

1. (a) The first law of thermodynamics may be written  $\Delta U = Q - W$ .

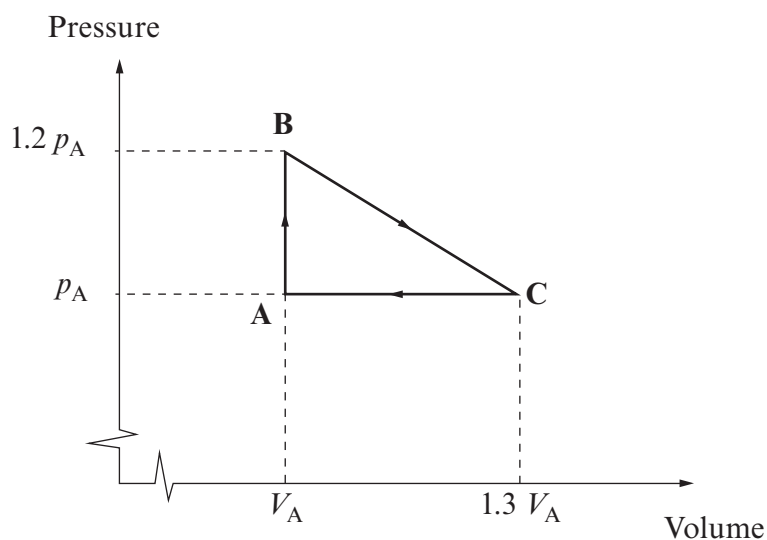
Explain carefully the terms

(i)  $\Delta U$  ..... [1]

(ii)  $Q$  ..... [1]

(iii)  $W$  ..... [1]

- (b) A sealed container with a leak-proof piston at one end contains 0.40 mole of an ideal gas. The gas is taken around a cycle (**ABCA**). The pressure and volume of the gas are shown on the graph where  $p_A = 1.01 \times 10^5$  Pa and  $V_A = 1.00 \times 10^{-2} \text{ m}^3$ .



Calculate the temperature at point C. [2]

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- (c) Determine the work done (if any) along the following paths, indicating clearly if it is done **on** or **by** the gas. [4]

(i) CA

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(ii) AB

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(iii) BC

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- (d) Determine the total heat transferred if the gas is taken around the cycle **three** times, stating clearly whether it flows in or out of the gas. [3]

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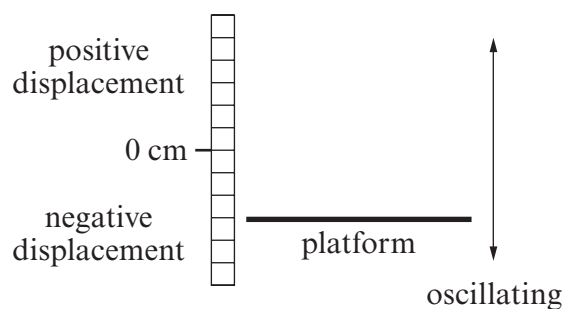
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3. A horizontal platform oscillates vertically with simple harmonic motion around a central position with a period 0.40 s and amplitude 5.0 cm.



- (a) Define simple harmonic motion.

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- (b) Determine

- (i) the maximum velocity of the platform;

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- (ii) the maximum acceleration of the platform.

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- (c) The platform is at its lowest position at time  $t = 0$ .  
The displacement  $x$  of the platform at later times is given by the equation:

$$x = A \sin(\omega t + \varepsilon)$$

Rewrite the equation giving correct numerical values for  $A$ ,  $\omega$  and  $\varepsilon$ .

[3]

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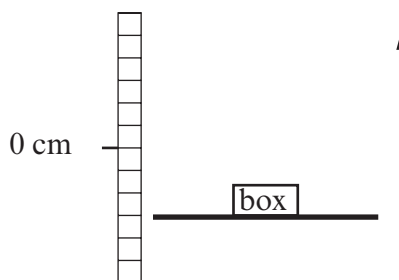
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(d)



A small box is carefully placed on the platform when it is at its lowest position. Before the platform reaches its highest position, the box loses contact. Find the displacement at which contact is lost.

[2]

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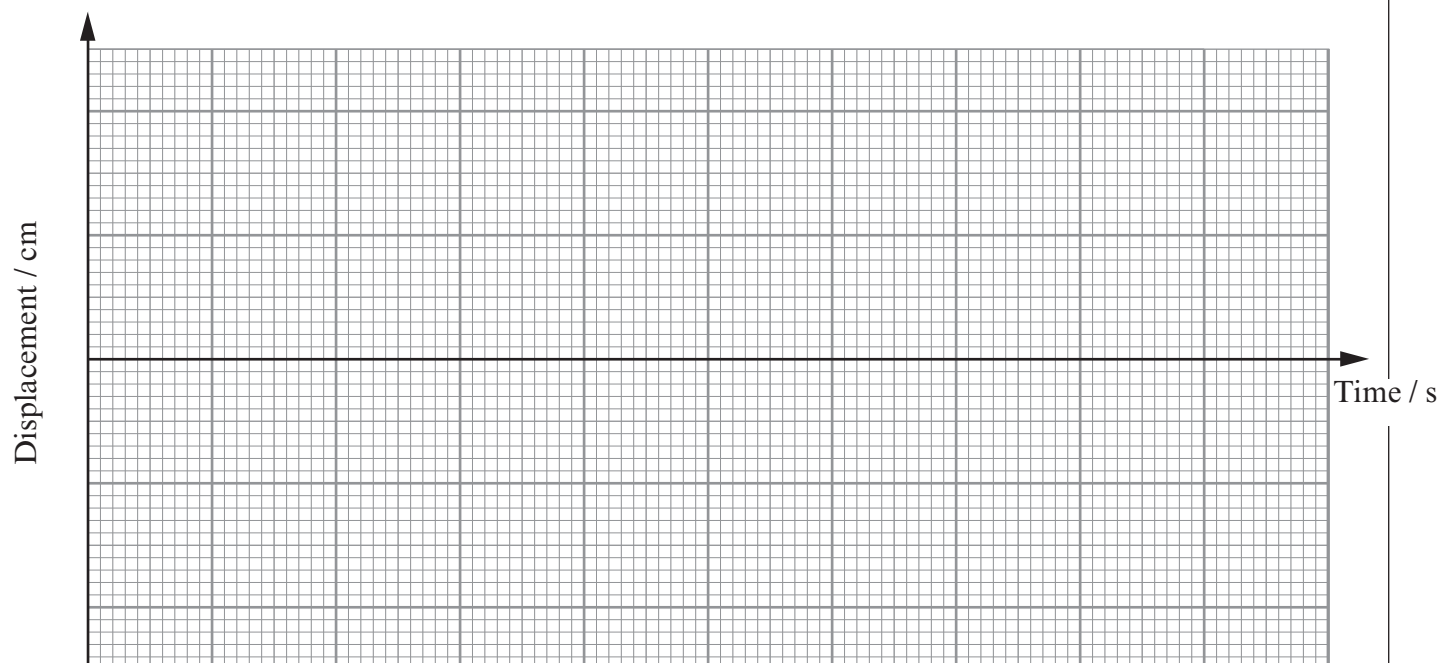
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4. (a) In a laboratory experiment, a load of mass  $m$  is supported in equilibrium at the lower end of a spring. The load is raised 2.0 cm from its equilibrium position, and is then released from rest so that it oscillates vertically with a period of 0.50 s. The amplitude then decreases to 1.0 cm after 5 oscillations.

(i) Sketch a displacement–time graph for these 5 oscillations. [3]



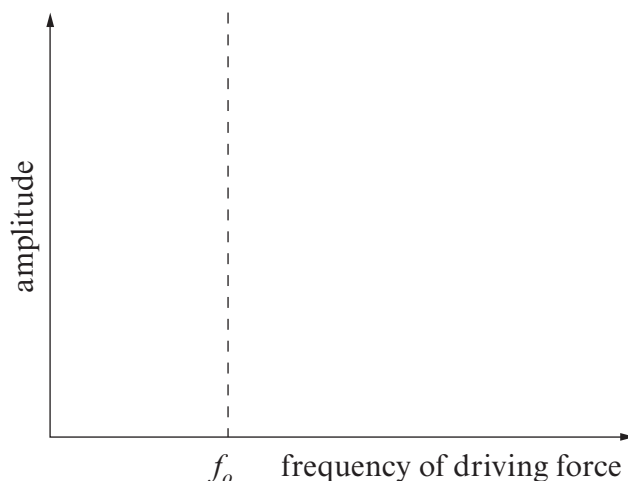
(ii) Suggest a cause for the observed damping. [1]

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(b) A driving force of frequency  $f$  is now applied to the top end of the spring. The frequency of the driver can be varied from zero to a frequency well beyond the natural frequency  $f_o$  of the spring system.

- (i) Sketch the variation of the amplitude of the motion of the load with the frequency of the driving force on the axes below. Label the curve as A. [1]



- (ii) If the damping on the system is increased slightly, sketch the variation of the amplitude with frequency on the same axes. Label this curve as B. [1]
- (iii) Explain what is meant by *resonance*. [1]

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- (iv) Give a practical example of resonance. Identify the driving force of the system and the responding oscillator. [3]

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5. A canister of volume  $0.025 \text{ m}^3$  contains helium gas at a pressure of  $3.04 \times 10^5 \text{ Pa}$  and a temperature of  $280 \text{ K}$ . (Relative molecular mass of helium = 4.0)

(a) Calculate:

- (i) the number of moles of the gas in the canister; [1]

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- (ii) the number of helium molecules in the canister; [1]

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- (iii) the density of the gas; [2]

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- (iv) the rms speed of the helium molecules. [2]

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- (b) The product of the pressure and volume of an ideal gas may be expressed as

$$pV = nRT.$$

The product may also be written in terms of the mean square speed of the molecules as

$$pV = \frac{1}{3}Nm\overline{c^2}.$$

- (i) Derive in clear steps a formula that shows how the internal energy of the ideal gas depends on the temperature of the gas. [4]

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- (ii) Calculate the internal energy of the helium gas in the canister. [1]

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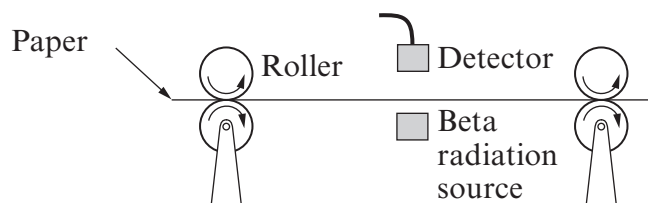
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## SECTION A

1. The thickness of paper is measured using a beta radiation source and detector (see below).



- (a) Explain why it would be inappropriate to use either alpha radiation or gamma radiation for this task. [2]

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- (b) The beta radiation source most commonly used is strontium-90 which decays as shown. Place the correct numbers on the dotted lines. [2]



- (c) The half life of strontium-90 is 28.8 years. Show that its decay constant is  $7.6 \times 10^{-10} \text{ s}^{-1}$ . [2]

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- (d) If the initial activity of the strontium-90 source is 140 GBq, calculate its activity after 10 years. [2]

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- (e) Calculate the mass of strontium-90 required to produce an activity of 140 GBq. [3]

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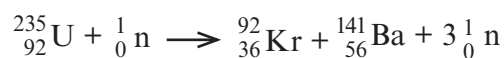
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2. One of the nuclear reactions that occurs inside a nuclear power station is:



The masses of the relevant nuclei are as follows:

$$\text{Mass of } {}_{92}^{235}\text{U} = 234.9933 \text{ u} \qquad \text{Mass of } {}_{36}^{92}\text{Kr} = 91.9064 \text{ u}$$

$$\text{Mass of } {}_{56}^{141}\text{Ba} = 140.8836 \text{ u} \qquad \text{Mass of } {}_0^1\text{n} = 1.0087 \text{ u}$$

- (a) Calculate the energy released in this nuclear reaction (1 u = 931 MeV). [3]

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- (b) Explain briefly how this reaction can lead to a chain reaction. [2]

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- (c) Explain briefly the different purposes of the moderator and control rods in a nuclear reactor. [3]

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- (d) Discuss briefly the problems associated with disposing of waste products from a nuclear power station. [2]

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## SECTION B

The questions refer to the Case Study.  
Direct quotes from the original passage will not be awarded marks.

7. (a) Explain briefly why all the Solar System planets appear on the same horizontal line on the graph below. [1]

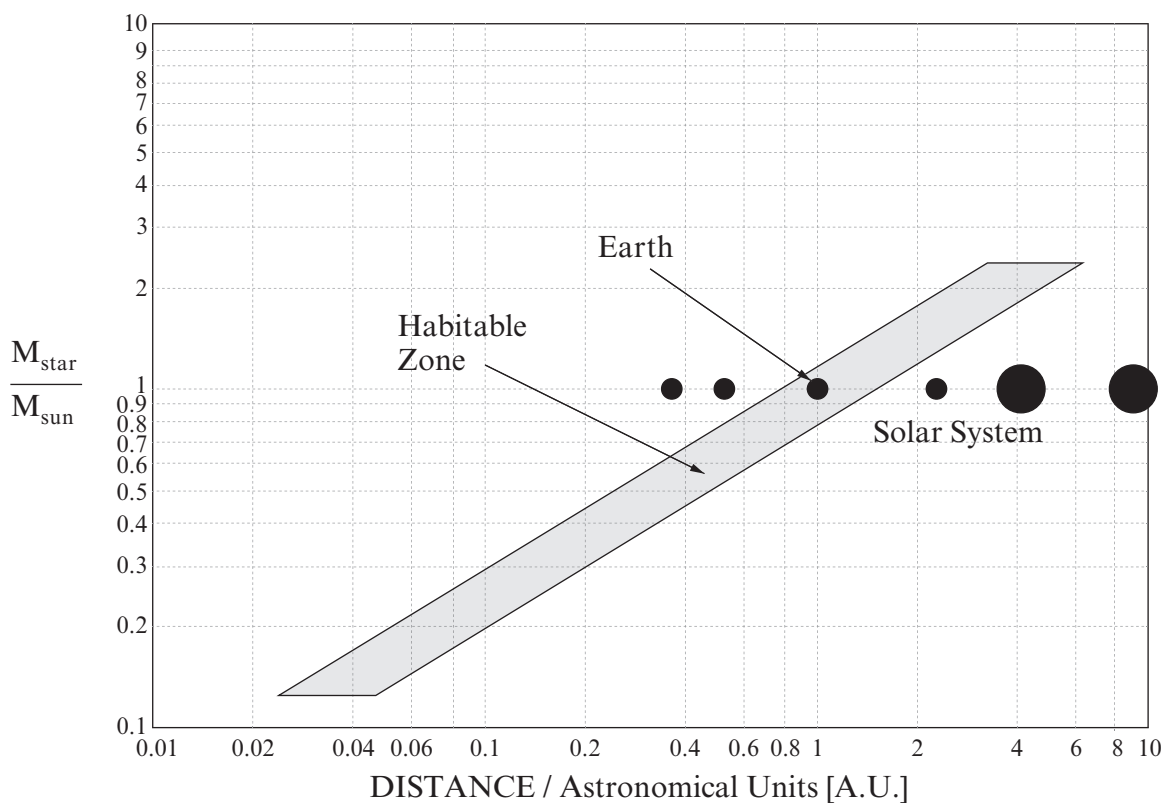
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Graph of Star Mass (relative to our Sun) v Planet Distance from the Star



- (b) Place crosses on the graph to represent:
- an exoplanet orbiting a star twice the mass of the Sun and at a distance four times the Sun-Earth separation; [1]
  - an exoplanet orbiting a star 0.25 times the mass of the Sun and at a distance of 0.04 times the Sun-Earth separation. [1]



- (c) Explain whether or not abundant liquid water could be found on **each** of the planets in part (b). [See also Paragraph 2.] [2]

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- (d) Derive the equation  $v_s = M_p \sqrt{\frac{G}{M_s d}}$  from the equations in the box in Paragraph 8. [2]

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- (e) Explain how the equation  $v_s = M_p \sqrt{\frac{G}{M_s d}}$  agrees with the statement “the Doppler method is most sensitive to large planets which are close to small stars”. [Paragraph 8.] [4]

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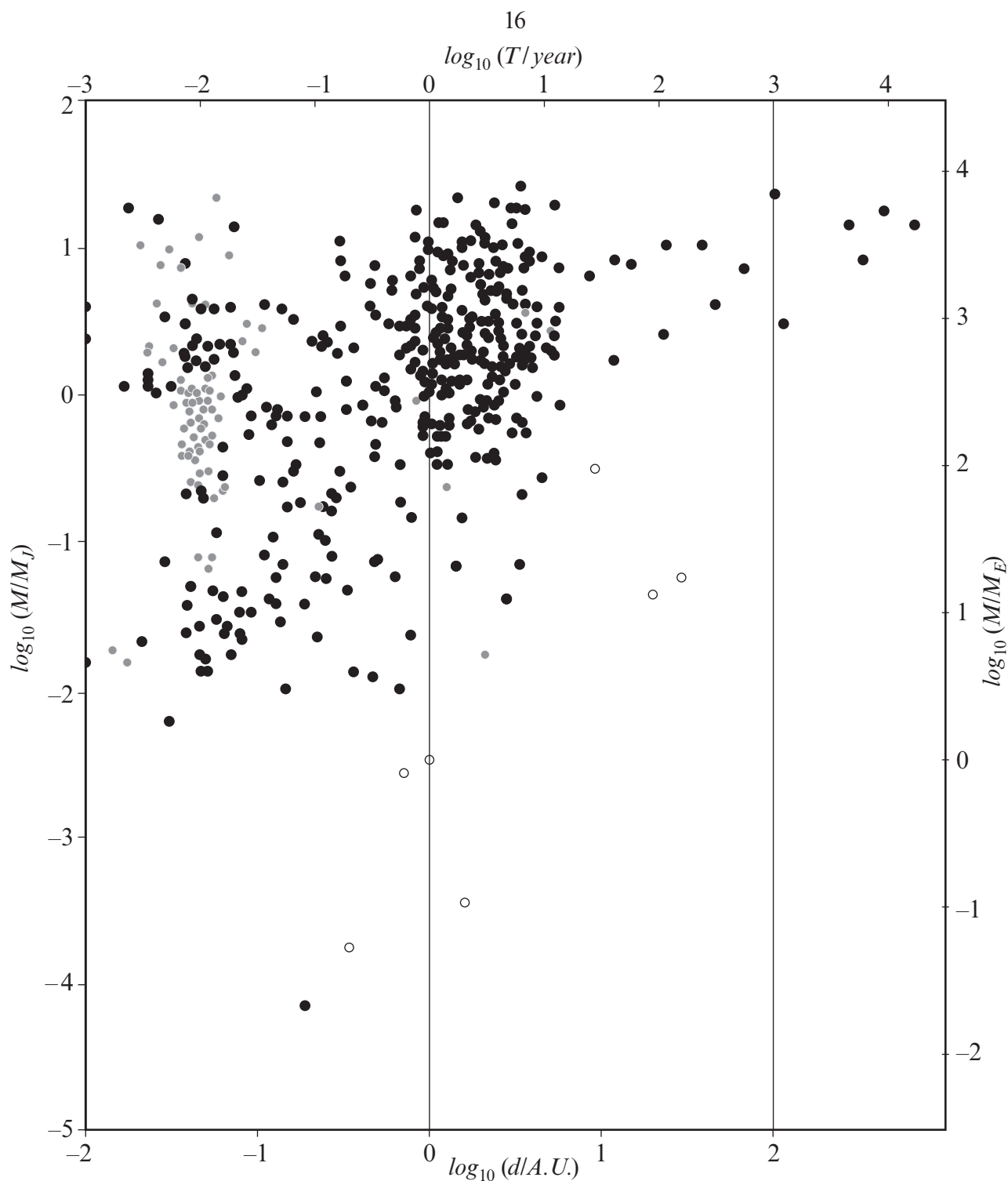
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- (f) Explain whether or not the orbital parameters scatter plot (above) confirms the statement “the Doppler method is most sensitive to large planets which are close to small stars.” [2]

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- (g) **Place a cross** to show the position of the planet Earth on the orbital parameters scatter plot. [2]
- (h) Jupiter's radius is  $\frac{1}{20}$  that of the Sun. Calculate the fractional (or percentage) change in the Sun's apparent intensity as Jupiter transits in front of the Sun (as measured by a very distant observer). [Paragraph 9.] [2]

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- (i) Explain briefly how radial velocity measurements combined with transit measurements lead to the mean density of an exoplanet. [Paragraph 21.] [3]

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Source

page 16 – [http://en.wikipedia.org/wiki/File:Exoplanet\\_Period–Mass\\_Scatter.png](http://en.wikipedia.org/wiki/File:Exoplanet_Period–Mass_Scatter.png)







**GCE A level**

1325/01-B

**PHYSICS**

**ASSESSMENT UNIT PH5**

A.M. MONDAY, 18 June 2012

**CASE STUDY FOR USE WITH  
SECTION B**

**Examination copy**

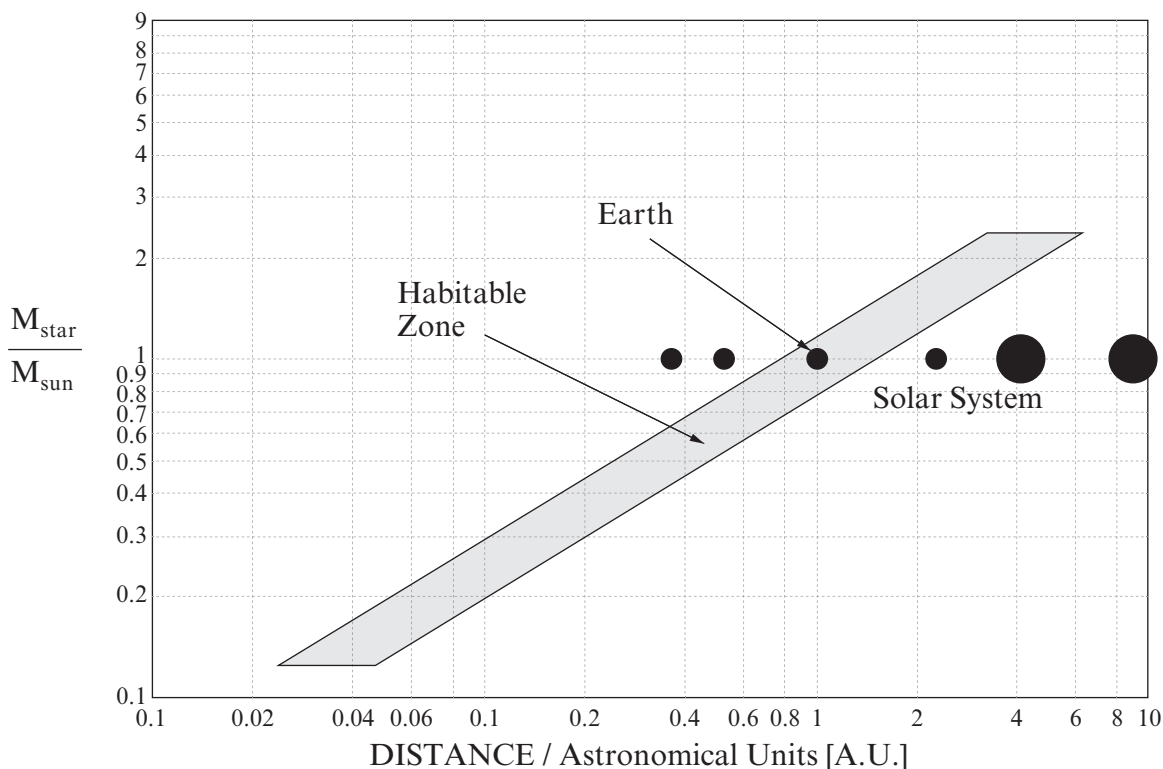
**To be given out at the start of the examination.**

**The pre-release copy must not be used.**

### Extrasolar planets

An **extrasolar planet**, or **exoplanet**, is a planet outside the Solar System. Astronomers have announced the confirmed detection of more than 500 such planets. Most exoplanets have been detected through radial velocity observations and other indirect methods rather than actual imaging and most of these are giant planets thought to resemble Jupiter. It is now known that a substantial fraction of stars have planetary systems, including at least around 10% of sun-like stars (the true proportion may be much higher). It follows that billions of exoplanets must exist in our own galaxy alone. There are over a thousand planet candidates awaiting confirmation by more detailed investigations, including nearly a hundred that may be in the “Habitable Zone” (see below).

Graph of Star Mass (relative to our Sun) v Planet Distance from the Star



This planetary habitability chart shows where life might exist on extrasolar planets based on our own solar system and life on Earth. The habitable zone represents the distance from the star where the temperature is not so hot that all the water evaporates and not so cold that all the water freezes.

### History of detection

Unconfirmed until 1992, extrasolar planets had long been a subject of discussion and speculation. In the sixteenth century the Italian philosopher Giordano Bruno, an early supporter of the Copernican theory that the Earth and other planets orbit the Sun, put forward the view that the fixed stars are similar to the Sun and are likewise accompanied by their own planets. In the eighteenth century the same possibility was mentioned by Isaac Newton in the “General Scholium” that concludes his *Principia*. Making a comparison with the Sun’s planets, he wrote “And if the fixed stars are the centres of similar systems, they will all be constructed according to a similar design and subject to the dominion of *One*.”

In early 1992, radio astronomers Aleksander Wolszczan and Dale Frail announced the discovery of planets around a pulsar, PSR 1257+12. This discovery was quickly confirmed, and is generally considered to be the first definitive detection of exoplanets. These pulsar planets are believed to have formed from the unusual remnants of the supernova that produced the pulsar, in a second round of planet formation, or else to be the remaining rocky cores of gas giants that survived the supernova and then decayed into their current orbits.

On October 6, 1995, Michel Mayor and Didier Queloz of the University of Geneva announced the first definitive detection of an exoplanet orbiting an ordinary main-sequence star (51 Pegasi). This discovery, made at the Observatoire de Haute-Provence, ushered in the modern era of exoplanetary discovery. Technological advances, most notably in high-resolution spectroscopy, led to the detection of many new exoplanets at a rapid rate.

### Detection methods

Planets are extremely faint compared with their parent stars. At visible wavelengths, they usually have less than a millionth of their parent star's brightness. It is extremely difficult to detect such a faint light source, and furthermore the parent star causes a glare that tends to wash it out.

For the above reasons, telescopes have directly imaged no more than about ten exoplanets. This has only been possible for planets that are especially large (usually much larger than Jupiter) and widely separated from their parent star. Most of the directly imaged planets have also been very hot, so that they emit intense infrared radiation; the images have then been made at infrared rather than visible wavelengths, in order to reduce the problem of glare from the parent star.

At the moment, however, the vast majority of known extrasolar planets have only been detected through indirect methods. The following are the indirect methods that have proven useful:

- **Radial velocity or Doppler method**

As a planet orbits a star, the star also moves in its own small orbit around the system's centre of mass. Variations in the star's radial velocity – that is, the speed with which it moves towards or away from Earth – can be detected from displacements in the star's spectral lines due to the Doppler effect. Extremely small radial-velocity variations can be observed, down to roughly  $1 \text{ m s}^{-1}$ . This has been by far the most productive method of discovering exoplanets. It has the advantage of being applicable to stars with a wide range of characteristics.

The Doppler shift of a spectral line is proportional to the orbital velocity of the star and we can use the following equation to approximate the orbital velocity of a star ( $v_s$ ).

$$v_s = M_p \sqrt{\frac{G}{M_s d}}$$

<p>from, <math>\frac{M_s v_s^2}{r_s} = \frac{GM_s M_p}{d^2}</math></p> <p style="text-align: center;">↑</p> <p>centripetal <math>F</math> = gravitational <math>F</math></p>	<p>and</p> <p style="text-align: center;">↑</p> <p>approximation of centre of mass equation</p>
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where  $M_p$  is the mass of the exoplanet,  $M_s$  is the mass of the star and  $d$  is the distance between them (the approximation is that the mass of the star is far greater than the mass of the planet). This equation explains why the Doppler method is most sensitive to large planets which are close to small stars.

### Transit method

If a planet crosses (or transits) in front of its parent star's disk, then the observed brightness of the star drops by a small amount. The amount by which the star dims depends on its cross-sectional area and on the cross-sectional area of the planet. For instance, the Earth has a radius approximately 100 times less than the Sun, so as it passes in front of the Sun an observer would notice a 0.01% drop in the Sun's apparent intensity. This has been the second most productive method of detection, though it suffers from a substantial rate of false positives (due to the small drop in intensities) and confirmation from another method is usually considered necessary.

- **Transit Timing Variation (TTV)**

TTV is an extension of the transit method where the variations in transit of one planet can be used to detect another. The first planetary candidate found this way was exoplanet WASP-3c, using WASP-3b in the WASP-3 system by Rozhen Observatory, Jena Observatory, and Toruń Centre for Astronomy. The new method can potentially detect Earth sized planets or exomoons.

- **Gravitational microlensing**

Microlensing occurs when the gravitational field of a star acts like a lens, magnifying the light of a distant background star. Planets orbiting the lensing star can cause detectable anomalies in the magnification as it varies over time. This method has resulted in only a few planetary detections, but it has the advantage of being especially sensitive to planets at large separations from their parent stars.

- **Astrometry**

Astrometry consists of precisely measuring a star's position in the sky and observing the changes in that position over time. The motion of a star due to the gravitational influence of a planet may be observable. Because that motion is so small, however, this method has not yet been very productive at detecting exoplanets.

- **Pulsar timing**

A pulsar (the small, ultradense remnant of a star that has exploded as a supernova) emits radio waves extremely regularly as it rotates. If planets orbit the pulsar, they will cause slight anomalies in the timing of its observed radio pulses. Four planets have been detected in this way, around two different pulsars. The first confirmed discovery of an extrasolar planet was made using this method.

- **Timing of eclipsing binaries**

If a planet has a large orbit that carries it around both members of an eclipsing double star system, then the planet can be detected through small variations in the timing of the stars' eclipses of each other. As of December 2009, two planets have been found by this method.

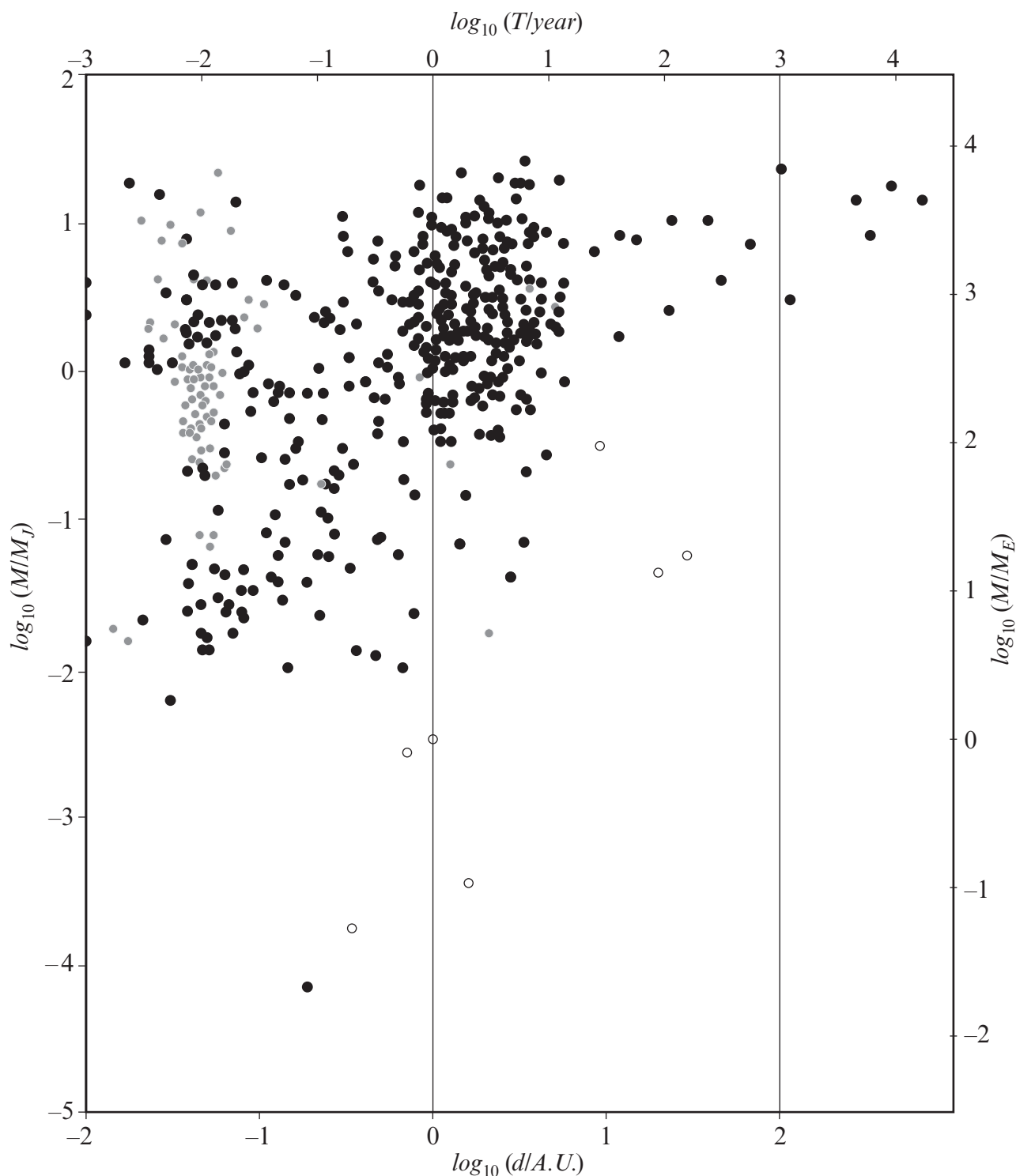
- **Circumstellar disks**

Disks of space dust surround many stars, and this dust can be detected because it absorbs ordinary starlight and re-emits it as infrared radiation. Features in the disks may suggest the presence of planets.

Most extrasolar planet candidates have been found using ground-based telescopes. However, many of the methods can work more effectively with space-based telescopes that avoid atmospheric haze and turbulence. COROT (launched December 2006) and Kepler (launched March 2009) are the two currently active space missions dedicated to searching for extrasolar planets. Hubble Space Telescope and MOST have also found or confirmed a few planets. There are also several planned or proposed space missions geared towards exoplanet observation, such as New Worlds Mission, Darwin, Space Interferometry Mission, Terrestrial Planet Finder and PEGASE.

### Orbital parameters

Scatter plot showing masses and orbital periods of extrasolar planets discovered.



Many exoplanets have orbits with very small radii, and are thus much closer to their parent star than any planet in our own solar system is to the Sun. Astronomers were initially very surprised by these “hot Jupiters”, but it is now clear that most exoplanets (or, at least, most high-mass <sup>17</sup> exoplanets) have much larger orbits, some located in habitable zones - suitable for liquid water and life.

### Mass distribution

The vast majority of exoplanets detected so far have high masses. Many are considerably more massive than Jupiter, the most massive planet in the Solar System. However, these high masses are in large part due to an observational selection effect: all detection methods are much more likely to discover massive planets. This bias makes statistical analysis difficult, but it appears that lower-mass planets are actually more common than higher-mass ones, at least within a broad mass range that includes all giant planets. In addition, the fact that astronomers have found several planets only a few times more massive than Earth, despite the great difficulty of detecting them, indicates that such planets are fairly common.

The results from the first 43 days of the Kepler mission “imply that small candidate planets with periods less than 30 days are much more common than large candidate planets with periods less than 30 days and that the ground-based discoveries are sampling the large-size tail of the size distribution”.

### Temperature and composition

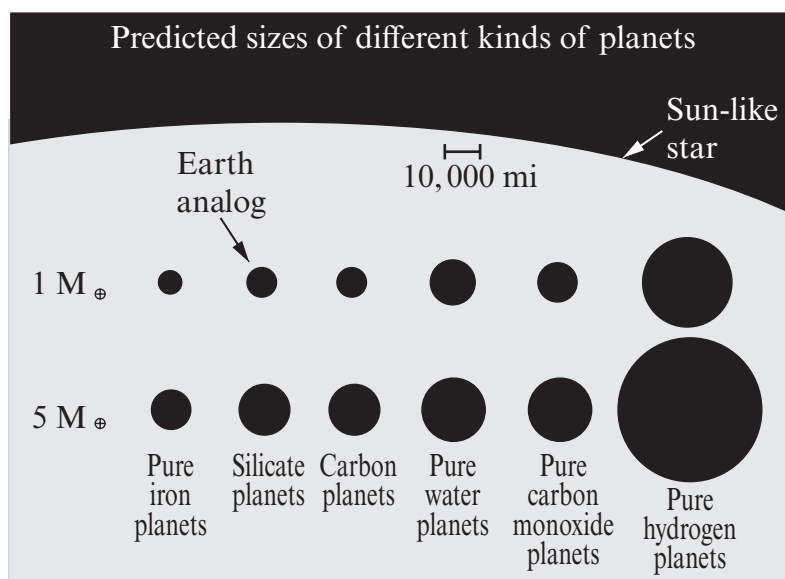
It is possible to estimate the temperature of an exoplanet based on the intensity of the light it receives from its parent star. For example, the planet OGLE-2005-BLG-390Lb is estimated to have a surface temperature of roughly  $-220^{\circ}\text{C}$  (roughly 50 K). However, such estimates may be substantially in error because factors such as the greenhouse effect may introduce unknown complications. A few planets have had their temperature measured by observing the variation in infrared radiation as the planet moves around in its orbit and is eclipsed by its parent star. For example, the planet HD 189733b has been found to have an average temperature of  $1205 \pm 9$  K ( $932 \pm 9^{\circ}\text{C}$ ) on its dayside and  $973 \pm 33$  K ( $700 \pm 33^{\circ}\text{C}$ ) on its nightside.

If a planet is detectable by both the radial-velocity and the transit methods, then both its true mass and its radius can be found. The planet’s density can then be calculated. Planets with low density are inferred to be composed mainly of hydrogen and helium, while planets of intermediate density are inferred to have water as a major constituent. A planet of high density is believed to be rocky, like Earth and the other terrestrial planets of the Solar System.

### Unanswered questions

Many unanswered questions remain about the properties of exoplanets. One puzzle is that many transiting exoplanets are much larger than expected given their mass, meaning that they have surprisingly low density. Several theories have been proposed to explain this observation, but none have yet been widely accepted among astronomers. Another question is how likely exoplanets are to possess moons. No such moons have yet been detected, but they may be fairly common.

Perhaps the most interesting question about exoplanets is whether they might support life. Several planets do have orbits in their parent star’s habitable zone, where it should be possible for liquid water to exist and for Earth-like conditions to prevail. Most of those planets are giant planets more similar to Jupiter than to Earth; if any of them have large moons, the moons might be a more plausible abode of life. Gliese 581g, thought to be a rocky planet orbiting in the middle of its star’s habitable zone, was discovered in September 2010 and, if confirmed, could be the most “Earth-like” planet discovered to date.



Various estimates have been made as to how many planets might support simple life or even intelligent life. For example, Dr. Alan Boss of the Carnegie Institution of Science estimates there may be a “hundred billion” terrestrial planets in our Milky Way Galaxy, many with simple life forms. He further believes there could be thousands of civilizations in our galaxy. Recent work by Duncan Forgan of Edinburgh University has also tried to estimate the number of intelligent 24 civilizations in our galaxy. The research suggested there could be thousands of them. Apart from the scenario of an extraterrestrial civilization that is emitting powerful signals, the detection of life at interstellar distances is a tremendously challenging technical task that will not be feasible for many years, even if such life exists.

**Sources:**

page 5 - [http://en.wikipedia.org/wiki/File:Exoplanet\\_Period-Mass\\_Scatter.png](http://en.wikipedia.org/wiki/File:Exoplanet_Period-Mass_Scatter.png)

page 6 - [http://en.wikipedia.org/wiki/File:Planet\\_sizes.svg](http://en.wikipedia.org/wiki/File:Planet_sizes.svg)