
Physics of Freefall

You will be familiar with acceleration due to gravity however it is worth revisiting the ideas.

What is Mass?

It appears that there are *two* distinct forms of mass, gravitational and inertial.

Gravitational Mass

A mass m in a uniform gravitational field experiences a force due to gravity given by

$$\mathbf{F} = m\mathbf{g}$$

from Newton's 2nd law of $\mathbf{F} = m\mathbf{a}$

$$\mathbf{a} = \frac{\mathbf{F}}{m} = \frac{m\mathbf{g}}{m} = \mathbf{g}$$

Thus we have that in a uniform gravitational field $\mathbf{a} = \mathbf{g}$.

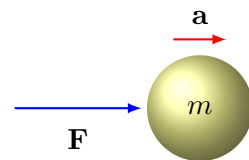
All masses will fall at the same rate in a particular gravitational field. Intuitively one can think of this as -

twice the mass equal twice the force – but this force has to accelerate twice the mass.

So is mass really a gravitational charge, a property of an object which both creates a surrounding gravitational field and experiences a force in a gravitational field?

Inertial Mass

However, you have seen Newton's 2nd law $\mathbf{F} = m\mathbf{a}$ giving us $m = \frac{\mathbf{F}}{\mathbf{a}}$. Here m is the inertial mass. Inertia is that property of a body which requires a force to accelerate it. Inertial mass exists whether or not the object is in a gravitational field. In classical (non-relativistic) physics inertial mass appears utterly distinct from gravitational mass.



Are they the same?

So we have two types of mass - mass as the amount of *gravitational charge* and mass being a measure of *inertia*. Are these two masses the same? Both Newton and Einstein believed in this equivalence. Experiments have so far failed to find a case where inertial mass is not

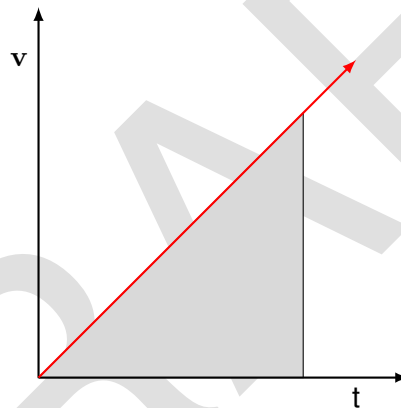
directly proportional to gravitational mass with a precision of about $1 : 10^{13}$. There is a Nobel prize going if you can prove they differ.

This apparent equivalence of inertial and gravitational mass is a foundation stone of Newton's Principia Mathematica and Einstein's General Theory of Relativity - where it is known as the *Weak Equivalence Principle*.

Freefall without Drag

At the earth's surface g is about 10 metres per second per second $m s^{-2}$. What does this mean? Starting from rest, after 1 seconds a mass will be moving at $10 m s^{-1}$, after 2 sec $20 m s^{-1}$ and so on.

$t \text{ sec}$	0	1	2	3	4	5	6
$v \text{ m s}^{-1}$	0	10	20	30	40	50	60

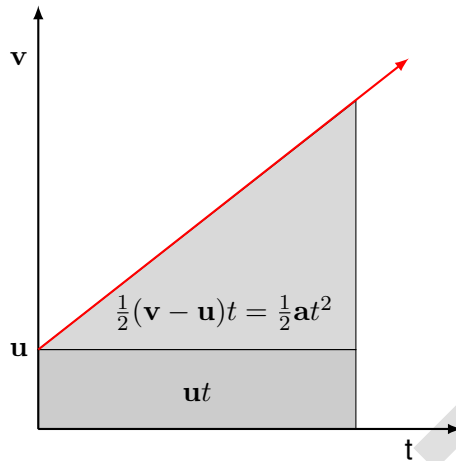


$$\text{area} = \int v dt = \text{displacement}$$

In this simple case we can see that $v = at$ and the displacement $s = \frac{1}{2}vt$. Substituting in for the velocity gives $s = \frac{1}{2}vt = \frac{1}{2}at^2$.

If we start with an initial velocity u , say $15 m s^{-1}$ we have:-

$t \text{ sec}$	0	1	2	3	4	5	6
$v \text{ m s}^{-1}$	15	25	35	45	55	65	75

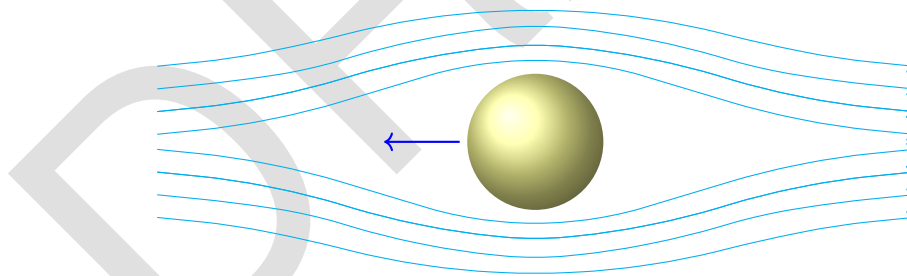


$$\text{area } s = ut + \frac{1}{2}(v - u)t = ut + \frac{1}{2}at^2$$

But what about friction?

Freefall with Drag

A body moving within a fluid experiences friction called drag. Its magnitude depends upon the body's size, velocity, surface, and shape as well as the fluid through which it moves. The problem is that drag is hideously complex as well as terribly important. There must be a shape for a plane, car, submarine which will minimise drag and thus maximise speed and fuel efficiency. Unfortunately since we cannot definitively solve the equations for drag we cannot calculate these perfect shapes.



low-speed .. laminal flow around a sphere

still working on this diagram

more to follow

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