1. (3pts.)
(a) Make a Table for the baryon octet that lists: name of baryon, quark content, \( I_3 \), \( S \), \( B \), \( Y \), \( Q \).
(b) Draw the \( Y - I_3 \) plane diagram for this octet.

2. (4 pts)
(a) Work through the derivation of Halzen&Martin eqns.[2.51] and [2.52] and give an explanation in your own words.
(b) The photon has \( J^{PC} = 1^{--} \). What is the minimal number of photons the \( \pi^0 \) meson decays into?
(c) Consider the charmonium \( 1S_0 (\eta_c) \) and \( 3S_1 (J/\Psi) \) states. The gluon has the same \( J^{PC} \) as the photon. Which of the two charmonium states decays into an odd number of gluons and which into an even number?

3. (3 pts.)
The “\( B \)” mesons are bound states of the \( b \) quark and an anti-light-quark (or vice versa). It is found that the lightest such \( B \) mesons have \( J^P = 0^-, 1^-, 0^+, 1^+, 2^+ \).
What are the \( S \) (total spin) and \( L \) (orbital angular momentum) quantum numbers for these 5 cases?
Why is the charge conjugation quantum number \( C \) inappropriate here?
Note: it is possible that more than one combination of \( (S, L) \) leads to the same \( J^P \).

4. (5 pts.)
Derive the two Maxwell’s equations involving sources from the lagrangian density,
\[
\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - j_{\text{ext}}^\nu A_\nu
\]
with \( F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \) and \( j_{\text{ext}}^\nu \), some fixed external 4-current.

5. (5 pts.)
This problem is a review problem from ordinary Quantum Mechanics, designed to remind you of the Schroedinger versus Heisenberg pictures. Results for the simple 1D harmonic oscillator will be very useful later on in Quantum Field Theory.
In the Schroedinger picture time dependence is carried by the state vector \( |\Psi\rangle_S \) according to,
\[
i\hbar \frac{\partial}{\partial t} |\Psi\rangle_S = \hat{H}_S |\Psi\rangle_S.
\]
In the Heisenberg picture states are time independent whereas operators evolve according to
\[ i\hbar \frac{d}{dt} \hat{A}_H = [\hat{A}_H, \hat{H}_H]. \]  
(1)

The relation between operators in the two pictures is given by,

\[ \hat{A}_H(t) = e^{i\hat{H}_S t/\hbar} \hat{A}_S e^{-i\hat{H}_S t/\hbar} \]  
(2)

We will assume that neither \( \hat{H}_S \) nor \( \hat{A}_S \) are explicit functions of time and that initial conditions are such that the Schroedinger and Heisenberg operators coincide at \( t = 0 \).

The well known example of the 1D oscillator has the following Hamiltonian in the Schrodinger picture,

\[ \hat{H}_S = \hbar \omega (\hat{a}_S^\dagger \hat{a}_S + \frac{1}{2}) \]  
(3)

with

\[ [\hat{a}_S, \hat{a}_S^\dagger] = 1 \]  
(4)

a) What happens to the Hamiltonian and the commutation relation (4) in the Heisenberg picture? You should be able to answer this without explicit expressions for \( \hat{a} \) and \( \hat{a}^\dagger \) in the Heisenberg picture.

b) What are \( \hat{a}_H(t) \) and \( \hat{a}_H^\dagger(t) \)? Get your answer in two different ways, i.e. using (1) or using (2) and verify that everything is consistent.

Note: you may find the following relation useful: \( e^A B e^A = e^{A^\gamma} B \) if \( [A, B] = \gamma B \).