



Western Australian Certificate of Education ATAR course examination, 2019

Question/Answer Booklet

12 PHYSICS

Name

Test 6 – Modern Physics

Student Number: In figures

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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

QUARKS	UP mass $2,3 \text{ MeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ 	CHARM $1,275 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ 	TOP $173,07 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ 	GAUGE BOSONS	GLUON 0 0 1 	HIGGS BOSON $126 \text{ GeV}/c^2$ 0 0 
	DOWN $4,8 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ 	STRANGE $95 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ 	BOTTOM $4,18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ 		PHOTON 0 0 1 	
	ELECTRON $0,511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ 	MUON $105,7 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ 	TAU $1,777 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ 		Z BOSON $91,2 \text{ GeV}/c^2$ 0 1 	
	ELECTRON NEUTRINO $<2,2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ 	MUON NEUTRINO $<0,17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ 	TAU NEUTRINO $<15,5 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ 		W BOSON $80,4 \text{ GeV}/c^2$ ± 1 1 	

Table of common mesons

Particle	Structure	Charge	Baryon Number	Strangeness
π^0	$u\bar{u} \text{ or } d\bar{d}$	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

<i>type</i>	<i>charge</i>	<i>baryon number</i>	<i>strangeness</i>
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

	<i>lepton number</i>
<i>particles:</i> $e^-, \nu_e; \mu^-, \nu_\mu$	+1
<i>antiparticles:</i> $e^+, \bar{\nu}_e; \mu^+, \bar{\nu}_\mu$	-1

Common Baryons

Name	Symbol	<i>B</i>	<i>S</i>	<i>c</i>	<i>b</i>	<i>t</i>	Quarks
Proton	p	+1	0	0	0	0	uud
Anti-proton	\bar{p}	-1	0	0	0	0	$\bar{u}\bar{u}\bar{d}$
Neutron	n	+1	0	0	0	0	udd
Anti-neutron	\bar{n}	-1	0	0	0	0	$\bar{u}\bar{d}\bar{d}$
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	<i>B</i>	<i>S</i>	<i>c</i>	<i>b</i>	<i>t</i>	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	$\bar{b}u$
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

$$v_{\text{galaxy}} = H_0 d \quad \text{where} \quad \begin{aligned} v_{\text{galaxy}} &= \text{recessional speed of galaxy (kms}^{-1}\text{)} \\ d &= \text{distance to galaxy (Mpc)} \\ H_0 &= \text{Hubble's constant (kms}^{-1}\text{Mpc}^{-1}\text{)} \end{aligned}$$

$$1.00 \text{ pc} = 3.26 \text{ light years}$$

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)

- (b) State and explain the other postulate.

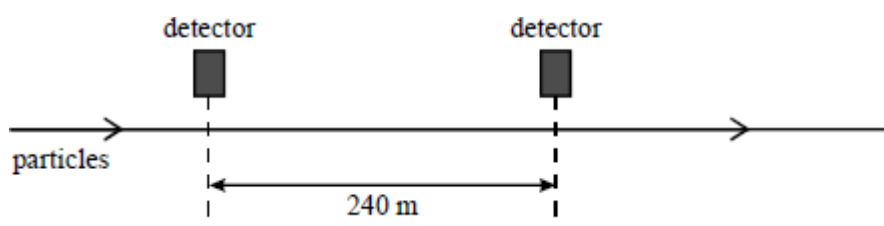
(2 marks)

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)

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

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 $0.840 \mu\text{s}$ to travel from one detector to the other.



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

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

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)
5. A proton is accelerated to a speed of $1.75 \times 10^8 \text{ ms}^{-1}$ by a high voltage in a linear accelerator. Determine the total energy of the particle at this speed. (3 marks)
6. A spaceship is approaching the Earth at $0.500c$ and shoots a canister away from the Earth at $0.650c$ relative to the Earth. What does an observer on the spaceship measure as the speed of the canister? (3 marks)

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)

- (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)

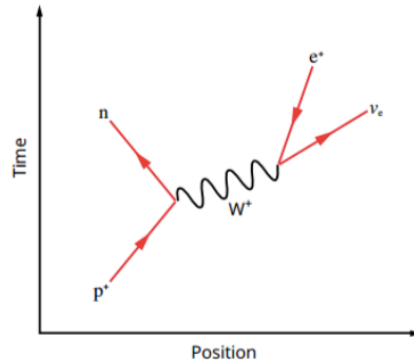
$$\pi^- \rightarrow e^+ + \nu_e$$

Is this decay possible? _____

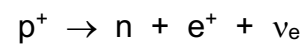
Reason

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

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:



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

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