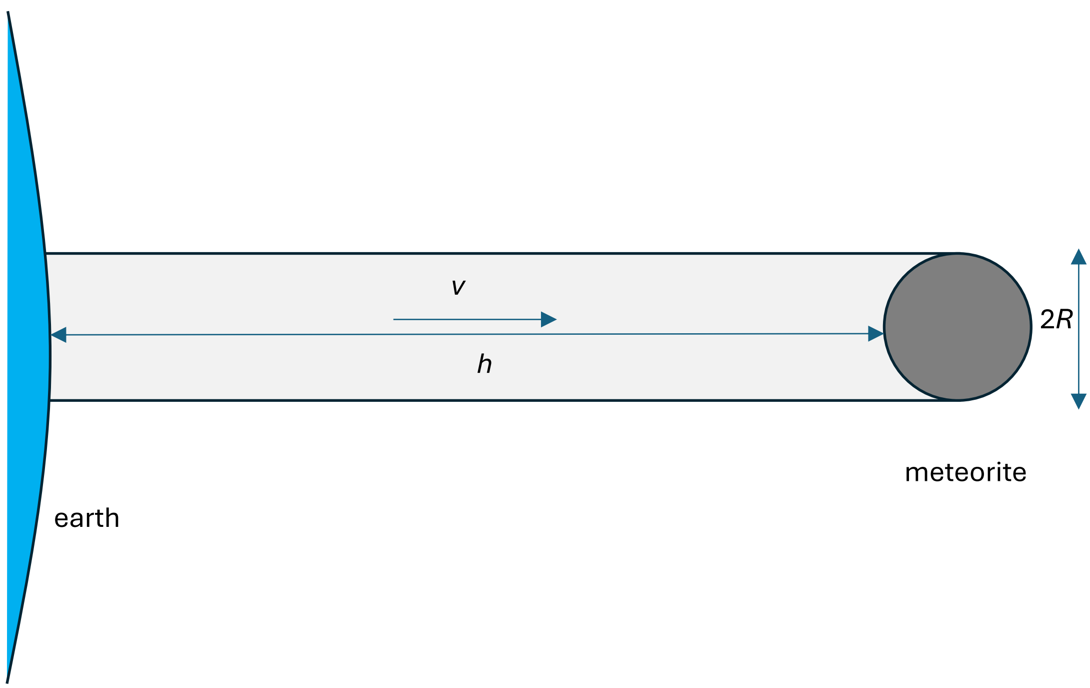
Teacher notes
Topic D

Meteorites, again.

A typical impact speed of a meteorite with the earth surface is about 20 km s^{-1}. This question concerns itself with whether a large meteorite will burn in the atmosphere or break up before impacting the surface.

(a) The heat absorbed by the meteorite as it travels through the atmosphere is modelled as follows: taking the meteorite to be at rest, the air is moving at the meteorite with speed *v*. Assume that the meteorite receives a fraction *f* of the kinetic energy of the air column of height *h*.



Show that total energy absorbed by the meteorite is $\frac{f}{2}\rho A h v^2$ where *A* is the area presented to air by the meteorite, i.e. πR^2.

(b) Deduce that the fractional mass of the meteorite that melts is given by $\frac{\Delta M}{M} = \frac{f\rho A h v^2}{2LM}$ where *L* is the latent heat of fusion.

(c) The following data are available:

f = 0.02
density of meteorite = 2500 kg m^{-3}
radius of meteorite R = 6.0 km
$L = 5.0\times 10^{6}\ \text{J kg}^{-1}$
h = 50 km
average density of air $\rho = 0.2\ \text{kg m}^{-3}$
density of air at surface = $1.2\ \text{kg m}^{-3}$

(i) Estimate $\frac{\Delta M}{M}$.
(ii) Comment on your answer.

(d) It can be shown that the force opposing the motion of the meteorite is given by $\frac{1}{2}C\rho A v^2$ where C is approximately 0.2. Meteorites break up when the pressure on them exceeds 500 MPa.
(i) Determine whether this meteorite will break up.
(ii) Comment on your answer.

(e) A large meteorite impacting the earth's surface would send a very large quantity of dust into the atmosphere. (The same effect on a larger scale would be if very many nuclear warheads were to explode in a local or global nuclear war.) Discuss the effect of this on the earth's climate.

Answers

(a) The kinetic energy of the air is $\frac{1}{2}mv^2 = \frac{1}{2}\rho V v^2 = \frac{1}{2}\rho A h v^2$ and a fraction *f* of this is absorbed.

(b) $Q = f\rho A h v^2 = \Delta m L$. Hence, $\frac{\Delta M}{M} = \frac{f\rho A h v^2}{2LM}$.

(c)

(i) The mass is $M = \frac{4\pi}{3}\rho R^3 = \frac{4\pi}{3} \times 2500 \times (6.0 \times 10^3)^3 = 2.3 \times 10^{15}$ kg.

$$\frac{\Delta M}{M} = \frac{f\rho A h v^2}{2LM}$$

$$\frac{\Delta M}{M} = \frac{0.02 \times 0.2 \times 50 \times 10^3 \times (20 \times 10^3)^2}{2 \times 5.0 \times 10^6 \times 2.3 \times 10^{15}} = 3.5 \times 10^{-12}$$

(ii) Very little mass will melt. This means that the meteorite will hit the surface essentially intact.

(d)

(i) The maximum pressure will be exerted when the speed and air density are greatest, i.e. right before impact. The pressure is

$$P = \frac{F}{A} = \frac{\frac{1}{2}C\rho A v^2}{A} = \frac{1}{2}C\rho v^2 = \frac{1}{2} \times 0.2 \times 1.2 \times (2.0 \times 10^4)^2 = 48 \text{ MPa}$$

(ii) This means the meteorite is unlikely to break up. This is bad news as a large meteorite will neither burn nor break up before hitting the surface.

(e) The dust (and smoke in case of nuclear war) would block sunlight from reaching the surface for years. This would imply a drop in average global temperatures and a substantial reduction in agricultural production. It is estimated that in the case of nuclear war, the average global temperature would be reduced by 1.25 K. This does not sound much but in the last ice age global average temperatures reduced by only 0.5 K!