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Astronomy
STANDARD LEVEL
Paper 2

Friday 29 April 2011 (morning)

90 minutes

MARKING SCHEME

INSTRUCTIONS TO EXAMINERS

- Items in brackets are not required.
- Significant Figures are ONLY penalised where noted.
- Terms underlined are explicitly required.
- EOR : Evidence Of Rule : normally associated with a methodology used.
- OWTTE : Or Words To That Effect.
- ORA : Or Reverse Argument.

The following information may be useful.

1 AU = 1.496×10^{11} m

1 parsec = 206265 AU = 3.09×10^{16} m = 3.26 light years

1 light year = 0.307 parsecs = 9.47×10^{15} m

$c = 3 \times 10^{8}$ m s^{-1}

$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

$L_{\odot} \approx 3.84 \times 10^{26}$ W

$T_{\odot} \approx 5770$ K

$M_{\odot} \approx 1.99 \times 10^{30}$ kg

$R_{\odot} \approx 6.96 \times 10^{8}$ m

$H_o \approx 72$ km s^{-1} Mpc^{-1}

$$z = \frac{H_o}{c} d$$

$$F = \frac{L}{4\pi d^2}$$

$$c = f\lambda$$

$$\lambda_{max} = \frac{2.90 \times 10^{-3}}{T}$$

$$PE = -\frac{GMm}{r}$$

$$E = mc^2$$

$$d = \frac{1}{\phi}$$

$$\frac{b_1}{b_2} = 2.5^{(m_2 - m_1)}$$

Section A
Answer ALL questions

1. This question is about Cepheid variables.

A Cepheid variable is a giant star and they constitute about two thirds of all variable stars. Figure 1 Shows the variation of the apparent magnitude as a function of time.

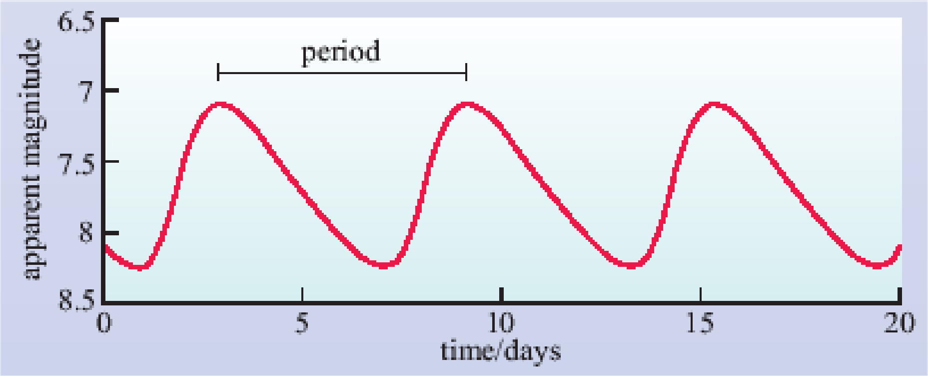


Figure 1. The variation of apparent magnitude for a Cepheid variable.

a) Briefly explain what causes the star's luminosity to vary in the way show in Figure 1.

ANSWER:

[1] : Any ONE from:

- **The size / diameter / radius of the star / photosphere changes**
- **And so, the temperature changes**
- **As a result of the ionisation of helium.**
- **The different ionisation of helium/material changes the opacity.**

b) Using Figure 1, estimate the maximum apparent magnitude, minimum apparent magnitude and period for the Cepheid.

ANSWER:

[1] : Brightest apparent magnitude : 7.0 – 7.1

Faintest apparent magnitude : 8.20 - 8.30

BOTH answers must be the right way round AND within the tolerances stated.

[1] : Period of variation : 6.0 – 6.5 days

c) Using your values for apparent magnitude, show that the ratio of maximum to minimum brightness for the Cepheid is approximately 3.2.

ANSWER:

The difference in Magnitude = (8.2–7.1) to (8.3-7.0) = 1.1 to 1.3

This means that the ratio of the brightness values is given by

$$\frac{b_1}{b_2} = 2.5^{(m_2 - m_1)} = 2.5^{(1.1 \text{ to } 1.3)} = 2.7 \text{ to } 3.3$$

[1] : Δm = 1.1 to 1.3

[1] : evaluation of $\frac{b_1}{b_2}$

d) Figure 2 shows how the Cepheid is used as a standard candle. This Figure indicates how the luminosity and period are related.

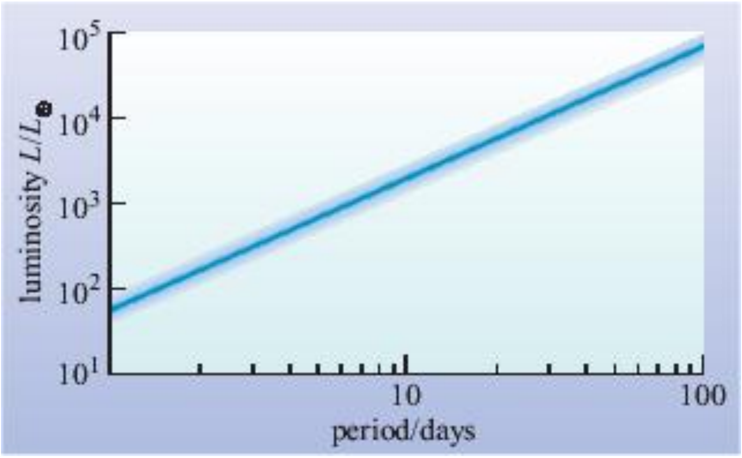
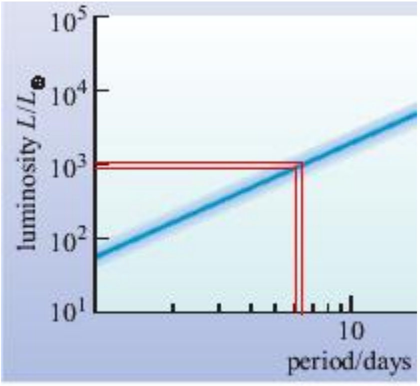


Figure 2. Luminosity – Period relationship for a Cepheid variable.

Use Figure 2 to find the luminosity of the Cepheid – ensure that you make it clear how you have come to your answer and express your answer in multiples of the solar luminosity.

ANSWER:



L = 900 to 1100 solar luminosities

[1] : indications on the Figure.

[1] : $\dfrac{\text{Luminosity}}{\text{Solar Luminosity}} = 900 \text{ to } 1100$

e) If the luminosity of a star is known and the flux density is measured, the distance to the star can be found.

Given that the flux density of the Cepheid is 3.2×10^{-6} W/m^2, show that the distance to the Cepheid is approximately 1.0×10^{17}m.

ANSWER:

$L = 1000 \times 3.84 \times 10^{26} = 3.84 \times 10^{29}$ W

$$\text{Using } F = \frac{L}{4\pi d^2} \quad \text{gives} \quad d = \sqrt{\frac{L}{4\pi F}} = \sqrt{\frac{3.84 \times 10^{29}}{4\pi \times 3.2 \times 10^{-6}}} = 9.77 \times 10^{16} \text{ m}$$

[1] : $L = 1000 \times 3.84 \times 10^{26} / 3.84 \times 10^{29}$

[1] : Evaluation (accept any value from 9.3×10^{16} **m to** 1.1×10^{17} **m)**

2. This question is about comets.

Comets typically consists of a compact nucleus, an atmosphere of gas and dust (the *coma*) and a tail directed away from the Sun. The comet is made of lumps of ice mixed with silicate particles.

It is said that:

... the path of a comet around the Sun has a large eccentricity.

a) Explain the above statement.

ANSWER:

Any ONE from:

- **The orbit is very elliptical.**
- **The semi-major axis is much greater than the semi-minor axis.**
- **The orbit deviates by a large amount from a circle.**

b) Figure 3 shows part of the path of a comet close to the Sun.

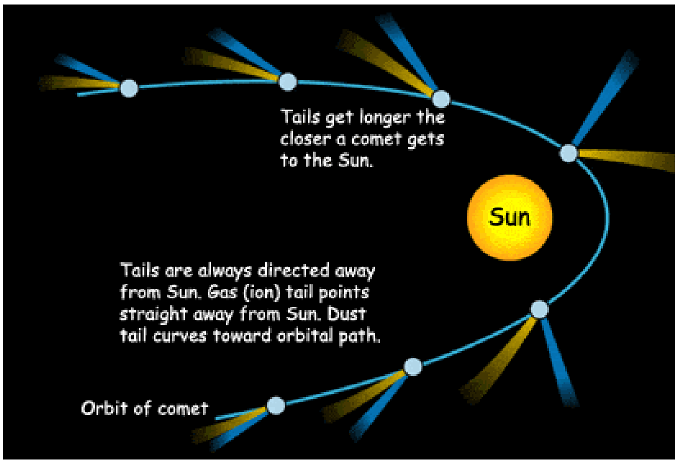


Figure 3. A comet's path close to the Sun.

Briefly explain why the comet's speed is seen to increase as it approaches the Sun.

ANSWER:

[2] : Any TWO from:

- **The comet is losing gravitational potential energy.**
- **(As a result of) conservation of energy ...**
- **... the kinetic energy is increasing.**

Note: Ignore answers based on a description of the gravitational force.

c) Briefly explain why the comet's tail becomes more extended when it is closer to the Sun.

ANSWER:

[2] : Any TWO from

- **The comet is moving faster / has a higher speed / has a greater kinetic energy.**
- **The solar radiation has a greater intensity.**
- **The comet disintegrates / sublimes / evaporates faster.**

d) There are two types of comet, called *long-period* and *short-period*. Explain the difference between these two types.

ANSWER:

[1] : Short-period comets - Any ONE from:

- **They will be seen more than once in the lifetime of a person.**
- **They have periods up to around 100 years.**
- **They have a period less than about 200y.**
- **They come from the Kuiper belt.**

[1] : Long-period comets - Any ONE from:

- **They will only ever be seen once.**
- **Their period (around the Sun) is millions of years.**

Note: NOT "They come from the Oort Cloud" since this is in the key to the next question.

e) Long-Period comets are thought to be predominantly from the Oort Cloud. This cloud probably forms the outer limit of the solar system. Comets are periodically sent from this cloud towards the Sun.

Explain how this periodic influence on the Oort cloud may be occurring.

ANSWER:

[1] : It is a result of a gravitational influence on the Oort cloud ...

[1] : Any ONE of ...

- **... as a result of passing through the disc of the Milky way.**
- **... due to the periodic influence of passing stars.**

f) Briefly explain why it is thought that comets may have played an important role in the development of life on the planet Earth.

ANSWER:

[1] : Any ONE from:

- **They seeded the planet with chemicals needs to develop life (OWTTE).**
- **They could deposit water onto the planet.**

3. This question is about the different types of galaxy which are observed in the universe.

The Hubble classification of galactic types described four main types of galaxy:

- Ellipticals (E0 to E7).
- Spirals (barred and unbarred) (Sa to Sc / SBa to SBc).
- Lenticulars.
- Irregulars.

a) Explain what the designations ‘E0’ to ‘E7’ mean.

ANSWER:

[1] : The number designates the eccentricity.
The number indicates the ratio of the major-to-minor axis.
The number indicates how elliptical / *stretched out* the orbit is.
The number is called the flattening factor.
[1] : E0 is for a sphere.
E7 is (thought to be) the largest number.

b) There are two types of spiral galaxy – barred and non-barred. State what causes the observed bar and what it indicates about the galaxy.

ANSWER:

[1] : The hydrogen (gas) is not symmetric about the galaxy / is extended along a line.
[1] : Barrs are considered to be a sign of galactic stability.

c) State Briefly state the similarities and differences between spiral and elliptical galaxies.

ANSWER:

Any [3] from:
Similarities include ...

- **Both are collections of stars.**
- **Both contain very old stars.**

Differences include ...

- **Spirals contain a lot of gas, ellipticals do not.**
- **Spirals have a disc while elliptical do not.**
- **The light output is concentrated at the centre for an elliptical and across the disc (and the spirals) for a spiral galaxy.**
- **Spirals galaxies have spiral arm while elliptical do not / elliptical have a smooth variation of light intensity with position.**

d) Classify the galaxies shown in Figure 4 as precisely as you feel you can. In each case, give a single specific type of galaxy.

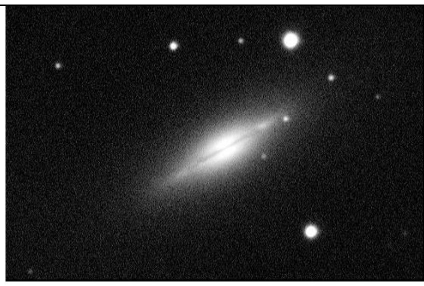
		
Spiral galaxy : Sc **M101 : The Pinwheel Galaxy**	**Elliptical galaxy : E2** **M32**	**Irregular galaxy** **NGC 4038**
		
Irregular galaxy **NGC 1569**	**Spiral galaxy : SBc** **M109**	**Lenticular galaxy : Accept $S0_1$, $S0_2$ or $S0_3$.** **NGC 5866**

Figure 4. Examples of different types of galaxy.

[3 marks]

ANSWERS:

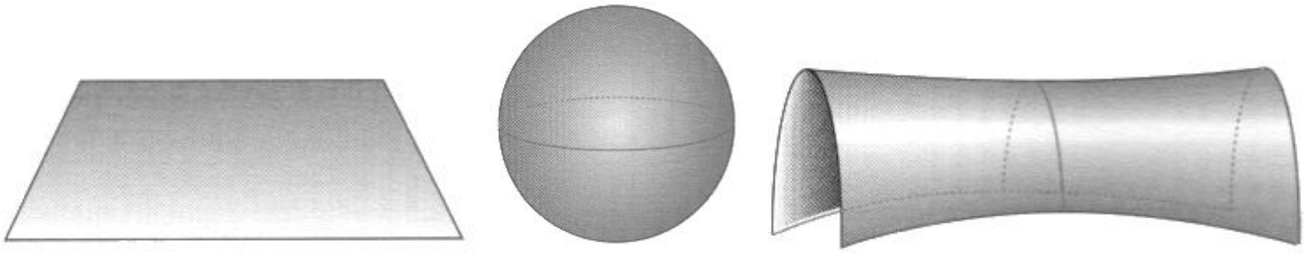
[3] : 1 mark for every two correct answers.

4. This question is about the shape of space-time.

In our present understanding of space-time, the local shape of space-time is distorted by objects with mass. Overall, however, the universe can have one of three possible shapes:

- Flat space-time.
- Spherical space-time.
- Saddle-shaped space-time.

These three shapes are shown in Figure 5.



(a) (b) (c)

Figure 5. Two dimensional representations of the three possible shapes for space-time.

Three tests that could be performed to distinguished between these shapes are:

- Considering parallel straight lines.
- The internal angles of a triangle.
- The circumference of a circle.

a) For each of the tests above, explain how they are able to distinguish between the three possible shapes for space-time :

ANSWER:

[2] : 2 marks for all 3 correct, 1 mark for 1 correct.
Parallel Straight lines:

(a) Flat	(b) Sphere	(c) Saddle
Never cross – they do not intersect	Parallel straight lines do intersect	Parallel straight lines diverge

[2] : 2 marks for all 3 correct, 1 mark for 1 correct.
Internal angles of a triangle:

(a) Flat	(b) Sphere	(c) Saddle
= 180°	> 180°	< 180°

[2] : 2 marks for all 3 correct, 1 mark for 1 correct.
Circumference of a circle:

(a) Flat	(b) Sphere	(c) Saddle
$= 2\pi r$	$< 2\pi r$	$> 2\pi r$

b) The parameter which can be said to distinguish between these three options is the density of space (ρ) compared with what is known as critical density (ρ_o).

For each possible space-time shape, state the conditions placed upon the density of space compared with critical density:

ANSWER:

[2] : 2 marks for all 3 correct, 1 mark for 1 correct.

Flat space-time : $\rho = \rho_o$.

Spherical space-time : $\rho > \rho_o$.

Saddle shaped space-time : $\rho < \rho_o$.

c) For a spherical space-time, briefly explain what this predicts for the continued expansion of the universe.

ANSWER:

[1] : The expansion will stop ...
[1] : ... at infinite time.

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

The following material is taken from an article released on 12 April 2007 from the NASA web site.

Black Hole Eclipse

NASA's Chandra X-ray Observatory has observed a remarkable eclipse of a supermassive black hole, allowing a disk of hot matter swirling around the hole to be measured for the first time.

The supermassive black hole is located in NGC 1365, a spiral galaxy 60 million light years from Earth. It contains a so-called active galactic nucleus, or AGN. Scientists believe that a black hole at the centre of the AGN is fed a steady stream of material from a surrounding disk. Matter just about to fall into a black hole should be heated to millions of degrees before passing over the event horizon, or point of no return. This super-heated disk material glows brightly in the X-ray part of the electromagnetic spectrum where Chandra can see it.

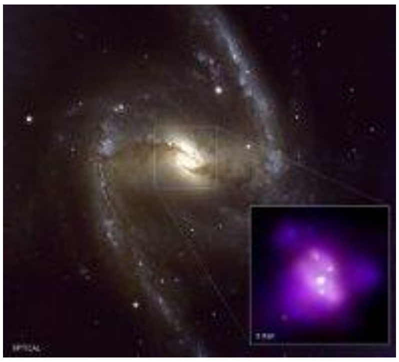


Figure 6. The black hole eclipse occurred in the core of this barred spiral galaxy, NGC 1365.

The disk of gas around the central black hole in NGC 1365 is much too small to resolve directly with a telescope. However, the disk was eclipsed by an intervening cloud. By recording the time taken for the disk to go in and out of eclipse, scientists were able to estimate the diameter of the disk.

The Chandra team directly measured the diameter of the X-ray source as about seven times the distance between the Sun and the Earth or 7 AU. For comparison, if such a disk were placed in our own solar system, it would swallow all the planets out to Mars and most of the asteroid belt as well.

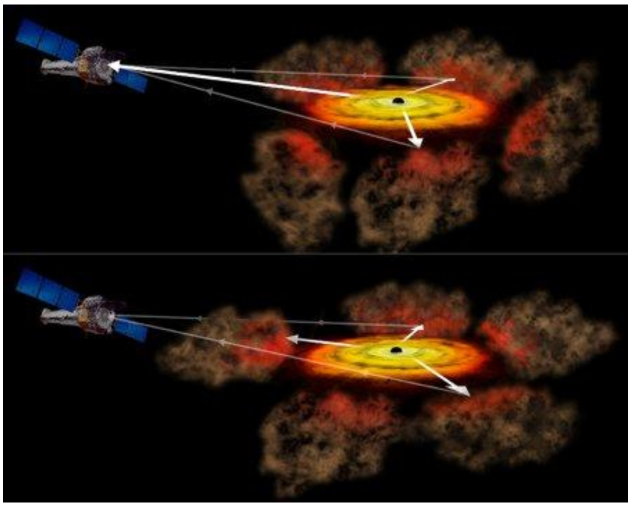


Figure 7. An artist's concept of Chandra observing the black hole eclipse.

According to these measurements, the source of X-rays is about 2 billion times smaller than the host galaxy NGC 1365 and only about 10 times larger than the estimated size of the black hole's event horizon. This is consistent with theoretical predictions.

"Thanks to this eclipse, we were able to probe much closer to the edge of this black hole than anyone has been able to before," said co-author Martin Elvis from CfA. "Material this close in will likely cross the event horizon and disappear from the universe in about a hundred years, a blink of an eye in cosmic terms."

In addition to measuring the size of this disk of material, Risaliti and his colleagues were also able to estimate the location of the dense gas cloud that eclipsed the X-ray source and central black hole. The Chandra data show that this cloud is one hundredth of a light year from the black hole's event horizon--much closer than anyone expected. So this is a bit of a puzzle.

"AGN [are among] the brightest objects in the cosmos and they are powerful probes of the early history of the Universe. It's vital we understand their basic structure," said Risaliti. "It turns out that we still have work to do to understand these monsters."

Black Hole Eclipse

a) Explain the following terms used in the article:

ANSWER:

[1] : Black Hole. Any ONE from
- **The remains of a huge/very big star (after it died).**
- **An object that is so massive that not even light can escape.**
- **An object that has an escape speed/velocity equal to/greater than the speed of light.**

[1] : Spiral Galaxy. Any ONE from
- **A type of galaxy that contains a disc, halo and spiral arms.**

Note: The students answer needs to distinguish between spiral galaxies and all others. If the above comment is made, two of the underlined terms are require for the mark.

[1] : Event horizon. Any ONE from
- **The point near a black hole where light cannot escape.**
- **The point near a black hole where the force of gravity is so large, nothing can escape.**
- **The point around a black hole where $v_{esc} = c$.**

b) How far away is NGC1365 from the Earth? Give your answer in metres.

ANSWER:

$$60 \text{ million lyr} = 60 \times 10^6 \times 9.5 \times 10^{15}$$

$$= 5.7 \times 10^{23} \text{ m}$$

[1] : x 9.5×10^{15}

[1] : 5.7×10^{23} (m)

c) The article speculates that NGC1365 contains an active galactic nucleus (AGN). Give TWO characteristics of an AGN.

QUESTION:

[2] : Any TWO from
- **Located at the centre of a galaxy.**
- **It has a large EM excess / output.**
- **Associated with a supermassive black hole.**
- **It accretes material (into the BH).**
- **Surrounded by dust / gas.**

d) Why is such a high temperature needed in order to generate x-rays?

ANSWER:

Any ONE from:

- **X-rays have a very high frequency.**
- **All objects give out EM radiation.**
- **The frequency of the light is proportional to/increases with T**

e) The material around the AGN will almost certainly contain hydrogen. Tick ONE box below to indicate the form of this hydrogen and explain why you have made this choice.

ANSWER:

Molecular	
Atomic	
Plasma	√

Tick ONE box only

[1] : At very high temperatures, collisions between atoms/molecules will break up the atoms into a plasma.

f) Considering temperature alone, if the temperature of the material falling into the AGN reaches 2,000,000K, do you think nuclear fusion is occurring in the gas. Explain your answer.

ANSWER:

The answer needs to give either YES or NO <u>AND</u> a valid reason. For example ...

[1] : Probably not ...
[1] : ... because the temperature needs to be above 4,000,000K in order to trigger nuclear fusion.

Or

[1] : Probably not ...
[1] : because a temp higher than 2,000,000K is needed to produce kinetic energies higher enough to allow the plasma to get close enough to fuse.

Or

[1] : Possibly (yes) ...
[1] : because there will always be a spread of temperatures and so, some of the material may be at (effective) temperatures above 2,000,000K/of 4,000,000K.

g) The diameter of the event horizon is given as 0.7AU. Use this data to show that the mass of the AGN is approximately 3.5 x 10^{37}kg.

ANSWER:

$$\tfrac{1}{2} mv^2 = \frac{GMm}{r}$$

At the event horizon, $v_{esc} = c$ so,

$$M = \frac{Rc^2}{2G} = \frac{0.7}{2} \cdot \frac{1.5 \times 10^{11} \times (3 \times 10^8)^2}{2 \times 6.67 \times 10^{-11}} = 3.54 \times 10^{37} \text{ kg}$$

[1] : Method mark – can be given for writing down $\tfrac{1}{2} mv^2 = \frac{GMm}{r}$

[1] : $M = \frac{Rc^2}{2G}$

Note: EOR is ok. For example, they could show $\frac{0.7}{2} \cdot \frac{1.5 \times 10^{11} \times (3 \times 10^8)^2}{2 \times 6.67 \times 10^{-11}}$.

[1] : 3.54 x 10^{37} kg

Note: there needs to be evidence that they actually did the calculation – by showing the additional sig fig.

h) If NGC1365 is similar to the Milky Way (Mass approximately $10^{11}M_{\odot}$) what percentage of its mass is contained within the central black hole?

ANSWER:

$$\% \text{ of mass} = \frac{3.5 \times 10^{37}}{10^{11} \times 1.99 \times 10^{30}} \times 100 = 1.8 \times 10^{-2} \%$$

[1] : EOR – formula or numbers.

[1] : 1.8 x 10^{-2} % / 2 x 10^{-2} %

i) The article refers to observations of galaxies such as NGC1365 as probes to the early history of the universe.

When we see NGC1365 now, how long has it taken for this light to reach us? Give your answer in years.

ANSWER:

60 million years.

j) If another civilisation were viewing the same galaxy but from only half the distance, how would you expect their view of the emitted radiation to differ from ours?

ANSWER:

The x-rays would be brighter. On the assumption that the output is symmetrical, the intensity is proportional to $1/r^2$ therefore brightness would be four time different.

[1] : For a valid difference.

[1] : One mark for a numerical aspect to the answer to show that the student has made use of the factor of 2 in the question.

** END OF QUESTION **

The following material is taken from an article released on 11 July 2007 from the NASA web site.

Great Perseids

Got a calendar? Circle this date: Sunday, August 12th. Next to the circle write "*all night*" and "*Meteors!*" Attach the above to your refrigerator in plain view so you won't miss the 2007 Perseid meteor shower.

"It's going to be a great show," says Bill Cooke of NASA's Meteoroid Environment Office at the Marshall Space Flight Centre. "The Moon is new on August 12th--which means no moonlight, dark skies and plenty of meteors." How many? Cooke estimates one or two Perseids per minute at the shower's peak.

Figure 8. A Perseid fireball photographed August 12, 2006, by Pierre Martin of Arnprior, Ontario, Canada.

The source of the shower is Comet Swift-Tuttle. Although the comet is nowhere near Earth, the comet's tail does intersect Earth's orbit. We glide through it every year in August. Tiny bits of comet dust hit Earth's atmosphere travelling 132,000 mph. At that speed, even a smidgen of dust makes a vivid streak of light--a meteor--when it disintegrates. Because Swift-Tuttle's meteors fly out of the constellation Perseus, they are called "Perseids."

"Earthgrazers are long, slow and colourful; they are among the most beautiful of meteors," says Cooke. He cautions that an hour of watching may net only a few of these--"at most"--but seeing even one makes the long night worthwhile.

As the night unfolds, Perseus climbs higher and the meteor rate will increase many-fold. "By 2 am on Monday morning, August 13th, dozens of Perseids may be flitting across the sky every hour." The crescendo comes before dawn when rates could exceed a meteor a minute.

For maximum effect, Cooke advises, "get away from city lights." The brightest Perseids *can* be seen from cities, he allows, but the greater flurry of faint, delicate meteors is visible only from the countryside. Scouts, this is a good time to go camping.

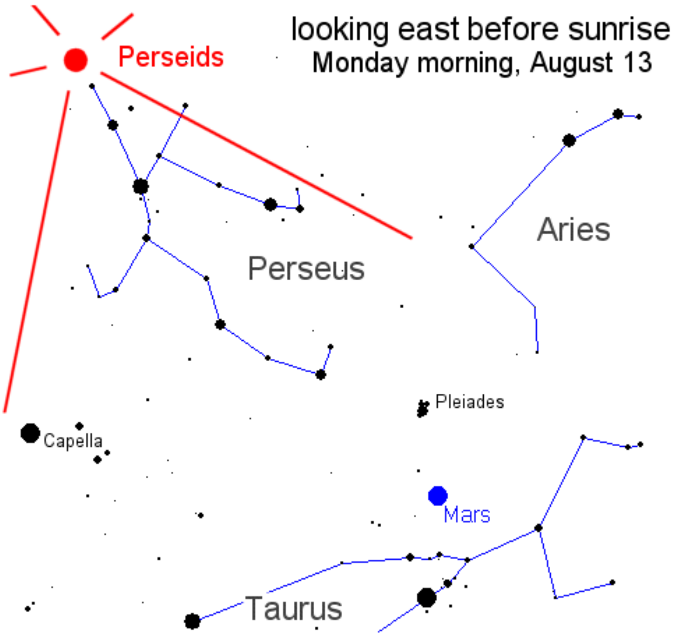


Figure 9. The eastern sky, viewed during the hours before sunrise on Monday, Aug. 13, 2007.

And there's a bonus: Mars. In the constellation Taurus, just below Perseus, Mars shines like a bright red star. Many of the Perseids you see on August 12th and 13th will flit right past it. Instead of following the meteor, you may find you have a hard time taking your eyes off Mars. There's something bewitching about it, maybe the red colour or perhaps the fact that it doesn't twinkle like a true star. You stare at Mars and it stares right back.

Earth and Mars are converging for a close encounter in December 2007. NASA is taking advantage by launching a new mission to Mars--the Phoenix Lander. Phoenix will touch down on an arctic plain where it can dig into the ground and investigate layers of soil and ice, searching for, among other things, a habitable zone for primitive microbes. The launch window opens on August 3rd, so by the time the Perseids arrive Phoenix may be hurtling toward the Red Planet. Landing: late Spring 2008.

Great Perseids

a) Explain the following terms used in the article:

ANSWER:

[1] : Comet.

- **Lump of rock and ice in orbit around the sun.**

[1] : Constellation.

- **A collection of stars forming a pattern in the sky.**

b) State one similarity and one difference between a New Moon and a Lunar Eclipse.

ANSWER:

[1] : Similarity: Any valid similarity e.g., In both cases you cannot see the moon.

[1] : Difference: Any valid difference e.g., For a lunar eclipse, the Earth is between the Sun and moon whilst for a new moon, the moon is between the Sun and the Earth.

c) Despite the fact that the comet Swift-Tuttle has long since left the Earth's vicinity, explain why we experience the Perseid meteor shower every August.

ANSWER:

[1] : This is when the Earth moves through the remains / debris / parts of the tail of the comet.

d) When particles of dust enter the Earth's atmosphere, fireballs can occur as shown in Figure 8. Explain how this light is produced.

ANSWER:

[2] : Any TWO from

- **High temperature is produced**
- **Due to friction.**
- **This excites the material (so that light is produced).**

e) Why are such fireballs rarely seen in the daytime?

ANSWER:

[1] : Any ONE from

- **There is too much light (from the Sun).**
- **The fireball is not bright compared with the Sun / daylight.**

f) Consider a dust particle entering the Earth's atmosphere as discussed in (d). One possible fate for the particle is that it grazes the atmosphere, entering the edge and then leaving again, back into space. Describe the two other possible fates for such a particle.

ANSWER:

[1] : It could completely burn up (in the atmosphere).

[1] : It could fall through the atmosphere and hit the Earth.

g) The article refers to the fact that the shower is best viewed away from city lights. Explain why this is

ANSWER:

[1] : light pollution.

[1] : Light pollution is worse/higher near cities (ORA).

h) Briefly discuss another different reason why the Pleiades shower might not be seen in the night sky.

ANSWER:

[1] : Any valid reason e.g., cloud cover.

[1] : The clouds are likely to be closer to Earth than the meteors and so, the light will not be seen / will be obscured.

i) Why does Mars look red in the night sky?

ANSWER

[1] : Any ONE from

- **due to iron oxide.**
- **The surface of Mars is iron oxide rich.**
- **The surface rock of mars is brown/grey in colour.**

Note: Not simply iron.

j) The article comments that Mars looks different to a star in the night sky because it does not twinkle. However, when viewed over a period of many weeks, Mars could be seen to show retrograde motion against the background of stars.

ANSWER:

[2] : Any TWO from

- **Earth's orbital speed is greater than that of Mars.**
- **Earth moves faster than Mars.**
- **Mars is viewed with respect to the (unmoving background) stars.**
- **Retrograde motion happens when Earth overtakes mars.**

[1] ; Retrograde motion is NOT shown with Venus.

NOTE: Students could get one or both of these marks with a good drawing.

k) The final paragraph refers to the proximity of Earth and mars as an opportunity to investigate Mars with the Phoenix Lander. Despite the fact that this would be very costly, give TWO benefits why this exploration would be a good thing to do.

ANSWER:

[2] : Any TWO valid reasons e.g.,

- **To look for (signs of) life.**
- **To investigate the composition of Mars.**
- **To see if the surface of Mars is like some of the meteorites on Earth.**
- **To explore other planets so humans can colonise.**

** END OF QUESTION **

END OF EXAMINATION PAPER