FY3403 Particle physics
Problemset 1

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SUGGESTED SOLUTION

Problem 1

a) 1. True. The best example is the photon. Other possible examples are the three types of neutrinos, but by now there is considerable evidence that the neutinos have some (small) mass. The eight types of gluons are also considered to have zero mass, but that is somewhat problematic since they cannot exist a isolated objects due to color confinement (they do not have electric charge, but another kind of ”color” charge). Finally the supposed carriers of gravitational interaction and gravitational radiation (the gravitons) are believed exist as particles without mass and charge, but have not been experimentally observed yet (and probably will not be observed for a very long time).

2. True. Neutrinos with low energy behave like that. To be more precise, the interaction length of a 1 MeV neutrino moving through solid lead (Pb) is about 2×10^{14} m (decreasing with energy like E^{-1} until extremely high energies). By the way, note that there are two interpretions of the word billion: In American English it denotes 10^9 (called milliard in Norwegian), while it means 10^{12} in Norwegian.

3. False. Antimatter has been seen since 1932 when Anderson first observed the positron. And many particle physics experiments have been run with beams of antiparticles (positrons or anti-protons).

4. True.

5. False. Protons are in turn made of quarks and gluons.

6. True. The energy will usually be provided in the form of kinetic energy of other particles.

7. False. They need more powerful (which usually means larger) accelerators to investigate heavier objects, which are smaller.

8. False. Magnets are used to bend and focus the particle beams, and to bend charged particles in detectors. The particles are usully accelerated in special cavities by microwave (electromagnetic) fields. There is an older type of accelerator where the acceleration is provided by the electric field caused by a steadily increasing magnetic field.

9. True. Assuming the laws of physics are the same now as in the early universe.

10. False and true! In current particle physics experiments gravity is the weakest of the fundamental forces. In fact, too weak to have been observed in particle physics experiments. However gravity is the only long range fundamental force which cannot be shielded; thus it wins when interactions between macroscopic objects are conserned. Also, the gravity force increases faster with energy than the other fundamental forces. Thus it is expected to be the strongest force when particles collide with

extremely high energy.

11. True. The current issue of Review of Particle Physics lists more that one hundred ”elementary” particles. (Also, the many hundred different isotopes of nuclei are subatomic particles.)

12. Basically true. And all known stable matter is made of leptons and quarks from the First family (generation). However, there are research attempts to make photonic fluids.

13. False. They will circulate the ring about 11 000 times per second, but they cross the border twice per round.

14. False. It is a secondary force of electromagnetic origin.

15. True. The Eiffel tower weighs about 7 000 tons; the central part of the LEP Delphi detector (which is mostly a magnet) weighs about 3 500 tons.

16. True. At least we hope it is true (because we hope the experiments will run for a long time, and attract recruitment from young people)! Perhaps some of the future physicists haven’t entered high school yet.

b) The Greek thinker Empedocles. Similar ideas where expressed by ancient Chinese and Indians.

c) The Greek root for the word atom, atomon, means that which cannot be divided. But the entities we call atoms are made of more fundamental particles!

d) About 99:999999999999%. I.e., about 1 part in 10^{14} is not empty space.

e) (i) The linear size of an atom is about 10^{10} m. (ii) The linear size an atomic nucleus is about 10^{14} m. (iii) The linear size a proton is about 10^{15} m. (iv) For all we know the electron may be exactly pointlike (but we don’t believe it is pointlike). Experimentally, the linear size of an elctron is at most 10^{18} m.

f) There are 3 types of leptons: The electron, the muon, and the tau-lepton (with their associated antiparticles and neutrinos/anti-neutrinos). There are 6 types of quarks, classified into 3 doublets: The doublet of the up and down quarks, the doublet of the charm and strange quarks, the doublet of the top and bottom quarks. All with their associated antiparticles, and with all quarks/antiquarks coming in three color variants.

g) Since the discovery of the muon in 1937.

h) The top quark. It was discovered 1995 in the Fermilab collider in Batavia, Illinois.

i) Probably because the charge conjugation+parity (i.e. CP) symmetry is broken. And because the universe was out of thermal equilibrium at some stages of its evolution.

j) Because the tau lepton is not light at all; it weighs almost twice as much as the proton.

k) $\tau^- \rightarrow e^- + \bar{\nu}_e + \nu_\tau$ is possible.

$\tau^- \rightarrow \mu^- + \nu_\tau$ is impossible: violates conservation of angular momentum, since the spin on the left hand side is half integer and on the right hand side is integer. (It also violates conservation of muon number, but that is a conservation law which we would be much more willing to revoke).

$e^- \rightarrow \mu^- + \bar{\nu}_\mu + \nu_e$ is impossible: it violates conservation of energy-momentum.

l) Each proton is made of two up-quarks and one down quark (plus some gluons to keep these together, plus a small sea of quark-antiquark pairs).

m) As far as we know of nothing more fundamental.

n) a-d.

o) We have three generations of matter particles. If you have a good explantation for why, please get it published in a physics journal asap!

p) There are four types: the strong interactions, the electromagnetic interactions, the weak interactions, the graviational interactions.

q) A certain internal quantum degree of freedom carried by quarks, antiquarks and gluons. Functions as a source for the gluon field (analogous to the electric charge functioning as a source for the electromagnetic field).

r) Gluons keep the quarks in a neutron or a proton together. But it may be a bit inaccurate to say that it is the gluons which keep all the nucleons (protons and neutrons) in a large atomic nucleus together. The old idea of Yukawa, that the nucleons are kept together by pions (and other composite particles, like the ρ-mesons) may still be a valid description.

s) It is not described at all (because gravity is not included in The Standard Model)!

t) A bubble chamber is a tank with superheated liquid (e.g. liquid hydrogen) which is prevented from boiling by the application of an overpressure. When the overpressure is released, the boiling initially occurs along the trails of charged ions left behind where fast charged particles have (recently) passed through the liquid. This creates tracks of bubbles which can be photographed through a window in the chamber. The bubble chamber is too slow, and it requires too much manpower to analyse the pictures. Modern detectors must be based on fast electronic registration, to be able to throw away uninteresting events immediately, and for fast storage of interesting events.