

King of Dumbs

Level: ♠ Technical

Can you make something from nothing? Conservation, no fear

Mass, energy and charge are never created or destroyed: they change form.

Lavoisier, a slide, a balloon and $E = mc^2$, with two widgets, in three levels.

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Scan to open the interactive lesson

<https://kingofdumbs.com/en/lessons/conservation-laws>

What you'll learn

- Conservation of mass and atoms (Lavoisier)
- Conservation of energy
- Conservation of charge and of the number of protons and neutrons
- $E = mc^2$: mass is energy too

Before this lesson

If something sounds like gibberish, these lessons explain it from scratch:

1. [What is a wall made of? Atoms and elements without fear](#)
2. [Joules, watts or calories? Energy and power without fear](#)

Symbols you'll meet

Δ change: how much it moved (♦♠) · E_a subscript: the label underneath (♦♠) · H° ° for standard, not degrees (♠) · Σ sum: add them all up (♠) · x_i index i: item number i (♠) · $\bar{x}$ bar on top: the average (♠) · $\cdot$ dot: multiply (or dot product) (♦♠) · $\rightarrow$ arrow: turns into / tends to (♦♠) · 10^{-3} negative exponent: divide (♦♠) · J/(mol·K) compound units (♠) · ν nu: coefficient or neutrino (♠) · τ tau: a characteristic time (♠) · π pi: 3.14159... (or a pion) (♠) · γ gamma: a photon (♠)

Throw a log on the fire. An hour later there's a handful of ash that weighs far less than the log. Where did the rest go? Did it turn into nothing?

The dumb question of this lesson is: **can you make something from nothing?** Or the other way round: can you make something vanish completely? The short answer is no. The universe keeps a few accounts that never fail. Things change shape, place or look, but the accounts always add up.

This lesson teaches four of those accounts: atoms, energy, electric charge, and the one that links mass and energy, the famous $E = mc^2$.

Pick your card: ♠ if you're starting from scratch, ♦ if a simple formula doesn't scare you, ♠ if you want the notation. You can switch at any time.

Nothing is lost: mass

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
number in front of each substance	stoichiometric coefficient v_j (negative for reactants)
$\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}$	$\sum_j v_j X_j = 0, v = (-1, -2, 1, 2)^T$
the same atoms of each element on each side	$A \cdot v = 0$, with A_{kj} the atoms of element k in species j
balancing the reaction	finding the null space of A : $\dim = \text{no. of species} - \text{rank}(A)$
mass of one mole	molar mass $M_j = \sum_k m_k A_{kj}$, with m_k the mass of one atom of element k
closed system	system with no exchange of matter with its surroundings

$$A = \begin{matrix} & \text{CH}_4 & \text{O}_2 & \text{CO}_2 & \text{H}_2\text{O} \\ \begin{matrix} \text{C} \\ \text{H} \\ \text{O} \end{matrix} & \begin{bmatrix} 1 & 0 & 1 & 0 \\ 4 & 0 & 0 & 2 \\ 0 & 2 & 2 & 1 \end{bmatrix} \end{matrix} \cdot v = 0$$

$$v = (-1, -2, 1, 2)^T \text{ (reactants } < 0)$$

$$\sum_j v_j M_j = \sum_k m_k (Av)_k = 0$$

A reaction is written as $\sum_j v_j X_j = 0$, with v_j negative for reactants and positive for products. Conserving each element k means $\sum_j A_{kj} v_j = 0$ for every k : $A \cdot v = 0$. Balancing a reaction is finding the null space of A .

For methane, A is 3×4 with rank 3, so the null space has dimension 1 and the reaction is fixed up to a factor: $v = (-1, -2, 1, 2)$. In Lavoisier's fermentation, $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2 \text{C}_2\text{H}_5\text{OH} + 2 \text{CO}_2$, there are three elements and three species, but the rank is 2 and again there is a single solution. When the null space has dimension greater than 1 (more species than $\text{rank}(A) + 1$), several reactions are possible, and chemistry, not algebra, decides which one happens.

Conservation of mass is a corollary. With $M_j = \sum_k m_k A_{kj}$:

$$\sum_j v_j M_j = \sum_k m_k (A \cdot v)_k = 0$$

This assumes each atom weighs the same inside and outside a molecule. It isn't exact: bond energy has mass too (block 4), but the error is one part in 10^{10} and no scale can see it. OpenStax puts it this way: there is no *detectable* change in the total quantity of matter (*Chemistry 2e*, 1.2).

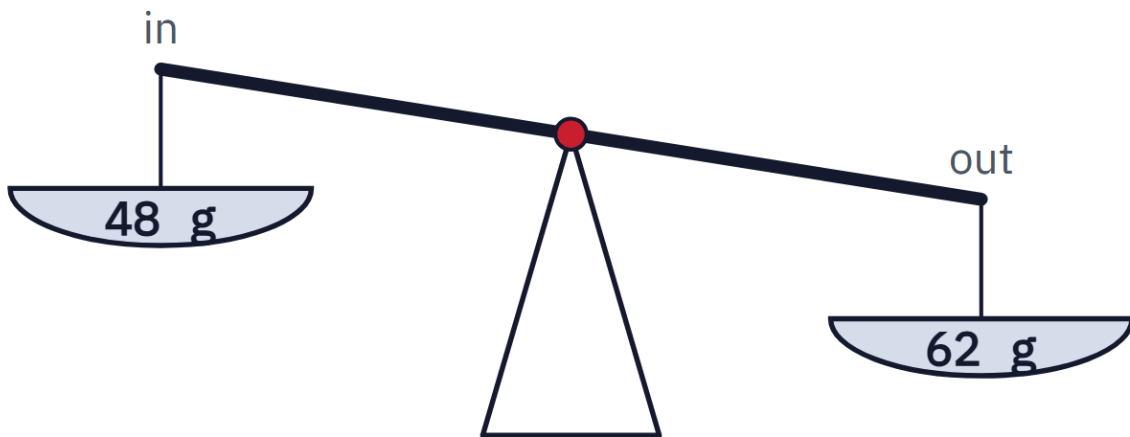
The King of Dumbs says:

The ash is light because the rest went up the chimney. Nothing vanishes: it goes somewhere else.



Try it: balance the recipe

Put a number in front of each substance until the same atoms of each element come out on each side. Watch the scale: when the atoms balance, so does the mass. Start with kitchen gas, then try rusting iron.



Recipe

- ☒ Burn kitchen gas
- ☐ Make water from hydrogen
- ☐ Rust iron
- ☐ Ferment grape juice (Lavoisier)



Atoms of each element

	in	out	
C	1	1	✓
H	4	2	✗
O	2	3	✗

Each number is a mole; mass is in grams.

It doesn't balance: H (4 → 2), O (2 → 3).



Interactive widget. Try it on the web: <https://kingofdumbs.com/en/lessons/conservation-laws>

Energy changes form, but it isn't used up

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
internal energy	U (a state function)
heat	$Q > 0$ if it enters the system
work	$W > 0$ if the system does it
the total energy is constant	$\Delta U = Q - W$ (first law)
motion energy	kinetic energy K ($\frac{1}{2}mv^2$ if $v \ll c$)
mass	mass m , with rest energy mc^2 (c , the speed of light)
no machine gives out energy without taking it from somewhere	no perpetual motion machine of the first kind
in any process	invariance under $t \rightarrow t + \tau \Rightarrow dE/dt = 0$ (Noether's theorem)

$$\Delta U = Q - W$$

$$E = mc^2 + K$$

$$t \rightarrow t + \tau \Rightarrow dE/dt = 0$$

(Noether, 1918)

In thermodynamics, conservation is written as the first law, $\Delta U = Q - W$, with Q the heat that enters and W the work the system does. OpenStax calls it “the law of conservation of energy stated in a form most useful in thermodynamics” (*College Physics 2e*, 15.1). A machine that, over each cycle ($\Delta U = 0$), gave $W > 0$ with $Q = 0$ would break it: that’s a perpetual motion machine of the first kind.

In relativity, energy is still conserved if you count it properly: a body of mass m has, besides its kinetic energy K , a rest energy mc^2 (OpenStax, 28.6). So $E = mc^2 + K$. Block 4 draws the consequences.

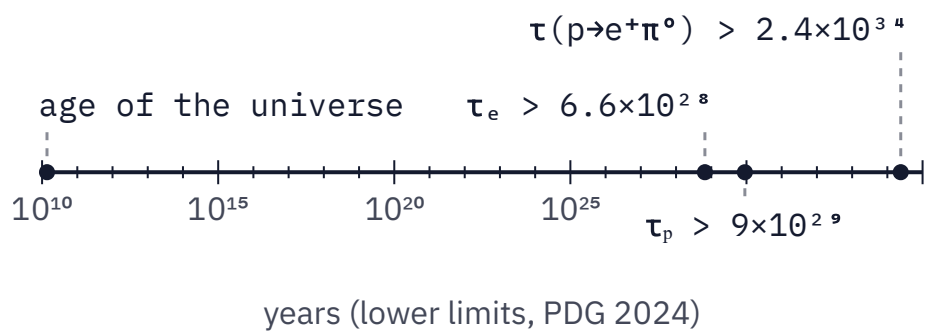
Why is it conserved? Because of a symmetry. Emmy Noether proved in 1918 that every continuous symmetry of the laws comes with a conserved quantity. If the laws don’t change from t to $t + \tau$ (an experiment gives the same result today as tomorrow), energy is conserved. Feynman tells the story in his *Lectures* (I, 52-3), together with the other two classic symmetries: space and rotation.



Accounts that never fail: charge, protons and neutrons

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
total charge	Σq , the sum of the charges q_i , conserved
protons + neutrons	baryon number B (baryons +1, antibaryons -1)
the electron and the antineutrino	electron lepton number L_e (e^- and ν_e : +1; e^+ and $\bar{\nu}_e$: -1)
antineutrino	$\bar{\nu}_e$
a neutron in the nucleus has turned into a proton	$n \rightarrow p + e^- + \bar{\nu}_e$ (β^- decay): Z goes from 6 to 7
takes on average	mean lifetime τ
a proton or an electron just vanished	channels $e \rightarrow \nu_e \gamma$ (neutrino and photon) and $p \rightarrow e^+ \pi^0$ (positron and neutral pion)
it has never been seen	lower limit on τ at 90 % confidence
People have looked for decades	charge: gauge symmetry of QED; B: an accidental symmetry that GUTs (grand unified theories) predict is broken



In particle physics, three numbers are checked separately (OpenStax, *University Physics* vol. 3, 11.2).
In $n \rightarrow p + e^- + \bar{\nu}_e$:

	Before	After
Σq	0	$+1 - 1 + 0 = 0$
B	1	$1 + 0 + 0 = 1$
L_e	0	$0 + 1 - 1 = 0$

The reaction $n \rightarrow e^+ + e^-$ conserves charge and energy, but not B (1 versus 0), and it doesn't happen.

The experimental limits (PDG 2024, review by Pich and Ramsey-Musolf):

- Charge:** $\tau(e \rightarrow \nu_e \gamma) > 6.6 \times 10^{28}$ years, from the Borexino experiment (*PRL* 115, 231802, 2015).
 That's about 4.8×10^{18} ages of the universe. The PDG links charge conservation to the gauge symmetry of quantum electrodynamics.
- Baryon number:** $\tau_p > 9 \times 10^{29}$ years in any channel, and $\tau(p \rightarrow e^+ \pi^0) > 2.4 \times 10^{34}$ years. Grand unified theories predict that B is violated, but no signal has been seen.

So chemistry's conservation "of elements" is a special case: without nuclear reactions, each nucleus keeps its Z. With them, what's conserved is charge and B.

E = mc²: mass is energy too

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
$E = mc^2$	$E_0 = mc^2$ and, in general, $E^2 = (pc)^2 + (mc^2)^2$, with p the momentum
Burning a mole of methane gives out 890 kJ	enthalpy of combustion $\Delta_c H^\circ = -890.7$ kJ/mol
speed of light	$c = 299,792,458$ m/s (exact)
mass that disappears	mass defect $\Delta m = \Sigma m_{\text{before}} - \Sigma m_{\text{after}}$
released energy	$Q = \Delta m \cdot c^2$
a ray of light	photon γ , with $m = 0$ and $E = pc$
passing close to an atomic nucleus	$\gamma + N \rightarrow e^- + e^+ + N$: the nucleus N takes the leftover momentum
electron-positron pair	$e^- + e^+$, with $E_\gamma \geq 2m_e c^2$
MeV	$1 \text{ MeV} = 1.602\,176\,634 \times 10^{-13} \text{ J}$; $1 \text{ u} \cdot c^2 = 931.494 \text{ MeV}$

$$E^2 = (pc)^2 + (mc^2)^2$$

$$\gamma + N \rightarrow e^- + e^+ + N, \quad E_\gamma \geq 1.022 \text{ MeV}$$

$$Q = \Delta m \cdot c^2$$

$$^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + n, \quad Q = 17.6 \text{ MeV}$$

$$Q / (m_D + m_T)c^2 \approx 0.38 \%$$

The general relation is $E^2 = (pc)^2 + (mc^2)^2$; at rest ($p = 0$) it becomes $E_0 = mc^2$, and for a photon ($m = 0$), $E = pc$ (OpenStax, 28.6). Einstein proposed it in 1905, in a three-page paper whose title asks whether the inertia (the mass) of a body depends on the energy it contains (*Ann. Phys.* 323, 639). He wrote it with other letters: a body that gives off an energy L as radiation loses a mass L/V^2 , with V the speed of light.

Mass-defect calculations, with $Q = \Delta m \cdot c^2$:

- **Combustion of methane:** $\Delta_c H^\circ = -890.7 \pm 0.4$ kJ/mol (NIST WebBook; OpenStax gives -890.8).
 $\Delta m = 8.907 \times 10^5 \text{ J} / c^2 = 9.9 \times 10^{-12} \text{ kg}$ per mole, out of 80.04 g of reactants: 1.24×10^{-10} .

- **Induced fission of ^{235}U :** $Q \approx 200 \text{ MeV}$ (OpenStax UP3, 10.5). $\Delta m/m = 200 / [(235.0439 + 1.0087) \times 931.494] = 9.1 \times 10^{-4}$.
- **$^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + \text{n}$:** $Q = 17.6 \text{ MeV}$ (OpenStax UP3, 10.6). With NIST masses, $\Delta m/m = 17.6 / (5.0302 \times 931.494) = 3.8 \times 10^{-3}$.

Pair creation conserves charge ($0 = -1 + 1$) and L_e ($0 = 1 - 1$). A photon on its own can't do it in empty space: in the pair's reference frame the total momentum is zero, and a photon has nonzero momentum in every frame ($E = pc \neq 0$). A third body has to take the leftover momentum, usually a nucleus: $\gamma + \text{N} \rightarrow e^- + e^+ + \text{N}$. NIST's XCOM tables compute pair production "in the field of the atomic nucleus" and in that of the electrons. It's the same reason why, the other way round, an electron and a positron can't annihilate into a single photon (OpenStax UP3, 11.2). Since the nucleus is heavy, it takes almost no energy, and the threshold stays at $2m_e c^2 = 2 \times 0.510\,998\,950\,69 \text{ MeV} = 1.022 \text{ MeV}$ (CODATA 2022; HyperPhysics gives the same threshold). That's why "making something from nothing" is impossible: the energy is paid in full, and the charge, B and L accounts stay at zero.

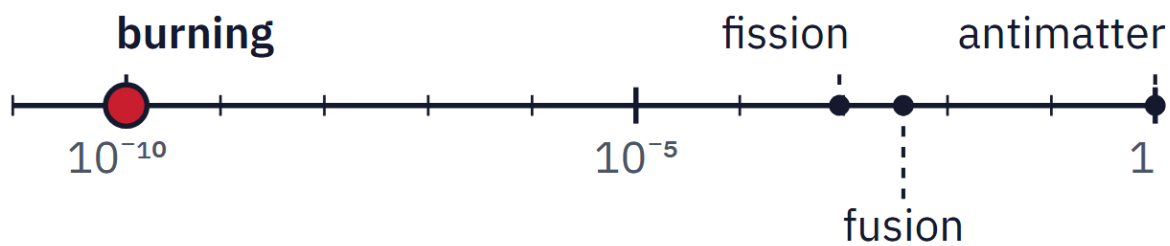
The King of Dumbs says:

You can make matter. But you pay for it in full with energy, and it always comes with its twin of opposite charge.



Try it: how much energy is in mass?

Choose what you do with the mass and how much you use. See how much of it turns into energy and how long that energy would last in a kettle or as food. Try a gram of matter with antimatter.



share of the mass that becomes energy

What you do with the mass

- ☒ Burn it, like gas with its oxygen
- ☐ Split uranium-235 (fission)
- ☐ Fuse deuterium and tritium (fusion)
- ☐ Bring it together with antimatter

Mass that reacts 1 kg

Share of the mass one part in 8.1×10^9

Mass that becomes energy 120 ng

Energy 1.1×10^7 J

2 kW kettle switched on 1.5 h

Food for one person 1.3 days

Of 1 kg, 120 ng turns into energy (one part in 8.1×10^9).



Interactive widget. Try it on the web: <https://kingofdumbs.com/en/lessons/conservation-laws>



Final challenge

1. You burn a log and 200 grams of ash are left. Where's the rest?

- a. It was destroyed by the fire
- b. It went into the air as gases, along with the oxygen it took
- c. It all turned into energy

2. A bike brakes to a stop. What happened to its motion energy?

- a. It disappeared
- b. It turned into heat in the brakes and the wheels
- c. It went back into the rider's legs

3. Can you create an electron?

- a. Yes, from nothing, in a lab
- b. Yes, with enough energy, and it always comes with its positively charged antiparticle
- c. No: matter can never be created



In three sentences

- 1. In a chemical reaction atoms only rearrange: none is created or lost, which is why what goes in weighs the same as what comes out.
- 2. Energy isn't created or destroyed either: it changes form (height, motion, heat...), and "using it up" means turning it into heat that's no longer useful.
- 3. Charge and the number of protons and neutrons always add up too, and mass is very concentrated energy ($E = mc^2$): you can make matter, but only by paying for it in full with energy.



Sources

- Lavoisier, *Traité élémentaire de chimie*, vol. 1 (Paris, Cuchet, 1789), ch. XIII: [Project Gutenberg](#). Cross-check: OpenStax, *Chemistry 2e*, [1.2](#). Balanced equations: [OpenStax, 4.1](#).
- Conservation of energy and the first law: OpenStax, *College Physics 2e*, [7.6](#) and [15.1](#). Symmetries: [Feynman, Lectures on Physics I, ch. 52](#); Noether (1918), [translation on arXiv](#).
- Charge: OpenStax, *College Physics 2e*, [18.1](#). Nuclear reactions: OpenStax, *Chemistry 2e*, [21.2](#) and [21.3](#). Baryon and lepton numbers: [OpenStax, University Physics vol. 3, 11.2](#).
- Experimental limits: [PDG 2024, Tests of conservation laws](#); Borexino, *PRL* 115, 231802 (2015), [doi:10.1103/PhysRevLett.115.231802](#).
- $E = mc^2$: Einstein, *Ann. Phys.* 323, 639 (1905), [doi:10.1002/andp.19053231314](#); [OpenStax, College Physics 2e, 28.6](#). Speed of light and electron mass (CODATA 2022): [c](#) and [\$m_e c^2\$](#) . Pair creation: [HyperPhysics](#) and [NIST XCOM](#).
- Combustion of methane: [NIST WebBook](#) and [OpenStax, Chemistry 2e, 5.3, table 5.2](#). Fission and fusion: OpenStax, *University Physics* vol. 3, [10.5](#) and [10.6](#). Atomic masses: NIST, [hydrogen](#) and [uranium](#).

How this lesson was made: researched and written with help from Claude, from the sources above, checked and cross-checked against a second source on 15 October 2026. Numbers without their own link are calculations from them and from the atoms and energy lessons. The drawings are our own.

Answers

1. **b)** It went into the air as gases, along with the oxygen it took. That's it. Atoms don't vanish: they go up the chimney.
2. **b)** It turned into heat in the brakes and the wheels. Good. Energy changes form: here, into heat.
3. **b)** Yes, with enough energy, and it always comes with its positively charged antiparticle. Exactly. You pay in energy and the total charge stays at zero.

A King of Dumbs lesson, kingofdumbs.com. Offline version; the original, with widgets you can play with, is at:
<https://kingofdumbs.com/en/lessons/conservation-laws>

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