W-16

HOLY CROSS COLLEGE

12 PHYSICS ATAR
TEST 9 - STANDARD MODEL

NAME: SOLUTIONS MARK: $\frac{}{53}$

1. What name is given to the modern quantum mechanical theory that describes the interaction of all matter at the fundamental level? [1 mark]

The Standard Model of particle physics.

2. By referring to your knowledge of particle physics, explain what is meant by the term ***fermion***. [2 marks]

- A particle that obeys the Pauli Exclusion Principle. (1)
- They have a $\frac{1}{2}$-integer spin. (1)

3. Identify two fermions that are different and describe how the properties of your chosen particles differ. [2 marks]

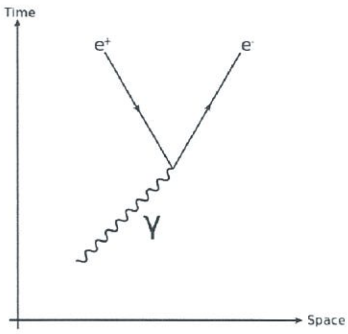
- Choose from e, μ, τ, ν_e, ν_μ, ν_τ ($\frac{1}{2}$ mark each)
- Have different mass and charge ($\frac{1}{2}$ mark each)

4. By referring to your knowledge of particle physics, explain what is meant by the term ***boson***. [2 marks]

- Don't obey the Pauli Exclusion Principle. (1)
- Are elementary force-carrying particles. $\Big\}$ Either (1)
- Have integer spin.

5. Consider the Feynman diagram shown here.

(a) Explain the process being described by this Feynman diagram. [2 marks]



- Photon is decaying. (1)
- Forms an electron and positron. (1)

(b) If the matter/antimatter pair produced travelling with a velocity of 3.70 x 10^5 ms^{-1}, calculate the frequency of the original boson. [4 marks]

$$E_k\text{ (electron)} = \frac{1}{2} m_e v^2$$
$$= \frac{1}{2}(9.11\times10^{-31})(3.70\times10^{5})^2$$
$$= 6.24\times10^{-20}\text{ J} \quad (1)$$
$$\therefore E_k\text{ (pair)} = 1.25\times10^{-19}\text{ J}. \quad (1)$$

$$E = hf \Rightarrow f = \frac{E}{h} = \frac{1.25\times10^{-19}}{6.63\times10^{-34}} = \underline{1.88\times10^{14}\text{ Hz}}. \quad (1)$$
(1)

6. Consider figure 1 and figure 2 shown below.

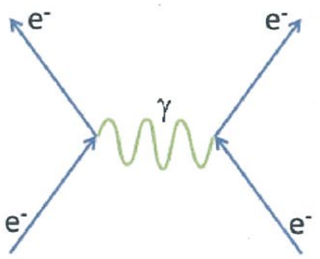


Figure 1

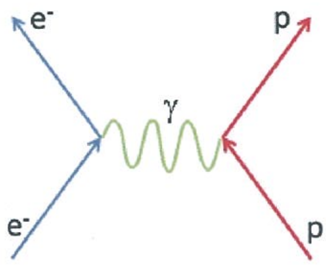


Figure 2

(a) Name the fundamental force that is being represented in these diagrams. [1 mark]

electromagnetic force

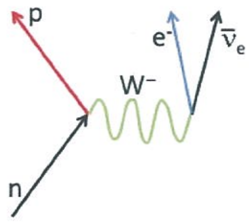
(b) Explain what process is being described by the Feynman diagrams shown as Figure 1 and Figure 2. [2 marks]

Figure 1 electron - electron repulsion (1)

Figure 2 electron - proton attraction (1)

7. The Feynman diagram shown here represents a common nuclear physics process.

(a) Name the process represented here. [1 mark]



Neutron decay, producing a proton, β particle (electron) and an electron antineutrino. (1).

(b) Write the balanced equation to represent the process shown in the above Feynman diagram. [2 marks]

$$n \rightarrow p^{+} + e^{-} + \bar{N}_e \qquad (2)$$

(c) Name the fundamental force that is being represented in the above diagram. [1 mark]

weak nuclear force

8. The following table shows some of the properties of the six flavours of quarks.

Quark Flavour	Strangeness	Charm	Bottomness	Topness
Up	0	0	0	0
Down	0	0	0	0
Strange	-1	0	0	0
Charm	0	+1	0	0
Bottom	0	0	-1	0
Top	0	0	0	+1

(a) Complete the table shown below for the particles given. [4 marks]

Particle	Constituent particles	Formula	Baryon or Meson	Charge	Baryon number	
Antiproton	Anti-up, anti-up, anti-down	$\bar{u}\bar{u}\bar{d}$	B	-1	-1	(1)
Kaon-minus	Anti-up, strange	$\bar{u}s$	M	-1	0	(1)
D-plus-s	Charm, anti-strange	$c\bar{s}$	M	1	0	(1)
Upsilon	Bottom, anti-bottom	$b\bar{b}$	M	0	0	(1)

(b) The four fundamental forces are:
A. Electromagnetic force
B. Weak nuclear force
C. Strong nuclear force
D. Gravitational force

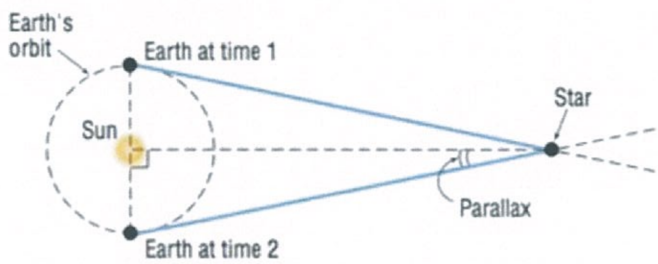
(i) Which of these forces mediate an interaction with the particles shown in the table of part (a)? [1 mark]

a. All of the forces shown.
b. A, B & C only.
c. B, C & D only.
d. A, C & D only.

ii. Will any of the particles shown in the table above interact with the Higgs boson? Explain your answer. [3 marks]

- yes (1)
- Higgs boson gives particles mass. (1)
- These particles have mass, hence they interact with the boson. (1)

9. The nearest star to the Sun (and thus the star with the largest parallax) is Proxima Centauri and has a parallax of 0.7687 arcsec.



Calculate the distance to Proxima Centauri:

(a) in parsecs. [2 marks]

$$d = \frac{1}{p} = \frac{1}{0.7687} = \underline{1.30\,pc} \quad (1)\ (1)$$

(b) in light years. [2 marks]

$$d = (1.30)(3.26) = 4.24 \text{ l.y.}$$

(c) in meters. [2 marks]

$$d = (4.24)(365.25)(24.0)(3.60\times10^{3})(3.00\times10^{8}) = \underline{4.01\times10^{16}\,m} \quad (1)\ (1)$$

10. State two pieces of evidence that support the Big Bang Theory and the expansion of the Universe. [2 marks]

- Redshift of absorption spectra. (1)
- Presence of the cosmic background radiation. (1).

11. Explain what is meant by the term ***redshift***. (1) (1) [3 marks]

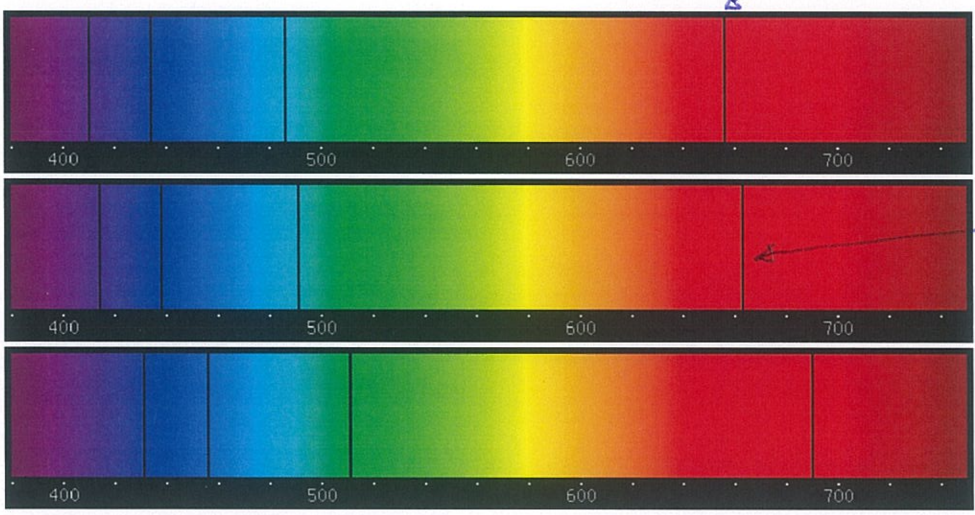
- light from galaxies moving away from Earth have longer wavelengths.
- Absorption spectral lines appear to have moved towards the red end of the spectrum. (1)

12. The spectral analysis given below shows the observed absorption spectra of hydrogen for the following cases:

(i) not moving.
(ii) moving away from you at 3,000 kms^{-1}.
(iii) moving away from you at 30,000 kms^{-1}.

$\lambda = 655nm$ (1)

i)
ii)
iii)



(1)

$\lambda = 662nm$

(a) ***Estimate*** the redshift of object (ii) with respect to the stationary observer (i). Show all estimates and working. [4 marks]

$$\text{shift} = \frac{\Delta\lambda}{\lambda}$$

$$= \frac{(662-655)\times10^{-9}}{655\times10^{-9}} \quad (1)$$

$$= \underline{0.011} \quad (1)$$

(b) Show that the recessional speed of object (ii) is around 3000kms^{-1} with respect to observer (i). Show all working. [3 marks]

$$V_{galaxy} = \frac{\Delta\lambda}{\lambda} c$$
$$= (0{\cdot}011)(3{\cdot}00 \times 10^{8}) \quad (1)$$
$$= 3{\cdot}30 \times 10^{6}\ ms^{-1} \quad (1)$$
$$= \underline{3{\cdot}30 \times 10^{3}\ kms^{-1}} \quad (1)$$

13. Hubble's Law demonstrates the direct linear relationship between distance to interstellar objects and their recessional velocities.

(a) Show, by algebraic manipulation, that Hubble's Law can be used to determine the age of the Universe. [3 marks]

$$V_{galaxy} = \frac{d}{t_{universe}} \quad \text{and} \quad V_{galaxy} = H_o d. \quad (1)$$
$$\Rightarrow \frac{d}{t_{universe}} = H_o d \quad (1)$$
$$\Rightarrow t_{universe} = \frac{1}{H_o} \quad (1)$$

(b) The most up-to-date and current best direct measurement of the Hubble constant is 73.8 km/sec/Mpc. Use this to calculate the age of the universe in years.

[4 marks]

$$H_o = 73{\cdot}8\ km/s/Mpc$$
$$= \frac{73{\cdot}8 \times 10^{3}}{(1{\cdot}00 \times 10^{6})(3{\cdot}26)(365{\cdot}25)(24{\cdot}0)(3{\cdot}60 \times 10^{3})(3{\cdot}00 \times 10^{8})} \quad (1)$$
$$= 2{\cdot}391 \times 10^{-18}\ s^{-1} \quad (1)$$

$$t_{universe} = \frac{1}{H_o} = \frac{1}{2{\cdot}391 \times 10^{-18}} = 4{\cdot}18 \times 10^{17}\ s \quad (1)$$
$$(1) \qquad = \underline{1{\cdot}32 \times 10^{10}\ yr}$$

Data

1.00 pc = 3.26 light years

Fundamental particles