ASTRONOMY (SL)

Exam Paper 2
May 2008

There are two sections:

Section A : Answer ALL questions.
Section B : Answer ONE question only.

ALL answers are to be written on the exam paper.

Calculators are allowed.

This exam paper has a total of 60 marks

Time Allowed : 90 minutes

Marking Grid	
Section A	**Marks**
1	
2	
3	
4	
Section B	**Marks**
5	
6	
Total / 60	

Section A

Answer ALL questions
You are advised to spend no more than 60 minutes on this section

1. This question is about the events which occur as a star comes to the end of its main sequence lifetime.

a) Figure 1 shows a cutaway of the Sun. Looking at this detail, label the points or regions shown with numbers.

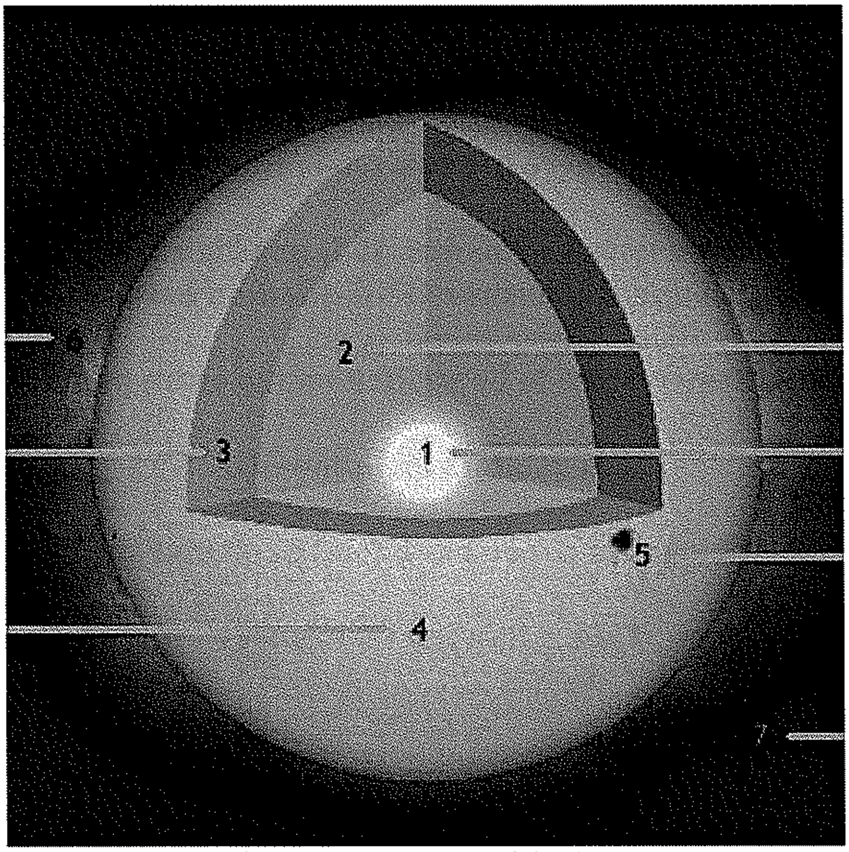

Figure 1. Cut-away of the Sun.

1. ……………………………………………..

2. ……………………………………………..

3. ……………………………………………..

4. ……………………………………………..

5. ……………………………………………..

6. ……………………………………………..

7. ……………………………………………..

[2 marks]

b) For the Sun on the main-sequence, hydrogen fusion occurs within the central 30%. Assuming that the Sun has a constant density throughout, how much mass is contained within this central region?
(It may be useful to recall that the volume of a sphere is given by $V = 4/3\ \pi r^3$)

....

....

....

....

....

[2 marks]

c) Fusion will stop when there is no more hydrogen in the central region. When this occurs, briefly state and explain what will happen to the size and temperature of this central region.

Size :

....

....

....

Temperature :

....

....

....

[2 marks]

d) The changes to the central region of the Sun will start a chain of events which will produce an expansion of the outer surface of the Sun. This will produce a reduction in the outer temperature of the Sun and a rise in the luminosity. Briefly explain why these changes occur.

Reduction in outer temperature :

....

....

....

Rise in luminosity :

....

....

....

[2 marks]

e) Figure 2 shows the main sequence on the Hertzsprung Russell diagram. The position of the Sun is clearly identified.

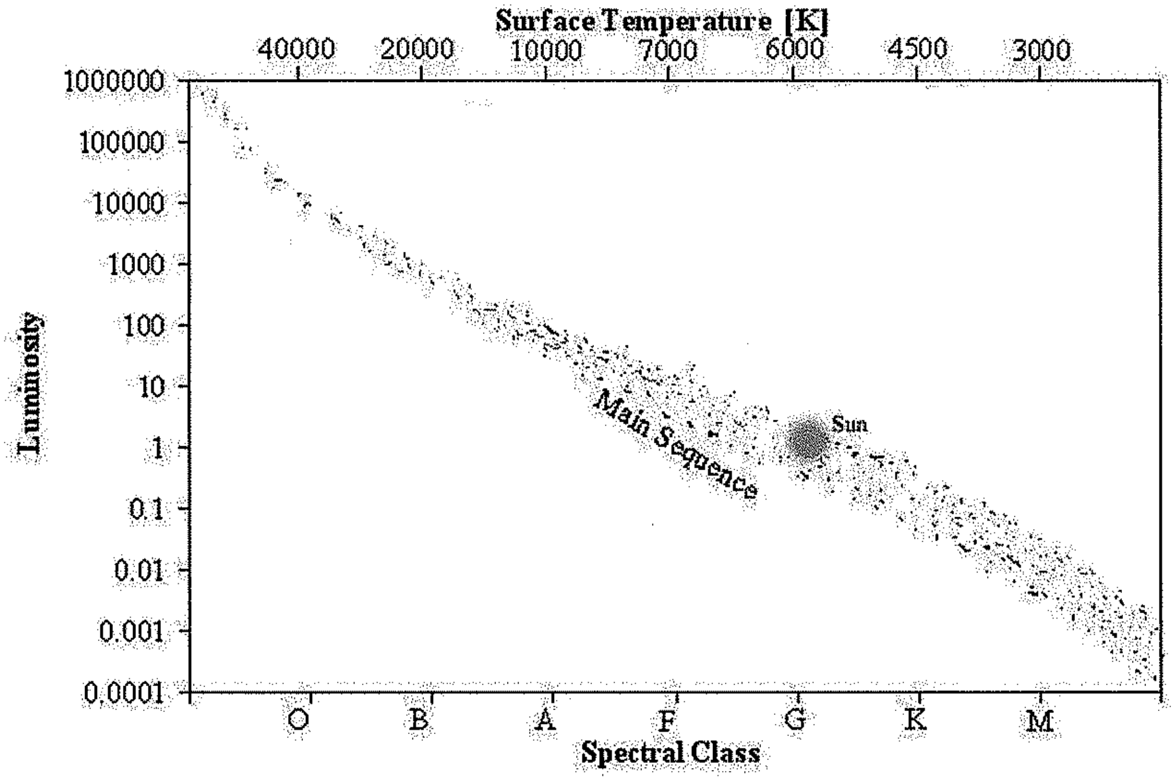

Figure 2. The Hertzsprung Russell diagram.

On Figure 2, draw a line or curve which shows how the luminosity and surface temperature change from the point where the Sun leaves the main sequence until it reaches its ultimate fate.

[2 marks]

BLANK PAGE

2. This question is about planetary differentiation.

One theory on the creation of the solar system is called the nebula theory. This suggests that a single nebula gave rise to the planets as well as the Sun.

Figure 3. Planetary accretion around the protostar.

When the material accreted to form the planets, this could have been either homogeneous or heterogeneous.

a) Briefly explain why homogeneous accretion may have been more likely.

....

....

....

....

....

[2 marks]

b) Homogeneous accretion would leave the planets undifferentiated. We know that the Earth is differentiated however. Briefly explain ONE piece of evidence that suggests that the Earth is a differentiated planet.

....

....

....

....

....

[2 marks]

c) For differentiation to occur, the material of the planet would need to readjusted itself and this would require a source of thermal energy (ie., heat).

State TWO possible sources of thermal energy that would allow a planet to differentiate.

Source 1 : ....

....

Source 2 : ....

....

[2 marks]

d) It is clear that energy from the Sun is the largest input of energy to the Earth. However, of the possible sources of thermal energy which could lead to differentiation, only one is presently felt to have any influence on the developing Earth. State what this source of thermal energy is and explain why it is still significant even though the Earth is around 5 billions years old.

....

....

....

....

....

[2 marks]

e) Although we feel that the Earth is fully differentiated, this may not be true for the other planets in the solar system.

From your knowledge of the planets, consider the terrestrial planets and the gas giants. In each case, indicate in the Table below if you think that **any** of the terrestrial planets or gas giants may still be undergoing differentiation

	Differentiation is still happening	Differentiation is NOT happening
The Terrestrial Planets :		
The Gas Giants :		

(Tick once in each row)

[2 marks]

3. This question is about the Galactic Ladder.

There are many methods of measuring galactic distances, each with its limitations and shortcomings. In summary, these methods are based on:

- Geometric considerations.
  - Trigonometric Parallax.
- Standard Candles.
  - Cepheid Variables.
  - Supernovae.
- Galactic properties.
  - Tully-Fisher.
  - Brightest Cluster galaxy.
  - Hubble's Law.

The various methods have limitations on the distances over which they are useful. These are shown in Figure 4 in what is referred to as the *galactic ladder*.

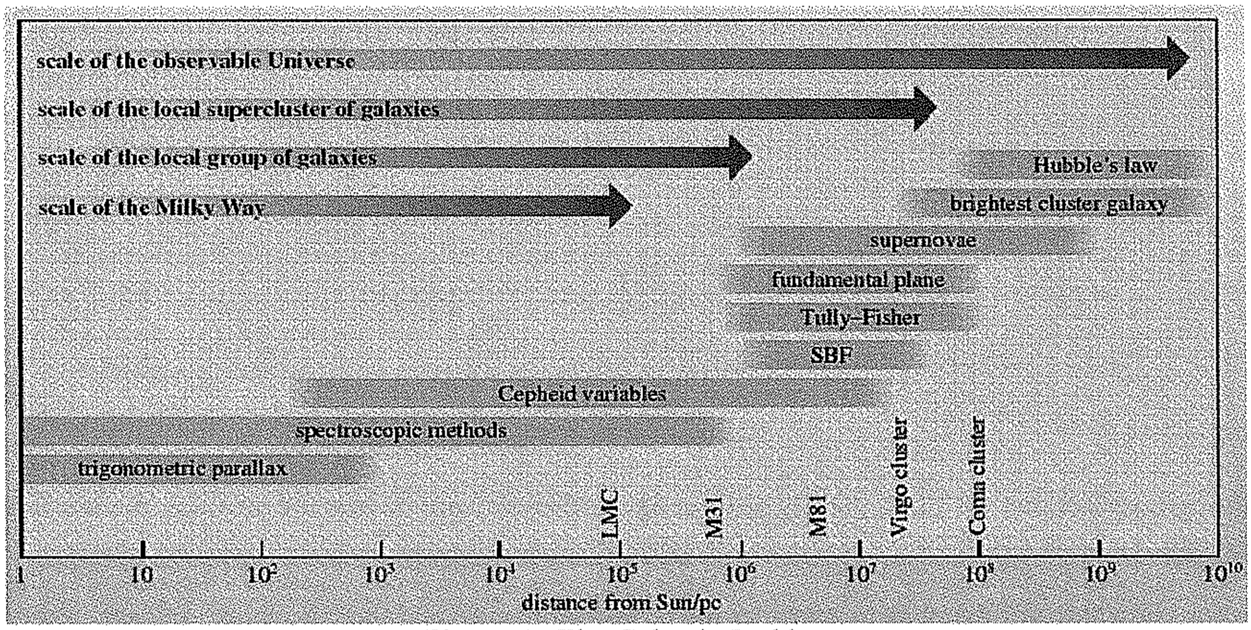

Figure 4. The Galactic Ladder.

a) Explain why the method of trigonometric parallax can NOT be used to measure the distance to the nearest galaxy.

....

....

....

....

[2 marks]

b) Chose a single 'Standard candle' method and a 'Galactic Property' method and state the range over which it is a useful technique and explain how it is used to measure the distance to a galaxy.

Standard Candle method chosen : .... Useful range : .... pc

....

....

....

....

....

....

....

....

....

....

....

[3 marks]

Galactic Property method chosen : .... Useful range : .... pc

....

....

....

....

....

....

....

....

....

....

....

[3 marks]

c) One of the techniques listed above has a particularly important part to play in our estimate of the age of the universe. State which technique this is and how it can be used for this estimate.

....

....

....

....

....

[2 marks]

BLANK PAGE

4. This question is about the history of our understanding of gravitation.

Kepler's third law gives a description of the motion of the planets around the Sun. This law was stated as

$$(\text{Orbital Period})^2 \propto (\text{Orbital Distance})^3$$

Isaac Newton explained this by considering that every object with the property called 'mass' has a gravitational field around and any two such objects, produce two fields which interfere to produce the resulting attraction given by:

$$F = G\frac{Mm}{r^2}$$

a) Consider the Earth around the Sun. If the mass of the Earth is taken as 6.0×10^{24}kg, calculate the force of attraction between the Earth and the Sun.

....

....

....

[2 marks]

b) As the earth moves around the Sun, what is the direction of the force of gravity holding the Earth in its motion?

....

[1 mark]

c) Consider the motion of the Earth around the Sun. Kepler stated that this was an ellipse however, if drawn, the eccentricity of the orbit is very small and it is shown in Figure 5 as a simple circle.

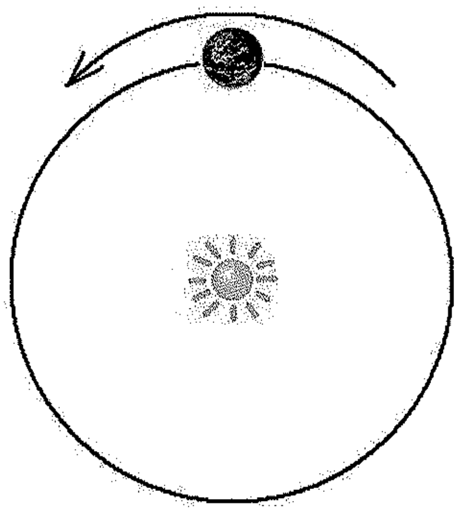

Figure 5. Motion of the Earth around the Sun.

Einstein considered what would happen to the orbit of the Earth if a catastrophe occurred and the Sun disappeared.

In Figure 5, indicate with an arrow the subsequent motion of the Earth if the Sun were to disappear.

[2 marks]

d) Einstein was concerned that there was no time-effect in Newton's equation. The prediction was that if the Sun disappeared, then the Earth would somehow know about this instantaneously. Einstein did not think this was possible. He concluded that the information on the disappearance of the Sun could only be known by the Earth after a time had passed such that this information could be transferred to the Earth.

At what speed would this information be transferred through space?

....

[1 mark]

e) How long would it take for this information to reach the Earth?

....

....

....

[2 marks]

f) Einstein's model of gravity described space and time and being one thing called space-time. If the Sun disappeared, then this would cause ripples in space-time and the Earth would respond to the disappearance of the Sun once the ripples reached it.

Using Einstein's model of space-time, how is the motion of the earth around the Sun explained.

....

....

....

....

....

[2 marks]

Section B

Answer ONE question only.

You are advised to read BOTH questions before starting your answer and spend no more than 20 minutes on this section

BLANK PAGE

The following material is taken from an article released on 18 December 2007 from the NASA web site.

NASA Announces Discovery of Assault by a Black Hole

A powerful jet from a supermassive black hole is blasting a nearby galaxy, according to new data from NASA observatories. This never-before witnessed galactic violence may have a profound effect on planets in the jet's path and trigger a burst of star birth in its destructive wake.

This real-life scene is playing out in a faraway binary galaxy system known as 3C321. Two galaxies are in orbit around one another. A supermassive black hole at the core of the system's larger galaxy is spewing a jet in the direction of its smaller companion.

Figure 6. A composite image of 3C321.

"We've seen many jets produced by black holes, but this is the first time we've seen one punch into another galaxy," says Dan Evans, a scientist at the Harvard-Smithsonian Centre for Astrophysics and leader of the study. "This jet could be causing all sorts of problems for the smaller galaxy."

Jets from super massive black holes produce large amounts of radiation, especially high-energy X-rays and gamma-rays, which can be lethal in large quantities. The combined effects of this radiation and particles travelling at almost the speed of light could severely damage the atmospheres of planets lying in the path of the jet. For example, protective layers of ozone in the upper atmosphere of planets could be destroyed.

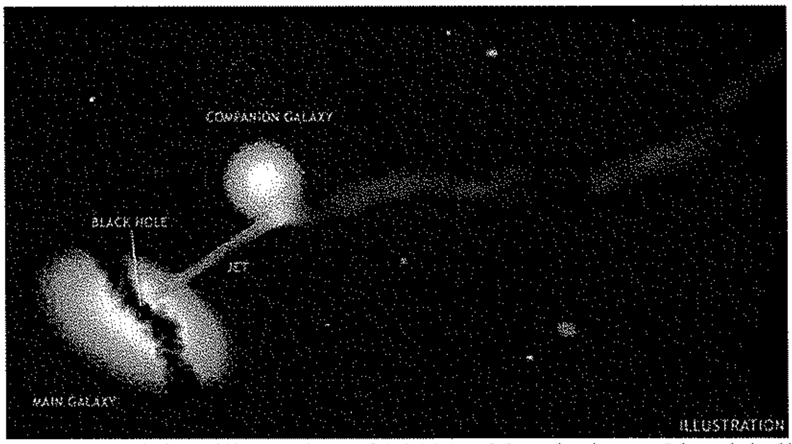

Figure 7. An artist's illustration of 3C321 with galaxies and jets labelled.

The effect of the jet on the companion galaxy is likely to be substantial, because the galaxies in 3C321 are extremely close at a distance of only about 20,000 light years apart. They lie approximately the same distance as Earth is from the centre of the Milky Way galaxy.

It's possible that the event is not all bad news for the beleaguered galaxy. The massive influx of energy and radiation from the jet could spark the formation of large numbers of stars and planets after its initial wake of destruction is complete. In the distant future, say researchers, whole new star systems may have the lethal jet to thank for their very existence.

NASA Announces Discovery of Assault by a Black Hole

The article discusses the jet of energy emitted from a supermassive black hole.

a) Define the following terms used in the article:

Black Hole : ....

....

....

Galaxy : ....

....

....

[2 marks]

b) In what way is a supermassive black hole different to a 'normal' black hole?

....

....

[1 mark]

c) The article comments on the fact that the supermassive black hole is emitting a jet of radiation.

Give TWO examples of the constituents of this radiation:

....

....

....

[2 marks]

d) It is thought that there is a supermassive black hole at the centre of all galaxies although few show signs of jets. Explain the reason why, in the case of 3C321, a jet of radiation is being emitted?

....

....

....

....

....

....

[2 marks]

e) The two main types of galaxy showing spectral excess are 'Active Galaxies' and 'Starburst Galaxies'. State and explain which of these two galaxies is more likely to describe the situation in 3C321?

....

....

....

....

....

[2 marks]

f) What is the distance between the galaxies in 3C321. Give your answer in both light years and metres.

....

....

Distance = ... lights years.

Distance = ... m

[1 mark]

g) The mass of the Milky Way is approximately $10^{11}M_{\odot}$. If the two galaxies in 3C321 were of the same mass as the Milky Way, what would be the force of gravity between them?

....

....

....

....

....

[2 marks]

h) The article refers to the possibility that the ozone layer in the upper atmosphere of planets could be destroyed for any planet in the path of the jet.

Explain why the energy of this jet does not decrease in proportion to r^2 as in the case of the Sun's radiation intensity.

....

....

....

....

[1 mark]

i) What is ozone?

....

....

[1 mark]

j) Explain how such radiation could destroy an ozone layer.

....

....

....

[2 marks]

k) If such an ozone layer did exist on a planet, what might this indicate about the planet?

....

....

....

[2 marks]

l) Explain how such a jet might "… spark the formation of large numbers of stars … ".

....

....

....

....

....

....

[2 marks]

**END OF QUESTION **

The following material is taken from an article released on 29 March 2007 from the NASA web site.

Big Auroras on Jupiter

So you thought Northern Lights were big in Alaska? "That's nothing," says Randy Gladstone of the Southwest Research Institute in San Antonio, Texas. "Jupiter has auroras bigger than our entire planet."

Last month, Gladstone and colleagues used NASA's Chandra X-ray Observatory to capture this picture:

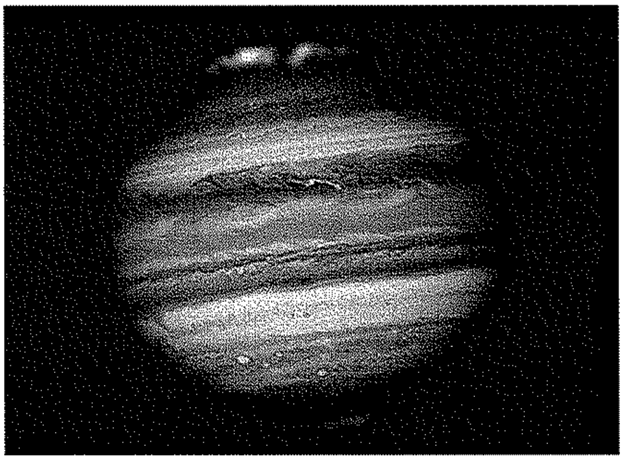

Figure 8. X-ray auroras observed by the Chandra X-ray Observatory overlaid on a simultaneous optical image from the Hubble Space Telescope.

The purple ring traces Jupiter's X-ray auroras. Gladstone calls them "Northern Lights on steroids. They're hundreds of times more energetic than auroras on Earth."

Chandra has observed Jupiter's auroras many times before, but this recent dataset is exceptional both in length and quality. Gladstone hopes it will help him solve some mysteries lingering for almost 30 years.

Jupiter's auroras were discovered by the Voyager 1 spacecraft in 1979. A thin ring of light on Jupiter's nightside looked like a stretched-out version of our own auroras on Earth. But those early photos merely hinted at the power involved. The real action, astronomers soon learned, was taking place at high-energy wavelengths invisible to the human eye. In the 1990s, ultraviolet cameras on the Hubble Space Telescope photographed raging lights thousands of times more intense than anything ever seen on Earth, while X-ray observatories saw auroral bands and curtains bigger than Earth itself.

Jupiter's hyper-auroras never stop. "We see them every time we look," says Gladstone. You don't see auroras in Alaska every time you look, yet on Jupiter the Northern Lights always seem to be "on."

Gladstone explains the difference: On Earth, the most intense auroras are caused by solar storms. An explosion on the sun hurls a billion-ton cloud of gas in our direction, and a few days later, it hits. Charged particles rain down on the upper atmosphere, causing the air to glow red, green and purple. On Jupiter, however, the sun is not required. "Jupiter is able to generate its own lights," says Gladstone.

The process begins with Jupiter's spin: The giant planet turns on it axis once every 10 hours and drags its planetary magnetic field around with it. As any science hobbyist knows, spinning a magnet is a great way to generate a few volts—it's the basic principle of DC motors. Jupiter's spin produces 10 *million* volts around its poles.

"Jupiter's polar regions are crackling with electricity," says Gladstone, "and this sets the stage for non-stop auroras."

The polar electric fields grab any charged particles they can find and slam them into the atmosphere. Particles for slamming can come from the sun, but Jupiter has another, more abundant source nearby: the volcanic moon Io, which spews oxygen and sulfur ions (O^+ and S^+) into Jupiter's spinning magnetic field.

Figure 9. A volcano on Io, photographed by New Horizons in Feb. 2007.

Somehow, these ions make their way to Jupiter's poles where electric fields send them hurtling toward the planet below. Upon entering the atmosphere, "their electrons are first stripped away by molecules they run into, but as they slow down they start grabbing electrons back. The 'charge exchange reaction' produces intense X-ray auroras," he explains.

"Jupiter's auroras have never been observed by so many telescopes at once," says Gladstone. "I'm really excited by these data, and the analysis is just beginning."

Big Auroras on Jupiter

a) Define the following terms used in the article:

Auroras : ....

....

....

Nightside : ....

....

....

[2 marks]

b) Figure 8 shows banding on the image of Jupiter. Explain what this banding indicates.

....

....

....

....

....

[2 marks]

c) Explain why the auroras discussed in the article can not be seen with a normal telescope.

....

....

....

[2 marks]

d) The article refers to solar storms sending material from the Sun to the Earth in a few days. If the time taken was 2 days, what is the average speed of this material?

....

....

....

....

[3 marks]

e) In reality, the material from the Sun leaves the photosphere at a speed higher than that calculated in (d) and it reaches a distance of 1AU with a slower speed. Explain why the speed decreases with distance from the Sun.

....

....

....

....

[2 marks]

f) Jupiter has an orbital distance of 5.2AU. Calculate how much weaker the solar flux density is at this distance compared with its value for the Earth.

....

....

....

....

[2 marks]

g) Explain why it is expected that Jupiter will show differential rotation.

....

....

....

....

....

[2 marks]

h) How would you expect this type of motion to change the planet's magnetic field with time?

....

....

....

....

[1 mark]

i) Despite the reduced solar flux, Jupiter seems to have a plentiful supply of charged particles. Where do these come form?

....

....

....

[2 marks]

j) Why is such a source of material unlikely to be applicable for the Earth?

....

....

....

[2 marks]

** END OF QUESTION **

END OF EXAMINATION PAPER