Imaging & Biophotonics

<table>
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<tr>
<th>Module Code</th>
<th>PHYS96022</th>
<th>FHEQ Level</th>
<th>Level 6</th>
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<tr>
<td>Pre-requisites</td>
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<tr>
<td>Primary Department</td>
<td>Physics</td>
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<tr>
<td>Module Leader</td>
<td>Dr Chris Dunsby</td>
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<td>Additional Teaching Departments</td>
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<tr>
<td>Teaching Staff</td>
<td>Dr Chris Dunsby + Associates</td>
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<td>Programmes on which the Module is delivered</td>
<td>Core/Elective</td>
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<td>All UG Physics programmes (F300, F303, F309, F325, F390, F3W3)</td>
<td>Elective</td>
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**Learning Outcomes**

**Geometrical Optics:**
- Define and use ray vectors and ray transfer matrices
- Define the paraxial approximation
- Derive and apply individual and compound ray transfer matrices
- Describe cause and correction of spherical and chromatic aberration
- Analyse a simplified ‘ray model’ of optical trapping

**Scalar Wave Optics:**
- Derive and apply solutions of 1-D and 3-D wave equation
- State the definition and equation for intensity
- Describe the generalisation to polychromatic sources

**Interferometry and Optical Coherence Tomography:**
- Describe basic construction of a Michelson interferometer
- Contrast the difference between monochromatic and broadband illumination in a Michelson interferometer
- Define and derive coherence length and its influence on axial spatial resolution
- Describe application to biomedical imaging (OCT A-scan)
- Lateral spatial resolution of OCT under different regimes
- Consider the effect of reflectivity and dispersion mismatch in OCT

**Light-Tissue Interactions and Fluorescence:**
- Derive the macroscopic attenuation due to absorption and scattering and relate to mean free path
- Describe the main transitions and time-scales involved in fluorescence (classical model)
- Describe the phenomena photo-bleaching, fluorophore-blinking and photo-toxicity
- Identify and describe parameters for quantitative fluorescence measurements

**Widefield Microscopy Techniques and Diffraction Limited Resolution:**
- Describe/sketch basic anatomy of a widefield microscope
- Describe the contrast achievable in optical microscopy
- Geometrical optics analysis of a microscope
• Derive the far-field (Fraunhofer) diffraction integral
• Demonstrate properties of a lens
• Describe how resolution is limited in a microscope using coherent light
  o Coherent transfer function and the coherent point spread function
• Analyse how phase contrast microscopy works
• Describe how resolution is limited in a microscope using incoherent light
  o Optical transfer function and the incoherent point spread function
• Incoherent 3-D point spread function

Optical Sectioning Microscopy:
• Analysis and spatial resolution of optically sectioning linear and nonlinear microscopy
• Compare the relative advantages/disadvantages of wide-field, confocal and multi-photon microscopy

Super-Resolved Microscopy:
• Describe how FRET can be employed to provide sub-diffraction information
• Classify and use the methods for FRET determination (i.e. intensity, spectral and lifetime)
• Describe the technique STED and how it modifies the expression for diffraction limited resolution
• Illustrate the concept behind localisation microscopy
• Describe the methods for fluorophore switching and the limit to the achievable resolution
• Contrast and compare these techniques for imaging beyond the diffraction limit

Description of Content

Optical techniques for control, interaction and interrogation are common in experimental science and diagnostics. In this course optical techniques for biological/biomedical imaging (e.g. microscopy) will be discussed and analysed. Students will develop an understanding of relevant light-matter interactions, how they generate and/or confound image contrast and metrology, as well as develop an appreciation of the opportunities for optical techniques in biology/biomedicine and an understanding of how the underlying physics limits their performance. This course covers the physics of imaging and related processes and no biology is taught or required.

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