PX453-15 Advanced Quantum Theory

24/25

Department
    Physics
Level
    Undergraduate Level 4
Module leader
    Nicholas d'Ambrumenil
Credit value
    15
Module duration
    10 weeks
Assessment
    100% exam
Study location
    University of Warwick main campus, Coventry

Description

Introductory description

The module sets up the relativistic analogues of the Schrödinger equation and introduces quantum field theory. The best equation to describe an electron, due to Dirac, predicts antiparticles, spin and other surprising phenomena. However, Dirac's equation also shows the need for quantum field theory (QFT). This is where the wavefunctions of matter and light themselves are quantized (made into operators), which automatically builds in the correct fermionic or bosonic statistics of the underlying fields.

Module web page

Module aims

This module should start from the premise that quantum mechanics and relativity need to be mutually consistent. The Klein Gordon and Dirac equations should be derived as relativistic generalisations of the Schrödinger and Pauli equations. The module should introduce quantum fields and illustrate how they can describe phenomena in interacting particle systems, such as superconductivity.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

1. Introduction to Relativistic Quantum Mechanics (QM). Problems with the non-relativistic QM; phenomenology of relativistic quantum mechanics, such as pair production. Derivation and interpretation of the Klein- Gordon Equation
2. The Dirac Equation (DE). Derivation of the DE; spin; gamma matrices and equivalence transformations; Solutions of the DE; Helicity operator and spin; Dirac spinors; Lorentz transformation; interpretation of negative energy states; non-relativistic limit of the Dirac equation; gyromagnetic ratio of electron; fine structure of the hydrogen atom
3. Introduction to 2nd Quantisation. Creation and annihilation operators, harmonic oscillator. Spin-statistics theorem. Fermionic quantum fields. Many-particle states
4. Mean-field theory and Bogoliubov transformations. Possible applications to superconductivity and magnetism
5. The density matrix, mixed and pure states, entanglement

Learning outcomes

By the end of the module, students should be able to:

- Describe the Klein Gordon and Dirac equations, their significance and their transformation properties
- Explain how some physical phenomena including spin, the gyromagnetic ratio of the electron and the fine structure of the hydrogen atom are accounted for within relativistic quantum mechanics
- Define and manipulate quantum fields
- Describe some many-particle states
- Define and work with the density matrix

Indicative reading list

Modern Particle Physics, Mark Thomson, CUP 2013
Quantum Field Theory, Eduardo Fradkin, Princeton 2019
Quantum Electrodynamics, R.P. Feynman, Addison-Wesley 1998
Quantum Phases of Matter, Subir Sachdev, CUP 2023

View reading list on Talis Aspire

Subject specific skills

Knowledge of mathematics and physics. Skills in modelling, reasoning, thinking.

Transferable skills

Analytical, communication, problem-solving, self-study

Study

Study time

Type	Required
Lectures	30 sessions of 1 hour (20%)
Private study	120 hours (80%)
Total	150 hours

Private study description

Working through lecture notes, solving problems, wider reading, discussing with others taking the module, revising for exam, practising on past exam papers

Costs

No further costs have been identified for this module.

Assessment

You must pass all assessment components to pass the module.

Assessment group B1

	Weighting	Study time
Advanced Quantum Theory	100%	
Answer 3 questions		

- Answerbook Pink (12 page)
- Students may use a calculator

Feedback on assessment

Personal tutor, group feedback

[Past exam papers for PX453](#)

Availability

Courses

This module is Optional for:

- UPXA-FG31 Undergraduate Mathematics and Physics (MMathPhys)
    - Year 4 of FG31 Mathematics and Physics (MMathPhys)
    - Year 4 of FG31 Mathematics and Physics (MMathPhys)
- Year 4 of UPXA-F303 Undergraduate Physics (MPhys)

This module is Core option list B for:

- Year 4 of UPXA-F3FA Undergraduate Physics with Astrophysics (MPhys)