

Temperature Scales: Celsius, Fahrenheit and Kelvin

How do you convert between Celsius, Fahrenheit and Kelvin?

●○○ Beginner

Foundations

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What is it?

Temperature measures how hot or cold something is: in particle terms, how fast its particles are moving on average. Three scales are in common use:

- **Celsius (°C):** used in most of the world and in the laboratory. Water freezes at 0 °C and boils at 100 °C (at 1 atm).
- **Fahrenheit (°F):** used for everyday temperatures in the United States. Water freezes at 32 °F and boils at 212 °F.
- **Kelvin (K):** the SI unit of temperature, used in chemistry and physics calculations. It starts at **absolute zero** (0 K), the lowest possible temperature.

	°C	°F	K
Absolute zero	-273.15	-459.67	0
Celsius equals Fahrenheit	-40	-40	233.15
Water freezes	0	32	273.15
Body temperature (about)	37	98.6	310.15
Water boils (1 atm)	100	212	373.15

KEY IDEA

$$T_F = \frac{9}{5} T_C + 32$$

$$T_C = \frac{5}{9} (T_F - 32)$$

$$T_K = T_C + 273.15$$

The Celsius and Fahrenheit scales give the **same number at -40**: $-40\text{ °C} = -40\text{ °F}$.

Why does it matter?

- **Chemistry needs kelvin.** The gas laws, reaction rates and thermodynamics all use absolute temperature. Using °C in the gas laws gives wrong answers.
- **Data comes in different units.** Recipes, weather reports and older US data often use °F, so you need to convert reliably.
- **Checking answers.** Knowing a few reference points (0 °C = 32 °F, 100 °C = 212 °F) lets you spot a wrong conversion at once.

How does it work?

1. Why the factor 9/5 and the 32?

Between freezing and boiling water there are **100 Celsius degrees** (0 to 100) but **180 Fahrenheit degrees** (32 to 212). So one Celsius degree is larger:

$$\frac{180\text{ }^{\circ}\text{F}}{100\text{ }^{\circ}\text{C}} = \frac{9\text{ }^{\circ}\text{F}}{5\text{ }^{\circ}\text{C}} = 1.8\text{ }^{\circ}\text{F}/^{\circ}\text{C}$$

The +32 is there because the Fahrenheit scale puts the freezing point of water at 32, not 0.

2. Celsius to Fahrenheit

Multiply by 9/5 (1.8), **then** add 32:

$$T_{\text{F}} = \left(\frac{9\text{ }^{\circ}\text{F}}{5\text{ }^{\circ}\text{C}} \right) T_{\text{C}} + 32\text{ }^{\circ}\text{F}$$

3. Fahrenheit to Celsius

Do the reverse, in reverse order: subtract 32 **first**, then multiply by 5/9:

$$T_{\text{C}} = \left(\frac{5\text{ }^{\circ}\text{C}}{9\text{ }^{\circ}\text{F}} \right) (T_{\text{F}} - 32\text{ }^{\circ}\text{F})$$

4. Kelvin

A kelvin is the **same size** as a Celsius degree; the scale is just shifted so that zero is absolute zero:

$$T_{\text{K}} = T_{\text{C}} + 273.15$$

$$T_{\text{C}} = T_{\text{K}} - 273.15$$

To go between °F and K, go through °C.

5. Where Celsius and Fahrenheit meet

Is there a temperature with the same number on both scales? Call that number x and put it into the conversion formula for both T_C and T_F :

$$\begin{aligned}x &= \frac{9}{5}x + 32 \\x - \frac{9}{5}x &= 32 \\-\frac{4}{5}x &= 32 \\x &= -40\end{aligned}$$

So $-40\text{ }^{\circ}\text{C} = -40\text{ }^{\circ}\text{F}$. On the graph below, this is where the conversion line crosses the line “ $^{\circ}\text{F} = ^{\circ}\text{C}$ ”. Above -40 , the Fahrenheit number is always larger; below -40 , the Celsius number is larger.

6. Temperature changes

A temperature **change** has no offset (the 32 and 273.15 cancel out):

- a change of $1\text{ }^{\circ}\text{C}$ = a change of **1 K** = a change of **1.8 $^{\circ}\text{F}$**
- e.g. warming by $10\text{ }^{\circ}\text{C}$ is warming by 10 K, or by $18\text{ }^{\circ}\text{F}$

THINK OF IT LIKE THIS

Think of two rulers, one marked in centimetres and one in inches, but with their zeros at different places. To convert, you must allow for both the **different size of the marks** (the $9/5$) and the **different starting points** (the 32). The kelvin “ruler” has marks the same size as Celsius, but its zero starts 273.15 marks lower.

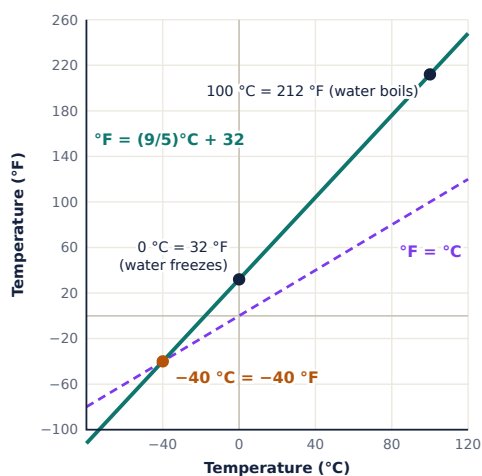
MORE PRECISELY

Since 2019 the kelvin has been defined by fixing the value of the Boltzmann constant; the Celsius scale is defined from it by $T_C = T_K - 273.15$, so 273.15 is exact. Under this definition, water at 1 atm freezes at almost exactly $0\text{ }^{\circ}\text{C}$ and boils at about $99.97\text{ }^{\circ}\text{C}$, not exactly $100\text{ }^{\circ}\text{C}$. For school chemistry, $0\text{ }^{\circ}\text{C}$ and $100\text{ }^{\circ}\text{C}$ are used.

Visualise it

Fahrenheit against Celsius

$^{\circ}\text{F} = (9/5)^{\circ}\text{C} + 32$ is a straight line; it meets $^{\circ}\text{F} = ^{\circ}\text{C}$ at -40 .



Water points at 1 atm. The dashed line shows where the $^{\circ}\text{F}$ and $^{\circ}\text{C}$ numbers would be equal.

The conversion is a straight line; it crosses the line $^{\circ}\text{F} = ^{\circ}\text{C}$ at -40 .

Worked example

WORKED EXAMPLE: Celsius to Fahrenheit

Question: Room temperature is 25°C . What is this in $^{\circ}\text{F}$?

Step 1 Multiply by $9/5$, then add 32:

$$\begin{aligned}T_{\text{F}} &= \left(\frac{9^{\circ}\text{F}}{5^{\circ}\text{C}}\right)(25^{\circ}\text{C}) \\&\quad + 32^{\circ}\text{F} \\&= 45^{\circ}\text{F} + 32^{\circ}\text{F} \\&= 77^{\circ}\text{F}\end{aligned}$$

Step 2 The units of $^{\circ}\text{C}$ cancel, leaving $^{\circ}\text{F}$. Room temperature is **77°F** .

 WORKED EXAMPLE: Fahrenheit to Celsius

Question: A normal body temperature is 98.6 °F. What is this in °C?

Step 1 Subtract 32 first, then multiply by 5/9:

$$\begin{aligned}T_C &= \left(\frac{5\text{ }^{\circ}\text{C}}{9\text{ }^{\circ}\text{F}}\right) \\&\quad \times (98.6\text{ }^{\circ}\text{F} - 32\text{ }^{\circ}\text{F}) \\&= \left(\frac{5\text{ }^{\circ}\text{C}}{9\text{ }^{\circ}\text{F}}\right) (66.6\text{ }^{\circ}\text{F}) \\&= 37.0\text{ }^{\circ}\text{C}\end{aligned}$$

Step 2 The units of °F cancel, leaving °C. Body temperature is **37.0 °C**.

 WORKED EXAMPLE: Fahrenheit to kelvin

Question: A lab is at 68 °F. What is this in kelvin?

Step 1 Convert to °C first:

$$\begin{aligned}T_C &= \left(\frac{5\text{ }^{\circ}\text{C}}{9\text{ }^{\circ}\text{F}}\right) \\&\quad \times (68\text{ }^{\circ}\text{F} - 32\text{ }^{\circ}\text{F}) \\&= 20\text{ }^{\circ}\text{C}\end{aligned}$$

Step 2 Then convert to kelvin:

$$\begin{aligned}T_K &= 20\text{ }^{\circ}\text{C} + 273.15 \\&= 293.15\text{ K}\end{aligned}$$

Step 3 The lab is at **293 K** (293.15 K).

Common mistake

 COMMON MISTAKE: Adding 32 before multiplying

For °C to °F, multiply **first**, then add 32 °F. For 25 °C: $(9\text{ }^{\circ}\text{F}/5\text{ }^{\circ}\text{C})(25\text{ }^{\circ}\text{C}) + 32\text{ }^{\circ}\text{F} = 77\text{ }^{\circ}\text{F}$. Adding first would give $(9/5)(25 + 32) = 102.6$, which is wrong (and mixes °C with °F).

 COMMON MISTAKE: Forgetting to subtract 32 first

For °F to °C, subtract 32 °F **before** multiplying by 5/9. For 98.6 °F: $(5\text{ °C}/9\text{ °F})(98.6\text{ °F} - 32\text{ °F}) = 37.0\text{ °C}$. Multiplying first would give $(5/9)(98.6) - 32 = 22.8$, which is wrong.

 COMMON MISTAKE: Writing °K

Kelvin temperatures have **no degree sign**: write 298 K, not 298 °K. Also, kelvin temperatures are never negative.

 COMMON MISTAKE: Converting a temperature change like a temperature

A rise of 10 °C is a rise of $(1.8\text{ °F}/\text{°C})(10\text{ °C}) = 18\text{ °F}$, not 50 °F. Use only the factor 1.8 °F/°C for changes; don't add 32 °F.

 NOTATION NOTE

- T_C , T_F and T_K are the same temperature expressed on different scales.
- Some books write $T(\text{°F}) = 1.8 T(\text{°C}) + 32$; 1.8 and 9/5 are the same number.
- The unit is “kelvin” (lower-case k), with the symbol K: “300 kelvin”, not “300 degrees Kelvin”.

Remember this

 REMEMBER THIS

- °C → °F: multiply by 9/5, then add 32. °F → °C: subtract 32, then multiply by 5/9.
- K = °C + 273.15; no degree sign on K; kelvin is never negative.
- -40 °C = -40 °F: the only temperature where the two numbers agree.
- Checkpoints: 0 °C = 32 °F = 273.15 K; 100 °C = 212 °F = 373.15 K.

References

1. Bureau International des Poids et Mesures (BIPM). The International System of Units (SI), 9th ed.; BIPM, 2019.
[Link](#)
2. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

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