WESLEY COLLEGE

By daring & by doing

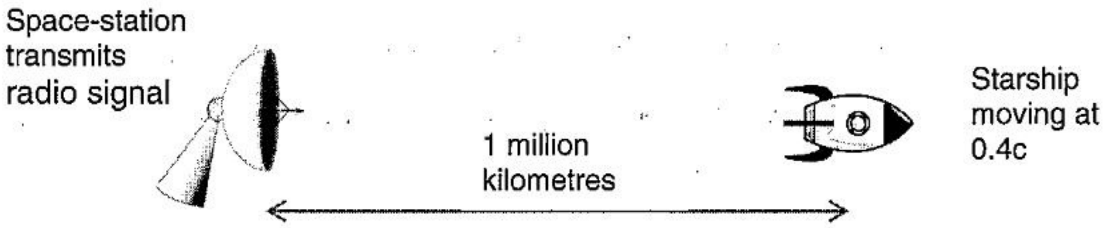
Name Answer. /50

2016

Year 12 Physics
Relativity, Particle Accelerators, Standard Model and Cosmology

Question 1

In the frame of reference of the galaxy that they are situated in, a starship is moving away from a space-station at 0.4c. The space station is at rest. The space-station starts to transmit a radio signal to the starship when it is a distance of 1 million kilometres from the space-station.



a) What is the speed of the radio signal in the frame of reference of the starship? (1)

$3 \times 10^8 ms^{-1}$

b) Explain how time is progressing on the space-station in the reference frame of the starship (2)

Time moves slower ✓ on the Space station as it is moving at relativistic speed ✓ from the frame of reference of the starship.

c) The occupants of the starship state that the distance they have travelled is less than one million kilometres while observers on the space station describe the distance as one million kilometres. Explain who is correct and why? (2)

Both correct ✓ in their own frame of reference. Starship moves at relativistic speed so its distance is contracted ✓

Question 2

(a) Calculate the relativistic mass of an electron travelling around the synchrotron at 99% of the speed of light. (Rest mass of an electron is $9.1093897 \times 10^{-31}$ kg). (2)

$$m_{rel} = \frac{9.1093897 \times 10^{-31}}{\sqrt{1 - \frac{(0.99)^2}{(3\times10^8)^2}}} \checkmark$$

$$= 6.457 \times 10^{-30} \text{ kg} \checkmark$$

(b) Why is more energy needed to accelerate an electron as its speed increases? (1)

Mass of the electron will increase
So more energy is needed to accelerate it.

(c) A spaceship travels away from Earth at 85% of the speed of light. A NASA technician on Earth calculates that ship will travel for 8 years at this speed. Calculate how much time will elapse on the spaceship as viewed from Earth. Give your answer in years to 2 decimal places. (3)

$v = 0.85c$

$$\frac{1}{\sqrt{1 - \frac{(0.85)^2}{1^2}}} \checkmark$$

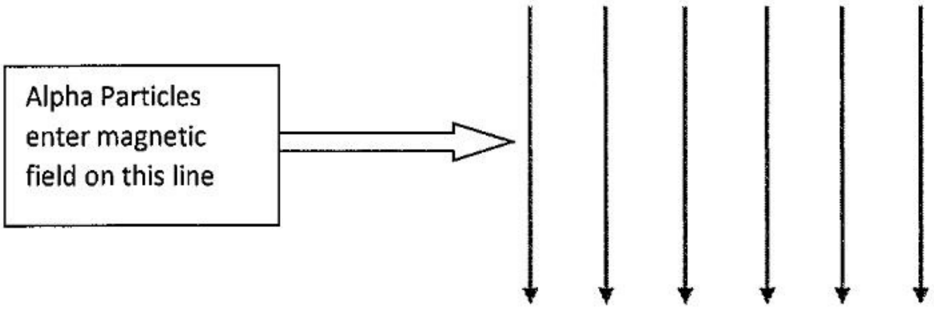
$$= 1.8983 \checkmark$$

$$\text{time} = \frac{8\text{yr}}{1.8983}$$

$$= 4.21 \text{ years} \checkmark$$

Question 3

A source of radiation emits alpha particles (He^{2+}) which are fed into a uniform magnetic field as indicated in the diagram below. They enter with a speed of 2.80×10^{7} m s^{-1} and experience a magnetic force of 6.54×10^{-12} N.



a) Calculate the magnetic flux density of the magnetic field.

(2)

$F = Bqv$

$B = \frac{F}{qv} = \frac{6.54 \times 10^{-12}}{3.20 \times 10^{-19} \times 2.8 \times 10^{7}}$ ✓

$= \underline{0.730 \text{ T}}$ ✓

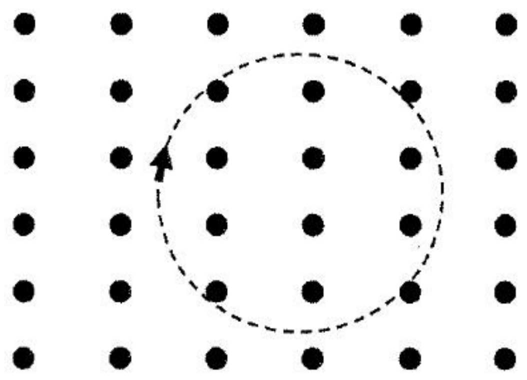
b) State the direction of force on the alpha particles as they enter the field. Circle a response

(1)

Up   Down   Left   Right   (Into page)   Out of page

Question 4

a) A particle of charge q and mass m has gone into clockwise circular motion in a uniform magnetic field B within a vacuum chamber. It is moving at speed v with a radius r. The situation is shown in the diagram below.



i. State whether the particle has a positive or negative charge.

(1)

ii. Show by clear algebraic steps and with reference to equations on the data sheet, that the following relationship for the period of circular motion is true.

(3)

$$T = \frac{2\pi m}{qB}$$

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

$mv = qB$

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

$m \times \frac{2\pi r}{T} = qB$ ✓

$\therefore T = \frac{2\pi m}{qB}$ ✓

iii. The particle has a mass of 4.14×10^{-12} kg and a charge of 5.80 nC. The magnetic field has a flux density of 95.0 mT. Calculate how many times the particle goes around in a circle in a time of 4.00 seconds.

(3)

$T = \frac{2\pi m}{qB}$

$= \frac{2 \times \pi \times 4.14 \times 10^{-12}}{5.8 \times 10^{-9} \times 0.095}$ ✓

$= 4.72 \times 10^{-2}$ s ✓

$\frac{4}{4.72 \times 10^{-2}} = 84.7$ times. ✓

Question 5

In the Standard Model hadrons are particles that are composed of quarks. A baryon is composed of three quarks e.g. utb. A meson is composed of two quarks – one quark is normal matter and the other is an antimatter quark e.g. $d\bar{s}$. A table of quarks is shown below left.

Complete the table below right by giving examples of quark combinations that could make the hadrons described.

(4)

Quark	Charge (e)
Up (u)	$+\frac{2}{3}$
Down (d)	$-\frac{1}{3}$
Top (t)	$+\frac{2}{3}$
Bottom (b)	$-\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$
Strange (s)	$-\frac{1}{3}$

Hadron	Charge (e)	Quark combination	
A positively charged baryon	+2	utc	(uut)(uuu)(utt)(ucu)
A neutral baryon	0	udb	(ddu)(tbs)
A negatively charged meson	-1	~~dt~~	$(\bar{u}b)(\bar{u}d)$ [illegible]
A positively charged meson	+1	~~cs~~ $c\bar{s}$	$(t\bar{d})(u\bar{d})$

Question 6

(a) A proton is made up of 3 quarks, what are the charges on each quark?

~~(2)~~ (1)

$+2/3 + 2/3 + -1/3 = +1$ ✓

(b) Explain your answer. (1)

Charge on the proton is +1 so it must be composed of uud quarks.

(c) If a neutron is made up of 3 quarks, what are the charges on each quark?

~~(2)~~ (1)

$-1/3 + -1/3 + +2/3 = 0$ ✓

(d) Explain your answer. (1)

Charge on the neutron is zero so it must be composed of ddu quarks.

Question 7

In 1964 Murray Gell-Mann put forward a model of particle physics where heavy sub-atomic particles (hadrons), such as the proton or neutron or pion, are actually composite particles made of different combinations of more fundamental particles known as quarks. There are 6 quarks whose quantum number values are listed below; each quark has an antiquark of exactly opposite quantum numbers.

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

According to this standard model the neutron is a baryon made of three quarks and has the composition **udd**, with charge Q = 0, baryon number B = +1 and other numbers S = c = b = t = 0; the pion (π^+) is a meson made of a quark-antiquark pair and has composition $\mathbf{u\bar{d}}$, charge Q = +1, baryon number B = 0 and other numbers S = c = b = t = 0.

(a) The neutrino was only detected many years after it was first predicted theoretically. Explain why the neutrino was (and still is) so hard to detect.

(2)

It has no charge and very little mass. ✓
Therefore it has few interactions with anything else in which it could be detected.

(b) Another class of matter particle in the standard model is the leptons. State two general properties of leptons that distinguish them from the hadrons.

(2)

- Low mass
- Are fundamental particles so not made up of quarks.
- No interactions as a consequence of the strong nuclear force.

Any 2 ✓✓

(c) Give the quark composition of the following hadrons:

(i) the sigma plus baryon (Σ^+), with Q = +1, B = +1, and S = -1 and c = b = t = 0 (1)

uus

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

dsc

(iii) the D^+ meson, with Q = +1, B = 0, c = +1 and S = b = t = 0 (1)

$c\bar{d}$

(iv) the strange B meson (B^0_s), with Q = 0, B = 0, S = -1, b = +1 and c = t = 0

$s\bar{b}$

(d) When a K^- meson collides with a proton, the following reaction can take place.

$$K^- + p \rightarrow K^0 + K^+ + X$$

X is a particle whose quark structure is to be determined.

The quark structure of the mesons in the reaction is given below.

particle	**quark structure**
K^-	$s\bar{u}$
K^+	$u\bar{s}$
K^0	$d\bar{s}$

Is the original K^- particle a hadron, a lepton or an exchange particle? (1)

Hadron (made up of quarks).

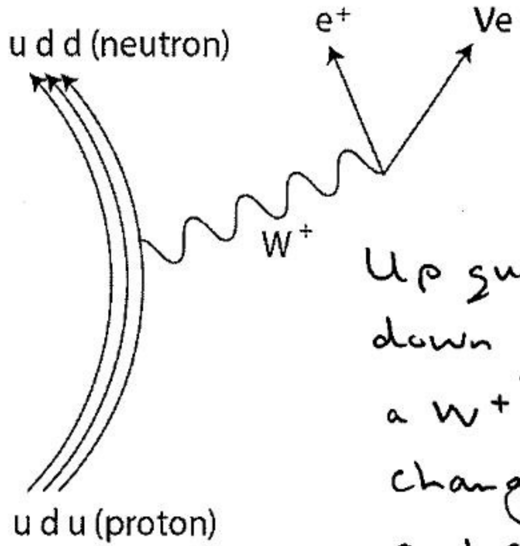
If X has a baryon number = 1 what is its quark structure? (1)

X = sss

usu

Question 8

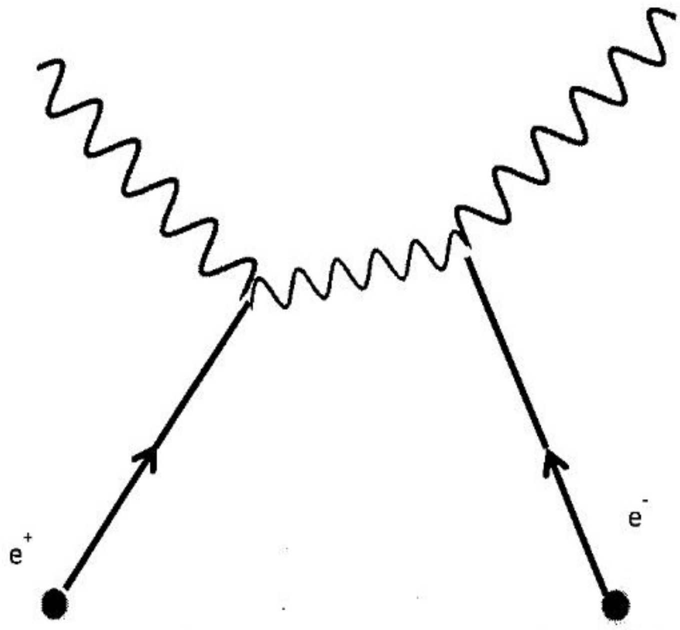
(a) Describe the following reaction. Is it a strong, electromagnetic or weak reaction?
(3)



weak reaction ✓

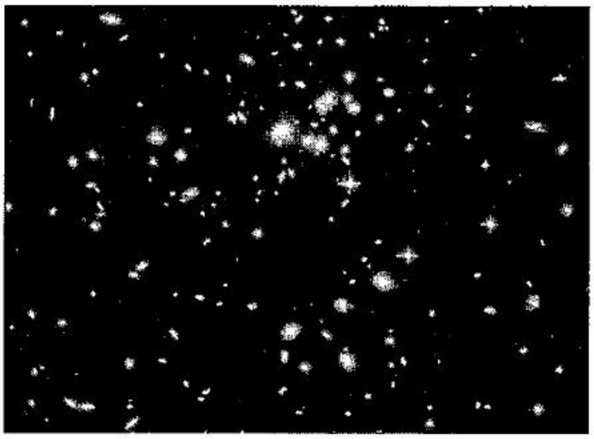
Up quark changes to a down quark by emitting a W^+ boson. It then changes to a positron and an electron neutrino. ✓

(b) Describe the following reaction. Why are the products particularly useful in PET scans of patients in hospital?
3



Positron and electron annihilate ✓
with the emission of two gamma photons. ✓
The gamma photons are used in body imaging. ✓

Question 9



Edwin Hubble established that distant galaxies are moving away from us with a velocity proportional to their distance; this relationship is written as $v = H_0 d$ where the constant of proportionality H_0, known as Hubble's constant, indicates the rate of expansion of the universe. A galaxy cluster that is 400 million light years distant is measured to be moving away from us at a speed of 8.7×10^6 m/s.

(a) Use this data about the galaxy cluster to estimate a value for Hubble's constant in units of *km/s* per *mega light-year.* (2)

Speed = $8.7 \times 10^6 \, ms^{-1}$

Distance = 400 MLY

$H_0 = \frac{8700 \, kms^{-1}}{400 \, MLY}$ ✓

$= 22 \, kms^{-1} \, MLY^{-1}$ ✓

(b) Use your value of Hubble's constant to estimate the age of the universe, expressing your answer to the nearest billion years. (2)

* $\frac{1}{H_0}$ = 1 MLY per $22 \, kms^{-1}$

$= 1.0 \times 10^6 \times 3 \times 10^5 \, kms^{-1} \times 3600 \times 24 \times 365$ ✓

$= \frac{3 \times 10^{11} \, kms^{-1} \times 1 \text{ year}}{22 \, kms^{-1}} = 1.38 \times 10^{10}$ years ✓

(c) The line emission spectra observed from elements in distant stars can be compared to line emission spectra from the same elements in a laboratory. Explain why these spectra would be not be identical and what would this indicate about the motion of the stars. (2)

Lines will have shifted towards the red end of the spectrum. ✓
Red shift indicating an increase in the wavelength as the star moves away ✓

* $\frac{1}{22}$ $= 0.045 \times 1.0 \times 10^6 \times 3.26 \times 300{,}000 \times 3600 \times 24 \times 365$

$= 4.25 \times 10^{17}$ sec.

$/ (3600 \times 24 \times 365)$

$= 1.35 \times 10^{10}$

$= 13.5 \times 10^9$ years

End of test

or just $0.045 \times 1.0 \times 10^6 \times 300000$

$= 1.35 \times 10^{10}$

13.5×10^9 YRS