## M. 4 Free Fall

We say that an object is in free fall if the only force acting on it is its weight ( not strictly true there is air resistance also). eg. dropping a ball from a building.

## M.4.1 Acceleration During free fall

Aristotle said that objects fell towards Earth because they contained earth element, that heavier object would fall faster because they contained more earth element. Galileo performed extensive and thorough experiments where he showed Aristotle to be incorrect. He suggested that all objects fall at the same rate, light objects appeared to fall slower because friction (air resistance) had a greater effect on them.

Video: $\quad$ NASA Video clip - Hammer and Feather
For a body travelling in the vertical direction close to the Earth's surface, with no friction.
We have $\Sigma \mathrm{F}=\mathrm{m}$ a
The only force acting is weight

$$
\begin{array}{ll}
\therefore & \Sigma F=W \\
& W=\mathrm{ma} \\
\text { but } & W=\mathrm{mg} \\
\text { so } & \mathrm{mg}=\mathrm{ma} \\
\therefore & \mathrm{a}=\mathrm{g}
\end{array}
$$

So for vertical motion the acceleration is constant and is equal to g , the gravitational field strength ( $9.8 \mathrm{~N} \mathrm{Kg}^{-1}$ ).
Since the acceleration is constant we can use the constant acceleration formulae.

## M.4.2 Air Resistance

Air resistance is opposite to the direction of travel. It is down if the object is travelling up, and up if the object is travelling down. So a diagram is needed to be drawn, $\Sigma \mathrm{F}$ and go from there.

However, air resistance is more complicated than that because it is not constant, but proportional to the velocity. It increases as the velocity increases.

Let's look at the example of an object falling downwards. As it falls downwards the velocity increases and the air resistance increases accordingly. After a while the air resistance will equal the weight force ( in size opposite in direction) and the following will happen.

$$
\mathrm{AR}=\mathrm{W}
$$

then $\quad \Sigma \mathrm{F}=\mathrm{W}-\mathrm{AR}=0$
from $\quad \Sigma F=\mathrm{m}$ a
we get $\mathrm{a}=0$
and if $\mathrm{a}=0$, then the velocity must be constant.
This is known as the terminal velocity.

Examples Parachute, feather, table tennis ball, car

## M.4.3 Points to Note

1. No Friction

When a body is thrown up it comes to rest momentarily at the top of the path. $\mathbf{a}=\mathbf{g}$ still.
2. If air resistance $=0$, then $\mathrm{a}=\mathrm{g}$ for all masses.

Example 1
A rock with a mass of 5 Kg is dropped from a height of 45 m . It starts at rest, air resistance is zero and $\mathbf{g}=9.8 \mathrm{~m} / \mathrm{s}^{2}$
a) What is it's acceleration 2.0 sec. after it is released?

Freefall $\rightarrow \mathrm{a}=9.8 \mathrm{~m} / \mathrm{s}^{2}$
b) How fast will it be going after 2.0 sec .?

$$
\begin{aligned}
& \mathrm{a}=9.8 \quad \mathrm{t}=2.0 \quad \mathrm{u}=0 \quad \mathrm{v}=? \\
& v=u+a t \\
& v=0+9.8 \times 2 \\
& v=19.6 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

c) How long will it take to reach the ground?

$$
\begin{aligned}
& \mathrm{a}=9.8 \mathrm{t}=? \quad \mathrm{u}=0 \quad x=45 \\
& x=u t+\frac{1}{2} a t^{2} \\
& 45=0 \times t+\frac{1}{2} \times 9.8 \times t^{2} \\
& 45=4.9 \times t^{2} \\
& 9.18=t^{2} \\
& t=3.03 \mathrm{sec}
\end{aligned}
$$

d) How fast will it be going just before it hits the ground?

$$
\begin{aligned}
& a=9.8 \quad v=? \quad u=0 \quad x=45 \\
& v^{2}=u^{2}+2 a x \\
& v^{2}=0^{2}+2 \times 9.8 \times 45 \\
& v^{2}=822 \\
& v=29.7 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

e) What would the acceleration be if the air resistance was 3 N ?

$$
\begin{aligned}
& \Sigma F=m a \\
& W-3=5 \times a \\
& 5 \times 9.8-3=5 \times a \\
& 46=5 \times a \\
& a=9.2 \mathrm{~m} / \mathrm{s}^{2}
\end{aligned}
$$

## Example 2

The initial speed of a stone projected vertically upwards is $21.0 \mathrm{~m} / \mathrm{s}$.
a) What is the maximum height reached?

$$
\begin{aligned}
& u=21.0 \quad v=0 \quad a=-9.8 \quad x=? \\
& v^{2}=u^{2}+2 a x \\
& 0^{2}=21.0^{2}+2 \times-9.8 \times x \\
& 19.6 x=441 \\
& x=22.5 \mathrm{~m}
\end{aligned}
$$

b) How long does it take to reach the highest point and what is the total time it is in the air?
$u=21.0 \quad v=0 \quad a=-9.8 \quad t=?$
$v=u+a t$
$0=21+-9.8 t$
$9.8 t=21$
$t=2.14 \mathrm{sec}$
c) How long is the stone more than 10 m above the ground?

$$
\begin{aligned}
& u=21.0 \quad x=10 \quad a=-9.8 \quad t=? \\
& x=u t+\frac{1}{2} a t^{2} \\
& 10=21 t+\frac{1}{2} \times-9.8 \times t^{2} \\
& 10=21 t-4.9 \times t^{2} \\
& \text { Solve using CAS } \\
& t=0.546,3.740 \quad \text { These are the times at } 10 \mathrm{~m} \\
& \text { Time above } 10 \mathrm{~m}=3.740-0.546=3.194 \text { seconds }
\end{aligned}
$$

## (THIRD TEST AT THIS POINT)

## Revision: $\quad$ Text Page 374 Questions 1 - 10

