However we saw previously that virtually all of the satellites of the planets have *synchronous rotation*, i.e. their rotation period equals their orbital period, such that the same face points to the planet at all times. In this case, the satellite is essentially not rotating with respect to the planet. Thus the tidal bulge produced by the gravitational pull of the planet does not move, and so does not produce a frictional heating effect in the satellite. Indeed, the satellites of the planets have reached their current state of synchronous rotation because the action of tidally-induced frictional heating slows the rotation of the satellite down, due to rotational energy being converted to heat. The slowing continues until the satellite reaches synchronous rotation. At this point, we might expect tidal heating to stop. However it is clear that bodies like Io are undergoing significant tidal heating *now*. Why is this?

The answer lies in the effect of orbital eccentricity, and Kepler's laws. The example in Figure 7.6 shows a synchronously rotating satellite at ten places on its elliptical orbit, separated at equal time intervals (and because of Kepler's second law, equal areas are swept out in these equal time intervals). The red radial lines drawn from the planet to the satellite represent the direction of the gravitational force, and thus the line along which the tidal bulge of a satellite will act. The blue arrows show the direction of a face of the satellite. When the satellite is at its closest point to the planet, the face points along the gravitational force direction. We know that the planet will then rotate 360° in each complete orbit, and so during each of the ten equal time intervals, it will rotate just 36° (i.e. each successive blue arrow is rotated by 36°). However, you can see that, as a result, for most of the orbit the face does not then precisely point along the line of gravitational force. In fact only at two points in the orbit does it do this. As the satellite orbits, the face moves 'forward' of the red line, and then moves 'behind' the red line. If you were watching the satellite while standing on the planet, you would see the face turn slightly one way for half the orbit, and then turn back the other way for the second half. This is called **libration.** As the satellite *librates*, the gravitational bulge is 'dragged' back and forth, causing frictional heating.

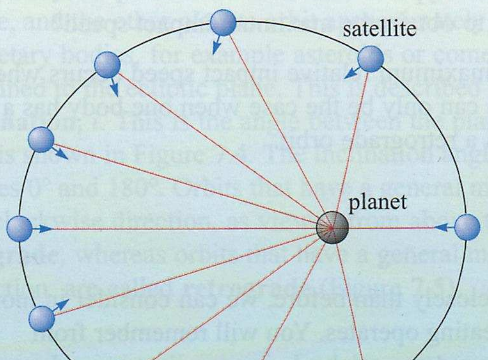


Figure 7.6 The figure represents a synchronously rotating satellite at ten places on its elliptical orbit, separated at equal time intervals. The planet rotates 360° in each complete orbit, and so during each of the ten equal time intervals it rotates 36° (i.e. each successive blue arrow is rotated by 36°).

Thus bodies that are in synchronous rotation can undergo significant tidal heating *only* if they are in orbits that have eccentricities that are not zero. This is the case for many of the satellites of the giant planets, and this mechanism gives rise to the tidal heating within satellites such as Io.

QUESTION 7.5

In the following cases, decide whether the satellite might undergo tidal heating.

(a) A newly formed satellite that is in a circular orbit, and has a rotation period that is much less than its orbital period.

(b) An ancient satellite that has acquired synchronous rotation, and has a circular orbit.

(c) An ancient satellite that has acquired synchronous rotation, and has a significant orbital eccentricity.

7.3 Asteroids

Asteroids are by far the most abundant named objects in the Solar System. Over one hundred thousand asteroids have been detected, with over thirty thousand having well determined orbits, most of these occupying the **asteroid belt** between about 2 and 4 AU from the Sun (between the orbits of Mars and Jupiter, Figure 7.7). The total mass of all the bodies in the current asteroid belt is only about one-thousandth of an Earth mass, although originally, a few Earth masses of material would have been available in the solar nebula in the region. In the 19th and early 20th centuries, astronomers thought that the asteroid belt represented fragments of a single planet which had somehow disintegrated catastrophically. However the asteroids are now thought to represent fragments of *many* small planetary bodies that never managed to accrete into one single body. This is due to the strong gravitational influence of the newly formed Jupiter 'stirring up' the asteroid population, causing collisions which would repeatedly break up the bodies and so impede the formation of one single large object.

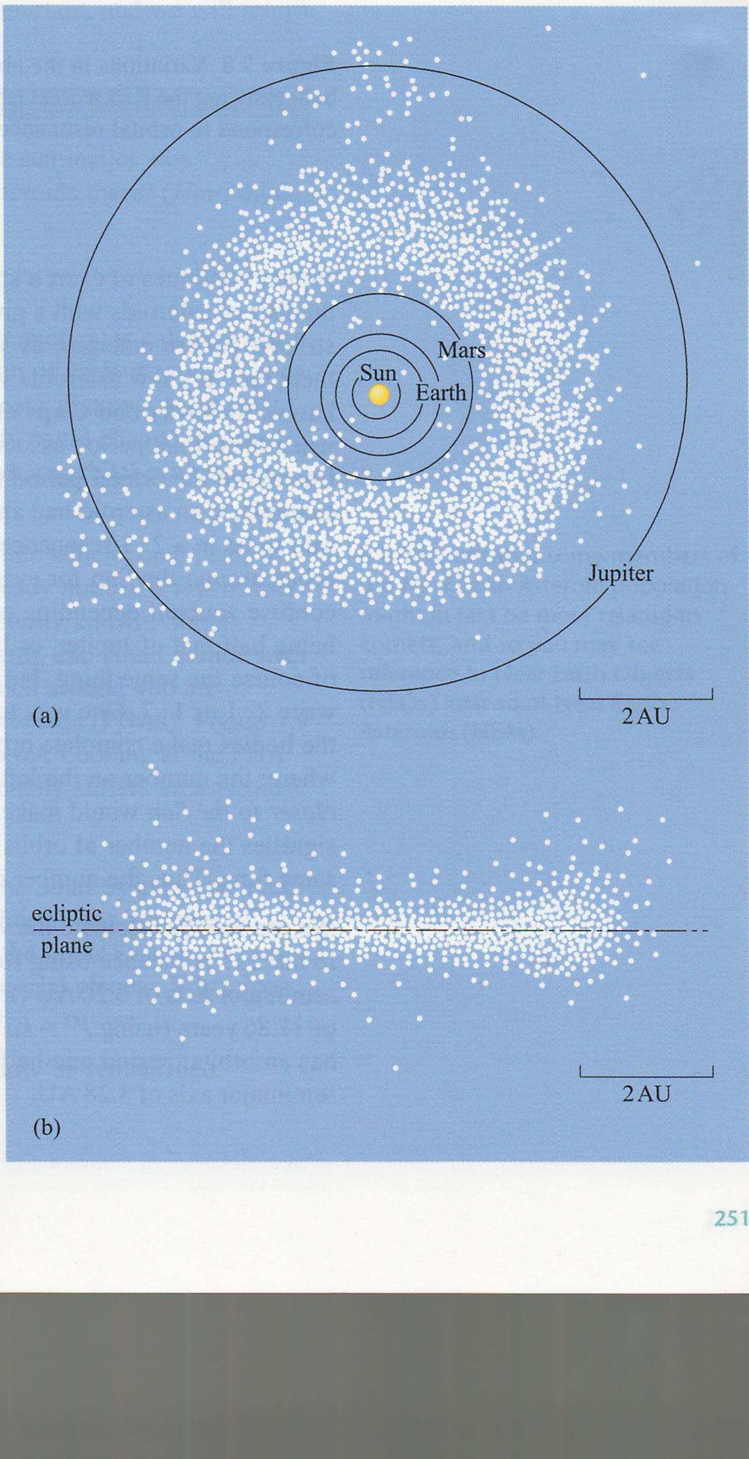


Figure 7.7 (a) A representation of the asteroid belt. It is seen that the asteroid belt is actually a diffuse cloud, or swarm of orbiting bodies. (b) A cross-section through the belt, shown on the same scale. Each individual asteroid shown moves in an orbit inclined to the ecliptic plane, so that sometimes it is above it, and sometimes below. You can imagine that collisions between asteroids will be quite common.

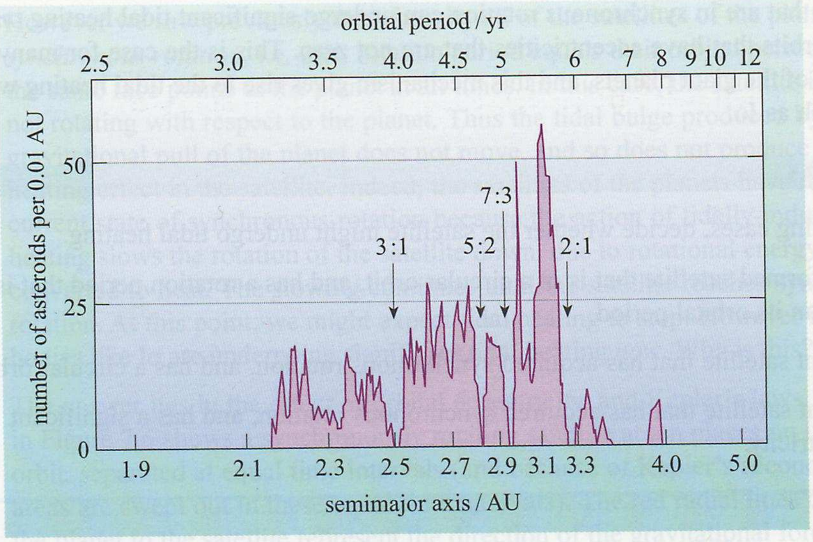


Figure 7.8 Variations in the abundance of asteroids within the asteroid belt, showing the Kirkwood Gaps at values of semimajor axis which correspond to orbital resonances with Jupiter.

Jupiter continues to exert a strong influence on the asteroid belt. When we plot the number of asteroids with a given semimajor axis interval against semimajor axis, a striking pattern emerges, as shown in Figure 7.8. There are spaces, or gaps, where there are very few asteroids with a particular value of semimajor axis. These gaps, known as **Kirkwood Gaps** after their discoverer, are not random. They occur when the orbital period associated with a given value of semimajor axis, is a simple fraction of the orbital period of Jupiter. This is known as **orbital resonance**. For example, if an asteroid had an orbital period half that of Jupiter, then it would be said to be in a 2 : 1 resonance (we say, 'two-to-one resonance'), i.e. it makes two orbits around the Sun for every one orbit Jupiter makes. Sometimes you can confuse yourself depending on whether you think in terms of the asteroid's period being half that of Jupiter, or Jupiter's period being double that of the asteroid. It is of course the same thing, but it can cause people to be confused as to whether to write 2 : 1 or 1 : 2. One way to avoid confusion is to consider the number of times the bodies make complete orbits of the Sun. Then use an often followed convention where: the number on the left side signifies the number of orbits that the body *closer to the Sun* would make in a given period of time, and the number on the right signifies the number of orbits the body *further from the Sun* would make in the same time. Thus the number on the left will be larger than the number on the right.

We can readily calculate the value of the semimajor axis associated with an object in the 2 : 1 resonance using Kepler's third law. We know that Jupiter has a semimajor axis of 5.20 AU (from Appendix A, Table A1) and thus an orbital period of 11.86 years (using $P^2 = ka^3$ from Section 7.2). So an object in the 2 : 1 resonance has an orbital period one-half of this, i.e. 5.93 years, which corresponds to a semimajor axis of 3.28 AU.

QUESTION 7.6

At what semimajor axis value would you expect to find a gap in the asteroid belt semimajor axis distribution corresponding to a 3 : 1 resonance with Jupiter?

The effect on a small body that is orbiting the Sun, and is also in orbital resonance with a large body, can have two outcomes. For the small body in the resonance, there will be times when it is being accelerated forward in its orbit by the gravitational pull of the larger body, and other times when it is being decelerated. The cumulative effect of these forces is to distort the orbit of the smaller object, until it no longer has a resonant period, and its former orbit remains unoccupied. This is the process at work to produce the Kirkwood Gaps, where many of the resonances are cleared of objects. However, another possible outcome of some resonances, is that the small object gets locked into its orbit, and the gravitational influence of the larger body essentially holds the smaller object in its orbit for long periods of time. These *stable resonances* can be very important, and we will return to this point in Section 7.4.

QUESTION 7.7

If you travelled to the distance from the Sun equal to the semimajor axis associated with a Kirkwood Gap, might you find any asteroids there? (*Hint*: think about the effect of orbital eccentricity.)

The changing of a body's orbital elements (or orbital parameters) is called **orbital evolution** and is the key to understanding the distribution of various minor bodies throughout the Solar System today. Orbital evolution means that over time (this could mean thousands or millions of years) a minor body could change its orbit significantly within the Solar System. A good example where orbital evolution is critical, is in the *Near Earth Asteroid* population.

Near Earth Asteroids (NEAs), are bodies that have orbits which come near (or indeed cross) the orbit of the Earth. You might have already noticed a few of these objects in Figure 7.7. There are almost 2000 NEAs currently known. Some objects in the NEA group can come very close to the Earth, and could collide with the Earth at some time in the future. This subset, of which around 400 are currently known, are called **Potentially Hazardous Asteroids** (PHAs). Figure 7.9 shows the orbits of known PHAs in relation to Earth's orbit. Looking at the PHA orbits, it is perhaps not surprising that the Earth occasionally suffers an asteroid impact!

It is thought that some members of the Near Earth Asteroid population might in fact be more related to comets, and so you may see reference to Near Earth Objects (NEOs) instead of Near Earth Asteroids (NEAs).

■ Today, well over 4 billion years after the origin of the Solar System, there are still numerous asteroids that could collide with the Earth. The lifetimes of these asteroids must be short relative to the age of the Solar System, because they are rapidly removed by collisions with the terrestrial planets. What does this imply?

❑ The supply of Earth-crossing asteroids must somehow be replenished.

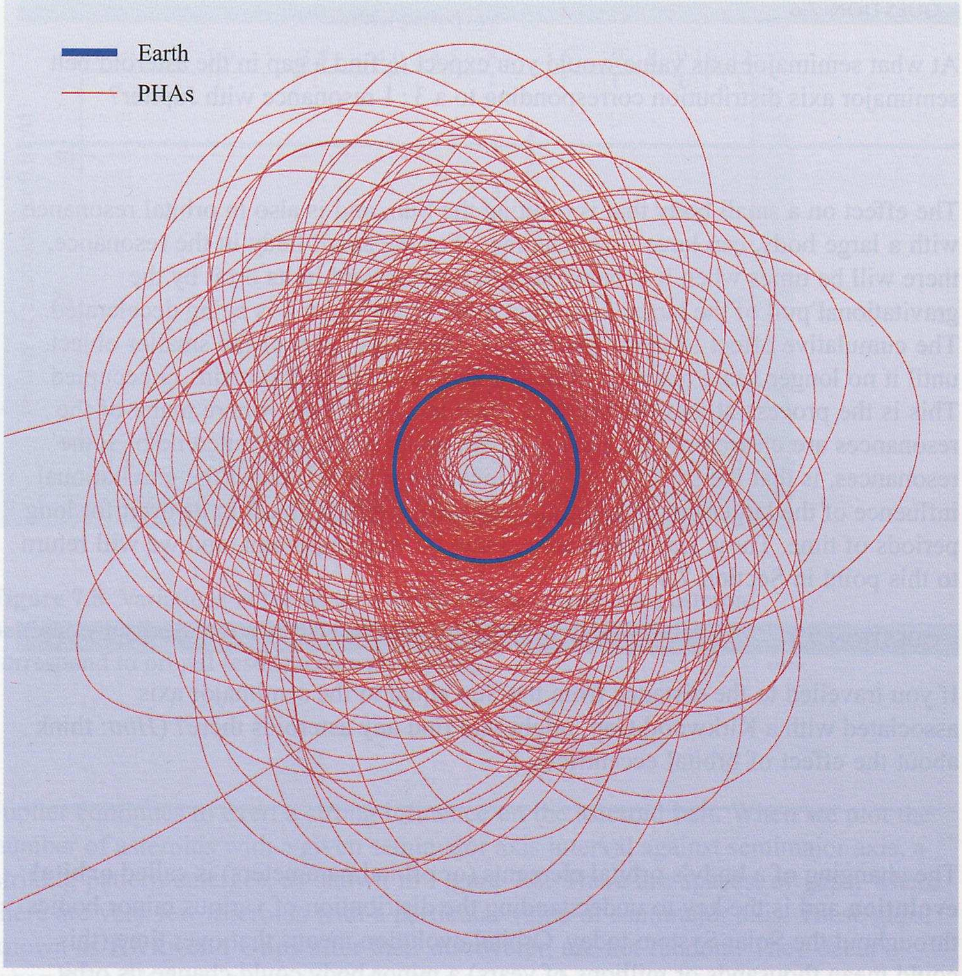


Figure 7.9 The orbits of known Potentially Hazardous Asteroids (PHAs). The orbit of Earth is also shown.

The very fact that we see NEAs today means that the NEA population is being continually replenished, and this happens because of the orbital evolution of objects in the inner asteroid belt. The long-term gravitational effects of Jupiter (and even Mars) give rise to a slow 'conveyor belt', which delivers bodies to the inner Solar System (although you should also appreciate that it can be a two-way process – bodies that are already in the inner Solar System can evolve outwards again). Some of the objects that make it into the inner Solar System might eventually hit one of the terrestrial planets.

It is thought that some members of the Near Earth Asteroid population might in fact be more related to comets, and so you may see reference to Near Earth Objects (NEOs) instead of Near Earth Asteroids (NEAs).

7.3.1 Asteroid sizes

The largest main belt asteroid, discovered in 1801, is (1) Ceres (pronounced 'series') which has a diameter of 913 km. The next biggest is (2) Pallas, with a diameter of 523 km. (Note that the asteroids are numbered, and so the full name is, for example, (1) Ceres, although often, you will see only the name being used.) As we go smaller and smaller, the asteroids become more numerous. So while there is only 1 asteroid larger than, say, 600 km (i.e. Ceres), there are 7 larger than 300 km, 81 larger than 150 km, and so on. Note that for each reduction in size the number rises steeply. This behaviour is described by a size distribution. This concept will sound familiar to you after considering impact crater size–frequency distributions in Chapter 4 (Box 4.1). It is exactly the same concept, except we are now thinking in terms of asteroid diameter rather than crater diameter.

Figure 7.10 shows the cumulative size distribution of known asteroids in the asteroid belt. We see that there are many more small asteroids than large ones. The data 'flattens out' at small sizes (10 km or smaller) but this partly due to *observational selection*; we simply have not yet discovered all the small asteroids. The gradient of the dashed line in Figure 7.10 is significant when considering where most of the material in the asteroid belt is concentrated. In other words, we could ask, is most of the material (i.e. the mass) to be found in the few largest asteroids, or is most of it distributed amongst the numerous small bodies? It turns out that, if all the data followed the same slope as the dashed line shown in Figure 7.10, the total mass of objects contained in each logarithmic diameter step would be approximately the same. For example, the total mass of all asteroids with diameters between 1 and 10 km would be the same as those with diameters between 10 and 100 km. If however the slope of the data was shallower than the dashed line (i.e. more towards the horizontal), this would indicate that the largest bodies accounted for most of the mass contained in the asteroid belt. Conversely, if the data were steeper than the dashed line, most of the mass would be contained in the smaller bodies. The data in Figure 7.10 lies close to the dashed line in the middle region of the plot, but if we were to take all the data together, a best fit straight line would be somewhat shallower than the dashed line. Thus most of the mass in the asteroid belt is concentrated in the few largest asteroids.

As many of the impact craters seen on planetary bodies are caused by the impact of asteroids, it follows that the impact crater size distribution must broadly reflect the asteroid size distribution in some way. So if we expect a large asteroid to make a large crater, and a small asteroid to make a smaller crater, then because there are far more small asteroids, we would expect to see far more small impact craters on planetary surfaces. Indeed, this is what you found in Chapter 4, with the crater size–frequency distribution.

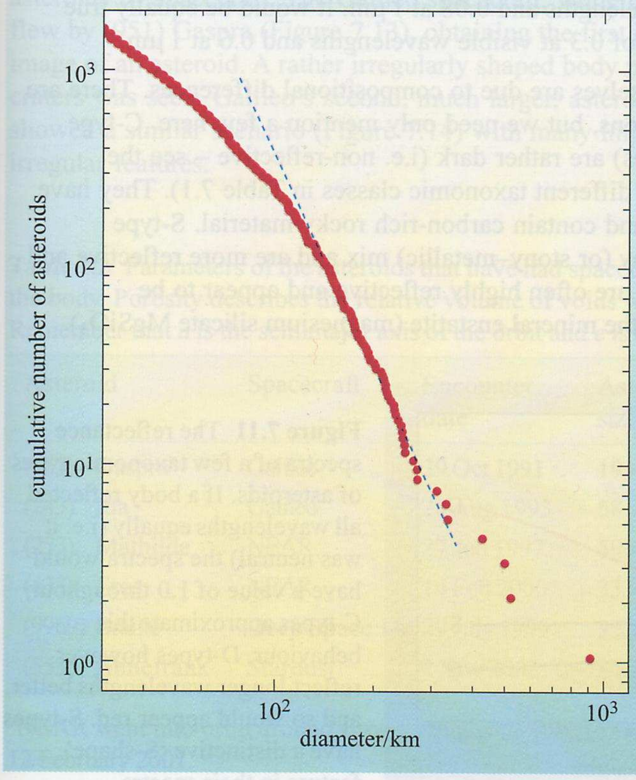


Figure 7.10 The cumulative size distribution of the known bodies in the asteroid belt, plotted logarithmically. The graph tells us the number of asteroids that have diameters greater than a given value.

7.3.2 Asteroid types

Not all asteroids are the same. The composition will depend on how and where an asteroid was formed, and what thermal, physical and chemical processing has happened to it since. Different types of asteroid are sorted into **taxonomic classes**, and the basis for deciding what class a body belongs to, comes from observational astronomy.

One useful parameter that we would like to know is how reflective the asteroid's surface is. In other words we would like to determine the *albedo* (a concept you came across in Chapter 5), and more precisely how the albedo changes at different wavelengths of light. However, much of the time, we cannot easily determine absolute values of the albedo, as we do not have an accurate knowledge of how big the asteroid actually is. In other words, you cannot always tell if you are observing a reflective small object, or a less reflective but larger object. What we can do however is to determine the *relative* efficiency with which the asteroid reflects sunlight, as a function of the wavelength of the light. This is called a **reflectance spectrum**. For example, a body that simply reflected all the sunlight equally would have a *neutral* reflectance spectrum, whereas a body that reflected light more efficiently at longer wavelengths would have a more *red* appearance. It is the precise nature (particularly the slope) of the reflectance spectrum that identifies the taxonomic class. Figure 7.11 shows typical reflectance spectra associated with three taxonomic classes. Because we do not know the absolute reflectance values, we plot the different asteroids simply over the top of each other, forcing the relative reflectance value to be 1.0 at the wavelength of about 0.55 μm, i.e. a representative value for visible light. For example, a relative reflectance value of 2.0 at 1.0 μm means that the body reflects light with double the efficiency at 1 μm as it does at visible wavelengths (where the relative reflectance value is 1.0). This would be true for an object with an albedo of, for example, 0.04 at visible wavelengths and 0.08 at 1 μm. It would be equally true for an object with an albedo of 0.3 at visible wavelengths and 0.6 at 1 μm.

Table 7.1 The typical albedo values of selected taxonomic classes of asteroids.

Taxonomic Class	Albedo
E	0.25 to 0.60
S	0.10 to 0.22
C	0.03 to 0.07
M	0.10 to 0.18
P	0.02 to 0.06
D	0.02 to 0.05

The taxonomic classes themselves are due to compositional differences. There are many classes, and sub-divisions, but we need only mention a few here. C-type asteroids (carbonaceous types) are rather dark (i.e. non-reflective – see the typical albedo values for the different taxonomic classes in Table 7.1). They have neutral reflectance spectra, and contain carbon-rich rocky material. S-type asteroids are generally a stony (or stony–metallic) mix and are more reflective and somewhat more red. E-types are often highly reflective and appear to be predominantly composed of the mineral enstatite (magnesium silicate $MgSiO_3$).

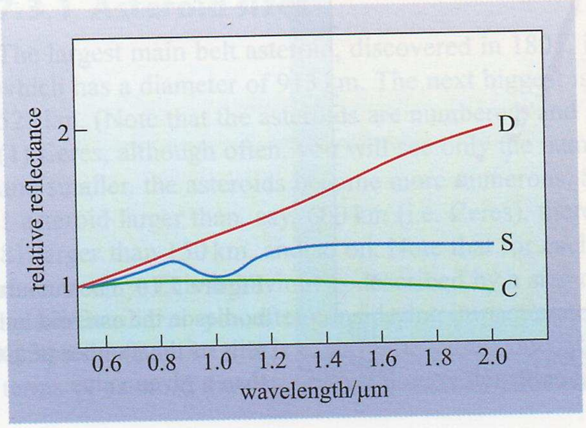


Figure 7.11 The reflectance spectra of a few taxonomic types of asteroids. If a body reflected all wavelengths equally (i.e. it was neutral) the spectra would have a value of 1.0 throughout; C-types approximate this behaviour. D-types however reflect longer wavelengths better, and so would appear red. S-types have a distinctive 'S-shape' feature in their spectra.

D-types (dark type) are extremely dark and red. M-types (metallic type) are thought to be made of mostly iron and nickel, with P-types (pseudo-M type) also thought to have a major metallic component in the composition. It is thought that C and D-types are probably quite primitive (least processed) bodies, whereas E-types, S-types and M-types are likely to be fragments from a larger body, which underwent differentiation (as discussed in Chapter 2) so producing a metallic core, and a rocky mantle. Such fragments might collide with Earth and be collected as meteorites. Figure 7.12 shows that different classes of asteroid generally occupy different regions in the asteroid belt. This is a consequence of the fact that the region of formation (distance from the Sun) affected the composition of the asteroid.

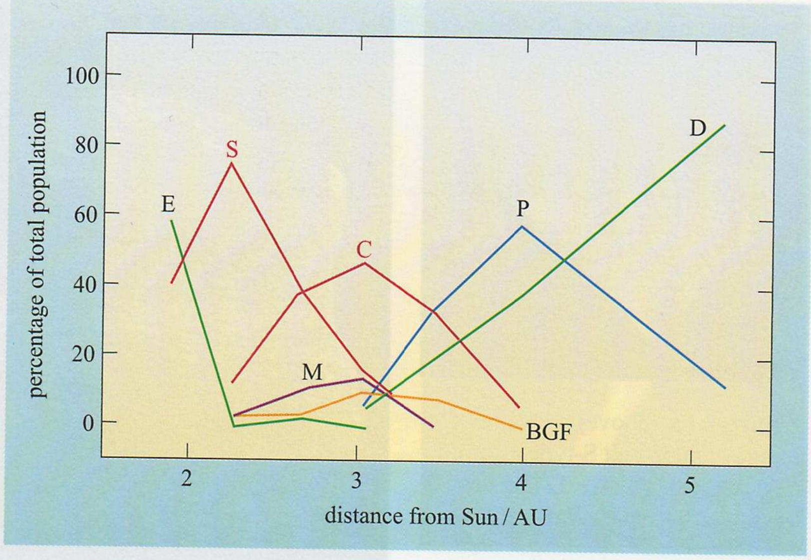


Figure 7.12 Distribution of some of the major classes of asteroid within the asteroid belt as a function of distance from the Sun. B, G and F-types are sub-classes of C-types.

7.3.3 Asteroids up close

Until relatively recently, what we knew about asteroids was based on ground-based observations. But now a handful of spacecraft missions have come very close to asteroids allowing us to learn about these minor bodies in much greater detail than before. Table 7.2 details some close fly-bys of asteroids by spacecraft. The Galileo spacecraft, while en route to Jupiter, flew by (951) Gaspra (Figure 7.13), obtaining the first ever high-resolution image of an asteroid. A rather irregularly shaped body peppered with impact craters was seen. Galileo's second, much larger, asteroid target, (243) Ida, showed a similar scenario (Figure 7.14) with many impact craters and irregular features.

Table 7.2 Parameters of the asteroids that have had spacecraft fly-bys. The sizes indicated refer to the major and minor axes of the body. Porosity describes the relative volume of voids within the object (so a completely solid body has a porosity of 0%). Remember that *a* is the semimajor axis of the orbit and *e* is the eccentricity of the orbit.

Asteroid	Spacecraft	Encounter date	Asteroid size/km	Taxonomic class	Density /kg m^{-3}	Porosity	*a* /AU	*e*
(951) Gaspra	Galileo	29 Oct 1991	19×12	S-type	2500 ± 1000?	30%?	2.21	0.17
(243) Ida	Galileo	28 Aug 1993	58×23	S-type	2600 ± 500	30%	2.86	0.05
(253) Mathilde	NEAR	27 Jun 1997	59×47	C-type	1300 ± 200	80%	2.65	0.27
(433) Eros	NEAR	14 Feb 2000[a]	33×13	S-type	2700 ± 30	25%	1.46	0.22
(9969) Braille	Deep Space 1	29 July 1999	2.2×1	?	?	?	2.34	0.43
(5535) Annefrank	Stardust	2 Nov 2002	8×4	?	?	?	2.21	0.06

[a]NEAR went into orbit around Eros on this date. It remained there for a year and then landed on the surface of Eros on 12 February 2001.

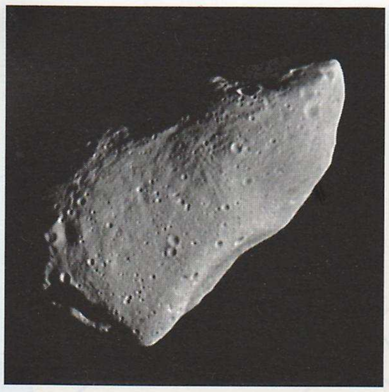


Figure 7.13 (above)
Image of main belt S-type asteroid (951) Gaspra (19 km × 12 km) taken by the Galileo spacecraft. (NASA)

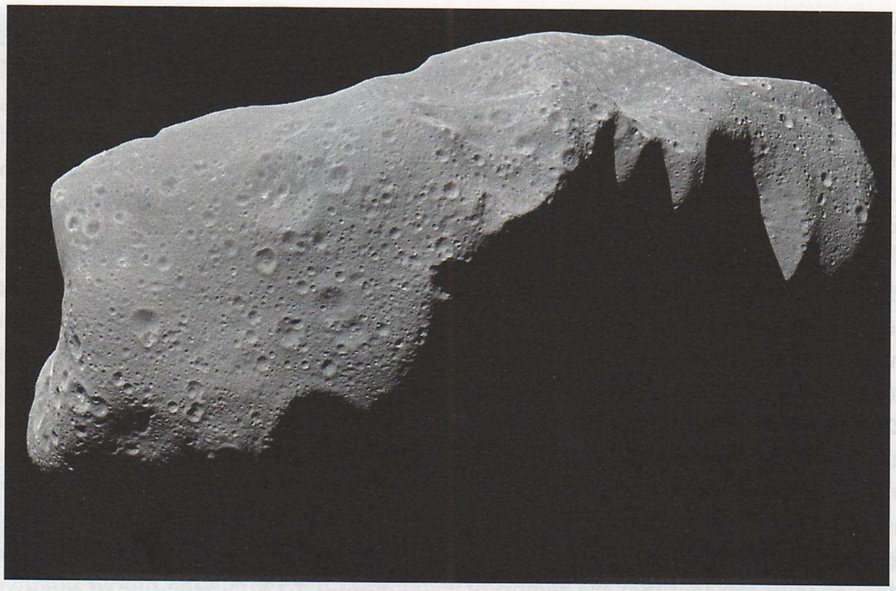


Figure 7.14 (above) Image of main belt S-type asteroid (243) Ida (58 km × 23 km), taken by the Galileo spacecraft. The rather jagged shadow line is a consequence of the asteroid being illuminated only from one direction (from the Sun). This causes a great contrast between the sunlit areas and the shadow areas, which look as black as the background space. (NASA)

QUESTION 7.8

Look at Figure 7.14, the image of the 58 km × 23 km asteroid, (243) Ida. Remembering the types of crater that you met in Chapter 4, how would you describe the craters on Ida?

Surprisingly, Ida was also found to have a much smaller satellite asteroid (named Dactyl) orbiting around it (Figure 7.15). Binary asteroids that orbit each other now appear to be more common than was previously thought, with several examples being discovered recently by ground-based telescopic studies.

Gaspra and Ida are S-type asteroids, but a C-type asteroid, (253) Mathilde (Figure 7.16), was encountered by the NEAR (or NEAR Shoemaker) spacecraft, on its way to its main target (433) Eros (an S-type Near Earth Asteroid). On reaching Eros (Figure 7.17), NEAR went into orbit about the asteroid (a major technical achievement) and spent a full year taking scientific data.

Figure 7.15 Image of Ida's satellite asteroid, Dactyl (1.6 km × 1.2 km) taken by the Galileo spacecraft. (NASA)

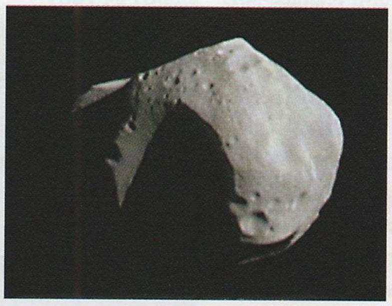


Figure 7.16 Image of main belt C-type asteroid (253) Mathilde (59 km × 47 km), taken by the NEAR spacecraft. (NASA)

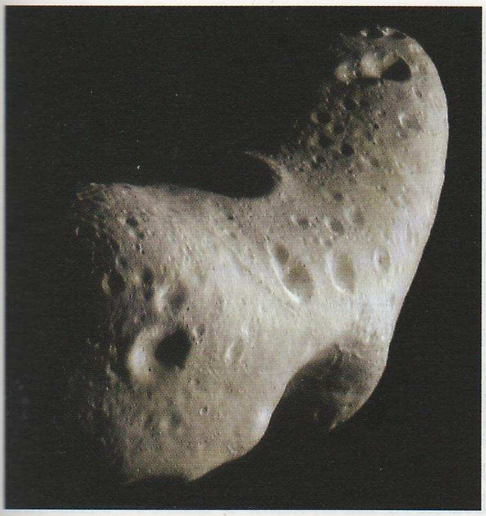


Figure 7.17 Image of near Earth S-type asteroid (433) Eros (33 km × 13 km) taken by the NEAR spacecraft. (NASA)

Figure 7.18 Image of the main belt asteroid (5535) Annefrank (8 km × 4 km) obtained by the Stardust spacecraft. (NASA)

Figure 7.19 The radar image of Near Earth Asteroid (4179) Toutatis (5 km × 2 km). Toutatis is extremely elongated. (Calvin J. Hamilton)

The asteroid (9969) Braille was encountered by the technology-proving spacecraft, Deep Space 1. Indeed the fly-by was the closest yet undertaken, being just 15 km from the asteroid. However imaging of the asteroid was not very successful. Asteroid (5535) Annefrank however, was encountered by the Stardust mission in November 2002, returning the image shown in Figure 7.18.

A close fly-by of a spacecraft is not the only way that detailed information on the shape of an asteroid can be determined. By using some of the world's most powerful radio transmitters in conjunction with some of the world's largest radio telescope dishes (for example the huge Arecibo radio telescope in Puerto Rico), radar techniques can be used to image the asteroid. This technique involves sending radio wave pulses towards an asteroid, and then receiving a reflection, or echo, back on Earth. By complex processing of the returned signals, an image representation of the asteroid can be constructed. Such an image, of the asteroid (4179) Toutatis, is shown in Figure 7.19. Repeated observations of an asteroid as it rotates, allows a full 'shape model' to be derived, an example of which is shown in Figure 7.20.

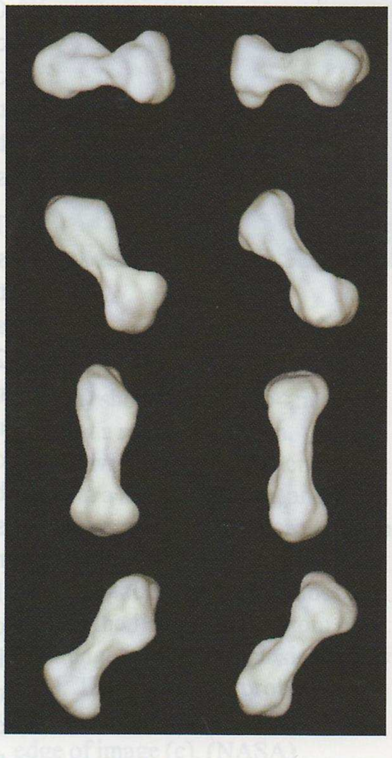


Figure 7.20 The 'shape model' of main belt asteroid (216) Kleopatra (220 km × 95 km) derived from radar observations. Kleopatra bears a remarkable resemblance to the kind of bone favoured by dogs! (NASA)

We have seen that the asteroids imaged so far, are non-spherical. A good description of them might be 'potato-shaped'. This is not unexpected. Observations from the ground often show the brightness of asteroids increasing and then decreasing regularly. This behaviour is illustrated in Figure 7.21, which is an example of an asteroid's **lightcurve**. As the light we see from the asteroid is simply reflected light from the Sun, the amount of light we receive is related to its albedo, and the cross-sectional area of the region of the asteroid that is illuminated. So if a 'potato-shaped' body is spinning, then you will see a changing cross-sectional area, and hence a changing brightness. You can convince yourself of this by simply looking at an irregularly shaped body (e.g. a potato) and turning it while considering how the cross-sectional area changes. The *period* of the lightcurve tells us how long the asteroid takes to spin, and the *amplitude* of the lightcurve (the difference between the maximum and minimum brightness) depends on how elongated the body is. Thus the lightcurve tells us the spin rate, and the ratio of the longest side to the shortest side.

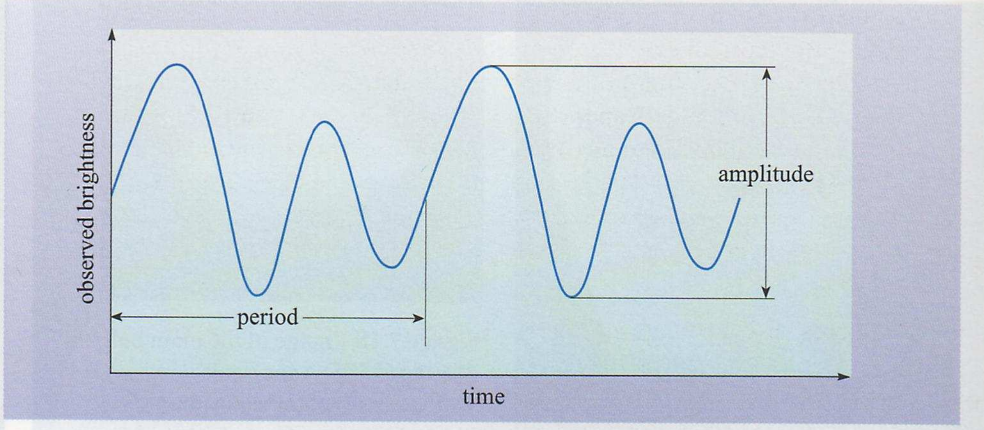


Figure 7.21 A schematic of an asteroid lightcurve, showing the amplitude (difference between the maximum and minimum brightness) and the period (time taken for one full axial revolution of the body). Note that a lightcurve produced by the irregular shape of an object is double peaked (rather than a sine wave), and that a spherical object would give an amplitude of zero (i.e. we would say it had a 'constant lightcurve').

Some asteroids have lightcurves that display very little variation, indicating that the asteroid is spherical (or near spherical). Some of the largest asteroids are thought to have undergone differentiation in a similar way to the terrestrial planets (as you met in Chapter 2). During this process the body maintains a spherical shape due to compression under its own gravity. However, subsequently, when the asteroids had cooled so that they were solid throughout, impacts could fragment and break parts off the parent asteroid, creating much more irregular shapes. This said, most asteroids that are larger than a few hundred kilometres in diameter, tend to be approximately spherical due to gravitational compression.

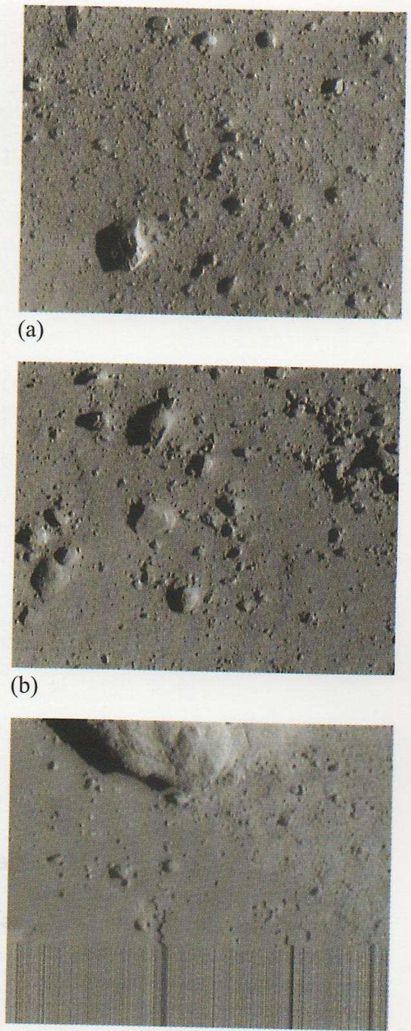
The motion of binary asteroids with respect to each other, or indeed the motion of a spacecraft around an asteroid, can be used to derive masses for the asteroids, and thus (if the asteroid size is known) indicate the density of the asteroid. S-type asteroids Ida and Eros were found to have densities of around 2600 kg m^{-3} and 2700 kg m^{-3} respectively. Remembering that S-types are predominantly rocky, one might have anticipated a density somewhat higher than this. For example, typical stony meteorites (which are thought to come from fragmented S-type asteroids) have densities of around 3400 kg m^{-3}. The lower densities of Ida and Eros suggest that the bodies might be slightly *porous*, i.e., the asteroids are not solid rock, but have a structure with voids in it (similar to what you would find for a pile of rocks). Even more surprising, the density of the C-type Mathilde was found to be around 1300 kg m^{-3} which appears very low indeed. Additionally, ground-based observations of another C-type asteroid, Eugenia, have indicated a similar density of 1200 kg m^{-3}. In fact these results suggest that C-type asteroids might be up to 80% porous. Even recent observations of some M-type binary asteroids have indicated a much lower density than might have been expected, again suggesting high porosity. These results show that some (perhaps most) asteroids are probably not solid lumps of rock and metal, but are more like a **rubble pile** of fragments of all sizes, bound together by their own gravity.

After the NEAR spacecraft had been orbiting Eros for a year, the decision was made to manoeuvre NEAR such that it landed on the surface of Eros (even though it was not designed to do this!). This allowed some images to be obtained during the descent, of unprecedented resolution. Figure 7.22 shows three images taken just before 'touch down'. Boulders and pebbles are clearly seen, with many of the boulders being partly buried by regolith (i.e. fine particle 'soil'). To the lower left of Figure 7.22c, there are fewer boulders and a smoother dusty area. These type of regions have been nicknamed *ponds* and are thought to be areas where fine regolith has gathered, covering larger boulders beneath the surface. Figure 7.23 also shows views of the surface of Eros. 'Ponds' are also seen in Figures 7.23a and c, with a more 'rugged' appearance (i.e. more boulders, and less regolith covering) being seen in Figure 7.23d.

The NEAR data show that impacts that produce boulders and other smaller particles play a large part in determining the nature of the asteroid surface. Asteroids can no longer be thought of as lumps of bare rock, but are often collections of smaller fragments, or at least can suffer significant *fracture* due to impacts. Future spacecraft missions will further investigate the nature of asteroids. For example, the Japanese MUSES-C mission has been designed to go to a Near Earth Asteroid, and attempt to bring some small samples of the surface back to Earth, allowing detailed chemical composition analyses to be done in the laboratory.

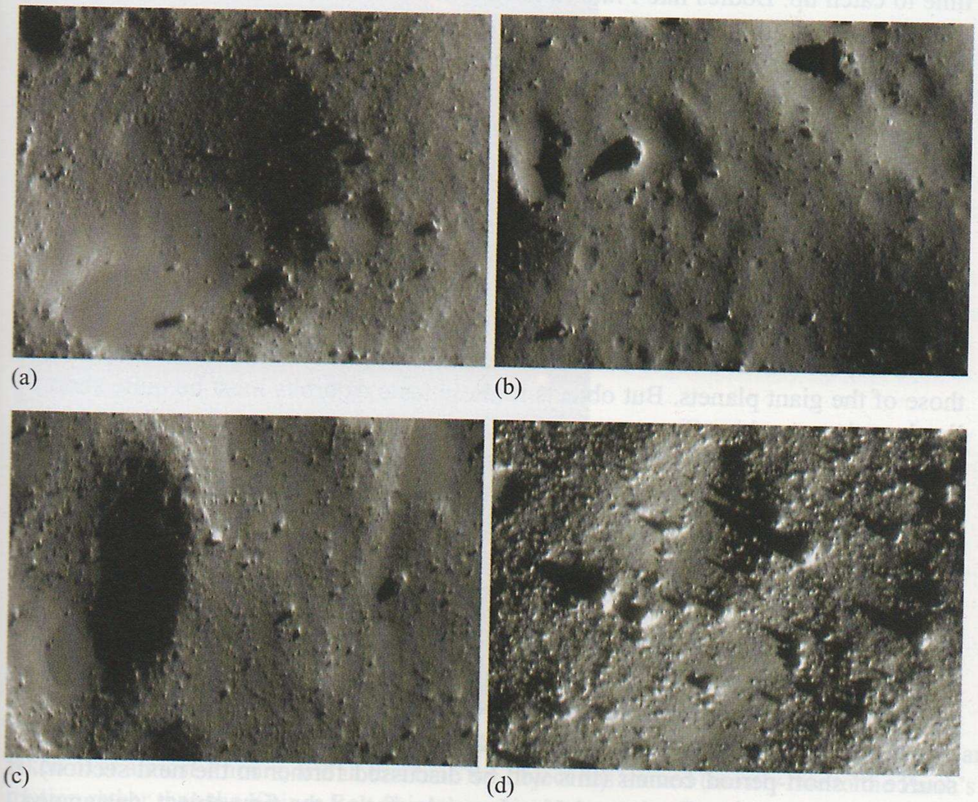
QUESTION 7.9

Imagine an asteroid of diameter 1 km, of unknown taxonomic class, is about to hit the Moon. Will it make any difference to the impact crater produced, whether the asteroid was S-type, or C-type?



(a) (b) (c)

Figure 7.22 The last images from the descent sequence of NEAR. Part (a) shows a region 54 m across taken at a range of 1150 m, (b) shows a region 12 m across taken at a range of 250 m, and (c) shows a region 6 m across taken at a range of 120 m; this is the final image obtained before the loss of signal (the lines at the bottom of the image indicate when signal was lost). The spacecraft probably landed about 7 m to the left of the edge of image (c). (NASA)



(a) (b) (c) (d)

Figure 7.23 Four images of the surface of Eros, where regolith appears to have collected in depressions on the surface. A 'pond' is particularly evident in the lower left region of Figure (a). Figures (a) and (b) show regions about 550 m across. Figures (c) and (d) show regions about 230 m across. (NASA)