

<b>Academic Year</b>	2020/21	<b>Semester</b>	2
<b>Course Coordinator</b>	Assoc. Prof. Sun Handong		
<b>Course Code</b>	PH4409		
<b>Course Title</b>	Quantum Electronics		
<b>Pre-requisites</b>	PH1105 (Optics, Vibrations and Waves) and PH2101 (Quantum Mechanics I)		
<b>No of AUs</b>	4 AU		
<b>Contact Hours</b>	Lecture: 39 hours, Tutorial: 12 hours (3 hr – lecture; 1 hr – tutorial)		
<b>Proposal Date</b>	October 2020		

### Course Aims

This course intends to equip you with the fundamental concept and principles of key topics in advanced optics and nonlinear optics. You will gain knowledge in the mechanisms of beam manipulation, generation of ultrafast laser pulses, optical resonators, wavelength conversion, nonlinear absorption etc. Based on this knowledge, you will be able to make both predictions and interpretation in important applications such as in lasers and advanced optics. In conclusion, after taking this course, your problem-solving skills will be sharpened and you will have the necessary foundation to tackle problems in advanced photonics related research.

### Intended Learning Outcomes (ILO)

Upon the successful completion of this course, you (as a student) would be **able to**:

1. use the concepts and methods (such as postulates of ray optics) to analyse and solve problems for practical applications (such as examining various optical components (planar mirrors, parabolic mirrors, elliptical mirrors and spherical mirrors, prisms, beam splitters, lenses and light guides) and their unique properties, and apply the ray equation and paraxial wave equation to graded-index optical components.).
2. apply ray transfer matrix to simple optical components, cascaded optical components and periodic optical systems.
3. examine the solutions of the Helmholtz equation for plane waves and spherical waves.
4. apply the Fresnel approximation to spherical waves to obtain the paraboloidal wave and the validity of the Fresnel approximation, and establish the relation between Wave Optics and Ray Optics.
5. apply wave optics to describe polychromatic & pulsed Light.
6. apply Ray-Transfer Matrix to characterize and manipulate Gaussian beams.
7. use optical components to generate Hermite-Gaussian beams, Laguerre-Gaussian beams and Bessel beams.
8. apply Gaussian optics to analyse and design laser resonators
9. apply Maxwell equations to describe and analyse nonlinear optical media.
10. use the concepts and method of wave optics to investigate the origin and manipulation of nonlinear optical processes
11. use the concepts and method of quantum mechanics to investigate the origin and manipulation of nonlinear optical processes
12. apply the principles of Nonlinear Optics to wavelength conversion, THz generation and detection, supercontinuum, intensity related refractive index, photorefractive effect, stimulated Raman scattering etc.

## Course Content

### Ray Optics

Postulates of Ray Optics  
Simple Optical Components  
Graded-Index Optics  
The Eikonal Equation  
Matrix Optics

### Wave optics

Postulates of Wave Optics  
Monochromatic Waves  
Relation between Wave Optics and Ray Optics  
Simple Optical Components  
Interference  
Polychromatic & Pulsed Light

### Beam Optics

The Gaussian Beam  
Transmission through simple optical components  
Transmission through an arbitrary optical component  
Hermite-Gaussian beams  
Laguerre-Gaussian Beams  
Bessel Beams

### Resonator optics

Planar-Mirror Resonators

- Resonator Modes;
- Density of Modes
- Losses and Resonance Spectral Width
- Sources of Resonator Loss;
- Photon Lifetime;
- Q-Factor
- Off-axis Resonator Modes

Spherical-Mirror Resonators

- Ray Confinement – confinement conditions, g-parameters, planar, confocal and concentric resonators
- Gaussian Beam – a mode of the spherical mirror resonator
- Resonance Frequencies
- Hermite-Gaussian Modes

### Nonlinear Optical Phenomena

Sum- and difference-frequency generation  
Parametric versus nonparametric Process  
Formal definition of nonlinear optical susceptibility  
Anharmonic oscillator model  
Properties of the nonlinear susceptibility  
Time-domain description of optical nonlinearities

### Wave Description on NLO

The Wave Equation for Nonlinear Optical Media  
The Coupled-Wave Equations for Sum-Frequency Generation  
The Manley–Rowe Relations  
Sum-Frequency Generation  
Second-Harmonic Generation  
Phase-Matching Considerations  
Optical Parametric Oscillators  
Quasi-Phase-Matching

**Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility**

Introduction of Perturbation theory  
Schrödinger equation calculation of the nonlinear optical susceptibility  
Density Matrix Formalism of Quantum Mechanics  
Perturbation solution of the Density matrix equation of motion  
Density Matrix Calculation of the Linear Susceptibility  
Density Matrix Calculation of the Second-order Susceptibility  
Density Matrix Calculation of the Third-Order Susceptibility  
Electromagnetically Induced Transparency

**The Intensity-Dependent Refractive Index**

Descriptions of the Intensity-Dependent Refractive Index  
Tensor Nature of the Third-Order Susceptibility  
Propagation through Isotropic Nonlinear Media  
Nonlinearities Due to Molecular Orientation  
Thermal Nonlinear Optical Effects  
Semiconductor Nonlinearities

**Assessment (includes both continuous and summative assessment)**

Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team / Individual	Assessment Rubrics
1. Final Examination	All	Competency (1,2,4,5)	60%	Individual	Point-based marking (not rubric-based)
2. CA1: Project and presentation	All	Communication (1,2,3) Creativity (1,2) Character (1,2,3)	10%	group	Rubrics marking- Appendix 1
3. CA2: Homework	All	Competency (1,2,3,4) Character (1,2)	10%	Individual	Point-based marking (not rubric-based)
4. CA3: Mid-term Test	1-8	Competency (1,2, 4,5)	20%	Individual	Point-based marking (not rubric-based)
Total			100%		

**Formative feedback**

Formative feedback is given through discussion within tutorial lessons. Feedback is always provided for your response to each question.

Feedback is also given after each midterm on the common mistakes and level of difficulty of the problems.

Feedback is also given during consultant discussion.

<b>Learning and Teaching approach</b>	
<b>Approach</b>	<b>How does this approach support students in achieving the learning outcomes?</b>
<b>Use of Learning Catalytics</b> (tutorial and lecture)	This helps to engage you and serves to identify any prior misconceptions that you may have in order to better assist you in your learning journey.
<b>Lectures</b>	Warm-up questions will be raised first, followed by lectures that further explains the physics based on the questions. Then wrap-up questions will also be provided.
<b>Tutorial</b>	You will review main concepts learned in lectures with TAs. This helps you to digest and understand better.
<b>Homework</b>	The homework comprises standard textbook practice questions that are covered during tutorial.
<b>Reading and References</b>	
Text book:	
<ol style="list-style-type: none"> <li>1. "Fundamental of Photonics", Bahaa E. A. Saleh and Malvin Carl Teich, Wiley-Interscience ISBN: 978-0-471-35832-9</li> <li>2. "Nonlinear Optics", R.W. Boyd, Academic Press, 3<sup>rd</sup> Edition, ISBN: 978-0-323-85057-5</li> </ol>	
Other references:	
<ol style="list-style-type: none"> <li>1. "Quantum Electronics", A. Yariv, 3<sup>rd</sup> Edition, Wiley, ISBN: 0471609978 (ISBN13: 9780471609971)</li> <li>2. "The principles of Nonlinear Optics", Y. R. Shen, John Wiley, ISBN: 978-0-471-43080-3</li> </ol>	
<b>Course Policies and Student Responsibilities</b>	
<i>Absence Due to Medical or Other Reasons</i>	
If you are sick and unable to attend your class / Mid-terms, you have to:	
<ol style="list-style-type: none"> <li>1. Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-terms.</li> <li>2. Submit the original Medical Certificate* or official letter of excuse to administrator.</li> <li>3. Attend the assigned replacement class (<i>subject to availability</i>) and make-up mid-terms (<i>subject to availability</i>).</li> </ol>	
* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.	

### Academic Integrity

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values.

As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the [academic integrity website](#) for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

### Course Instructors

Instructor	Office Location	Phone	Email
Assoc. Prof. Sun Handong	SPMS-PAP-04-12	65138083	hdsun@ntu.edu.sg

### Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Ray Optics	1,2	Lecture notes – Ray Optics(I)
2	Ray Optics, Wave Optics	1,2,3	Lecture notes – Ray Optics(II)+ Wave Optics(I)
3	Wave Optics	3,4,5	Lecture notes – Wave Optics(II)
4	Beam Optics	6	Lecture notes – Beam Optics(I)+ Beam Optics(II)
5	Beam Optics, Resonator Optics	7,8	Lecture notes – Beam Optics(III)+ Resonator Optics(I)
6	Resonator Optics	8	Lecture notes – Resonator Optics(II)
7	Revision and Midterm test,		
8	Nonlinear Optical Phenomena	9	Lecture notes – NLO 1-Fundamental- NLO Susceptibility
9	Wave Description on NLO	10	Lecture notes – NLO 2-wave description of NLO
10	Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility	11	Lecture notes – NLO 3-QM Theory of NLO-I&II
11	Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility	11	Lecture notes – NLO 3-QM Theory of NLO-II&III
12	The Intensity-Dependent Refractive Index	12	Lecture notes – NLO 4- Intensity dependent Refractive Index

13	Project Presentation, Revisions		
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**Appendix 1**

By default, you would receive the same marks as your team. However, your score may vary if there is evidence that you did not contribute to your team.

**Project Presentation**

<b>Criteria</b>	<b>Does not meet standard (0 - 2) (Prestructural)</b>	<b>Nearly Meets Standard (3 - 4) (Unistructural)</b>	<b>Meets Standard (5 - 6) (Multi-structural)</b>	<b>Exceeds Standard (7 - 8) (Relational)</b>	<b>Far Exceeds Standard (9 - 10) (Extended Abstract)</b>
<b>Organization and structure</b>	No clear structure apparent to the presentation. Ideas appear scattered and incoherent. No clear distinction between introduction of background concepts, presentation of main results, and conclusions.	Somewhat structured presentation. Distinct sections such as introduction, results, conclusions, etc. exist, but sections are incomplete and their content scattered / unstructured.	Structured presentation. Distinct sections such as introduction, results, conclusions, etc. exist, and their content is mostly organized. Key conclusions are only apparent after reading the conclusions slide.	Well-structured presentation. Distinct sections such as introduction, results, conclusions, etc. exist, their content is well-organized throughout the presentation, and the key conclusions are clear throughout.	Above standard structured presentation. Content of introduction, results, conclusions, etc. are well organized throughout the entire presentation, presenting content not only comprehensively, but efficiently.
<b>Visual presentation (e.g. design of presentation slides)</b>	Ineffective or no use of presentation technology (e.g. PowerPoint) at all.	Somewhat effective use of presentation technology (e.g. PowerPoint slides). Technology is used but content presented is mostly illegible and disorganized.	Effective use of technology (e.g. PowerPoint slides). Information legible and well-organized throughout most of the presentation.	Effective use of technology (e.g. PowerPoint slides). Information legible and well-organized throughout the entire presentation.	Effective and creative use of technology (e.g. PowerPoint slides). Information is not legible but also well-structured. Additional technology / applets (e.g. PPT animations) are being used to further illustrate complex concepts.

<p><b>Effectiveness of oral presentation and Q&amp;A</b></p>	<p>Does not communicate ideas effectively. Uses pace, tone and style ineffectively (monotonous style) and hence loses attention of audience through most of the presentation.</p>	<p>Communicates ideas somewhat effectively. Ideas are mostly comprehensible and communicated somewhat effectively by use of pace, tone and style. Maintains attention of audience in some parts of the presentation.</p>	<p>Communicates ideas in an effective and understandable manner. Uses pace, tone and style effectively, most of the time. Catches the interest of the audience through most of the presentation</p>	<p>Communicates difficult or complex ideas in an effective and understandable way. Uses pace, tone and style effectively all the time, and catches the interest of the audience, or engages the audience throughout</p>	<p>Far exceeds expectations of a fourth year student in communicating complex scientific concepts. Uses pace, tone and style not only effectively but also creatively. Never loses interest and engagement of the audience</p>
<p><b>Individual Contribution</b></p>	<p>Little to no effective contribution in the presentation and Q&amp;A portions, displays little knowledge in the chosen topic.</p>	<p>Contribution in the presentation and Q&amp;A portions reflect only one aspect the chosen topic. Limited insights.</p>	<p>Contribution in the presentation and Q&amp;A portions reflect more than one aspect of the chosen topic, but does not connect them as a coherent whole. Insights may be unoriginal.</p>	<p>Contribution in the presentation and Q&amp;A portions reflect depth of knowledge not only in an individual segment, but in the whole topic. Insights are thoughtful and analytical.</p>	<p>Contribution in the presentation and Q&amp;A portions reflect coherence, fluency, and depth of knowledge in the whole topic. Comes across as an integral part of the team. Insights are critical and offer new or unique perspectives on the topic.</p>

## **Graduate Attributes**

### **What we want our graduates from *Physics and Applied Physics* to be able to do:**

Upon the successful completion of the PHY, APHY and PHMA programs, graduates should be able to:

<b>Competency</b>	1	demonstrate a rigorous understanding of the core theories and principles of physics involving (but not limited to) areas such as classical mechanics, electromagnetism, thermal physics and quantum mechanics  [PHMA only] demonstrate a rigorous understanding of the core theories and principles of mathematical sciences involving (but not limited to) areas such as analysis, algebra and statistical analysis
	2	read and understand undergraduate level physics content independently;
	3	make educated guesses / estimations of physical quantities in general;
	4	apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems;
	5	develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations;
	6	critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed;
	7	demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions.
<b>Creativity</b>	1	propose valid approaches to tackle open-ended problems in unexplored domains;
	2	

		offer valid alternative perspectives/approaches to a given situation or problem.
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<b>Communication</b>	1	describe physical phenomena with scientifically sound principles;
	2	communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public;
	3	communicate effectively with team members when working in a group.

<b>Character</b>	1	uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results;
	2	readily pick up new skills, particularly technology related ones, to tackle new problems;
	3	contribute as a valued team member when working in a group.

<b>Civic Mindedness</b>	1	put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society.
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