The Standard Model

Part of the University of London post-graduate lectures in high-energy physics

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Detailed syllabus

1 Introduction: matter and forces (4 hours)

- Matter content of the Universe
- Forces
  - Gravity
  - The weak force
  - Electromagnetism
  - The strong force
- Concepts of local gauge invariance, gauge interactions and symmetry breaking
- Grand unified theories

TOTAL: 4 hours

2 Experimental concepts (1 hours)

- Experimental possibilities
- Cross section
- Luminosity
- Natural units and conversion factors

TOTAL: 5 hours

3 Experiments of the last 60 years (2 hours)

- Bubble chambers
- Neutrino experiments
- High-energy colliding-beam experiments: early e^+e^- and pp, LEP, HERA, Tevatron, future

TOTAL: 7 hours

4 Non-relativistic quantum mechanics (3 hours)

- Schrödinger's equation and probability current
- Heisenberg and interaction picture
- Harmonic oscillator using Dirac operators
- An-harmonic oscillator and Rayleigh-Schrödinger perturbation theory
- The Lagrangian
- The Dirac delta function
- The Heaviside unit step function

TOTAL: 10 hours

5 Special relativity (1 hour)

- Quick introduction: four-vectors, Lorentz transformation, light cone
- Relativistic kinematics, centre-of-mass energy, Mandelstam variables

TOTAL: 11 hours

6 Relativistic spin-0 particles (1 hour)

- The Klein-Gordon equation
- Perceived problem in the Klein-Gordon equation
- Feynman-Stückelberg interpretation of negative energy solutions

TOTAL: 12 hours

7 Calculating amplitudes (1 hour)

- Possible approaches
- Propagator approach

TOTAL: 13 hours

8 Spinless $e^-\mu^-$ scattering (3 hours)

- Electrodynamics of spinless particles
- Definition of the cross section
- Number of final states
- Flux factor
- Cross section evaluation

TOTAL: 16 hours

9 Relativistic spin-1/2 particles (5 hours)

- Non-relativistic description. Pauli matrices, commutation relations, rotations in 3D, SU(2)
- The Dirac equation, α and β matrices and γ matrices
- The adjoint Dirac equation and the conserved probability current
- Solutions of the Dirac equation
- Orthogonality and normalisation
- Spin, γ^5 and helicity
- Completeness relation
- Possible forms of interaction in the Dirac theory

TOTAL: 21 hours

10 $e^-\mu^-$ scattering (3 hours)

- Electron in an EM field
- Trace theorems
- $d\sigma/d\Omega$ for the process

TOTAL: 24 hours

11 e^+e^- annihilation to $\mu^+\mu^-$ (2 hours)

- Obtain from above scattering result
- R at e^+e^- colliders
- Helicity conservation at high energies

TOTAL: 26 hours

12 Massless spin-1 particle – the photon (3 hours)

- Maxwell's equations and definition of the classical potential
- Lorentz condition and gauge transformation
- Virtual photons and the photon propagator
- Real & virtual photons and significance of longitudinal and time-like photons

TOTAL: 29 hours

13 Compton scattering (2 hours)

TOTAL: 31 hours

14 Massive spin-1 particles (2 hours)

- The Proca equation
- Polarization vectors
- Propagator for virtual vector bosons
- Propagator for unstable virtual vector bosons

TOTAL: 33 hours

15 Charge current weak interactions (5 hours)

- Introduction
- Relation between G_F and g_w
- Leptonic CC processes, νe^- scattering
- O(n), U(n) and SU(n)
- CKM matrix
- νq scattering
- π/K decay to e/μ
- Calculation of W width

TOTAL: 38 hours

16 Neutral current weak interactions (2 hours)

- Weinberg-Salam model
- Neutral current processes
- Z^0 peak

TOTAL: 40 hours

17 QCD (3 hours)

- Deep inelastic scattering
- Quark-parton model
- Drell-Yan process
- Evolution of the structure functions

TOTAL: 43 hours

18 Local Gauge Invariance and determination of the form of interaction (3 hours)

- Local gauge invariance of the EM field
- Local gauge invariance and the electroweak interaction
- Trilinear and Quadrilinear couplings
- Local gauge invariance and QCD
- Evolution of the coupling constants

TOTAL: 46 hours

19 Spontaneous symmetry breaking (4 hours)

- Some models
- Weinberg model
- Masses of W and Z
- Coupling to W and Z
- Fermion masses
- Mass matrices and the KM matrix
- Cosmological problem
- Lagrangian of the Standard Model

TOTAL: 50 hours

20 Beyond the Standard Model (2 hours)

- Grand Unified Theories

TOTAL: 52 hours

21 Neutrino physics (4 hours)

- Neutrinos masses and mixing
- The see-saw mechanism

TOTAL: 56 hours

Recommended books

- I.J.R. Aitchison and A.J.G Hey, "Gauge theories in particle physics", Vols. I and II, IoP publishing, 3rd Ed. (2003).
- F. Halzen and A.D. Martin, "Quarks and leptons: an introductory course in modern particle physics", Wiley (1984).
- D.M. Gingrich, "Practical Quantum Electrodynamics", Taylor and Francis (2006).

Other useful texts

- R.K. Ellis, W.J. Stirling and B.R. Webber, "QCD and collider physics", Cambridge (1996).
- E.A. Paschos, "Electroweak Theory", Cambridge (2007).
- B.R. Martin and G. Shaw, "Particle physics", Wiley (1992).
- W.S.C. Williams, "Nuclear and particle physics", Oxford (1991).
- The Review of Particle Physics, `http://pdg.lbl.gov/`
- J.D. Bjorken and S.D. Drell, "Relativistic Quantum Mechanics", McGraw (1964).
- e.g. G. Arfken, "Mathematical Methods for Physicists", Academic Press (1985).