**City University of Hong Kong**
**Course Syllabus**

**offered by Department of Physics**
**with effect from Semester A 2022/23**

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## Part I Course Overview

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|---|---|
| **Course Title:** | **Advanced Wave Functional Materials for Energy Applications** |
| **Course Code**: | **PHY6525** |
| **Course Duration:** | **1 semester** |
| **Credit Units**: | **3** |
| **Level**: | **P6** |
| **Medium of Instruction:** | **English** |
| **Medium of Assessment:** | **English** |
| **Prerequisites**: *(Course Code and Title)* | **Nil** |
| **Precursors**: *(Course Code and Title)* | **Nil** |
| **Equivalent Courses**: *(Course Code and Title)* | **Nil** |
| **Exclusive Courses**: *(Course Code and Title)* | **PHY8525 Advanced Wave Functional Materials for Energy Applications** |

## Part II Course Details

### 1. Abstract
*(A 150-word description about the course)*

Nowadays, economic development relies heavily on energy resources and energy technologies. Considerable efforts have been devoted to the design of novel materials for energy related applications, especially for the generation and storage of clean and renewable energies such as solar energy. Among these materials, wave functional materials such as metamaterials and photonic crystals are promising candidates due to their unusual properties. This course aims to provide students a detailed introduction and comprehensive understanding of wave functional materials. It will emphasize the underlying physical mechanism responsible for their unusual properties such as resonance enhancement of light absorption. Practical applications such as energy harvesting and storage, photon detection, and wireless power transfer will also be discussed. By the end of this course, students will gain essential knowledge and master necessary numerical and analytical techniques to design wave functional materials.

### 2. Course Intended Learning Outcomes (CILOs)
*(CILOs state what the student is expected to be able to do at the end of the course according to a given standard of performance.)*

| No. | CILOs | Weighting* (if applicable) | Discovery-enriched curriculum related learning outcomes (please tick where appropriate) | | |
|---|---|---|---|---|---|
| | | | *A1* | *A2* | *A3* |
| 1. | Describe the important concepts in wave physics | 20% | | √ | |
| 2. | Explain the physical mechanism responsible for the properties of photonic crystals, metamaterials and 2D thin-film materials | 30% | | √ | |
| 3. | Relate the material properties to the applications | 10% | | √ | |
| 4. | Identify the limitations of the current wave functional materials | 10% | | √ | |
| 5 | Apply numerical and analytical techniques to design wave functional materials | 30% | | | √ |
| | ** If weighting is assigned to CILOs, they should add up to 100%.* | 100% | | | |

*A1: Attitude*
*Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.*

*A2: Ability*
*Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines or applying academic knowledge to self-life problems.*

A3: *Accomplishments*
*Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.*

### 3. Teaching and Learning Activities (TLAs)
*(TLAs designed to facilitate students' achievement of the CILOs.)*

| TLA | Brief Description | CILO No. | | | | | | Hours/week (if applicable) |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1. | Lectures | √ | √ | √ | √ | √ | | 26 hrs/13 wks |
| 2. | Tutorials | | √ | √ | | √ | | 6 hrs/ 6 wks |
| 3. | Group project and presentation | | √ | √ | √ | √ | | 6 hrs/ 6 wks |

## 4. Assessment Tasks/Activities (ATs)

*(ATs are designed to assess how well the students achieve the CILOs.)*

| Assessment Tasks/Activities | CILO No. | | | | | | Weighting* | Remarks |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| Continuous Assessment: 50% | | | | | | | | |
| Assignment | √ | √ | √ | √ | √ | | 10 | |
| Presentation | √ | √ | √ | √ | √ | | 20 | Group project |
| Report | | √ | √ | √ | √ | | 20 | Group project |
| Examination: 50% (duration: 2 hours) | | | | | | | | |
| Examination | √ | √ | √ | | √ | | 50 | |
| ** The weightings should add up to 100%.* | | | | | | | 100% | |

## 5. Assessment Rubrics

*(Grading of student achievements is based on student performance in assessment tasks/activities with the following rubrics.)*

Applicable to students admitted in Semester A 2022/23 and thereafter

| Assessment Task | Criterion | Excellent (A+, A, A-) | Good (B+, B) | Marginal (B-, C+, C) | Failure (F) |
|---|---|---|---|---|---|
| 1. Assignment | Understanding the important concepts of wave physics; Ability of applying analytical methods to study material properties | High | Moderate | Basic | Not reaching marginal level |
| 2. Presentation | Understanding the physical mechanisms, applications, and limitations of selected/designed wave functional material; Identify challenges and further development | High | Moderate | Basic | Not reaching marginal level |
| 3. Report | Having an in-depth understanding of the selected/designed wave functional material, including its properties, wave manipulation functionalities and limitations of performance | High | Moderate | Basic | Not reaching marginal level |

Applicable to students admitted before Semester A 2022/23

| Assessment Task | Criterion | Excellent (A+, A, A-) | Good (B+, B, B-) | Fair (C+, C, C-) | Marginal (D) | Failure (F) |
|---|---|---|---|---|---|---|
| 1. Assignment | Understanding the important concepts of wave physics; Ability of applying analytical methods to study material properties | High | Significant | Moderate | Basic | Not reaching marginal level |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2. Presentation | Understanding the physical mechanisms, applications, and limitations of selected/designed wave functional material; Identify challenges and further development | High | Significant | Moderate | Basic | Not reaching marginal level |
| 3. Report | Having an in-depth understanding of the selected/designed wave functional material, including its properties, wave manipulation functionalities and limitations of performance | High | Significant | Moderate | Basic | Not reaching marginal level |

**Part III Other Information** (more details can be provided separately in the teaching plan)

**1. Keyword Syllabus**

*(An indication of the key topics of the course.)*

- Wave physics
  - Wave equations, harmonic modes, eigenvalue problems, symmetry of eigenmodes, periodic systems, band structures, Bloch wave, phase velocity, group velocity, density of states, retarded Green's function
  - Transmission, reflection, permittivity and permeability tensors, polarizability, bulk modulus, mass density
  - Electromagnetic wave vs. acoustic wave
- Metamaterials
  - Resonant elements, dispersion, effective material parameters, effective medium theory, negative refractive index, subwavelength imaging, perfect lens, cloaking, effect of loss
  - Metamaterial wave absorber, metamaterials-based energy harvester, metamaterial photodetectors, wireless power transfer with metamaterials
- Photonic crystals
  - Photonic band gaps, multilayer film, evanescent modes in band gaps, defect modes, surface states, photonic crystal waveguide, woodpile crystal, quality factor of lossy cavities
  - Photonic-crystal fibers, photonic-crystal lasers, narrow-band filter, resonant light absorption and radiation, photonic crystals for solar energy applications
- 2D materials
  - Properties of graphene, graphene electronic devices, graphene spintronics, transparent conducting electrodes, graphene-based supercapacitors, graphene-based materials in lithium-ion batteries, graphene-based fuel cells and solar cells
  - Other layered 2D materials (e.g., boron nitride nanosheets, transition metal oxides, silicene, etc.)

**2. Reading List**

**2.1 Compulsory Readings**

*(Compulsory readings can include books, book chapters, or journal/magazine articles. There are also collections of e-books, e-journals available from the CityU Library.)*

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| 1. | "Photonic Crystals: Modelling the Flow of Light", J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Princeton University Press, 2nd ed., 2008. |
| 2. | "Waves in Metamaterials", L. Solymar; E. Shamonina, Oxford University Press, 2009. |
| 3. | "Acoustic Metamaterials and Phononic Crystals", P. A. Deymier, Springer, 2013. |
| 4. | "Graphene: Fundamentals and Emergent Applications", J. H. Warner, F. Schaffel, M. Rummeli, A. Bachmatiuk, Elsevier, 2012. |

**2.2 Additional Readings**

*(Additional references for students to learn to expand their knowledge about the subject.)*

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| 1. | "Optical Properties of Photonic Crystals", K. Sakoda, Springer, 2nd ed., 2004. |
| 2. | "Tutorials in Metamaterials", M. A. Noginov, V. A. Podolskiy, CRC Press, 2011. |
| 3. | "Metamaterials for Perfect Absorption", Y. P. Lee, J. Y. Rhee, Y. J. Yoo, K. W. Kim, Springer, 2016. |
| 4 | "Graphene: A New Paradigm in Condensed Matter and Device Physics", E. L. Wolf, Oxford University Press, 2016. |