Diploma Programme
Programme du diplôme
Programa del Diploma

Astronomy
Standard level
Paper 2

Friday 29 April 2016 (morning)

Candidate session number

1 hour 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer one question.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- The maximum mark for this examination paper is **[60 marks]**.

21 pages

2216 – 9005

You may find the following information useful

$1\,\text{AU} = 1.5 \times 10^{11}\ \text{m}$

$H_0 \approx 72\ \text{km s}^{-1}\ \text{Mpc}^{-1}$

1 light year $= 0.31$ parsecs $= 9.5 \times 10^{15}\ \text{m}$

$c = 3.00 \times 10^{8}\,\text{m s}^{-1}$

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

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

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

$T_{\odot} \approx 5770\,\text{K}$

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

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

$k = 1.38 \times 10^{-23}\ \text{JK}^{-1}$

$M_{\oplus} = 5.98 \times 10^{24}\ \text{kg}$

1 parsec $= 206\,265\,\text{AU} = 3.1 \times 10^{16}\,\text{m} = 3.3$ light years

$1^{\circ} = 3600$ arc-sec $= 1.75 \times 10^{-2}$ rads

$$M_J = \frac{9}{4}\left(\frac{1}{2\pi n}\right)^{\frac{1}{2}} \frac{1}{m^2}\left(\frac{kT}{G}\right)^{\frac{3}{2}}$$

$$F = \frac{GM_1M_2}{r^2}$$

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2}$$

$$v = \frac{d}{t}$$

$$z = \frac{H_0}{c} d = \frac{\lambda_{\text{obs}} - \lambda_{\text{em}}}{\lambda_{\text{em}}}$$

$$F = ma$$

$$c = f\lambda$$

$$\text{KE} = \frac{1}{2}mv^2$$

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

$$\text{GPE} = mgh$$

$$v_{\text{esc}} = \sqrt{\frac{2GM}{R}}$$

$$m_{\text{B}} - m_{\text{A}} = -2.5\log\left[\frac{b_{\text{B}}}{b_{\text{A}}}\right]$$

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

$$E = mc^2$$

$$L \approx 4\pi R^2 \sigma T^4$$

$$L = F.4\pi d^2$$

$$\text{f} = \frac{[\text{a} - \text{b}]}{\text{a}}$$

$$N = R \,.\, f_{\text{p}} \,.\, n_{\text{e}} \,.\, f_{\text{l}} \,.\, f_{\text{i}} \,.\, f_{\text{c}} \,.\, L$$

$$L.\theta = d$$

Please **do not** write on this page.

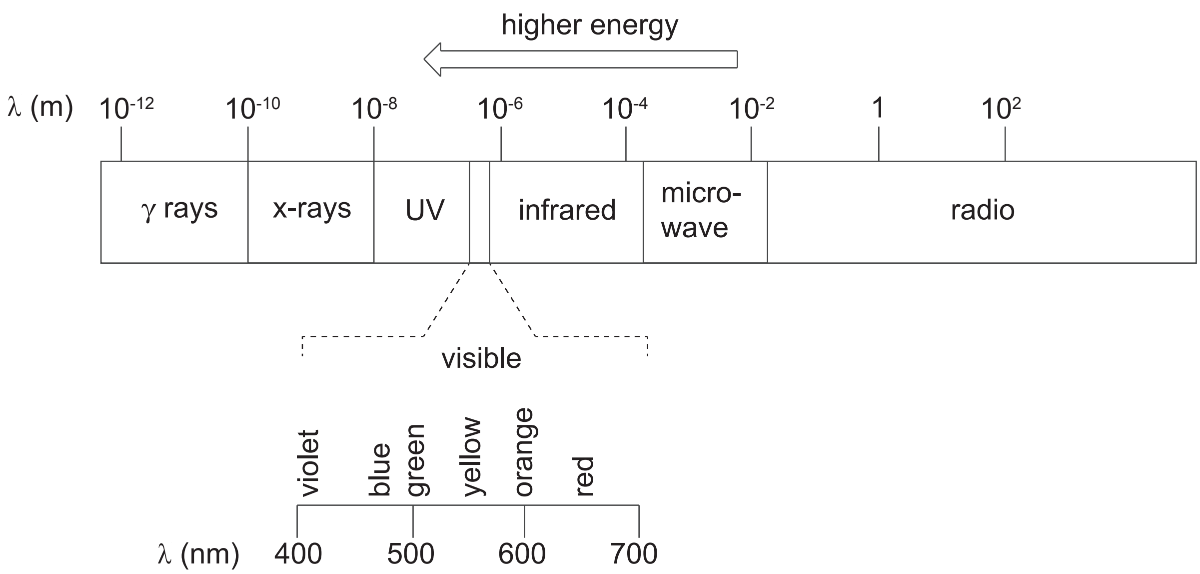
Answers written on this page
will not be marked.

Section A

Answer **all** questions. Write your answers in the boxes provided.

1. This question is about sources of electromagnetic radiation.

Figure 1: The electromagnetic spectrum



[Source: http://chemwiki.com]

The electromagnetic output of a tungsten filament lamp is close to a black-body radiation curve.

(a) Calculate the wavelength of the peak of the spectrum of a tungsten filament lamp at a temperature of 2300 °C. [3]

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(b) Identify where on the electromagnetic spectrum tungsten's peak emission lies. [1]

. . . .

(c) Explain if the composition of the filament of the lamp can be determined by studying its emitted spectrum. [2]

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

Figure 2 shows a different type of domestic light source – a neon lamp. Such lamps have a red colour and their most common use is in advertising.

Figure 2: Neon lights

[Source: https://upload.wikimedia.org/wikipedia/commons]

The lamp consists of a container with a low pressure neon gas. When switched on, electrons flow through the tube, collide with and excite the neon atoms which emit radiation as they relax. The glass tube and its contents appear to be transparent.

(d) Explain why emission from a neon lamp is not likely to follow a black-body radiation output. [2]

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(e) State what sort of spectrum you would expect to be produced by a neon lamp. [1]

. . . .

. . . .

(f) Outline why the composition of the gas can be determined by studying the emitted spectrum. [1]

. . . .

. . . .

. . . .

2. This question is about planet development within the early solar nebula.

In the 19th century, the astronomical world was engaged in a quest to find a planet which was thought to orbit the Sun within the orbit of Mercury. The planet was called Vulcan and it was inferred from an anomalous movement of Mercury around the Sun, not predicted by Newton's laws.

(a) On the assumption that Vulcan did exist, explain if you expect it to be primarily a rocky or gas planet. Your answer should refer to the nebula theory for the creation of the solar system. [2]

. . . .

. . . .

. . . .

(b) Calculate the planet's mass, in kg, if Vulcan's radius was 1800 km and its density 5000 kg m^{-3}. Express your answer to **two** significant figures. [2]

. . . .

. . . .

. . . .

(c) Calculate Vulcan's escape velocity, in km s^{-1}. [2]

. . . .

. . . .

. . . .

(d) Compare quantitatively Vulcan's escape velocity to the Earth's value of 11 km s^{-1}. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 2 continued)

(e) With reference to your answer to (d), predict, giving a reason, how the density of Vulcan's atmosphere would compare to that of the Earth. [1]

. . . .
. . . .
. . . .

(f) It was thought that the initial atmosphere of Vulcan was largely hydrogen and helium gas. Describe the process which stripped this atmosphere from the planet. [2]

. . . .
. . . .
. . . .

3. This question is about using standard candles to measure the distances of galaxies.

A standard candle is an object that has a known luminosity due to some characteristic effect or property.

One such object is a type 1a supernova, which has a peak luminosity taken to be $5.50 \times 10^{9} L_{\odot}$.

(a) A supernova has a measured peak brightness of 1.4×10^{-13} W m^{-2}. Show, using this data, that the distance to the supernova is approximately 1×10^{24} m. Assume the radiation is not affected by the interstellar medium. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Calculate the new distance if the brightness of the supernova had been reduced by 15 % as a result of the interstellar medium. [2]

. . . .

. . . .

. . . .

. . . .

(c) State **two** ways in which the interstellar medium could reduce the energy reaching the Earth. [2]

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 3 continued)

(d) This method of using a type 1a supernova as a standard candle is only useful up to a maximum distance of around 1000 Mpc. Outline why it cannot be used above this distance. [1]

. . . .

. . . .

(e) Outline the method used to calculate distances above 1000 Mpc. [2]

. . . .

. . . .

. . . .

. . . .

4. This question is about cosmological red-shift.

Figure 3 shows the Andromeda galaxy – thought to be the largest galaxy in the local group.

Figure 3: The Andromeda galaxy

[Source: https://upload.wikimedia.org/wikipedia/commons]

The measured distance to Andromeda is 2.40×10^{22} m, its motion in this question is considered to be completely radial and it has a measured red-shift of –0.001001.

(a) Explain the significance of the negative value for the measured red-shift of Andromeda. [2]

. . . .

. . . .

(b) Calculate the cosmological red-shift for Andromeda using Hubble's law. [2]

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 4 continued)

(c) Using the measured red-shift and the answer to (b), calculate Andromeda's red-shift due to its motion through space, **and** its actual speed travelling through spacetime. [2]

Andromeda's red-shift: . . . .

. . . .

Actual speed: . . . .

. . . .

(d) Predict, giving a reason, if there is a limit to the theoretical value that the cosmological red-shift can take. [2]

. . . .

. . . .

. . . .

. . . .

(e) If the relative speed of Andromeda were to remain a constant, calculate how long it will take before it collides with the Milky Way. Express your answer to the nearest 0.1 billion years. [2]

. . . .

. . . .

. . . .

. . . .

Section B

Answer **one** question. Write your answers in the boxes provided.

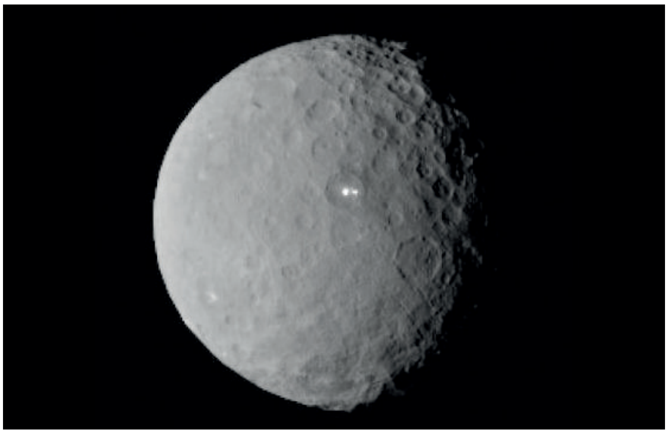
5.

"Bright spot" on Ceres has dimmer companion

Dwarf planet Ceres continues to puzzle scientists as NASA's Dawn spacecraft gets closer to being captured into orbit around the object. The latest images from Dawn, taken nearly 29 000 miles (46 000 kilometres) from Ceres, reveal that a bright spot that stands out in previous images lies close to yet another bright area.

"Ceres' bright spot can now be seen to have a companion of lesser brightness, but apparently in the same basin. This may be pointing to a volcano-like origin of the spots, but we will have to wait for better resolution before we can make such geologic interpretations," said Chris Russell, principal investigator for the Dawn mission, based at the University of California, Los Angeles.

Figure 4: The Dwarf planet Ceres



[Source: http://www.nasa.gov]

Using its ion propulsion system, Dawn will enter orbit around Ceres on 6 March. As scientists receive better and better views of the dwarf planet over the next 16 months, they hope to gain a deeper understanding of its origin and evolution by studying its surface. The intriguing bright spots and other interesting features of this captivating world will come into sharper focus.

"The brightest spot continues to be too small to resolve with our camera, but despite its size it is brighter than anything else on Ceres. This is truly unexpected and still a mystery to us," said Andreas Nathues, lead investigator for the framing camera team at the Max Planck Institute for Solar System Research, Gottingen, Germany.

Dawn visited the giant asteroid Vesta from 2011 to 2012, delivering more than 30 000 images of the body along with many other measurements, and providing insights about its composition and geological history. Vesta has an average diameter of 326 miles (525 kilometres), while Ceres has an average diameter of 590 miles (950 kilometres). Vesta and Ceres are the two most massive bodies in the asteroid belt, located between Mars and Jupiter.

Adapted from an article released on the NASA website, 27 February 2015

(a) State **one** similarity and **one** difference between a planet and a dwarf planet. [2]

Similarity: . . . .

. . . .

. . . .

Difference: . . . .

. . . .

. . . .

(b) State the name of a dwarf planet in the solar system that does not belong to the asteroid belt. [1]

. . . .

(c) The asteroid belt is thought to have formed as a result of the proximity of Jupiter. Explain how Jupiter's presence helped form an asteroid belt within the solar system. [3]

. . . .

. . . .

. . . .

. . . .

(d) The mass of Ceres is thought to be $\frac{1}{6370}$ the mass of Earth.

Using this information, show that the mass of Ceres is approximately 9.4×10^{20} kg.

Your answer should be given to **more than two** significant figures. [1]

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 5 continued)

(e) Calculate the gravitational field strength at the surface of Ceres using your answer to (d) and data from the article. [2]

. . . .

. . . .

. . . .

. . . .

(f) Calculate the volume and density of Ceres. [3]

Volume: . . . .

. . . .

. . . .

Density: . . . .

. . . .

. . . .

(g) The article theorizes that the bright spots could have a volcanic-like origin. Suggest how volcanic action could result in bright spots on the surface. [2]

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 5 continued)

(h) The bright spots are close to the centre of what appears to be an impact basin. Suggest how such an impact could lead to bright spots. [2]

. . . .
. . . .
. . . .
. . . .

(i) With reference to your answers to (e) and (f), comment on whether they support the idea of an impact causing the bright spots observed on the surface of Ceres. [2]

. . . .
. . . .
. . . .
. . . .

(j) State **two** reasons for the importance of investigating the events that produced Ceres' bright spots. [2]

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

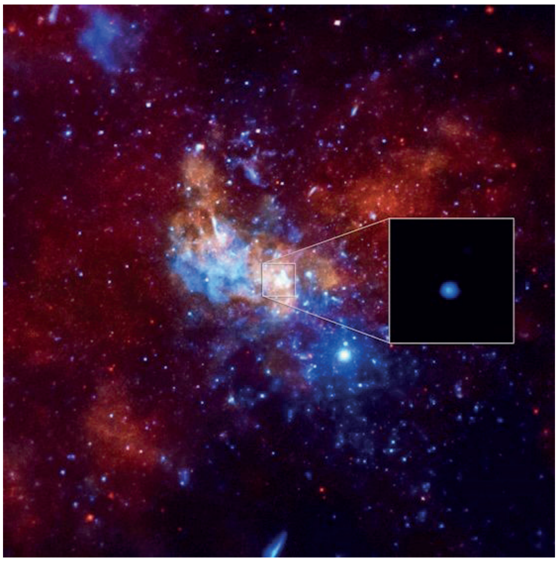
6.

NASA's Chandra detects record-breaking outburst from Milky Way's black hole

Astronomers have observed the largest X-ray flare ever detected from the supermassive black hole at the centre of the Milky Way galaxy. This event, detected by NASA's Chandra X-ray Observatory, raises questions about the behaviour of this giant black hole and its surrounding environment.

The supermassive black hole at the centre of our galaxy, called Sagittarius A*, or Sgr A*, is estimated to contain about 4.5 million times the mass of our sun.

Figure 5: X-ray emission from the centre of the Milky Way



[Source: http://www.nasa.gov/sites]

Astronomers made the unexpected discovery while using Chandra to observe how Sgr A* would react to a nearby cloud of gas known as G2. An X-ray flare was detected from Sgr A* 400 times brighter than its usual, quiet state. Astronomers estimate that G2 was 24 billion km away. The Chandra flare observed was about a hundred times closer to the black hole.

The researchers have two main theories about what caused Sgr A* to erupt. The first is that an asteroid came too close to the supermassive black hole and was torn apart by gravity. The debris from such a tidal disruption became very hot and produced X-rays. "If an asteroid was torn apart, it would go around the black hole for a couple of hours – like water circling an open drain – before falling in," said co-author Fred Baganoff of the Massachusetts Institute of Technology in Cambridge, Massachusetts. A second theory is that the magnetic field lines reconfigure to produce an outburst, in the same way as is seen on the sun.

"The bottom line is the jury is still out on what's causing these giant flares from Sgr A*," said co-author Gabriele Ponti of the Max Planck Institute for Astrophysics in Garching, Germany. "Such rare and extreme events give us a unique chance to use a mere trickle of infalling matter to understand the physics of one of the most bizarre objects in our galaxy."

Adapted from an article released on the NASA website, 6 January 2015

(a) Suggest why the supermassive black hole being observed has the name Sagittarius A*. [1]

. . . .

. . . .

(b) Explain why we cannot actually see what is happening around the very centre of the black hole. [2]

. . . .

. . . .

. . . .

. . . .

(c) Describe the central region of the Milky way which is relevant to this article. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(d) The article states that the X-ray flare was detected from a supermassive black hole. Outline why this statement is likely to be incorrect. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 6 continued)

(e) Suggest the mechanism by which the X-rays may be produced. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(f) Calculate the difference in magnitude between the observed flare and the usual quiet state of Sgr A*. [3]

. . . .

. . . .

. . . .

. . . .

(g) Using information from the article, show that the mass of the supermassive black hole is approximately 9×10^{36} kg.

Your answer should be given to **more than one** significant figure. [1]

. . . .

. . . .

(h) Calculate the distance of the event horizon from the centre of the black hole. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 6 continued)

(i) Calculate the distance between the flare and the event horizon and show that this is approximately the same distance as the orbital radius of Mars, which is 1.52 AU. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

(j) Outline why the X-ray flare is **not** thought to be a danger to the Earth. [1]

. . . .

. . . .

Please **do not** write on this page.

Answers written on this page
will not be marked.

Please **do not** write on this page.

Answers written on this page
will not be marked.

Please **do not** write on this page.

Answers written on this page will not be marked.