YEAR 12 PHYSICS
ASSIGNMENT 7 - STANDARD MODEL

Name: ______________________________ **Mark:** $\frac{\quad}{41}$

1. The Milky Way galaxy (our galaxy) and the Andromeda galaxy are approximately 250 000 light years apart, and they are approaching each other at a rate of 110 kms^{-1}. Scientists know this because of the blue-shift of light coming from the Andromeda galaxy.

   Read the following statements and circle 'True' or 'False'. (3 marks)

Light reaching the Milky Way from the Andromeda galaxy arrives slightly faster than 3×10^8 m s^{-1}.	True	False
Light reaching the Andromeda galaxy from the Milky Way galaxy would be red-shifted.	True	False
The Andromeda galaxy must be on a collision course with the Milky Way galaxy.	True	False

2. The recession speed of a Cepheid variable star was determined as 28 800 kms^{-1} moving away from the Earth. Assume that the star's motion was due only to the expansion of space.

   The star's recession speed v_{rec} is linked to Hubble's constant, H_0, by the relationship:

$$v_{rec} = H_0 \times d$$

   where d is the distance of the star from the observer.

   (a) Using appropriate assumptions and Hubble's constant of 1.86×10^{-5} kms^{-1}light-year^{-1}, determine the star's distance from an observer on the Earth. Include units in your answer, and show **all** workings. (3 marks)

$$v_{rec} = H_0 d$$

$$\Rightarrow d = \frac{v_{rec}}{H_0} \quad (1)$$

$$= \frac{(28800)}{1.86\times10^{-5}} \quad (1)$$

$$= \underline{1.55\times10^{9} \text{ light years}} \quad (1)$$

(b) Estimate the star's current distance from the Earth (in light-years), taking account of the distance that the star travelled while the light from the star travelled to Earth. Show **all** assumptions and workings. (5 marks)

Assume that the expansion of space during transit time can be ignored. (1)

Total time $t = 1.55 \times 10^9 \times 60 \times 60 \times 24 \times 365.25$

$= 4.891 \times 10^{16}$ s (1)

Total distance $d = (2.88 \times 10^7)(4.891 \times 10^{16})$

$= 1.409 \times 10^{24}$ m

$= 1.49 \times 10^8$ light years (1)

$\therefore$ Current position $d_{now} = 1.49 \times 10^8 + 1.55 \times 10^9$

$= 1.7 \times 10^9$ light years (1)

(Answer must be 1 or 2 significant figures) (1)

(c) Estimate how long it would take for light to travel from the current position of the star to an observer on Earth. Explain why this must be an estimate. (2 marks)

1.7×10^9 years (1)

Space will continue to expand while the light travels to the observer, so the path length is greater. (1)

OR Time is based on a previous estimate of distance.

3. An exotic hadron, initially seen over 40 years ago, has recently been confirmed at the European Organization for Nuclear Research (CERN). The Z(4430) particle consists of four quarks: a charm, an anti-charm, a down, and an anti-up.

Use the following table to show the calculation required to determine the charge of the Z (4430) particle. (2 marks)

Table of quarks		
Name	**Symbol**	**Electrostatic charge**
Up	u	+ ⅔ e
Down	d	-⅓ e
Strange	s	-⅓ e
Charm	c	+ ⅔ e
Bottom	b	-⅓ e
Top	t	+ ⅔ e

$$Z(4430) = c + \bar{c} + d + \bar{u}$$
$$= +\tfrac{2}{3}e - \tfrac{2}{3}e - \tfrac{1}{3}e - \tfrac{2}{3}e \quad (1)$$
$$= -1e \quad (1)$$

4. A space probe travels along a line from the Earth to Uranus at a constant speed of 0.95c relative to the solar system. Just as it reaches midway between the two planets, it sends laser beams out to the Earth and Uranus at the same time. At what speed do the laser beams approach the Earth and Uranus, respectively? (3 marks)

Speed of laser beam approaching the Earth: $3.00 \times 10^8 \text{ ms}^{-1}$ (1)

Speed of laser beam approaching Uranus: $3.00 \times 10^8 \text{ ms}^{-1}$ (1)

To an observer on Uranus, will the light from the space probe appear red shifted, or blue shifted? Circle the correct answer.

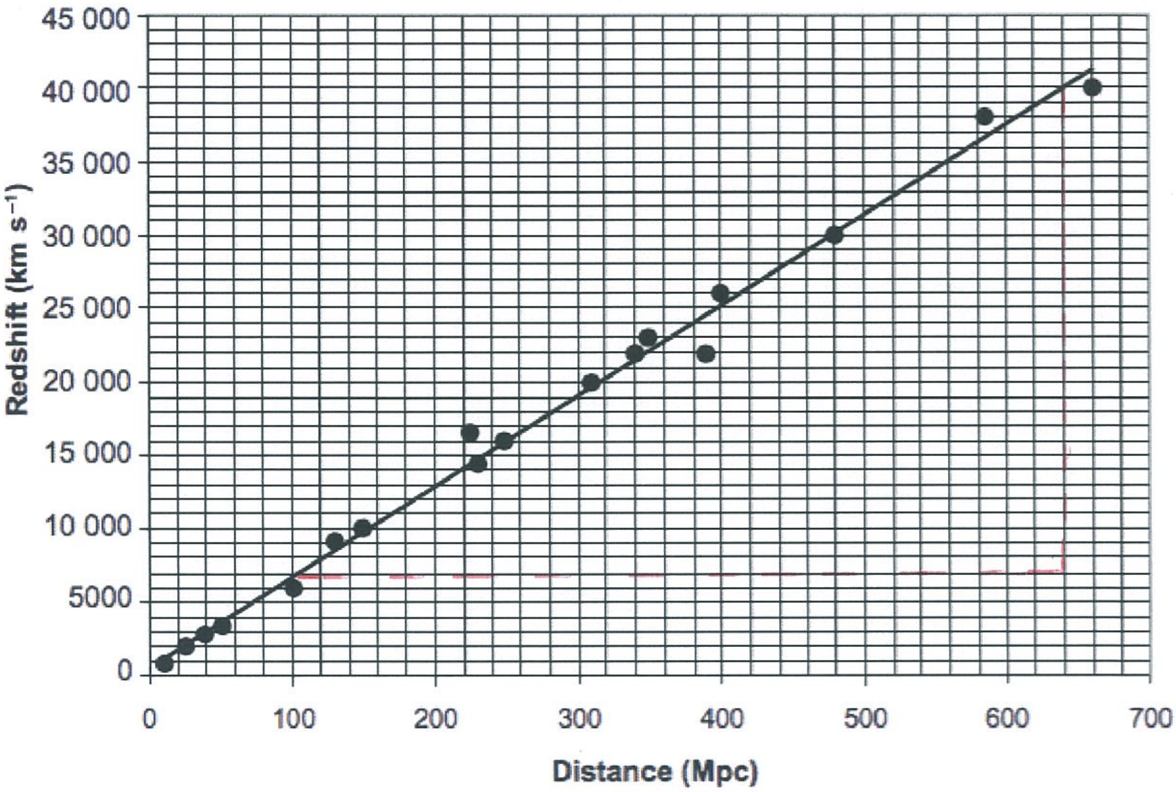
red shifted blue shifted (1)

5. Describe briefly the relationship between the mass and energy of an accelerating object as its speed approaches, but cannot exceed, the speed of light in vacuum, *c*. (3 marks)

- Energy and mass are related by $E = mc^2$. (1)
- As an object reaches relativistic speeds, its mass increases as it accelerates. (1)
- As the speed approaches c, the mass increases dramatically, requiring an increasing amount of energy that limits the gain in speed. (1)

6. Hubble's law can be used to estimate the maximum size of the observable Universe. The graph below indicates the relationship between recessional speed of a star (or galaxy) and the distance to that star (or galaxy).

Distances are given in megaparsecs (Mpc) where 1 Mpc = 3.26 light years.



(a) The vertical axis is labelled 'redshift' with units for velocity (kms^{-1}). Explain briefly the relationship between redshift and the speed of the object. (2 marks)

- Redshift refers to dark lines in the solar spectrum appearing to move towards the red end of the spectrum. (1)
- The faster the recessional velocity of a galaxy, the greater the redshift observed. (1)

(b) Use the gradient of the graph to extrapolate a value for the maximum distance, in Mpc, for a galaxy to be observed from the Earth. Show **all** workings. (3 marks)

$$\text{gradient} = \frac{(40\,000 - 7000)}{(640 - 100)}$$

$$= 61.1 \text{ kms}^{-1} \text{ Mpc}^{-1} \quad (1)$$

$$\text{Maximum speed} = 3.00\times10^{8} \text{ ms}^{-1} = 3.00\times10^{5} \text{ kms}^{-1} \quad (1)$$

$$\text{gradient} = \frac{3.00\times10^{5}}{d}$$

$$\Rightarrow \quad d = \frac{3.00\times10^{5}}{61.1}$$

$$= 4.91\times10^{3} \text{ Mpc} \quad (1)$$

7. A distant star is seen by an astronomer using a powerful telescope to be travelling toward the Earth with a velocity of 0.1c.

(a) At what velocity does the light reach the telescope? (1 mark)

3.00×10^{8} ms^{-1} (1)

(b) What is it about the starlight's spectrum that tells the astronomer that the star is approaching? Explain your answer. (2 marks)

- The absorption spectrum will be blue-shifted. (1)
- Characteristic dark lines will appear to be shifted towards the blue end of the spectrum. (1)

8.

Table of quarks

Name	Symbol	Electrostatic charge
Up	u	+ ⅔ e
Down	d	-⅓ e
Strange	s	-⅓ e
Charmed	c	+ ⅔ e
Bottom	b	-⅓ e
Top	t	+ ⅔ e

Table of baryons

Particle	Composition
p^{+}	u u d
n	u d d
Σ^{+}	u u s
Σ^{0}	u d s
Σ^{-}	d d s
Ω^{-}	s s s

(a) Use the information in the above tables to explain why the electrostatic charge on the Σ^0 particle is neutral. (2 marks)

$\Sigma^0 = uds$

$= +\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e$ (1)

$= 0$ (1)

(b) It is possible for another baryonic particle to exist in nature with a positive electrostatic charge equal to that of the proton. What would its quark composition be, given that this particle contains two up quarks and is **not** a proton? (1 mark)

uub or uus (1)

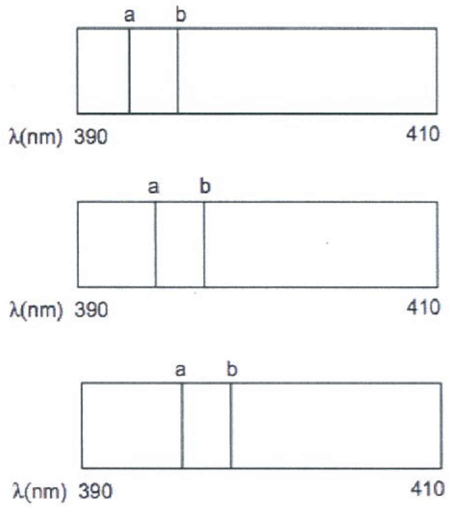
9. A geostationary satellite orbits the Earth at an altitude of 35 000 km. It travels at a speed of approximately 3000 ms^{-1}.

Relativistic effects may cause a clock on board the satellite to run a little slower or a little faster than the same clock on the surface of the Earth. Considering the factors that may lead to relativistic effects, complete the table below. (3 marks)

Factor leading to relativistic effect	Change in factor	Effect on time shown by clock
gravitational field	decreased	faster
velocity	increased	slower

[1 mark each]

10. The figure below shows three simplified absorption spectra for ionised calcium. Many of the absorption lines and the background colour have been removed. In all three spectra the same two absorption lines, 'a' and 'b', are shown. The top spectrum is an example of a spectrum recorded in a laboratory on Earth; the lower two have been recorded from two different galaxies.



Our Sun's calcium absorption spectrum as seen from Earth.

The calcium absorption spectrum of Galaxy NGC 2903.

The calcium absorption spectrum of Galaxy NGC 3147.

(a) Explain why absorption spectra appear as dark lines on an otherwise continuous electromagnetic spectrum. (3 marks)

- Light from the interior of the star passes through the cooler gases in the "atmosphere".
- Frequencies of light equivalent to principle energy levels in the atoms are absorbed.
- Re-emitted photons are scattered, so the intensity in the original direction is reduced.

(b) Which galaxy is further away from Earth? Justify your answer. (3 marks)

- NGC 3147 (1)
- Absorption lines are shifted further to the red end of the spectrum. (1)
- The greater the red-shift, the further away is the object. (1)