−1 for 2 or more answers not in 3 sig figs (ie 1 chance allowed)

YEAR 12 PHYSICS, UNIT 4

2016 Relativity & Standard Model Test

NAME: ______________________________

TOTAL MARKS: **/51**

TIME ALLOWED FOR THIS PAPER

Working time for paper: 55 minutes

MATERIAL REQUIRED/RECOMMENDED FOR THIS PAPER

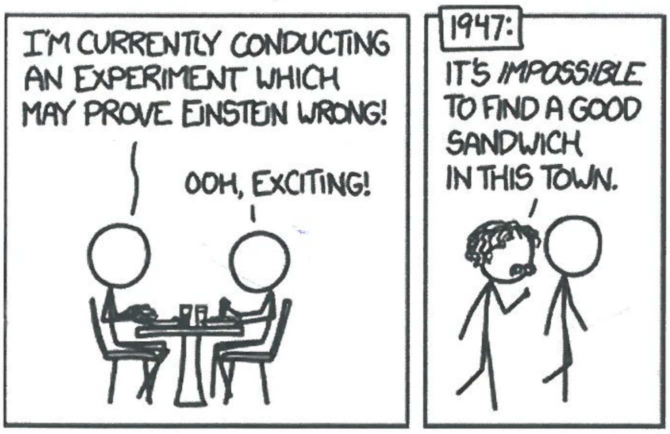
TO BE PROVIDED BY THE SUPERVISOR

This Question/Answer Booklet.
Physical formulae and constants sheet.

TO BE PROVIDED BY THE CANDIDATE

Standard Items: Pens, pencils, eraser, correction fluid, ruler, highlighters.

Special Items: Non-programmable calculators satisfying the conditions set by the Curriculum Council for this course, drawing templates, drawing compass and a protractor.

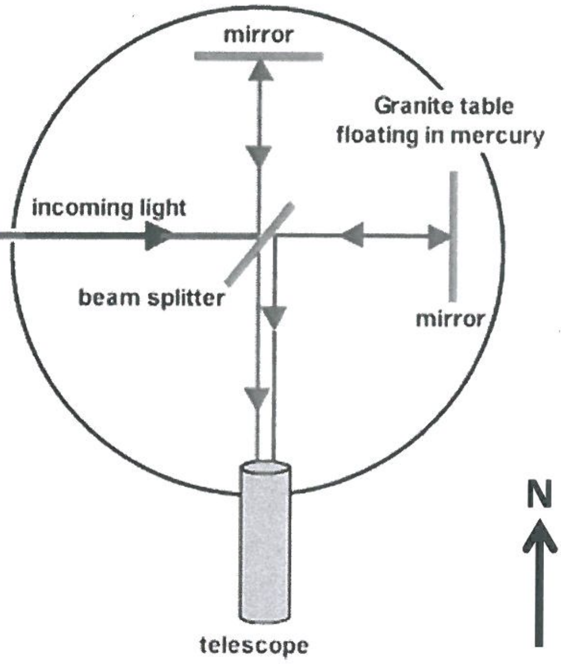


SECTION A: Short Answers

Marks allocated: 28 out of 51 total (55%)
This section contains 7 questions. Answer ALL of the questions and show full working.

Question 1 [5 Marks]

The diagram below schematically illustrates the famous Michelson-Morley Experiment. It was designed to detect the presence of a background 'aether' in the universe. The aether was hypothesised in response to Maxwell's calculation (from theory) that the velocity of light in a vacuum should be a constant, c, which was a difficult idea to accept/explain at the time.



a) Explain why the existance of the aether was seen by some scientists as necessary given Maxwell's discovery. [1]

× If speed of light is a constant then it was thought that there must be a reference frame which is at 'absolute rest'. ✓
OR
× It was thought that EMR needed a medium of some sort

b) Explain the basic operation of the experiment. It may help your explanation to assume that the apparatus is set up with the north diraction as marked and that the apparatus (and the Earth's surface) is moving east-west space through space. [2]

Incoming light is split into 2 rays, one tavelling N-S, one E-W. The E-W ray is in the direction of ✓ the Earth's movement through the aether so the velocity "will be changed" / (OR) the light rays will arrive back ✓ at the beam splitte. / telescope at different times

c) What did Michaelson and Morely expect to see (in the telescope) if the aether existed? [1]

An interference pattern ✓

(No mark for 'light rays arriving at different times') as this is covered in b).

Question 2 [3 Marks]

It is said that the teenage Einstein asked the following question: "What would I expect to see in a mirror if I carried it in my hands and ran at the speed of light?".

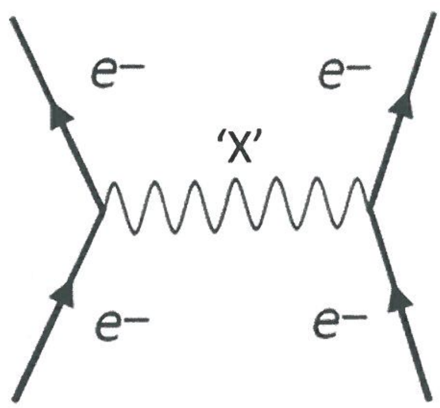
a) State the two postulates that the adult Einstein made when developing his theory of Special Relativity. [2]

- Laws of Physics same in all IRF's. ✓
- Speed of light is constant & same in all IRF's. ✓

b) Given these postulates, how would you answer the teenage Einstein's question? [1]

He would see his own face / no change ✓

Question 3 [3 Mark]



a) The diagram right illustrates the repulsion of two electrons. What is the specific particle 'X' which is exchanged to carry this electromagnetic repulsive force?

photon ✓

b) Another boson is responsible for the force which binds quarks together. What is the name of this force?

strong (nuclear) force ✓

c) What is the name of this boson?

gluon ✓

Question 4 [2 Marks]

In the Standard Model quarks are considered to be elementary particles and therefore the fundamental constituent of matter. Quarks usually bond in pairs or triplets to form many of the particles with which we are familiar, but recent evidence from KEKB (a Japanese particle accelerator) hints at the existence of exotic hadrons comprised of 'tetra-quarks' and even 'penta-quarks' (hadrons comprised of 4 or 5 quarks, respectively). Use the following table to show the calculation required to determine the **charge** on the following particles:

Quark	Symbol	Charge
up	u	$+^2/_3$
down	d	$-^1/_3$
charm	c	$+^2/_3$
strange	s	$-^1/_3$
top	t	$+^2/_3$
bottom	b	$-^1/_3$

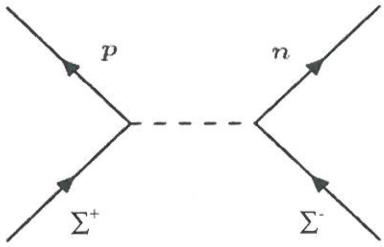
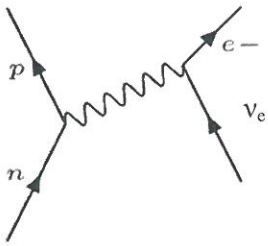
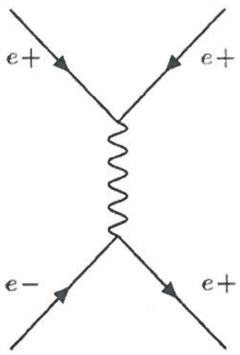
a. Z(4430) = ($\bar{u}$,d,c,$\bar{c}$) = $-^2/_3 -^1/_3 +^2/_3 -^2/_3 = -1e$ ✓

b. Θ^+ = (u,u,d,d,$\bar{s}$) = $+^2/_3 +^2/_3 -^1/_3 -^1/_3 -^1/_3 = +1e$ ✓

Question 5 [5 Marks]

Three interactions are shown on the next page, under a table of particle properties. Some of these may be impossible. For each example, state in the 'working' section **any and all** conservation law(s) which are violated using the information in the table. If no conservation laws are violated then write the equation for it in the 'working' section. Be sure to show all working (please note that these diagrams flow from **bottom to top** and arrows are **reversed** for anti-particles)

Name	Symbol	Baryon #	L_e	L_μ	L_τ	Strangeness #
Electron	e^-	0	1	0	0	0
Positron	e^+	0	-1	0	0	0
Neutron	N	1	0	0	0	0
Proton	P	1	0	0	0	0
Sigma +	Σ^+	1	0	0	0	-1
Sigma -	Σ^-	1	0	0	0	-1

Feynman Diagram	Working
	Charge not conserved ✓ Strangeness not conserved ✓
	$n + \nu \rightarrow p + e^-$ ✓
	charge not conserved ✓ Lepton # not conserved ✓

Question 6 [5 Marks]

In the Standard Model of particle physics, hadrons are composed of combinations of quarks or antiquarks. Hadrons are further divided into two families: Baryons and mesons.

(a) Describe the difference in quark composition between a baryon and a meson. [2]

Baryons : 3 quarks or 3 anti quarks ✓
(½) (½)

Mesons : 1 quark, one antiquark ✓ (½ mark if stated '2 quarks')

(b) Below is a list of the 6 different quarks that make up hadrons.

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

State the composition of the following hadrons: [3]

(i) the neutron, with Q = 0, B = +1, and S = c = b = t = 0

udd ✓

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

scu ✓

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

$\bar{s}u$ ✓

Question 7 [6 Marks]

The Big Bang theory describes the history of space-time as starting from a small singularity and expanding into our current universe over around 14 billion years.

(a) Describe how the phenomenon of redshift was utilised by Hubble and others to provide evidence to support the Big Bang theory [2]

ANY 2

× Spectra from distant stars/galaxies is compared to known spectra of same elements.

× The Dopplar effect shifts λ of spectral lines to the red end of spectrum if source is receding

× Hubble et al. collected spectra & found most galaxies were receding, suggesting a cosmic expansion

(b) Name two other observations which support the Big Bang theory and for each one write a brief discription of how it supports the theory [4]

✓ × Cosmic microwave background radiation ✓

✓ × the presence, λ and intensity of background radiation 'left over' from the Big Bang agreed with theory

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✓ × the high proportion of light elements in the universe

✓ × Most matter was created in the Big Bang & as this created only light elements, it is expected to be of a much higher proportion (or the proportion of ordinary matter which is H/He predicted in theory agrees with observations).

OR

+ Evolutionary change of early galaxies to older ones

+ Observations of bodies in the most distant regions of the universe gives a view of the early universe. These are confirmed to be different in nature to more 'modern' galaxies

SECTION B: Problem Solving Marks Allotted: 23 marks out of 51 (45%)

This section contains 4 questions. Answer ALL of the questions in the space provided and show full working.

Question 8 [6 Marks]

The average lifetime of a pi-meson travelling towards Earth through our atmosphere is 2.6 x 10^{-8} s (in its' own reference frame). If the pi-meson is travelling at a speed of 0.96c, find the following:

a. The average lifetime as measured by an observer on Earth.[2]

$$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{2.6\times10^{-8}}{\sqrt{1-\frac{0.96^2\cancel{c^2}}{\cancel{c^2}}}} = \frac{2.6\times10^{-8}}{0.28} ✓$$

$$= 9.29\times10^{-8}\ s ✓$$

✓ [award 1 mark if equation incorrectly applied but successfully calculated – eg. $t \leftrightarrow t_o$]

b. The average distance travelled before decaying as measured by an observer on Earth. [2]

$$s = vt = 0.96\times3\times10^8\times9.29\times10^{-8} ✓$$

$$= 26.8\ m ✓$$

c. The average distance travelled before decaying as measured by an observer in the same reference frame as the pi-meson. [2]

Length is contracted for pi-meson

$$L = L_o\sqrt{1-\frac{0.96^2\cancel{c^2}}{\cancel{c^2}}}$$

$$= 26.8\times0.28$$

$$= 7.49\ m ✓✓$$

[No mark this time if L & Lo are reversed or s=vt used. γ has already been calculated in a)]

Question 9 [9 Marks]

A sample of ionised gas inside a particle accelerator is observed to have a proper mass of 2.5×10^{-5} kg. It is accelerated to 0.99c. Find the following:

a. Relativistic mass of the sample: [2]

$$m = \frac{m_0}{\sqrt{1-v^2/c^2}} = \frac{2.5\times10^{-5}}{\sqrt{1-\frac{0.99^2\cancel{c^2}}{\cancel{c^2}}}} = \frac{2.5\times10^{-5}}{0.1411}$$

$$= 1.77\times10^{-4}\ \text{kg}$$

b. Relativistic momentum of the sample: [2]

(The fact that the equations for p & E do not list m as m_0 seems to have confused many of my students. They should have identified the m as rest mass before now!!)

$$p = \frac{m_0 v}{\sqrt{1-v^2/c^2}} = \frac{2.5\times10^{-5}\times0.99\times3\times10^{8}}{0.1411} = 5.26\times10^{4}\ \text{kg ms}^{-1}$$

(½) (½)

[Award 1 mark max if m' is used instead of m_0]

c. Kinetic energy of the sample: [2]

$$E_K = (\gamma-1)m_0c^2$$

$$= \left(\frac{1}{0.1411}-1\right)2.5\times10^{-5}\times(3\times10^8)^2 = 1.37\times10^{13}\ \text{J}$$

[Award 1 mark max if total relativistic mass is calculated]

d. Suppose that the sample was to be further accelerated to 0.999c. How much kinetic energy would the sample need to gain in order to achieve this speed? Express your answer as a percentage of your answer to part c: [3]

$$\text{New } E_K = 2.5\times10^{-5}\times(3\times10^8)^2\left(\frac{1}{\sqrt{1-\frac{0.999^2\cancel{c^2}}{\cancel{c^2}}}}-1\right)$$

$$= 2.25\times10^{12}(22.37-1)$$

$$= 4.81\times10^{13}\ \text{J}$$

[Again award 1 out of 2 if successfully calc. total rel. energy]

$$\%\ \text{gain} = \frac{(4.81-1.37)\cancel{\times10^{13}}}{1.37\cancel{\times10^{13}}}\times100$$

$$= 251\%\ \text{increase}$$

[No mark for calculating $\frac{4.81}{1.37}\times100$]

Question 10 [4 Marks]

You are a judge faced with a Physics student trying to argue his way out of a ticket for running a red light. The Physics student claims that, due to the speed at which he was travelling, the red light appeared Doppler-shifted (blueshifted) to him and therefore appeared green. Fortunately, you took your Law degree with a minor in Physics and so you are able to calculate the student's velocity with respect to the traffic light. Assuming that red light has a wavelength of 650nm and green light has a wavelength of 550nm, determine the speed the student would need to be travelling towards the light to see this shift in colour.

The Doppler shifted wavelength of light is given by the equation:

$$\lambda' = \lambda * \frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}}$$

Where λ = emitted wavelength, λ' = the observed wavelength, and v is the velocity of the light source ***away*** from the observer.

$$550 \times 10^{-9} = 650 \times 10^{-9} \times \frac{\sqrt{1 + \frac{v}{c}}}{\sqrt{1 - \frac{v}{c}}}$$

$$550^2 = 650^2 \times \frac{\left(1 + \frac{v}{c}\right)}{\left(1 - \frac{v}{c}\right)} \quad \text{or} \quad \frac{550^2}{650^2} = \frac{1 + v/c}{1 - v/c} \checkmark$$

$$302500\left(1 - \frac{v}{c}\right) = 422500\left(1 + \frac{v}{c}\right)$$

$$302500 - 302500\frac{v}{c} = 422500 + 422500\frac{v}{c}$$

$$-422500\frac{v}{c} - 302500\frac{v}{c} = 422500 - 302500$$

$$-725000\frac{v}{c} = 120000$$

$$\frac{v}{c} = \frac{120000}{725000}$$

$$\frac{v}{c} = 0.1655$$

$$v = 0.1655c$$

$$= 4.97 \times 10^7 \, ms^{-1}$$

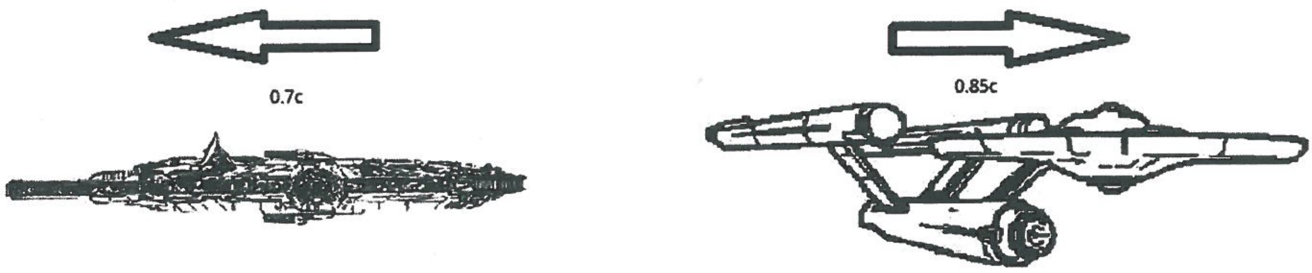
(Note: direction is assumed & only speed is required)

✓✓✓ (−1 for each error)

(subtract 1 if direction is incorrectly stated)

Question 11 [4 Marks]

The 'Millennium Falcon' and the 'USS-Enterprise NCC-1701' are travelling in exactly opposite directions (they are from completely different franchises after all!), as viewed from a third party on some small planet in the Delta Quadrant. The observer measures their speeds as 0.7c and 0.85c respectively. Find:



a. The speed of the Falcon as measured by the Enterprise. [3]

$$u' = \frac{u - v}{1 - \frac{vu}{c^2}} = \frac{-0.7c - 0.85c}{1 - \frac{0.85\cancel{c} \times -0.7\cancel{c}}{\cancel{c^2}}}$$ ✓ correct substitution

✓ (correct equation)

$$= \frac{-1.55c}{1 + 0.595} = \underline{-0.972c}$$

ie $0.972c$ (accept + or -)

✓ correct calc.

b. The speed of the Enterprise as measured by the Falcon.[1]

Same as above

$\underline{0.972c}$ ✓ (again accept + or -)