(1) (1)

Write your name here

Surname | Other names

Pearson Edexcel GCSE

Centre Number | Candidate Number

Astronomy

Unit 1: Understanding the Universe

Wednesday 7 June 2017 – Morning

Paper Reference

Ladies and Gentlemen,

I urge you to treat these expanded answers as an integral part of our studies. To reinforce your understanding of the material, perhaps you could find the time to make notes on what appear to be the key elements of my detailed responses to the questions? Regard my suggestion as Homework for the next few weeks. The task will initially appear formidable, but less so if the assignment is spread over the time interval as advised.

The Mark Scheme is provided for the examiners' guidance, to enable them simply to "score" the candidates' scripts. The Examiners' Reports are designed to give you a sound and detailed grasp of the thoroughness and accuracy, which your script needs to display, in order for full marks to be awarded. They also give you an idea of the range of knowledge exhibited by all the candidates, whilst outlining the principal sources of error in pupils' reasoning.

→

1 (a)

1 (a)

Why do I write so much in my written work? There are several answers to this question. Before I try to explain the rationale behind my exceedingly detailed treatment, it is important for me to state, quite unequivocally: "You must decide how to make the best use of my suggestions. Yes, it will be time-consuming for you to absorb everything. I am aware of my colleagues' expectations in the other ten G.C.S.E. subjects. Just do your best."

The History of Astronomy is the (auto) biographies of the greatest astronomers. It is essential to have a historical perspective, whatever the subject being studied.

I am anxious for you to acquire an appreciation of the cultural importance of Astronomy, as part of your Education, in its widest sense.

Another strand of this personal philosophy is that you : shall develop a deeper and more critical understanding of the Physics behind the questions.

DF

2017, November 2

1 (a)

2

2

Answer ALL questions.

Some questions must be answered with a cross in a box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 (a) Which of these planets is the largest? **(1)**

- ☒ **A** Jupiter
- ☐ **B** Mars
- ☐ **C** Neptune
- ☐ **D** Saturn

(b) A lunar eclipse can occur at which of these phases? **(1)**

- ☐ **A** First Quarter
- ☒ **B** Full
- ☐ **C** Last Quarter
- ☐ **D** New

(c) The point in the Earth's orbit where it passes closest to the Sun is called: **(1)**

- ☐ **A** Aphelion
- ☐ **B** Elongation
- ☐ **C** Equinox
- ☒ **D** Perihelion

(d) Which of these planets **cannot** be seen with the naked eye? **(1)**

- ☐ **A** Jupiter
- ☒ **B** Neptune
- ☐ **C** Saturn
- ☐ **D** Venus

(Total for Question 1 = 4 marks)

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2 (a) Which of these is a dwarf planet?

(1)

- ☐ **A** Callisto
- ☒ **B** Ceres
- ☐ **C** Moon
- ☐ **D** Triton

Pronounced "Series". Discovered in 1801, by G. Piazzi, the largest asteroid. Diameter 940 km, so is small by planetary standards.

(b) The Large Magellanic Cloud is an example of a:

(1)

- ☐ **A** Cluster
- ☒ **B** Galaxy
- ☐ **C** Nebula
- ☐ **D** Nova

One of the two Clouds of Magellan (the explorer), situated around 70 000 pc of our Galaxy. Neither the Large nor Small Cloud is visible from Europe.

(c) The average distance between the Earth and the Moon is:

(1)

- ☐ **A** 3500 km
- ☐ **B** 13 000 km
- ☒ **C** 380 000 km
- ☐ **D** 150 000 000 km

Apogee : 407 000 km.
Perigee : 356 000 km.
A substantially elliptical orbit around the Earth.

(d) The average diameter of the Earth is:

(1)

- ☐ **A** 3500 km
- ☒ **B** 13 000 km
- ☐ **C** 380 000 km
- ☐ **D** 150 000 000 km

The Earth should be described as an oblate spheroid, although the equatorial radius is only slightly greater than the polar radius (by about 40 km).

(e) Which of these planets does **not** have a satellite system?

(1)

- ☐ **A** Earth
- ☐ **B** Jupiter
- ☐ **C** Neptune
- ☒ **D** Venus

(f) Which part of the Sun has the **highest** temperature?

(1)

- ☐ **A** Chromosphere
- ☒ **B** Corona
- ☐ **C** Photosphere
- ☐ **D** Sunspot

Around 2000000k.
cf the Photosphere, which is about 5700k.
And much, much less dense.

(g) Which type of telescope is **only** found on satellites orbiting the Earth?

(1)

- ☐ **A** infra-red
- ☐ **B** radio
- ☐ **C** visible light
- ☒ **D** X-ray

Water vapour within the terrestrial atmosphere is particularly effective at blocking the X-ray region of the electromagnetic Spectrum.

(Total for Question 2 = 7 marks)

P 4 8 5 0 8 A 0 5 4 4

Turn over ▶

3 Figure 1 shows an image of Pluto taken by the New Horizons space probe in 2015.

Figure 1

(Source: © NASA)

(a) (i) Which of these planets comes closest to Pluto?

(1)

- ☐ **A** Jupiter
- ☐ **B** Mars
- ☒ **C** Neptune *
- ☐ **D** Saturn

The reason is that the eccentricity of the orbit of Pluto is high (~ 0.27), whereas that of Neptune is 0.009. Pluto does, for a relatively short time interval, become the closer of the two.

(ii) Pluto was discovered by:

(1)

- ☐ **A** Galileo Galilei
- ☐ **B** William Herschel
- ☐ **C** Isaac Newton
- ☒ **D** Clyde Tombaugh

In 1930, fourteen years after Percival Lowell's death, who predicted the existence of Pluto many years earlier.

* The last perihelion of Pluto was in 1989. It was not until 1999 that the distance from the Sun exceeded that of Neptune.

P 4 8 5 0 8 A 0 6 4 4

(b) Pluto has a much larger orbit and takes longer to orbit the Sun than the Earth.

State **two other** differences between the orbital paths of Pluto and the Earth.

(2)

1 Eccentricity of the orbit of the Earth is 0·017 (Pluto's e = 0·27)

2 Axial tilt of the Earth is 23·4°; that of Pluto is 122·5°.

(c) In 2006, Pluto was reclassified as a dwarf planet.

State **one** reason for this change.

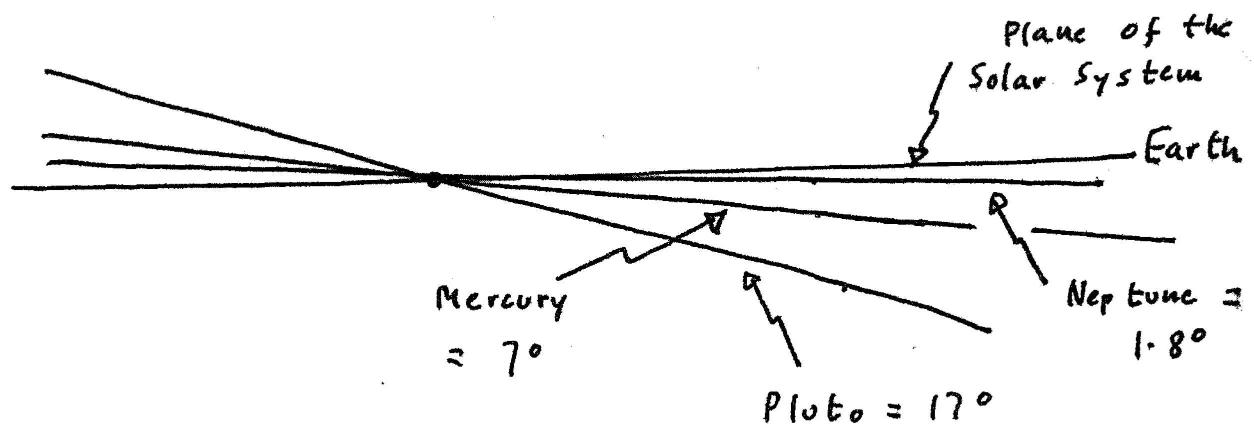
(1)

Refer to the Mark Scheme. I remain strongly of the opinion that it should be reclassified as "a planet".

(Total for Question 3 = 5 marks)

(b) continued

3. Orbital tilt of the Earth (to the plane of the Solar System) is zero; that of Pluto is 17° (See below)



P48508A0744

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4 Around 200 BCE, the Greek astronomer Eratosthenes heard that the Sun was directly overhead at midday on June 21st in the southern Egyptian city of Syene.

Observing the Sun on June 21st in Alexandria, in the north of Egypt, he found that it was **not** directly overhead at midday.

He used these observations to prove that the Earth was a sphere.

(a) Explain, using a carefully-labelled diagram, how these observations prove that the Earth cannot be flat.

(3)

Please refer to the detailed sheet, with which you were provided at the beginning of the course. The diagram which I drew for you is self-explanatory — considerably clearer than that in the Textbook.

(b) Eratosthenes went on to use his observations to make an estimate for the size of the Earth.

What **two** measurements would Eratosthenes need to take to calculate the circumference of the Earth?

(2)

1 The distance, due North, of Alexandria from Syene (in the modern unit of measurement) = 500 miles

2 The direction of light from the Sun, measured from the zenith at Alexandria.

P48508A0844

(c) In Eratosthenes' time there were other observations that showed the Earth is a sphere.

State **one** of these observations. (1)

Please refer to the examples in the Mark Scheme.

(Total for Question 4 = 6 marks)

(b) continued.

An angular difference of the position of the Sun, viewed from Alexandria, was 7·5°. This was due to the distance of 500 miles from Syene.

From a simple ratio,

$$\frac{7\cdot5^\circ}{500\text{ miles}} : \frac{360^\circ}{\text{The circumference of the Earth, } C_E}$$

Re-arranging:

$$C_E = \left(\frac{360^\circ}{7\cdot5^\circ}\right) \times 500\text{ miles}$$

$$= 48 \times 500\text{ miles}$$

$$\therefore C_E = 24{,}000\text{ miles}$$

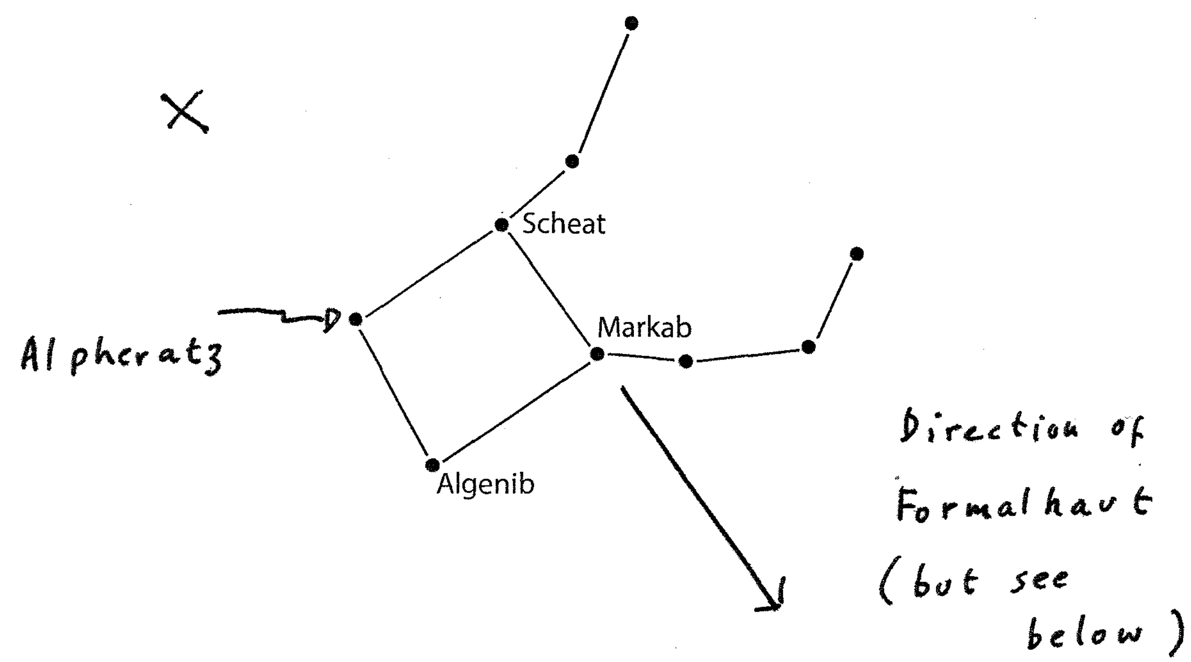
Remarkably close to the current measurement...

Turn over ▶

JF²

5 Figure 2 shows part of the constellation of Pegasus.

The Greek winged horse, born from the blood of Medusa, after Perseus chopped off her head. The square of the flying horse, Pegasus, is one of the landmarks in Southern skies. As an indication of how clear your skies are, see how many stars you can see in the actual square. If the answer is none, then your skies are extremely unclear.



In 1923, in its wisdom — and for no apparent reason, the International Astronomical Union "took" the top left star of the Square, Alpheratz, and "fixed" it in the constellation of Andromeda. The star still is in Andromeda...

Figure 2

(a) (i) Draw an arrow on Figure 2 to show how this constellation may be used to find the star Fomalhaut. (Not visible from our latitude) (1)

(ii) Show the approximate position of the Andromeda Galaxy (M31) on Figure 2. Use the letter **X**. (1)

(11)

(b) This group of stars has only been referred to as Pegasus since the time of the Ancient Greeks.

Explain why the name 'Pegasus' was not used before that time. (1)

See my "JF²" clarification at the beginning

(c) The Andromeda Galaxy is listed in the Messier Catalogue as M31.

Why did Charles Messier include the Andromeda Galaxy in his catalogue? (1)

Charles Messier's instrumentation did not resolve M 31 into individual stars.

(d) The star Markab has an apparent magnitude of 2.5 and an absolute magnitude of –0.7.

(i) This means that the star's distance from Earth must be: (1)

Absolute = Magnitude =

☐ **A** exactly 10 pc

☒ **B** greater than 10 pc

☐ **C** less than 10 pc

☐ **D** not possible to calculate from these data

(ii) Explain your choice.

At 10 pc, Markab has a magnitude difference, Δm, of 3.2. ∴ The brightness difference is $(2.51)^{3.2} \approx 16$

That is, Markab would be sixteen times brighter than its observable brightness.

This means that Markab lies at a distance greater than 10 pc. For the star to be sixteen times fainter, the inverse-square law tells us that Markab lies at a distance of 4 × 10 pc = 40 pc

(Total for Question 5 = 6 marks)

(12)

6 (a) Venus has the highest surface temperature of all the planets in the Solar System because: (1)

☐ **A** it is closest to the Sun

☐ **B** it is the largest inferior planet

☐ **C** its clouds reflect a very high proportion of the Sun's light

☒ **D** its atmosphere is almost entirely carbon dioxide

One of the consequences of such a dense atmosphere is that the surface of Venus is subject to an atmospheric pressure much greater than that on the Earth.

(b) Which **one** of these statements about the lunar phase cycle is correct? (1)

☐ **A** it takes the same time as the Moon's orbital period

☐ **B** it takes one year

☒ **C** it is 2.2 days longer than the Moon's orbital period — Its synodic period.

☐ **D** it is 2.2 days shorter than the Moon's orbital period

(c) The most southerly latitude where the Sun is above the horizon for 24 hours on 21st June is called the: (1)

☐ **A** Antarctic Circle

☒ **B** Arctic Circle

☐ **C** Tropic of Cancer

☐ **D** Tropic of Capricorn

(d) Light from a distant galaxy that is moving away from the Earth will appear to have a: (1)

☐ **A** greater brightness

☐ **B** higher frequency

☐ **C** higher speed

☒ **D** longer wavelength

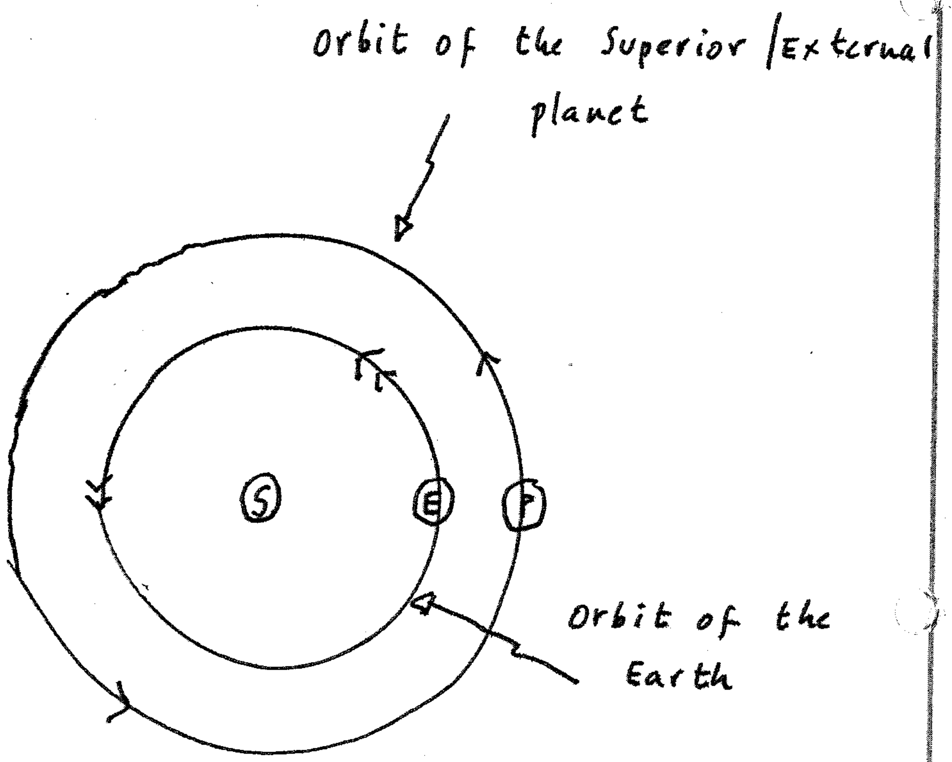
(e) A planet is said to have reached **opposition** for an observer on Earth when: (1)

- ☐ **A** it appears to cross the face of the Sun
- ☒ **B** it is directly opposite the Sun in the sky
- ☐ **C** it is directly behind the Sun in the sky
- ☐ **D** it is directly in line with another planet in the sky

Only planets outside the orbit of the Earth can exhibit this phenomenon

(Total for Question 6 = 5 marks)

6(e) continued



Hence, the planet will be due South at midnight, when the Sun reaches its lowest point, due North, below the horizon.

7 Sarah made the drawing of a gibbous Moon shown in Figure 3.

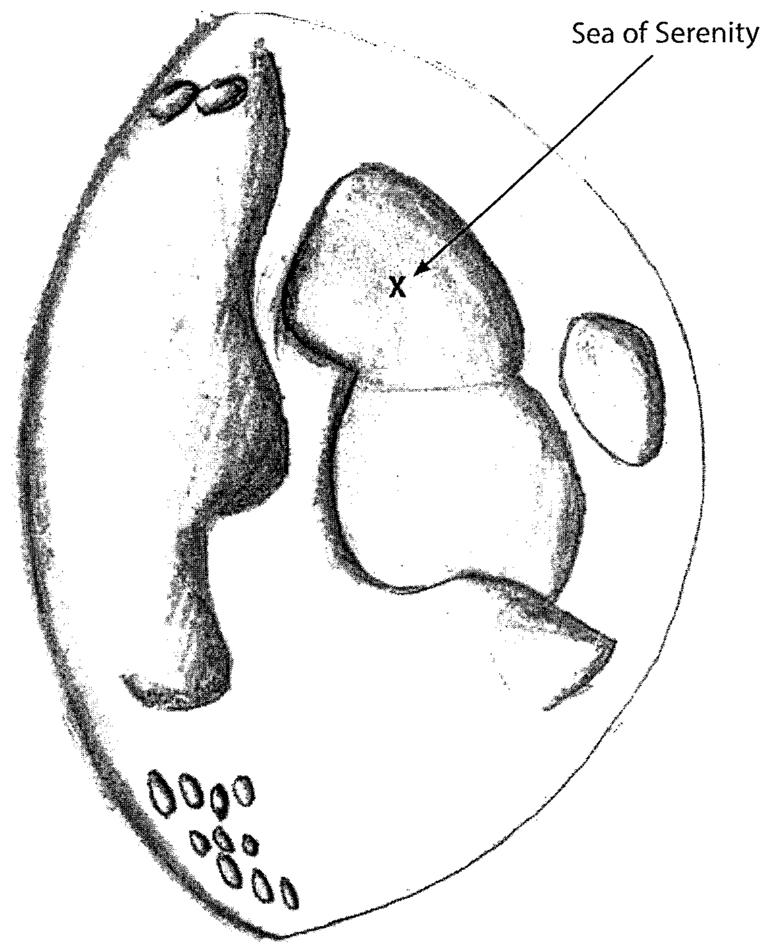


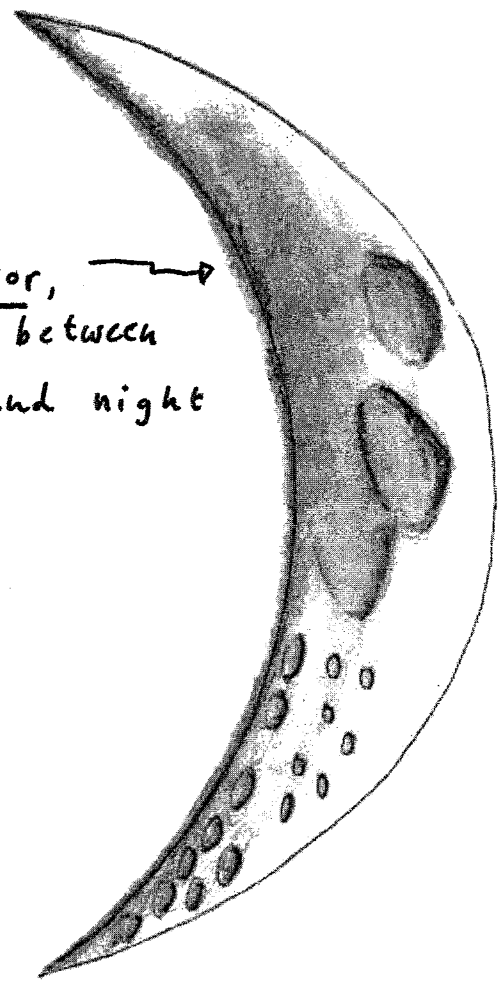
Figure 3

(a) Label on Figure 3 the position of **three** named lunar features.

The position of the Sea of Serenity has been labelled for you. (3)

Refer to the labelled diagram on the Mark Scheme.

(b) A few weeks later, Sarah made another drawing of the Moon, shown in Figure 4.



The terminator, → the boundary between the daylit and night hemispheres.

Figure 4

When drawing this sketch, Sarah found it much easier to draw details of the craters.

Explain why the craters were easier to draw on this occasion.

(2)

Most craters are best seen when close to the terminator, because their floors are partly or covered with shadow. (Near Full Moon, the shadows almost disappear, and a crater such as Theophilus becomes hard to identify

(c) Even though Sarah waited for over one month, she was only able to draw half of the Moon's surface.

Explain why we can only ever see about half of the Moon's surface from Earth.

You may use a carefully-labelled diagram to support your answer.

(2)

The Moon rotates on its axis in exactly the same time it takes to complete one orbital revolution around the Earth. This means, roughly, that the same hemisphere of the Moon is always facing the Earth.

JF2

However, there is a qualification. The Moon rotates on its axis at a constant rate, but because its orbit is elliptical, it does not move along at a constant rate. Following Kepler's Second Law of Motion, it moves most quickly at perigee.

This means that the rotation and the

(Total for Question 7 = 7 marks)

orbital position become periodically "out of step", and the Moon seems to rock slightly from side to side, so we can see a little way beyond alternate limbs (edges). This is called libration in longitude. There is also libration in latitude, because the equator of the Moon is appreciably tilted to the plane of its orbit. These librations mean that, over a period of time, 59% of the Lunar surface becomes visible, although we can never see more than 50% at any one moment.

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8 Figure 5 shows part of a star map from the area around the constellations Ursa Major and Ursa Minor.

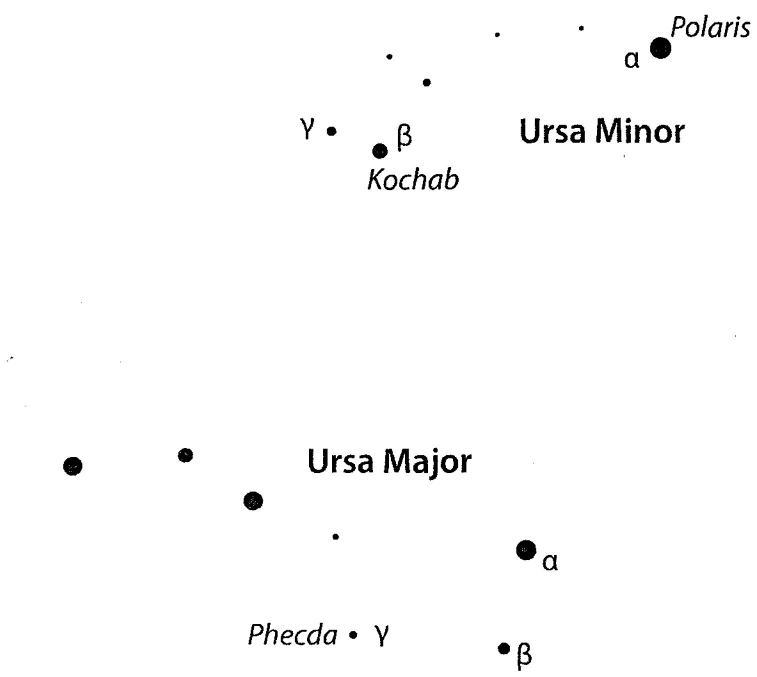

Figure 5

(a) What is the significance of the Greek letters (α, β, γ) next to the stars in Figure 5? **(1)**

α indicates brightest star; β the next bright and γ the faintest star

(b) Name a well-known asterism that can be seen in Figure 5. **(1)**

The Plough

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(c) Two of the brightest stars in Figure 5 are Phecda (γ in Ursa Major) and Kochab (β in Ursa Minor). Their coordinates are shown in Table 1.

	Right ascension (h : min)	Declination (°)
Phecda	15h 20min	72°
Kochab	14h 50min	74°

Table 1

The Ancient Egyptians referred to these two stars as the 'Eternal' or 'Immortal' ones.

Egypt has a latitude of around 30°N.

Explain, using **astronomical** information from Table 1, why they gave them this name.

(3)

The angular distance of Phecda from the Pole Star is 18°; that of Kochab is 16°
The co-latitude of Egypt is 60°.

∴ both stars will always be above the horizon at the latitude of Egypt.

(Total for Question 8 = 5 marks)

∴ Both stars are circumpolar

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*9 Figure 6 shows the meteor that was seen from the Russian city of Chelyabinsk in February 2013.

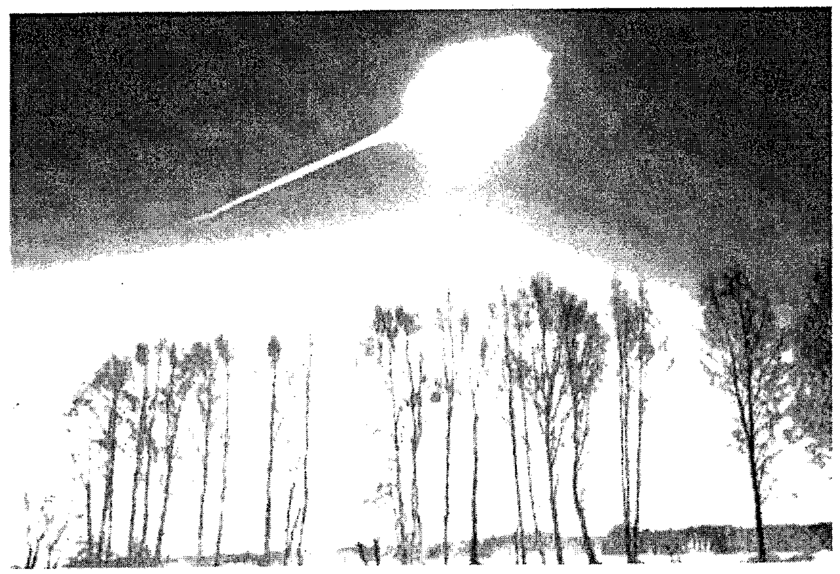


Figure 6

(Source: © Marat Ahmetvaleev)

This is an eyewitness account of the event.

> 'Shortly after sunrise this morning a burning hot meteor from **beyond our Solar System** crashed into the Earth's atmosphere above the city of Chelyabinsk. **This meteor shone even more brightly than the Sun.** Many people on their way to work saw the blinding light and felt the incredible heat of this **shooting star**. Scientists are now searching the area to **collect meteors that may have landed** near the city, for further study.'

In this account, four phrases have been highlighted in **bold**. These phrases can be improved.

Explain, using astronomical terminology, how these phrases can be improved.

(5)

'beyond our Solar System'

Originated far from the Sun, but within the Solar System, perhaps the belt of asteroids

'This meteor shone even more brightly than the Sun.' *

Its apparent magnitude exceeded −26

Meteoroid – in orbit around the Sun.
Meteor – visible in the atmosphere of the Earth
Meteorite – An object that has arrived at the surface of the Earth

P 4 8 5 0 8 A 0 2 0 4 4

* This alleged brightness is astonishing.

'shooting star'

A meteor. "Fireball" is reserved for an exceptionally bright meteor.

'collect meteors that may have landed'

The term should be "meteorite".

(Total for Question 9 = 5 marks)

JF²

① A meteor is the transient, incandescent trail left by a meteoroid (a cometary or meteoroid fragment) being destroyed in the atmosphere of the Earth (at an altitude of between 70 km and 120 km)

② A meteorite is a small extraterrestrial body of silicate or metallic composition, found on the surface of the Earth. Most meteorites probably originate in the asteroid belt. The majority are generally of the size of a grain of rice, or a few centimetres in diameter

③ The term "meteoroid" refers (mainly) to dust particles, ejected mostly from a comet or fragment from an asteroid, in orbit around the Sun.

10 Figure 7 shows patches of brightly-coloured lights in the night sky over Iceland (Latitude = 65°N).

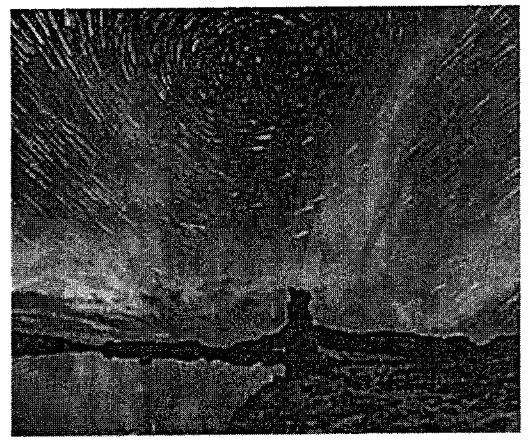


Figure 7

(Source: © Vincent Brady)

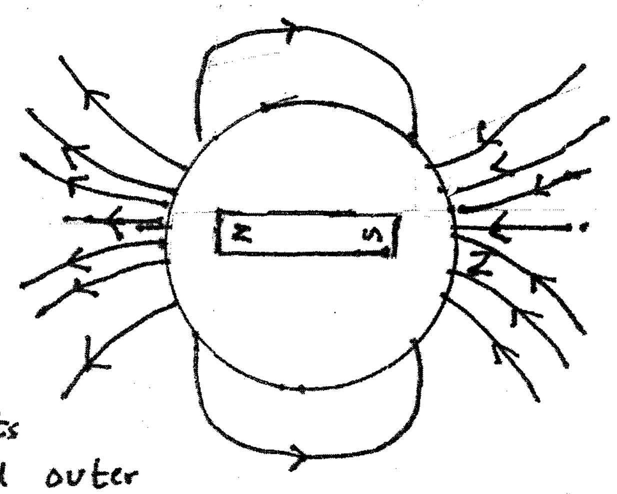
(a) State the full astronomical name for this phenomenon. **(2)**

The Aurora Borealis

(b) Explain how these patches of coloured light are created.

Draw a labelled diagram to support your answer. **(3)**

Displays of aurorae are related to solar radiations, which are commonly observed in the Arctic and Antarctic regions. The charged particles emitted by the Sun interact with the magnetic poles of the Earth, because the accelerated particles produce their own magnetic fields. They spiral inwards about the magnetic lines of force that radiate from the magnetic poles.



Schematic cross-section through the Earth, showing the form of the dipole magnetic field created by convection currents within the liquid outer core (lines show the attitude of freely suspended compass needles at different latitudes).

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(c) Explain why the images of stars in Figure 7 are slightly curved lines, rather than dots.

(2)

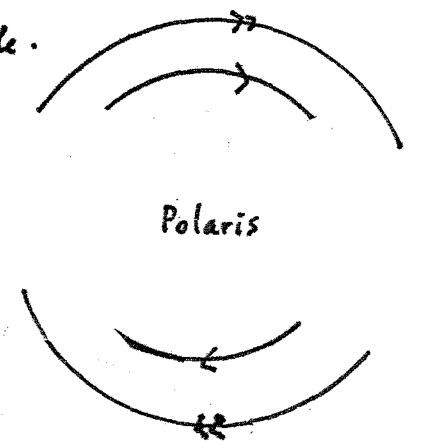
The relative faintness of aurorae means that a long exposure is required to obtain any detail on the photograph.

Stars close to the celestial poles (where

(Total for Question 10 = 7 marks)

the magnetic flux density of the Earth's field will be greatest) are circumpolar. The rotation of the Earth means that the star trails will arcs of circles.

Clearly, complete circles will not be obtained, because a 24-hour photograph is not possible.



I hope that you have the general idea.

11 Figure 8 shows the globular cluster 47 Tucanae.

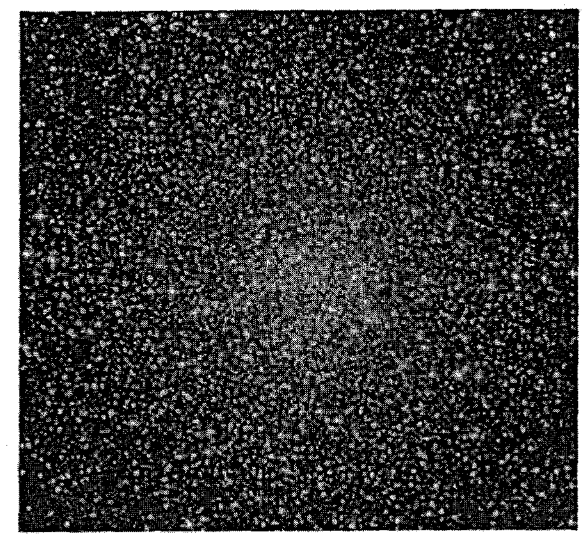


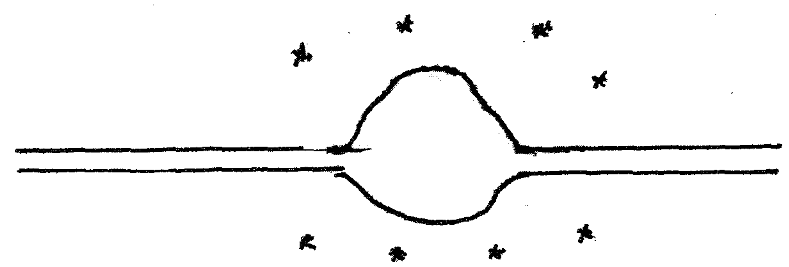
Figure 8

(Source: © NASA)

(a) (i) Where are globular clusters located in relation to the Milky Way?

Use a sketch of the Milky Way galaxy in your answer.

(2)



Each cluster can contain up to one million stars, arranged in a spherical form; near the centre of the cluster the stars seem to be closely packed, with separations of only light-days or light weeks. The clusters are distant, with most around 7000 pc away. About one hundred have been observed within our Milky Way Galaxy.

(ii) State **one** way in which a star in a globular cluster differs from a star in the Milky Way, apart from its location.

(1)

① The star is likely to be extremely old.
② ∴ red, due to its age.
③ Probably has evolved off the Main Sequence and has become a giant

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(25) (25)

(b) Table 2 shows some astronomical data about 47 Tucanae.

Visible to the unaided eye, from the Southern Hemisphere. Telescopic aid is required for individual stars to be resolved.

Apparent magnitude: *	4.9
Right ascension:	0h 24min
Declination:	-72°
Angular diameter: *	0.5°

Table 2

Better? Miguel? Rafael? Paco? Pablo?

Owen is observing from Costa Rica (Latitude = 10°N) using a small pair of binoculars. He is planning to make some detailed drawings of 47 Tucanae.

Owen is clearly an incurable optimist.

Identify **two** difficulties that Owen will encounter when making these observations and suggest a solution for each one.

(4)

Difficulty:

Binoculars would not gather enough light for a bright image. The angular resolution would be inadequate.

Solution:

A telescope would be essential for the required resolving power. It would require a large aperture for any detail to be discerned.

Difficulty:

The angular height above Owen's horizon would be small.

Solution:

Owen would be wise to re-locate, where the seeing conditions might be better.

(Total for Question 11 = 7 marks)

* About the same angular size as the Moon, but $(2\cdot5)^{16}$ times fainter. That is, roughly one million times fainter.

Turn over ▶

$m_{Moon} = -12 \quad \therefore \Delta m = 16-17$

$m_{47\ Tucanae} = 5 \quad \therefore \Delta B = (2\cdot5)^{16/17}$ times fainter

(26) (26)

12 (a) (i) A star has a heliocentric parallax angle of one tenth of a second of arc (0.1″). This means its distance from Earth is:

(1)

☐ **A** 0.1 parsec

☐ **B** 1 parsec

☒ **C** 10 parsecs

☐ **D** 100 parsecs

(ii) Star X is three magnitudes dimmer than Star Y. This means that the two stars differ in brightness by:

(1)

☐ **A** 3 times

☐ **B** 4 times

☐ **C** 9 times

☒ **D** 16 times

$\Delta m = 3$

$\therefore \Delta B = (2\cdot5(1))^3$

$= 16$

(iii) The asteroid Vesta orbits the Sun at an average distance of 2.4 AU. According to the equation

$T^2 = r^3$

it will orbit the Sun once every:

(1)

I dislike this expression, because the units do not agree. However, candidates are expected to use it, without understanding the derivation.

☐ **A** 1.8 years

☒ **B** 3.7 years

☐ **C** 5.8 years

☐ **D** 13.8 years

$T^2 = (2\cdot4\ A.U.)^3$

$\therefore T = [(2\cdot4)^3]^{\frac{1}{2}} = 3\cdot7$ years

(b) (i) When observing from a latitude of 50°N on the Earth, the Pole Star will appear to have an altitude of:

(1)

above the observer's horizon.

Were the observer at the North Pole, Polaris would be overhead. At the equator, the Pole star would be on the observer's horizon.

☐ **A** 0°

☐ **B** 40°

☒ **C** 50°

☐ **D** 90°

P 4 8 5 0 8 A 0 2 6 4 4

(ii) When observing from a latitude of 50°N on the Earth, the Celestial Equator will have a maximum altitude of:

(1)

- ☐ **A** 0°
- ☒ **B** 40°
- ☐ **C** 50°
- ☐ **D** 90°

(Total for Question 12 = 5 marks)

13 Figure 9 shows the planet Mars.

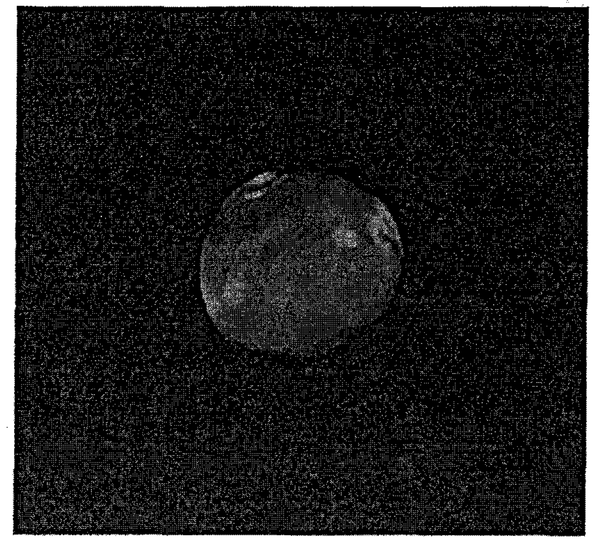

Figure 9

(Source: © NASA)

The planet Mars has two moons orbiting it – Phobos and Deimos. Although Mars can be seen with the naked eye from Earth, Phobos and Deimos were not discovered until 1877, using a large telescope.

(a) Explain why these two moons are so much harder to see than the planet Mars itself.

(2)

The moons are small, with diameters around 30 km and 20 km, respectively. This means that a small telescope would not have sufficient resolving power to enable the satellite to be discerned.

They are also close to the surface of Mars.

T_{Phobos} = 7hrs.

T_{Deimos} = 28 hours

(b) Describe the most likely origin of these two moons.

(2)

Originally two small asteroids, between the orbits of Mars and Jupiter. I must stress that this is merely a theory, but the smallness of the moons, suggest their histories.

I provided this answer before I read part (c).

(29) (29)

Discovered in 1877 by Asaph Hall.

(c) Table 3 contains some information about these two moons and their orbits.

	Average distance from Mars (km)	Orbital period (hours)	Diameter of moon (km)
Phobos (Fear)	9377	7.7	22.2
Deimos (Panic)	23 460	30.4	12.6

Table 3

Incidentally, both moons are in synchronous rotation and move in almost-circular orbits near to the equatorial plane of Mars.

The planet Mars rotates on its axis once every 24.7 days.

Describe how the two moons would **appear to move** for an observer standing on the surface of Mars.

Use data from Table 3 to explain your answer.

(4)

To an observer on the planet, Phobos would rise in the West, cross the sky in around four hours and set in the East, whilst the interval between successive risings would be no more than eleven hours, taking into account the rotation of Mars itself.

Deimos is much the more distant of the moons, and since it is about half the diameter of of Phobos, it will subtend a considerably smaller angle. Also, it will move more slowly against the stellar background.

(Total for Question 13 = 8 marks)

The time period of revolution of Deimos is a little longer than the day on Mars, which is 24 hrs 36 minutes. This means that the

It is interesting to know that Jonathan Swift "predicted these two Martian moons in his 1727 tale, "Gulliver's Travels". The astronomers of Laputa had "discovered two lesser stars, or satellites, which revolve around Mars, whereof the innermost is distant from the centre of the primary planet exactly three of its diameters".

(29(a)) (29(a))

interval between two successive risings over the Martian surface is 132 hours. Phobos has a much shorter period of revolution (7.2 hours) and revolves around Mars more than three times during one Martian day! No other planetary satellite * has a revolutionary period which is less than the rotational period of the primary. Phobos, accordingly, rises in the West and sets in the East, to rise again eleven hours later, so it passes across the sky twice every Martian night, apparently travelling in the opposite direction. The moons of Mars, if not the oddest in the Solar System, are unique in their motions.

* A reminder:

(i) rotation — motion about an axis.

(ii) revolution — motion in an orbit.

Example:

The Jovian satellite, Io, has a period of revolution of 1.77 days; the rotational period of Jupiter is 9.9 hours.

Clearly, the distinction between the two words is an important difference.

*14 Table 4 shows some information about the planet Venus.

average distance from the Sun	0.7AU
orbital period	225 days
rotation period	243 days
diameter (Earth =1)	0.95
gravity at surface (Earth = 1)	0.91
surface temperature (average)	465°C
atmospheric pressure (Earth = 1)	90
atmosphere	96% carbon dioxide 3% nitrogen

Table 4

A group of astronomers wish to take some detailed measurements of surface conditions on Venus and are planning to send a manned mission to the planet.

Discuss some of the difficulties in sending a mission of this kind along with its advantages over sending a robotic probe.

Your answer should include information from Table 4.

Not even remotely feasible with current technology...

(6)

My first thoughts are:

Even though the Sun will remain invisible from the surface of Venus, it will take ages to both rise and set.

How do you feel about your "day" being longer than the "year"?

Reflect on the huge atmospheric pressure, and that the atmosphere of Venus provides complete cloud cover.

The rotation of the planet is retrograde; this means that if the Sun were visible, it would be seen to rise in the West and set in the East.

Clearly, the environment is hostile — so you can see the advantages of a robotic probe.

Much of answer required of you is common sense.

The Mark Scheme treatment is perfectly adequate.

P 4 8 5 0 8 A 0 3 0 4 4

15 Figure 10 shows an image of the Sun.

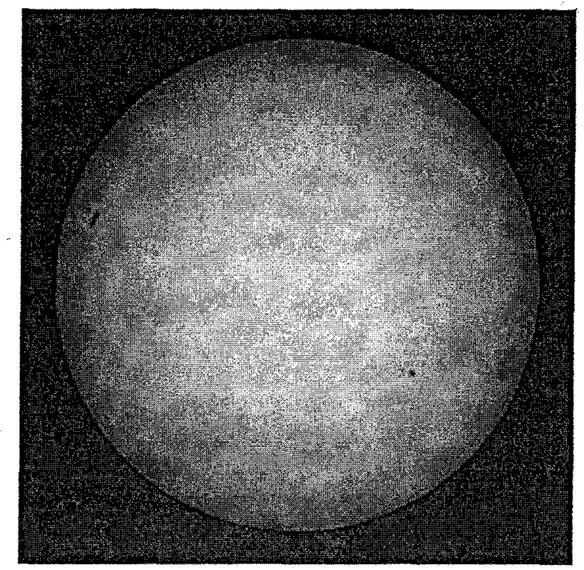

Figure 10

(Source: © NASA)

(a) Explain how large numbers of helium nuclei are produced every second in the Sun.

(3)

The core of the Sun is thought to have a temperature of around 15 000 000 K, with a density of about 100 000 kg m^{-3} (nearly eight times the density of liquid Mercury). At these temperatures and pressures, Hydrogen nuclei and electrons have huge values of kinetic energy. Their random motions mean that, when they collide with one another, Hydrogen nuclei fuse to form Helium nuclei, with the release of huge amounts of radiant energy. This process results in the loss in mass of the Sun at a rate of 4 × 10^{9} kg s^{-1}. Mass has been converted into energy, which travels from the Solar core to the photosphere.

(b) The Sun is known as a Main Sequence star.

Describe the stages of evolution it will pass through once it stops being a Main Sequence star.

(2)

① After leaving the Main Sequence, the Sun is predicted to undergo a series of gravitational contractions, each leading to internal heating and the initiation of further nuclear fusion reactions.

(Total for Question 15 = 5 marks)

15(b) continued

(2) The more massive the star, the higher the temperature that can be achieved in its interior and the more massive (heavier) the nuclei that can be synthesised / synthesized*.

(3) A star, the Main sequence mass of which is comparable with that of the Sun, becomes a red giant and (probably) ends by shedding a planetary nebula and becomes a white dwarf.

(4) A star, the Main sequence mass of which is about eight times that of the Sun, becomes a supergiant and explodes as a supernova, leaving an extended supernova remnant and a neutron star (that might be a black hole) or a pulsar.

The Main sequence: where stars spend most of their evolution. The more massive the star, the shorter the time on the Main sequence.

* The opposite of "analysed"

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16 Figure 11 shows the Moon.

Figure 11

(Source: © NASA)

*(a) Explain the Giant Impact Hypothesis for the formation of the Moon.

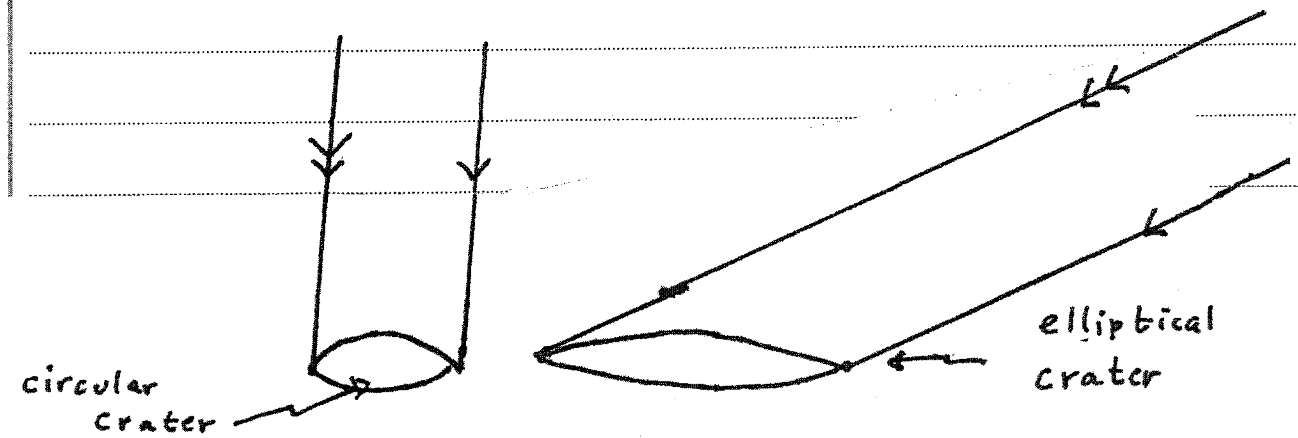
You may use a clearly-labelled diagram as part of your explanation.

(4)

"Impact cratering" is the most pervasive process affecting the surfaces of solid bodies in the Solar System.

Circular craters form even if the impact angle is quite low. Elliptical craters are formed only at angles of incidence below about 10°.

Unless decelerated by an atmosphere, impacts between different objects in the Solar System occur at hypervelocity, typically > 10 km s^{-1}.



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(b) Observation of the Earth and Moon system has produced evidence to suggest that the Giant Impact Hypothesis is correct.

Describe in detail **two** of these pieces of evidence.

(4)

1 The "Great Bombardment" is thought to have occurred between 4400 and 4000 million years ago, when meteorites rained, to produce the oldest basins, such as the Mare Tranquillitatis. Also considered is the idea that a large body collided with the Earth. Débris vaporized and escaped into space → and subsequently collected to form the Moon.

2 Further evidence of ancient impacts is to be seen in the cratered surface of the Moon and other rocky planets and satellites. Some craters can be detected on Earth, but their features have been largely eroded by tectonic action and weathering.

(Total for Question 16 = 8 marks)

The formation of an impact crater may be divided into three distinct phases: contact and compression, excavation and modification. The first two phases last for a few seconds and the modification phase lasts only a few minutes. Even in the largest impacts, cratering is the most rapid geological process known.

The origin of the Moon and its surface features have long been the subject of debate. Seismic data collected by detectors deployed during the Apollo landings reveal that, if the Moon has any core at all, it must be small. The Moon is relatively depleted in volatile elements, such as K, Na and Rb, but enriched in refractory elements, such as Sr and U. The current theory to explain the formation of the Moon is that it was generated from the accretion of débris that was ejected from a late-stage giant impact between two planetary embryos.

17 Figure 12 shows a series of radio wave pulses from an object discovered by radio astronomers in the 1960s.

At the time these objects were referred to as 'pulsars'.

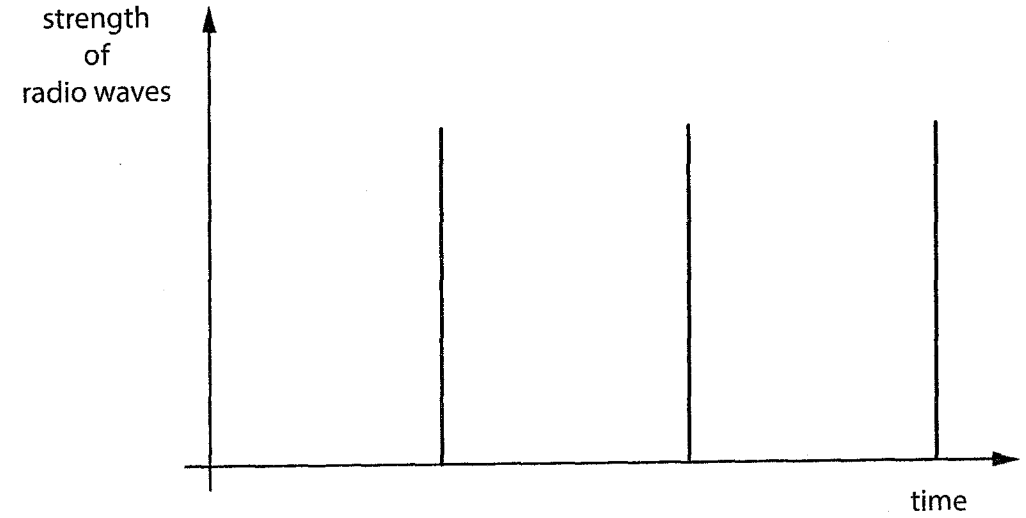


Figure 12

(a) These radio waves are now known to come from a neutron star.

Explain why the radio waves from a neutron star appear as pulses when received on Earth. You may use a clearly-labelled diagram to support your answer.

(3)

Pulsars are rapidly rotating, highly magnetised neutron stars, which produce beamed radio emission. As the star rotates the beam is swept around the sky. If the orientation is such that the beam sweeps across the Earth, regular pulses of radio emission can be detected, repeated as the pulsar rotation period. It was deduced that the pulses had an extra-terrestrial source because they came from a fixed direction in space. That is, they were detected by the telescope at intervals of one sidereal day (23 hr 56 m). The pulses and the period were so short that it was concluded that the source must be small.

		cf the Sun
Typical density ($kg\ m^{-3}$)	$10^{16} \rightarrow 10^{18}$	1400
Typical mass (kg)	$> 1.4 M_{\odot}$	$M_{\odot}$
Typical radius (km)	10	6.9×10^{5}
Typical rotational periods	0.1 s	25 days
Surface temperature (K)	$\approx 10^{6}$	5800

(b) When these signals were detected, they were first thought to be produced by intelligent life forms.

Explain why astronomers made this suggestion with reference to Figure 12.

(2)

The signals were so rhythmical that for a few days it was even thought that they were artificial. (Incidentally, the theory of neutron stars was first considered in the 1930s by L. Landau and R. J. Oppenheimer).

Such a star is formed when the core of a supernova collapses in a supernova explosion.

(Total for Question 17 = 5 marks)

The telescope used in the discovery of pulsars (a form of radio telescope).

(a) 2048 dipole antennae, making up a four-acre array, were constructed by graduate students in a field near Cambridge. The instrument was designed for a wavelength, $\lambda \approx 3.68$ m, frequency 81.5 MHz (81.5 million Hz). Here is a list of the main components.

- 1.67×10^{3} kg of copper wire,
- 14 miles of support catenary,
- 8.5 miles of coaxial cable,
- 30 miles of wire for reflecting screens.

One of the students in Anthony Hewish's 1964 Group, Jocelyn Bell (now Jocelyn Bell-Burnell) was investigating the properties of the interplanetary medium. She found that, at certain times, the telescope detected regular, short pulses of radio waves. They were far too regular to be explained by twinkling. Could they, perhaps, have been due to interference from some Earth-bound sources of radio waves?

18 Figure 13 shows how the apparent magnitude of a Cepheid variable star varies with time.

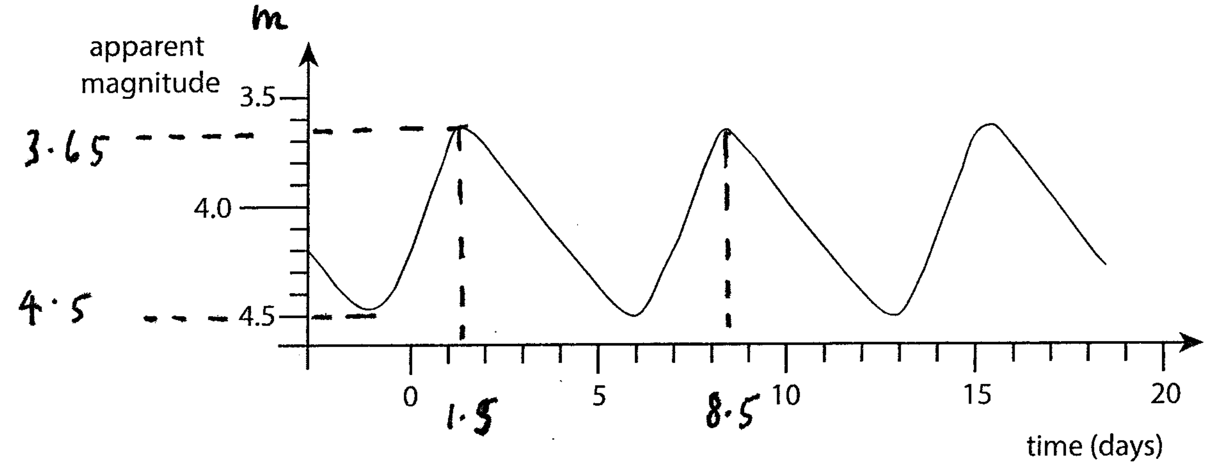


Figure 13

(a) Use Figure 13 to determine the period of this variable star. **(2)**

7 days

(b) Figure 14 shows the connection between the period of a Cepheid variable star and its absolute magnitude.

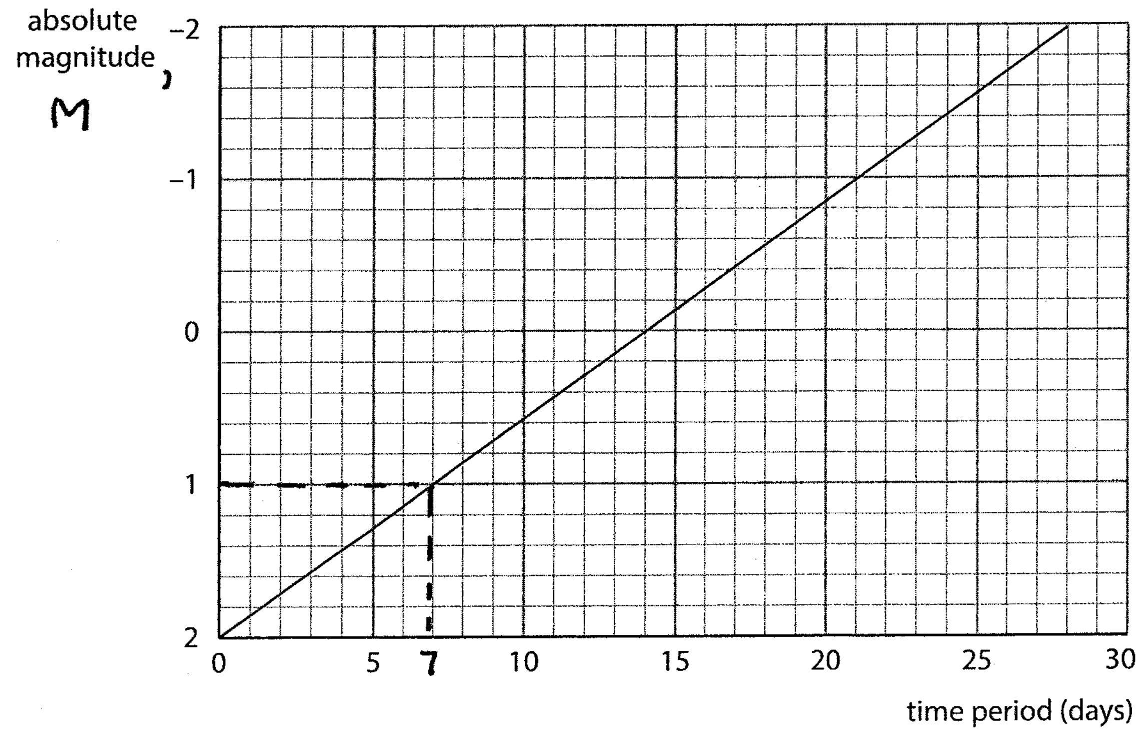


Figure 14

(i) Use Figure 14 to determine the absolute magnitude of this Cepheid variable star. **(1)**

M = 1·0

(ii) Make an estimate of the distance to this star, using information from Figure 13 and your answer to part (b) (i).

Explain your working clearly. **(3)**

The average apparent magnitude, $\bar{m}$ is 4·0. This magnitude difference, Δm between this M = 3

That is Δm = 3

∴ ΔB = $(2{\cdot}1)^3$

= 16

The inverse-square law means that the star is four times 10pc

= 40pc

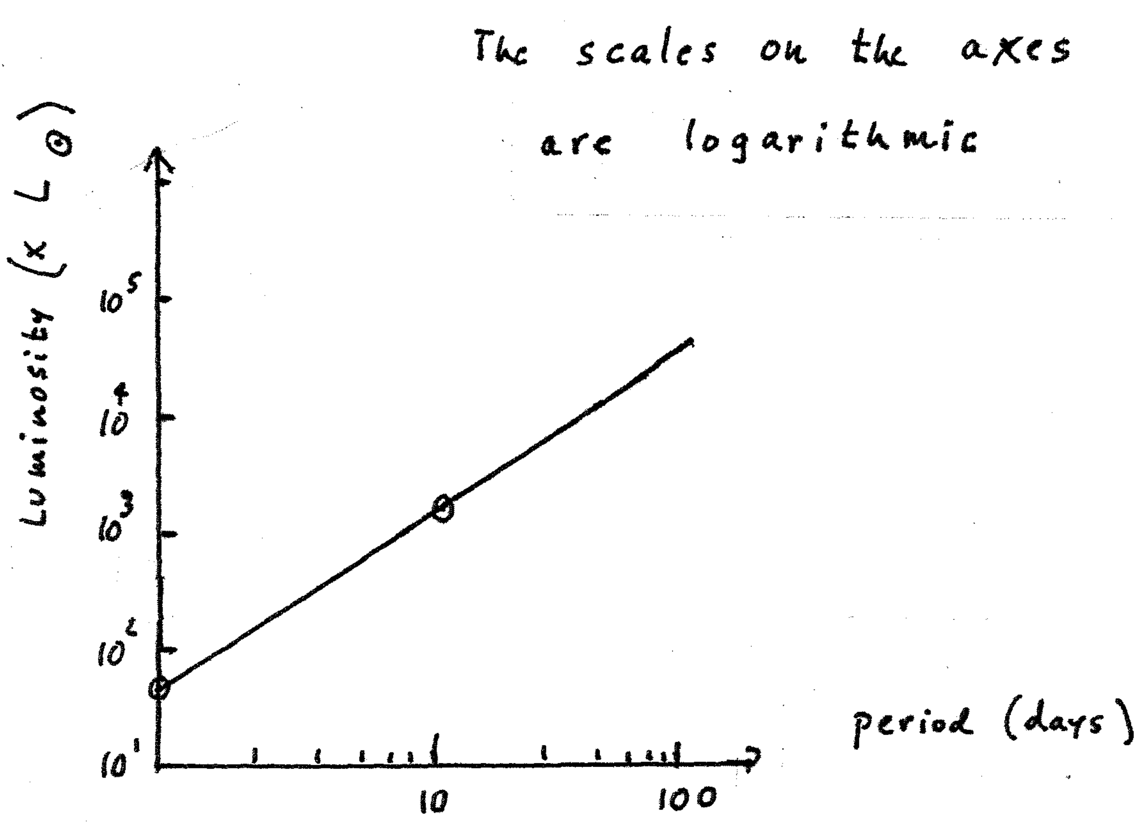
(Total for Question 18 = 6 marks)

Henrietta Leavitt (1868 – 1927)

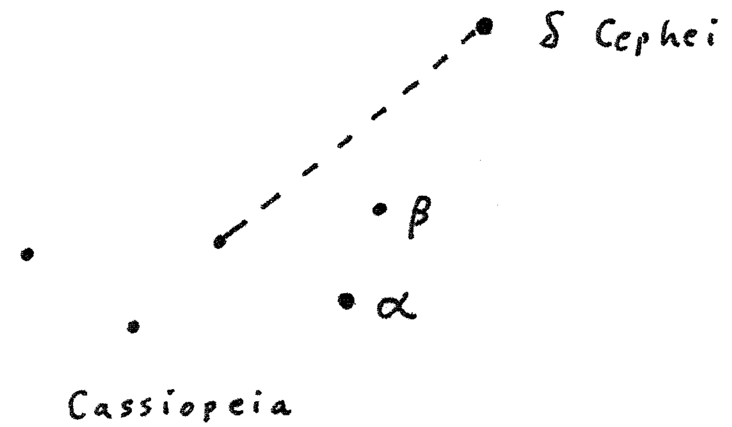
Developed an interest in Astronomy while an undergraduate at Radcliffe College (now part of Harvard University). She graduated in 1892. Illness caused her to become partially deaf, immediately after graduation.

From 1895 – 1900 was a volunteer at the Harvard College Observatory, becoming a staff member in 1900, where she worked until her early death, from cancer. Best known for her work on variable stars, Henrietta identified over 2400, doubling the number known in her day. Her discovery of the Cepheid ("seefeed") period – luminosity relationship gave the first means of measuring extragalactic (beyond the Milky Way Galaxy) distances, and led to the recognition that the Magellenic Clouds are 39.

are actually two companion galaxies to the Milky Way at (for that time) unprecedented distances from the Sun.



The best-known member of this class is Delta (δ) Cephei, in the constellation of Cepheus.



The magnitude range is from 4·4 to 3·5, so that the star is always visible with the unaided eye. The period, or interval between one maximum and the next, is 5·3 days.

The Cepheids are examples of Intrinsic variables, which change in brightness as a result of physical changes in the stars themselves.

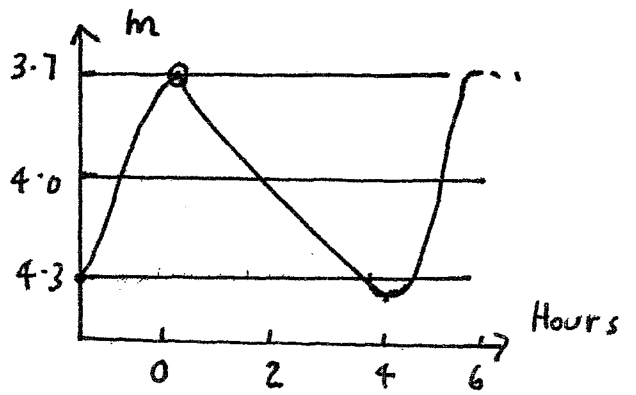
Extrinsic variables change as a result of geometrical effects. The majority of this type are eclipsing binaries.

About two-thirds of all variable stars are pulsating variables. They are intrinsic variables, with luminosity, temperature and radius all changing with time. Cepheids, named after δ Cephei, the first to be discovered in 1784, by the English astronomer, John Goodricke (1764 - 1786), are one of the most important classes of pulsating variables. They are regular variables, with periods of anything from about a day to around 100 days, with luminosity changes by a factor of 10. Cepheids help us to understand some of the processes that drive evolution at certain stages as a star grows older. They provide us with yet another way of measuring stellar distances.

The "Cephied Variable" Method of Distance Determination

Short-period variable stars. The variations are perfectly regular and are linked with the luminosity of the star.

Cepheids are giant stars and are common in the Galaxy. What makes them so important is the period-luminosity relationship. That is, a Cepheid with a period of (say) 5·3 days will have the same luminosity, in terms of the Sun, as any other Cepheid with a 5·3-day period. The longer the period, the greater the luminosity. Thus, Eta Aquilae, in the Eagle, a Cepheid with a period of 7·2 days, is more powerful than Delta Cephei itself. Once the luminosities and apparent magnitudes have been measured, the distances can be calculated.



δ Cephei

Cepheids are intrinsic variables.

Median light is the time mid-way between minimum and maximum values of brightness.
A Cepheid with a period which is ten times longer than another Cepheid is approximately two magnitudes brighter $= \left([2 \cdot 512]^2 \right)$ at median light. The distances of the Magellanic Clouds were first measured around 1912 by Henrietta Leavitt at Harvard University.

19 Figure 15 shows the Planck satellite. Measurements from this satellite have been used in the search for Dark Matter.

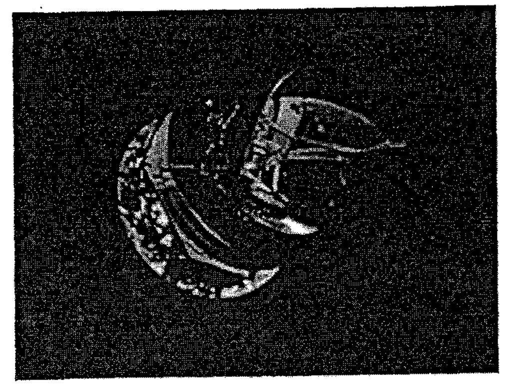


Figure 15

(Source: © European Space Agency)

(a) Describe **one** observation that astronomers have made that suggests the existence of Dark Matter.
(1)

In the 1930s, the Bulgarian astronomer (his parents were Swiss) realised that a "nearby" cluster of galaxies was behaving in a way that implied its mass was

(b) Describe **two** practical difficulties involved in detecting Dark Matter.
(2)

1 Cannot be detected by the emission or absorption of radiation.

2 No detectable interaction with other matter.

→ much greater than the mass of the stars in the galaxies within it. He inferred that some unknown dark matter accounted for 400 times (sic) as much material as luminous matter, glowing stars and hot gas across the entire cluster. The sheer amount of dark matter was a big surprise, suggesting that most of the Universe was not in the form of stars and gas but something else.
He postulated that "gravitational "lensing" of background

40 (a) continued

galaxies would be the most direct way to probe the dark matter in the Universe.

*(c) Describe the current evidence for Dark Energy.

3)

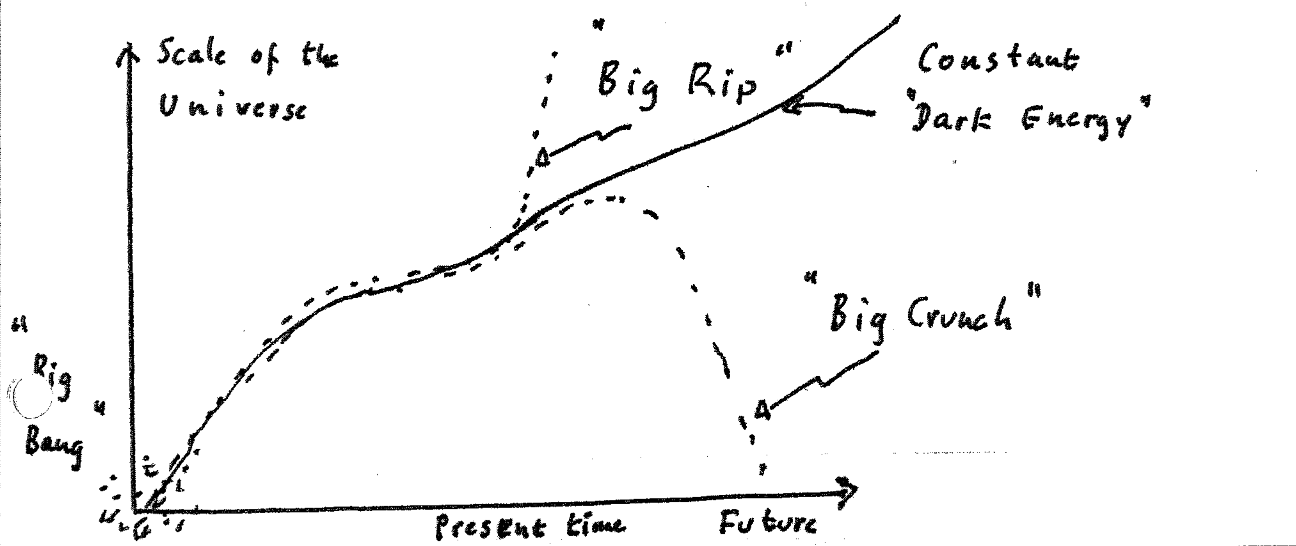
In the spirit of genuine scholarship, I have to write that the origin of Dark Energy remains elusive. All we know is that it is a form of energy associated with the vacuum of free-space, creating a negative pressure in regions devoid of gravity-attracting matter, and thus causing regions of empty space to conflate.

(d) State the effect that Dark Energy could have on the future of the universe.

(1)

It could be a factor in causing the expansion of the Universe to accelerate.

(Total for Question 19 = 7 marks)



We know its strength, roughly, from the supernovae observations, but we do not know much more. It is truly a constant — whether it always takes the same value right across the Universe and for all time (as do gravity and the speed of light) — or whether its value changes with time, so that it might have a different value just after the "Big Bang", compared with now or in the future. In its more general form, it has also been called "quintessence".

41(a)

The name alludes to the fifth element of the ancient Greeks (after earth, air, fire and water), which was supposed to constitute the heavenly bodies. In its modern cosmological (the Universe on a large scale, such as superclusters of galaxies) "quintessence" can be thought of as an exotic form of matter.

The main candidates for "Dark Energy" can be summarised as follows:

Dark Energy
- Einstein's Cosmological Constant ?
- Quantum Vacuum Energy ?
- Quintessence ?

U. S. physicist, Hans Christian von Baeyer, put it rather well:

> "Space, he said, "is empty of matter, but filled with surprises."

It is still not known how this elusive force manifests itself or how it arises within the Physics of the "Big Bang".

41(a)

42

20 Earth is the only planet in the Solar System with large quantities of liquid water on its surface.

(a) State **two** reasons why liquid water is able to exist on the surface of the Earth. (2)

1 The distance of Earth from the Sun means that water remains in liquid form over a wide range of temperature on a considerable area of the Earth's surface. Were the temperature too high, the water would have vaporised; too low and it would have frozen. The high specific heat capacity

2 of water is a major factor in its remaining as a liquid. Most of the surface water exists in the oceans which act as a reservoir. The polar caps on Earth form another part of the water reservoir.

*(b) A number of theories have been proposed to explain how liquid water formed on Earth.

Describe in detail **one** theory that accounts for the existence of liquid water on the Earth's surface. (3)

The elemental components of water — Hydrogen and Oxygen — were created at the birth of the Universe, around fourteen billion years ago. As the "Desiderata" states:

"You are a child of the Universe, no less than the trees and the stars."

We cannot be certain when — and how — the conditions for these elements to fuse came about. In the early days since the formation of the Earth, temperatures must (cont..)

(c) Describe a piece of evidence that might help astronomers to decide which is the correct theory for the existence of liquid water on Earth. (1)

The latest research suggests that the different (isotopic) forms of Hydrogen in asteroids appear to be more similar to those we find on the Earth. There is the usual speculative element involved here.

(Total for Question 20 = 6 marks)

TOTAL FOR PAPER = 120 MARKS

The boiling point of water depends, to a certain extent, on its purity. Much the more important is the external pressure exerted by the atmosphere. The same applies to its freezing point (the "colligative" properties). The b.p. decreases as the atmospheric pressure lowers. Can you imagine trying to make tea with water boiling at (say) 50°C ?

42

20(b) continued

have been high, leading to the vaporisation / evaporation? of water from the surface of the Earth. Considerable cooling is required before water can return to its liquid phase. Current theories accounting for the existence of liquid water suggest the rôles of comets and asteroids, because of their ice contents. The difference between water on the Earth and water in most comets: sometimes Deuterium, a slightly more massive form of Hydrogen, symbol D, ^2H, occurring as 156 parts per million. There tends to be a slightly greater abundance of ^2H in the composition of some comets.

In writing about the properties of liquid water, I must mention its anomalous expansion — of vital importance where aquatic life is concerned. Most liquids contract when cooled, and continue to do so as their temperatures are reduced. Water is an exception to this, in one particular aspect. It is true that it contracts as it is cooled from (say) 30°C. Maximum density of this liquid occurs at 4°C; if cooled further, water then expands and its density decreases. Water then rises, to (say) the top of a river or lake. This means that, in winter-time, the lakes and rivers contain water at 4°C at the bottom, although the temperature at the surface might be below freezing-point. Thus, the water freezes downwards, enabling aquatic life to live in water under Arctic conditions.

In fact, the formation of an ice-layer at the surface of a lake insulates from the cold air the liquid water remaining below the ice. For double the depth of ice to form requires much more than twice the time; to increase the depth three-fold requires considerably more than thrice the time.