PHYS3C24
Sample Questions for Section A of the ExamPaper

Q1. What distinguishes the strong interaction from the charged current weak interaction in the way that they conserve quark numbers? Write down an example of a reaction that proceeds via strong interactions and one that proceeds via a weak charged current interaction that illustrate your answer and draw the relevant Feynman diagrams.

Q2. What are the three factors which determine the magnitude of the invariant amplitude ? At the HERA ep collider, the dominant scattering process is $eq \to eq$ via the exchange of a photon or Z^0. If the square of the momentum transfer (Q^2) is 10 GeV^2 what is the approximate ratio for the rate of the electromagnetic and weak interaction? What is the ratio when $Q^2 = 10^5$ GeV^2 ?

Q3. What is meant by the spectator model for the decay of hadrons ? Draw a Feynman diagram for the decay of the $B_S \to D_S + e^+ + \nu_e$. The B_S meson contains a strange quark and an anti-b quark, while the D_S meson contains an anti-charm quark and a strange quark.

Q4. A free quark cannot be observed. What experimental evidence exists to support the claim that quarks exist and what properties of quarks are known ?

Q5. What are the principle components of a calorimeter and what is each component used for? What are the differences between an electromagnetic and a hadronic calorimeter, both in terms of the particles they can detect and their design ?

Q6. Give two techniques by which one could determine in principle whether a particle of a given momentum is a proton or a positron ?

Q7. What are the experimental signatures and with what detectors would one measure the following processes: $W \to e\nu$ and $W \to$ [illegible]?

Q8. Draw and label a diagram of the simplest multi-wire proportional chamber. Explain what happens when a charged particle traverses such a chamber.

Q9. Describe the physical analogy underlying liquid drop model of nucleon binding energies? What aspects of the model are not contained within this analogy?

Q10. Describe the analogy between the atomic shell model of atomic structure and the shell model of nuclear structure. In what way does the nuclear model differ from the atomic one? What is the experimental evidence for the shell model of nuclear energy levels ?

Q11. What consequences in principle follow if neutrinos have non-zero masses? Describe very briefly one way in which the mass of the electron neutrino be measured?

Q12. What are the six ways (decays/transmutations) in which a nucleus can undergo change in order to become more stable? Write down typical reactions in each case.

Q13. Explain why a sustained fission chain reaction is not possible in natural Uranium. Give one ways in one can overcome this problem in a practical reactor.

Q14. The particle Y^- can be produced in the strong interaction process

$$K^- + p \to K^+ + Y^-$$

Deduce its baryon number, strangeness, charm and beauty, and using these, its quark content. The $Y^-(1311)$ decays by the reaction

$$Y^- \to \Lambda + \pi^-$$

Give a rough estimate of its lifetime.

Q15. Explain why naturally occurring nuclei of mass number ≤ 60 are stable against α-decay. [Binding energy of α-particle is 28.3 MeV]. α-decay is energetically possible for nuclei with $A > 160$, but in practice is not observed until $A > 220$. Explain why this is.

Q16. Which of the following reactions are allowed and which are forbidden by the conservation laws appropriate to weak interactions?

$$\nu_\mu + p \to \mu^+ + n$$
$$\nu_e + p \to n + e^- + \pi^+$$
$$\Lambda \to \pi^+ + e^- + \bar{\nu}_e$$
$$K^+ \to \pi^0 + \mu^+ + \nu_\mu$$
$$K^0 \to e^+e^-$$
$$\tau^- \to e^- + \nu_e + \bar{\nu}_\tau$$

Q17. Why are all modern accelerators now of the collider design? At an electron-proton collider, a 30 GeV electron beam collides at an angle of 10 degrees with a 820 GeV proton beam. Evaluate the total centre-of-mass energy and calculate the energy of an electron beam that would be required to produce the same centre-of-mass energy in a fixed-target experiment using a proton target.

Q18. Pions and protons, both with momentum 2 GeV/c, travel between two scintillation counters distance L metres apart. What is the minimum value of L necessary to differentiate between the particles if the time-of-flight can be measured with an accuracy of 200 ps?

Q19. A photon is Compton scattered off a stationary electron through a scattering angle of 60 degrees and its final energy is half its initial energy. Calculate the value of the initial energy in MeV.

Q20. Describe the processes whereby an electron loses energy when traversing matter. Which of them is most important at high energies?

Q21. How would you measure the lifetime of a B hadron ? What type of detector would you use and what measurements would you need to make?

Q22. Explain why deep inelastic scattering data give evidence for the existence of quarks. How are the interactions between the quarks taken into account and why is this essential to explain the data?

Q23. What is the phenomenon known as *scaling* and what is the experimental evidence for it? What are *scaling violation* and how does QCD account for them?

Q24. Describe two pieces of evidence for the existence of *colour*?

Q25. Use lepton universality and lepton-quark symmetry to estimate the branching ratios for the decay $b \to c + e^- + \bar{\nu}_e$, where the b and c quarks are bound in hadrons. Ignore final states that are Cabibbo-suppressed relative to the lepton modes.

Q26. State briefly why it is necessary to introduce a Higgs boson into the Standard Model. One way of looking for the Higgs boson H is in the reaction $e^+e^- \to Z^0H$. For a Higgs boson with mass < 120 GeV, the branching ratio for $H \to b\bar{b}$ is predicted to be 85%. Why will looking for b-quarks help distinguish $e^+e^- \to Z^0H$ from the background reaction $e^+e^- \to Z^0Z^0$?

Q27. Draw Feynman diagrams for the decays $\pi^- \to \mu^-\bar{\nu}_\mu$ and $\pi^0 \to \gamma\gamma$. Use these to explain why the decay rate of the charged pion much smaller than that of the neutral pion?

Q28. Give an example of evidence that nucleons within nuclei have an energy level structure. The energy level diagram for the first four levels assuming the potential is a simple harmonic oscillator of frequency ω (ie the energy levels are $(n + \frac{1}{2})\hbar\omega$ are:

2p, 1f

2s, 1d

1p

1s

Explain the notation and work out the number of nucleons that can be accommodated in each level. What interaction must be added to the Hamiltonian to modify the energy level structure to recover the correct magic number sequence?

Q29. Outline very briefly, and without detailed calculations, the assumptions of the shell model that *can* make predictions about the spins and parities of nuclei Assume that in the shell model the nucleon energy levels are ordered

$$1s,\ 1p_{3/2},\ 1p_{1/2},\ 1d_{5/2},.....$$

What are the ground-state spin and parity quantum numbers expected in the single-particle shell model for the nuclei ^{39}K?

Q30. If the Sun were formed 4.6 billion years ago and initially consisted of 9×10^{56} hydrogen atoms and since then has been radiating energy via the PPI chain

$$4(^{1}H) \rightarrow {}^{4}He + 2e^{+} + 2\nu_{e} + 2\gamma + 24.68\,\mathrm{MeV}$$

at a detectable rate of 3.86×10^{26} watts, how much longer will it be before the Sun's supply of hydrogen is exhausted?