ARANMORE CATHOLIC COLLEGE

YEAR 12 PHYSICS 3A3B - 2010

ASSIGNMENT 6 - ASTROPHYSICS

NAME: SOLUTIONS MARK: /50

1. The Doppler shift in the wavelength of light emitted by galaxies can be used to measure the speed with which they are moving towards or away from the Earth. Like the Sun, galaxies emit a wide range of wavelengths. The analysis of the absorption spectra of light from galaxies can have two spectral lines missing due to the absorption by calcium ions as light passes through the gases surrounding galaxies. In the constellation Eridanus which is visible in the western sky between January to April there is a spiral galaxy NGC 1357. The wavelength of one of the calcium absorption lines in the spectrum from NGC 1357 is 399.72 nm. The same line in the calcium spectrum measured in a laboratory on Earth is 396.85 nm.

   a) Is the spiral galaxy NGC 1357 moving towards or away from the Earth? (1 mark)

   b) Justify your answer to (a) using a brief explanation and a diagram. (4 marks)

   c) Calculate the velocity of NGC 1357 using the relationship $\frac{\Delta\lambda}{\lambda_{rest}} = \frac{v}{c}$ where:

   $\Delta\lambda = \lambda_{shifted} - \lambda_{rest}$

   λ_{rest} is the wavelength of the fixed source and v is the speed of the moving source. (3 marks)

   d) A star has a recessional velocity of 58.9 km s^{-1}. Calculate the 'red shift' that would be expected in the calcium 396.849 nm absorption line from this star using the above relationship. (3 marks)

2. On the Hubble website, the claim is made that "Hubble is one of NASA's most successful and long-lasting science missions". Provide three reasons why the Hubble telescope has been so successful compared to larger Earth-based telescopes. (6 marks)

3. The 'Big Bang' theory is a model used to explain the origin of the universe. Describe two pieces of scientific evidence which support this theory. (4 marks)

4. Briefly describe the four main types of sub-atomic particles, namely the leptons, baryons, mesons, and bosons. (6 marks)

5. Draw the Feynman diagram for the β^+ decay of Nitrogen-12 to Carbon-12 at the fundamental level of a quark conversion via the emission of a W^+ boson and its subsequent decay into a positron and an electron-neutrino. (4 marks)

6. In the science fiction series Star Trek, Captain Kirk orders the starship Enterprise to travel from Earth on a rescue mission to Alpha Centauri (4.2 light-years away). Due to battle damage, the fastest speed that the Enterprise can travel at is just below the speed of light. The crew includes twins and while one of two identical twins is on the mission to Alpha Centauri the other remains on Earth.

   a) The Enterprise can only manage a speed of $0.98c$ (c = speed of light). At this speed, how long will the starship take to travel to Alpha Centauri and return as seen from Earth? (2 marks)

   b) The time dilation equation is:

$$t_0 = t.\sqrt{1 - \frac{v^2}{c^2}}$$

   where t_0 is the apparent time elapsed on the starship and t is the actual time taken for the trip. For the crew on board, what appears to be the time taken to travel to Alpha Centauri and return? (3 marks)

   c) On the return to Earth the twins are no longer the same age, one is older. Which twin has aged more and by how much? (2 marks)

7. Muons are formed when cosmic radiation impacts air molecules 10 km up in the Earth's atmosphere. About 10000 muons reach every square meter of the Earth's surface every minute. The mean lifetime of a stationary muon is 2.2×10^{-6} seconds before it decays. Muons travel at speeds of up to 0.999c and can penetrate deep into rock. They are detectable deep underground and underwater. Rossi and Hall in 1940 were able to "prove" the effect of time dilation on high speed muons. They measured muon impacts on a scintillation counter at an altitude of 3000 metres (568 counts h^{-1}) and at sea level (412 counts h^{-1}).

   a) What distance would a muon be expected to travel in its mean lifetime? (Not including any special relativity effects) (2 marks)

   b) Using the information from (a) would you expect many muons to reach the Earth's surface from where they were formed? (1 mark)

   c) Using the equation below, calculate the mean lifetime of a muon in its own (moving) frame of reference. (3 marks)

$$t_0 = t.\sqrt{1 - \frac{v^2}{c^2}}$$ where t_0 is the actual time and t is the apparent time.

   d) What distance would a muon be expected to travel in its mean lifetime taking into account special relativity? (2 marks)

   e) Would you now expect more muons to reach the Earth's surface? (2 marks)

   f) How did the data collected by Hall and Rossi "prove" time dilation actually exists? (2 marks)

ASSIGNMENT 6 - SOLUTIONS

(1.) (a) AWAY FROM THE EARTH.

(b) (1) - WAVELENGTH HAS INCREASED FROM 396.85nm TO 399.72nm
(1) - THIS CORRESPONDS TO A SOURCE MOVING AWAY FROM OBSERVER
(2) - DIAGRAM OF RIPPLE TANK OR CAR SIREN ILLUSTRATING THE DOPPLER EFFECT (BOTH SHORTENING & LENGTHENING λ)

(c) (1) $v = \frac{\Delta\lambda}{\lambda} \times c = [(399.72 - 396.85)/396.85] \times 3 \times 10^8$ (1)
$= 2.17 \times 10^6 \, ms^{-1}$. (1)

(d) (1) $\Delta\lambda = \frac{v\lambda}{c} = \frac{58900 \times 396.849}{3 \times 10^8}$ (1)
$= 0.0779$ nm (1)
OR $\lambda = 396.849 + 0.078 = 396.927$ nm.

(2.) - NO ATMOSPHERIC EFFECTS
e.g. - DISTORTIONS DUE TO DIFFERING REFRACTIVE INDICES
- OBSCURING BY DUST OR CLOUDS
- IR WAVELENGTHS ARE ABSORBED BY MOISTURE & CO_2 IN ATMOSPHERE
- NEAR UV WAVELENGTHS ABSORBED BY OZONE IN UPPER ATMOS.
- CONTINUOUS OPERATION
- EARTH-BASED TELESCOPES ONLY AT NIGHT
- " " ONLY CLOUDLESS CONDITIONS/CLIMATE.
(1 MARK EACH - ANY 6 PTS OR EXPLANATION)

(3.) - REDSHIFT AND EXPANSION
- HUBBLE'S LAW AND EXPANSION
- COSMIC MICROWAVE BACKGROUND RADIATION AND EXPANSION OR COOLING
(ANY TWO OF ABOVE + DESCRIPTION)
1 MARK EACH + 1 MARK EACH DESCRIPTION

(4.) (1) – LEPTONS – FUNDAMENTAL – INTERACT VIA WEAK FORCE
e.g. ELECTRONS, MUONS, TAUS, NEUTRINOS.

(1) – BOSONS – FUNDAMENTAL – FORCE-MEDIATING PARTICLES
e.g. PHOTONS, GLUONS, W^+, W^-, Z^0.

(1) – BARYONS – MADE OF 3 QUARKS OR 3 ANTIQUARKS

(1) – INTERACT VIA THE STRONG NUCLEAR FORCE
e.g. PROTONS, NEUTRONS.

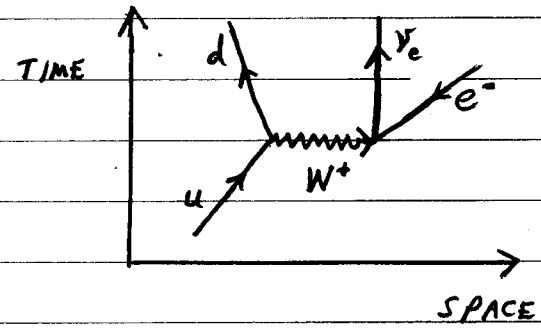
(1) – MESONS – MADE OF 1 QUARK AND 1 ANTIQUARK

(1) – INTERACT VIA STRONG FORCE
e.g. PIONS, KAONS.

(5.) $^{12}_{7}N \rightarrow {}^{12}_{6}C + {}^{0}_{1}e^{+} + \nu_e$.

$p \rightarrow n + e^+ + \nu_e$.

$u \rightarrow d + e^+ + \nu_e$.



1 – FOR GRAPH/AXES
1 – FOR $u \rightarrow d$ (OR $p \rightarrow n$)
1 – FOR W^+ etc
1 – FOR e AND ν_e

(6.) (a) $t = \frac{8.4c}{0.98c}$ (1) $= 8.57$ yrs. (1)

(b) $t_0 = t\sqrt{1-(0.98)^2}$ (1) $= 8.57 \times 0.199$ (1) $= 1.70$ yrs. (1)

(c) – EARTH TWIN IS OLDER (1)
– AGE DIFFERENCE IS $8.57 - 1.70 = 6.87$ yrs. (1)

(7.) (a) $s = v \times t$

$= 0.999 \times 3 \times 10^8 \times 2.2 \times 10^{-6}$ (1)

$= 660\ m.$ (1)

(b) - AVERAGE MUON ONLY TRAVELS 660m FROM 10 km UP BEFORE IT DECAYS, HENCE VERY FEW WOULD REACH EARTH'S SURFACE

(c) $t_o = t\sqrt{1-(0.999)^2}$ (1)

$t = (2.2 \times 10^{-6}) / 0.0447$ (1)

$= 4.9 \times 10^{-5}\ s.$ (1)

(d) $s = v \times t$

$= 0.999 \times 3 \times 10^8 \times 4.9 \times 10^{-5}$ (1)

$= 14700\ m.$ (1)

(e) (1) - YES

(1) - AVERAGE MUON TRAVELS NEARLY 15 km BEFORE IT DECAYS SINCE THEY FORM ABOUT 10km UP IN ATMOSPHERE ON AVERAGE (ie. MOST) MUONS WILL REACH EARTH'S SURFACE.

(f) (1) - MOST MUONS (~73%) TRAVELLED 3000 METERS WITHOUT DECAYING

(1) - THIS WOULD TAKE THEM LONGER ($\sim 1 \times 10^{-5}$ s) THAN THEIR AVERAGE LIFETIMES, HENCE TIME SLOWS DOWN FOR THEM AT SUCH HIGH SPEEDS (0.999c).