On Setting the Speed of Light

How a Measured Value Was Set as Exact and Used to Define the Metre

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Abstract

The sentence "the speed of light is exactly 299 792 458 $\mathrm{m\,s^{-1}}$" is routinely presented as though it reports an infinitely precise observation of nature. It does not. The metre and the second existed before this numerical value could be measured. In 1975, 299 792 458 $\mathrm{m\,s^{-1}}$ was recommended as a measured value whose uncertainty was limited principally by the realisation of the metre. In 1983, the same integer was set as exact by resolution of the General Conference on Weights and Measures, and the metre was redefined through it. Measurement produced the value; the Committee set the certainty. Thereafter, no experiment expressed within the present International System of Units could revise the numerical value of c. Any uncertainty or discrepancy had to be assigned to the realisation of the units, the apparatus, the measurement pathway or the surrounding theory. This paper reconstructs that reversal and argues that certainty was not discovered in nature but placed in the symbols, after which material uncertainty was made answerable to the exact symbolic reference.

Introduction

We are repeatedly told that the speed of light in vacuum is exactly

$$c = 299,792,458 \text{ m s}^{-1}.$$

For me, that sentence should never be allowed to stand by itself. Its grammar says far more than the historical measurement can support. It places exactness in light, makes the integer appear to have been found within the world, and removes the human decision by which the number acquired its present status.

The more accurate statement is that **the International System of Units sets the numerical value of c at exactly 299 792 458 when it is expressed in metres per second**. The qualification changes everything. Nature did not present the Committee with a dimensioned integer. A speed written in metres per second requires a metre and a second before its numerical value can be formed. Those units, their instruments and their uncertainties all preceded the number.

The speed of light was therefore measured through an inherited symbolic and material framework. The resulting value remained answerable to further measurement until 1983. In that year, a metrological committee turned the relation around: it set the measured integer as exact and used it to define the metre. From that point onwards, the number was no longer permitted to move in response to measurement. Measurement had to move in relation to the number.

This is not merely the story of a more reproducible standard. It is the story of how an uncertain measurement became a perfect symbolic reference, how an institutional resolution set that perfection, and how the uncertainty of the measured world was subsequently organised around it.

Before certainty

Before the number was set, there was no exact measured speed of light. There were increasingly refined measurements, each dependent upon a realised length, a realised time, an instrument, a method and an estimate of uncertainty. A later measurement could alter the accepted value because the number remained downstream of the observation.

This is the ordinary direction of empirical correction:

$$\text{interaction} \longrightarrow \text{measurement} \longrightarrow \text{number with uncertainty} \longrightarrow \text{possible revision.}$$

The uncertainty was not an embarrassment added to an otherwise perfect number. It disclosed the status of the number. It told us that the symbolic result had been produced through finite comparison and remained open to another interaction with the world.

The history of the metre shows the material pathway from which the later integer emerged. In 1889, the first General Conference on Weights and Measures sanctioned a particular platinum-iridium prototype. At the temperature of melting ice, that bar was to represent the metric unit of length. It could be located, inspected and compared with other bars. It also had to be supported under stated conditions, observed through instruments and protected from alteration.

The prototype had extent, but it did not provide certainty. Temperature, engraved lines, material stability, optical comparison and the condition of the artefact all entered the measurement. Every transfer from the prototype to another standard carried a chain of comparison and uncertainty. Nothing in the material event offered an infinitely exact metre.

The metre is transferred into a count

By the middle of the twentieth century, interferometry allowed lengths to be reproduced through wavelengths of light more precisely than national bars could be compared with the international prototype. In 1960, the eleventh General Conference replaced the bar definition. One metre was set equal to 1 650 763.73 wavelengths in vacuum of a specified radiation from krypton-86.

That number was not announced by the krypton atom. It was selected so that the new wavelength standard reproduced the existing metre as closely as the available measurements permitted. The metre came first; the count was fitted to it. The 1960 resolution formally removed the bar from the definition, but the registered extent of the bar continued through the selected numerical relation.

The second passed through a similar transfer. In 1967, the thirteenth General Conference defined it as the duration of 9 192 631 770 periods of a specified caesium-133 radiation. Again, an inherited unit was set into a count so that the new atomic realisation would preserve the second already in use.

By the early 1970s, optical frequency could be connected to the caesium standard while optical wavelength could be compared with the krypton-defined metre. The speed of light could then be formed through

$$c = \lambda f.$$

The numerical result joined two prior trajectories. Frequency carried the second; wavelength carried the metre. The integer that would later appear self-sufficient was being produced by a network of material standards, experimental transitions, instruments and agreed symbolic operations.

The value before it was set

In 1975, the fifteenth General Conference recommended the value

$$c = 299,792,458 \text{ m s}^{-1}.$$

The resolution attached an estimated relative uncertainty of $\pm 4 \times 10^{-9}$ and stated that this corresponded to the uncertainty in realising the metre. The integer was therefore not an exact observation. It was the recommended centre of a finite measurement interval.

At this stage, the direction of reference remained visible:

$$\text{realised metre} + \text{realised second} \longrightarrow \text{measured value of } c.$$

The measurement could still answer back. A better realisation of the metre, a different wavelength comparison or an unrecognised experimental effect could, in principle, require the recommended number to change. The value possessed remarkable precision, but it did not possess perfection.

Its final digits carried the old bar, the krypton count, the caesium count, interferometers, lasers, frequency chains, laboratories, comparison procedures and human judgement about uncertainty. None of that history appeared when the number was written alone. The measurement trajectory had already been compressed into the integer.

1983: the Committee sets the certainty

In 1983, the seventeenth General Conference adopted a new definition of the metre. Its own resolution records the decisive reasoning. Measurements of the speed of light had become limited principally by the realisation of the existing metre. The Conference wished to maintain the numerical value recommended in 1975 and noted that setting it as exact would produce no appreciable discontinuity in the unit of length within the uncertainty of the previous definition.

The metre was then defined as the length of the path travelled by light in vacuum during 1/299 792 458 of a second. At that moment, the status of the number changed. The Committee did not perform an experiment that eliminated the remaining uncertainty. It set the number so that uncertainty could no longer attach to it.

The transition can be stated in two sentences:

> Measurement produced the value.
>
> The Committee set the certainty.

Before 1983, 299 792 458 $\mathrm{m\,s^{-1}}$ was a measured recommendation capable of revision. After 1983, the same symbols formed an exact defining relation. The number had passed from the output of measurement into the rules governing measurement.

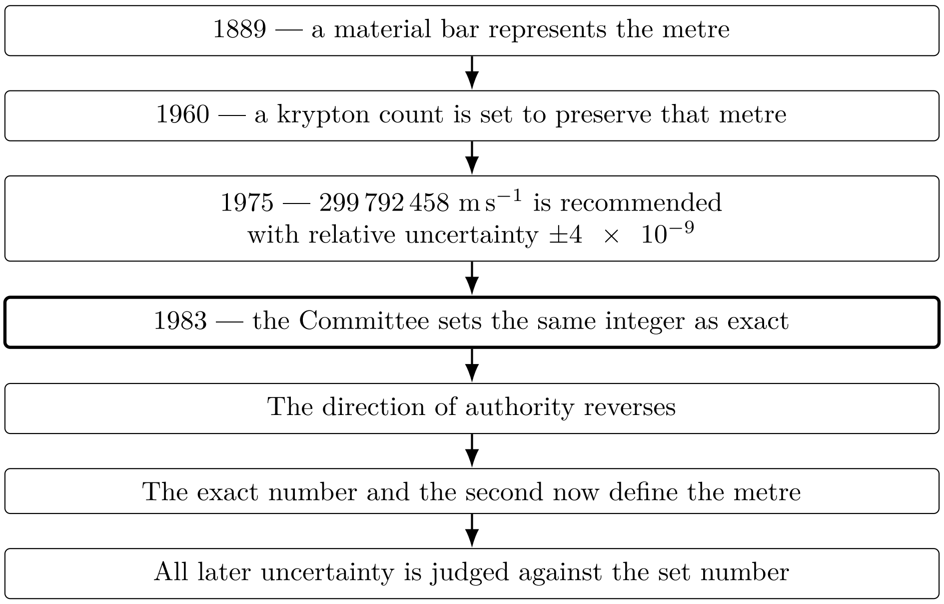

Figure 1: The measured value becomes an exact defining authority.

The diagram shows the reversal that the familiar definition conceals. The earlier metre helped produce the measured value of c. The set value of c then became part of the means by which every later metre would be realised. The measured output was hardened into an exact input.

Why "set" matters

Official metrological language usually says that the numerical value was *fixed*. For me, *set* carries more of the event. *Fixed* sounds passive and technical, as though a loose part had been secured or an erroneous value corrected. It allows the person reading the sentence to forget that someone acted.

Set retains the actor, the action and the resulting state. A committee sets a value. A clock is set against a reference. A rule is set before an activity begins. Concrete sets and ceases to flow. Something set in stone is removed from ordinary revision. A mathematical set establishes what is admitted and what remains outside. Each of these meanings is active in the transition of 1983.

The number was not selected without constraint. It was poured into an inherited mould. The requirement of continuity with the previous metre shaped the choice. But once it had set, the mould could disappear from the ordinary account. The integer appeared solid, self-supporting and natural, while the material and institutional trajectory through which it had formed receded from view.

The number 299 792 458 became perfect, not because measurement reached perfection, but because the symbolic system ceased to permit a remainder. Its exactness is the consequence of setting.

What was decided, and by whom?

The decision was international in a specific institutional sense. The General Conference on Weights and Measures operates through the Metre Convention and representatives of participating states. Its resolution had authority within the international metrological system. It would therefore be inaccurate to say that no international institutional decision occurred.

But this was not a vote by the world that uncertainty had ended. There was no universal scientific referendum on whether an exact property of nature had been found, no public decision by humanity to place this integer beyond empirical revision, and no observation capable of producing infinite certainty. A delegated body made a metrological resolution within the authority granted to it for maintaining units.

That body had the administrative authority to set the SI definition. It did not thereby acquire authority over nature. Yet the ordinary sentence "the speed of light is exactly 299 792 458 $\mathrm{m\,s^{-1}}$" collapses these two forms of authority. A rule of the measuring language is presented as an exact discovered property of the world.

The provenance should never be omitted. The responsible statement is:

> Within the International System of Units, the numerical value of the speed of light in vacuum was set by resolution of the General Conference on Weights and Measures at exactly 299 792 458 $\mathrm{m\,s^{-1}}$. The value was selected to preserve continuity with the previously realised metre and cannot be revised by further SI measurement while the present definitions remain in force.

This sentence is longer because the history is part of the meaning. Removing it produces a more efficient statement but also a different claim.

Where the uncertainty went

The official account says that uncertainty moved into the practical realisation of the metre. That is correct inside the metrological framework, but it does not capture the full epistemic change. Before 1983, uncertainty stood above the numerical value and could require its correction. After 1983, certainty was placed in the numerical relation, and uncertainty was made subordinate to it.

The new hierarchy became

$$\boxed{c \equiv 299,792,458\ \mathrm{m\,s^{-1}}\ \text{exactly}}$$

$$\Downarrow$$

$$\text{all material realisations, instruments and observations carry uncertainty.}$$

The physical world did not become exact in 1983. Laboratories still had to realise the second, generate and stabilise radiation, establish a path, account for environmental conditions, operate instruments and retain comparisons. Every interaction remained finite. What changed was where uncertainty was permitted to appear.

Suppose an experiment now returns 299 792 457.8 $\mathrm{m\,s^{-1}}$. Within the present SI, that result cannot become a revised speed of light in vacuum. The discrepancy must be placed in the realised metre, the realised second, the apparatus, the path, the uncertainty analysis, the experimental conditions or the theoretical identification of what was measured. The set integer does not submit to the observation; the observation must establish its admissibility relative to the integer.

This is the precise sense in which the number can now never be changed by measurement. A future General Conference could replace the definition, just as earlier definitions were replaced. But that would be another act of setting. It would alter the measuring system rather than report a refined value of c within the metre and second presently defined through it.

Uncertainty did not disappear. It was expelled from the defining number and redistributed across the measured world.

A God-like number inside the system

The phrase *God-like* may sound excessive, but it identifies the structural position the number now occupies. It is declared exact. It is protected from empirical correction. It supplies a reference against which uncertainty is judged. Every admissible SI measurement of length must be made coherent with it.

The analogy does not say that metrologists worship the number or that the number possesses agency. It concerns the geometry of authority. The defining integer is placed beyond the reach of the measurements it governs. If a conflict appears, the surrounding account must change while the central relation remains untouched.

Before 1983, there was no certainty of this kind in the measured value. There was only a highly refined estimate with a stated uncertainty. The Committee created a perfect number inside the symbolic system and then made the system refer material uncertainty to that perfection.

This perfect number is not the behaviour of light itself. It is the numerical value that light must possess when expressed through the SI metre and second. The distinction is subtle, but once removed, a convention of representation becomes an ontological declaration.

Closure and the direction of later physics

The setting of c does not by itself demonstrate that any particular later theory is false, nor does it simply cause dark matter or every paradox in physics. The more important connection is structural. When foundational symbols are exact and protected, an observation that does not fit cannot be allowed to revise them. The discrepancy must be absorbed elsewhere.

The trajectory then takes the form

$$\begin{aligned}\text{set symbolic foundations} &\longrightarrow \text{observation does not fit}\\ &\longrightarrow \text{additional entity, correction or framework}\\ &\longrightarrow \text{foundations remain set.}\end{aligned}$$

Dark matter offers a striking example of this geometry. Observed motions do not agree with the established description when only registered matter is included, so an additional entity is inferred to preserve the larger framework. This does not prove that dark matter does not exist. It shows where the existing language allows revision to occur. The inferred contents of the universe may be transformed before the exact symbolic foundations are reopened.

Physics can therefore accumulate paradoxes, invisible entities and increasingly elaborate models while continuing to describe its starting relations as certainties. A framework whose foundational symbols cannot answer to measurement may be extraordinarily productive, but it also narrows the routes through which an anomaly can return to those foundations.

For me, this is why the history of the metre matters beyond metrology. It gives us a documented moment at which a measured value ceased to be revisable and became an exact authority. It shows how a practical decision can harden into the apparent furniture of the universe, and how the language of certainty can hide the committee act from which that certainty arose.

Conclusion

The speed of light was not measured to be exactly $299\,792\,458\ \mathrm{m\,s^{-1}}$. The metre and second existed before that numerical value could be formed. They enabled the measurements through which the value was recommended in 1975 with a stated uncertainty. In 1983, the General Conference set the same integer as exact and redefined the metre through it.

Measurement produced the value. The Committee set the certainty.

Once set, the number ceased to be an empirical result capable of correction within the same unit system. The material world remained uncertain, but uncertainty was henceforth referenced to a perfect symbolic relation. Any disagreement had to be found outside the defining integer.

The old platinum-iridium bar has not vanished completely from this story. Its registered extent passed into the krypton count, from there into the measured numerical value of c, and from there into the exact integer through which the metre is now defined. The bar disappeared from the final sentence, but its trajectory remains compressed within the number.

The issue is therefore not whether the modern metre is useful. The issue is whether a useful convention should be spoken of as though it were an exact observation of nature. A committee may set the language of an international measuring system. It cannot, by that act alone, remove uncertainty from the world.

The uncertainty went everywhere except into the symbol that had been set beyond its reach.

Primary historical sources

- Declaration of the 1st CGPM (1889): sanction of the international prototype metre
- Resolution 6 of the 11th CGPM (1960): krypton-86 definition of the metre
- Resolution 1 of the 13th CGPM (1967): caesium-133 definition of the second
- Resolution 2 of the 15th CGPM (1975): recommended value for the speed of light
- Resolution 1 of the 17th CGPM (1983): definition of the metre and exact value of c
- BIPM: present definition of the metre