The Standard Model Problems

1. State the name of all 12 fermions.

2. A hadron is a composite particle formed from particles in the standard model.
    a. Describe in more detail what a hadron is and give an example.
    b. Some hadrons have the fundamental electric charge while others have a zero net charge. Why, despite being made up of particles with less than the fundamental charge, is the fundamental charge still considered to be the smallest non-zero electric charge any stable particle can have?

3. All forces within the universe are explained using one or more of four fundamental forces. One of these fundamental forces is called the weak nuclear force.
    a. Name the remaining three fundamental forces.
    b. List all four fundamental forces in order of relative strength from strongest to weakest.
    c. List all four fundamental forces in order of their range from longest to shortest

d. Give an example of the role the weak nuclear force plays in the interaction between matter particles.

e. What is the force mediating particle of the weak nuclear force?

f. There is one force mediating particle that has been hypothesised but has not yet been experimentally confirmed. Which particle is this and to which fundamental force is it connected with?

4. Define the following terms.
   a. Fundamental force
   b. Fermion
   c. Gauge boson
   d. Baryon
   e. Quark
   f. Lepton
   g. Meson
   h. Hadron

5. Some properties of the quarks is shown in the table below. Note that both electric charge and strangeness have the opposite sign for an antiquark.

Quark	Relative Electric Charge	Strangeness
Up	+2/3	0
Down	-1/3	0
Top	+2/3	0
Bottom	-1/3	0
Charm	+2/3	0
Strange	-1/3	-1

   a. What is the charge of a down quark in coulombs?

   b. Protons and neutrons are baryons made of only up and down quarks. Using the charge of the individual quarks as evidence, determine the quark composition of both a proton and a neutron.

   c. A pion$^+$ is an up-antidown meson. Showing calculations, determine the charge of a pion$^+$.

   d. A kaon is a collection of mesons with a ±1 strangeness. Due to other limitations, kaons must contain an up, down, antiup or antidown quark. What is the quark composition of a kaon with a -1 charge?

   e. What is the quark composition of a neutral kaon with a +1 strangeness?

6. The nucleus of an atom has two forces acting within it. One that wants to hold the nucleus together and one that wants to break it apart.
   a. Name the force responsible for holding the nucleus together.

b. Name the mediating particle for this force.

c. Name the force responsible for breaking the nucleus apart.

d. Name the mediating particle for this force.

e. One of these forces can interact with neutrons while the other can interact with electrons. Clarify which force is capable of interacting with of each of these particles and explain why each force does not interact with the other particle.

7. The electrons in a one litre jug of water repel the electrons in another jug of water placed 30.0 cm away with more force than would act between two Earths placed right next to each other.
   a. Explain why the electron repulsion is larger than the dual Earth attraction.

   b. Explain why the huge force between the electrons in the two jugs of water does not cause an observable acceleration of either jug.

8. Neutrinos are in such high abundance within the universe that in a single second, billions of them pass through every square centimetre of our bodies but without any physical signs.
    a. Describe the difference between the particle composition of a neutrino and a neutron.

    b. Describe the characteristics of a neutrino that allow such large numbers of them to exist without having any physical impact.

    c. Only one of the fundamental forces interacts significantly with neutrinos. Which is it?

    d. One detector of neutrinos has been built into a cubic kilometre of ice in the South Pole, creatively called the IceCube Neutrino Observatory. Suggest a reason for using such a large volume of ice for the detection of neutrinos.

9. The Big Bang theorises the order of the formation of particles and larger astronomical bodies. These particles and objects in alphabetical order are:
    - hadrons
    - heavy atoms
    - leptons
    - light atoms
    - nuclei
    - quarks
    - stars

    Rearrange this list so that it is in the theoretical order in which these particles and objects formed within the timeline of the universe as predicted by the Big Bang theory.

10. The timeline of the formation of the early universe can be broken into several stages based on which particles and forces were present during each stage.
    a. List the order in which the unified force separated into the four fundamental forces observable today.

    b. The creation of matter and antimatter from energy (pair production) does not usually last because they quickly annihilate again. However, in the early stages of the universe the matter and antimatter pairs did not annihilate immediately. Explain why.

    c. Our current understanding of the relationship between matter and energy requires that when energy forms into matter it also requires the creation of antimatter to conserve quantities such as charge. What evidence suggests that in the early universe this conservations was not followed?

    d. Explain why no new nuclei formed once the universe had expanded and cooled below a critical temperature.

    e. The cosmic microwave background shows slight variances in the density of the universe. Explain why this is necessary for the formation of stars.