	1. Radionuclides for nuclear medicine
		2. Methods for production of radionuclides
	3. The gamma camera	1. Introduction
		2. Gamma camera
		3. Collimator
		4. Scintillator
		5. Examples
2. 22Feb21	4. Single photon emission computed tomography	1. Introduction
		2. Reconstruction
		3. Attenuation correction
		4. Scattering correction
		5. Examples
	5. Positron emission tomography I	1. Principles of positron emission tomography
		2. System resolution
		3. Sensitivity
3. 01Mar21	6. Positron emission tomography II	1. Types of coincidence event
		2. System resolution
		3. Data acquisition
		4. Comparison of sensitivity and corrections
		5. Examples

Week	Lecture	Section
3. 01Mar21	7. Introduction to MRI and quantum-mechanical foundations	1. Introduction to MRI
		2. Quantum mechanical foundations
4. 08Mar21	8. Classical development of principles of MRI	1. Classical derivation of Larmor equation
		2. Rotating the magnetisation
		3. Free induction decay
	9. Determination of T1 and T2	1. Determination of the spin-lattice relaxation time, T1
		2. Determination of the spin-spin relaxation time, T2
6. 15Mar21	10. Magnetic Resonance Imaging: spatial localisation	1. Slice selective excitation
		2. Encoding spatial information in k-space
		3. Encoding spatial information into net magnetisation
	11. Magnetic Resonance Imaging: contrast	1. Spin-echo sequence for proton-density weighted image
		2. Spin-echo sequence for T1-weighted image
		3. Spin-echo sequence for T2-weighted image
		4. Comparison of T1, T2, and proton-weighted images
		5. Inversion recovery
7. 22Mar21	12. Magnetic Resonance Imaging: artefacts	1. Aliasing (wraparound) and the Nyquist theorem
		2. Truncation artefact; Gibbs phenomenon
		3. Random motion artefacts
	13. More MRI artefacts	1. MRI artefacts: periodic motion
		2. MRI artefacts: chemical shift

The Physics Undergraduate office will release the week's material by the end of the morning on Monday each week

Assessment: 100% by examination

1 hour remote timed assessment

- Four questions
- **All** questions compulsory