YEAR 12 PHYSICS, UNIT 4

Modern Physics Test

NAME: Solutions **TOTAL MARKS:** **/55**

TIME ALLOWED: 55 minutes

INSTRUCTIONS:

Write your answers in the spaces provided beneath each question. The value of each question is shown with each question.

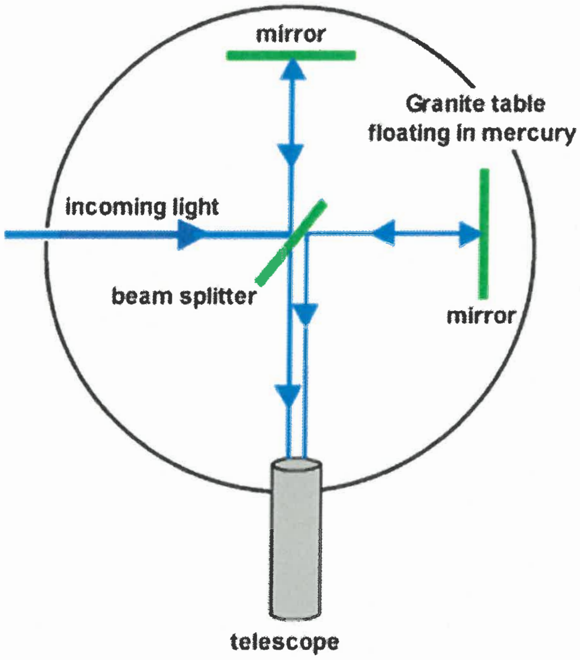
Sufficient working should be provided with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show full working will not necessarily be awarded full marks.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three significant figures** where applicable using scientific notation and include appropriate units where applicable.

When estimating numerical answers, or reading off a graph, show your working or reasoning clearly. Give final answers to a maximum of **two significant figures** and include appropriate units where applicable.

Question 1 [4 marks]

The diagram below schematically illustrates the famous Michelson-Morley Experiment, conducted in an attempt to provide evidence for the existence of 'luminiferous aether'.



a) Explain what Michelson & Morley expected to observe (in the telescope) and how this would have provided evidence for the existence of aether: [2]

- They expected to observe an interference pattern.
- The two paths of light had no path-difference in their length. The only way an interference pattern could form is if the speed of light on each path was different, due to Earth's motion through the 'aether'.

b) The notion of aether arose from ideas of classical relativity. If the aether could have been proven to exist, it would have provided an explanation for two problems with classical relativity; what were these problems? [2]

- Aether would have provided a medium for EM Radiation.
- Aether, as a frame of 'absolute rest', would have explained why 'c' was constant for all reference frames (ie. it would have been measured w.r.t. the aether).

Question 2 [3 marks]

The lowest reported value for the Hubble constant is around 67 km s^{-1} Mpc^{-1}. Given that 1 parsec (pc) = 3.09 x 10^{16} m, calculate the age of the universe predicted by this value. Give your answer in years.

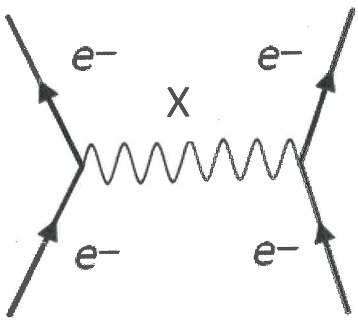
$$1\ \text{Mpc} = \frac{3.09 \times 10^{16}}{1000} \times 10^{6} = 3.09 \times 10^{19}\ \text{m}$$ (from datasheet).

$$\frac{67\ \text{km s}^{-1}\ \text{Mpc}^{-1}}{3.09 \times 10^{19}\ \text{km}} = 2.168 \times 10^{-18}\ \text{s}^{-1}$$ ✓

$$t = \frac{1}{H_0} = \frac{1}{2.168 \times 10^{-18}} = 4.612 \times 10^{17}\ \text{s}$$ ✓

$$\text{Ans} \div (365.25 \times 24 \times 60 \times 60) = 1.46 \times 10^{10}\ \text{yrs} \approx \boxed{14.6\ \text{Billion Yrs.}}$$ ✓

Question 3 [5 marks]



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

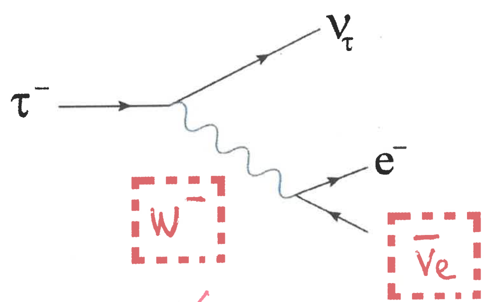
Photon ✓

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

– Strong Nuclear Force (or Strong Force). – Gluon

✓ ✓

c) The diagram (right) shows tau decay. Identify the missing particles.

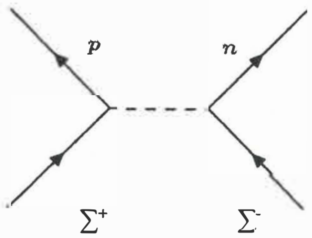
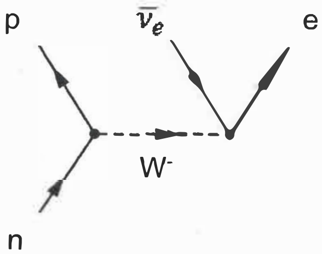


✓ ✓

Question 4 [3 marks]

For each particle interaction shown below, 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 “ALLOWED” in the 'working' section. Please note that, for the interactions shown as diagrams, the ‘time’ axis flows from **bottom to top.** [5]

Name	Symbol	Baryon #	Strangeness
Proton	p	1	0
Neutron	n	1	0
Sigma-plus	Σ^+	1	-1
Sigma-minus	Σ^-	1	-1
Sigma-neutral	Σ^0	1	-1
Pion-plus	π^+	0	0

Diagram	Working
	Before B = 2 Q = 0 L = 0 CHARGE VIOLATED ✓ After B = 2 Q = +1 L = 0
	$\boxed{\text{ALLOWED}}$ ✓
$\Sigma^0 \rightarrow \bar{p} + \pi^+$	Before B = 1 Q = 0 L = 0 BARYON VIOLATED ✓ After B = -1 Q = 0 L = 0

Question 5 [7 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 the phenomenon of redshift and briefly explain its role in providing evidence to support the Big Bang theory. [3]

- The spectra of distant bodies is observed and analysed, and compared to a known spectrum of identical compounds on Earth.
- The degree of shift in wavelength (or frequency) can be determined and thus the recessional velocity calculated.
- These observations lead us to the conclusion that the Universe is receding from us/expanding in all directions, as predicted by the Big Bang Theory.

(b) Prior to the Big Bang Theory, another model called the Steady State Model held sway within the scientific community. Briefly outline this model and detail any one piece of evidence that has led the scientific community to abandon the model in favour of the Big Bang Theory. [4]

- Steady State Theory suggests that the Universe has no beginning or end in time; it is eternal and unchanging on a large scale.
- It suggests that matter is continuously created to maintain a constant density as the Universe expands.

EVIDENCE (only need one of the combinations below):

- Steady State Theory does not predict the existence of the **Cosmic Microwave Background**.
- The discovery of this radiation provides significant evidence against the Steady State Theory.

OR

- Steady State Theory does not adequately account for the observed **ratios of light elements**.
- This insufficiency is a reason it has fallen out of favour.

Question 6 [2 marks]

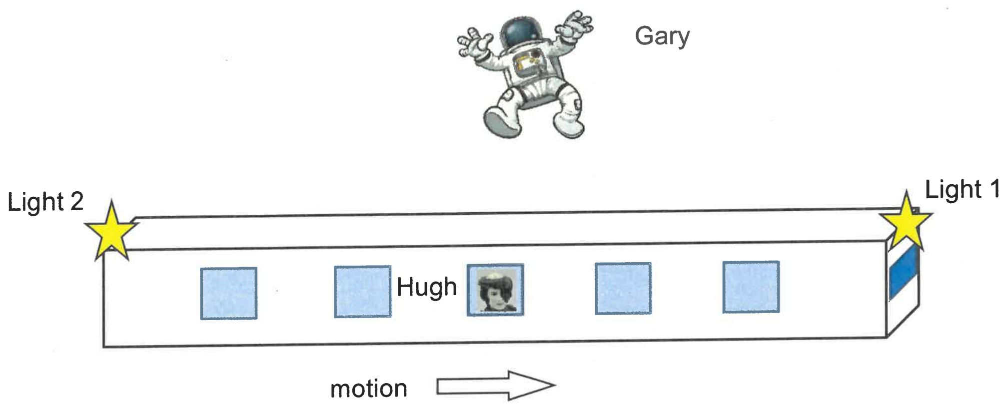
State the two postulates of Special Relativity:

- The principle of classical relativity should hold for all inertial reference frames (also expressed as: There is no such thing as absolute rest).
  (also expressed as: There is no experiment that can detect the motion of your own inertial reference frame).
- Maxwell's Equations were correct (i.e. speed of light in a vacuum 'c' is constant in all inertial reference frames).

Question 7 [9 marks]

Astronaut Gary is floating in space and is surprised to see a Borg Spaceship flying past. He sees it passing at a constant velocity, close to the speed of light. The spacecraft has light 1 at the front and light 2 at the rear. Gary **sees the two lights 1 and 2 illuminate simultaneously** as the ship passes. Hugh is a passenger in the middle of the ship. He also sees the lights.

Given this information, circle the correct statements below for questions a), b) and c).



a)
i) Gary sees light from 1 *reach Hugh* before light from 2
ii) Gary sees light from 2 *reach Hugh* before light from 1
iii) Gary sees light from 1 and 2 *reach Hugh* at the same time

Explain your answer

Gary observes Hugh travelling towards 1 & away from 2.
As Gary saw both lights flash simultaneously, travelling at a constant speed 'c', he will see light 1 reach Hugh first. [2]

b)
i) Hugh sees light from 1 arrive before 2
ii) Hugh sees light from 2 arrive before 1
iii) Hugh sees both lights arrive at the same time [1]

c)
i) Hugh concludes that the lights flashed simultaneously
ii) Hugh concludes that light 1 flashed before light 2
iii) Hugh concludes that light 2 flashed before light 1 [1]

d) Hugh and Gary have identical stopwatches set to countdown from one minute. As Hugh passes Gary, both stopwatches commence their countdown. Hugh states that his stopwatch will finish the countdown first but Gary states the opposite. Explain who is correct and why.[2]

- Both are correct.
- Each is in motion relative to the other. Clocks in motion run slower than for a stationary observer (i.e. each will view the other as being subject to time dilation).

e) Hugh measures his ship as a square prism of width 10 m and length 80 m. Gary observes the spaceship as a perfect cube. Calculate the ship's velocity relative to Gary. [3]

$$L = L_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$\Rightarrow \quad 10 = 80 \sqrt{1 - \frac{v^2}{c^2}}$$

$$\therefore \quad \frac{1}{8} = \sqrt{1 - \frac{v^2}{c^2}}$$

$$\frac{1}{64} = 1 - \frac{v^2}{c^2}$$

$$v^2 = 0.984375\, c^2$$

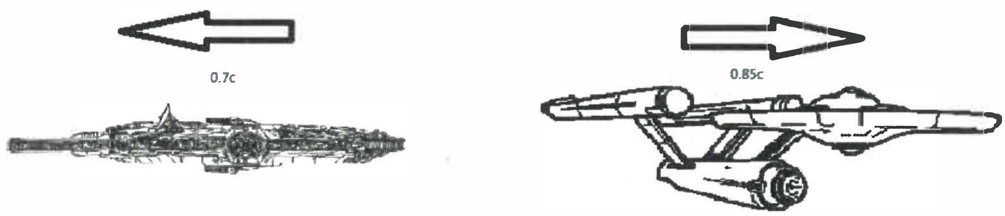
$$\boxed{v = 0.992\, c}$$

1 - Correctly identify length & proper length.
1 - Correct working.
1 - Correct Answer.

Question 8 [4 marks]

The 'Millennium Falcon' (shown left, below) and the 'USS-Enterprise' (shown right) 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 (Falcon) and 0.85c (Enterprise). Find:

$u = -0.7c$ $\qquad$ $v = 0.85c$



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

$$u' = \frac{u - v}{1 - \frac{vu}{c^2}} = \frac{-0.7c - 0.85c}{1 - \frac{(-0.7)(0.85)c^2}{c^2}} = \frac{-1.55c}{1.595}$$

$$= \boxed{-0.972c}$$

Correct Equation ✓
Correct Sign convention ✓
Correct Answer ✓

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

+0.972 c $\qquad$ (from a).

*Note - students may use a sign convention where the right direction is negative, in which case (a) should be positive and (b) should be negative.

For part (a), a better reading for "correct sign convention" would be "acknowledges vector nature of the problem" by indicating directions of key values.

Question 9 [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]

Baryon : 3 quarks or 3 antiquarks. ✓ ($\frac{1}{2}$ each)

Meson : 1 quark and 1 antiquark ✓

(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

ddu ✓

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

usc ✓

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

$u\bar{s}$ ✓

Question 10 [7 marks]

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

a. Relativistic mass of the sample: [1]

$$M = \frac{M_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{2.5\times10^{-10}}{\sqrt{1-\frac{0.99^2 \cancel{c^2}}{\cancel{c^2}}}} = \boxed{1.77\times10^{-9}\ \text{kg}}$$ ✓

b. Relativistic momentum of the sample: [1]

$$P = \frac{Mv}{\sqrt{1-\frac{v^2}{c^2}}} = (1.77\times10^{-9})(0.99\times3\times10^{8}) = \boxed{5.26\times10^{-1}\ \text{kg}\,\text{m}\,\text{s}^{-1}}$$ ✓

c. Kinetic energy of the sample: [2]

*Alternatively, if they rearrange eqns on data sheet to get an expression for KE, give 1 mark for that, then 1 mark for applying it to get correct answer.

$$KE = (\gamma-1)M_0c^2$$ ✓

$$= \left[\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right]M_0c^2 = \left[\frac{1}{\sqrt{1-0.99^2}} - 1\right](2.5\times10^{-10})(3\times10^{8})^2 = \boxed{1.37\times10^{8}\ \text{J}}$$ ✓

d. The sample enters a bending magnet. If the radius of its path in the magnet field is 80 m and the magnetic field is 2.5 T, calculate the charge of the ionised sample [3]

$$r = \frac{Mv}{qB} \Rightarrow q = \frac{Mv}{rB}$$ ✓

$$q = \frac{(1.77\times10^{-9})(0.99\times3\times10^{8})}{80\,(2.5)}$$

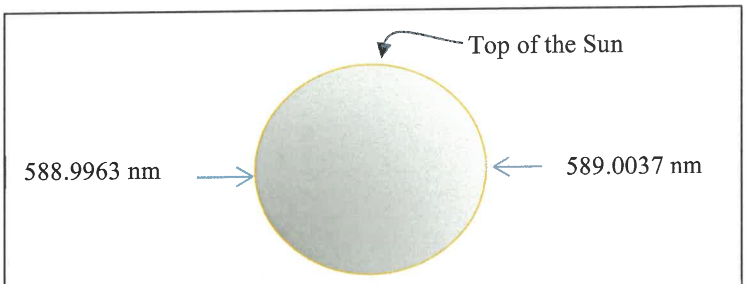
⊛ Use relative mass at this speed. ✓

$$\boxed{q = 2.63\times10^{-3}\ \text{C}}$$ ✓

Question 11 [6 marks]

Spectral analysis sunlight shows the presence of Sodium. The 'sodium-D' emission line occurs at a wavelength of 589 nm when measured on Earth.

The shift of this wavelength when viewed at the equator on either side of the Sun allows the surface speed and thus rotational period to be calculated.



Wavelengths of 589 nm Sodium-D line emission from the Sun, as observed from Earth

a) With reference to the above diagram state the direction of rotation of the Sun when viewed from above. Circle one of the options below and briefly explain your response. [2]

Clockwise **Anti-clockwise** **Impossible to determine** ✓

Explain briefly

Increase in $\lambda \Rightarrow$ Red shift $\therefore$ Moving AWAY. ✓

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

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

Where Δλ = difference of emitted wavelength compared to laboratory wavelength, λ = laboratory wavelength, and v is the velocity of the light source. Use this equation, along with data in the diagram above and in your data sheet, to calculate the **period of rotation** of the Sun, in days. [4]

$$\frac{0.0037}{589} = \frac{v}{3\times10^8} \checkmark$$

$$\Rightarrow v = 1884.55 \text{ m/s} \checkmark$$

$$T = \frac{2\pi r}{v}$$

$$= \frac{2\pi(6.96\times10^8)}{1884.55}$$

$$= 2320499 \text{ s} \checkmark$$

$$= \boxed{26.9 \text{ days}} \checkmark$$

END OF TEST