Year 12 ATAR Physics

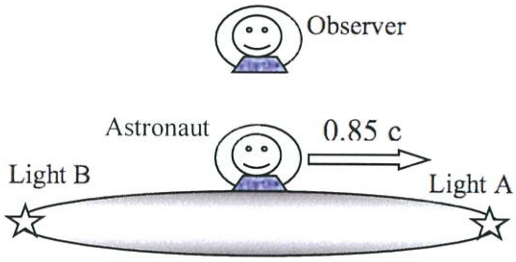
Cosmology Test 2018

NAME: Answers.

Total Marks – 52

1. **(4 marks)**

An astronaut flies past an observer at a constant 85% of the speed of light in the reference frame of the observer. Her spacecraft has light A at the front and light B at the rear. When the astronaut is directly in front of the observer as shown, she sees the two lights A and B illuminate simultaneously (i.e. at the same time!).



a) From the frame of reference of the astronaut explain what order the lights will go on for the observer.

(2)

Observer will see light B flash first, followed by light A. This is because light from A is travelling away from the observer, while light from B is travelling towards the observer.

b) The astronaut and the observer both have identical stopwatches set to countdown from one minute. As the astronaut passes the observer both stopwatches commence their countdown. The astronaut states that her own stopwatch will finish the countdown first but the observer states the opposite. Explain who is correct and why.

(2)

They are both correct from their own frame of reference. Each person sees the other as having a very fast relative speed from their own f. of ref. so for them, the faster moving 'object' will experience time dilation.

2. **(2 marks)**

On Friday January 24, 2014, Hubble's Constant was re-measured and determined to be $(73.8 \pm 2.4)\ \text{kms}^{-1}\text{Mpc}^{-1}$. How old is the Universe, given that 1 Mpc = 3.086×10^{22} m? [ignore the error component]

age = $1/H_0$

$\therefore H_0 = 73.8/(3.086 \times 10^{19}) = 2.39 \times 10^{-18}\ s^{-1}$ (or $7.547 \times 10^{-11}\ yr^{-1}$)

$\therefore$ age $= \dfrac{1}{2.39 \times 10^{-18}} = 4.18 \times 10^{17}$ s (or 1.325×10^{10} yrs)

or 13.3 billion years.

3. **(7 marks)**

A lead ion (Pb^{2+}) of mass 3.44 x 10^{-25} kg is accelerated to a speed of 77% the speed of light in a particle accelerator. The total energy of the lead ion is given by its mass-energy equivalence which is the sum of its rest energy ($E = mc^2$) and its kinetic energy.

a) Calculate the kinetic energy of the lead ion.

(4)

$\frac{mc^2}{\sqrt{(1-v^2/c^2)}} = mc^2 + K.E. \quad \therefore K.E. = \frac{mc^2}{\sqrt{(1-v^2/c^2)}} - mc^2$

$\therefore K.E. = 3.44\times10^{-25} \times (3\times10^8)^2 / \left(\sqrt{(1 - \frac{0.77^2c^2}{c^2}}\right) - 3.44\times10^{-25} \times (3\times10^8)^2$

$= 3.096\times10^{-8} / (\sqrt{0.4071}) - 3.096\times10^{-8}$

$= 4.852\times10^{-8} - 3.096\times10^{-8} = 1.76\times10^{-8}$ J.

b) Calculate the value of kinetic energy of the lead ion according to Newtonian physics **and** state whether there is a significant difference compared to the solution in part a).

(3)

$E_K = \frac{1}{2}mv^2 = \frac{1}{2} \times 3.44\times10^{-25} \times (0.77 \times 3\times10^8)^2$

$= 9.18\times10^{-9}$ J. which is 52.3% of the above answer so it is VERY significant!

4. **(7 marks)**

A spacecraft is moving away from Earth at a speed of 0.85c. The spacecraft fires a probe back towards Earth. As viewed from Earth the probe is moving at 0.60c towards Earth.

a) Determine the speed of the probe in the frame of reference of the spacecraft.

(3)

let $u = 0.85c$, $v = -0.60c$,

$u' = u - v / (1 - \frac{uv}{c^2}) = 0.85c - (-0.6c) / (1 + (0.85 \times 0.6))$

$\therefore u' = 1.45c / 1.51 = 0.96c$

(or $u' = 2.88\times10^8 ms^{-1}$).

b) The probe has a length dimension along its direction of motion. There are three frames of reference in this situation – from the Earth, from the spacecraft and from the probe. Circle the best response from the following options

A. The length is the same in all three frames of reference.

B. The length is longest from the probe and shortest from the Earth

C. The length is shortest from the probe and longest from the Earth

D. The length is longest from the probe and shortest from the spacecraft.

(1)

c) Explain your reasoning to part b) with reference to appropriate physics principles and formulae. No calculation is required.

(3)

- probe relative to Earth = 0.60c
- probe relative to spacecraft = $u' = 0.96c$
- probe relative to itself has speed = 0

∴ longest length will be that from the probe (i.e. it actual or true length), and shortest length will be from spacecraft, since relative speed between them is greatest!

5. **(3 marks)**

Explain the role that gauge bosons (i.e. the force carriers that carry the four fundamental forces in Physics) play in the standard model and give an example of a gauge boson, stating its range and how it can interact with other particles.

(3)

- gluons, force carriers for the strong nuclear force, responsible for keeping same charges quarks together in both protons and neutrons and also for keeping protons together in the nucleus; they dominate within the nucleus, at a range $\sim 10^{-15}$ m.
- could similarly discuss W^+, W^-, Z bosons for weak nuclear force or photons for electromagnetic force or gravitons for grav. force.

6. **(10 marks)**

The Hubble Space telescope observes distant galaxies to gather evidence to support the Big Bang Theory. The line absorption spectrum of light passing through a metallic vapour in galaxy M104 shows one line with a wavelength of 563.7 nm. The same line in the spectrum measured on Earth is 561.4 nm.

a) Calculate the recessional velocity of galaxy M104 using the following relationship:

(3)

$$\frac{\Delta\lambda}{\lambda_{rest}} = \frac{v}{c_0}$$ where $\Delta\lambda = \lambda_{shifted} - \lambda_{rest}$ and v = recessional velocity (m s^{-1})

$\lambda_{rest} = 561.4$ nm, $\lambda_{shifted} = 563.7$ nm,

$\therefore \Delta\lambda = 563.7 - 561.4 = 2.3$ nm

$\therefore \Delta\lambda / \lambda_{rest} \times C_0 = V = 2.3/561.4 \times 3 \times 10^8$

$\therefore V = 0.004097 \times 3 \times 10^8 = 1.23 \times 10^6 \, ms^{-1}$.

b) Using Hubble's law, calculate the distance in Mpc to galaxy M104 using the velocity you calculated. *(If you could not solve for the velocity then use a value of 1.23×10^6 m s^{-1})*

(2)

Hubble's law states that: $v = H_0 d$

v = recessional velocity (km s^{-1})
d = distance in megaparsec (Mpc)
$H_0 = 74.0$ km s^{-1} Mpc^{-1}

$V = 1.23 \times 10^6 \, ms^{-1} = 1.23 \times 10^3 \, kms^{-1}$

$\therefore d = V/H_0 = 1.23 \times 10^3 / 74 = \cancel{1.66 \times 10^4}$ MPC.

$= 16.6$ Mp

c) How many years has it taken light from this galaxy to reach Earth? (1 parsec = 3.26 light year)

(2)

16.6 ~~1.66 × 10~~ MpC $= 1.66 \times 10^7$ pC $\times 3.26$

$= 5.41 \times 10^7$ ly.

= 54.1 million light years, so time = 54.1 million years.

d) Explain how the wavelengths of light observed from Galaxy M104 can become redshifted.

(3)

- all galaxies are moving AWAY from each other as the Universe expands
- as such, ~~they~~ wavelength of the light they emit gets stretched (Doppler Effect) to longer values
- $\therefore$ shifting to the red end of the visible spectrum.

7. **(11 marks)**

A spacecraft of rest mass 500 kg is moving away from Earth at a speed of 0.68c. A light on the spacecraft is flashing 4 times per second in the reference frame of the spacecraft.

a) Determine the frequency of the flashes for an observer on Earth. (4)

$f_0 = 4\,Hz \therefore t_0 = 1/4 = 0.25\,s$

$t = t_0/\sqrt{(1 - v^2/c^2)} = 0.25/\sqrt{(1-0.68^2)}$

$\therefore t = 0.25/\sqrt{(0.5376)} = 0.25/0.733$

$\therefore t = 0.341\,s$

$\therefore f = 1/0.341 = 2.93\,Hz$

(or 2.93 flashes per second).

b) Calculate the relativistic momentum of the spacecraft from the reference frame of the Earth. (3)

$P = mv/\sqrt{(1-v^2/c^2)}$; from above, $\sqrt{(1-v^2/c^2)} = 0.733$

$P = 500 \times 0.68 \times 3 \times 10^8 / 0.733$

$\therefore P = 1.39 \times 10^{11}\ kgms^{-1}$ (or Ns).

c) With reference to the relativistic momentum equation, explain why it is impossible for the spacecraft to travel away from Earth at the speed of light. (2)

If $V = C$, then $\sqrt{(1-v^2/c^2)} = 0$!

$\therefore$ P would be infinite, suggesting that 'mV' would be infinite, and since $V = C$, mass would have to be infinite which is impossible in a closed Universe which has a definitive mass!

d) For an observer on Earth what is the speed of the light flashes as they arrive from the spacecraft? Briefly explain your reasoning. (2)

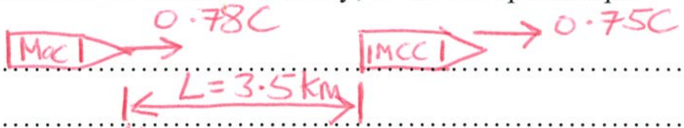
– ALWAYS $3 \times 10^8 \, ms^{-1}$

– one of Einstein's postulates states that 'c' is constant in ALL inertial reference frames.

8. **(8 marks)**

During the annual 1000 Mm Intergalactic race being observed from Earth, the spaceship IMCC 1, travelling at a velocity of 0.75c narrowly leads Mackillop 1 which fires its boosters increasing its velocity to 0.78c. IMCC 1 believes its lead is 3.50 km, when in fact it is actually greater.

a). Determine the relative velocity, U' of the spaceships. (4)



$U' = u - v / (1 - uv/c^2) = 0{\cdot}78c - 0{\cdot}75c / (1 - (0{\cdot}78 \times 0{\cdot}75))$

$\therefore U' = 0{\cdot}03\,c / 0{\cdot}415 = 0{\cdot}0723c$ (or $2{\cdot}17 \times 10^7 \, ms^{-1}$).

b). Use your answer to determine the actual lead that IMCC 1 has over Mackillop 1 at the time it fired its boosters. (3)
[If you could not answer part a)., assume that U' is 0.07c]

3·5km is the perceived / contracted length, L

$\therefore 3{\cdot}5 = L_0 \times \sqrt{(1 - v^2/c^2)}$ where $V = U' = 0{\cdot}0723c$

$\therefore 3{\cdot}5 = L_0 \times \sqrt{(0{\cdot}9948)}$ $\therefore L_0 = 3{\cdot}5 / 0{\cdot}9974 = 3{\cdot}51\,km.$

c). Calculate the ratio of the real time it will take Mackillop 1 to catch up to IMCC 1 compared to that observed by the Earth audience. (1)

$t = t_0 / \sqrt{(1 - v^2/c^2)}$; from above $\sqrt{(1 - v^2/c^2)} = 0{\cdot}9974$

$\therefore t/t_0 = 1/0{\cdot}9974 = 1{\cdot}003$

or $t : t_0 = 1{\cdot}003 : 1$

END OF TEST ☺