M15/4/ASTRO/SP2/ENG/TZ0/XX

Diploma Programme
Programme du diplôme
Programa del Diploma

Astronomy
Standard level
Paper 2

Thursday 30 April 2015 (morning)

Candidate session number

1 hour 30 mintues

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]**.

2215 – 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

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

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

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

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

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

$$F = ma$$

$$c = f\lambda$$

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

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

$$\text{GPE} = mgh$$

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

$$m_B - m_A = -2.5\log\left[\frac{b_B}{b_A}\right]$$

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

$$E = mc^2$$

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

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

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

$$N = R \,.\, f_p \,.\, n_e \,.\, f_l \,.\, f_i \,.\, f_c \,.\, L$$

$$L.\theta = d$$

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Answers written on this page
will not be marked.

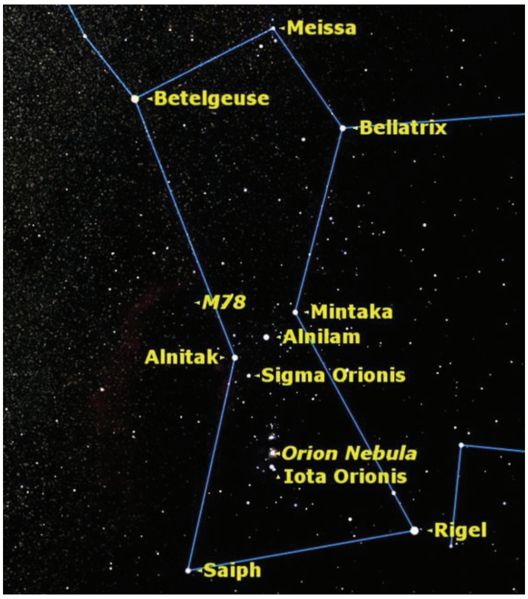
Section A

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

1. This question is about the constellation of Orion.

In modern astronomy, the celestial sphere is divided into 88 constellations, or areas of the sky. Within that structure, there are patterns of stars referred to as asterisms. In the constellations of Orion, there is an asterism referred to as Orion the Hunter, shown in **Figure 1**.

Figure 1: The Hunter asterism



[Sources: http://www.atam.org/OrionMythology.html
http://www.space.com/14566-constellation-orion-rigel-betelgeuse-stars-skywatching.html]

Table 1: Four stars in the constellation of Orion

Star	Apparent magnitude	Distance (ly)	Luminosity (W)	Apparent brightness ($W\ m^{-2}$)	Absolute brightness ($W\ m^{-2}$)	Absolute magnitude
Betelgeuse	0.43	643	4.61×10^{31}	7.19×10^{-8}	4.03×10^{-5}	– 6.7
Rigel	0.18	772	4.84×10^{31}			
Bellatrix	1.62	243	2.46×10^{30}	3.69×10^{-8}	2.05×10^{-6}	– 2.7
Mintaka	2.23	900	3.46×10^{31}	3.78×10^{-8}	2.88×10^{-5}	– 5.0

(This question continues on the following page)

(Question 1 continued)

(a) With reference to the 88 constellations, briefly explain what the term the zodiac refers to. [1]

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(b) By considering the data given in **Table 1**, deduce, giving a reason, which of the four stars would appear to be the brightest in the night sky. [1]

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(c) Calculate the values of apparent brightness, absolute brightness and absolute magnitude for Rigel using the information in **Table 1**. [3]

Apparent brightness: . . . .
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Absolute brightness: . . . .
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Absolute magnitude: . . . .
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(Question 1 continued)

(d) **Table 2** gives the mass of the four stars in solar mass. Assuming all four stars are approximately on the same line directly from the Earth, use the data from **Table 1** and **2** to state, giving a reason, which **two** stars have the strongest gravitational force acting between them. [2]

Table 2: Mass of four stars in Orion

Star	Stellar Mass (solar mass)
Betelgeuse	7.7
Rigel	18
Bellatrix	8.4
Mintaka	20

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(e) Calculate the force between the two stars referred to in (d) and compare your answer to the gravitational attraction between the Earth and the Sun. [3]

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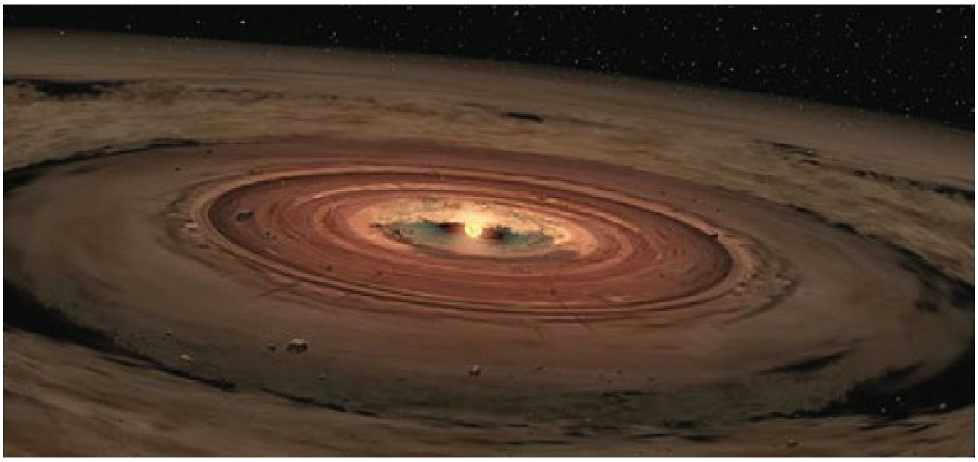
2. This question is about the Nebula theory for the origin of the solar system.

Figure 2: The nebula model for the creation of the solar system



[Source: http://www.universetoday.com/18847/life-of-the-sun]

(a) There are two extremes for the nebula theory – the minimum and maximum model.

Distinguish between these two models with reference to the total mass of the nebula. [2]

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(b) Explain how one of the nebula models discussed in (a) allows us to understand why the Sun has 99.8 % of the mass of the solar system but only a small fraction of its angular momentum. [1]

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(Question 2 continued)

(c) Considering the four fundamental forces of nature, state which one is thought to be responsible for the coagulation of tiny grains within the nebula, to form small planetesimals? [1]

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(d) The coagulation rate will depend on the density of the nebula material. Explain how the coagulation rate is expected to vary with distance from the Sun. [2]

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(e) Considering a nebula containing many planetesimals, explain the term **runaway growth** leading to the formation of a planetary embryo. [2]

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(f) Briefly explain how the accretion mechanisms occurring in the nebula lead to the formation of the Moon around the Earth. [2]

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3. This question is about distance measurements in the universe.

Measuring the distances to nearby galaxies is important in order to understand their properties, their luminosities and their evolution. Name and briefly describe an appropriate method that could be used to measure the distance to each of the classes of objects listed below.

(a) A star 10 parsecs away. [3]

. . . .

(b) Galaxies in the local group. [3]

. . . .

(c) Galaxies beyond the local supercluster. [3]

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(This question continues on the following page)

(Question 3 continued)

Figure 3: The Andromeda galaxy

[Source: http://en.wikipedia.org/wiki/Andromeda_Galaxy]

(d) Early measurements of the brightness of Andromeda estimated its distance from Earth to be approximately 3.5×10^{22} m. It has recently been shown however, to be closer than this.

Explain what effect could have caused the original measurement to be an over-estimate. [1]

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4. This question is about the creation of the universe.

A student attends a lecture on the creation of the universe. A number of points are made which the student makes a note of, in order to ask her teacher when she is back at school.

Consider the following five statements. In each case give a brief answer to explain the point.

(a) The idea of red-shift can be used to explain Olber's paradox. [2]

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(b) Normal red-shift is not the same as cosmological red-shift. [2]

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(c) The universe is assumed to be homogeneous and isotropic. [2]

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(Question 4 continued)

(d) The idea of spacetime means that we do not need a force of gravity in order to explain orbits. [2]

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(e) We know that the universe cannot be too old because it is mainly hydrogen and helium. [2]

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Section B

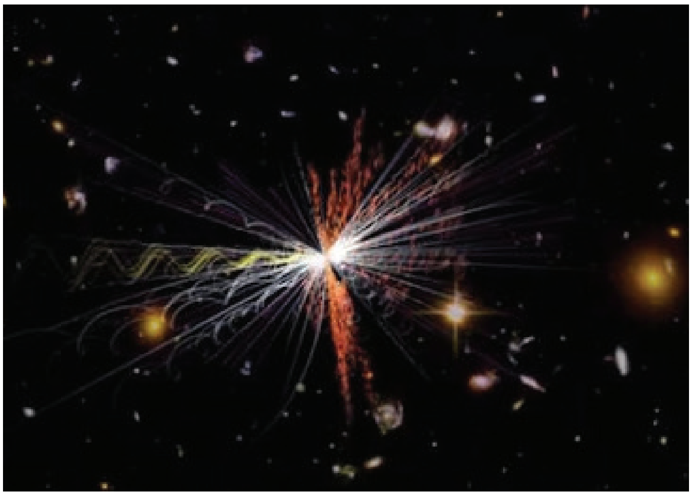
Answer **one** question. Write your answers in the boxes provided.

5.

A whiff of dark matter on the ISS

In science fiction, finding antimatter on board your spaceship is not good news. Usually, it means you're moments away from an explosion. In real life, though, finding antimatter could lead to a Nobel Prize.

On 3 April, researchers led by Nobel Laureate Samuel Ting of MIT announced that the Alpha Magnetic Spectrometer, operating onboard the International Space Station, has counted more than 400,000 positrons, the antimatter equivalent of electrons.



[Source: http://science.nasa.gov/science-news/science-at-nasa/2013/14apr_ams]

"These data show the existence of a new physical phenomenon," and "it could be a sign of dark matter."

In its first 18 months of operations, the AMS analyzed 25 billion cosmic ray events. Of these, an unprecedented number were unambiguously identified as positrons.

Cosmic rays are subatomic particles such as protons and helium nuclei accelerated to near-light speed by supernova explosions and other violent events in the cosmos. Researchers have long known that cosmic rays contain a sprinkling of antimatter. But where do the positrons come from? The Universe is almost completely devoid of antimatter, so the positron fraction of cosmic ray electrons, near 10 %, is surprising.

One explanation is dark matter. Astronomers know that the vast majority of the material Universe is actually made of dark matter rather than ordinary matter. They just don't know what dark matter is. It exerts gravity, but emits no light. A leading theory holds that dark matter is made of a particle called the neutralino. Collisions between neutralinos should produce a large number of high-energy positrons, which the AMS should be able to detect with unprecedented sensitivity.

"So far the evidence supports the hypothesis of dark matter. But," Ting cautions, "it does not rule out another possibility – pulsars." Pulsars are strongly-magnetized neutron stars formed in the aftermath of supernova explosions. They can spin on their axes thousands of times a second, flinging particles into space. Among these particles are pairs of electrons and positrons. AMS can distinguish between pulsars and dark matter but more data at higher energies is needed. "To decide which is the correct explanation. It is only a matter of time, perhaps months or a few years." Between now and then, the mystery of dark matter could be solved, once and for all.

Adapted from an article released on NASA website, 15 April 2013

(a) The article refers to positrons as being the antimatter equivalent of electrons. Using this as an example, if an electron and positron come into contact, they will annihilate.

Briefly explain the term annihilate. [2]

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(b) The equation for such an annihilation event is shown below. Complete this equation by adding the correct numbers on the left and writing down the products on the right. [3]

$$^{\dots\dots}_{\dots\dots}e + ^{\dots\dots}_{\dots\dots}e \rightarrow \dots\dots\dots\dots\dots\dots$$

(c) Calculate the total energy released as a result of this reaction. (Note: The mass of an electron is, $m_e = 9.11 \times 10^{-31}$ kg). You should express your answer in SI units. [2]

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(Question 5 continued)

(d) Calculate how much energy would be released if all of the positrons detected by the AMS were annihilated. [2]

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(e) State what cosmic rays are and briefly explain why they are predominantly protons and helium nuclei. [2]

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(f) Explain the following terms discussed in the article: [6]

Pulsar: . . . .
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Dark Matter: . . . .
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Supernova: . . . .
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(This question continues on the following page)

(Question 5 continued)

(g) State **one** property of neutralinos. [1]

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(h) Briefly state **two** reasons why it is important to identify whether dark matter exists. [2]

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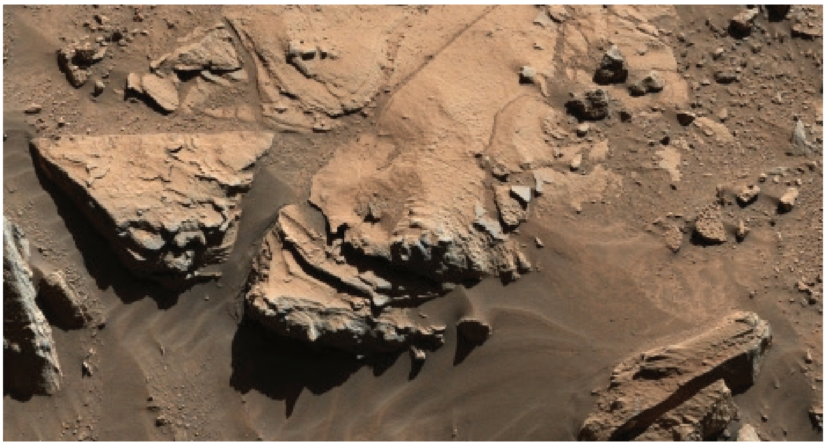
6.

NASA's Curiosity rover drills sandstone slab on Mars



[Source: http://www.jpl.nasa.gov/news/news.php?release=2014-142]

Curiosity is a 900 kg car-sized robotic rover exploring the Gale Crater on Mars. The crater is an estimated 3.4 to 3.8 billion-year-old impact crater, hypothesized to have first been filled in by sediments; first water-deposited, and then wind-deposited, possibly until it was completely covered. Wind erosion then scoured out the sediments, leaving an isolated 5.5 km high mountain at the centre of the 154 km wide crater. Thus, it is believed that the rover may have the opportunity to study two billion years of Martian history in the sediments exposed in the mountain.

Portions of rock powder collected by the hammering drill on NASA's Curiosity Mars rover from a slab of Martian sandstone will be delivered to the rover's internal instruments.

Rover team members at NASA's Jet Propulsion Laboratory, Pasadena, received confirmation of Curiosity's third successful acquisition of a drilled rock sample. The fresh hole in the rock target, visible in images from the rover, is 1.6 cm in diameter and about 6.5 cm deep.

The full-depth hole for sample collection is close to a shallower test hole drilled last week in the same rock, which gave researchers a preview of the interior material as tailings around the hole. "The drill tailings from this rock are darker-toned and less red than we saw at the two previous drill sites," said Jim Bell of Arizona State University. "This suggests that the detailed chemical and mineral analysis that will be coming from Curiosity's other instruments could reveal different materials than we've seen before."

The mission's two previous rock-drilling sites, at mudstone targets in the Yellowknife Bay area, yielded evidence last year of an ancient lakebed environment with key chemical elements and a chemical energy source that long ago provided conditions favourable for microbial life.

Sample material will be sieved, then delivered to onboard laboratories for determining the mineral and chemical composition: the Chemistry and Mineralogy instrument (CheMin) and the Sample Analysis at Mars instrument (SAM). The analysis of the sample may continue as the rover drives on from The Kimberley toward Mount Sharp. One motive for the team's selection of Windjana for drilling is to analyze the cementing material that holds together sand-size grains in this sandstone.

Adapted from an article released on NASA website, 6 May 2014

(a) The rover's weight on the planet is 3.34 kN. Use this information to show that the gravitational field strength on the surface of Mars is almost $4\,N\,kg^{-1}$. [2]

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(b) The planet has an estimated diameter of 6.77×10^6 m. Use this information to show that the mass of Mars is approximately 6×10^{23} kg. [2]

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(c) Calculate the density of Mars. [2]

. . . .

(d) State a single value, with uncertainty, for the age of the Gale Crater. [2]

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(This question continues on the following page)

(Question 6 continued)

(e) If the Earth is 4.5 billion years old, deduce how old the Earth was when the crater was created. State the assumption being made in answering this question. [2]

Age of Earth: . . . .

. . . .

Assumption: . . . .

. . . .

(f) Describe briefly how the impact which produced the Gale Crater could have had an influence on the development of life on Earth. [2]

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(g) Suggest why it is important for the rover to sample from as wide an area as possible. [1]

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(This question continues on the following page)

(Question 6 continued)

(h) Using information from the article, show how the rock taken by Curiosity will be sampling material covering approximately the last 20,000 years of Mars' history. [3]

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(i) Suggest **two** reasons why it is important for mankind to explore other planets by sending Rovers to them. [2]

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(j) Venus is the closest planet to Earth. Explain why Mars was chosen for this exploration and not Venus. [2]

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