CHAPTER 1

"Magnificent desolation"

No, not a still from a science-fiction movie but a real (*Apollo 17*) astronaut by the "Station 6 Boulder" on the North Massif of the Moon's Taurus–Littrow Valley! The South Massif can be seen on the far side of the valley. The *Apollo 17* mission in December 1972 was the last expedition to the Moon's airless surface. (NASA photograph.)

Feverishly excited, I sat cross-legged in front of the family television set and watched the fuzzy, indistinct, shapes of Neil Armstrong and Buzz Aldrin moving about amid the grey wash that was the surface of the Moon. The fact that the picture was of poor quality because it had been beamed back to Earth through a quarter of a million miles of space did little to dampen my enthusiasm. I could also make out part of the spidery form of their space vehicle extending from the grey wash into the black stripe that represented the airless sky over the Moon. The sound quality was also poor. The words of those first men on the Moon sounded crackly and wheezy and so were often difficult to decipher, so I listened hard. I was a young boy at the time but my sense of the significance of what I was witnessing was intense. I heard Neil Armstrong's words before he stepped onto the lunar soil. I heard Buzz Aldrin describe the scenery around him as "magnificent desolation". I wished I was there with them to see it.

I was born just after the beginning of what used to be called 'the Space Age'. As far back as I can remember I have been interested in things scientific and technical and have been infected with a particular passion for matters astronomical. I avidly read books about science and astronomy. By the time of that first Moon landing I had acquired an old pair of binoculars and had been bought a very small terrestrial telescope. Whenever I was allowed to go outside after dark I turned these humble instruments towards the Moon and gazed at the dark patches and the craters that they imperfectly revealed. The proper astronomical telescope I yearned for was at that time beyond my means.

Those who were around at the time will remember the feverish excitement and air of expectation that gradually built up through the 1960s as the world's space agencies rapidly made the advances towards that first manned Moon landing. As well as a huge variety of merchandising such as books, booklets, posters, and kits to make plastic models of various rockets, television companies enthusiastically broadcast news items and informative programmes about the 'space race'. Our television screens were also awash with many science-fiction shows – *Doctor Who* and *Space Patrol* (called *Planet Patrol* in the USA) being particular favourites of mine – that featured space travel to other worlds. The fantasy shows reflected the public's yearning for real astronauts to travel through space and walk on real alien worlds. I very much shared that yearning.

The next few years brought further advances and more space missions. The pictures and sound got clearer. The Christmas of 1970 was significant for me in that my parents bought me a 'proper' astronomical telescope. It was a 3-inch (76 mm) Newtonian reflector. Yes, it was still smaller than the size of instrument recommended for useful work but I shall never forget the thrill of turning it to the Moon for the first time and seeing the large iron-grey lunar 'seas' and the rugged mountain ranges and magnificent craters come into sharp focus.

A few years were to pass before I was able to graduate to more powerful telescopes. I was to spend many hours 'learning my craft' at the eyepiece of that first 'proper' one. I didn't know it then but observing the Moon through telescopes was to become an important part of my life. After graduating in astronomy and physics, I was even to spend several years as a Guest Observer of the Royal Greenwich Observatory and so get to use professional telescopes to carry out, amongst other projects, lunar research.

I must have spent several thousands of hours of telescope time observing the Moon. You might have thought that I would be tired of it by now. Absolutely not! I hope to show you why not in the pages of this book. I hope that you, like me, will be thrilled anew every time you view the spectacle of our neighbouring world's "magnificent desolation".

1.1 AN ORBITING ROCK-BALL

Even today there are people (amazingly, even some in our western society) who are unaware of the Moon's true nature and status. I should hope that this does not apply to any of the readers of this book. However please let me, for completeness if for no other reason, state some of the basic facts. The Moon is a solid, rocky, body with an equatorial diameter of 3476 km. It orbits the Earth at a mean distance of 384 000 km. Though often appearing brilliant in the night sky, the Moon does not emit any light of its own generation. It shines mainly because of reflected sunlight, with a very small contribution from fluorescence caused by the re-radiation at visible wavelengths of invisible short-wave solar radiations and absorbed kinetic energy from solar-wind bombardment.

The Moon's diameter is over a quarter of that of the Earth (12 756 km for comparison) and this has led many to consider the Earth and Moon as

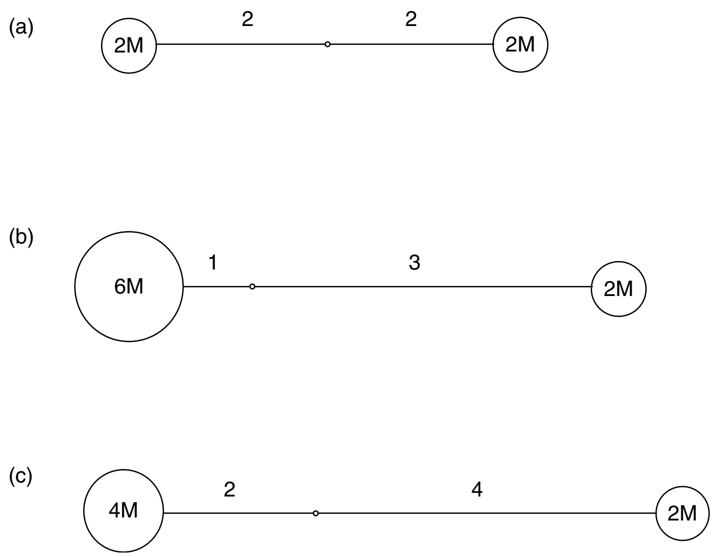

Figure 1.1 The positions of the barycentre for bodies of differing masses. The distances of each of the barycentres from the bodies are in the inverse ratios of their masses in each of these cases.

a double-planet system, rather than as a true parent planet (the Earth) and attendant satellite (the Moon). Certainly the statement that 'the Moon orbits the Earth' is an approximate one. In truth both orbit their *barycentre*, or common centre of mass. For two co-orbiting bodies of equal mass the centre of mass of the system lies exactly half way between their centres – see Figure 1.1(a). In the case of one body being more massive than the other, the barycentre is still in mid-space but is shifted towards the more massive body. In fact the ratio of the distances from each body to the barycentre is in the inverse ratio of their masses. This point is illustrated by Figure 1.1(b) and 1.1(c). In the case of the Earth and Moon, the Moon's mass is 7.35×10^{22} kg and that of the Earth is 5.98×10^{24} kg (81 times more massive). This results in the ratio of the distances from the centre of the Moon to the barycentre and from the centre of the Earth to the barycentre being 81:1. Put another way, the barycentre lies 1/82 of the way along a line joining the centre of the Earth to the centre of the Moon; 1/82 of 384 000 km is a little under 4700 km and so the barycentre lies inside the Earth's globe. The Earth may 'wobble' as the Moon orbits but the statement about the Moon orbiting the Earth is approximately true and I, at least, think that this fact qualifies the Moon as the Earth's satellite rather than them both being regarded as a double planet.

1.2 PHASES AND ECLIPSES

Nowadays most people are aware that the Sun acts as the central hub of our Solar System and that the planets orbit at various distances from it.

I have detailed elsewhere the story of how the ancients came to realise this (*Astronomy In Depth*, published by Springer–Verlag in 2003) but suffice it to say here that the researches of Copernicus and Galileo in the sixteenth and early seventeenth centuries were pivotal. Of course, one body was not displaced from its situation of orbiting the Earth, as the ancients had mistakenly believed was the case for all the other bodies of the Solar System: the Moon.

The Moon's *sidereal period*, the time it takes to complete one circuit of the Earth, is 27.3 days. At the beginning of the seventeenth century Johannes Kepler had determined that the orbits of the planets about the Sun were elliptical, rather than being circular in form as had been thought by Copernicus. The Moon's orbit is also elliptical. At the point of closest approach, *perigee*, the Moon's distance is 356 410 km. This increases to 406 679 km at *apogee*.

Figure 1.2 provides the usual elementary explanation of how the Moon's phases are produced over a complete cycle, or *lunation*. What the diagram does not reveal is why it is that the length of the cycle is not 27.3 days, the same as the sidereal period. The reason is that while the Moon is making its circuit of the Earth, the Earth itself is moving along its own orbit around the Sun. Hence the direction of the sunlight changes a little with time, instead of being fixed as implied in the diagram. Consequently, the Moon has to go a little further than one circuit round the Earth to go from one new Moon to the next. So, the length of a lunation, or *synodic period* is 29.5 days.

As well as the phases, *earthshine*, sometimes called 'the old Moon in the New Moon's arms' is another commonly recognised phenomenon. Figure 1.3 shows it well. Most obvious to the naked eye when the Moon is little more than a thin crescent but seen more often with optical aid, this is caused by reflected sunlight from the Earth shining on the Earth-facing part of the Moon experiencing night. Leonardo da Vinci is credited as being first to explain this effect correctly. In part, the earthshine is easiest to see when the Moon's crescent is thin because there is not so much glare from the sunlit portion. Also, when the Moon appears as a crescent from the Earth, the Earth appears gibbous from the surface of the Moon. One could say that the apparent phase of the Earth as seen from the Moon is the opposite of that of the Moon seen from the Earth. So, when the Moon's crescent is thin the amount of reflected light from the Earth shining on the Moon is nearly at its maximum. Apart from the foregoing, the apparent brightness of the earthshine also depends on the amount of cloud cover in the Earth's atmosphere (as seen from the surface of the Moon, the Earth would appear at its most brilliant when largely covered in highly reflective clouds). Finally, the observing conditions local to the observer also have an

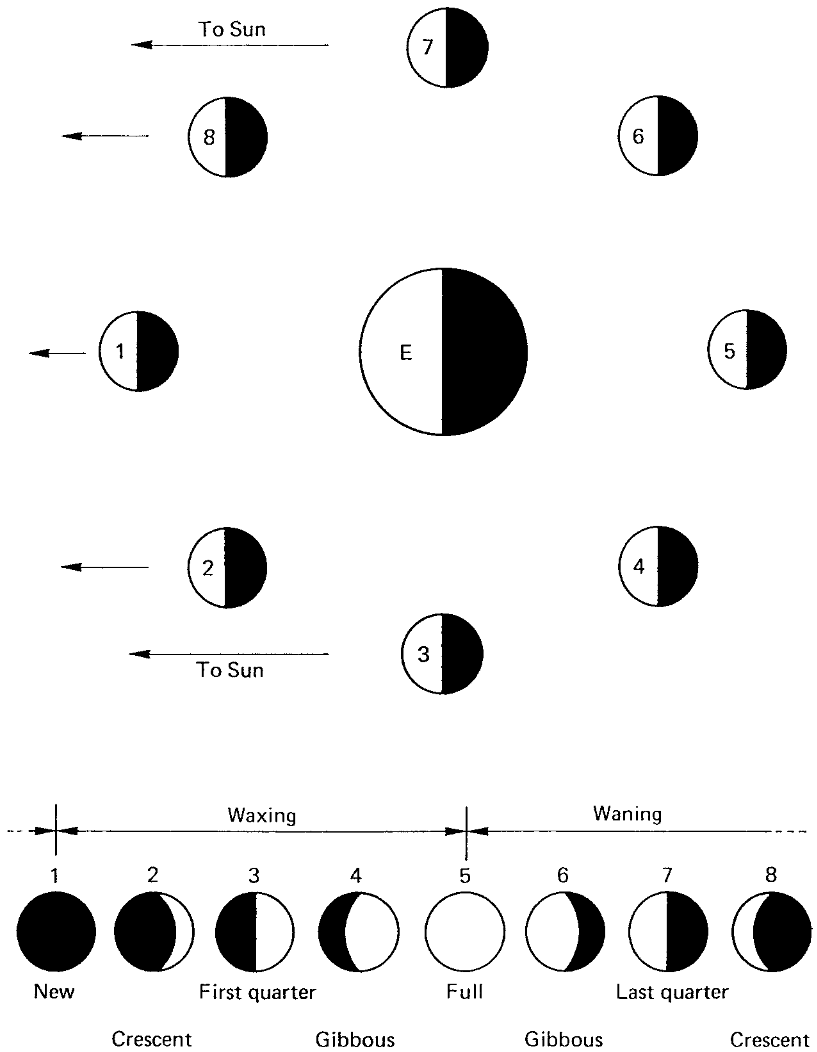

Figure 1.2 The phases of the Moon. The upper section of the diagram illustrates the Moon in various positions in its orbit, while the corresponding phases that we see from the surface of the Earth are shown in the lower section.

important bearing. Poor transparency and haze both inhibit the visibility of earthshine, just as one would expect.

Another inaccuracy in Figure 1.2 is that it does not represent the true three-dimensional relationship between the Earth, the Moon and the Sun. Realising that the Earth casts a huge cone-shaped shadow into space, one might imagine that every full Moon our satellite ought to pass into this shadow cone (see Figure 1.4). Of course such, *lunar eclipses* do occur but certainly not at the time of every full Moon. Neither do *solar eclipses* occur at every new Moon (Figure 1.5), even though the diagram might suggest that the Moon should pass exactly between the Sun and

Figure 1.3 Earthshine. (a) Photographed by the author with an ordinary camera fitted with a 58 mm f/2 lens on 3M Colourslide 1000 film.

the Earth at these times. What the diagram does not show is that the plane of the Moon's orbit about the Earth is inclined slightly (actually by about 5°) to the plane of the Earth's orbit about the Sun.

A useful concept in astronomy is that of the *celestial sphere*. In this the sky that surrounds the Earth is represented as the inner surface of a

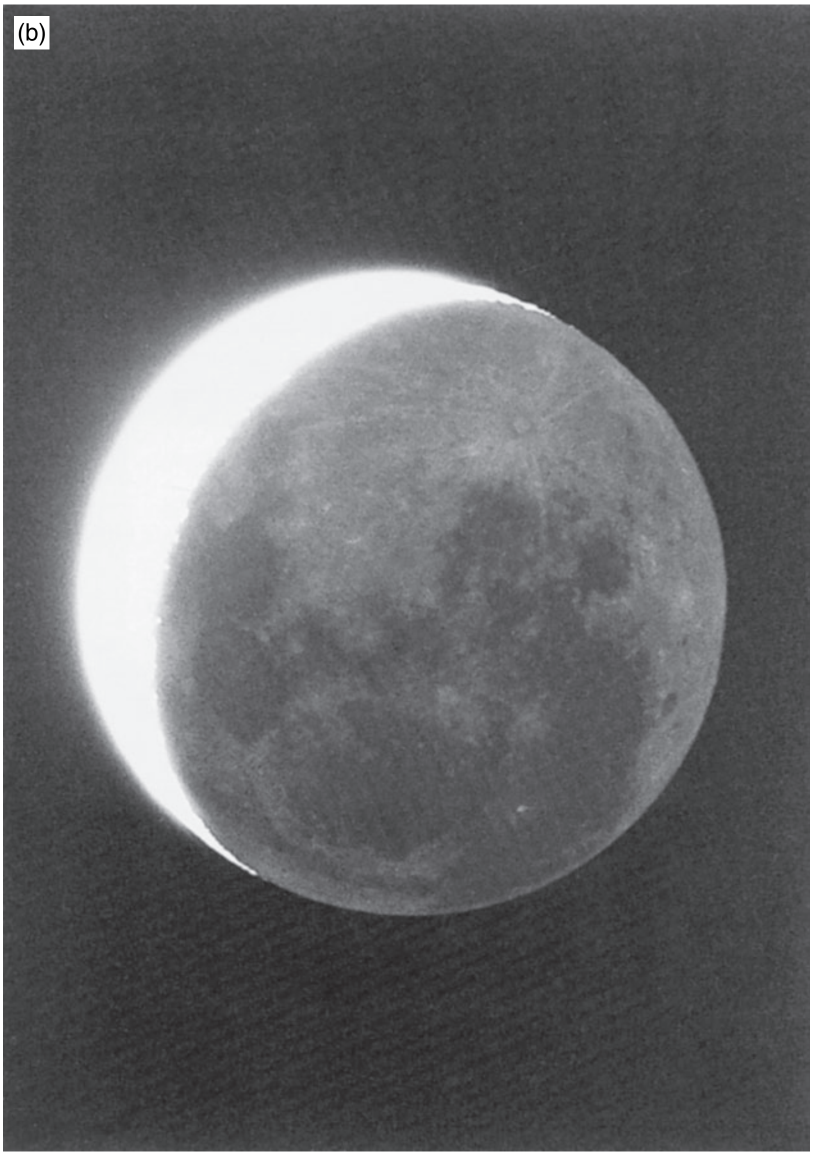

Figure 1.3 (*cont.*)
(b) A close-up, photographed by Tony Pacey on 1993 March 26^{d} 19^{h} 35^{m} UT, using his 305 mm f/5.4 Newtonian reflector. The sunlit portion of the Moon is heavily overexposed in this 12 second exposure on *Ilford FP4* film.

sphere, the Earth itself being a tiny dot at the centre of the sphere. All the stars, celestial bodies and the paths along which any of the celestial bodies appear to move can be shown as projections onto this imaginary sphere. Figure 1.6 shows such a celestial sphere on which is projected the monthly orbit of the Moon. Also shown is the yearly apparent path of the Sun across the sky, which results from our orbit around the Sun (in effect the Sun appears to move once around the sky, through the constellations

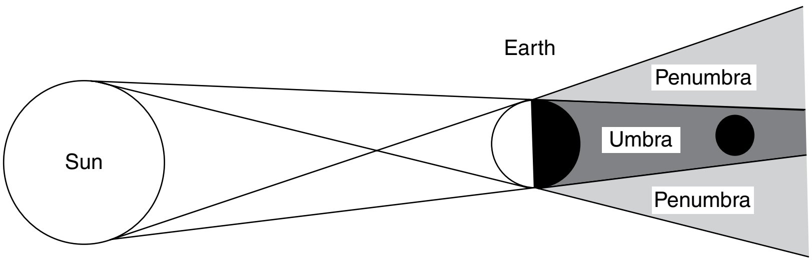

Figure 1.4 Lunar eclipses. With the Moon (black disk) in the position shown, a total lunar eclipse would be the result. This diagram is grossly out of scale for the sake of clarity.

of the Zodiac, taking one year to complete one circuit). The Sun's annual path across the sky is known as the *ecliptic*.

The different inclinations of the Moon and Earth's orbital planes are reflected in the inclinations of the ecliptic and the Moon's path on the celestial sphere. Note how the Moon's path and the ecliptic cross at two diametrically opposite points on the celestial sphere. Where the Moon crosses the ecliptic going from north to south it is said to be at its *descending node*. Crossing south to north, it is then at its *ascending node*.

Notice how the only times the Moon and the Sun can appear exactly together in the sky (put another way, both appearing to be in the same direction as seen from Earth) are when both are at either the ascending node, or the descending node, at the same instant. Remembering that the

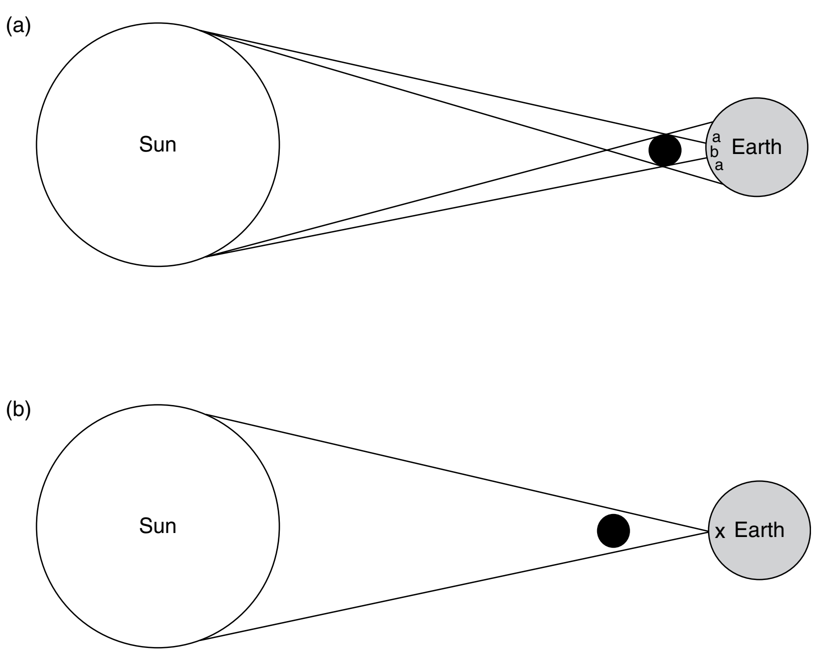

Figure 1.5 Solar eclipses. (a) An observer stationed at **b** would see a total solar eclipse, while someone in the regions shown as **a** would see a partial eclipse. (b) An observer at position **x** would see an annular eclipse. The diagrams are grossly out of scale for the sake of clarity.

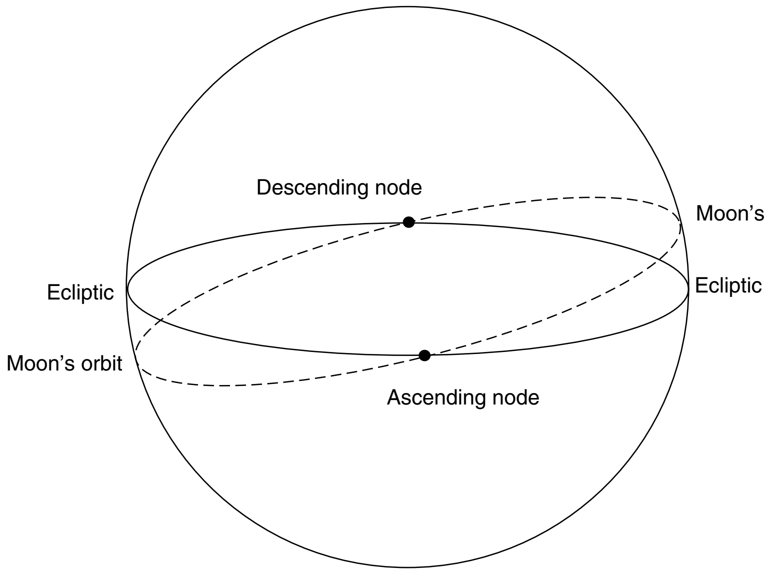

Figure 1.6 The orbit of the Moon projected onto the celestial sphere.

condition for eclipses to occur is that the Earth, Sun and the Moon must simultaneously lie along the same straight line at the time of full Moon (for a lunar eclipse) or new Moon (for a solar eclipse), it is not hard to see why eclipses are relatively rare. For the vast majority of lunations new Moons occur with the Moon appearing just a little north or just a little south of the Sun in the sky. Similarly, the Moon manages to miss the Earth's shadow cone, passing either north or south of it, at the time of most full Moons.

The situation shown in Figure 1.4, very much out of scale for the sake of clarity, is that for a *total lunar eclipse*, where the Earth passes through the full shadow, or *umbra*. First the Moon enters the partial shadow, or *penumbra*. The dimming of the full Moon is only very slight at that time. As the Moon enters the umbra so a 'bite' begins to appear and the direct sunlight is progressively cut off. For a typical total lunar eclipse it will take about an hour for the Earth's shadow to completely sweep across the Moon's surface (see Figure 1.7). Then all the direct sunlight will be cut off. The only light reaching the surface of the Moon then is that refracted and scattered by the Earth's atmosphere. Usually the Moon then looks very strange, bathed as it then is by a copper-coloured glow. For an eclipse of maximum duration, totality lasts about an hour and then the umbral shadow leaves the Moon over the course of another hour or so.

How much dimming there is, and the precise colourations seen, vary from eclipse to eclipse (and can even vary during the course of an eclipse). Also, the size of the Earth's umbral shadow can vary a little from eclipse

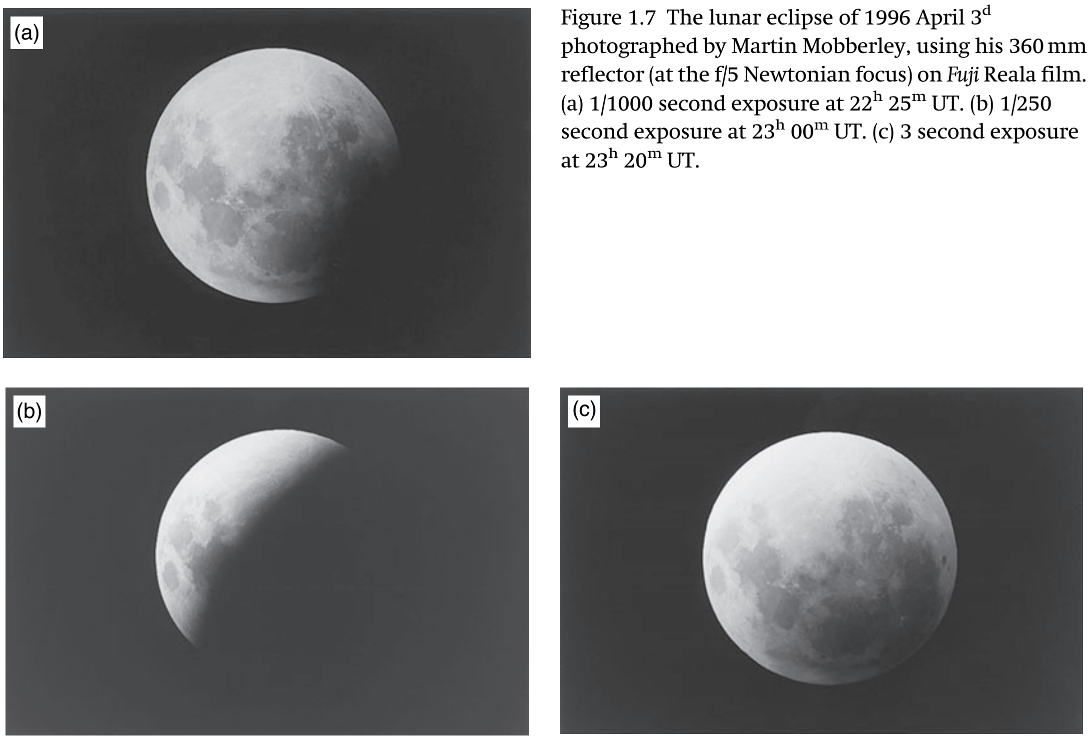

Figure 1.7 The lunar eclipse of 1996 April 3^{d} photographed by Martin Mobberley, using his 360 mm reflector (at the f/5 Newtonian focus) on *Fuji* Reala film. (a) 1/1000 second exposure at $22^{h}\ 25^{m}$ UT. (b) 1/250 second exposure at $23^{h}\ 00^{m}$ UT. (c) 3 second exposure at $23^{h}\ 20^{m}$ UT.

to eclipse, so altering the precise timings and the durations of the eclipses. There is no mystery about these variations. They reflect the state of the Earth's atmosphere at the time of each of the eclipses.

Actually, it might be that for a particular eclipse the Moon is not particularly close to its orbital node and may, as a result, only partially enter the umbral shadow. In that case a *partial lunar eclipse* results. If the Moon misses the umbra altogether, the result is then termed a *penumbral eclipse*, though most casual observers will be hard-pressed to spot the very slight dimming that results. On average, about two lunar eclipses are visible each year from somewhere on the Earth's surface.

The darkness of a lunar eclipse can be rated using the *Danjon scale*. A Danjon 0 eclipse is the darkest. At mid-totality the Moon is almost invisible. A Danjon 1 eclipse is very dark, with a deep-brown or grey umbra, and surface details on the Moon are difficult to make out. A Danjon 2 eclipse is usually deep red, or reddish brown in colour, though near the edge of the umbra the Moon can look bright orange. A Danjon 3 eclipse is brighter still, though the umbra still looks coppery red and its edge is often coloured bright yellow. A Danjon 4 eclipse is the brightest, with the Moon looking bright orange or even yellow at mid-totality.