

King of Dumbs

Level: ♠ Technical

Joules, watts or calories? Energy and power without fear

Energy is how much; power is how fast. Joules, watts, kcal and kWh explained with a bathtub, why fast means hot and how to compare scales, in three levels.

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<https://kingofdumbs.com/en/lessons/joules-watts-or-calories>

What you'll learn

- Energy and its units: joule, kilocalorie and kilowatt hour
- Power and the watt
- The difference between energy and power
- Heat versus temperature
- Comparing powers on a log scale

Before this lesson

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

1. [How much is \$7 \times 10^{27}\$? Huge numbers without fear](#)

Symbols you'll meet

Δ change: how much it moved (♦♠) · E_a subscript: the label underneath (♠) · $\bar{x}$ bar on top: the average (♠) · $\approx$ approximately equal (♦♠) · $\equiv$ is defined as (♠) · $\cdot$ dot: multiply (or dot product) (♠) · 10^{-3} negative exponent: divide (♠) · e the number e (≈ 2.718) (♠) · $\log$ logarithm: how many times do I multiply? (♠) · σ sigma: depends on the lesson (♠) · τ tau: a characteristic time (♠) · ϵ epsilon: something tiny (♠) · dE/dt derivative: the rate of change (♠) · $\int$ integral: adding up slivers (♠)

A kettle's label says **2,000 W**. An electricity bill talks about **kW** and **kWh**. A yoghurt, about **kcal** and **kJ**. And the dumb question of this lesson is: **do all of those measure the same thing?**

Almost. There are two different questions in there: **how much** energy you need, and **how fast** it's delivered. The first is measured in joules (or calories, or kWh); the second, in watts. Mixing them up is so common that education research finds it even among future physics teachers. Pulling them apart clears up more doubts than you'd think, especially the "is that even possible?" kind.

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

Energy: how much

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
pushing with a force over one metre	$W = \int \mathbf{F} \cdot d\mathbf{x}$
the joule	$J = N \cdot m = kg \cdot m^2 \cdot s^{-2}$
it is conserved	$\Delta E = 0$ in an isolated system
kilocalorie	$kcal_{th} \equiv 4184 \text{ J}$ ($cal_{th} \equiv 4.184 \text{ J}$)
electronvolt	$1 \text{ eV} \equiv 1.602\,176\,634 \times 10^{-19} \text{ J}$
kilowatt hour	$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$

$$W = \int \mathbf{F} \cdot d\mathbf{x}$$

$$[J] = N \cdot m = kg \cdot m^2 \cdot s^{-2}$$

$$1 \text{ cal}_{th} \equiv 4.184 \text{ J} \quad \equiv \text{exact by definition}$$

$$1 \text{ eV} \equiv 1.602\,176\,634 \times 10^{-19} \text{ J}$$

$$1 \text{ kWh} = 10^3 \text{ W} \times 3600 \text{ s} = 3.6 \times 10^6 \text{ J}$$

The work done by a force along a path is $W = \int \mathbf{F} \cdot d\mathbf{x}$, and the work-energy theorem equates it to the change in kinetic energy, $W = \Delta E_k$. The joule is the SI derived unit for energy, work and heat: $1 \text{ J} = 1 \text{ N} \cdot \text{m} = 1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$. That energy is conserved in an isolated system follows from the laws of physics not changing over time (Noether's theorem).

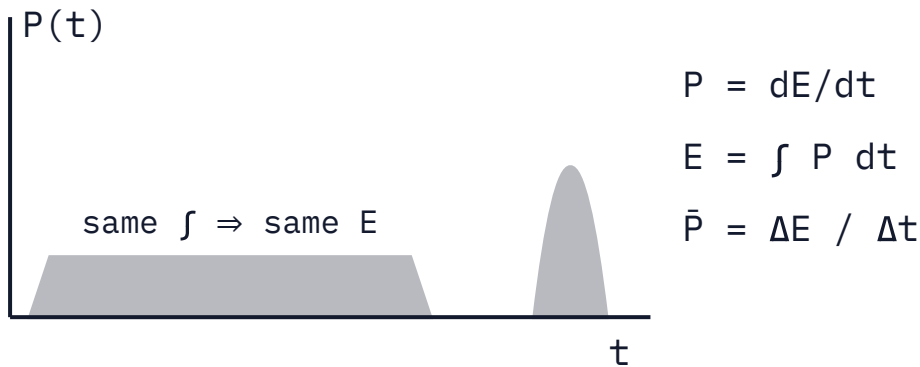
Several conversions are exact by definition. Since the 2019 SI redefinition, the elementary charge is fixed at $e = 1.602\,176\,634 \times 10^{-19} \text{ C}$, and the electronvolt with it. The thermochemical calorie is defined as 4.184 J . Careful: the IT calorie is 4.1868 J and the “mean” one about 4.190 J (NIST SP 811), so in a fine calculation you have to say which one you're using.

Dimensional analysis: any energy expression must come out in $kg \cdot m^2 \cdot s^{-2}$. For example, $m \cdot g \cdot h = kg \cdot m \cdot s^{-2} \cdot m$. If a formula doesn't balance in units, it's wrong before you plug in any numbers.

Power: how fast

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
energy divided by time	$P = dE/dt$ (instantaneous); $\bar{P} = \Delta E / \Delta t$ (mean)
power times time; the area	$E = \int P(t) dt$
watt	$W = J \cdot s^{-1} = kg \cdot m^2 \cdot s^{-3}$
megawatt; 1 GW	$1 MW = 10^6 W$; $1 GW = 10^9 W$
the shorter the effort, the more power	power-duration curve $P_{max}(\Delta t)$, decreasing



Instantaneous power is the time derivative of energy, $P = dE/dt$, and the energy transferred over an interval is its integral, $E = \int P(t) dt$. The mean power $\bar{P} = \Delta E / \Delta t$ is the height of the rectangle with the same area as the real profile. For a force acting on a moving body, $P = \mathbf{F} \cdot \mathbf{v}$.

The power on an appliance label is the rated power: a maximum or an average under test conditions. For actual consumption you have to integrate the profile $P(t)$, which is what a meter does.

Physics and engineering always separate two limits: **energy** (how much fuel or battery) and **power** (how much the motor, the cable or the heat sink can take). A problem that's feasible in energy can be impossible in power. Lightning shows it: about $9.5 \times 10^8 J$ for a typical four-stroke flash (Cooray, 1997; the EPA lists estimates from $10^8 J$), a household-sized energy delivered in a fraction of a second.

The cyclist's power-duration curve is the same phenomenon in a body: 836–895 W as the best 15 s average against 342–394 W over 30 min (Vogt et al., 2007). The maximum sustainable power falls as the effort gets longer.

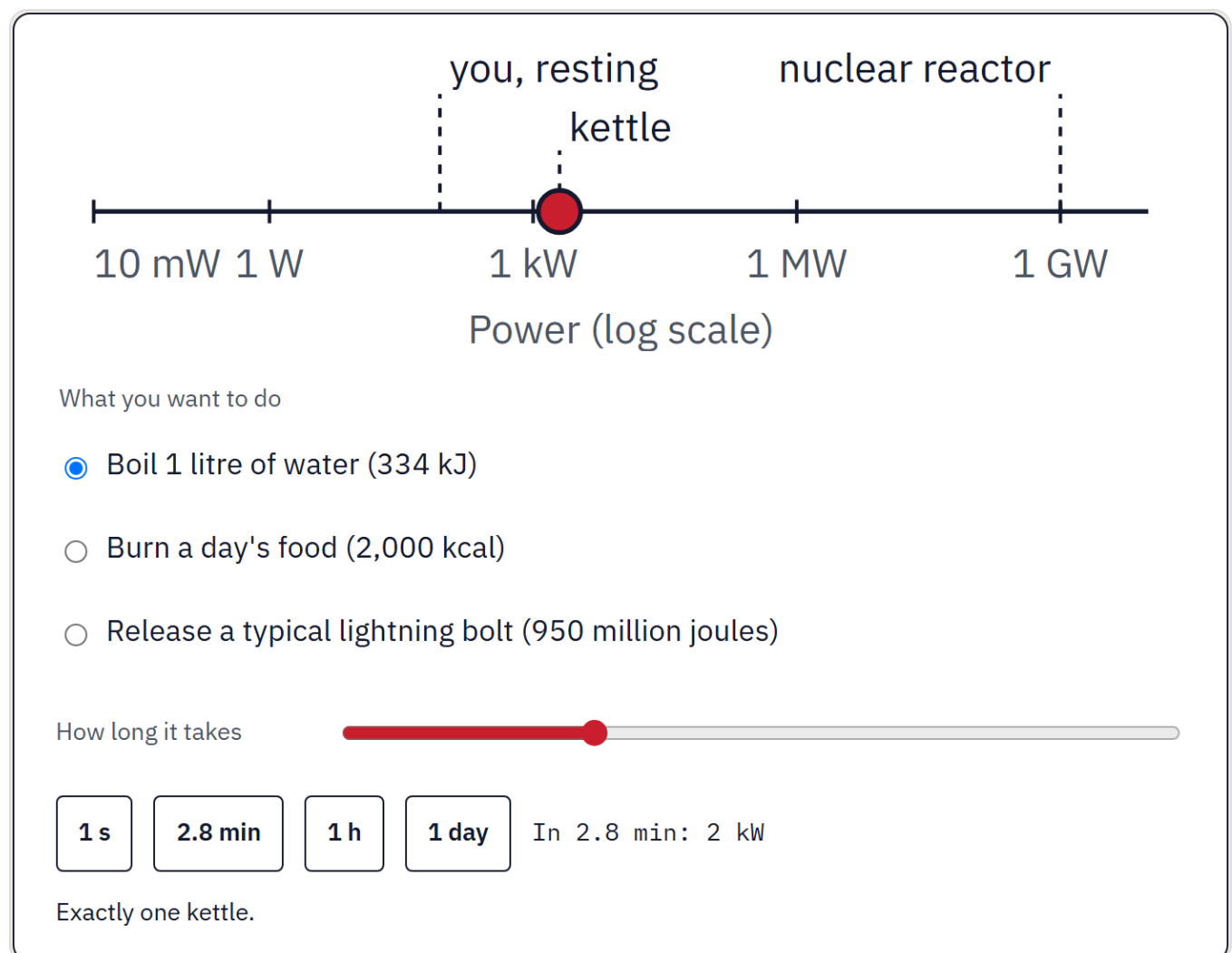
The King of Dumbs says:

Saying a kettle “uses 2,000 watts” is like saying a car “uses 120 km/h”. That’s how fast it goes, not how much it uses.



Try it: same energy, different pace

Choose what you want to do and how long it takes. The energy of each task doesn’t change; watch how the power shoots up as you shorten the time, and what it compares to.

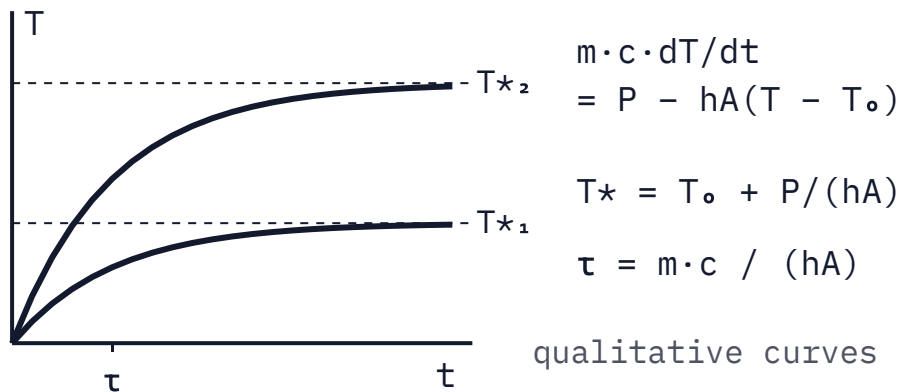


Interactive widget. Try it on the web: <https://kingofdumbs.com/en/lessons/joules-watts-or-calories>

Heat and temperature: why fast means hot

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
how agitated the particles are	$k_B \cdot T$: thermal energy scale ($\frac{1}{2}k_B T$ per quadratic degree of freedom)
kelvin	$k_B \equiv 1.380\,649 \times 10^{-23} \text{ J/K}$ (fixes the K)
specific heat	$c = (1/m) \cdot dQ/dT$
what comes in minus what goes out	$m \cdot c \cdot dT/dt = P - P_{\text{out}}(T)$
conduction and convection	$P_{\text{out}} \approx hA(T - T_o)$ (Newton's law of cooling)
radiation	$P_{\text{rad}} = \epsilon \sigma A(T^4 - T_o^4)$



Energy balance for a body of mass m and specific heat c receiving power P : $m \cdot c \cdot dT/dt = P - P_{\text{out}}(T)$. If the loss is proportional to the difference with the surroundings (Newton's law of cooling, $P_{\text{out}} = hA(T - T_o)$), the solution is $T(t) = T_o + (P/hA)(1 - e^{-(t/\tau)})$, with $\tau = m \cdot c / (hA)$. The equilibrium $T^* = T_o + P/(hA)$ grows linearly with P .

Radiation follows the Stefan-Boltzmann law, $\epsilon \sigma A(T^4 - T_o^4)$. For small differences it linearises to $4\epsilon \sigma T_o^3(T - T_o)$ and adds to h ; at body temperature it's the main route of heat loss, around 60% at rest.

Why speed is a heat problem and not an energy problem: with a fixed E delivered over a time t , $P = E/t$. If $t \ll \tau$, the system is almost adiabatic and $\Delta T \approx E/(m \cdot c)$: all the energy stays. If $t \gg \tau$, the temperature follows the power, $\Delta T \approx P/(hA) = E/(hA \cdot t)$. Shortening t raises the equilibrium ΔT up to the adiabatic ceiling.

Since 2019 the kelvin is defined by fixing $k_B = 1.380\,649 \times 10^{-23} \text{ J/K}$, which ties temperature to energy: at 300 K, $k_B \cdot T \approx 4.1 \times 10^{-21} \text{ J} \approx 0.026 \text{ eV}$.



From a person to the Sun: comparing scales

♦ → ♠ From intermediate to technical

In ♦ we said	In ♠ we write
log scale	$x = \log_{10}(P / 1 \text{ W})$
kilo, mega, giga	$k = 10^3, M = 10^6, G = 10^9, T = 10^{12}$
steps of ten	orders of magnitude: $\Delta \log_{10} P$
the three-step method	Fermi estimate: $P \approx E/t$
the Sun	$L_{\odot} = 3.828 \times 10^{26} \text{ W}$ (nominal, IAU 2015)

$$k = 10^3 \quad M = 10^6 \quad G = 10^9 \quad T = 10^{12}$$

$$\log_{10}(P_{\text{rest}} / \text{W}) \approx 1.9$$

$$\log_{10}(P_{\text{reactor}} / \text{W}) = 9$$

$$\log_{10}(P_{\odot} / \text{W}) \approx 26.6$$

Fermi: $P \approx E / t$ → compare with the table

On a log scale the position is $x = \log_{10}(P/1 \text{ W})$, so a constant ratio is a constant distance. Person at rest: $\log_{10} 87 \approx 1.9$. Reactor: 9. Sun, with the IAU nominal luminosity ($3.828 \times 10^{26} \text{ W}$): ≈ 26.6 . Between person and reactor there are 7.1 orders of magnitude, which is the log of the ratio.

A Fermi estimate pins down the order of magnitude with known quantities. $P \approx E/t$ with E and t within a factor of 2 or 3 of their real values is enough to classify a process, because the references in the table are several orders of magnitude apart.

An example to sharpen it: total solar irradiance at 1 au is 1361 W/m^2 (IAU 2015). Matching 1 GW takes collecting $10^9/1361 \approx 7.3 \times 10^5 \text{ m}^2$, about 0.73 km^2 outside the atmosphere, with no losses and no night. Every real correction (atmosphere, angle, night, efficiency) multiplies that area.



Final challenge

1. A kettle's label says 2,000 W. What does that number tell you?

- a. How much energy it stores inside
- b. How fast it turns electricity into heat
- c. How much you'll pay each month

2. You boil a litre of water in a 1,000 W kettle and another litre in a 2,000 W one, with no losses. What changes?

- a. The 2,000 W one uses twice the energy
- b. They use the same energy; the 2,000 W one takes half the time
- c. The 1,000 W one can't bring it to the boil

3. A spark from a bonfire is very hot, yet you barely feel it if it lands on your hand. Why?

- a. It's so small it carries very little energy, even though its temperature is high
- b. Sparks are cold inside
- c. Skin can't feel temperature



In three sentences

1. Energy is the how much (joules, kcal and kWh are the same thing in a different glass) and power is the rate (watts, joules per second).
2. The same energy in less time takes more power, and almost all of it ends up as heat: if it comes in faster than it goes out, the temperature rises.
3. To judge whether something is possible, work out the energy, divide it by the time and compare it with references: a person (about 80 W), a kettle (2,000 W) and a reactor (1 GW).



Sources

- Unit conversions (calorie, kWh, tonne of TNT, horsepower): [NIST SP 811, appendix B.8](#). Electronvolt: [NIST CODATA](#). Joule and watt in the SI: [BIPM, SI Brochure](#).
- Kelvin and the Boltzmann constant: [IUPAC Gold Book](#) and [BIPM, kelvin appendix](#).
- Food labels in kJ and kcal: [Regulation \(EU\) 1169/2011](#), Annex XV. Power and energy terms on the Spanish bill: [IIT Comillas](#) (in Spanish). Automatic cut-off above contracted power: [Royal Decree 1955/2000, art. 92](#) (in Spanish).
- Specific heat of liquid water: [NIST WebBook](#) ($C_p \approx 75.4 \text{ J}/(\text{mol}\cdot\text{K})$ at 25°C , divided by 18.015 g/mol) and [OpenStax, College Physics 2e, table 14.1](#) ($4186 \text{ J}/(\text{kg}\cdot^\circ\text{C})$).
- Basal metabolic rate (68 W and 87 W): [Harrison, University of Toronto](#), cross-checked with [OpenStax, College Physics 2e, table 7.4](#) (85 W). Routes of body heat loss: [OpenStax, Anatomy and Physiology 2e, 24.6](#) and [OpenAnesthesia](#).
- Power of Tour de France cyclists: Vogt et al., *Int J Sports Med* 28, 756 (2007), [doi:10.1055/s-2007-964982](#).
- Power of a typical nuclear reactor: [US DOE](#). Energy of a lightning bolt: Cooray, *J. Geophys. Res.* 102 (1997), [doi:10.1029/96JD01917](#), and [EPA AP-42, ch. 14.3](#).
- Nominal solar luminosity and total solar irradiance: IAU 2015, Resolution B3, [arXiv:1510.07674](#).
- Confusion between energy, power and force among future physics teachers: Sağlam-Arslan and Kurnaz, *Asia-Pacific Forum on Science Learning and Teaching* 10(1), 2009, [conclusions](#). Heat versus temperature: [IOP Spark](#).

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 13 October 2026, and translated from Spanish by Claude. Figures without their own link are calculations based on them. The drawings are my own.

Answers

1. **b)** How fast it turns electricity into heat. That's it: watts are a rate. What you use depends on how long you leave it on.
2. **b)** They use the same energy; the 2,000 W one takes half the time. Exactly: same water, twice the tap.
3. **a)** It's so small it carries very little energy, even though its temperature is high. Good. Temperature says how hot; energy, how much. A spark has lots of the first and little of the second.

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

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