M12/4/ASTRO/SP2/ENG/TZ0/XX

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SCHOOL BASED SYLLABUS

ASTRONOMY
STANDARD LEVEL
PAPER 2

Monday 30 April 2012 (morning)

1 hour 30 minutes

Candidate session number

0	0							

Examination code

2	2	1	2	–	9	0	0	4

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]*.

0128

26 pages

The following information may be useful

$1\,\text{AU} = 1.496\times10^{11}\text{ m}$

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

$1\text{ light year} = 0.307\text{ parsecs} = 9.47\times10^{15}\text{ m}$

$c = 3.00\times10^{8}\text{ m s}^{-1}$

$G = 6.67\times10^{-11}\text{ N m}^2\text{ kg}^{-2}$

$\sigma = 5.67\times10^{-8}\text{ W m}^{-2}\text{ K}^{-4}$

$L_\odot \approx 3.84\times10^{26}\text{ W}$

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

$M_\odot \approx 1.99\times10^{30}\text{ kg}$

$R_\odot \approx 6.96\times10^{8}\text{ m}$

$k = 1.38\times10^{-23}\text{ JK}^{-1}$

$M_\oplus = 5.98\times10^{24}\text{ kg}$

$1\text{ parsec} = 206\,265\text{ AU} = 3.09\times10^{16}\text{ m} = 3.26\text{ light years}$

$1^\circ = 3600\text{ arcsec} = 1.75\times10^{-2}\text{ rads}$

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

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

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

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

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

$$F = ma$$

$$c = f\lambda$$

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

$$\lambda_{max} = \frac{2.90\times10^{-3}}{\text{T}}$$

$$\text{GPE} = mgh$$

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

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

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

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

$$E = mc^2$$

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

$$L = F4\pi d^2$$

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

$$L\theta = d$$

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

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

$$\frac{\text{b}_1}{\text{b}_2} = 2.5^{(\text{m}_2-\text{m}_1)}$$

0228

SECTION A

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

1. This question is about the Jeans criteria for contraction of a nebula to form a star.

It is thought that stars are born from a gas cloud which is widely dispersed but condenses due to a gravitational attraction. Sir James Jeans (Figure 1) argued that such a gas could be unstable and contract if its mass were greater than a critical value known as the Jeans mass (M_J).

Figure 1: Sir James Jeans

(a) The value of M_J depends on three parameters, written as n, m and T. For each of these, state what the symbol stands for. *[3]*

n: . . . .

m: . . . .

T: . . . .

(This question continues on the following page)

(Question 1 continued)

(b) The equation for the Jeans mass is shown below. By considering this, tick **one** box in each row of the table below to indicate how each of the three parameters would affect gravitational collapse. *[3]*

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

	… make gravitational collapse **more** likely.	… make gravitational collapse **less** likely.
An increase in *n* would …		
An increase in *m* would …		
An increase in *T* would …		

(c) For a particular cloud with a total mass of 1.0×10^{31} kg, the values of *n*, *m* and *T* are shown below.

$$n = 1.0 \times 10^{9}\,\text{m}^{-3}$$
$$m = 3.4 \times 10^{-27}\,\text{kg}$$
$$T = 100\,\text{K}$$

Show that the value of M_J is approximately 2×10^{32} kg and, therefore, the cloud is not likely to collapse due to gravitational effects. Your answer should be expressed to at least 2 significant figures. *[2]*

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(Question 1 continued)

(d) Such clouds as the one discussed in (c), can be triggered to collapse if some event changes the values of n, m and/or T. One such possible trigger is a supernova explosion.

If a supernova occurred near the cloud in (c) and the result was to compress the cloud so that n increased to $1 \times 10^{13}\,\text{m}^{-3}$, show that the change in the value of M_J now makes the cloud likely to collapse. *[2]*

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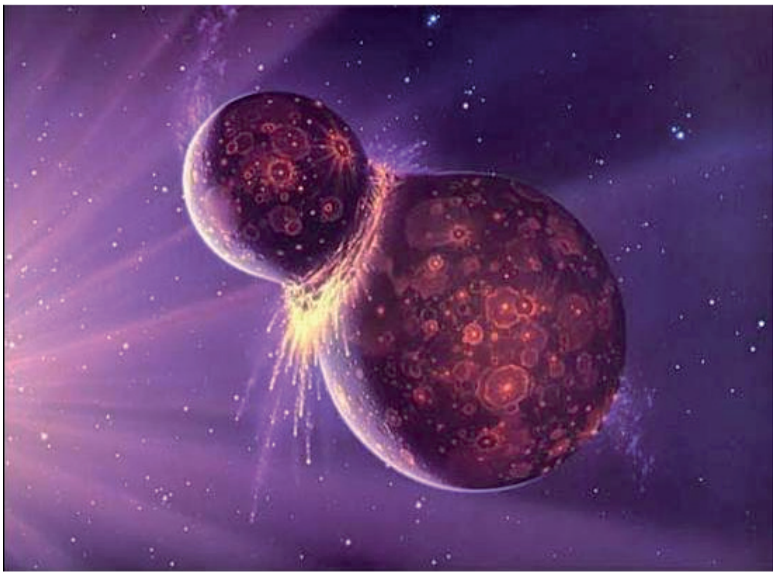
2. This question is about the Moon.

(a) There are two types of satellite, natural and artificial. Complete the table below by giving an example of an artificial satellite in orbit around the Earth. *[1]*

Natural satellite in orbit around the Earth	The Moon
Artificial satellite in orbit around the Earth	

(b) At present, it is felt that the Moon was generated by the last great *giant impact* in which a planetary embryo struck the forming Earth.

Figure 2: Creation of the Moon through a giant impact (artist's impression)



[Source: http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question38.html]

Explain how this impact resulted in the Moon being in orbit around the Earth. *[2]*

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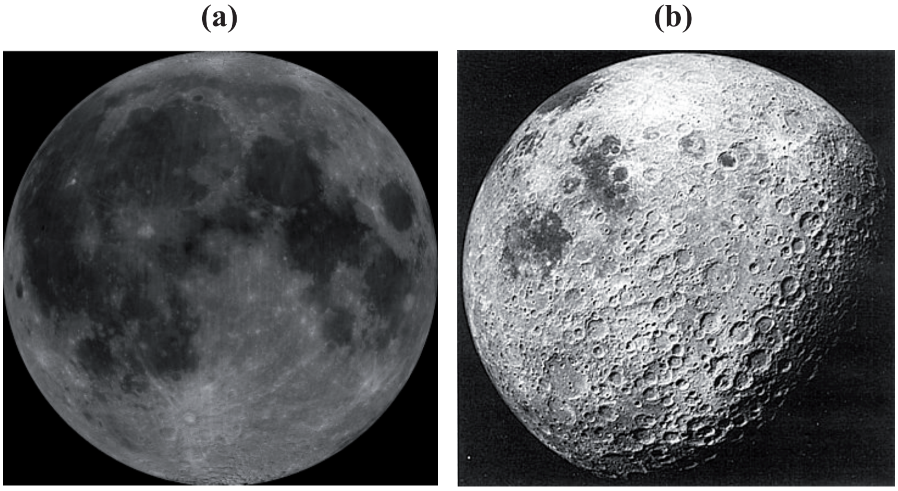
(Question 2 continued)

(c) When viewed, the Moon has two distinct faces, shown in Figure 3.

Figure 3: The front (a) and back (b) faces of the Moon



By considering surface features, state **one** difference between these two faces and explain how this difference is likely to have arisen. *[2]*

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(d) From the Earth, the back face of the Moon is never seen. Explain what this tells us about the orbit of the moon around the Earth. *[2]*

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(Question 2 continued)

(e) During a total lunar eclipse, the Moon is often seen as a faint red disc in the night sky (Figure 4).

Figure 4: A lunar eclipse

Draw a diagram to show how the relative positions of the Earth, Sun and Moon produce a total lunar eclipse. *[1]*

(This question continues on the following page)

(Question 2 continued)

(f) Explain how light gets to the Moon during a total lunar eclipse and so, why the Moon often looks red. *[2]*

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3. This question is about the Milky Way galaxy.

(a) The Milky Way is known as a spiral galaxy (Figure 5).

Figure 5: An impression of the Milky Way galaxy

Spiral galaxies are noted for having three basic parts. One is called the *disc* (which contains the spiral arms). State the other two parts of a spiral galaxy. *[2]*

1: . . . .

2: . . . .

(b) The spiral arms of the Milky Way were once incorrectly thought to be the regions where stars were concentrated. This is now known to be false.

Explain what produces the spiral arms. *[2]*

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(Question 3 continued)

(c) Most of the young (newly formed) stars of the Milky Way lie in the disc. Explain this fact. *[2]*

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(d) It is thought that the spiral arms of the Milky Way are not due to the light output from a fixed set of stars. If this were so, then they would be expected to wind up around the rotating galaxy – a problem known as the winding dilemma.

Explain the generally fixed shape of the spiral arms, hence showing how this dilemma can be explained. *[2]*

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(e) If other stars in the Milky Way are observed, it is seen that those stars which are both behind us and further out from the galactic centre show red-shift. Explain why this observation does **not** mean that the galaxy is expanding. *[2]*

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

There is a theory which suggests that the ultimate fate of the universe will be determined by how strong the gravitational forces are within it. To try to quantify this, it has been found useful to consider the density ρ of the universe compared with the so-called critical density ρ_o.

The critical density is estimated to be approximately $1 \times 10^{-26}\,\text{kg}\,\text{m}^{-3}$. If the universe has an overall average density greater than this, then it is thought that the universe will stop expanding and contract. If the density of the universe is less than this, then the universe will expand forever.

(a) The age of the universe is thought to be 13.8×10^{9} years. Show that this time is approximately equal to $4.4 \times 10^{17}\,\text{s}$. Your answer should be expressed to at least 3 significant figures. *[1]*

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(b) From the moment of the Big Bang, the size of the observable universe has expanded at the speed of light. Using your answer to (a), what would be the radius of the observable universe? Express your answer in metres. *[2]*

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(Question 4 continued)

(c) Assuming that the observable universe has expanded since the Big Bang, equally in all directions, calculate the volume of the visible observable universe. *[2]*

(It may be useful to recall that the volume of a sphere is given by $V = \frac{4}{3}\pi r^3$)

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(d) The number of stars in the observable universe is suggested to be 3×10^{22}. If it is assumed that there is no other significant mass in the universe and if the stars are assumed to have an average mass of $1\,M_{\odot}$, calculate the total mass of the observable universe in kg. Express your answer to the appropriate number of significant figures. *[1]*

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(e) Calculate the density of the observable universe. Express your answer to the appropriate number of significant figures. *[2]*

(It may be useful to recall that $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$)

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(Question 4 continued)

(f) By considering how your answer to (e) compares with the critical density of the universe, comment on the ultimate fate of the universe. *[2]*

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Answers written on this page
will not be marked.

SECTION B

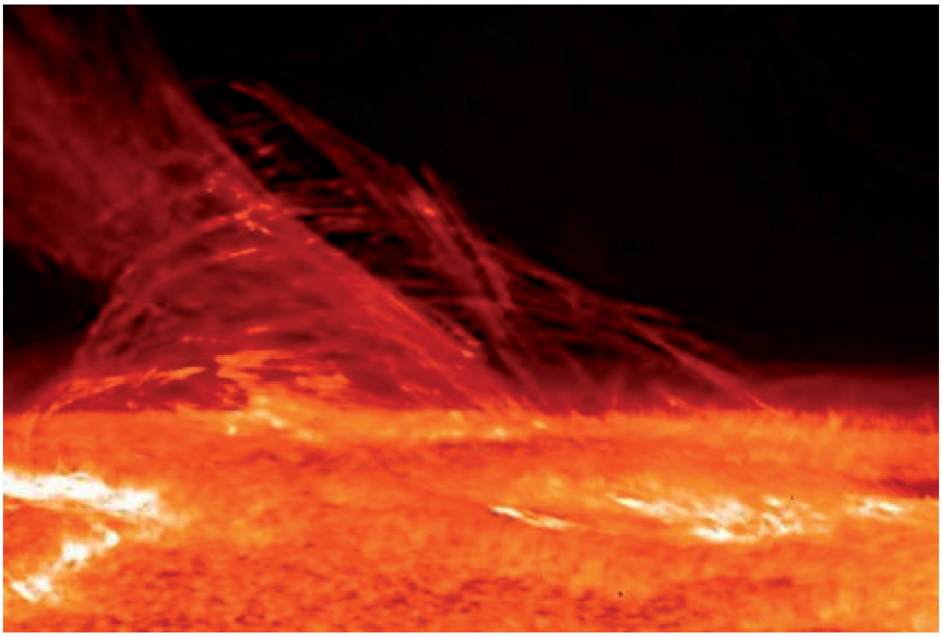
*Answer **one** question. Write your answers in the boxes provided.*

5.

New Phenomena on the Sun

It's enough to make you leap out of your seat: A magnetic vortex almost as big as Earth races across your computer screen, twisting, turning, finally erupting in a powerful solar flare. Japan's Hinode spacecraft recorded just such a blast on January 12 2007.

Figure 6: A solar flare in the chromosphere
(Recorded by JAXA's Hinode spacecraft on January 12 2007)



The Hinode spacecraft was launched in September 2006 from the Uchinoura Space Centre in Japan on a mission to study sunspots and solar flares. Hinode's Solar Optical Telescope, which some astronomers liken to "a Hubble for the Sun", produces crystal-clear images with 0.2 arc-second resolution. (Comparison: 0.2 arc-second is a tiny angle approximately equal to the width of a human hair held about 100 metres away.) "We're getting movies like these all the time now," he says.

The latest results are visually stunning, but the most amazing thing about it, notes Davis, is that "We used to think the chromosphere was a fairly uneventful place, but Hinode is shattering those misconceptions."

Chromosphere means "sphere of colour". It's the name astronomers of the nineteenth century gave to a narrow and very red layer of the sun's atmosphere they saw peeking over the edge of the Moon during solar eclipses. The colour comes from the chromosphere's abundant hydrogen which emits light at a wavelength of 6563 Angstroms, also known as "hydrogen alpha" light. Hinode's telescope is equipped with filters tuned to this specific colour.

Figure 7: The chromosphere during a solar eclipse

The view from space is impressive. Visually, the chromosphere has threads of magnetism jutting up. Hinode's movies show the threads swaying back and forth as if blown by a gentle breeze. There is nothing gentle, however, about "spicules" shooting into the chromosphere from the underlying photosphere. "These are jets of gas as big as Texas," says Davis. "They rise and fall on time scales of 10 minutes."

And then there are the explosions. "The fact that Hinode is able to observe solar flares taking place in the chromosphere is very important," he says.

The origin of solar flares is a mystery. Researchers have long known that flares develop from magnetic instabilities near sunspots, but even after centuries of studying sunspots, no one can predict exactly when a flare is about to happen. This is a problem for NASA because astronauts in space are vulnerable to intense radiation and high-energy particles produced by the explosions. An accurate system of forecasting would help explorers stay out of harm's way.

Hinode may be looking right into the genesis zone of flares. If so, "it could teach us how flares work and improve our ability to predict them".

Adapted from an article released on 21 March 2007 from the NASA web site.

New Phenomena on the Sun

(a) The article states that Hinode's resolution is 0.2 arcsec. Hinode is in orbit around the Earth and so it has an orbital distance from the Sun of 1AU. Using this data, show that the smallest object it can see on the Sun is approximately 1.5×10^5 m. *[2]*

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(b) Explain why it was felt that the chromosphere would be a fairly uneventful place. *[1]*

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(c) Why is the largest output from the chromosphere due to hydrogen emission? *[1]*

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(d) The most abundant output from the chromosphere was stated as 6563 angstroms. Write this wavelength down in metres, without the use of any prefixes. *[1]*

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(Question 5 continued)

(e) Calculate the frequency of the radiation in (d). Express your answer to the appropriate number of significant figures and include the correct unit. *[2]*

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(f) Explain how this radiation is produced in hydrogen. *[2]*

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(g) Why is this chromospheric radiation not normally seen when the Sun is observed? *[1]*

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(h) The article refers to the threads of magnetism in the chromosphere swaying back and forth as if blown by a breeze.

What could be the origin of a breeze that could produce this effect? *[1]*

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(Question 5 continued)

(i) If no actual breeze does exist, what else could possibly move the chromosphere "threads"? *[1]*

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(j) The period of the spicules is given as 10 minutes. Calculate the frequency of their production. *[2]*

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(k) Explain what is meant by "magnetic instabilities" near sunspots. *[2]*

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(l) Explain how such magnetic instabilities might produce solar flares through a process known as "magnetic recombination". *[2]*

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(Question 5 continued)

(m) Give at least two reasons why a solar flare may be a problem for the Earth. *[2]*

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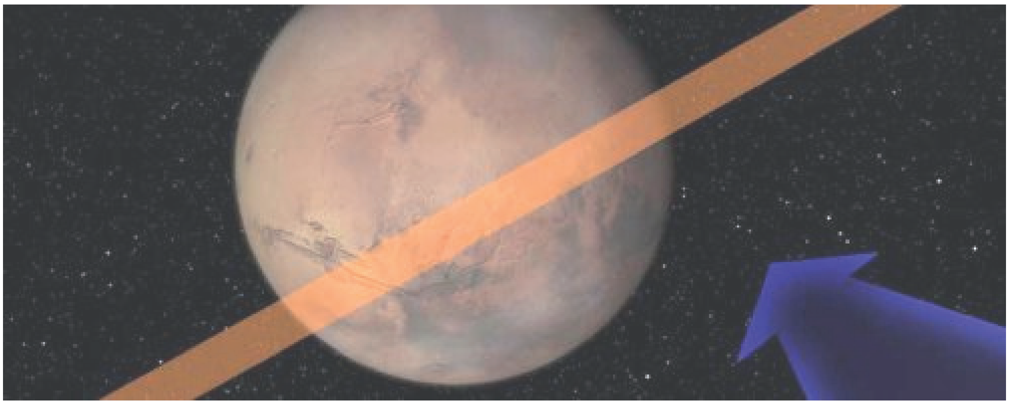
6.

Asteroid Threatens to Hit Mars

Astronomers funded by NASA are monitoring the trajectory of an asteroid named 2007 WD5 that is expected to cross the orbital path of Mars early next year. Calculations by NASA's Near-Earth Object Office at the Jet Propulsion Laboratory indicate that the 164 ft wide asteroid may pass within 30 000 miles of Mars at about 6.00 am EST on January 30 2008.

"Right now asteroid 2007 WD5 is about half-way between the Earth and Mars and closing the distance [to Mars] at a speed of about 27 900 miles per hour," said Don Yeomans, manager of the Near Earth Object Office at JPL.

Figure 8: Artist's rendering uses an arrow to show the predicted path of the asteroid on January 30 2008.
The orange band indicates the area it is expected to pass through.



There is a 1-in-75 chance of 2007 WD5 hitting Mars; researchers can't be more confident than that because of uncertainties in the asteroid's orbit. If this unlikely event were to occur, however, the strike would happen somewhere within a broad band across the planet north of where the Opportunity rover is.

"We estimate such impacts occur on Mars every thousand years or so," said Steve Chesley, a scientist at JPL. "If 2007 WD5 were to thump Mars on January 30, we calculate it would hit at about 30 000 miles per hour and might create a crater more than half-a-mile wide." The Mars rover Opportunity is currently exploring a crater approximately this size.

Such a collision could release about three megatons of energy. Scientists believe an event of comparable magnitude occurred here on Earth in 1908 in Tunguska, Siberia, but no crater was created. The object was disintegrated by Earth's atmosphere before it hit the ground, although the air blast devastated a large area of unpopulated forest. The Martian atmosphere is much thinner than Earth's so a similar sized impactor would be more likely to reach the ground.

Because the asteroid has been tracked for little more than a month, there is still some uncertainty about the path it will take. "Over the next five weeks, we hope to gather more information from observatories so we can further refine the asteroid's trajectory," says Yeomans. More data could eliminate or confirm the possibility of an impact.

Adapted from an article released on 21 December 2007 from the NASA web site.

Asteroid Threatens to Hit Mars

(a) The numerical data listed below is taken from the article. Using the conversions also given below, convert these values into SI units and write them in the boxes below. In each case, express your answer to an appropriate number of significant figures. *[3]*

1 foot = 0.305 m
1 mile = 1609 m
1 hour = 3600 s

	Units from the article	Values when converted to SI units
Asteroid diameter	164 ft	m
Asteroid speed	27 900 mph	$m\,s^{-1}$

(b) Define the following terms used in the article. *[2]*

Escape velocity: . . . .

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Asteroid: . . . .

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(c) Is there any significant chance that 2007 WD5 is likely to collide with the Earth in the near future? Explain your answer. *[2]*

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(Question 6 continued)

(d) The article refers to the fact that the Opportunity rover is on Mars. Where does the article indicate the impact may occur with respect to the location of the rover? Also, briefly comment on **two** reasons why the rover may have been sent to explore Mars. *[3]*

Location of the Impact: . . . .

Reason 1: . . . .

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Reason 2: . . . .

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(e) The mass and radius of Mars are 6.4×10^{23} kg and 3.4×10^{6} m respectively. Calculate the escape velocity for Mars. Express your answer to the appropriate number of significant figures. *[2]*

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(f) The escape velocity calculated in (e) is an approximate value and does not take into account the planet's atmosphere. If the atmosphere were included in this assessment, explain how it would affect the value of the escape velocity. *[2]*

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(Question 6 continued)

(g) If the asteroid is assumed to be spherical with the diameter given in (a) and a density of $5000\,\text{kg}\,\text{m}^{-3}$, calculate the mass of the asteroid. Express your answer to 3 significant figures. *[2]*

(Note: $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$ and the volume of a sphere is given by $V = \frac{4}{3}\pi r^3$)

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(h) Assuming that the present speed of 2007 WD5 in (a) does not change as it approaches Mars, and also assuming that it is pulled into the planet Mars, the speed it ultimately hits the surface with would be expected to increase by the escape speed of the planet (calculated in (e)). However, the prediction stated in the article is only around $13\,400\,\text{m}\,\text{s}^{-1}$. Calculate the expected collision speed and explain this difference. *[2]*

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(i) The article states that it is more likely that an impact will occur because the atmosphere of Mars is thinner than on the planet Earth. Explain why the thinner atmosphere of Mars makes an impact more likely. *[1]*

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(This question continues on the following page)

(Question 6 continued)

(j) Why is there significant uncertainty in the asteroid's path, even though it has been monitored for over a month? *[1]*

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