Summary of Lectures with Problems
FYS3415 – Spring 2026

University of Oslo

1 Introduction

The course FYS3415 provides an introduction to quantum information theory, beginning with mathematical foundations and progressing toward applications in quantum computing, communication, and cryptography.

2 Mathematical Foundations

The course begins with linear algebra, including vector spaces, bases, and linear operators. Important concepts include eigenvalues, spectral decomposition, and classes of operators such as Hermitian and unitary operators.

3 Classical and Quantum Computing

Classical computation is introduced through Boolean functions and circuits, emphasizing reversibility and universality. Quantum computation is then formulated through postulates, introducing qubits, the Bloch sphere, and one-qubit gates.

4 Multi-Qubit Systems

Tensor products are used to describe systems of multiple qubits. The computational basis, controlled gates, and the quantum circuit model are introduced.

5 Measurement and Entanglement

Key quantum features such as the no-cloning theorem, measurement theory, and entanglement are studied. Protocols such as teleportation and superdense coding demonstrate quantum advantages.

6 Mixed States and Density Operators

Density operators are introduced to describe mixed states. Topics include POVMs, partial trace, Schmidt decomposition, and purification.

7 Quantum Channels and Noise

Quantum channels are described using Kraus operators. Examples include depolarizing and amplitude damping channels. Distance measures such as trace distance and fidelity are introduced.

8 Quantum Algorithms

Quantum algorithms such as Deutsch–Jozsa and Grover's algorithm demonstrate computational advantages over classical approaches.

9 Error Correction and Information Theory

Quantum error correction codes, including the Shor code, are introduced. Concepts from information theory such as entropy and the Holevo bound are studied.

10 Nonlocality and Cryptography

Bell's inequality and nonlocality highlight foundational aspects of quantum mechanics. Quantum cryptography, including BB84, is discussed.

11 Conclusion

The course provides a comprehensive foundation in quantum information science, integrating mathematical rigor with physical applications.

Problems

Problem 1: Linear Algebra

Let A be a 2×2 Hermitian matrix. Show that its eigenvalues are real.

Problem 2: Qubits

Write a general qubit state and show that global phase does not affect measurement outcomes.

Problem 3: Tensor Products

Compute the tensor product $|0\rangle \otimes |1\rangle$ and express it in vector form.

Problem 4: Measurement

Using the Born rule, compute the probability of measuring $|1\rangle$ for the state

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle).$$

Problem 5: Entanglement

Show that the Bell state

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

cannot be written as a product state.

Problem 6: Density Operators

Construct the density matrix for a mixed state with equal probability of $|0\rangle$ and $|1\rangle$.

Problem 7: Quantum Channels

Explain what a Kraus operator representation is and give an example.

Problem 8: Grover's Algorithm

What is the complexity of Grover's algorithm compared to classical search?

Problem 9: Entropy

Define the von Neumann entropy and explain its significance.

Problem 10: Bell Inequality

What does violation of Bell's inequality imply about local realism?