WILLETTON SENIOR HIGH SCHOOL
YEAR 12 PHYSICS

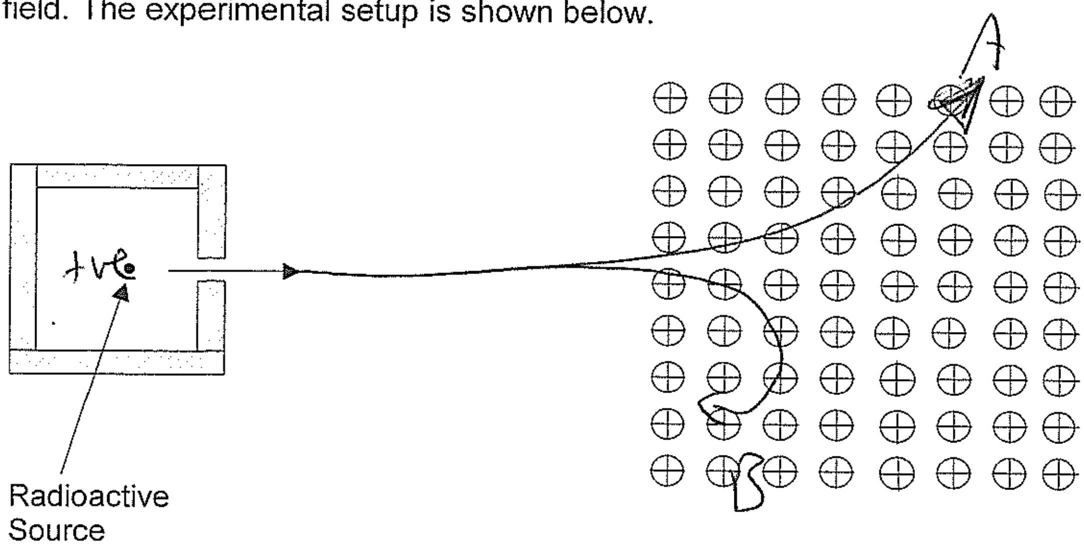
RELATIVITY, COSMOLOGY AND ELECTRIC AND MAGNETIC FIELDS TEST 2013

NAME: Solutions TEACHER ______________________

MARKS: __________/50

Answer the questions in the spaces provided.

1. A radioactive source is used to fire alpha particles (He^{2+} ions) into a magnetic field. The experimental setup is shown below.



a) On the diagram carefully indicate a possible path for the alpha particles when they enter the magnetic field. Label the path (A). (1 mark)

up 1

b) If an electron was fired into the magnetic field, carefully indicate a possible path for that particle when it enters the magnetic field. Label the path (B) (1 mark)

down $\frac{1}{2}$

Smaller radius $\frac{1}{2}$

2

2 (8 marks)

In the science fiction series Willo Trek, Captain Taylor orders his Starship 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 Starship can travel at is just below the speed of light. Captain Taylor's identical twin brother remains on Earth.

(a) The Starship 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)

$V = S/t$ $\quad t = S/V$

$= \frac{4.2}{0.98}$

$= 4.28$ Years

$\times 2$ 8.56 Years

or

$V = 0.98 \times 3 \times 10^8$ m/s

$S = 4.2 \times 24 \times 365.25 \times 3600 \times 3 \times 10^8 = \cancel{\ldots} \times 10^{?}$ m

$t = \frac{S}{V}$

$= 1.35 \times 10^8$ seconds

$\times 2 = 2.70 \times 10^8$ sec

(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? ~~(2 marks)~~

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

$= 8.56 \times \sqrt{1 - \frac{0.98^2}{1^2}}$

$= 8.56 \quad 0.19899$

$= 1.71$ Years

* Total − 1 for not doubling distance

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

Earth twin 8.56 Years

Starship twin 1.71 Years

Earth twin is 6.85 Years older

(d) When the Starship is travelling just under the speed of light, as well as time being affected, what are the other two relativistic effects on the starship that occur? (2 marks)

- Length decreases in the direction of travel.
- Mass increases

8

3. A muon is a sub-atomic particle with the same charge as an electron and 206 times an electron's mass. These particles are produced in the Earth's upper atmosphere (15.0 km above the ground) and 'rain' down on the surface, where they can penetrate deep into the Earth. However, muons are not stable and very quickly decay. A stationary muon is known to decay in around 2.20 μs.

(a) If a muon is created in the upper atmosphere and heads directly to the ground at a constant speed of 0.9c, how far would it be expected to travel during its measured stationary lifespan? (1 mark)

$V = 0.9 \times 3 \times 10^8 ms^{-1}$
$= 2.7 \times 10^8 ms^{-1}$
$S = ?$
$t = 2.20 \times 10^{-6}$ seconds

$S = tv$
$= 2.20 \times 10^{-6} \times 2.7 \times 10^8$
$= 594 m$

1

(b) Scientists working on the Earth routinely detect muons at ground level. Calculate the apparent lifespan of these muons and explain how Einstein's special theory of relativity can explain why a large number of these particles reach the Earth's surface although it seems that they should not last long enough for the trip. (3 marks)

$S = 15000 m$
$V = 2.7 \times 10^8 ms^{-1}$
$t = ?$

$t = \frac{S}{V}$
$= \frac{15000}{2.7 \times 10^8}$
$= 5.55 \times 10^{-5}$ seconds 2

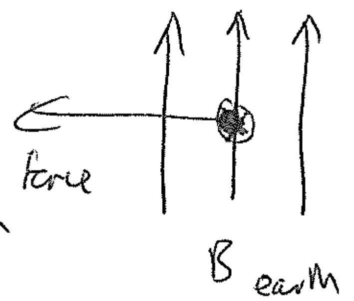
Time is dilated in the muons reference frame because it is travelling at relativistic speed. 1

(c) If the muon in part a) travels directly down through a region where the horizontal component of the Earth's magnetic field is 30 μT, calculate the strength and direction of the resultant force on the particle. (2 marks)

$V = 2.7 \times 10^8 ms^{-1}$
$B = 30 \times 10^{-6} T$
$q = 1.6 \times 10^{-19} C$

$F = qvB$
$= 1.6 \times 10^{-19} \times 2.7 \times 10^8 \times 30 \times 10^{-6}$
$= 1.30 \times 10^{-15} N$

1½



½

6

4. An electron gun in an electron microscope accelerates electrons from rest through a potential of 100 kV before firing them at the target specimen. What is the velocity of the electrons when they emerge from the microscope? (3 marks)

$V = 100\,000\,V$

$v = ?$

$$v = \sqrt{\frac{2Vq}{m}}$$

$$= \sqrt{\frac{2\times10^5 \times 1.6\times10^{-19}}{9.11\times10^{-31}}}$$

$$\boxed{= 1.87\times10^{8}\,ms^{-1}}$$

ignore direction

5. A uniform electric field is created between 2 plates 80 mm apart and 300 mm long, by inducing a potential difference of 12 V between them.

(a) What is the field strength between the plates? (1 mark)

$$E = \frac{V}{d} = \frac{12}{0.08} = 1.50\times10^{2}\,Vm^{-1}$$

(b) How much work is done on a proton moved from the negative to the positive plate? (1 mark)

$$Work = Vq$$

$$= 12\times1.6\times10^{-19}$$

$$\boxed{= 1.92\times10^{-18}\,J}$$

(c) Calculate the impact velocity of a proton released on the surface of the positive plate as it moves towards the negative plate. (4 marks)

$$v = \sqrt{\frac{2Vq}{m}}$$

$$= \sqrt{\frac{2\times12\times1.6\times10^{-19}}{1.67\times10^{-27}}}$$

$$\boxed{= 4.79\times10^{4}\,ms^{-1}}$$

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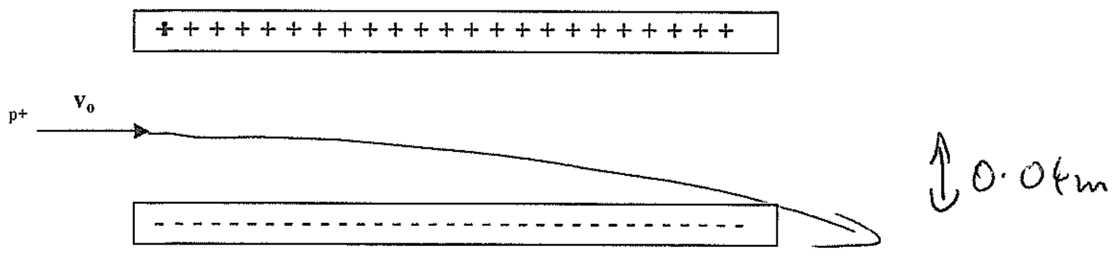
(d) If a proton is fired directly between the plates at right angles to the field, what minimum initial velocity v_o is required in order to ensure the proton reaches the other end without colliding with a plate? (4 marks)



$$a = \frac{F}{m}$$

$$= \frac{Eq}{m}$$

$$= \frac{1.50 \times \cancel{16} \times 10^{-19}}{1.67 \times 10^{-27}}$$

$$a = \underline{1.44 \times 10^{10}\ ms^{-2}}$$ 1

$$S = \cancel{ut} + \tfrac{1}{2}at^2$$

$$t = \sqrt{\frac{2 \times 0.04}{1.44 \times 10^{10}}}$$

$$= \underline{2.36 \times 10^{-6}\ \text{seconds}}$$ 1

$$V = \frac{S}{t}$$

$$= \frac{0.3}{2.36 \times 10^{-6}}$$

$$\boxed{= 1.27 \times 10^{5}\ ms^{-1}}$$ 2

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6. American astronomer Edwin Hubble was able to calculate the speed at which galaxies were receding from their redshift. He used the formula $v_{galaxy} = (\Delta\lambda/\lambda) \times c$
Where: v_{galaxy} is the speed of the observed galaxy ($m\ s^{-1}$)

$\Delta\lambda$ is the change in wavelength (m)

λ is the normal wavelength (m)

c is the speed of light ($m\ s^{-1}$)

(a) What is redshift? Explain how it is caused. (3 marks)

Redshift is the increase in λ of a wave caused by the source of the wave moving away from the observer

The ~~reason~~ recession of the source causes a change in λ towards the red end of the spectrum.

(b) Using the redshift formula, $v_{galaxy} = (\Delta\lambda/\lambda) \times c$, calculate the recession speed of the NGC 4889 galaxy if the wavelength of a spectral line of ionised calcium measured in the laboratory is 393.3 nm but has a wavelength of 401.8 nm when observed in light from the galaxy. (1 mark)

$$V = \frac{401.8 - 393.3}{393.3} \times 3 \times 10^8$$

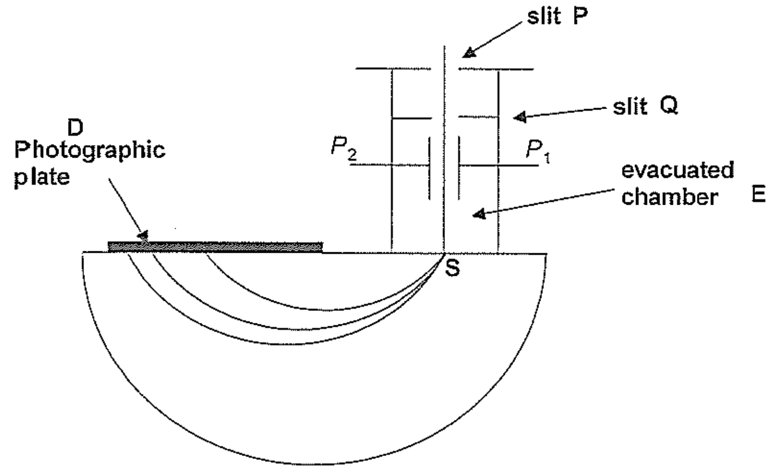
$$\boxed{= 6.5 \times 10^6 \, m s^{-1}}$$

$-\frac{1}{2}$ if they divide by 401.8 nm

4

7. (5 marks)

In the apparatus shown in the sketch, a beam of singly-charged positive ions $^{20}_{10}Ne$, $^{21}_{10}Ne$, $^{22}_{10}Ne$ ions passes through the slits P and Q and enters the evacuated chamber E. A uniform magnetic flux is applied throughout E.



(i) If the magnetic field is of flux density 0.60 T and the force on the ions is 5.01×10^{-14} N, find the velocity of the ions that emerge from S.

(Note: $q = +1.6 \times 10^{-19}$C)

(2 marks)

$B = 0.6T$
$F = 5.01 \times 10^{-14} N$
$q = 1.6 \times 10^{-19} C$
$v = ?$

$F = qvB$

$V = \frac{F}{qB}$

$V = 5.27 \times 10^5 ms^{-1}$ 2

(ii) The ions of one isotope form a trace on the photograph plate D at a distance of 38.0 cm from the slit S. Find the mass number of the isotope.

(3 marks)

Note: 1 u = 1.66×10^{-27} kg

$r = \frac{mv}{qB}$

$m = \frac{rqB}{V}$

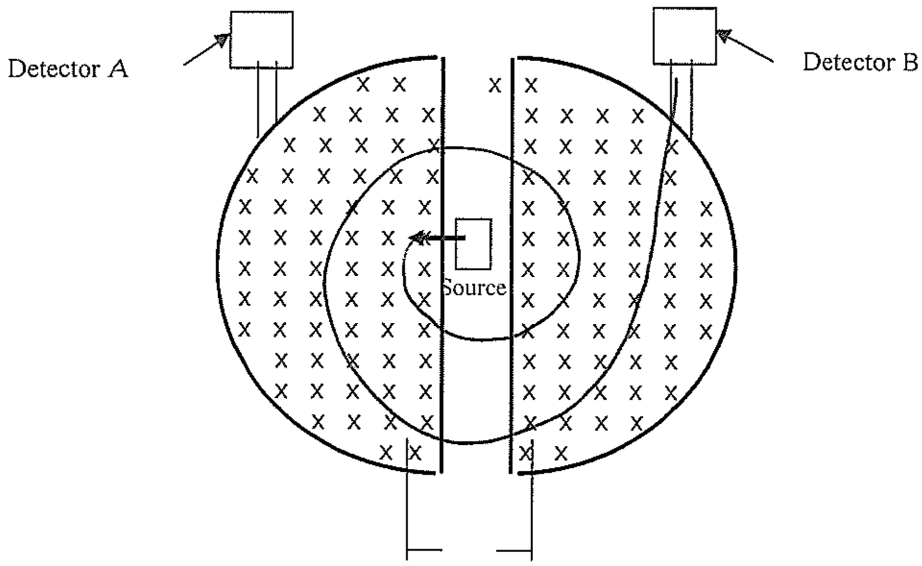
$= \frac{0.19 \times 1.6 \times 10^{-19} \times 0.6}{5.27 \times 10^5}$

$\boxed{3.49 \times 10^{-26} kg}$

5

8 **(8 marks)**

Consider a proton fired from the source in a cyclotron as shown in the diagram below:



Draw the path of a proton to the detector

(this will be detector A OR B). (2 marks)

(b) Explain why it is important to have an alternating electrical potential difference between the two "dees".

(2 marks)

The potential difference between the Dees is accelerating the particle. As the particle is attracted to a negative Dee, the same Dee must become positive to repel the particle a fraction of a second later..

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(c) Explain why the radius increases as the proton moves around the cyclotron. (2 marks)

$r = \frac{mv}{qB}$

as the velocity increased due to the potential difference between the Dee's, the radius will increase due to the relationship $r = \frac{mv}{qB}$

(d) Using equations on your data sheet, derive the expression:

$$r = \frac{mv}{qB}$$

Where r is the path radius, m is mass of the particle, q is the particle's charge and B is the magnetic field strength.

(2 marks)

9. Particles called quarks are the building blocks of other sub-atomic particles. (4 marks)

Table 1: Some properties of quarks

Quark	Charge, q	Strangeness, S
Up	+2/3	0
Down	-1/3	0
Charm	+2/3	0
Strange	-1/3	-1
Top	+2/3	0
bottom	-1/3	0

Use Table 1 to determine the values of the charge and strangeness quantum numbers for the particles in Table 2

Table 2: Properties of some sub-atomic particles

Particle	Quark composition	Charge, q	Strangeness, S
Lambda	up, down, strange	0	-1
Xi	up, strange, strange	0	-2
Sigma minus	down, down, strange	-1	-1

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$$F = \frac{mv^2}{r} \qquad F = qvB$$

$$qvB = \frac{mv^2}{r}$$

$$r = \frac{mv^{\cancel{2}}}{q\cancel{v}B}$$

$$r = \frac{mv}{qB}$$