Homework 1: The Standard Model

1. The emission of beta particles in radioactive decay is evidence for the existence of
   A quarks
   B electrons
   C gluons
   D neutrinos
   E bosons.

2. One type of hadron consists of two down quarks and one up quark.

   The charge on a down quark is $-{}^{1}/_{3}$.

   The charge on an up quark is $+{}^{2}/_{3}$.

   Which row in the table shows the charge and type for this hadron?

	Charge	Type of hadron
A	0	baryon
B	+1	baryon
C	-1	meson
D	0	meson
E	+1	meson

3. A student makes the following statements about sub-nuclear particles.

   I The force mediating particles are bosons.
   II Gluons are the mediating particles of the strong force.
   III Photons are the mediating particles of the electromagnetic force.

   Which of these statements is/are correct?

   A I only
   B II only
   C I and II only
   D II and III only
   E I, II and III

4. Which of the following lists the particles in order of size from smallest to largest?
   A helium nucleus; electron; proton
   B helium nucleus; proton; electron
   C proton; helium nucleus, electron
   D electron; helium nucleus, proton
   E electron; proton; helium nucleus

5. Three students each make a statement about antiparticles.

   I An antiparticle has the same mass as its equivalent particle.
   II An antiparticle has the same charge as its equivalent particle.
   III Every elementary particle has a corresponding antiparticle.

   Which of the statements is/are correct?

   A I only
   B II only
   C I and III only
   D II and III only
   E I, II and III

6. A student makes the following statements about a proton.

   I A proton is a fermion.
   II A proton is a baryon.
   III A proton is a meson.

   Which of these statements is/are correct?

   A I only
   B II only
   C III only
   D I and II only
   E I and III only

7. Identify the force-mediating particle associated with the electromagnetic force.

   A gluon
   B photon
   C electron
   D muon
   E W^+

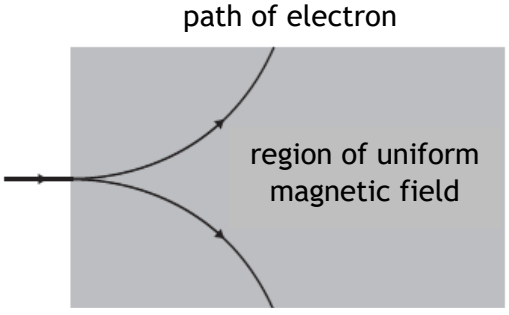
8. Identify the row in the table which correctly identifies the number of quarks in a baryon and the number of quarks in a meson.

	Number of quarks in a baryon	Number of quarks in a meson
A	1	3
B	2	2
C	2	1
D	3	2
E	3	3

9. Identify the difference between the mass of the proton and the mass of an electron in terms of orders of magnitude.

   A -31
   B -27
   C -16
   D 4
   E 3

10. An electron and another particle of identical mass pass through a uniform magnetic field. Their paths are shown in the diagram.



   This observation provides evidence for the existence of
   A neutrinos
   B antimatter
   C quarks
   D protons
   E force mediating particles

11. Information on the properties of three elementary particles together with two types of quarks and their corresponding antiquarks is shown in the tables below.

Properties of Elementary Particles			
Particle	**Number of quarks**	**Charge**	**Baryon number**
Proton	3	+e	1
Anti-proton	3	-e	-1
Pi-meson	2	-e	0

Properties of quarks and anti-quarks		
Particle	**Charge**	**Baryon number**
Up	$+\frac{2}{3}e$	$+\frac{1}{3}$
Down	$-\frac{1}{3}e$	$+\frac{1}{3}$
Anti-up	$-\frac{2}{3}e$	$-\frac{1}{3}$
Anti-down	$+\frac{1}{3}e$	$-\frac{1}{3}$

(a) Using information from the tables above, show that a proton consists of two up quarks and one down quark.
(b) State the combination of quarks that forms a pi-meson.

12. The following strong interaction has been observed.

$$K^- + p \rightarrow n + X$$

The K^- is a strange meson of quark composition $\bar{u}$ s.
The u quark has a charge of +2/3.
The d quark has a charge of −1/3.

(a) Determine the charge of the strange quark.
(b) Use the appropriate conservation law to determine whether particle X is positive, negative or neutral.
(c) State whether particle X is a baryon or a meson. Justify your answer.

13. The equation for a β^- decay can be written as:

$$n \rightarrow p + \beta^- + \bar{\nu}$$

(a) For each of these four particles, state its name, and where appropriate, its quark composition.
(b) Write a similar equation for a β^+ decay.
(c) State the interaction associated with β decay.

In 1995 scientists at CERN created atoms of antihydrogen.

(d) Name the particles that make up an atom of antihydrogen.
(e) State the charge of an atom of antihydrogen.
(f) Explain why it is not possible to store atoms of antihydrogen.

14. In February 2000 scientists at CERN announced that they had made some quark-gluon plasma, QGP, the extremely dense energetic matter that was present throughout the universe about 1μs after the Big Bang. This was done by colliding lead ions in a particle accelerator.

(a)

(i) A particular isotope of lead has 82 protons and 124 neutrons in its nucleus. Write the symbol for this isotope of lead in the form

$$^{x}_{y}Z$$

(ii) State the other particle present in an atom of this isotope of lead.

(b) When QGP existed in the early universe, all the particles in the table below were present.

Quarks			Leptons		
Name	**Symbol**	**Charge**	**Name**	**Symbol**	**Charge**
up	u	+2/3	**electron**	$e-$	-1
down	d	-1/3	**electron-neutrino**	v_e	0
charm	c	+2/3	**muon**	μ	-1
strange	s	-1/3	**muon-neutrino**	v_μ	0
top	t	+2/3	**tau**	$\tau -$	-1
bottom	b	-1/3	**tau-neutrino**	v_τ	0

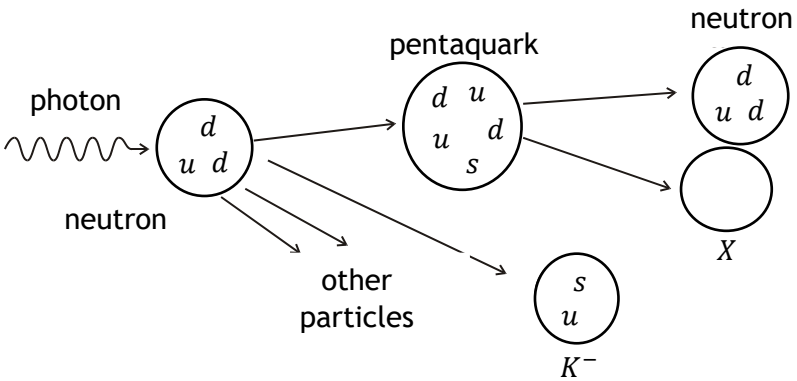
(i) Describe briefly the circumstances required for the remaining quarks in the table to be created.

(ii) The early universe also contains positrons.
Describe how the positron compares to the electron.

15. In July 2003 scientists at the SPring-8 synchrotron in Japan announced the discovery of a pentaquark – a particle made up of 5 quarks.

(a) Previously, quarks had been known to occur in two types of combinations called hadrons. Name these two types and describe the quark combination of each.

(b) The diagram shows some of the particles involved in the production and decay of the pentaquark, including the quark composition for several of them.



(i) Name **one** quantity conserved during the decay of the pentaquark.

(ii) The table below shows the charges of the six types of quarks as a fraction of the charge of a proton.

Quark type			Charge
up	charm	top	2/3 *e*
down	strange	bottom	-1/3 *e*

Determine the charge of the pentaquark. Express your answer as a fraction of the charge of a proton.

(iii) Determine the charge of particle X.

(iv) Suggest a possible quark composition for particle X. Justify your answer.