Course Title: **Quantum Optics**

Credit Hrs: 3

Prerequisites: Modern Physics, Applied Physics, Differential Equations, Linear Algebra

Course Description:

This course provides the theoretical and conceptual framework required to understand nonclassical optical phenomena such as single-photon behavior, quantum interference, photon correlations, entanglement, and squeezing. These phenomena form the operational basis of quantum key distribution, photonic quantum computing, precision quantum metrology, and integrated quantum photonic systems. The course is offered as a **core subject**. while remaining realistic with respect to current institutional infrastructure.

Course Objectives:

Objectives of the course are:

- Develop a rigorous understanding of the quantum nature of light
- Bridge classical optics concepts with quantum optical descriptions
- Explain how photons are generated, manipulated, and detected in practical systems
- Enable interpretation of experimental quantum optical results
- Prepare students for advanced coursework and research in quantum information science

Course Learning Outcomes (CLOs)

After successful completion of this course, students will be able to:

Explain the limitations of classical optics and justify the necessity of a quantum description of light

Describe quantum states of light and their physical and statistical properties

Analyze coherence, correlation, and interference phenomena in quantum optical systems

Explain quantum photodetection and optical measurement as quantum processes

Analyze quantum light–matter interaction mechanisms and optical resonant systems

Evaluate photon sources, entanglement generation methods, and practical system limitations relevant to quantum information science

Course Contents

Week	Contents
1	**Photons as a QIST platform** Why photonics is special for quantum communication and sensing. Optical modes, bandwidth, and practical constraints unique to light. Overview of key optical experiments and system blocks
2	**Optical modes and quantum states used in practice** Optical mode concept: spatial mode, spectral mode, temporal mode, polarization mode. What “single photon,” “weak coherent pulse,” and “thermal light” mean operationally. How state preparation is realized physically.
3	**Photon statistics as measurable fingerprints** What photon statistics mean in real measurements. How classical light differs from antibunched light in observed data. Practical signatures: multiphoton contamination, background light
4	**Coherence in optical systems (interference readiness)** Temporal coherence and linewidth in lasers and filtered photons. Spatial coherence and mode quality (beam quality, coupling to fiber).Why coherence is the “currency” of interferometry.
5	**Photodetection as a real measurement system (hardware literacy)** Detector types at the level of system behavior (click detectors and timing detectors). Efficiency, dark counts, jitter, dead time, after pulsing. How detector imperfections bias results and how to correct interpretation.

6	**Correlation experiments (HBT) as a diagnostic tool** Intensity correlation measurement as a system test. Interpreting antibunching and bunching in real data. Timing-window effects and practical coincidence counting logic
7	Midterm Exam
8	**Optical beam splitters and interferometers (component-level analysis)** Beam splitters as the central photonic building block Single-photon interference in an interferometer. Loss, phase drift, stability, and visibility degradation mechanisms.
9	**Two-photon interference (HOM) as a quality benchmark** Indistinguishability: time, spectrum, polarization, and mode overlap. Visibility as a performance metric. What HOM tells you about source purity and system alignment.
10	**Optical entanglement generation (how it is done physically)** How entanglement is generated using photon pairs and interferometric schemes. Polarization and path encoding at system level. Practical sources of reduced entanglement quality (background, multipair, mismatch).
11	**Photon-pair sources (SPDC) in engineering terms** What SPDC is and what it produces physically Heralding concept and why it is imperfect Brightness versus fidelity tradeoff; multipair noise Filtering and coupling tradeoffs for system performance
12	**Single-photon sources and performance metrics** Single-photon emitters versus heralded sources (comparative view). Practical metrics: purity, brightness, indistinguishability, stability. What makes a “usable” single-photon source for QIST tasks

13	**Loss and noise budgeting in photonic quantum systems** System loss sources: coupling loss, propagation loss, component loss. Detector noise and background noise. Simple end-to-end reasoning: when a protocol becomes infeasible
14	**QKD and quantum communication (optics implementation focus)** Optical transmitter/receiver blocks: sources, modulators, channels, detectors. Why weak coherent pulses are used; what limits performance. Practical channel effects: polarization drift, dispersion, turbulence (overview)
15	**Integrated photonics and system integration roadmap** On-chip photonics overview: sources, circuits, detectors (conceptual) Packaging, coupling, stability, and manufacturability constraints. Capstone discussion: reading a modern photonic QIST system paper
16	Final Exam