KINGSWAY CHRISITAN COLLEGE

12 ATAR Physics 2016
End of Unit Test

The Standard Model

Name: *ANSWERS*

NOTE: Formula and constants sheet may be used.
All answers are to be accurate to three significant figures.
Marks will be given to correct working and diagram despite an incorrect final answer.
Conversely, working is required to demonstrate how a correct final answer was arrived at.

SECTION A	60	
SECTION B	20	
TOTAL	**80**	

PART A – Short answer questions

Question 1 (8 marks)

The table below shows the 6 types of sub-nuclear particles known as quarks and lists their properties.

NAME	SYMBOL	Charge (Q)	Baryon Number (B)	Strangeness (S)	Charm (c)	Bottomness (b)	Topness (t)
Up	u	$\frac{+2}{3}$ e	$\frac{1}{3}$	0	0	0	0
Down	d	$\frac{-1}{3}$ e	$\frac{1}{3}$	0	0	0	0
Strange	s	$\frac{-1}{3}$ e	$\frac{1}{3}$	-1	0	0	0
Charmed	c	$\frac{+2}{3}$ e	$\frac{1}{3}$	0	+1	0	0
Bottom	b	$\frac{-1}{3}$ e	$\frac{1}{3}$	0	0	-1	0
Top	t	$\frac{+2}{3}$ e	$\frac{1}{3}$	0	0	0	+1

When a K^- meson collides with a proton, the following reaction can take place.

$$K^{-\text{¿}+p \to K^{0}+K^{+\text{¿}+X\text{¿}}\text{¿}}$$

X is a particle whose quark structure is to be determined.

The quark structure of the mesons in the reaction is given below.

particle	**quark structure**
K^-	$s\bar{u}$
K^+	$u\bar{s}$
K^o	$d\bar{s}$

(a) Is the original K^- particle a hadron, a lepton or an exchange particle? Explain.

The original K^- particle is a hadron ✓
as it is composed of quarks. ✓

(2 marks)

(b) A proton has a charge of +1 and its s, c, b and t values are all zero. State the quark structure of a proton.

uud

(1 mark)

(c) State and explain whether X is a charged particle.

Negatively charged ✓
Based on law of conservation of charge – it must have a charge of -1 ✓
(or shows charges of all species to prove the balancing figure must be -1)

(2 marks)

(d) Given that X has a baryon number of 1, deduce the quark structure of X. Show your reasoning.

(3 marks)

$$K^{-¿+p \rightarrow K^0 + K^{+¿+X¿}¿}$$

So for strangeness *-1 + 0 1 + 1 + ?* ✓

Conservation of strangeness means that X must have a strangeness of ***-3*** ✓

Therefore, since the strange quark has a strangeness of -1, the quark structure must be:
X = sss ✓

Question 2 (6 marks)

(a) For the particles listed below, circle those that are composed of quarks.

Proton   Electron   Neutrino   Neutron   Photon   Positron

(1 mark)

(b) The existence of the neutrino was theorised by Pauli in 1930 but it was not until 1956 that they were detected. Explain, referring to two properties of the neutrino, why they were so difficult to detect.

The neutrino has nearly zero mass so is hard to detect by the effects of collision ✓
The neutrino has no charge so has no electromagnetic interactions ✓
Hence it hardly interacts at all with other matter and tends to pass straight through any detection apparatus ✓ *(any 2 points)*

(2 marks)

(c) Can electrons and neutrinos be subject to the strong force? Explain.

No

Electrons and neutrinos are leptons ✓
Only quarks feel the strong force ✓
(no marks for just saying 'no' – explanation needed)

(2 marks)

(d) If neutrinos are involved in a collision reaction, why is it unlikely that this was governed by the electromagnetic force?

Neutrinos have no charge and so are not affected by the electromagnetic force

(1 mark)

Question 3 (6 marks)

A positron-electron pair can be formed from a high energy gamma ray.

(a) Use Einstein's energy-mass equivalence to calculate the minimum energy, in **electron-volts**, of a gamma ray that could result in the production of such a pair.

(3 marks)

The mass of a positron-electron pair is $2 \times 9.11 \times 10^{-31}$ kg ✓

The minimum energy needed to create the mass of the positron-electron pair is

$E = mc^2$

$E = (2 \times 9.11 \times 10^{-31}) \times (3 \times 10^8)^2$

$E = 1.64 \times 10^{-13}$ J ✓

Hence $E = \dfrac{1.64 \times 10^{-13}}{1.60 \times 10^{-19}} = \underline{1.02 \text{ MeV}}$ ✓

(b) If an electron collided with a positron, explain what would happen.

This is an example of matter article meeting its equivalent anti-matter particle ✓
Annihilation takes place ✓
Resulting in the particles disappearing and energy being released (as a photon) ✓

(3 marks)

Question 4 (2 marks)

State two general properties of leptons that distinguish them from the hadrons.

Low mass compared to hadrons ✓
Fundamental particles – not composed of quarks ✓
Do not interact by the strong nuclear force ✓

(any two points)

(2 marks)

Question 5 (4 marks)

Give the quark composition of the following hadrons:

(a) the sigma plus baryon ($^{+}$), with Q = +1, B = +1, and S = -1 and c = b = t = 0

uus

(b) the charmed Xi baryon (Ξ^{0}_{c}), with Q = 0, B = +1, S = -1, c = +1 and b = t = 0

dsc

(c) the D^{+} meson, with Q = +1, B = 0, c = +1 and S = b = t = 0

$c\bar{d}$

(d) the strange B meson (B^{0}_{s}), with Q = 0, B = 0, S = -1, b = +1 and c = t = 0

$s\bar{b}$

Question 6 (4 marks)

Fill in the following table

Hadron	**Charge (e)**	**Quark combination**

Just examples – accept any valid alternatives as long as fulfils the rules on quark composition and charge given

A positively charged baryon	+2	*e.g. utc* ✓
A neutral baryon	0	*e.g. udb* ✓
A negatively charged meson	-1	*e.g.* $d\,\bar{t}$ ✓
A positively charged meson	+1	*e.g.* $c\,\bar{s}$ ✓

(4 marks)

Question 7 (4 marks)

Galaxy NGC 3351 is in the constellation of Leo. It is a distance of 11.7 megaparsecs from Earth. One parsec equals 3.26 light-years. A light-year is the distance travelled by light in one year. Calculate the distance to NGC 3351 in kilometres.

Distance (ly) = $(11.7 \times 10^{6}) \times 3.26 = 38\ 142\ 000$ *ly* ✓

1 ly in metres = $s \times t = (3 \times 10^{8}) \times (365 \times 24 \times 60 \times 60)$
1 ly = 9.4608×10^{15} *m* ✓

Distance to NGC 3351 = distance (ly) $\times\ 9.4608 \times 10^{15}$
Distance to NGC 3351 = $38{,}142{,}000 \times 9.4608 \times 10^{15}$
Distance to NGC 3351 = 3.61×10^{23} *m* ✓
Distance to NGC 3351 = $\underline{3.61 \times 10^{20}\ \text{km}}$ ✓

Question 8 (4 marks)

Electrons are fundamental particles that cannot be split. When high energy electrons are fired at individual protons or neutrons (nucleons), the electrons penetrate the nucleons in an inelastic collision, resulting in the electrons being scattered through a range of angles. This is evidence that a nucleon contains small dense regions of charge.

(a) Explain what is responsible for these regions of charge.

Quarks ✓ *(the fundamental particle that make up Hadrons)*

(1 mark)

(b) State how many charge regions you would expect in a proton or a neutron.

Three. ✓

(1 mark)

(c) Explain how a neutron can have separate regions of charge when the charge of a neutron is zero.

The individual charge on each quark can be positive or negative ✓
but the sum of charges of each quark equals zero. ✓

(2 marks)

Question 9 (5 marks)

Aluminium-29 decays to Silicon-29 by beta emission as described in the nuclear equation:

$$^{29}_{13}Al \rightarrow {}^{29}_{14}Si + {}^{0}_{-1}\beta + {}^{0}_{0}\overline{\nu} + energy$$

(a) Identify the particle with the symbol ${}^{0}_{0}\overline{\nu}$

Anti-neutrino

(1 mark)

(b) Which force is involved in this decay reaction

Weak force

(1 mark)

(c) The beta particle is an electron that has come from the nucleus. Explain how the beta particle and the ${}^{0}_{0}\overline{\nu}$ particle appeared.

Consider one of the neutrons in the aluminium nucleus.
One of the down quarks in the neutron decays into an up quark ✓
a beta negative particle and an anti-neutrino. ✓
The neutron has become a proton which remains in the nucleus (now Silicon) and the beta negative particle and the anti-neutrino are ejected. ✓ (knowledge of the intermediate virtual W-boson is

desired but not necessary but if the answer to the last of the three points above is only worth ½ mark, then award ½ mark for mention of boson)

(3 marks)

Question 10 (3 marks)

The resolving power of any telescope defines whether an observer can clearly see two distant stars as two separate images. An angle of 10^{-5} radians between two clear images is considered to be the minimum acceptable. This angle is denoted by in the equation

$$\Phi = \frac{\lambda}{D}$$

where is the wavelength of the radiation received and
D is the diameter of the receiving dish or antenna

An optical telescope with a 10 m diameter dish can collect useful information in the optical range of wavelengths. The proposed Square Kilometre Array radio wave telescope, intended to detect electromagnetic radiation at a wavelength of 21 cm, needs to cover an area of hundreds of square kilometres. Explain this difference.

Description	**Marks**
$D = \frac{\lambda}{10^{-5}}$	1
[SKA] = 0.21 m [light] = 5×10^{-7} m (1)	1
D [SKA] = 2100 m D [Optical] = 5×10^{-2} m (1)	1
*Detailed calculations are **not** required but students must show they appreciate the wavelength of radio waves is about 100 000 times larger than those of light waves so the receiving dish [minimum] must be about 100 000 times bigger*	
	Total 3

Question 11 (10 marks)

Determine which of the following reactions can occur. For those that cannot occur, determine the conservation law (or laws) violated and show evidence for your conclusion.

Deduct ½ mark if no evidence given

No marks if just says 'no' without any explanation or incorrect explanation

(a) p 0

No ✓

Baryon number violated: 1 00 ✓

(b) $p + p \quad p + p \quad {}^{0}$

Yes – this reaction can occur ✓

(c) $p \quad p \quad p$

No ✓

Baryon number violated: 1 + 1 10 ✓

(d)

Yes – this reaction can occur ✓

(e) $n \quad p \quad e \quad \overline{\upsilon}_e$

Yes – this reaction can occur ✓

(f) n

No ✓

Baryon number violated: 0 01 ✓

Muon-lepton number violated: 0 10 ✓

Question 12 (4 marks)

The Steady State Theory (also called The Infinite Universe Theory) was a model developed by the respected astronomer Fred Hoyle and others in 1948. It proposed that the universe had no beginning or end over infinite time. Fred Hoyle is reported to have used the phrase 'Big Bang' as a derogatory term when referring to an alternative theory that is nowadays the most widely accepted.

Describe two piece of observational evidence that support the Big Bang Theory.

Cosmic microwave background radiation – thermal radiation that fills universe uniformly and is left over from the big bang (observable by sensitive radio telescopes) ✓ ✓

Red shift of light observed from distant galaxies indicates that they are receding. ✓ ✓

Stars such as Cepheid variables indicate distance to galaxies, this information in conjunction with recessional speed data from red shift supports Hubble's Law.
(Any 2 appropriate and well supported points)

PART B – Comprehension

Question 13 Hubble's Law (20 marks)

When a source of waves is moving, a stationary observer notices a change in frequency of the waves. This effect is observed for both longitudinal and transverse waves. For example, if an ambulance moves towards you the sound frequency you hear is higher than the frequency its siren is emitting. This is known as the Doppler Effect.

If a source of electromagnetic waves, such as a star, is travelling away from an observer then the wavelengths of the lines in its electromagnetic spectrum are shifted to higher values. This is called red shift. An equation for the relationship is as follows:

$$z = \frac{\Delta\lambda}{\lambda}$$

It can also be shown that:

$$z = \frac{v}{c_0}$$

z = red shift
$\Delta\lambda$ = change in wavelength (moving source) (nm)
λ = wavelength of stationary source (nm)
v = recessional speed of galaxy (m s^{-1})
c_0 = speed of light in a vacuum (m s^{-1})

Edwin Hubble analysed the red shifts of various galaxies in 1920 and deduced that most galaxies are moving away from the Earth, this suggests that the Universe is expanding. Hubble also discovered that the further away a galaxy is, the bigger its red shift and the faster it is moving away. This relationship is known as Hubble's Law and can be stated algebraically as follows:

$$v_{galaxy} = H_0 . d$$

v_{galaxy} = recessional speed of galaxy (km s^{-1})
d = distance to galaxy (Mpc)
H_0 = Hubble's constant (km s^{-1} Mpc^{-1})

The distances to galaxies can be estimated by observing Cepheid Variables within a galaxy. A Cepheid Variable is a class of star that pulsates. The relationship between the period of pulsation and the size of the star is very precise. An understanding of how brightness diminishes with distance allows astronomers to estimate distances to galaxies with a high degree of confidence.

The following data was recorded by the Hubble Space Telescope for five galaxies.

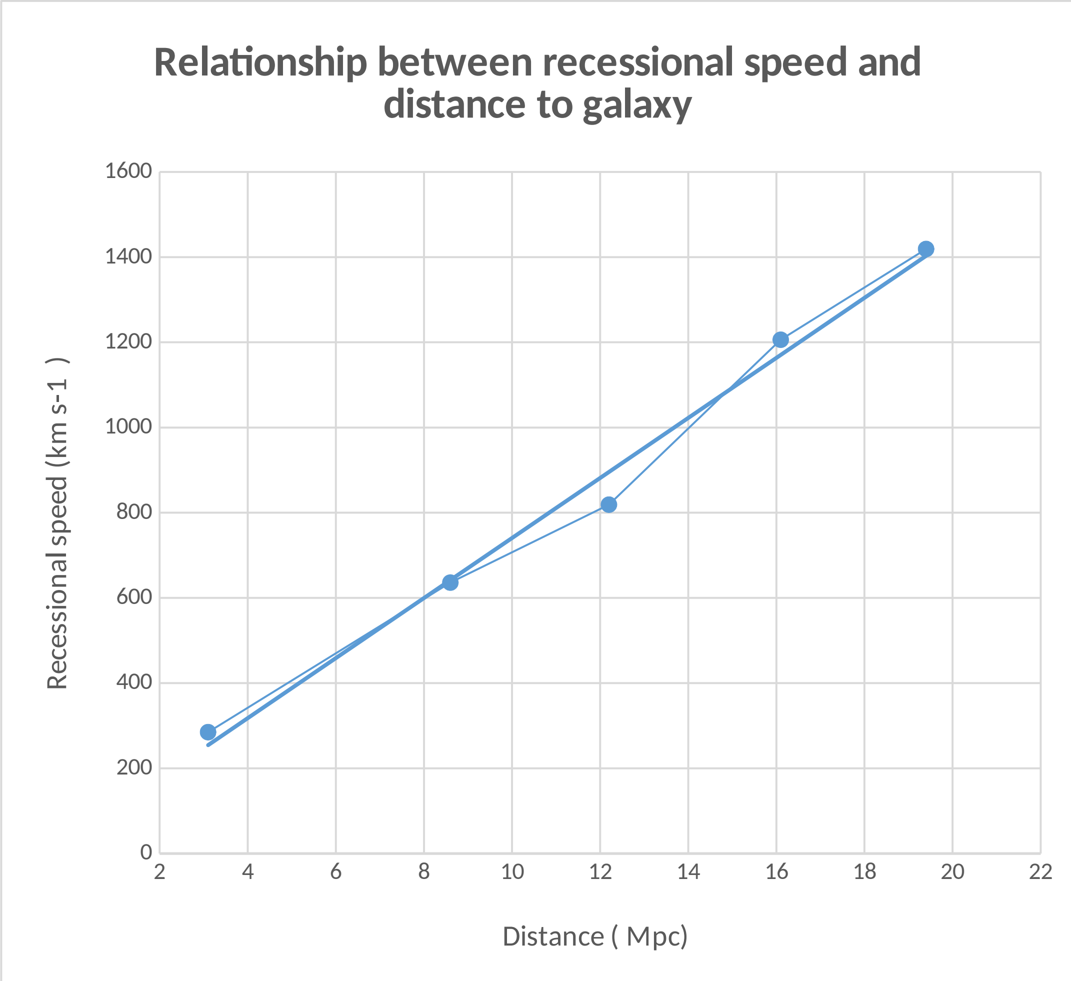
Distance (Mpc)	**Red shift - z**	**Recessional speed of galaxy** $\mathbf{v_{galaxy}}$ (km s^{-1})
3.1	0.00095	285
8.6	0.00212	*636*
12.2	0.00273	*819*
16.1	0.00402	*1206*
19.4	0.00473	*1419*

(a) Calculate the appropriate values in the final column of the table (the first value has been done for you)

(2 marks)

(b) Plot a correctly labelled graph of **recessional speed** versus **distance to galaxy** on the graph paper and draw a line of best fit.

(4 marks)



Correct plotting ✓ labels✓ units✓ line of best fit ✓

(c) Calculate a value for Hubble's constant, in the correct units, showing how you obtained this value from your graph.

Identifies rise and run on line of best fit ✓ (not data points)

H_0 = gradient = rise / run (need to show construction lines on graph)
e.g. H_0 = 1440 / 20 ✓
H_0 = 72.0 km s^{-1} Mpc^{-1} ✓
Allow small range for "line of best fit" variations

(3 marks)

(d) State three reasons why you think that measurements of Hubble's constant have varied widely since Hubble's first determination in 1920.

- *Improved technology to measure red shift (diffraction gratings)*
- *Better telescopes (e.g. Hubble and others located in space – no atmospheric distortion.)*

- *More Cepheid Variables discovered – better averages on distance measurements.*
  Any 2 credible points ✓ ✓

(2 marks)

(e) Why does the value of red shift z, have no units?

Same units top and bottom so it is a ratio of length ✓

(1 mark)

(f) A line in the spectrum of ionised calcium has a wavelength of 393.3 nm when measured in the laboratory. When similar light from the galaxy NGC 3350 is measured, its wavelength is 394.64 nm. Use the red shift formulae to determine the recessional speed of this galaxy.

(2 marks)

$\Delta\lambda / \lambda = v / c_0$

$v = (\Delta\lambda \times c_0) / \lambda$

$v = ((394.64 - 393.3) \times 3 \times 10^8) / 393.3$ ✓

$v = 1.02 \times 10^6$ m/s ✓ $(= 1.02 \times 10^3$ km/s)

(g) For the recessional speed you calculated in part f), use your graph and the line of best fit to determine the distance to this galaxy in Mpc.

(1 mark)

From the graph is approximately 14 Mpc ✓

(h) Determine how many years it takes for light from galaxy NGC 3350 to reach Earth. (1 parsec = 3.26 ly)

(2 marks)

14 Mpc = 14 $\times$ 10^6 $\times$ 3.26 = 45.64 million light years ✓
So it takes light approximately 45.6 million years to reach Earth ✓
Suggest a range be allowed.

(i) Using your value of Hubble's constant from (c), calculate the age of the universe (in years)
(3 marks)

$$\text{Time} = \frac{1}{H_0} = \frac{1}{72} = 0.0139 \ \frac{\text{Mpc}^{-1}}{\text{km s}^{-1}}$$

$$\text{Time} = 0.0139 \ \frac{\text{Mpc}^{-1}}{\text{km s}^{-1}}$$

$$\text{Time} = 0.0139 \ \chi \ \frac{(3.26 \ \chi \ 10^6) \ \chi \ (3 \ \chi \ 10^8) \ \chi \ (365 \ \chi \ 24 \ \chi \ 3600) \ \mathbf{m}}{1000 \ \mathbf{m\,s^{-1}}}$$

$$\text{Time} = 0.0139 \ \chi \ 3.084 \ \chi \ 10^{19} \ \mathbf{s}$$

$$\text{Time} = 4.287 \ \chi \ 10^{17} \ s$$

$$\text{Time} = \frac{4.287 \ \chi \ 10^{17} \ s}{365 \ \chi \ 24 \ \chi \ 3600}$$

$$\text{Time} = 1.36 \ \chi \ 10^{10} \ \text{years}$$

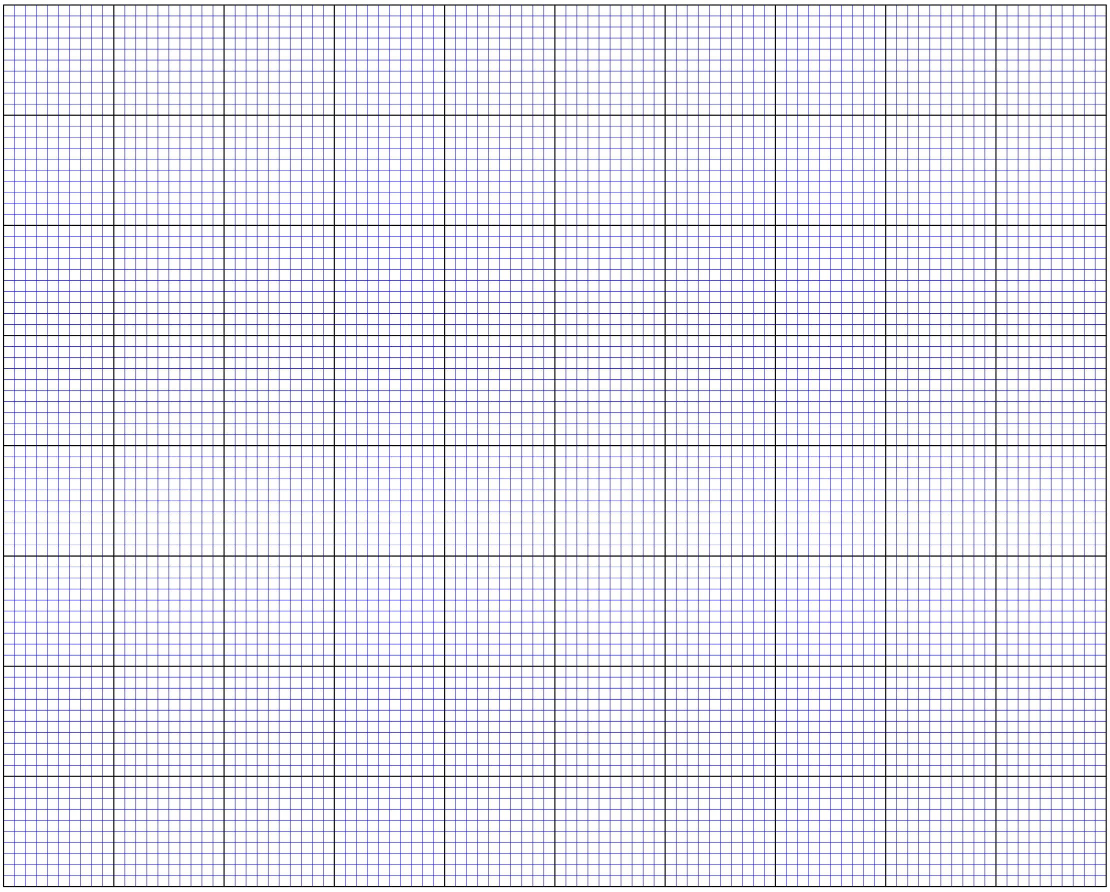
Time = 13.5 billion years

(other methods acceptable as long as they arrive at the same answer)

End of Test

The LAST test!

Additional working space and spare graph paper



Spare page (to continue **written** answers if required)

Spare page (to continue calculation answers if required)