Write your name here

Surname	Other names

Pearson Edexcel GCSE

Centre Number	Candidate Number

Astronomy

Unit 1: Understanding the Universe

Wednesday 4 June 2014 – Afternoon
Time: 2 hours Not remotely enough.

Paper Reference
5AS01/01

You must have:
Calculator, ruler

Suggested Answers

TA005978770

Instructions

Ladies and Gentlemen,

Please believe me — it was not my intention to include so much JF² material. I just got carried away... you all know how it is with your own work. Pity me: it took around twenty hours to write the enclosed, mainly for your delectation and edification. The JF² material is really important.

DF
2014, October 15

- Questions labelled with an asterisk (*) are ones where the quality of written communication will be assessed
  - *you should take particular care on these questions with your spelling, punctuation and grammar, as well as the clarity of expression.*

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

Turn over

P43292A

1/1/1/1/1/1

P 4 3 2 9 2 A 0 1 4 0

PEARSON

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 Figure 1 shows a sketch of an asterism.

Three stars are labelled **X**, **Y** and **Z**.

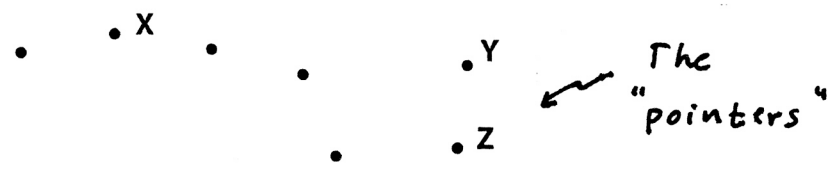

Figure 1

(a) What is the name of this asterism?

(1)

The Plough

(b) To which bright star do **Y** and **Z** point?

(1)

- ☐ **A** Arcturus
- ☐ **B** Fomalhaut
- ☒ **C** Polaris
- ☐ **D** Sirius

(c) Through a small pair of binoculars star **X** is actually two stars that appear very close together.

What is the name of this type of star?

(1)

- ☐ **A** binary star
- ☒ **B** double star
- ☐ **C** eclipsing star
- ☐ **D** neutron star

(d) When observed from the UK, the stars in Figure 1 never set below the horizon.

What name do astronomers use for such stars?

(1)

☒ **A** circumpolar stars

☐ **B** meridian stars

☐ **C** pointer stars

☐ **D** shooting stars

(Total for Question 1 = 4 marks)

2 (a) Which planet has an orbit between those of Jupiter and Uranus?

(1)

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

(b) Which planet contains the Great Red Spot?

(1)

- ☒ **A** Jupiter
- ☐ **B** Mars
- ☐ **C** Uranus
- ☐ **D** Venus

(c) Which of the following is equal to the mean distance between the Earth and the Sun?

(1)

- ☒ **A** 1 AU
- ☐ **B** 1 ly
- ☐ **C** 1 pc
- ☐ **D** 1 Mpc

(d) Which dwarf planet is closest to the Sun?

(1)

- ☒ **A** Ceres Pronounced "Series"
- ☐ **B** Eris
- ☐ **C** Makemake
- ☐ **D** Pluto

(e) Where is the likely origin of most short-period comets?

(1)

- ☐ **A** Asteroid Belt
- ☒ **B** Kuiper Belt
- ☐ **C** Oort Cloud
- ☐ **D** Zodiacal Band

(f) In which region of the sky might an astronomer observe a planet?

(1)

- ☐ **A** Asteroid Belt
- ☐ **B** Milky Way
- ☐ **C** Oort Cloud
- ☒ **D** Zodiacal Band

Referring to a "Line of animals"

(Total for Question 2 = 6 marks)

3 (a) What type of galaxy is the Milky Way?

(1)

- ☐ **A** elliptical
- ☐ **B** irregular
- ☐ **C** lenticular
- ☒ **D** spiral

(b) Which of the following does **not** belong to our Local Group of galaxies?

(1)

- ☐ **A** M31, the Andromeda Galaxy
- ☐ **B** The Large Magellanic Cloud
- ☐ **C** The Small Magellanic Cloud
- ☒ **D** NGC 4151, a Seyfert galaxy

(c) Which of these objects is furthest away from the Earth? a !

(1)

- ☒ **A** 3C 273, a quasar
- ☐ **B** M31, the Andromeda Galaxy
- ☐ **C** The Large Magellanic Cloud
- ☐ **D** M15, a globular cluster

(d) What lies at the centre of an Active Galactic Nucleus (AGN)?

(1)

- ☐ **A** a neutron star
- ☐ **B** a supercluster
- ☒ **C** a super-massive black hole
- ☐ **D** a globular cluster

(e) What is the name given to the observed increase in the wavelengths of light from distant galaxies?

(1)

The "Redshift"

(Total for Question 3 = 5 marks)

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Question 4 is on the next page

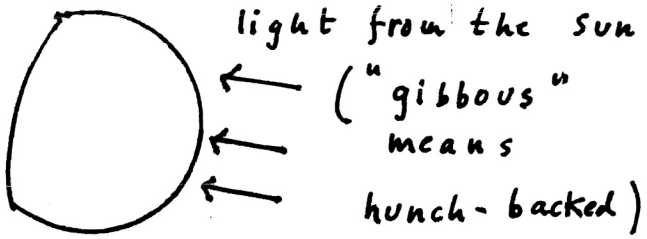
4 (a) How long is the lunar phase cycle?

(1)

- ☐ **A** 27.3 days
- ☐ **B** 28.0 days
- ☒ **C** 29.5 days
- ☐ **D** 31.7 days

(b) In the space below, sketch a **gibbous** Moon.

(1)



Between the phases First Quarter and Full

(c) From which of the following locations are aurorae most likely to be observed?

(1)

- ☐ **A** Equator
- ☒ **B** South Pole
- ☐ **C** Tropic of Cancer
- ☐ **D** Tropic of Capricorn

(d) Which part of the Sun is mainly visible by eye during a total solar eclipse?

(1)

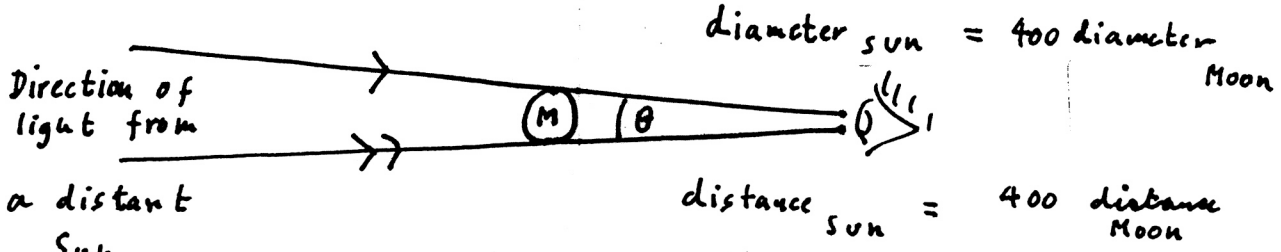
Corona (meaning "crown")

(e) Although the Sun is much larger than the Moon, they appear to be the same size in the sky.

In the space below, draw a labelled diagram to explain this.

(2)

It is impossible to draw to scale.
Essentially, the Sun and the Moon subtend the same angle at the Earth $(0.5^\circ) = \theta$



diameter $_{sun}$ = 400 diameter $_{Moon}$

distance $_{sun}$ = 400 distance $_{Moon}$

(Total for Question 4 = 6 marks)

5 (a) Figure 2 shows the Ring Nebula, a planetary nebula.

(Source: NASA)

Figure 2

(i) Which type of star lies at the centre of a planetary nebula?

(1)

A White Dwarf

(ii) What is the size of this type of star compared with the Sun?

(1)

Considerably smaller

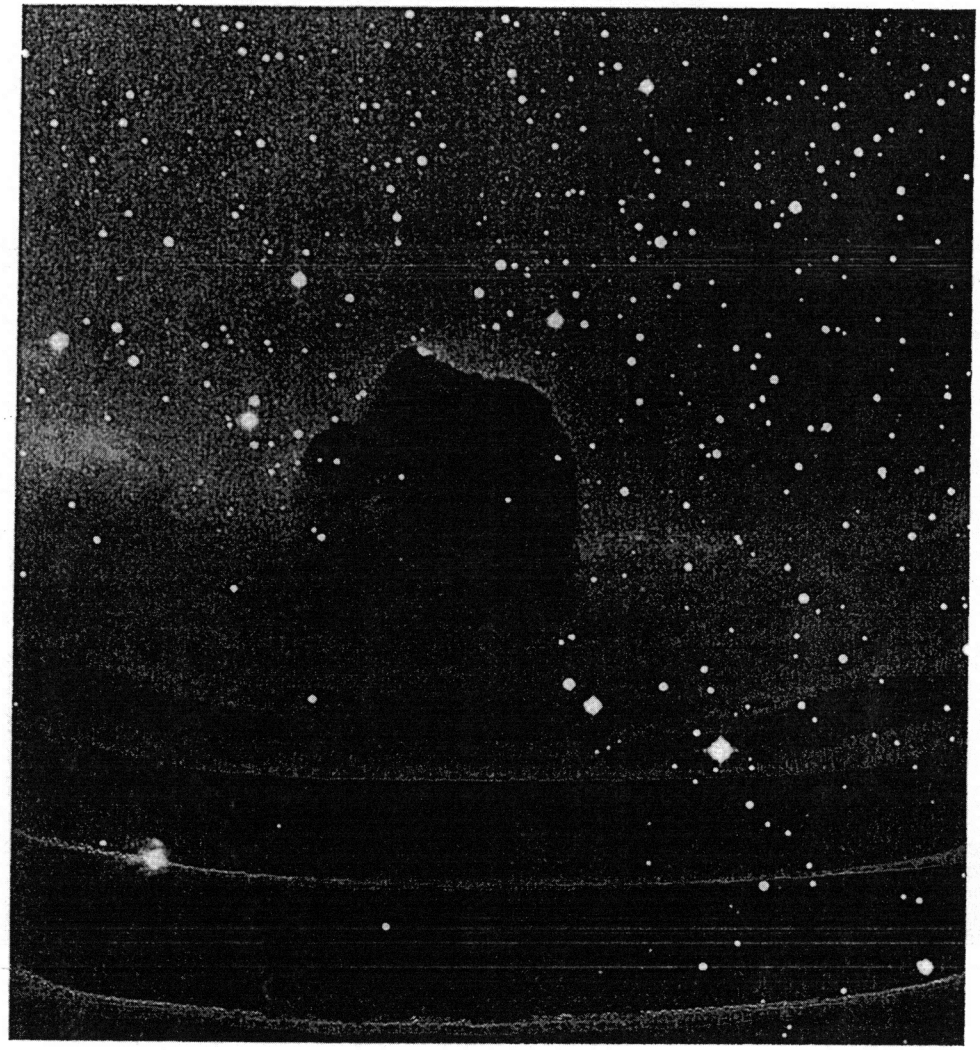
(iii) Which stage of stellar evolution is shown in Figure 2?

(1)

The star is approaching the end of the evolutinary period

Note: "Evolution" describes a slow/gradual change; "Revolution" a rapid change

(b) Figure 3 shows the Horsehead Nebula, an absorption nebula.



(Source: NASA)

Figure 3

Which stage of stellar evolution is shown in Figure 3?

The coalescence of interstellar material, or star formation. (1)

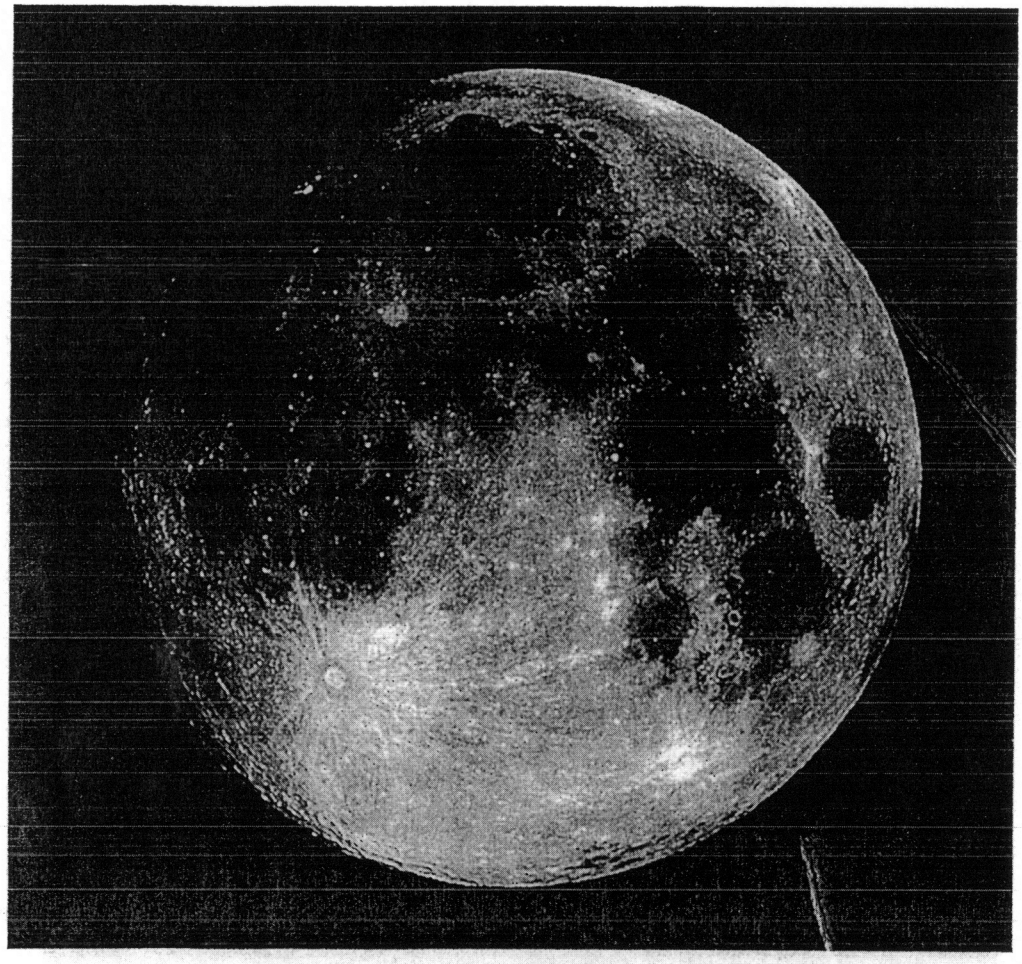
(c) Which principal part of the electromagnetic spectrum do astronomers use to detect:

(i) neutron stars; Radio waves. Typically, a star of a mass of $2 M_{\odot}$ and R = 10 km (1)

(ii) black holes? X-rays. A region surrounding an "old", massive, collapsed star (1)

(Total for Question 5 = 6 marks)

6 Figure 4 shows the Moon's near side.



(Source: NASA)

Figure 4

(a) What is the name of the large:

(i) dark grey areas;

Maria (1)

(ii) light grey areas?

Terrae (1)

?

(b) What evidence is there that the dark grey areas are younger in age? (1)

There are fewer craters in the dark grey areas.

(c) The Moon does not possess an atmosphere.

Why is this?

It's weak Gravitational Field Strength of $1{\cdot}6\ N\ kg^{-1}$ cf. with that of the Earth: $10\ N\ kg^{-1}$:

(d) Rilles and wrinkle ridges are features on the surface of the Moon.

(i) Describe briefly the nature of rilles.

*Crack-line features on the surface of the Moon. True rilles are collapse features, but some are crater-let-chains.

(ii) State **one** way in which a wrinkle ridge is different from a rille.

Wrinkle ridges tend to have greater dimensions, above the Lunar surface.

(Total for Question 6 = 6 marks)

* They are alternatively known as "clefts".

⑥ (c) continued

It means that the so-called "velocity of escape" from the Lunar surface —— low at $2{\cdot}4\ km\ s^{-1}$ has allowed gaseous materials to evaporate / leak.

For information:

v_e Earth = $11(2)\ km\ s^{-1}$

v_e Jupiter = $60\ km\ s^{-1}$

v_e Saturn = $36\ km\ s^{-1}$

v_e Mars = $5\ km\ s^{-1}$

v_e Sun = $617\ km\ s^{-1}$

v_e Pallas = $0{\cdot}3\ km\ s^{-1}$

} This indicates a large variation within the Solar System.

v_e Pluto = $1\ km\ s^{-1}$

v_e Neptune = $25\ km\ s^{-1}$

n over ▶

7 (a) Which astronomer was the first to propose that the Sun, and not the Earth, was at the centre of the known Universe?

(1)

- [x] **A** Copernicus
- [ ] **B** Kepler
- [ ] **C** Newton
- [ ] **D** Tycho Brahe

Mikolaj Kopernic, usually known to us by his Latinised name, Copernicus. His Sun-centred theory was published in 1543.

(*) (b) In 1609 Galileo made some important discoveries to confirm that the Earth was **not** at the centre of the known Universe

State **two** of these discoveries.

1 Observed the mountains and craters of the Moon.

2 Identified the Milky Way

3. Observed the four principal moons of Jupiter.

4. Found that the planet Venus exhibited phases, similar to those of the Moon.

(c) Which astronomer was the first to **explain** planetary motion in terms of an inverse square law?

(1)

Sir Isaac Newton, published his work on Gravitation, in his monumental book, the "Principia", in 1687.

(Total for Question 7 = 4 marks)

Newton explained the Mathematics behind Johannes Kepler's three laws of Planetary Motion, which were enunciated between 1609 and 1618.

Remember that the history of Astronomy is inextricably connected to the lives of the great astronomers.

(*) "Science came down from Heaven to Earth on the inclined plane of Galileo." →

Galileo's greatest contribution to Physics was a change of treatment. He brought

8 A group of students was planning a naked-eye observing session.

They made a list of some equipment they would need:

warm clothes

torches fitted with red filters

planispheres

(a) Why did the students plan to use red filters with their torches?

"dark" is an adjective; "darkness" is the noun.
∴ to maintain darkness-adapted eyes.

(b) State **two** key pieces of information that the students would obtain from their planispheres.

1 Objects which do not change their relative positions in the sky. For example, stars, star-clusters, constellation shapes

2 .....

(c) The students also referred to the Messier Catalogue to aid their planning.

State **two** different **types** of astronomical object contained in the

1. Nebulae, some of which were later re-named "Galaxies" (but never by Edwin Powell Hubble!)

1 .....

2. Star clusters, both Open and Globular.

2 .....

3. Galaxies, later identified as "Island Universes", beyond the Milky Way System.

(Total for Question 8 = 5 marks)

(*) Charles Messier (in France) compiled the first, proper catalogue of star-clusters and nebulae, not because he was particularly interested in them, but because he kept on confusing them with comets —— in which he was very interested (altogether he discovered more than a dozen).

back the scientific attitudes of Pythagoras and Archimedes: "Experimental knowledge should be codified by abstract mathematical ideas." He made huge contributions to Mechanics, thus paving the way for Newton's later, seminal work.

9 A student sketched a side view of the Milky Way galaxy.

This is shown in Figure 5.

Surely, a proper noun?

A typical cluster can contain up to one million stars, arranged near the nuclear bulge, which is surrounded by the halo.

Near the centre of the cluster, the stars are so tightly packed that they merge into a glowing mass. Few are within 6000 pc of the Sun

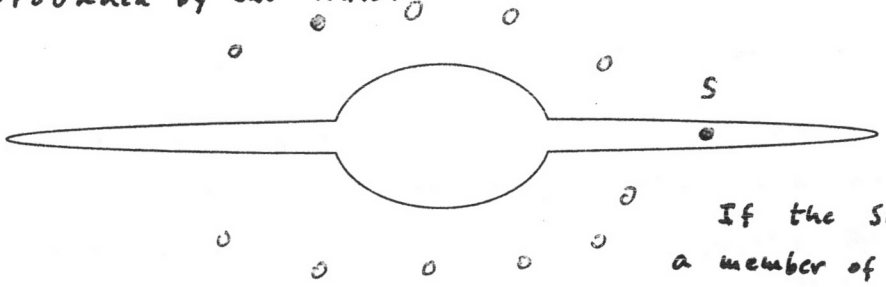


Figure 5

If the Sun were a member of a cluster, the night sky would be superb; there would be no true darkness.

(a) (i) On Figure 5, indicate the approximate location of the Sun. Use the letter **S**.

(1)

(ii) On Figure 5, draw about 10 **small circles** to show the distribution of globular clusters.

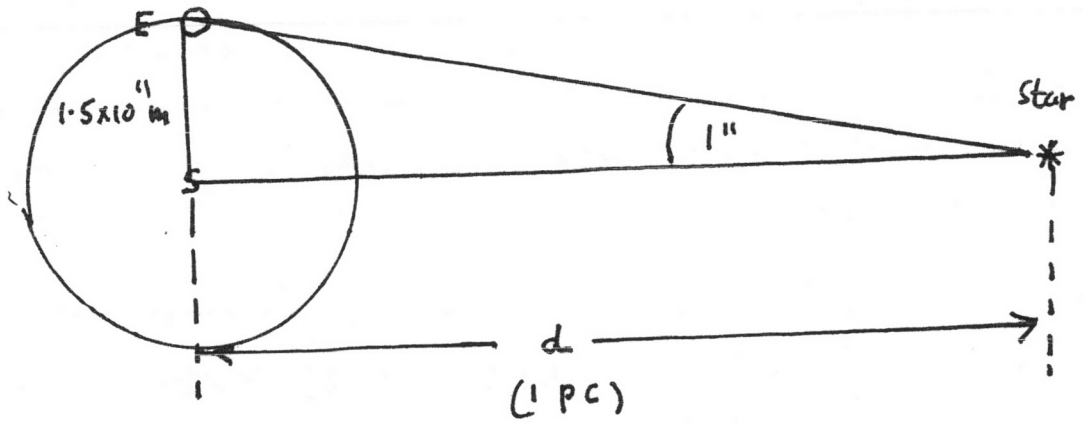
(1)

(b) What is the approximate diameter of the Milky Way galaxy?

(1)

- ☐ A 15 kpc
- ☐ B 15 Mpc
- ☒ C 30 kpc
- ☐ D 30 Mpc

"parsec": the distance from the Sun at which the radius of the orbit of the Earth would subtend an angle of 1" (one arc-second)



From the above diagram,

$\tan 1'' = \frac{1.5\times10^{11}\ m}{d}$ Rearranging: $d = \frac{1.5\times10^{11}\ m}{\tan 1''}$

$\Rightarrow d = 3.1\times10^{16}\ m \approx \frac{2.1\times10^{5}\ A.U.}{}$

(c) Name the part of the Milky Way Galaxy where:

(i) young stars are located;

In the spiral arms. (1)

(ii) dust is found.

In the plane of the Galaxy; when we look in this direction, we are looking at the so-called "Milky Way". (1)

(d) (i) Which region of the electromagnetic spectrum do astronomers use to map the spiral arms?

(1)

- [x] **A** radio waves
- [ ] **B** sound waves
- [ ] **C** ultraviolet
- [ ] **D** X-rays

(ii) Why is it not possible to map the spiral arms using visible light?

The "visible" part of the Electromagnetic Spectrum cannot penetrate the dust material.

(Total for Question 9 = 7 marks)

JF² (9) (a) amplified. (more detailed) "Our" Galaxy

Mass ~ $1 \times 10^{11} M_\odot \sim 2 \times 10^{41}$ kg.

Thickness = 1000 pc (1 pc = 206000 A.U.)

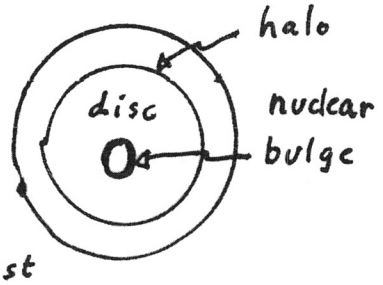
Diameter ~ 25000 pc ⟶ 30000 pc.

Distance of the Sun from the centre ~ 8000 pc

Period of revolution of the Sun around the centre ~ 2×10^8 years

Distance of the Sun above the Galactic plane = 8 pc

Diameter of the bulge ~ 6 kpc.



The halo and the bulge are roughly spherical; sometimes regarded as a single component —— the Galactic Spheroid. "Our" Galaxy is not the largest in the Local Group, which consists of up to one hundred galaxies.

10 (a) A student observed the Perseid meteor shower in August 2012 and drew some meteor trails on a star chart, as shown in Figure 6.

the Perseids

Maximum: August 13. Maximum hourly rate ~ 80

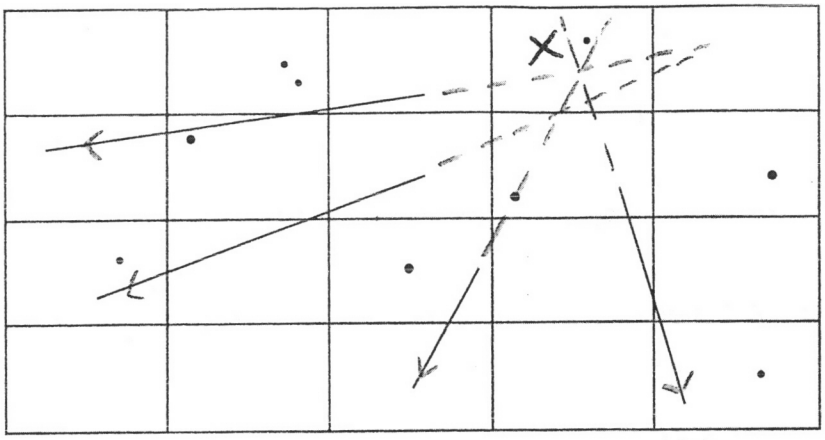


Figure 6

(i) On Figure 6, mark the position of the radiant.

Use the letter **X**.

(1)

(ii) Why is the Perseid meteor shower so-named?

The radiant is located in the Constellation Perseus.

(iii) Why does this meteor shower occur every August? JF²

Meteors tend to travel in swarms, so that every time the Earth passes through a swarm, a shower of "shooting-stars" is observed. Each shower has its own radiant.

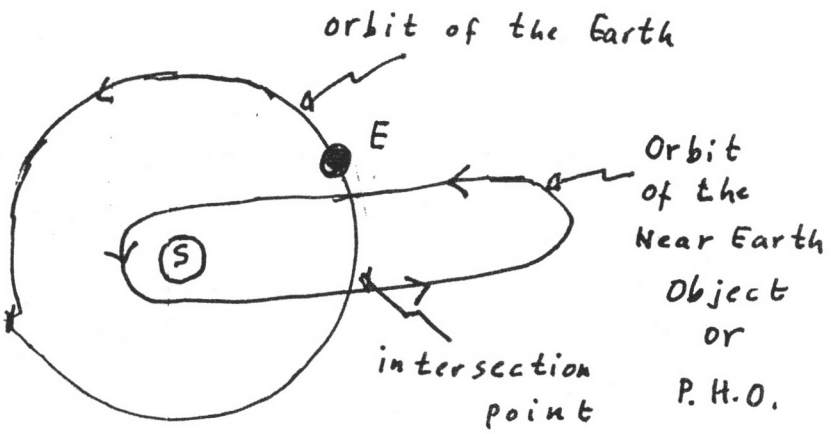
As a comet orbits the Sun, it leaves a dusty trail, and this is responsible for the meteor shower with which it is associated. For example, the October Orionids are the débris of Halley's comet, while the Perseids are associated with Comet Swift-Tuttle, which has a period of 130 years, its last perihelion in 1992.

The August Perseids are reliable; other showers are less consistent. For example, the Leonids of November 17 can be spectacular. The Earth has to intersect every swarm at the right time.

(b) There have been recent concerns about Potentially Hazardous Objects (PHOs).

(i) Sketch a labelled diagram showing the orbit of a PHO. Include the Sun and Earth on your diagram.

(2)



(ii) Why is it important to monitor the motion of PHOs?

(1)

To enable the risk of a collision to be assessed realistically. What possible "contingency plans" should be made? What could be done, if this occurs? The consequences would be catastrophic.

(Total for Question 10 = 7 marks)

Potentially Hazardous Objects | Near Earth objects

2005 YU55. The closest approach to Earth: 2011, November 8 @ 23:28 G.M.T.

A close approach to Venus is predicted for 2029. This will perturb the orbit of the asteroid, so that, in 2041, it will again pass by the Earth.

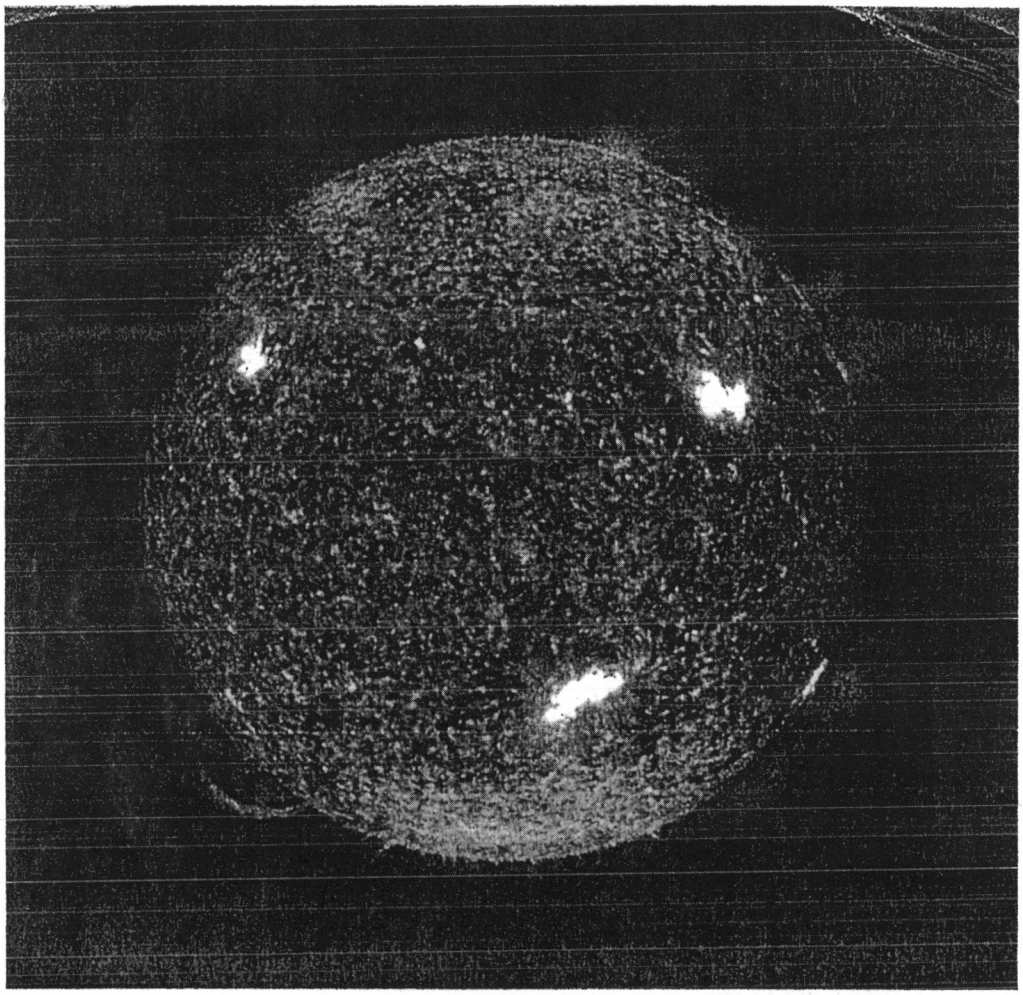
In 2072 it will have a close encounter with Mars.

Eros, a sausage-shaped asteroid, less than 30km long, can approach the Earth within 0·27 A.U.

In 1937, Hermes, an even smaller asteroid, "brushed past us" at only twice the distance of the Moon.

Two other asteroids, Icarus and Phaethon, have paths which will carry them a good deal closer to the Sun than the orbit of Mercury, so that, at perihelion, they must be red-hot.

11 (a) Figure 7 shows an X-ray image of the Sun.



(Source: NASA)

Figure 7

(i) Where should X-ray telescopes be located?

well above the atmosphere of the Earth.

(1)

(ii) On Figure 7 some white patches are visible.

What is the **significance** of these?

(1)

The image of the chromosphere is mottled with bright specks, some of which are gathered together into extensive bright regions called plages (the French word for "beach" that is pronounced "plah-je"). These are →

(b) A group of students observed the Sun with the aid of a H-alpha filter fitted to their telescope.

(i) Why does the H-alpha filter improve observations of the Sun?

H-alpha (prounced "aitch alpha"), the H indicates that the emitted light is coming from Hydrogen atoms and alpha the first (longest) wavelength of visible light

(ii) Name **one** feature in the solar atmosphere that the students might observe using this filter.

Filaments: quite common in Hα images; they are caused by huge clouds of relatively cool gas held high above the chromosphere by magnetic forces.

(Total for Question 11 = 4 marks)

11(b) (i) and (ii) continued. JF2

The majority of light from the Sun reaching the Earth comes from the photosphere, we also receive small amounts of light from layers of hot, thin gaseous material that surround the photosphere. The outer layers of the Sun may be regarded as its atmosphere, though the term must be treated with the same degree of caution that is used when referring to the photosphere as the Solar "surface".

Close to the photosphere is a shallow region with a pink or reddish tinge, of depth of a few thousand kilometres. It is called the chromosphere (meaning the "sphere of colour") and constitutes the inner (or lower) Solar atmosphere. The extensive outer (upper) Solar atmosphere is called the corona (meaning the "crown"), with a temperature of 2000000 K.

Much can be learnt (I prefer "learned") from observations of the Solar disc, provided that they are restricted to wavelengths where the chromosphere is more prominent than the photosphere. An example is the Hα image, produced by red light, a narrow range centred on 656·3 nm.

11(a)(ii) continued

Often seen in parts of the chromosphere that are directly above the active regions of the photosphere (the Solar surface) that contain sunspots.

12 (a) Despite the recent interest in space travel, manned exploration of the Solar System has so far been restricted to the Moon.

(i) Explain why radio communication between astronauts and Earth would be a major problem on a space mission to Mars.

(2)

The time required for a signal from the Earth to reach its destination: for example, at the distance of Jupiter, the message would take sixteen minutes. The reply? Another sixteen minutes.

(ii) Describe **two** further problems that astronauts might encounter on such a space mission.

(2)

1 1. Psychological problems (difficult to assess on Earth)

2. Meteoroid strike.

3. Unexpected consequences of long-term exposure

2 to Solar radiation.

4. Technical (major) malfunction of the spacecraft.

(iii) Why would Venus be an unsuitable destination for manned exploration?

How would you feel about the Sun rising in the West and setting in the East? And a "day" lasting 243 Earth day? (Longer than the Sidereal period of the planet). Yes, on Earth we are a bit set in our ways... The rotation of Venus is <u>retrograde</u>.

You might step outside for a breath of fresh Carbon Dioxide. The first successful space craft to Venus was Mariner 2, in December 1962. It found that the surface was too hot for water to exist, and that there was no significant magnetic field. The mean surface temperature is 480°C. The atmosphere is chiefly Carbon Dioxide, with clouds containing Sulphuric acid. Its atmospheric pressure is thought to be at least one hundred times greater than that at the surface of the Earth. That is, $P_{Venus} \geq 1 \times 10^7$ Pa. Venus might not be the most welcoming environment for Earthlings.

*(b) Describe some of the methods used to obtain evidence for extraterrestrial life in the Solar System.

(3)

(1) The SETI programme (Search for Extra-Terrestrial Life), by broadcasting radio waves at regular and extended intervals, in all directions.

(2) Probes to analyse material from planetary atmospheres and surfaces

(3) Radar mapping of planetary surfaces.

(Total for Question 12 = 8 marks)

13 Lucy carried out a simple experiment in which she noted the length of the shadow cast by a small vertical stick at different times.

Table 1 gives her results.

time (GMT)	shadow length / mm
11:52	110
11:56	90
12:00	80
12:04	75
12:08	80
12:12	93

The (pen) umbral region of the shadow will make it difficult for its length to be measured accurately.

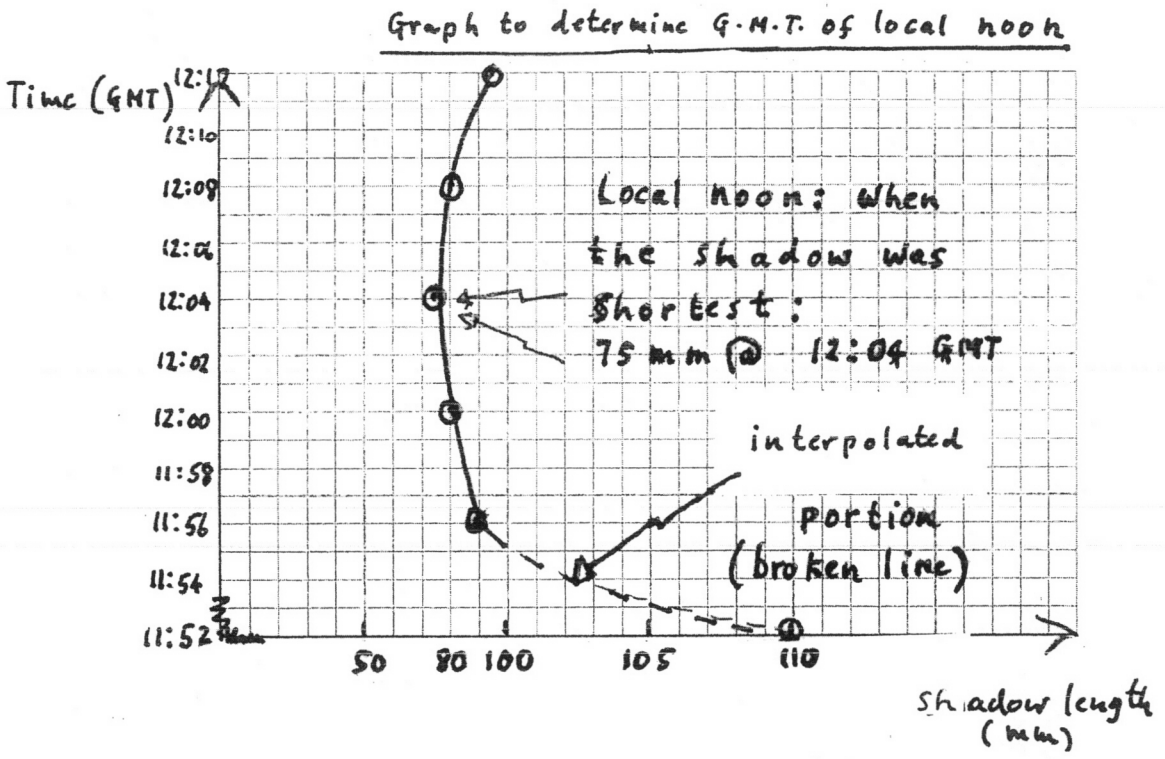
A longer stick should have been used, to enable the error in measuring the shadow length to be less significant.

Table 1

(a) Use Lucy's data to plot a suitable graph of shadow length against time.

Label the axes and draw a smooth line-of-best-fit through the data.

(3)



(b) Use the graph to determine the time (GMT) of local noon to the nearest minute.

Show clearly on the graph how you determined the time of local noon.

(2)

Note:

A graph should always have a title.

Time = ...

(c) On the date that Lucy carried out her experiment, the Equation of Time was +2 min.

Determine Lucy's longitude.

Use the formula:

Equation of Time = Apparent Solar Time – Mean Solar Time

(3)

At Lucy's place of observation, the Sun culminated (reached its highest point in the sky) at 12:04, from the graph. This meant that she was West of the Greenwich Meridian, where the Sun had reached its highest point at 12:00.

(Total for Question 13 = 8 marks)

That is, four minutes before the time of the shortest shadow where Lucy was working.

Now, the Earth rotates at a rate of 15° hour^{-1},

Or 1° in 4 minutes.

That is the Astronomy explained; the remainder makes use of the formula.

Incidentally, I have plotted Time (G.M.T.) as the ordinate, as this is the independent variable, the shadow length being the dependent variable, represented on the abscissa.

There will still be a curve, if you plot the shadow length as the ordinate, although the orientation will be different.

+2 minutes = Apparent Solar Time − 12:04

∴ A.S.T. = 12:06 corresponding to 1.5° W.

14 (a) What is the value of the mean diameter of the Earth?

(1)

- ☐ **A** 6500 km
- ☐ **B** 7500 km
- ☒ **C** 13 000 km
- ☐ **D** 15 000 km

Be careful here: we usually work with the radius of the Earth, $6{\cdot}4 \times 10^6$ m. So the diameter is $\approx 13 \times 10^6$ m.

(b) Give **two** pieces of evidence that show that the Earth is not flat.

(2)

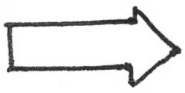
1 High-altitude photographs of the Earth, showing its curvature

2 The shape of the shadow of the Earth on the Lunar surface, during an eclipse.

(c) Describe how the circumference of the Earth was first calculated by the Greek mathematician Eratosthenes.

You may use a diagram if you wish.

(3)



14.(b) continued

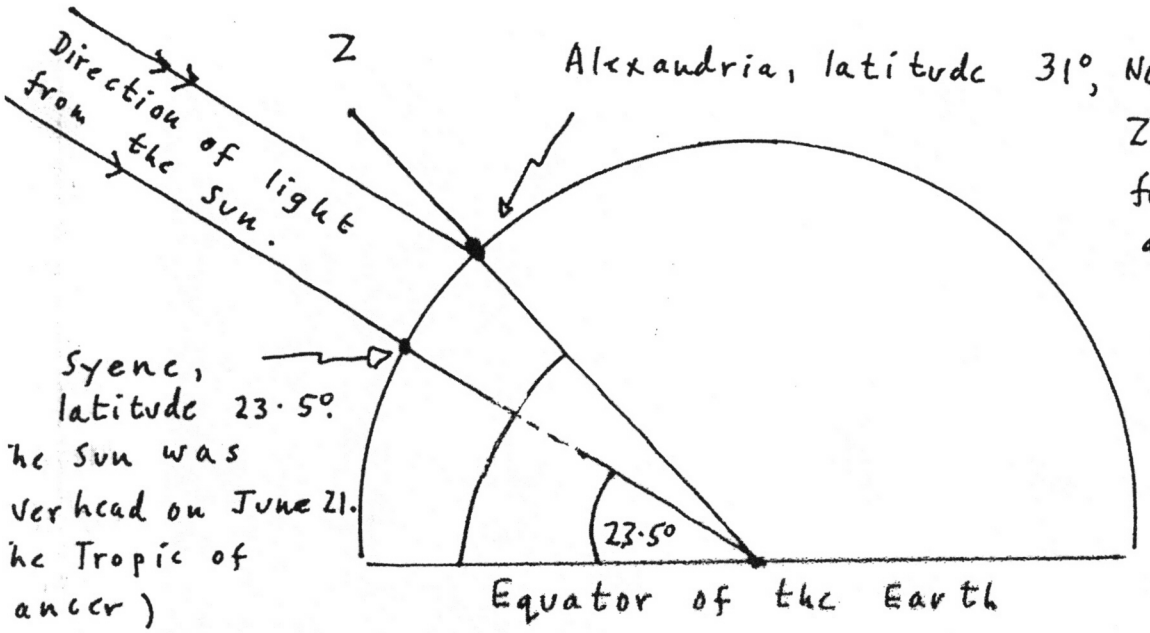
3. Photographs of the Earth taken from the Moon.

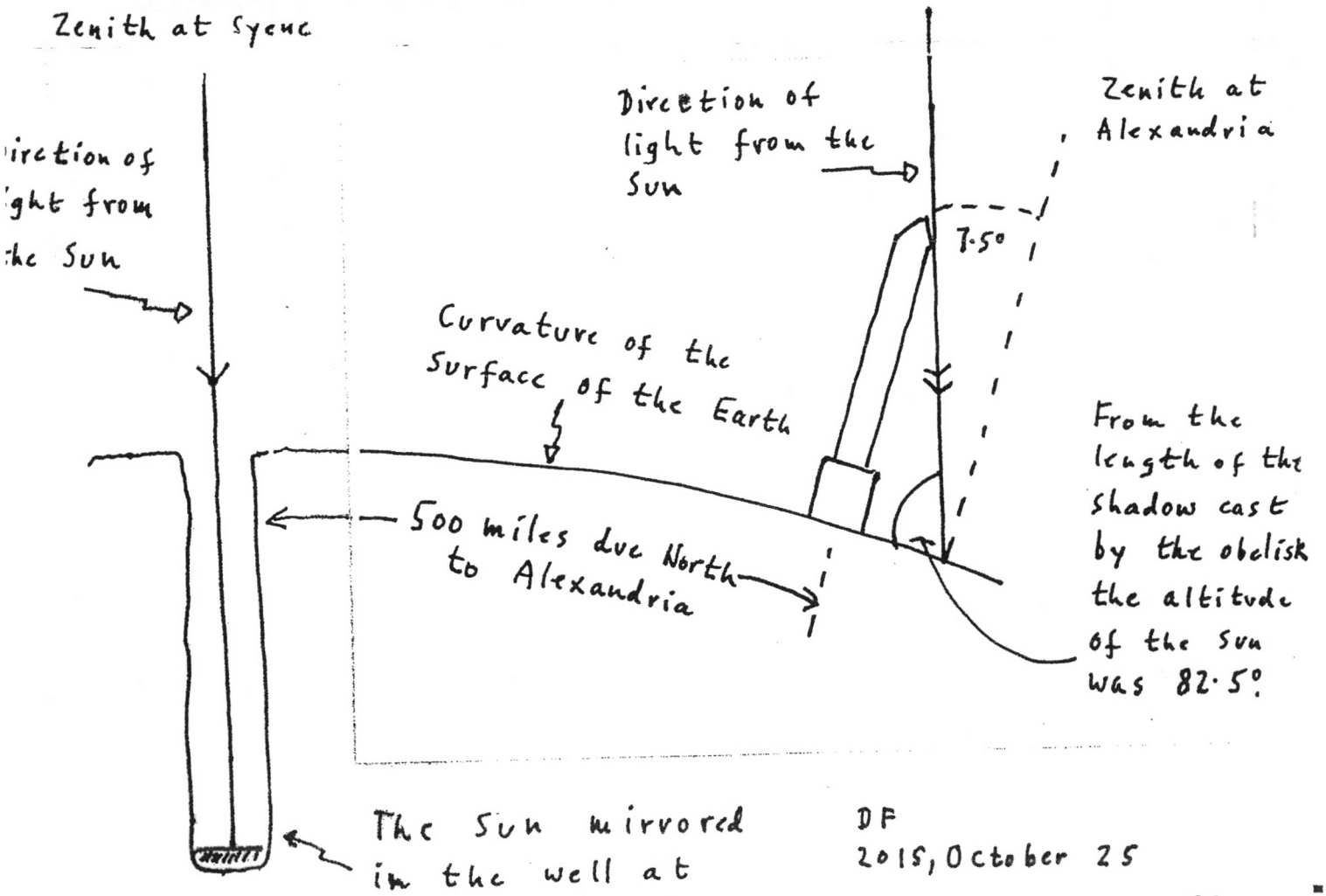
4. The disappearance / appearance of sea vessels, as they approach an observer's horizon.

(Total for Question 14 = 6 marks)

The observations of Eratosthenes and the interpretation of his measurements

Eratosthenes of Alexandria, living about 230 B.C., used solar observations, with a knowledge of geometry and geography, to calculate the circumference of the Earth.





DF
2015, October 25

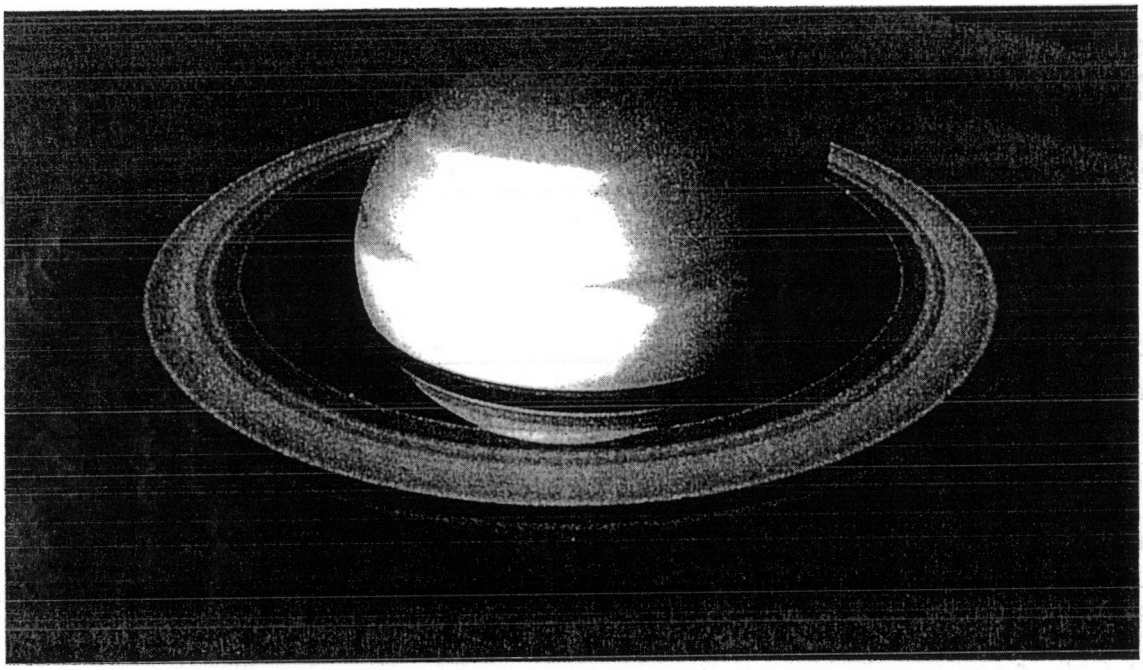
15 Most planets in our Solar System possess a system of natural satellites or moons.

(a) Name **two** planets that do **not** possess moons.

(1)

Mercury and Venus

(b) Figure 8 shows the planet Saturn and its magnificent rings.



(Source: NASA)

Figure 8

Describe the physical nature and chemical composition of the rings.

Physical nature They are not solid, but are comprised of icy particles and boulders, the majority of which lie between a few centimetres and a few metres in diameter.

Chemical composition Ice and frozen Hydrogen compounds.

(15) (b) continued.

The ring particles orbit the planet in the same plane, creating an amazingly thin disc, depth 100 m (sic). Being icy, they are highly reflective. There are "gaps" in the rings. These arise because of the gravitational influence of the satellites (at least thirty) of Saturn.

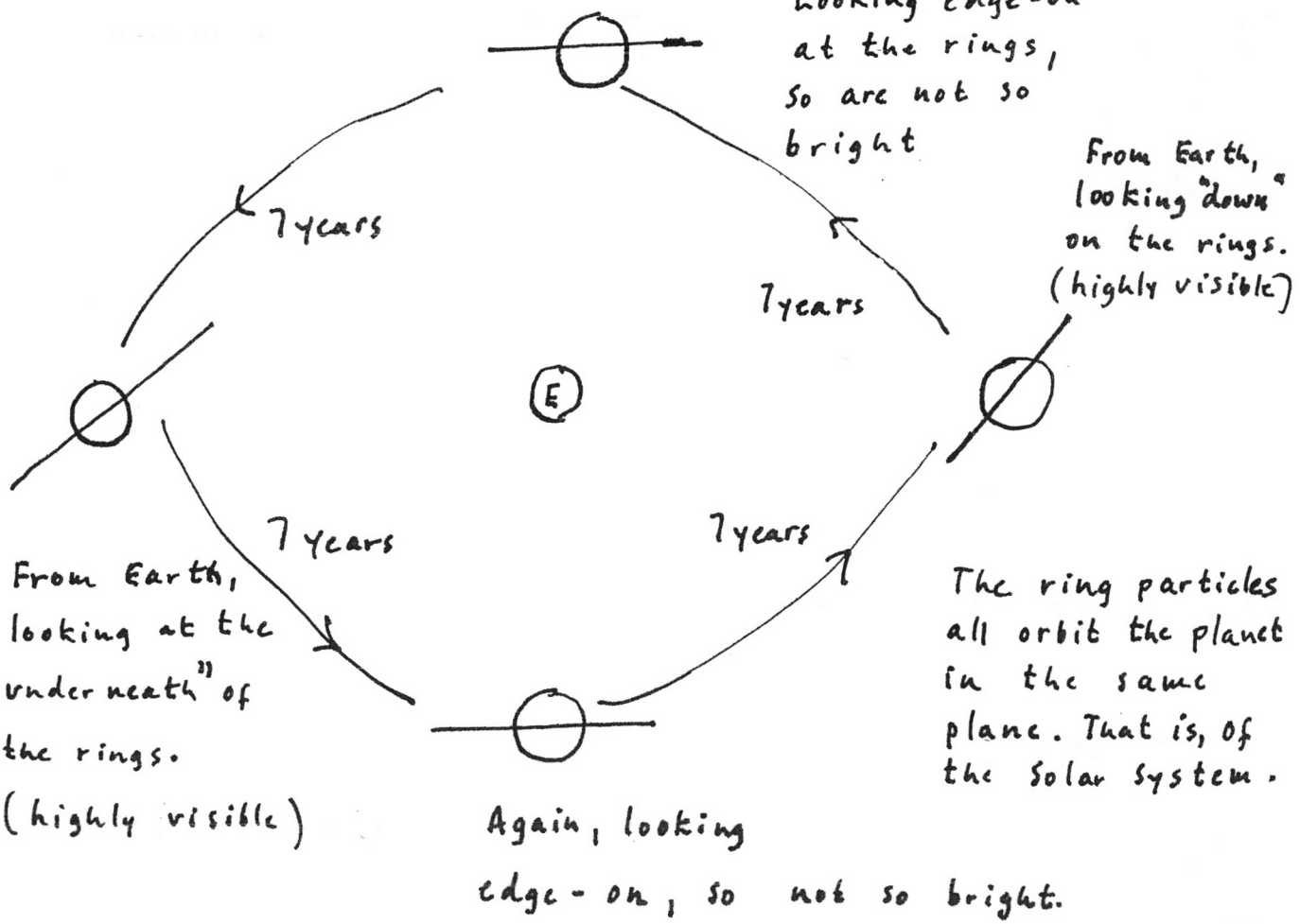
(c) Contrast possible origins of the moons of Mars and Neptune.

The moons of Mars are currently thought to be "captured" asteroids; those of Neptune were formerly Kuiper Belt objects.

Each particle obeys K III. Other planets (the giant ones) also have ring systems, albeit not on the same scale as those of Saturn, making them much harder to see.

The moons

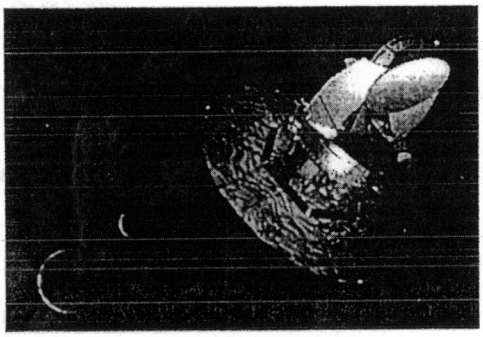
Mimas (R = 199 km); Titan (R = 2580 km) larger than the Moon; Enceladus (R = 250 km); Tethys (R = 530 km); Dione (R = 560 km); Rhea (R = 760 km), and Iapetus (R = 720 km)



16*(a) Describe how the Cosmic Microwave Background (CMB) radiation was discovered. /3

In 1965, Arno Penzias and Robert Wilson discovered an unexpected warm glow in the sky. Working on their microwave antenna, in New Jersey, the Bell Laboratory physicists detected a faint signal emanating from every direction, that would not go away. At first they thought it was mundane —— perhaps pigeon droppings clogging their sensitive horn. Eventually, they realised that the bath of warmth which had been detected was cosmic in origin. They had found the predicted afterglow of the Big Bang.

(b) Figure 9 shows an artist's impression of the Wilkinson Microwave Anisotropy Probe (WMAP) which was launched in 2001 to study the CMB radiation.



(Source: NASA)

Figure 9

(i) Describe the specific purpose of WMAP.

"WMAP": Wilkinson Microwave Anisotropy Probe. The sky is not the same temperature all over. The microwaves appear warmer in one hemisphere by 2·5 millikelvin ($2 \cdot 5 \times 10^{-3}$ K). Discovered soon after the background radiation itself, the heat pattern is known as the "dipole", to its two poles,

(ii) Explain the significance of WMAP's observations to cosmologists.

Further observations show that the sky is speckled with hot and cold spots. These so-called "ripples" are of great interest, because they were imprinted shortly after the Big Bang. They were first seen in 1992 by NASA's COBE satellite, which revealed numerous patches about the angular

(Total for Question 16 = 6 marks)

16 (b) (i) continued. Definitely JF2

hot and cold. This temperature difference arises from the Doppler Effect, due to the motion of the Earth: the Solar System is moving at 600 km s^{-1} relative to the Universe.

16 (b) (ii) continued

size of the full Moon. In 2003, a more detailed map was revealed by the Wilkinson Microwave Anisotropy Probe (WMAP) satellite, which broke up the spots into a further rash. These ripples originated when the Universe was extremely hot. After the Big Bang, the cosmos expanded, then cooled, and a host of subatomic particles, plus protons and electrons, were formed. These conclusions helped us to understand the mechanisms connected with the early Universe.

17 (a) Define the **parsec**.

The distance to a star which has a parallax angle of one second of arc.

Or, perhaps easier: the distance at which the Astronomical Unit would subtend an angle of 1"

(b) (i) With the aid of a diagram, describe how distances to nearby stars are determined using heliocentric parallax.

(3)

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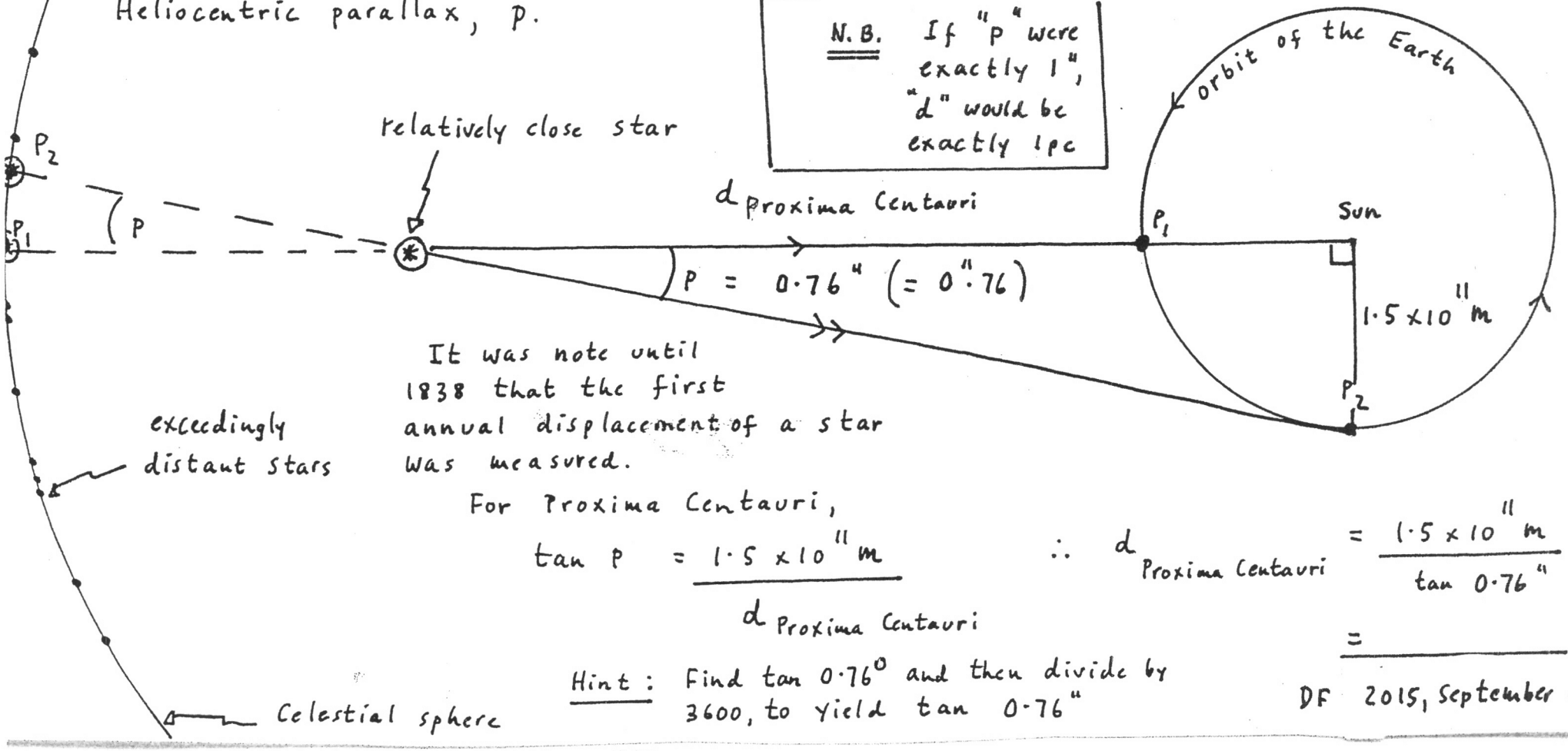
The Heliocentric (centred on the Sun) parallax of a star

Stars are immensely distant : apart from the Sun, the nearest is almost one million Earth - Sun distances. For such large distances, a large base-line is required in order to detect a shift due to parallax. Clearly, the radius of the Earth would be hopelessly inadequate. Instead, two positions of the Earth in its orbit around the Sun are used. In fact, stellar distances are so huge, that an accuracy of one minute of arc is far from sufficient to detect any parallactic displacement: small fractions of seconds of arc are required. [Note : $60' = 1^\circ$; $60'' = 1'$ $\therefore$ $3600'' = 1^\circ$]

The angle subtended by the radius of the orbit of the Earth at the star is the Heliocentric parallax, p.

N.B. If "p" were exactly 1", "d" would be exactly 1pc



It was note until 1838 that the first annual displacement of a star was measured.

For Proxima Centauri,

$$\tan p = \frac{1·5 \times 10^{11}\ m}{d_{Proxima\ Centauri}} \quad \therefore \quad d_{Proxima\ Centauri} = \frac{1·5 \times 10^{11}\ m}{\tan 0·76''} =$$

Hint : Find $\tan 0·76^\circ$ and then divide by 3600, to yield $\tan 0·76''$

DF 2015, September 15

33

Still very distant, by the scale of the Solar System.

(ii) Why is this method only suitable for relatively nearby stars?

Refraction effects in the atmosphere of the Earth make the measured angles unreliable. Not used for objects at a distance greater than about 50 pc.

(c) Some data for a galaxy are given below:

absolute magnitude = -22.0

distance = 10 Mpc

This is an unsatisfactory question: at a distance of 10 pc, we would be inside the galaxy. It is truly a meaningless question

Use this data to calculate the apparent magnitude of this galaxy.

Use the formula $M = m + 5 - 5 \log d$

I hate this so-called Modulus Equation! It replaces the interesting exercise of using, and understanding, the Inverse-Square law

M = Absolute Magnitude.
m = Apparent Magnitude
d = distance in parsecs

We shall calculate the answer from first principles, using the fundamental inverse-square law.

The actual distance of the galaxy is 10 Mpc.
Were it at 10 pc, its Absolute Magnitude would be −22·0.
At a distance of 10 pc, it would be one million (10^6) times closer.
So, the brightness difference would be $10^6 \times 10^6 = 10^{12}$
That is, on being transferred from 10 pc to 10 Mpc, the galaxy has become 10^{12} times fainter

Reminder:
$(2 \cdot 512)^5 = 100$
$(2 \cdot 512)^{10} = 10000$ etc.

Hence, using $\Delta B = (2 \cdot 512)^{\Delta m}$
To what power, Δm, does (2·512) have to be raised to give 10^{12}?
Take logarithms (base 10) to both sides:

$\log_{10} 10^{12} = \Delta m \cdot \log_{10} 2 \cdot 512$

Rearranging:

$$\Delta m = \frac{\log_{10} 10^{12}}{\log_{10} 2 \cdot 512} = 30$$

$\therefore m = 8$

The galaxy would be 30 magnitudes fainter

18 (a) Maxwell plotted a graph of radial velocity of some distant galaxies (v) against their distance from Earth (d) and drew a line-of-best-fit.

Figure 10 shows Maxwell's graph.

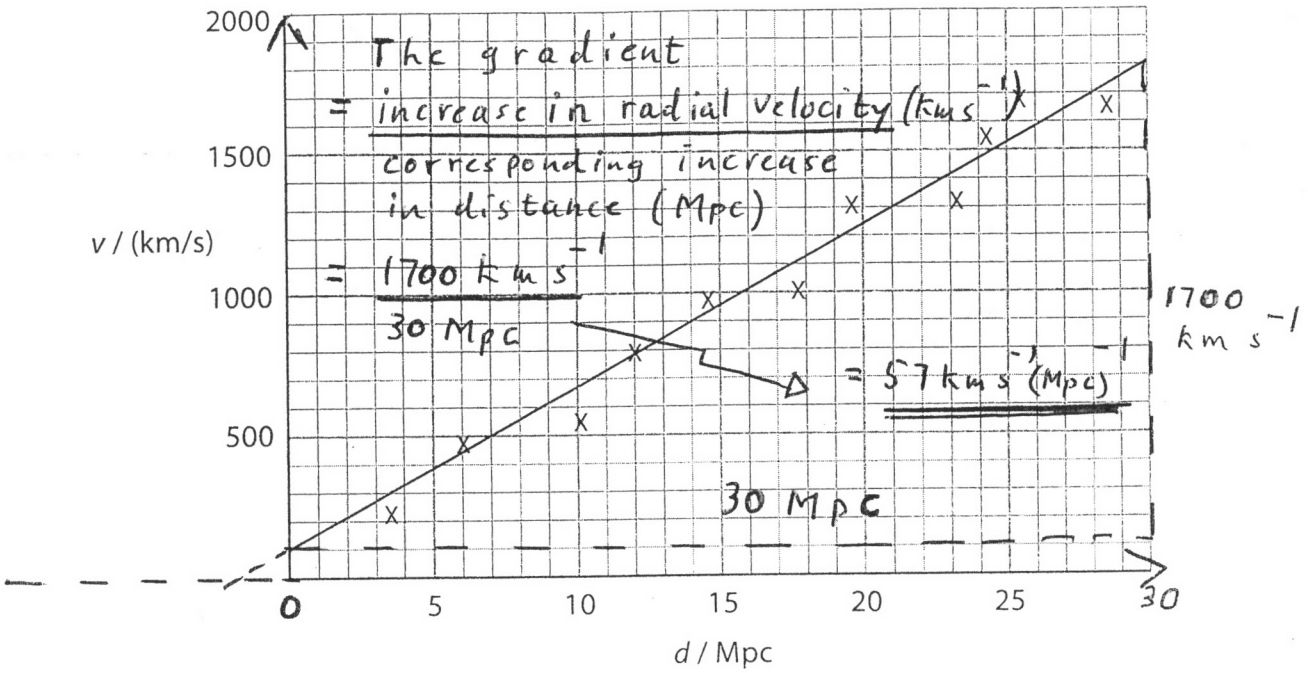


Figure 10

The symbol for this constant (H_0)

Use the graph to determine the Hubble Constant.

Write the value correct to **two** significant figures and give the unit.

Show clearly on the graph how you determined the Hubble Constant. (4)

Edwin Powell Hubble, the distinguished American observational astronomer, showed that $v \propto d$ (radial velocity of recession of the nebula; d = distance of the nebula)

Hubble Constant = $57\ \text{km s}^{-1}(\text{Mpc})^{-1}$

As far as I know, Hubble did not use the modern word "galaxy" — he preferred "nebula"

$\Rightarrow \boxed{v = H_0 d}$

dependent. The subscript zero, is the current value.

$\therefore \boxed{\frac{v}{d} = H_0}$

It is better to refer to the "Hubble Parameter," because "H" appears to be time-

(b) Which important quantity can be deduced from the Hubble Constant?

(1)

- ☐ **A** age of the Earth
- ☐ **B** age of the Solar System
- ☐ **C** age of the Sun
- ☒ **D** age of the Universe

(Total for Question 18 = 5 marks)

19 (a) State **three** pieces of information that astronomers can obtain by studying the spectrum of a star.

1 ... Rotational velocity from the Doppler Effect

2 ... The radial velocity ④ The elements present

3 ... Spectroscopic binaries in the star

The power (luminosity)

*(b) Explain how astronomers use the spectrum of a star to classify its spectral type.

(3)

The spectrum of a star gives information about the composition which is really confined to its outer layers. This could include the degree of ionised Helium, Calcium, Titanium, Temperature related to spectral class, the Hydrogen Balmar lines, & that the range of O, B, A, F, G, K and M.

(Total for Question 19 = 6 marks)

Note: It is better to write the units of H_0 as "$km\ s^{-1}(Mpc)^{-1}$" not "$km\ s^{-1}\ Mpc^{-1}$". Can you see the reason that I prefer the former?

20 Figure 11 shows a star chart with some of the stars in the constellation Pisces.

Some stars are labelled with Greek letters.

The dashed line represents the ecliptic.

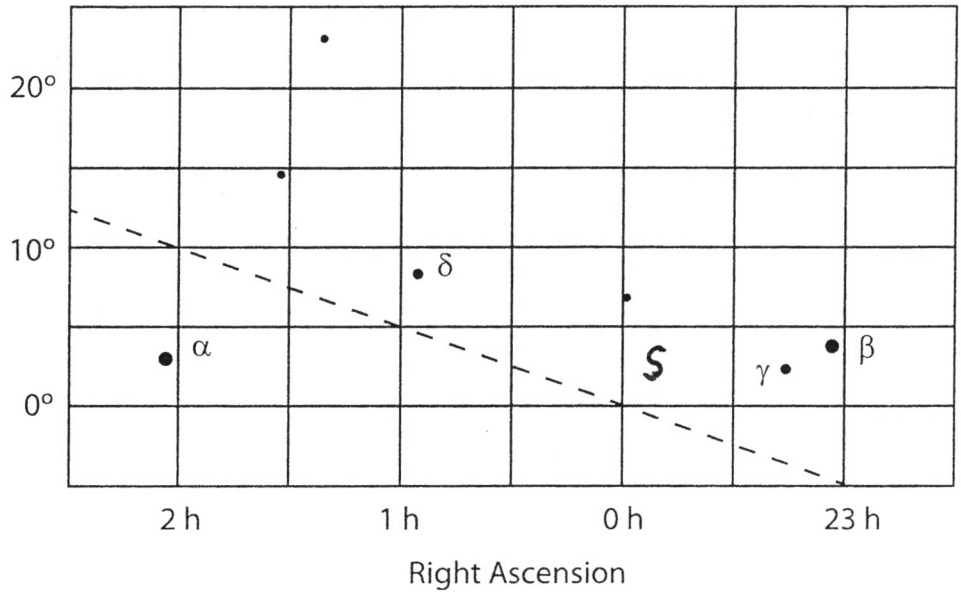


Figure 11

(a) Which quantity is represented on the vertical axis?

- ☒ **A** declination
- ☐ **B** elongation
- ☐ **C** elevation
- ☐ **D** opposition

Measured from the projection of the Earth's Equator onto the Celestial Sphere.

(b) (i) What is the significance of the Greek letters α, β etc?

These indicate the relative brightnesses of the stars: α the brightest, β the next and so on.

(ii) What is the significance of the ecliptic on a star chart?

It shows the apparent path of the Sun in the sky, as a consequence of the orbital motion of the Earth.

(iii) Indicate on Figure 11 the position of the Sun on March 21st.

Use the letter **S**. As the Sun crosses the Celestial Equator, travelling from South to North.

(1)

(c) (i) An observer at longitude 3°E observes the culmination of star δ at 01:20 GMT.

At what time would an observer at longitude 1°W observe the culmination of δ?

The longitude difference is 4°. The observer West of the Greenwich Meridian would see the star culminate later, at 01:36

(ii) Estimate the latitude, to the nearest degree, from which star α could be observed at an observer's zenith.

(2)

See below

(Total for Question 20 = 8 marks)

TOTAL FOR PAPER = 120 MARKS

(c)(i) continued.

The Earth rotates 360° in 24 hours. That is 15° hour^{-1},

∴ to rotate 4° requires 16 minutes.

(c) (ii)

From the chart, I estimate that the Declination of the star labelled α to be + 3°. Therefore, the observer's latitude would have to be 3° North.

Consider Polaris, Declination + 90°.

Only at the North Pole would the Pole Star be observed directly overhead. For an observer on the Equator, Polaris would graze the Horizon.