

The Molar Mass of Carbon-12 Is No Longer Exactly 12

— The 2019 SI Revision Moved an Equals Sign from Definition to Empirical Law — Yet the Departure Is

4.2×10^{-9} , Only 1.17 Times the Uncertainty — [Paper 295]

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— *From thinking to syncing.* —

Abstract

“One mole is the amount in 12 g of carbon-12” was for a long time a definition. The 2019 SI revision made it no longer a definition. This paper asks how the standing of that equals sign changed—the answer is it moved from definition to empirical law. No new mathematical theorem and no new law is claimed. First, the direction of definition was reversed. Before, mass fixed the count; now, the count fixes the mass (Section 2). Second, this is the core of the paper. $M(^{12}\text{C}) = 11.9999999958$ g/mol, and it is no longer exactly 12 (Section 3). Third, but the departure is not yet significant. The difference of 4.2×10^{-9} g/mol is only 1.17 times the uncertainty of 3.6×10^{-9} (Section 3). Fourth, so it is not “it departed” but “it became able to depart”. What changed is not the value but the standing of the equals sign (Section 4). Fifth, the same happened to four units. Kilogram, ampere, kelvin, mole—and the triple point of water is no longer exactly 273.16 K (Section 5). Sixth, the separator is which side was fixed. The fixed side becomes definition; the remaining side becomes measurement (Section 6).

Scope of this paper (scope note): No new mathematical theorem and no new law is claimed—the 2019 SI revision, the defined value of the Avogadro constant, the CODATA value of $M(^{12}\text{C})$, and the molar mass constant are all standard. We do not build metrology—all we use is one subtraction and one division. We do not argue the merits of the revision—why it was made and which definition is better are not treated. We look only at how the standing of an equals sign moved. We do not enter experimental detail—neither the silicon-sphere determination of the Avogadro constant nor the watt balance is treated at all. We do not assert a departure from 12—the difference of 4.2×10^{-9} is 1.17 times the uncertainty and is not significantly different from 12. This paper does not claim “it is no longer 12” but states “there is no longer a guarantee that it is 12”. We do not track CODATA updates—11.9999999958(36) is a recommended value at one epoch and may be revised. The claim is the structure, not the number. We do not exaggerate the practical impact—a relative 3.5×10^{-10} is invisible in everyday analytical chemistry (relative 10^{-4}). It shows only in the world of mass standards. Relation to earlier papers: Paper 16 showed that the equals sign too has distinct roots—this paper is an instance of one equals sign changing its root within history. In 2019 it moved from the equals sign of definition to that of empirical law. Paper 95 separated convention from fact and treated the defined value of c —the N_A here is a defined constant of the same type as c , having moved to the side of the scaffolding. Paper 268 showed that the triple point being a point is not an experimental fact—this paper sets beside it that that triple point’s temperature also ceased to be a definition in the same revision. Paper 196 showed that “pressure” is four separate quantities—this paper treats one quantity whose equals sign can hold two standings. What is added is computing the departure of $M(^{12}\text{C})$ from 12 as 4.2×10^{-9} g/mol, confirming that it is only 1.17 times the uncertainty, lining up the same exchange across four units, and placing the separator at which side was fixed.

1. Notation and the Question

On 20 May 2019 the definitions of the SI base units were revised. For the mole the change was as follows.

Epoch	Definition	Direction
Before 2019	the amount in 12 g of carbon-12 is 1 mol	mass fixes the count
From 2019	$N_A = 6.02214076 \times 10^{23}$ /mol exactly	the count fixes the mass

Question: What became of the equation $M(^{12}\text{C}) = 12 \text{ g/mol}$?

Observation 1.1

Before the revision this equation was a definition. Nothing to measure, no error—it was so because it had been decided so.

Observation 1.2

Paper 16 showed that the equals sign too has distinct roots. The equals sign of a definition, of an identity, and of an empirical law are written alike but differ in standing—this paper is an instance of one equals sign changing its root.

2. The Direction of Definition Was Reversed

Observation 2.1

The chain before the revision ran thus.

Weigh out 12 g of carbon-12 (mass is the starting point)

↓ the number of atoms therein is 1 mol

↓ **measure** that number to obtain N_A (it carries error)

Observation 2.2

The chain after the revision runs thus.

Declare $N_A = 6.02214076 \times 10^{23}$ (the count is the starting point, no error)

↓ collect that number of carbon-12 atoms

↓ **measure** their mass to obtain $M(^{12}\text{C})$ (it carries error)

Observation 2.3

The error has changed places. Before, N_A carried the error and $M(^{12}\text{C})$ was exact—now N_A is exact and $M(^{12}\text{C})$ carries the error.

Observation 2.4

Under either system, not one physical fact has changed. A carbon atom weighs the same and so does a gram—what changed is only the choice of which to fix as convention (Paper 95).

3. The Core: $M(^{12}\text{C})$ Is 11.9999999958 g/mol

Check 3.1:

Quantity	Value
N_A (defined)	$6.02214076 \times 10^{23}$ /mol exactly
$M(^{12}\text{C})$ (measured)	11.9999999958 g/mol
Its uncertainty	$\pm 3.6 \times 10^{-9}$ g/mol
Departure from 12	4.2×10^{-9} g/mol
In relative terms	3.5×10^{-10}

Observation 3.2

This is the core of the paper. $M(^{12}\text{C})$ is no longer exactly 12—the number 12 is now an object of measurement.

Check 3.3: But is the departure significant?

Quantity	Value
Departure / uncertainty	1.1667

Observation 3.4

The departure is only **1.17** times the uncertainty. It is not significantly different from 12—present measurements are equally consistent with its being exactly 12.

Observation 3.5

This is the exact way to put it—not “it has departed from 12” but “there is no longer a guarantee that it is 12”. Whether it has departed is for future measurement to decide—previously that question could not even be posed.

Check 3.6: We look at the molar mass constant $M_u = M(^{12}\text{C})/12$.

Quantity	Value
M_u	$9.999999996500 \times 10^{-4} \text{ kg/mol}$
Relative departure from 10^{-3} kg/mol	3.5×10^{-10}

Observation 3.7

The everyday rule “atomic weight $\times$ g/mol gives the molar mass” tacitly uses $M_u = 1 \text{ g/mol}$ exactly. That has become inexact by 3.5×10^{-10} —though almost no laboratory sees that decade.

4. Not “It Departed” but “It Became Able to Depart”

Check 4.1: We see where this difference could act.

Setting	Relative precision	3.5×10^{-10} is
Everyday analytical chemistry	10^{-4}	invisible
High-precision mass spectrometry	10^{-6}	invisible
Mass standards, atomic clocks	10^{-9}	barely visible

Observation 4.2

In practice nothing changed. The same computations give the same answers as before——what changed is not the value but the standing of the equals sign.

Observation 4.3

So this revision is an event on the side of logic, not of measurement. No new experiment refuted 12——12 was moved to a place where it could be refuted.

Observation 4.4

In the language of Paper 16, the equals sign changed its root.

	Before 2019	From 2019
$M(^{12}\text{C}) = 12 \text{ g/mol}$	equals of definition	equals of empirical law (1.17σ)
$N_A = 6.02214076 \times 10^{23}$	equals of empirical law	equals of definition

Observation 4.5

The two rows have exactly traded places. The total count of definitions and measurements is unchanged——only the choice of which to fix has been remade.

5. The Same Happened to Four Units

Check 5.1:

Unit	Old definition	New definition (constant fixed)
Kilogram	the international prototype	$h = 6.62607015 \times 10^{-34} \text{ J s}$
Ampere	force between two wires	$e = 1.602176634 \times 10^{-19} \text{ C}$
Kelvin	triple point of water, 273.16 K exactly	$k = 1.380649 \times 10^{-23} \text{ J/K}$
Mole	12 g of carbon-12	$N_A = 6.02214076 \times 10^{23} \text{ /mol}$

Observation 5.2

The right column is “exactly” throughout. The left column holds objects and phenomena; the right holds numbers——a convention is a number, not a thing.

Check 5.3: The kelvin row underwent the same exchange as the mole.

Temperature of the triple point of water	
Before 2019	273.16 K exactly (definition)
From 2019	273.1600 K ± 0.0001 K (measured)

Observation 5.4

Paper 268 showed that the triple point being a point is itself not an experimental fact. Here, further, the temperature of that point is no longer a definition either——for one and the same triple point, two separate reasons for “not a fact” now overlap.

Observation 5.5

In four units, equations that had been definitions became measured values. And in all four, the departure lies inside the present uncertainty——the revision was carried out continuously; no number jumped.

6. Separator: Which Side Was Fixed

Observation 6.1

Separator——what must be moved for the standing of an equals sign to change?Which side was fixed as convention.

	The fixed side	The remaining side
Standing	definition (no error)	measurement (with error)
Question one may ask	none	“is it really that value?”

Observation 6.2

Of the defined side one cannot ask “is it really so?”Because it is a convention——whether the question can be posed at all is what the difference in standing consists of.

Observation 6.3

Paper 95 treated the defined value of c .Since 1983, the speed of light is not an object of measurement——because the metre is defined from c .In 2019, N_A moved to the same side as c .

Observation 6.4

So the research programme of “measuring the Avogadro constant precisely” ended in 2019.The same apparatus still runs, but the name of what it measures has changed——it now realises the kilogram.

Observation 6.5

A point to write honestly——this paper does not argue which definition is better.What is shown is the structure of an equals sign having moved, not the merits of the revision——but writing “exactly 12” without noticing that the standing has moved is no longer accurate.

7. Roll Call and Closing

1. **The direction reversed** (Observations 2.1--2.2): **Mass fixes count $\rightarrow$ count fixes mass.**
2. **The error changed places** (Observation 2.3): **From N_A to $M(^{12}\text{C})$.**
3. **$M(^{12}\text{C}) = 11.9999999958$ g/mol** (Check 3.1): **No longer exactly 12.**
4. **Departure 4.2×10^{-9} g/mol** (Check 3.1): **Relative 3.5×10^{-10} .**
5. **Departure / uncertainty = 1.1667** (Check 3.3): **Not significant.**
6. **Not “it departed”** (Observation 3.5): **“The guarantee is gone.”**
7. **Invisible in practice** (Check 4.1): **Only at 10^{-9} .**
8. **Two rows trade places exactly** (Observation 4.4): **The totals are unchanged.**
9. **The same in four units** (Check 5.1): **The right column is all numbers.**
10. **The triple point is not exactly 273.16** (Check 5.3): **± 0.0001 K.**

Closing: The molar mass of carbon-12 is no longer exactly 12. The 2019 SI revision made N_A a defined value and the error changed places—before, mass fixed the count; now the count fixes the mass. The measured value is $M(^{12}\text{C}) = 11.9999999958$ g/mol, a departure from 12 of 4.2×10^{-9} g/mol, relative 3.5×10^{-10} . But it must be put exactly—the departure is only **1.17** times the uncertainty and is not significantly different from 12. Not “it has departed from 12,” but “there is no longer a guarantee that it is 12.” The same exchange happened in four units—kilogram, ampere, kelvin, mole. The triple point of water is no longer exactly 273.16 K either. One thing separates them—which side was fixed as convention. The fixed side becomes definition, and one can no longer ask “is it really that value?” The remaining side becomes measurement, and that question becomes askable. What moved in 2019 was not a value but which equals signs that question may be put to.

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