Particle Interactions Problems

1. State the baryon number **and** lepton number for the following particles.
    a. Proton
    b. Electron
    c. Neutron
    d. Antiproton
    e. Antineutron
    f. Tau
    g. Gluon
    h. Muon neutrino
    i. Antimuon
    j. Positron
    k. Kaon$^+$ (an $u\bar{s}$ meson)

2. During pair production, the energy of a photon is converted into pairs of fundamental particles. The particles formed are always a matching matter and antimatter pair.
    a. Describe the similarities and differences between matter and anti-matter.

    b. Justify why pair production is limited to the production of matching matter and antimatter particles.

    c. An electron has a lepton number of +1 and a -1 electric charge. An antitau has a lepton number of -1 and a +1 electric charge. Why can these two particles not be produced by pair production from a single photon?

    d. It is easier to cause the formation of electron/positron pairs than it is proton/antiproton pairs within the laboratory. Suggest a reason for this.

3. Beta decay is a form of nuclear decay where a neutron is converted into a proton while emitting a beta particle (an electron) and an antineutrino.
    a. Write out the particle reaction for beta decay.

    b. Show that the reaction is valid in regards to the conservation of baryon number.

    c. Show the reaction is valid in regards to the conservation of electric charge.

    d. Which flavour of antineutrino is produced during beta decay? Justify your choice.

4. An electron and positron undergoing annihilation may produce other massive particles via a virtual photon. One proposed reaction is given below.

$$e^{+} + e^{-} \rightarrow \bar{b}d + u\bar{d}$$

Is this reaction valid? Use conservation principles to justify your answer.

5. The collision of protons can produce a variety of different hadrons in addition to a pair of Z^0 bosons. One proposed reaction is shown below.

$$uud + uud \rightarrow Z^0 + Z^0 + uuc + b\bar{b}$$

Is this reaction valid? Use conservation principles to justify your answer.

6. Muons are created by the interaction of cosmic rays with the atmosphere. The muon is an unstable particle with a mean lifetime of 2.20 μs. It decays into a variety of products, one of which must be a muon neutrino.
   a. Why must one of the products of the decay be a muon neutrino?

   b. The reaction below shows the dominant decay for the muon and antimuon. There is one missing particle in both reactions. Write in the missing products.

$$muon\text{: } \mu^- \rightarrow \nu_\mu + \bar{\nu}_e + \_\_\_\_\_$$

$$antimuon\text{: } \mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + \_\_\_\_\_$$

7. Positron emission occurs during radioactive decay when a proton (uud) is converted into a neutron (ddu) and emits a positron.
   a. Explain why there must be more particles involved in the reaction for it to be valid.

   b. There is one missing particle on the product side. Write down the full reaction for this decay.

8. The existence of the antineutrino was confirmed experimentally in 1956 in the Cowan-Reines experiment. The Physicists used a nuclear reactor as a high density source of antineutrinos. The antineutrinos interacted with the protons of the hydrogen atoms in two nearby tanks of water to produce neutrons and positrons. The positron soon annihilated with nearby matter to produce a gamma ray. The gamma rays are detected by a material surrounding the tanks of water which gives off a flash of light when interacting with a gamma ray. Early trials gave positive results but the uncertainty of the evidence was disputed.

   Cadmium was added to the nuclear reactor. Cadmium atoms emit gamma rays when they capture a neutron. Pairs of gamma rays that were detected less than 5.00 ms apart were used as evidence the predicted reaction of an antineutrino with a proton had occurred. The experimental setup resulted in the detection of three gamma pairs per hour indicating three antineutron interactions per hour had occured.

   a. Name the three flavours of neutrinos

   b. Write the reaction for the interaction of an antineutrino with a proton.

   c. State the type of matter that the positron will annihilate with.

   d. Suggest a reason for the low rate of antineutrino detection.

   e. Antineutrinos permeate the entire universe. Why was the experiment conducted in a nuclear reactor?

   f. Describe why two gamma rays in quick succession was conclusive evidence for the existence of antineutrinos and removed the uncertainty of the early trials.

