HOLY CROSS COLLEGE

Life to the Full

Western Australian Certificate of Education
ATAR course examination, 2019

Question/Answer Booklet

12 PHYSICS

Name SOLUTIONS

Test 6 – Modern Physics

Student Number: In figures

Mark: $\overline{}$ 36

In words ______________________

____

Time allowed for this paper

Reading time before commencing work: five minutes
Working time for paper: fifty minutes

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer Booklet
Formulae and Data Booklet

To be provided by the candidate

Standard items: pens, (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set by the School Curriculum and Standards Authority for this course

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short Answers	-	-	-	-	-
Section Two: Problem-solving	8	8	50	36	100
Section Three: Comprehension	-	-	-	-	-
				Total	100

Instructions to candidates

1. The rules for the conduct of examinations at Holy Cross College are detailed in the College Examination Policy. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer Booklet.

3. Working or reasoning should be clearly shown when calculating or estimating answers.

4. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

5. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

   - Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
   - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(is) that you are continuing to answer at the top of the page.

6. Answers to questions involving calculations should be ***evaluated and given in decimal form***. It is suggested that you quote all answers to ***three significant figures***, with the exception of questions for which estimates are required. Despite an incorrect final result, credit may be obtained for method and working, providing these are ***clearly and legibly set out***.

7. Questions containing the instruction "estimate" may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. Give final answers to a maximum of two significant figures and include appropriate units where applicable.

8. Note that when an answer is a vector quantity, it must be given with magnitude and direction.

9. In all calculations, units must be consistent throughout your working.

Additional Data

Fundamental particles

Table of common mesons

Particle	Structure	Charge	Baryon Number	Strangeness
π^0	$u\bar{u}$ or $d\bar{d}$	0	0	0
π^+	$u\bar{d}$	+1	0	0
π^-	$\bar{u}d$	-1	0	0
K^0	$d\bar{s}$	0	0	+1
K+	$u\bar{s}$	+1	0	+1
K^-	$\bar{u}s$	-1	0	-1

Properties of quarks

antiquarks have opposite signs

type	*charge*	*baryon number*	*strangeness*
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of leptons

	lepton number
particles: e^-, ν_e; μ^-, ν_μ	+1
antiparticles: e^+, $\overline{\nu_e}$; μ^+, $\overline{\nu_\mu}$	–1

Common Baryons

Name	Symbol	*B*	*S*	*c*	*b*	*t*	Quarks
Proton	p	+1	0	0	0	0	uud
Anti-proton	$\bar{p}$	−1	0	0	0	0	$\overline{uud}$
Neutron	n	+1	0	0	0	0	udd
Anti-neutron	$\bar{n}$	−1	0	0	0	0	$\overline{udd}$
Lambda-plus	Λ^+	+1	0	+1	0	0	udc
Lambda-zero	Λ^0	+1	−1	0	0	0	uds
Sigma-plus	Σ^+	+1	−1	0	0	0	uus
Sigma-zero	Σ^0	+1	−1	0	0	0	uds
Sigma-minus	Σ^-	+1	−1	0	0	0	dds
Xi-zero	Ξ^0	+1	−2	0	0	0	uss
Xi-plus	Ξ^+	+1	−2	0	0	0	dss
Omega-minus	Ω^-	+1	−3	0	0	0	sss

Common Mesons

Name	Symbol	*B*	*S*	*c*	*b*	*t*	Quarks
Pion-plus	π^+	0	0	0	0	0	$u\bar{d}$
Pion-minus	π^-	0	0	0	0	0	$\bar{u}d$
Kaon-plus	K^+	0	+1	0	0	0	$u\bar{s}$
Kaon-minus	K^-	0	−1	0	0	0	$\bar{u}s$
Rho-plus	ρ^+	0	+1	0	0	0	$u\bar{d}$
Rho-minus	ρ^-	0	−1	0	0	0	$\bar{u}d$
phi	φ	0	0	0	0	0	$\bar{s}s$
D-plus	D^+	0	0	+1	0	0	$c\bar{d}$
D-zero	D^0	0	0	+1	0	0	$c\bar{u}$
D-plus-s	D^+_s	0	+1	+1	0	0	$c\bar{s}$
B-minus	B^-	0	0	0	−1	0	$b\bar{u}$
Upsilon	Υ	0	0	0	0	0	$b\bar{b}$

Redshift and recessional velocity

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

It can also be shown that:

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

where:

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

Hubble's Law

$$v_{galaxy} = H_0 d$$

where

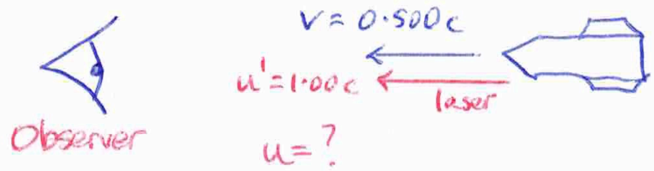
v_{galaxy} = recessional speed of galaxy (kms^{-1})
d = distance to galaxy (Mpc)
H_o = Hubble's constant ($kms^{-1}Mpc^{-1}$)

1.00 pc = 3.26 light years

1. (a) One of the two postulates of Einstein's theory of special relativity is that the speed of light is the same in any reference frame. Use the following example to show that this is correct.

A spaceship moving at 0.500c towards Earth fires a laser beam forwards at 1.00c relative to the ship. What is the speed of the laser measured from the Earth?

(3 marks)



$$u = \frac{v + u'}{1 + \frac{vu'}{c^2}} \quad (1)$$

$$= \frac{0.500c + 1.00c}{1 + \frac{(0.500c)(1.00c)}{c^2}} \quad (1)$$

$$= \frac{1.50c}{1.50}$$

$$= \underline{1.00\,c} \quad (1)$$

(b) State and explain the other postulate. (2 marks)

- The laws of Physics are the same in all inertial reference frames. (1)
- An inertial reference frame has constant velocity (non-accelerating) (1)

2. A stationary pion π^- has a rest mass of 2.49×10^{-28} kg and a half-life of 2.60×10^{-8} s.

(a) Calculate the momentum of a pion π^- travelling at 0.985c relative to an observer in a laboratory.

(3 marks)

$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Conversion (1)

$$= \frac{(2.49 \times 10^{-28})(0.985)(3.00 \times 10^8)}{\sqrt{1 - \frac{(0.985c)^2}{c^2}}} \quad (1)$$

$$= \underline{4.26 \times 10^{-19}\ \text{kg m s}^{-1}}\ \underline{\text{forwards}} \quad (1)$$

(b) Determine the distance, in a laboratory frame of reference, travelled by the pion in one half-life. (4 marks)

Observer

$v = 0.985c$

$t_0 = 2.60 \times 10^{-8}$

$t = ?$

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$= \frac{2.60 \times 10^{-8}}{\sqrt{1 - \frac{(0.985c)^2}{c^2}}} \quad (1)$$

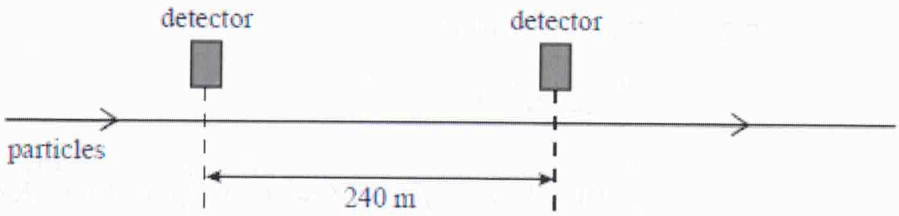
$$= 1.51 \times 10^{-7}\,s \quad (1)$$

$$s = vt$$

$$= (0.985)(3.00 \times 10^{8})(1.51 \times 10^{-7}) \quad (1)$$

$$= \underline{44.6\ m} \quad (1)$$

3. In a particle beam experiment, a short pulse of 1.00 ns duration of particles moving at constant speed passed directly between two detectors at a fixed distance apart of 2.40×10^2 m. The pulse took 0.840 μs to travel from one detector to the other.



(a) Calculate the speed of the particles. (2 marks)

$$v = \frac{s}{t}$$

$$= \frac{2.40 \times 10^{2}}{0.840 \times 10^{-6}} \quad (1)$$

$$= \underline{2.86 \times 10^{8}\ ms^{-1}} \quad (= 0.952c) \quad (1)$$

(b) Calculate the distance between the two detectors in the frame of reference of the particles. (3 marks)

$v = 0.952c$ ← Conversion (1)

$\ell_0 = 2.40 \times 10^{2}\,m$

observer on particle

$$\ell = \ell_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$= (2.40 \times 10^{2})\sqrt{1 - \frac{(0.952c)^2}{c^2}} \quad (1)$$

$$= \underline{73.5\ m} \quad (1)$$

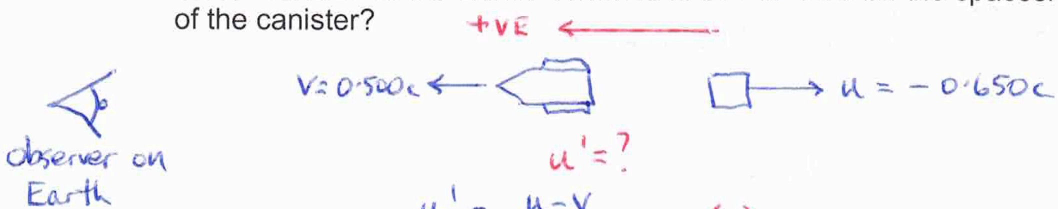
4. In a 'thought experiment' about relativity, a student stated that a twin who travelled from the Earth to a distant planet and back at a speed close to the speed of light would be the same age on return as the twin who stayed on Earth. Explain why this statement is ***not*** correct.
(3 marks)

- The twin on Earth is considered to be in a stationary reference frame. (1)
- The twin that travels near the speed of light experiences the proper time t_o. (1)
- The twin on Earth measures the time away as t, which is greater than t_o, so there is an age difference. (1)
(The twin on Earth is older.)

5. A proton is accelerated to a speed of 1.75 x 10^8 ms^{-1} by a high voltage in a linear accelerator. Determine the total energy of the particle at this speed.
(3 marks)

$$E_T = E_K + E_{rest}$$
$$= \frac{1}{2} m_o v^2 + m_o c^2$$
$$= \frac{1}{2}(1.67\times10^{-27})(1.75\times10^{8})^2 + (1.67\times10^{-27})(3.00\times10^{8})^2$$
$$= \underline{1.76\times10^{-10}\ J}$$

6 A spaceship is approaching the Earth at 0.500*c* and shoots a canister away from the Earth at 0.650*c* relative to the Earth. What does an observer on the spaceship measure as the speed of the canister?
(3 marks)



$$u' = \frac{u - v}{1 - \frac{uv}{c^2}} \quad (1)$$

$$= \frac{-0.650c - 0.500c}{1 - \frac{(-0.650c)(0.500c)}{c^2}} \ (1) = \frac{-1.15c}{1.32}$$

$$= -0.871c \quad (1)$$

$\therefore$ Appears to move away at 0.871c

7. This table may be useful in answering the questions which follow.

particle	baryon number	lepton number	strangeness
π^-	0	0	0
p	1	0	0
$\bar{p}$	−1	0	0
e^-	0	1	0
e^+	0	−1	0
$\bar{\nu}_e$	0	−1	0

The particle X, which is a strange particle, decays in the following way:

$$X \rightarrow \pi^- + p$$

(a) State whether X is a meson, a baryon or a lepton. (1 mark)

baryon (1)

(b) Use conservation laws (baryon number, lepton number and charge) to decide whether the following decay of the π^- is possible. Give a reason for your answer, showing some working. (2 marks)

$$\pi^- \rightarrow e^+ + \nu_e$$

Is this decay possible? No (1)

Reason

	LHS	RHS
charge	−1	+1
baryon		
lepton		

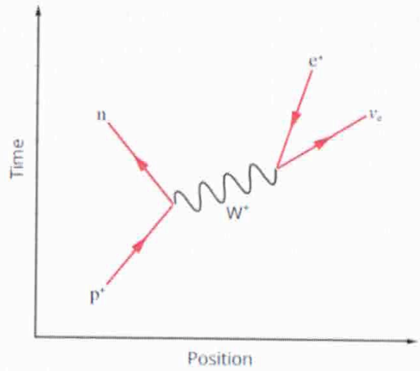
Charge is not conserved. (1)

(c) What is the difference between a baryon and a meson in terms of their structure? (2 marks)

Baryon – made up of 3 quarks (1)

Meson – 2 quarks (quark + anti-quark pair) (1)

8. The following Feynman diagram shows a proton decaying to form a neutron, releasing a positron and electron neutrino.



The equation for the process is:

$$p^+ \rightarrow n + e^+ + \nu_e$$

(a) What is W⁺ and what is its role in the process? (2 marks)

- W⁺ – gauge boson (1)
- Mediates the weak nuclear force. (1)

(c) Is this reaction possible? Show working to support your answer. (3 marks)

	LHS	RHS
charge	+1	0+1+0 = +1
baryon	+1	+1+0+0 = +1
lepton	0	0+(-1)+1 = 0

Working (2)

∴ possible (1)