Overview
Although the first laser was demonstrated in 1960, a significant proportion of the underlying physics predates this in areas such as atomic physics, quantum physics, optics and spectroscopy. However the advent of lasers has opened up many exciting aspects of physics and the particular beam characteristics of lasers, notably the coherence and intensity, have proved to be of immense scientific and technological importance. By studying the basic physics of laser media together with the system configurations that facilitate a range of desirable options for their operation, it is possible to understand why lasers are in a special category of optical sources. By considering the gain media together with options for the various configurations of the lasers, we can have insights into system designs that in some cases provide excellent spectral purity while in other instances broader bandwidth but ultrashort-pulse outputs (digital optics) can be produced. Although the subject of laser physics is more than fifty years old, there is still much active development of lasers, associated optical amplifiers and related devices, and their applications in everyday life from sophisticated high capacity communications to simple supermarket scanners continue to grow.

Aims & Objectives
The course aims to present various aspects of the foundations, design, operation and application of lasers. In particular the course will consider:

- fundamentals of light-matter interaction
- Einstein treatment of transition rates
- finite laser bandwidth and spectral broadening mechanisms - population inversion and optical amplification gain
- comparison of two, three, and four -level schemes - laser operation and gain saturation
- treatment of optical resonators and Gaussian beams - laser stabilisation and mode purification
- pulsed lasers by active and passive pulsing techniques - ultrashort lasers
- gas lasers: concepts and examples
- crystalline lasers: concepts and examples
- semiconductor lasers: concepts and examples

Learning Outcomes
Within the course structure offered, students will gain a good understanding of the building blocks of lasers. In particular, they will be able to

- predict fundamental (and ultimate) characteristics of laser systems based on specific laser materials, such as output power and lasing threshold
- assess and design the optical cavities for different laser systems
- determine the laser behaviour depending on the line broadening mechanism
- solve the rate equations in steady state for a laser
- find the interrelations between Einstein coefficients
- quantitatively describe the key characteristics of pulsed lasers and their interrelation
- describe concrete major example laser systems in detail and understand their technological challenges

Students should therefore gain a significantly enhanced understanding of how lasers work and which types of lasers are most relevant for specific performance specifications and subsequent applications.

Synopsis
This course represents a relatively broad coverage of subject matter relating to the operating principles of lasers through to the physics that underlies specific choices of configurations and associated key characteristics. At the outset, the requirements that arise for the establishment of a population inversion are considered followed by relevant gain-threshold and gain-saturation dynamics with reference to homogeneous and inhomogeneous spectral broadening in the laser media. Examples
are included for a range of distinctive laser types in which particular characteristics of solid-state, liquid and gaseous media are exploited. The subsequent structure of the course is then built on this foundation such that the spatial, spectral and temporal control of the outputs from lasers can be described in turn. This involves physical descriptions being presented on the topics of resonator stability and transverse modes, longitudinal resonator modes with spectral narrowing and tuning, and for the temporal domain techniques that include Q-switching, cavity dumping and mode locking. Relevant implementations of the lasers are mentioned briefly throughout this course to illustrate the suitability of these coherent light sources to a range of applications.

**Pre-requisites**
PH3081 or PH3082 or (MT2506 and MT2507)

**Anti-requisites**
None

**Assessment**
2 Hour Examination = 90%, tutorial work 10%

**Additional information on continuous assessment etc.**
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

7 tutorial sheets are set and expected to be answered by students during the semester. In each tutorial there are question that are flagged as being required to answer. Students self-report which they believe that they have completed. There are “whole-class” tutorials in this module. Students who have reported that they have completed questions will be selected from in order to lead a discussion on the solution. 10% of the module mark comes from these tutorial solutions, with an honesty-led self-reporting supported by a sampling in the whole-class tutorials of attainment in the solutions.

**Accreditation Matters**
This module may not contain material that is part of the IOP “Core of Physics”, but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP “Graduate Skill Base”.

**Recommended Books**
Please view University online record: [http://resourcelists.st-andrews.ac.uk/modules/ph4034.html](http://resourcelists.st-andrews.ac.uk/modules/ph4034.html)

**General Information**
Please also read the general information in the School's honours handbook.