HOLY CROSS COLLEGE

Life to the Full

Western Australian Certificate of Education
ATAR course examination, 2018

Question/Answer Booklet

12 PHYSICS

Name SOLUTIONS

Test 7 – Modern Physics

Student Number: In figures

Mark: $\overline{}$ 49

In words ______________________________

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Time allowed for this paper

Reading time before commencing work: five minutes
Working time for paper: sixty 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	13	13	60	49	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	$\overline{p}$	−1	0	0	0	0	$\overline{uud}$
Neutron	n	+1	0	0	0	0	udd
Anti-neutron	$\overline{n}$	−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	$s\bar{s}$
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

Circle the correct answer in the following multiple-choice questions.

1. The reaction $\mu^- \rightarrow e^- + \nu_e + \nu_\mu$ conserves: [1 mark]

   (a) muon lepton number but not electron lepton number.
   (b) electron lepton number but not muon lepton number.
   (c) neither muon lepton nor electron lepton number.
   (d) both muon and electron lepton numbers.
   (e) None of these is correct.

2. A conservation law that is not universal but applies only to certain kinds of interactions is conservation of: [1 mark]

   (a) lepton number.
   (b) baryon number.
   (c) spin.
   (d) charge.
   (e) strangeness.

3. In quantum electrodynamics (QED), electromagnetic forces are mediated by: [1 mark]

   (a) the interaction of electrons.
   (b) hadrons.
   (c) action at a distance.
   (d) the weak nuclear interaction.
   (e) the exchange of virtual photons.

4. The cosmic microwave background radiation is [1 mark]

   (a) radiation from the quasars that is redshifted.
   (b) produced from processes going on all over the present universe.
   (c) radiation from the Sun.
   (d) radiation from the Big Bang that was around when electrons and protons combined to form neutral hydrogen atoms.
   (e) radiation produced from electron-positron annihilation in the intergalactic regions.

5. The conservation law violated by the reaction $p \rightarrow \pi^0 + e^+$ is the conservation of: [1 mark]

   (a) charge.
   (b) energy.
   (c) linear momentum.
   (d) lepton number and baryon number.
   (e) angular momentum.

6. An emission line is seen in the spectrum of galaxy A at a wavelength of 459 nm. Analysis of this emission line shows that it has a ***rest*** wavelength in the laboratory of 450 nm.

(a) Calculate the redshift of this galaxy. [2 marks]

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

$$= \frac{(459-450)\times10^{-9}}{(450\times10^{-9})} \quad (1)$$

$$= \underline{2.00\times10^{-2}} \quad (1)$$

(b) Calculate the recessional velocity (in kms^{-1}) of galaxy A. [3 marks]

$$z = \frac{v}{c} \quad (1)$$

$$\Rightarrow v = (2.00\times10^{-2})(3.00\times10^{5}) \quad (1)$$

$$= \underline{6.00\times10^{3}\ kms^{-1}} \quad (1)$$

(c) Given that Hubble's constant (H_o) has a value of 72.0 $kms^{-1}Mpc^{-1}$, calculate the distance (in lightyears) to galaxy A. [4 marks]

$$v = H_o d$$

$$\Rightarrow d = \frac{6.00\times10^{3}}{72.0} \quad (1)$$

$$= 83.3\ Mpc \quad (1)$$

$$\therefore d = (83.3\times10^{6})(3.26) \quad (1)$$

$$= \underline{2.72\times10^{8}\ ly} \quad (1)$$

7. (a) A spacecraft of rest mass 90.0 tonnes is moving away from the Earth at a constant speed.

The crew of the spacecraft determine that it takes them 1.10 years to reach the star Alpha Centauri. Observers on Earth state that it took the spacecraft 4.50 years to complete the journey. Determine the speed of the spacecraft in the reference frame of Earth. [3 marks]

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

$$\Rightarrow 4.50 = \frac{1.10}{\sqrt{1-\frac{v^2}{c^2}}} \quad (1)$$

$$\Rightarrow 1 - \frac{v^2}{(3.00\times10^8)^2} = \frac{(1.10)^2}{(4.50)^2}$$

$$\Rightarrow 9.00\times10^{16} - v^2 = (5.975\times10^{-2})(9.00\times10^{16}) \quad (1)$$

$$\Rightarrow v = \sqrt{8.462\times10^{16}}$$

$$= \underline{2.91\times10^8 \text{ ms}^{-1}} \quad (1)$$

(b) The crew of the spacecraft argue that time recorded on their clocks was correct, but they could reach Alpha Centauri in a time of 1.10 years for a different reason. How is the journey time explained in the reference frame of the spacecraft? Explain with reference to physics principles - no calculation is required. [2 marks]

- According to special relativity, the length outside the reference frame will contract. (1)
- Therefore, the distance travelled will be shorter. (1)

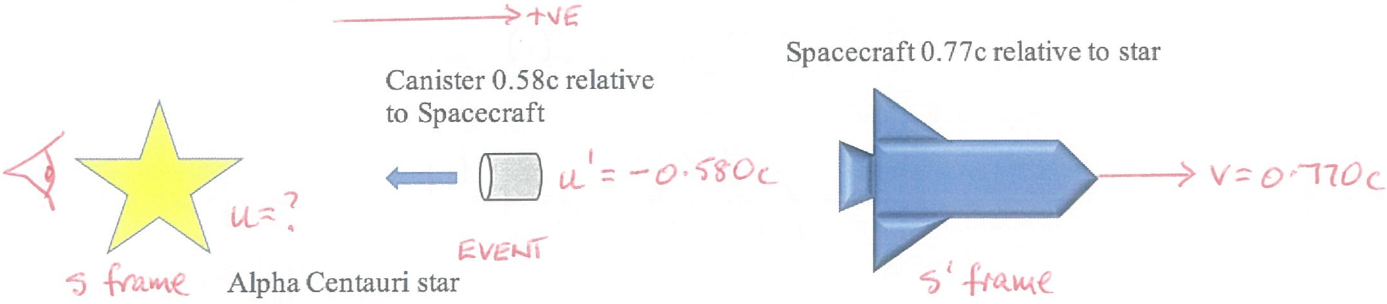
(c) As the spacecraft goes past Alpha Centauri, it changes its speed to a new constant value of 0.770 *c* in the reference frame of Alpha Centauri. Calculate the relativistic momentum of the spacecraft at this speed. [3 marks]

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

$$= \frac{(90.0\times10^3)(0.770)(3.00\times10^8)}{\sqrt{1-\frac{(0.770)^2c^2}{c^2}}} \quad (1) \quad (1)$$

$$= \underline{3.26\times10^{13} \text{ kg ms}^{-1}} \quad (1)$$

As the spacecraft is moving away from Alpha Centauri at a speed of 0.770 *c*, it fires a mail canister back towards Alpha Centauri. The canister moves at a speed of 0.580 *c* relative to the spacecraft.



(d) Determine the speed and direction of the canister in the frame of reference of Alpha Centauri. [3 marks]

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

$$= \frac{0.770c - 0.580c}{1 + \frac{(0.770c)(-0.580c)}{c^2}} \quad (1)$$

$$= \frac{0.190c}{0.5534}$$

$$= \underset{(1)}{\underline{0.343\,c}} \ \underset{(1)}{\underline{\text{away from Alpha Centauri}}}$$

(e) As the mail canister moves back towards Alpha Centauri, it directs a laser beam towards the star. What is the speed of the laser beam in the reference frame of Alpha Centauri? Explain briefly. [2 marks]

- Speed = 3.00×10^8 ms^{-1}. (1)
- Speed of light is constant in all inertial reference frames. (1)

8. An alien space ship is travelling at 0.650 c relative to the Earth. It sends a signal to the Earth's inhabitants by flashing a light every 0.270 seconds in the ship's frame of reference. Calculate the time between each flash of light from the Earth's frame of reference.

[3 marks]

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

$$= \frac{0.270}{\sqrt{1-\frac{(0.650c)^2}{c^2}}} \quad (1)$$

$$= \underline{0.355\,s} \quad (1)$$

9. Figure 3 below represents the decay of a particle X into a particle Y and two other particles. The quark structure of particles X and Y are shown in the diagram.

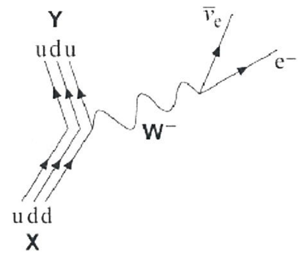


Figure 3

(a) Deduce the name of particle X. [1 mark]

- neutron (1)

(b) State the type of interaction that occurs in this decay. [1 mark]

- weak nuclear force – involves W⁻ boson
  – involves beta decay } Either (1)

(c) State the class of particles to which the W− belongs. [1 mark]

- bosons (1)

(d) Show clearly how charge and baryon number are conserved in this interaction. You should include reference to all the particles (including the quarks) in your answer.

[2 marks]

$udd \longrightarrow udu + e^- + \bar{\nu}$

	CHARGE	BARYON
LHS	$+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$	$\frac{1}{3}+\frac{1}{3}+\frac{1}{3}=1$
RHS	$+\frac{2}{3}-\frac{1}{3}+\frac{2}{3}-1=0$	$\frac{1}{3}+\frac{1}{3}+\frac{1}{3}-0-0=1$

∴ Charge conserved. (1)

∴ Baryon number conserved (1)

(e) State the quark constituents of $\bar{Y}$. [1 mark]

$\bar{Y} = \bar{u}\,\bar{d}\,\bar{u}$ (1)

(f) Name the only stable baryon. [1 mark]

proton (1)

(g) A muon is an unstable particle. The incomplete decay equation is shown below.

$$\mu^- \rightarrow \nu_\mu + e^- + \ldots\ldots\ldots$$

State the name of the missing particle. [1 mark]

L_μ: $+1 \rightarrow +1 + 0 + ?$ $\Rightarrow ? = 0$ $\therefore$ Can't be μ.

L_e: $0 \rightarrow 0 + 1 + ?$ $\Rightarrow ? = -1$ $\therefore \bar{\nu}_e$

electron antineutrino (1)

10. State what is meant by the term ***luminiferous aether*** and why it was important to classical Physics. [2 marks]

- Rigid, massless medium that carries electric and magnetic fields (light). (1)
- Light travels on this medium. (1)

11. Explain why the concept of the aether lost favour in physics and what theory replaced it. [4 marks]

- If the medium exists, then light could travel faster than c relative to the medium. (1)
- Michelson-Morley experiment found c is constant in all reference frames. (1)
- Einstein gave 2 postulates:
  - The laws of Physics are the same in all inertial reference frames. (1)
  - The speed of light is constant in all inertial reference frames. (1)

12. High-energy cosmic ray protons entering the upper atmosphere interact with the nuclei of oxygen and nitrogen atoms to give a group of particles known as <u>pions</u>. These pions then decay into <u>muons</u> that then move off at a speed of up to 0.994 *c*. These <u>muons</u> are formed at a height of between ten and fifteen thousand metres above the ground.

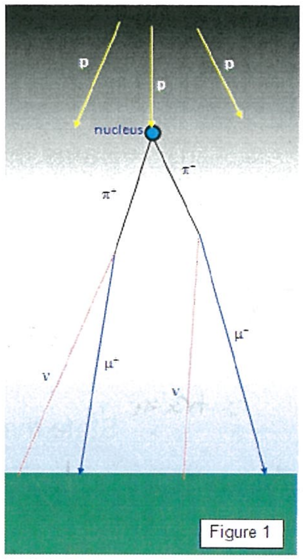


Figure 1

Explain the significance of muons for Einstein's Special Theory of Relativity. [3 marks]

- Proved Einstein's special theory of relativity. (1)
- Muons appear to have a longer decay lifetime as measured on Earth due to time dilation. (1)
- This allows the muons to travel further and reach the Earth's surface before decaying. (1)

13. Explain what is meant by the term ***inertial reference frame***. [2 marks]

- Frame of reference moving at constant velocity. (1)
- The Law of Inertia applies within them. (1)

End of questions