Light and Matter

Module Code	PHYS96024	FHEQ Level	Level 6
Pre-requisites	None	Co-requisites	None
Primary Department	Physics		
Module Leader	Dr Steve Kolthammer, Dr Riccardo Sapienza and Dr Will Branford		
Additional Teaching Departments	None		
Teaching Staff	Dr Steve Kolthammer, Dr Riccardo Sapienza and Dr Will Branford		
Programmes on which the Module is delivered			Core/Elective
BSc Physics (F300), MSci Physics (F303), BSc Physics with Theoretical Physics (F325), MSci Physics with Theoretical Physics (F390)			Core
MSci Physics with a Year in Europe (F309), BSc Physics with Studies in Musical Performance (F3W3)			Elective
Learning Outcomes	On completing the Light and Matter course, students will be able to: **Atoms, molecules and their interactions with light** • Describe the energy level structure of many-electron atoms, making use of the concepts of the central-field approximation, angular momentum conservation, and screening. Use appropriate notation. • Know the properties of angular momentum eigenstates and how to add angular momenta together. • Explain the idea of exchange symmetry and describe the effect of the residual electrostatic interaction for many-electron atoms. • Explain the origin of the spin-orbit interaction and show how it leads to the fine-structure splitting of atomic energy levels. • Explain the origin of hyperfine structure, and use perturbation theory to calculate hyperfine splittings. • Relate hyperfine structure to radio-astronomy and atomic clocks. • Use the Schrodinger equation to predict the behaviour of an atom interacting with an electromagnetic field. Describe the role of spontaneous emission in modifying this behaviour. • Develop the description of an atom interacting with light towards a picture of the atom as an oscillating electric dipole. • Describe the classical electron oscillator model of atoms and molecules interacting with light and use it to explain dispersion, absorption and scattering of light, and to calculate the refractive index of a gas and the cross-sections for Rayleigh and Thomson scattering. • Describe the fundamental processes of absorption, stimulated emission and spontaneous emission. Calculate steady-state populations for an atom interacting with light. • Explain how atomic spectra can be understood in terms of atomic energy levels and selection rules. Explain spectral line broadening and calculate the widths of spectral lines. • Show that a population inversion leads to amplification of light by stimulated emission. Explain how this is used to make lasers.		

	• Explain how lasers are used to cool atoms to low temperature. • Describe qualitatively how atoms bind to form molecules. Interpret the potential energy curves of diatomic molecules. • Describe the energy level structure of diatomic molecules, including the electronic, rotational and vibrational structure. Estimate the spacings between energy levels. **Interaction of light with solids** • Explain the different types of optical processes in solids: band to band transition, vibrational/rotational transition, free carrier absorption. • Describe the differences in the optical properties of semiconductors, dielectrics, glasses, metals, low dimensional semiconductors. • Understand how the dipole approximation leads to expressions for the rate of photon absorption and emission in solids. • Understand the derivation of the absorption coefficient for a direct gap crystalline semiconductor • Understand how selection rules control the optical properties of solids in particular for direct gap and indirect gap semiconductors • Explain what is meant by an exciton in a solid, and distinguish types of exciton. • Explain the concept of luminescence and show how luminescence and absorption are related. • Show how dimensionality influences the form of the joint density of states and hence the optical properties of low dimensional semiconductor structures. • Understand the origin and application of solid-state single photon sources • Use the classical dipole oscillator model to describe the optical response of metals. • Understand the origin of plasmonic effects in solids • Explain how optical properties of solids influence the choice of materials for applications in light detection and light emission **Interaction of magnetic fields with solids** • Understand the role of exchange in mediating magnetic interactions • Derive the classical and quantum models of local moment paramagnetism • Be able to calculate (spin only) magnetic moment μ for a defined electronic configuration; and convert to saturation magnetization for a ferromagnet. • Be able to relate magnetic moment/magnetization to (Zeeman) energy in applied field. • Know and understand the properties of different magnetic states: para-, dia-,ferro-, ferri-and antiferromagnetism. • Understand the Weiss model of ferromagnetism and the concept of a disordering (Curie) temperature • Understand the Weiss model of antiferromagnetism • Know the difference between hard” and “soft” ferromagnets; sources of magnetic anisotropy and how to improve permanent magnets; applications of soft and hard ferromagnets • Describe how ferromagnets exhibit hysteresis and be able to sketch a typical hysteresis loop. • Describe how the property of hysteresis enables the fabrication of memory devices.
Description of Content	1. Part I introduces the structure of atoms and molecules and their interactions with light, develops an understanding of how light is

scattered, dispersed and absorbed, and builds familiarity with applying methods of quantum mechanics. Applications studied include lasers, laser cooling, atomic clocks, and spectroscopy.

2. Part two of the course concerns the interaction of light with solids. We will address the treatment of light absorption and emission by semiconductors, metals and dielectrics and show how the electronic structure of the material controls the optical response in each case. For semiconductors, we develop the concepts of second year solid state physics to present a microscopic description of light absorption and emission. We show how the optical properties of particular solids enable applications in light emitting and light detecting devices.
3. The final part of the course deals with the interaction of magnetic and electric fields with solids and with the physics of the collective phases, of ferromagnetism, superconductivity and ferroelectricity in solids. We will show how these phases can be applied to memory devices.

Assessment		Assessment Type	Weighting
Written exam		Exam	100%
Learning & Teaching Hours	Independent Study Hours	Placement Hours	Total Hours
52	98	0	150
ECTS Credit	6	CATS Credit	12
Date of introduction	October 2016	Date of Last Revision	May 2020