江门中微子暑期学校： 问题 （耿朝强）

1. In QCD, the global symmetries are U(N)L×U(N)R or SU(N)L×SU(N)R×U(1)V×U(1)A, in which the anomalous chiral symmetry of U(1)A is broken down to a discreate symmetry due to the instanton effect. Please identify this discreate symmetry.
2. (a) For one generation of quarks and leptons without the right-handed neutrino, based on anomaly cancellation conditions, show that the U(1) symmetry in the standard group of SU(3)C×SU(2)L×U(1)can only be U(1)Y , where Y represents the normal hypercharges in the standard model. (b) For one generation of quarks and leptons with the right-handed neutrino, as it is (1, 1, 0) under SU(3)C×SU(2)L×U(1)Y , show that there can be an another U(1) gauge symmetry, such as U(1)B-L, which is also anomaly free. In fact, it can be shown that the gauged U(1)X symmetry in SU(3)C×SU(2)L×U(1)X×U(1)Y can be constructed by any linear combination of U(1)Y and U(1)B-L.
3. (a) Show that for the flat universe, 𝝮M + 𝝮DE = 1, where 𝝮represents the energy density, while M and DE stand for Matter and Dark Energy, respectively. (b) Based on Hubble’s law, estimate the velocity of the expanding space just outside of our current observed universe. (c) Calculate the ages of the universe at z=1000, 2, and -2, respectively, where z represents the redshift.