Answers to Coursebook questions – Chapter E1

1 The density is very small but light travels enormous distances to get to us and significant absorption may take place because the light will go through a large amount of gas on its long journey.

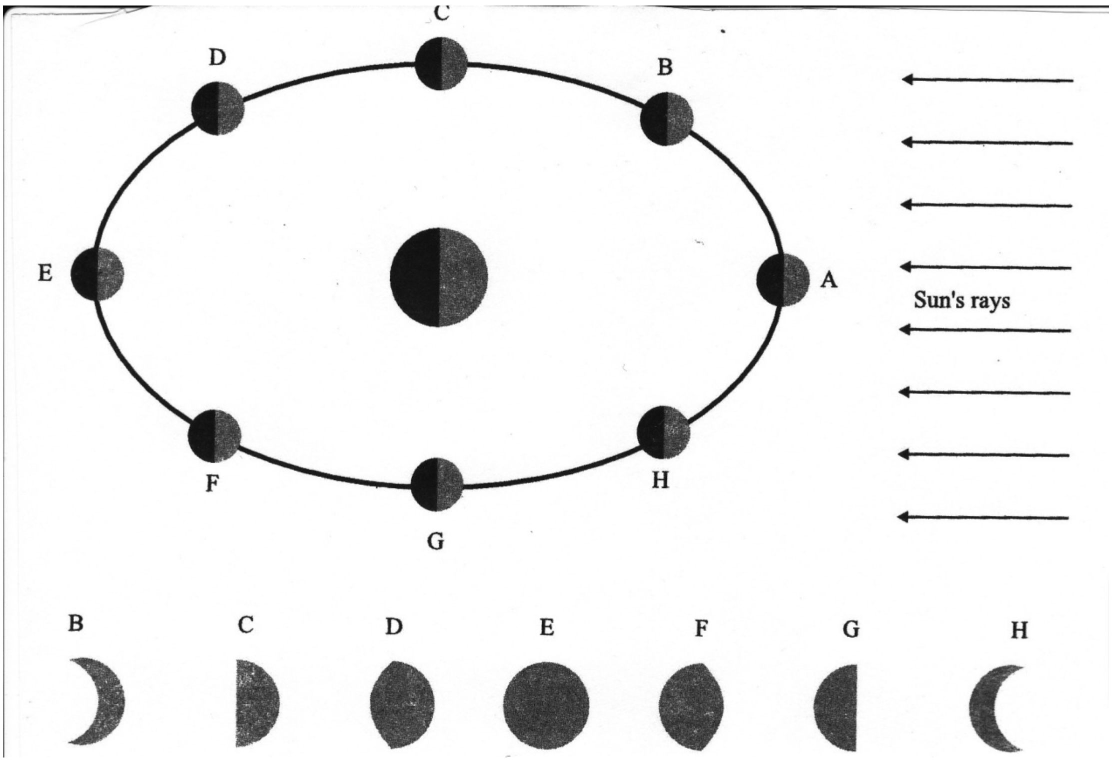
2 In the first optical photographs quasars could not be distinguished from photographs of stars. It was only after the spectrum of these objects was studied that it was realised that quasars could not be stars within our galaxy but very far away, bright and very active galactic centres.

3 Refer to **problem 1** in **chapter 6** (see page 372 in *Physics for the IB Diploma*), where we showed that the density of all nuclei is approximately the same, and of order 10^{17} kg m^{-3}.

4 The diameter d will be approximately equal to $d = D\theta$, where $D = 1.5 \times 10^{11}$ m is the earth–sun distance and θ is the angle subtended by the sunspot in radians.

Hence, $d = 1.5 \times 10^{11} \times \frac{4}{3600} \times \frac{\pi}{180} = 3 \times 10^{6}$ m.

5 The phases of the moon have to do with what fraction of the illuminated surface of the moon we can see from earth.



6 The radius of Jupiter is 6.9×10^{7} m and that of earth is 6.4×10^{6} m. Hence the number of earth volumes that fit into Jupiter's volume is

$$\left(\frac{6.9 \times 10^{7}}{6.4 \times 10^{6}}\right)^{3} \approx 1250.$$

7

Saturn: $\dfrac{5.69\times10^{26}}{\frac{4\pi}{3}(6.03\times10^{7})^{3}}=0.620\times10^{3}\text{ kg m}^{-3}$.

Uranus: $\dfrac{8.66\times10^{25}}{\frac{4\pi}{3}(2.56\times10^{7})^{3}}=1.23\times10^{3}\text{ kg m}^{-3}$.

Jupiter: $\dfrac{1.90\times10^{27}}{\frac{4\pi}{3}(6.91\times10^{7})^{3}}=1.37\times10^{3}\text{ kg m}^{-3}$.

Neptune: $\dfrac{1.03\times10^{26}}{\frac{4\pi}{3}(2.48\times10^{7})^{3}}=1.61\times10^{3}\text{ kg m}^{-3}$.

Mars: $\dfrac{6.42\times10^{23}}{\frac{4\pi}{3}(3.40\times10^{6})^{3}}=3.90\times10^{3}\text{ kg m}^{-3}$.

Venus: $\dfrac{4.87\times10^{24}}{\frac{4\pi}{3}(6.05\times10^{6})^{3}}=5.25\times10^{3}\text{ kg m}^{-3}$.

Mercury: $\dfrac{3.30\times10^{23}}{\frac{4\pi}{3}(2.44\times10^{6})^{3}}=5.42\times10^{3}\text{ kg m}^{-3}$.

Earth: $\dfrac{5.98\times10^{24}}{\frac{4\pi}{3}(6.38\times10^{6})^{3}}=5.50\times10^{3}\text{ kg m}^{-3}$.

8 The escape velocity is given by $v = \sqrt{\dfrac{2GM}{R}}$.

Mercury: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 3.30 \times 10^{23}}{2.44 \times 10^{6}}} = 4.2\,\text{km s}^{-1}$.

Mars: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 6.42 \times 10^{23}}{3.40 \times 10^{6}}} = 5.0\,\text{km s}^{-1}$.

Venus: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{6.05 \times 10^{6}}} = 10\,\text{km s}^{-1}$.

Earth: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{6.38 \times 10^{6}}} = 11\,\text{km s}^{-1}$.

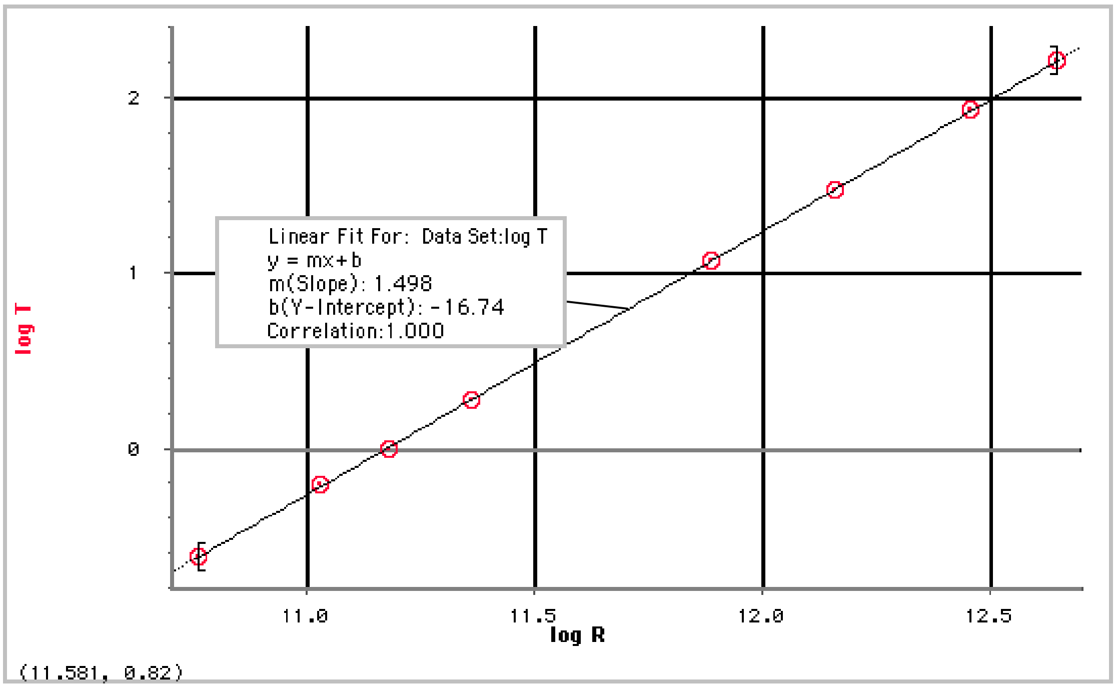
Uranus: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 8.66 \times 10^{25}}{2.56 \times 10^{7}}} = 21\,\text{km s}^{-1}$.

Neptune: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 1.03 \times 10^{26}}{2.48 \times 10^{7}}} = 24\,\text{km s}^{-1}$.

Saturn: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 5.69 \times 10^{26}}{6.03 \times 10^{7}}} = 35\,\text{km s}^{-1}$.

Jupiter: $\sqrt{\dfrac{2 \times 6.67 \times 10^{-11} \times 1.90 \times 10^{27}}{6.91 \times 10^{7}}} = 61\,\text{km s}^{-1}$.

9



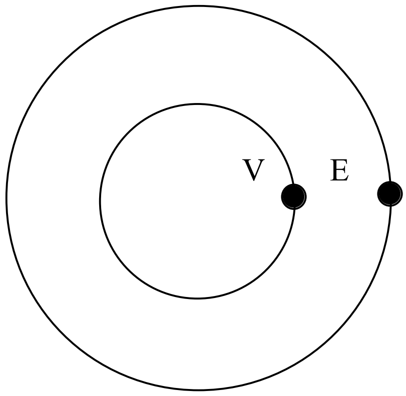
Logger Pro gives the line of best fit as $\log T = 1.498\log R - 16.74$.

This is consistent with Kepler's third law, which predicts $T^2 = \dfrac{4\pi^2 R^3}{GM}$,

which results in

$$2\log T = 3\log R + \log\frac{4\pi^2}{GM}$$
$$\log T = \frac{3}{2}\log R + \frac{1}{2}\log\frac{4\pi^2}{GM}$$
$$\log T = 1.50\log R + C$$

10 The distance separating the two planets at their closest is 0.3 AU.



The signal covers twice this distance in 300 s travelling at the speed of light.

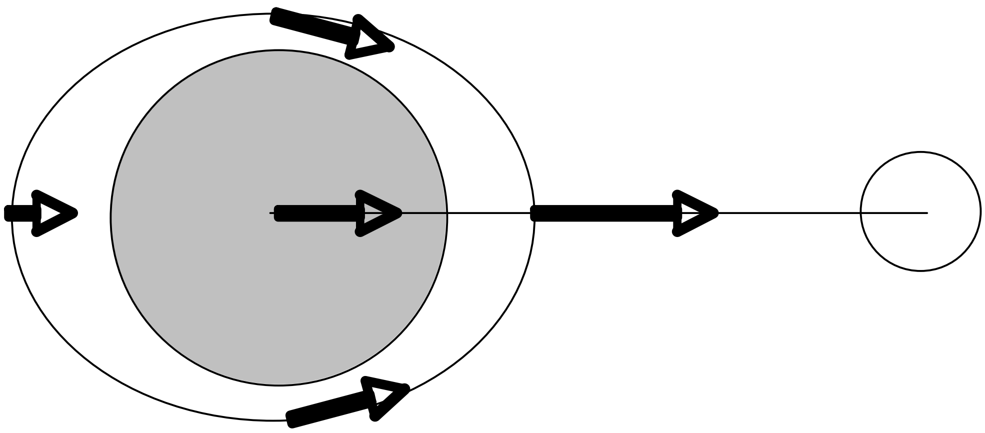
Hence, $2\times 0.3\,\text{AU} = 3.0\times 10^{8}\times 300 \Rightarrow 1\,\text{AU} = \dfrac{3.0\times 10^{8}\times 300}{0.6} = 1.5\times 10^{11}\ \text{m}$.

11 The diameter *d* will be approximately equal to $d = D\theta$, where $D = 3.8\times 10^{8}\ \text{m}$ is the earth–moon distance and θ is the angle subtended in radians.

Hence, $d = 3.8\times 10^{8}\times \dfrac{0.05}{3600}\times \dfrac{\pi}{180} = 92 \approx 10^{2}\ \text{m}$.

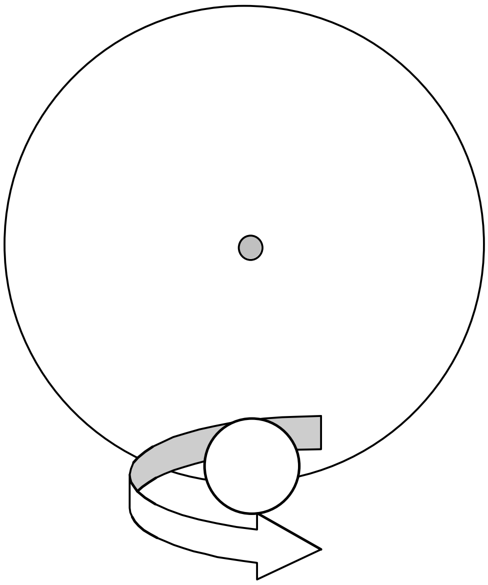
12 The moon rotates about its axis once in about 27 days, which is the same time it takes to complete a revolution around the earth. Therefore we never see the 'other' far side of the lunar surface.

The diagram shows a very exaggerated view of the earth that is assumed to be covered everywhere by water. The force on the side of the earth nearer the moon is greater than the force on the far side of the earth (only by a very small amount – the forces shown are exaggerated). This causes a **tidal bulge** on the water surface as shown. This is because the side near the moon is pulled towards the moon, the earth itself is pulled towards the moon and so the water on the far side is 'left behind'.



This is a common feature for moons orbiting planets. Orbits in which the period of rotation of a body around its axis is the same as the period of revolution of the body around another more massive body are called synchronous orbits. These orbits are the result of the gravitational interaction between the two bodies. The diagram above has to be changed when the rotation of the earth around its axis is taken into account. The result is that the bulge shown is not exactly aligned with the earth–moon line. In turn, this implies that the net gravitational effect of the moon on the earth is to slow it down. The earth has already made the moon have a synchronous orbit but the moon has not yet had the same effect on the earth (because the earth is more massive). But the earth's period of rotation around its axis is getting longer as a result of this interaction, and many billions of years in the future the earth, too, will be in a synchronous orbit with the moon, i.e. it will spin around its axis in the same time as the moon takes to complete one revolution around its axis and complete a revolution around the earth. The earth day will then be much longer than it is today (almost 47 of present days and the moon will be much further away).

13 The sun rises in the east and sets in the west because of the direction of the rotation of the earth about its axis, as shown in the diagram below.



The earth is spinning west to east and so the sun rises in the east.

The rising of the moon depends on the time of the year at the place of observation.

The case of the stars depends heavily on the position of the observer. For example, an observer at the north pole of the earth would see all the stars of the northern celestial hemisphere, and none of these would rise or set. The stars appear to form circles as the earth rotates, the circles being parallel to the equator of the earth. By contrast, for an observer at the equator all stars appear to rise and set as the earth rotates. The stars' paths in the sky are circles at right angles to the horizon. At an in-between location, some stars never cross the horizon and so never rise. Those that do cross the horizon appear to rise as the earth rotates.

14 $\dfrac{GMm}{r^2} = m\dfrac{v^2}{r} \Rightarrow v^2 = \dfrac{GM}{r}$.

Numerically, $v = \sqrt{\dfrac{GM}{r}} = \sqrt{\dfrac{6.67\times10^{-11}\times2.0\times10^{30}}{1.5\times10^{11}}} \approx 3.0\times10^4\ \text{m s}^{-1}$.

15 The speed of Europa is $v = \dfrac{2\pi r}{T} = \dfrac{2\pi\times6.71\times10^8}{3.55\times24\times3600} \approx 1.37\times10^4\ \text{m s}^{-1}$.

Now using $v^2 = \dfrac{GM}{r} \Rightarrow M = \dfrac{v^2 r}{G}$,

we find $M = \dfrac{(1.37\times10^4)^2\times6.71\times10^8}{6.67\times10^{-11}} = 1.9\times10^{27}\ \text{kg}$.

16 The speed of the sun is $v = \dfrac{2\pi r}{T} = \dfrac{2\pi\times2.8\times10^4\times9.46\times10^{15}}{211\times10^6\times365\times24\times3600} \approx 2.5\times10^5\ \text{m s}^{-1}$.

Now using $v^2 = \dfrac{GM}{r} \Rightarrow M = \dfrac{v^2 r}{G}$,

we find $M = \dfrac{(2.5\times10^5)^2\times2.8\times10^4\times9.46\times10^{15}}{6.67\times10^{-11}} = 2.5\times10^{41}\ \text{kg}$.

This is the mass that is enclosed within a radius of 28 000 ly. The mass in the galaxy outside this radius does not influence the motion of the sun.

17 Mercury and Venus have orbits within the earth's orbit and so appear close to the sun. Mercury, being the closest to the sun, appears for a short time only just before the sun rises or after it sets. Venus, being further away, is visible for a bit longer.