A Charged Battery Weighs More

Why "mass is always conserved" isn't quite true

You were taught that mass can never be created or destroyed – that in any change, the mass before equals the mass after. It's a brilliant rule of thumb. It's also, strictly speaking, false.

EXAM LINKS *AQA A-level Physics (7408): 3.2 Particles and radiation – mass–energy equivalence, $E = mc^2$; 3.8 Nuclear physics – binding energy and mass defect.*

"Mass is always conserved." It is one of the sturdiest rules in school science, drilled in from GCSE chemistry to physics: weigh everything before a reaction, weigh everything after, and the totals match. Nothing is ever truly lost. It works so well that for most of scientific history it was taken as an unbreakable law of nature.

Then, in 1905, a 26-year-old patent clerk named Albert Einstein wrote down four short symbols that quietly demolished it: $\boldsymbol{E = mc^2}$. Mass and energy, he showed, are not two separate things that each get conserved on their own. They are two forms of the *same* thing, and one can turn into the other.

What E = mc² actually says

The equation links the energy (E) locked up in an object to its mass (m), multiplied by the speed of light (c) squared. Because c is enormous – 300 million metres per second – and it is squared, c^2 is a staggeringly large number. That has two consequences. A tiny amount of mass holds a colossal amount of energy (this is why nuclear weapons and reactors are so powerful). And, running the logic backwards, adding energy to something adds a tiny, tiny amount of mass.

The battery that gains weight

Here is the consequence that ambushes most people. Charge up a battery – pump energy into it – and it becomes **more massive** than it was when flat. Not because you added any atoms, but because you added energy, and energy has mass. A charged laptop battery is heavier than the same battery empty by around two *picograms* (a picogram is a trillionth of a gram) – roughly the mass of a single small bacterium.

And it isn't just batteries. A wound-up watch spring is heavier than a relaxed one. A hot cup of coffee weighs very slightly more than the same coffee cold. A stretched elastic band is heavier than a slack one. In every case the difference is far too small to weigh on any real scale, but it is real, and it is a direct consequence of adding energy. The GCSE rule survives in the lab only because these mass changes are unimaginably small compared with the mass of the atoms themselves.

The deeper truth: mass rides along with energy

> The neatest way to hold all this in your head is to flip the old rule around. It is not that mass is conserved and energy is conserved as two separate accounts. It is that **energy** is the truly conserved quantity – and mass simply comes along for the ride, as one of the forms energy can take. In everyday reactions almost no energy converts to or from mass, so the two totals appear to balance separately and the old rule looks perfect. It is only when huge amounts of energy are involved – inside stars, nuclear reactors and particle accelerators – that the mass books visibly fail to balance, and Einstein's bookkeeping takes over.

Where the missing mass really matters

In the core of the Sun, hydrogen nuclei fuse into helium, and the helium that comes out weighs slightly less than the ingredients that went in. That missing mass hasn't vanished – it has become the sunlight warming your face, converted via $E = mc^2$. The Sun loses about four million tonnes of mass every second this way, and has done for billions of years. Nuclear power stations run on the same principle on a smaller scale. The "missing" mass in these reactions, called the **mass defect**, is something you will calculate directly in A-level nuclear physics – turning a rule you once thought was absolute into a precise, usable tool.

Terms explained

Mass–energy equivalence Einstein's principle that mass and energy are different forms of the same thing, linked by $E = mc^2$.

$E = mc^2$ The equation stating that an object's energy equals its mass multiplied by the speed of light squared.

Speed of light (c) A fundamental constant, about 3×10^8 m s^{-1}; because it is squared in $E = mc^2$, a little mass equals a lot of energy.

Picogram One trillionth (10^{-12}) of a gram – the scale of the mass a charged battery gains.

Nuclear fusion The joining of light nuclei into heavier ones, releasing energy; the process that powers the Sun.

Mass defect The small difference between the mass of a nucleus and the total mass of its separate parts; it corresponds to the binding energy via $E = mc^2$.

Key points

- "Mass is always conserved" is an excellent approximation, not an exact law.
- $E = mc^2$ shows mass and energy are two forms of the same thing.
- Adding energy adds mass: a charged battery, a hot drink and a wound spring are all slightly heavier.
- These everyday mass changes are far too small to measure, which is why the GCSE rule appears to hold.
- In the Sun and in nuclear reactors, mass visibly converts to energy – the basis of the mass defect you meet at A-level.

Think about …

- A hot cup of coffee is said to weigh more than the same coffee once cold. Explain why, and why you could never detect this on a kitchen scale.
- Why does the huge size of c^2 mean that a very small mass change releases a very large amount of energy?
- The Sun loses about four million tonnes of mass every second. Where does this mass go?
- A student says "mass and energy are each separately conserved". Rewrite this statement to make it correct.