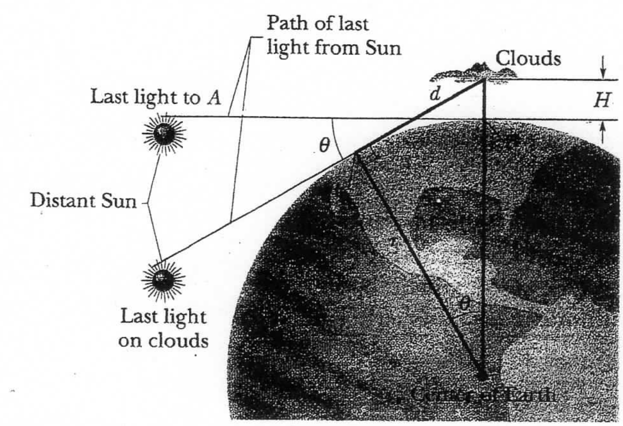

Fig. 1-3 The last sunlight reaching an observer at point A occurs at sunset. The last sunlight reaching clouds at height H above the observer occurs later, after the Sun appears to rotate through an angle θ. Height H and angle θ are exaggerated for clarity.

lence. The methane works its way into the upper atmosphere and undergoes chemical changes, resulting in an increase of water molecules and the bits of ice needed for the formation of the mesospheric clouds, as they are now called.

The mesospheric clouds are visible after sunset because they are in the upper portion of the atmosphere that is still illuminated by sunlight. They are not visible earlier in the day in spite of their illumination because the lower atmosphere is then too brightly lit for them to be distinguished. If the clouds are spotted overhead 38 min after sunset and then quickly dim, what is their altitude H?

Solution: Figure 1-3 shows the situation for the observer, who is at point A on Earth's surface, below the mesospheric clouds at altitude H. A **Key Idea** is that at sunset, the last sunlight reaching the observer follows a path that is tangent to Earth's surface at point A. A second **Key Idea** is that the last sunlight reaching the mesospheric clouds above the observer follows a path that is tangent to Earth's surface at point B. This occurs at time t = 38 min after sunset.

From Fig. 1-3, the angle between these two paths is θ, the angle through which the Sun appears to move about Earth during the 38 min. During a full day, which is approximately 24 h, the Sun appears to move through an angle of 360°. Thus, in time t = 38 min, the Sun appears to move through an angle

$$\theta = (38 \text{ min})\left(\frac{1 \text{ h}}{60 \text{ min}}\right)\left(\frac{360^\circ}{24 \text{ h}}\right) = 9.50^\circ.$$

From Fig. 1-3, this angle θ is also the angle between the Earth radii r to the two tangent points A and B. The figure shows a right triangle: one leg is r and the hypotenuse is $r + H$. Using the definition of the cosine function from trigonometry, we can write

$$\cos \theta = \frac{r}{r + H}. \tag{1-7}$$

From Appendix C, the (mean) radius of Earth is $r = 6.37 \times 10^6$ m. Substituting this and $\theta = 9.50°$ into Eq. 1-7, we have

$$\cos 9.50^\circ = \frac{6.37 \times 10^6 \text{ m}}{(6.37 \times 10^6 \text{ m}) + H},$$

which gives us

$$H = 8.86 \times 10^4 \text{ m} \approx 89 \text{ km}. \qquad \text{(Answer)}$$

The more frequent occurrence of the clouds in recent decades indicates that methane production on Earth's surface is changing even the mesosphere.

1-7 Mass

The Standard Kilogram

The SI standard of mass is a platinum–iridium cylinder (Fig. 1-4) kept at the International Bureau of Weights and Measures near Paris and assigned, by international agreement, a mass of 1 kilogram. Accurate copies have been sent to standardizing laboratories in other countries, and the masses of other bodies can be determined by balancing them against a copy. Table 1-5 shows some masses expressed in kilograms, ranging over about 83 orders of magnitude.

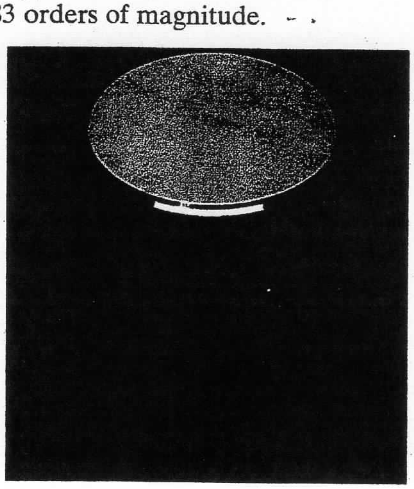

Fig. 1-4 The international 1 kg standard of mass, a platinum–iridium cylinder 3.9 cm in height and in diameter.

TABLE 1-5
Some Approximate Masses

Object	Mass in Kilograms
Known universe	1×10^{53}
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Small mountain	1×10^{12}
Ocean liner	7×10^{7}
Elephant	5×10^{3}
Grape	3×10^{-3}
Speck of dust	7×10^{-10}
Penicillin molecule	5×10^{-17}
Uranium atom	4×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}