On Removing Uncertainty Using Constants

How Setting Numerical Values as Exact Changes the Uncertainty Reported in Scientific Results

A Monograph in Finite Symbolic Mechanics

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2026

Abstract

Modern metrology fixes the numerical values of selected constants, including the speed of light in vacuum, the Planck constant, the elementary charge, and the caesium hyperfine transition frequency. This arrangement provides a stable and reproducible symbolic frame within which units may be realised and measurements compared. It does not, however, make the physical interactions through which those units are realised more precise. The exactness belongs first to a finite inscription and then to a definition. Every experimental encounter with that definition remains dependent upon instruments, interactions, calibration chains, environmental conditions, models, corrections, and finite acts of registration.

This monograph examines the difference between increasing the determinacy of a symbolic frame and increasing the precision of a physical encounter. It argues that fixing a previously measured value as a defining constant removes its uncertainty term from subsequent formal propagation, while redistributing the remaining uncertainty through the realisation and measurement system. The resulting uncertainty may be valid within the adopted metrological architecture, but its meaning is conditional upon the exact assignments and invariant relations that the architecture has admitted. Because these conditions are normally left outside the terminal statement of a result, a short expression such as $X \pm u_X$ is supported by a much larger, distributed and frequently undeclared textual container.

The argument is developed within Finite Symbolic Mechanics. A measurement is treated not as the passive reading of a pre-inscribed world, but as a finite symbolic trajectory extending from interaction, through registration and conversion, into calibration, computation, statistical interpretation, and publication. The monograph does not propose the rejection of the International System of Units, nor does it claim that definitional exactness falsifies experimental results. It instead asks that the exactness of the symbolic anchor be kept distinct from the uncertainty of its physical realisation, and that the compressed conditions of a scientific result be recognised as part of what has been claimed.

Preface

This work arose from an exploratory conversation about a deceptively simple fact: the numerical value assigned to the speed of light in vacuum is exact in the International System of Units. The conversation moved lightly, and at times absurdly, through metal standards, elected gods, motor-car speedometers, particle detectors, statistical significance, and the institutional dynamics of science. Humour allowed the assumptions surrounding measurement to become visible, but it also allowed several claims to travel further than the evidence could carry them. The present monograph retains the productive trajectory while separating its central argument from those excesses.

For me, the important conclusion is not that modern metrology has committed a simple error. The construction of stable units is an intelligible and practically necessary achievement. The problem begins when stability in the symbolic framework is allowed to appear as increased precision in the measured world. An exact definition can coordinate laboratories without making any interferometer, clock, detector, analogue-to-digital converter, or physical interaction exact. The definition changes the organisation of the account; it does not refine the physical encounter by declaration.

The monograph therefore proceeds cautiously. It distinguishes the exact inscription from the quantity it helps define, the definition from its realisation, and the realisation from the larger experimental result. It then examines how uncertainties propagate when constants are treated as measured quantities and how the formal budget changes when those constants are instead assigned zero uncertainty. Finally, it considers the objections that a metrologist, experimental physicist, statistician, or engineer might reasonably raise. Those objections are not staged merely to be defeated. They expose the difference between an operational defence of the present system and the epistemic question developed here.

Contents

Chapter 1

The Setting of the Measure

1.1 From artefact to relation

For much of the modern history of measurement, a unit could be traced through a chain that ended in a specified material artefact. The international prototype metre was a platinum–iridium bar whose marked interval served as the defining reference for length. Such an artefact made the authority of the unit materially visible. The metre was not merely described by a text; it was instantiated by a privileged object, preserved under specified conditions and approached through comparison.

The practical limitations of this arrangement are familiar. Any comparison with a material standard requires instruments, environmental control, optical or mechanical contact, procedures, corrections, and an account of uncertainty. The artefact can be stable enough for extensive technical use without becoming invariant. Copies can differ, surfaces can change, and the act of comparison can acquire a precision finer than the stability of the object being compared. None of this makes the artefact useless. It reveals that the unit is maintained through a system of relations rather than contained without remainder in a single object.

In 1960 the metre was redefined through radiation corresponding to a specified transition in krypton-86. In 1983 the definition was changed again by fixing the numerical value of the speed of light in vacuum at

$$c \equiv 299\,792\,458\ \mathrm{m\,s^{-1}}. \tag{1.1}$$

The metre could then be expressed as the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. The change was deliberately constructed to preserve continuity with the existing unit of length. The chosen digits carried forward the best established numerical value, so that the practical magnitude of the metre would not perceptibly jump when the new definition came into force.

The move from artefact to fixed constant is often described as a transition from an unstable human object to an invariant of nature. That description is operationally attractive, but it can conceal the continuing material work. A laboratory does not obtain a metre by reading Equation (1.1) alone. It must realise the definition through frequency standards, optical systems, interferometers, propagation models, environmental corrections, electronics, software, and comparison procedures. The bar has left the centre of the definition, but interaction has not left measurement.

1.2 The exactness of the inscription

The finite symbol sequence 299 792 458 is exact in a straightforward sense. Once adopted, there is no uncertainty about which decimal digits the definition contains. The inscription is not an approximation to another hidden numeral within the SI. It is the stipulated numerical value of c when expressed in metres per second. This exactness is symbolic and definitional before it is anything else.

The distinction matters because an expression such as Equation (1.1) resembles an empirical statement. Before 1983, a statement of the speed of light in metres per second was the reported outcome of measurements and therefore carried uncertainty. After 1983, the same style of equation became an identity participating in the definition of the metre. The grammatical surface changed very little, while the epistemic function changed substantially.

This passage can be represented schematically as

$$c_{\text{measured}} \pm u_c \quad \longrightarrow \quad c_{\text{defined}} \equiv 299\,792\,458\ \mathrm{m\,s^{-1}}. \tag{1.2}$$

The arrow in Equation (1.2) is not an improvement produced by a more refined final observation. It is an institutional and metrological operation. A numerical value selected from a history of measurement is given a new role: it becomes an anchor through which the unit is set. The inherited digits preserve continuity, but their continuity can also make the act of setting less visible. What had been measured becomes the exact relation through which later measurements are expressed.

1.3 The authority of the anchor

The authority to establish international units is exercised through treaty organisations, national metrology institutes, committees, resolutions, and systems of legal adoption. This authority need not be democratically universal in order to be technically effective. Units acquire practical authority because states, laboratories, manufacturers, engineers, regulators, and markets coordinate around them. Their success lies in the breadth and stability of this coordination.

It is tempting to turn this structure into either a scientific priesthood or an innocent administrative convenience. Neither description is adequate. The setting of a unit is a genuine exercise of symbolic authority, but it is also an attempt to solve a genuine coordination problem. The philosophical question is not whether committees are permitted to define units. Any shared unit requires some process of stabilisation. The question is what kinds of claim become possible after that stabilisation, and which parts of the stabilising trajectory subsequently disappear from view.

Chapter 2

Exact Definition and Finite Realisation

2.1 Four locations of exactness and uncertainty

The discussion becomes confused when every use of the word "exact" is treated as equivalent. At least four locations must be distinguished. The first is the exactness of the inscription: the adopted symbol sequence is fixed. The second is definitional exactness: the rules of the SI assign that sequence a precise role in establishing a unit. The third is realisation uncertainty: every practical enactment of the definition is finite and instrument-dependent. The fourth is model uncertainty: the physical and mathematical account that connects the registered interactions to the quantity being reported remains conditional.

These locations can be summarised without implying that they are independent stages. They form a coupled trajectory in which later operations inherit constraints from earlier ones.

Table 2.1: Distinct locations of exactness and uncertainty.

Location	Governing question	Character of the claim
Inscription	Which finite symbols were adopted?	Exact under the declared syntax and resolution.
Definition	What unit relation do those symbols establish?	Exact within the adopted metrological system.
Realisation	How is the definition enacted in a laboratory?	Finite, interactional, calibrated, and uncertain.
Model	How are registrations converted into a reported quantity?	Conditional upon physical, mathematical, computational, and statistical assumptions.

The exactness of the first two locations does not migrate automatically into the latter two. A perfect copy of the definition does not become a perfect clock. An exact value of c does not remove phase noise, cavity shifts, thermal effects, alignment errors, finite sampling, quantisation, detector response, or uncertainty in a measurement model. The definition supplies a stable relation against which such effects can be described.

2.2 Setting is not measuring

To set a number is not to measure that number without error. It is to stop treating the numerical value as an output of the active metrological system and to use it as a condition of that system. The distinction can be expressed in the difference between an observational statement and a rule of construction.

An observational statement has the general form

$$x = \hat{x} \pm u_x, \tag{2.1}$$

where $\hat{x}$ is an estimate and u_x represents an evaluated uncertainty under declared conditions. A defining statement instead has the form

$$\{x\}_U \equiv N, \tag{2.2}$$

where $\{x\}_U$ denotes the numerical value of a quantity when expressed in a unit system U, and N is fixed. The second statement sets part of the coordinate structure through which later observational statements are written.

The practical success of this operation is not in dispute. Laboratories can realise and disseminate units with increasing reproducibility. The error begins only if the exactness of the rule is described as though it were increased access to an exact physical thing. The unit has become more determinate in language; the physical interaction remains finite.

2.3 The closed relation

Once the metre is defined through c, an attempt to measure c in SI metres per second closes upon the definition. A discrepancy from Equation (1.1) cannot be interpreted inside the system as a revised SI numerical value of c. It must be assigned to the realisation of length, the realisation of time, propagation conditions, instrument behaviour, or the measurement model.

This closure does not prove that the physical relation represented by c is invariant. It establishes that the SI numerical expression of that relation is invariant. A search for physical variation must therefore introduce an independently realised reference or examine dimensionless ratios whose variation cannot be removed by a corresponding change of unit. The closed system has not falsified the question, but it has changed the form in which the question can be asked.

Within FSM, this is a change in admissible symbolic trajectories. Before the definition, a revised measured value of c in metres per second was an admissible terminal expression. After the definition, that trajectory is redirected. Any discrepancy must terminate elsewhere in the system. The act of setting therefore alters not only the value assigned to a quantity, but also the permissible grammar of future measurement claims.

Chapter 3

Uncertainty in a Cross-Related System

3.1 Propagation through a measurement model

Suppose that a reported quantity y is obtained from a measurement model

$$y = f(x_1, x_2, \ldots, x_n, c, h, e), \tag{3.1}$$

where the x_i represent measured inputs and c, h, and e represent constants entering the calculation. To first order, the combined variance may be written as

$$u_y^2 \approx \sum_{i,j} \frac{\partial f}{\partial q_i} \frac{\partial f}{\partial q_j} \operatorname{cov}(q_i, q_j), \tag{3.2}$$

where the vector $\boldsymbol{q}$ contains all quantities treated as uncertain inputs. If the inputs are taken as independent, Equation (3.2) reduces to the familiar root-sum-of-squares form

$$u_y^2 \approx \sum_{i} \left(\frac{\partial f}{\partial q_i} \right)^2 u_{q_i}^2. \tag{3.3}$$

The arithmetic consequence is immediate. If c, h, or e is an uncertain input, its variance and covariance terms participate in the result. If its uncertainty is set to zero by definition, those terms vanish from the formal propagation. Fixing the constant therefore changes the uncertainty model even though it does not alter the physical interaction being registered.

3.2 A simple example

For the relation

$$E = mc^2, \tag{3.4}$$

the relative combined standard uncertainty, when m and c are treated as independent uncertain inputs, is approximately

$$\left(\frac{u_E}{E}\right)^2 = \left(\frac{u_m}{m}\right)^2 + 4\left(\frac{u_c}{c}\right)^2. \tag{3.5}$$

Under the present SI, $u_c = 0$ by definition and the second term is absent. If c is restored as an empirically established quantity with $u_c > 0$, the term returns. No philosophical argument is needed for this arithmetic. The philosophical question concerns the legitimacy and meaning of placing u_c on one side or the other of zero.

The metrological answer is that c now defines the unit and is therefore not an uncertain input. That answer is internally coherent. It also restates the architecture being examined. It does not show that the underlying physical relation was encountered without uncertainty; it shows that the relation has been assigned the role of an exact coordinate condition.

3.3 Covariance and the danger of simple addition

The constants and measured values in a modern system are not a collection of independent numbers. They form a cross-related network. Calibrations share references, derived units share defining constants, and experimental quantities can be correlated through common instruments and models. It would therefore be incorrect simply to append historical uncertainties for c, h, and e to a present result without reconstructing the dependency and covariance structure. Such an operation could double-count uncertainty already represented elsewhere or fail to account for compensating correlations.

This caution does not remove the central point. Once the dependency structure has been unfolded, any admitted independent uncertainty must propagate. It cannot disappear because the final expression would be inconveniently larger. The proper comparison is between two complete architectures: one in which selected constants are exact defining relations, and another in which they remain empirically estimated inputs with provenance, covariance, and uncertainty.

The two architectures answer different questions. The first asks for the residual uncertainty of a result after the metrological frame has been fixed. The second asks how uncertainty would propagate if the frame itself remained within the empirical network. A result may be highly precise under the first question while carrying a more extensive uncertainty under the second.

3.4 Residual uncertainty

It is therefore useful to call the published uncertainty a *residual uncertainty*. The term does not imply that the published value is dishonest or incorrectly calculated. It indicates that the uncertainty is what remains after defining assignments, admissibility conditions, calibration conventions, and model boundaries have been established.

Let F denote the fixed symbolic frame and let M denote the active measurement model. A reported uncertainty may then be written schematically as

$$u_{\mathrm{reported}} = u(Y \mid F, M, H), \tag{3.6}$$

where H represents the accepted history, provenance, and invariant assumptions. The usual terminal expression suppresses the conditioning terms and displays only

$$Y = \hat{Y} \pm u_{\mathrm{reported}}. \tag{3.7}$$

The suppression is efficient because the framework is shared. It becomes misleading only when the conditional result is interpreted as an uncertainty detached from the frame that produced it.

Chapter 4

The Effect of the Anchor

4.1 Determinacy without increased encounter

The fixed constant acts as an anchor. It provides a stable location from which other symbolic relations can be constructed and compared. In a closed metrological system this is extraordinarily useful. Laboratories do not need to re-estimate the numerical value of c whenever they realise length. The frame remains stable while practical methods improve.

The anchor does not, however, make the registered interaction more precise. A photodetector receives no additional photons because a committee has fixed a number. A clock experiences no reduction in environmental perturbation. An interferometer acquires no improved alignment. An analogue-to-digital converter gains no additional resolution. The physical trajectory is unchanged; the symbolic treatment of one relation within that trajectory has been stabilised.

The distinction can be stated concisely:

$$\text{increased symbolic determinacy} \not\Rightarrow \text{increased physical precision.} \tag{4.1}$$

Equation (4.1) is the central proposition of this monograph. A defining anchor can improve coordination, reproducibility, and the intelligibility of comparisons. Those are real improvements. They must not be redescribed as a declaration-induced refinement of the physical encounter.

4.2 Relocation rather than elimination

When the uncertainty of a defining constant is set to zero, the difficulties of realisation do not vanish. They are relocated into other terms: frequency realisation, environmental corrections, optical path, detector timing, calibration, alignment, material response, numerical reconstruction, and model adequacy. The network remains finite even though one of its symbolic nodes has been fixed.

The relocation is partly mathematical and partly linguistic. Mathematically, variance terms associated with the defining constant are removed from the active propagation. Linguistically, the decision that authorised their removal recedes into standards, resolutions, technical appendices, and institutional memory. The final measurement can then be reported without repeating the history of the anchor.

This is why the anchor can appear to increase precision. The terminal expression has become shorter, and one source of variance no longer appears. Yet the physical content has not necessarily become more sharply encountered. The expression has become more determinate because part of its uncertainty has been converted into a rule.

4.3 The rounded-light thought experiment

The proposal to set c at exactly 300 000 000 metres per second provides a useful demonstration. If the second were retained, a new metre would satisfy

$$1\ \mathrm{m}_{\mathrm{new}} = \frac{299\,792\,458}{300\,000\,000}\mathrm{m}_{\mathrm{old}} = 0.9993081933\ldots\ \mathrm{m}_{\mathrm{old}}. \tag{4.2}$$

The new metre would be approximately 0.0691807% shorter. A physically unchanged object would therefore receive a numerical length approximately 0.0692286% larger when expressed in new metres. For many everyday measurements the difference would sit well inside existing tolerances. A motor-car speedometer would not provide a sensitive demonstration of the change.

The difference would nevertheless be large in precision metrology, manufacturing, geodesy, semiconductor fabrication, archival engineering, and any system requiring continuity between earlier and later dimensional records. The thought experiment therefore establishes two points at once. The exact numerical value is conventional and could be changed without altering the world, but the coordination system built around the existing unit makes even a small definitional change materially consequential.

The awkwardness of 299 792 458 is not evidence of a hidden conspiracy. It is a historical trace. The digits preserve the earlier measured value and thereby preserve continuity. At the same time, this inheritance allows the transition from estimate to definition to appear less abrupt than a rounded value would have made it. Continuity performs an epistemic compression: the act of setting is present in the history but faint in the contemporary equation.

Chapter 5

The Compressed Result

5.1 The terminal expression

A scientific result is commonly presented in a compact form such as

$$X = \hat{X} \pm u_X. \tag{5.1}$$

Equation (5.1) appears to contain the result. In practice it is the end of a much longer trajectory. Its terms depend upon unit definitions, practical realisations, calibration standards, sampling procedures, detector responses, corrections, models, statistical assumptions, software, and decisions about which sources of uncertainty are admitted.

An expanded statement would have to say that, within a named unit system whose defining constants have assigned exact values, using specified realisations of those units, accepting stated invariance conditions, and applying a particular instrument, calibration hierarchy, measurement model, correction procedure, and uncertainty evaluation, a registered symbolic outcome has been represented as $\hat{X} \pm u_X$. Such a sentence would be cumbersome, but its complexity belongs to the result. The short form does not abolish that complexity. It places it outside the visible expression.

The terminal result is therefore a compression supported by an external container. The container may be distributed across standards, detector papers, calibration certificates, software documentation, statistical protocols, cited measurements, and tacit disciplinary practice. A specialist can reconstruct portions of it by following references. Few readers, including specialists, are presented with the entire dependency chain at once.

5.2 Compression and symbolic drag

Within FSM, a compressed expression retains its effectiveness because a community supplies the omitted trajectories. The reader does not receive Equation (5.1) as an isolated mark. The equation activates a network of learned conventions. Symbols such as m, s, GeV, σ, and u draw authority from a wider framework that is rarely reproduced at the point of use.

This omission creates what may be called *symbolic drag*. The compact expression appears able to carry more certainty than has been inscribed within it. The missing support has not vanished; it is supplied by institutional memory and reader expectation. When the result travels outside its originating discipline, that support can be mistaken for a property of the expression itself.

The use of an exact defining constant deepens the compression. The constant no longer appears as an estimated input, and the history through which its value was selected is no longer active in the ordinary uncertainty budget. A measured trajectory has been converted into a structural support. The result becomes easier to calculate and communicate, but more complex to describe completely.

5.3 Provenance as part of uncertainty

Uncertainty is often treated as a numerical accompaniment to a value. Within FSM, provenance is not merely supplementary documentation. It helps establish what the uncertainty means. A standard deviation obtained from repeated readings, an uncertainty arising from calibration, a bounded systematic allowance, and an uncertainty excluded by definition do not occupy the same position in the trajectory.

The complete object of interest is therefore not simply the pair $(\hat{X}, u_X)$, but a finite provenance-bearing structure

$$\mathcal{R} = (\hat{X}, u_X, F, M, H, A), \tag{5.2}$$

where F is the defining frame, M is the measurement model, H is the historical and calibration provenance, and A is the set of admissibility conditions under which the result is accepted. Equation (5.1) is a projection of $\mathcal{R}$, not its complete form.

This projection is often necessary. No paper can reproduce the entire history of metrology. The difficulty lies not in compression itself, but in forgetting that compression has occurred. A result becomes epistemically overextended when its residual uncertainty is read as though it included every uncertainty in the larger structure.

Chapter 6

Measurement as a Finite Symbolic Trajectory

6.1 The generonic boundary

Scientific instruments do not carry the measured world directly into a paper. Interactions occur at sensors, surfaces, junctions, cavities, crystals, fields, or other responsive structures. These interactions are converted into differences that an instrument can register. In contemporary systems the registered differences are commonly converted by analogue-to-digital processes into finite sequences of symbols.

The conversion marks a generonic boundary. On one side lies a physical interaction that has not yet become the reported symbol. On the other lies a finite symbolic stream that can be stored, filtered, corrected, reconstructed, compared, and interpreted. The boundary does not imply that the pre-symbolic side is formless. It indicates that the experimental result becomes available to the scientific account only through a finite registration.

Every subsequent stage operates upon this registered trajectory. Baseline subtraction, timing alignment, calibration, event reconstruction, dimensional conversion, statistical fitting, and graphical presentation are further symbolic operations. They can preserve, reveal, suppress, or reorganise patterns in the registration. They cannot recover an unlimited physical event independently of the distinctions captured at the boundary.

6.2 Layers are neither neutral nor arbitrary

It is common to respond to this layered structure in one of two ways. The first treats the instrument as a transparent window through which a pre-existing object is simply seen. The second treats every observation as a self-confirming product of the model. Both positions remove an important relation.

The instrument is not neutral because its geometry, material response, thresholds, sampling frequency, trigger logic, and reconstruction procedures determine which distinctions can enter the symbolic stream. Yet the result is not arbitrary because physical interactions can resist the expected trajectory. Instruments saturate, backgrounds differ from simulation, predicted signals fail to appear, and repeated observations can destabilise a model.

The evidential force of an experiment lies partly in this resistance. A system designed to detect a predicted pattern does not manufacture that pattern merely because it is capable of recognising it. The stronger question is whether alternative causes, detector artefacts, selection effects, and model failures have been given credible opportunities to produce or dissolve the registered structure.

6.3 Conditional significance

A reported significance such as five sigma is not an absolute measure of truth. It is a statement about the behaviour of a test statistic under a specified null model, after an analysis has defined event selection, background estimation, nuisance parameters, systematic effects, and a search domain. The number is conditional upon that structure.

This conditionality does not make the significance empty. It says that the data would be highly unusual under the stated background account. Experimental and theoretical systematic uncertainties may be included as nuisance parameters, while search procedures may correct for examining multiple possible locations. The resulting calculation can be technically rigorous within its declared scope.

The limitation is that no finite statistical model contains every possible failure of instrumentation, modelling, interpretation, or ontology. Sigma measures separation within a constructed hypothesis space. It does not measure the distance between a sentence and an unmediated world. As with measurement uncertainty, the terminal number is a compressed projection of a larger conditional structure.

Chapter 7

An Illustrative Case: The Higgs Result

7.1 What was registered

The Higgs-boson result provides a useful illustration because the inferred entity cannot be preserved and displayed as a macroscopic artefact. Proton collisions produce patterns of detector interactions. Electronic outputs are digitised, calibrated, and reconstructed as tracks, clusters, momenta, energies, and candidate decay products. Distributions are then compared with signal and background models.

It is therefore imprecise to say that experimenters saw a Higgs boson in the ordinary visual sense. They registered a repeatable family of event structures and inferred a short-lived common process whose measured properties were compatible with those expected of a Higgs boson. The semantic entity "Higgs boson" compresses this trajectory.

The opposite statement, that the result was only a bump manufactured by a desired model, is also inadequate. The 2012 searches extended over mass ranges rather than examining only a single preordained value. The look-elsewhere effect was evaluated, different decay channels contributed, and the ATLAS and CMS detectors recorded different collision samples at different interaction points using different detector technologies and analysis systems. Their independence was not absolute, because they shared the LHC, much theoretical infrastructure, and a broad experimental culture. It was nevertheless meaningful with respect to many detector-specific and analysis-specific failures.

7.2 The system attractor

The Standard Model supplies a powerful attractor within high-energy physics. It shapes the design of detectors, the classification of events, the construction of backgrounds, the allocation of attention, and the language in which deviations are described. Collaborations, institutions, funding systems, software, and publication practices deepen this basin. A result compatible with the established framework can travel more readily than a registration for which no stable category exists.

This does not establish that convergence upon the Higgs interpretation was solely institutional. The complete dynamical system includes the registered interactions themselves. Those interactions can resist desired outcomes. The absence of many predicted extensions of the Standard Model demonstrates that the LHC does not simply yield whatever its community wishes to find.

The appropriate question is therefore not whether an attractor exists. It plainly does. The question is how much of the convergence is imposed by the symbolic and institutional basin, how much is constrained by the registered interaction, and how effectively the experimental design permits the interaction to resist the expected trajectory. This question remains open and can be asked without dismissing either the technical achievement or the epistemic limitation of the result.

7.3 What the result means

Within the framework developed here, the most careful statement is that multiple finite registration trajectories, produced under specified collision and detector conditions, converged upon a model-compatible semantic entity with residual uncertainties evaluated inside a fixed metrological and statistical system. That statement is less vivid than "the Higgs boson was found", but it better preserves the route through which the entity became admissible.

The longer statement does not deny the result. It prevents the inferred entity from being separated from its provenance. The Higgs boson may remain the most effective and resistant compression of the registered patterns without becoming a directly encountered noun detached from the machinery, models, and symbolic relations that support it.

Chapter 8

Final Discussion: Objections, Replies, and the Remaining Difference

8.1 Objection: the constants are definitions, not uncertain inputs

The strongest metrological objection is that the argument assigns uncertainty to the wrong object. Once c, h, and other constants define the units, their numerical values in those units are exact by construction. Asking for their uncertainty inside the SI is therefore like asking for uncertainty in the number of centimetres assigned to a metre. The exact value does not assert a perfect physical measurement; it establishes the scale in which measurements are reported. Practical realisations retain uncertainty, and metrology already requires that uncertainty to be evaluated.

This objection is correct within the operational architecture of the SI. The present argument does not require definitional constants to carry uncertainty while they continue to perform that defining role. It instead observes what follows from giving them that role. A formerly measured relation is removed from the set of uncertain inputs and placed into the fixed frame. The resulting uncertainty is consequently conditional upon the frame. Metrology is entitled to make this choice for coordination, but the choice does not demonstrate increased precision in physical interaction.

The remaining difference is therefore one of description. The metrological account says that no uncertainty has been omitted because the defining constant is not a measurand. The present account says that an empirical trajectory has been converted into a definitional condition, and that the conversion must remain visible when the epistemic scope of the result is discussed. These statements can coexist, provided definitional exactness is not mistaken for physical exactness.

8.2 Objection: restoring uncertainty would double-count existing terms

A second objection is mathematical. Current measurement uncertainties already include calibration, realisation, environmental effects, instrument response, and other contributions. Adding the historical uncertainty of a defining constant on top of those budgets could count the same dependency twice. Constants and measurements are correlated, so a simple root-sum-of-squares enlargement would be invalid.

This objection is also correct as a warning against a naive calculation. A comparison between fixed and empirical architectures requires the full covariance and traceability network to be reconstructed. The present argument does not endorse attaching an arbitrary additional error bar to a finished result. It says that, under an alternative architecture in which a constant remains an empirical input, every independent uncertainty and covariance associated with it must participate in the propagated result. Whether the final increase is large, small, or partly compensated is a quantitative question. That it must be examined is an arithmetic requirement.

8.3 Objection: changing a unit cannot alter statistical evidence

A statistician may object that redefining the metre, while consistently transforming all quantities, cannot turn a five-sigma result into a different significance. Likelihood ratios and equivalent test statistics are dimensionless. A mere change of coordinates does not alter the evidential separation between a signal and a background model.

This objection identifies an important boundary. The rounded-light thought experiment demonstrates the conventionality and historical continuity of the unit; it does not by itself weaken an experimental significance. The deeper issue arises only when the alternative system changes which relations are treated as exact, which uncertainties are active, and how their covariance enters the measurement model. Even then, the effect upon a particular significance must be calculated rather than assumed. The monograph therefore rejects the claim that a unit redefinition alone would mechanically convert five sigma into some smaller number.

8.4 Objection: the necessary conditions are already documented

An experimentalist may reply that scientific papers do not hide their conditions. Methods sections, calibration papers, detector descriptions, standards, software repositories, uncertainty tables, and cited statistical procedures contain the required information. Repeating the full SI definition and traceability chain in every result would make communication impossible without adding useful information for the intended reader.

This objection explains why compression is necessary. No finite paper can reproduce the entire framework from first principles, and specialists are entitled to rely upon shared standards. The concern is not that every dependency must be printed after every number. It is that the terminal result can travel beyond the local literature while retaining an appearance of self-contained certainty. The supporting text exists distributively, but the boundary between included and excluded uncertainty is rarely stated in plain form.

A practical response would not require encyclopaedic repetition. Results could state that their uncertainty is residual within a named unit, calibration, model, and statistical frame, while machine-readable provenance records preserve the deeper dependency structure. The purpose would be to mark the compression, not to abolish it.

8.5 Objection: all observation is model-conditioned

A philosopher or physicist may object that no measurement is free of theory. The use of a model does not make an experiment circular, because models generate risky predictions that interactions may fail to satisfy. The Higgs searches, for example, were capable of returning no compatible excess, just as many searches for other proposed phenomena have done.

The present argument accepts this objection. Model-conditioning is not sufficient evidence of fabrication or circularity. A scientific system becomes epistemically valuable when its registrations can resist its expectations. The task is therefore to examine the geometry of that resistance: which deviations can be registered, which are filtered out, which are reclassified as systematic effects, and which can destabilise the governing model. Describing the Standard Model as an attractor is the beginning of an analysis, not a verdict upon every result obtained within it.

8.6 Objection: exact constants are a practical achievement

An engineer or metrologist may reasonably insist that fixed constants allow reproducible units to be realised in many laboratories without dependence upon a unique material object. The system supports trade, manufacturing, medicine, navigation, communication, and scientific comparison. Reintroducing uncertain defining values might degrade coherence without producing a useful alternative.

This objection is persuasive as a practical defence of the SI. Nothing in the argument requires the present system to be abandoned. A symbolic anchor can be extremely useful without being physically sacred. The proposal is not to make clocks stop working or to replace the metre with an unstable artefact. It is to keep the category of the achievement clear. The SI improves coordination and the potential precision of realisation; its fixed inscriptions do not make the encountered world exact.

8.7 Objection: the criticism weakens public confidence

It may finally be argued that emphasising conditionality encourages the mistaken belief that scientific measurements are arbitrary. Public communication often uses direct nouns and compact results because a full account would obscure rather than clarify. The language of discovery can be defensible when a model-supported entity has survived extensive tests.

The danger is real, but concealment is not the only alternative to misunderstanding. Confidence founded upon the belief that definitions are discoveries and models are direct images is fragile. A more durable account would explain why finite, conditional measurements can remain powerful. Scientific results do not need to be absolute in order to resist error, coordinate action, and constrain future explanations.

The practical difference between the two sides is therefore smaller than the philosophical language sometimes suggests. Both accept that definitions are exact, realisations are uncertain, and measurements depend upon models. The point of disagreement concerns what the short result is allowed to imply. The conventional account often treats the fixed framework as settled background. The present account treats that framework as part of the provenance of the claim and therefore as part of what must remain recoverable.

8.8 The remaining proposition

After the objections have been admitted, the central proposition remains intact. Fixing a defining constant stabilises a cross-related symbolic system. It removes that constant's uncertainty from formal propagation by changing its role from measured input to defining condition. It does not refine the physical interaction by declaration. The residual uncertainty of a later result can be rigorously evaluated within the fixed system, but it is conditional upon the fixed relations, realisation procedures, model boundaries, and admissibility decisions that support it.

The complexity omitted from the terminal result has not disappeared. It has been transferred into a distributed text and a shared institutional memory. The shorter the result becomes, the more work its external container may be performing. The proper response is neither to reject the result nor to worship the anchor, but to preserve the trajectory through which the result became possible.

Chapter 9

Conclusion

The history of the metre shows a movement from a privileged artefact, through an atomic spectral relation, to a unit set by an exact numerical value assigned to the speed of light in vacuum. This movement has increased reproducibility and strengthened international coordination. It has also made the act of setting less materially visible. The authority once concentrated in a bar is now distributed across inscriptions, definitions, instruments, institutions, and practical realisations.

For FSM, the decisive distinction is between the exactness of the anchor and the finitude of the trajectory. The numeral is exact as an adopted symbol sequence. The relation is exact within the definition. The realisation remains uncertain, and the measurement remains conditional upon its model and provenance. When these locations are collapsed, symbolic determinacy can be mistaken for physical precision.

The arithmetic of uncertainty makes the consequence plain. Quantities admitted as uncertain inputs contribute variance and covariance terms to propagated results. Quantities fixed by definition do not. This does not mean that metrologists have made an elementary computational mistake. It means that the uncertainty budget reports what remains after the frame has been set. Its validity is internal to that architecture, while its wider meaning depends upon remembering the architecture.

The central conclusion may therefore be held in two connected sentences. A fixed constant does not increase the precision of the physical encounter; it increases the determinacy of the symbolic frame in which that encounter is reported. A published uncertainty is not the uncertainty of an encounter in isolation; it is the residual uncertainty admitted after the measurement system has fixed its defining relations and compressed its supporting trajectory.

This conclusion does not close the inquiry. It gives the inquiry a clearer starting point. Future work may examine how defining anchors, calibration chains, analogue-to-digital boundaries, statistical models, institutional attractors, and resistant registrations interact in particular experiments. The purpose will not be to dismantle measurement, but to unfold what measurement has compressed.

Appendix A

A General Propagation Form

Let $\boldsymbol{q} = (q_1, \ldots, q_n)^\mathsf{T}$ be the vector of quantities admitted as uncertain inputs to a differentiable measurement model $y = f(\boldsymbol{q})$, and let $\boldsymbol{\Sigma}$ be their covariance matrix. The first-order propagated variance is

$$u_y^2 \approx \boldsymbol{J}\boldsymbol{\Sigma}\boldsymbol{J}^\mathsf{T}, \tag{A.1}$$

where

$$\boldsymbol{J} = \begin{bmatrix} \partial f/\partial q_1 & \cdots & \partial f/\partial q_n \end{bmatrix} \tag{A.2}$$

is the Jacobian row vector evaluated at the estimated input values. A defining constant does not appear as an uncertain component of $\boldsymbol{q}$, or equivalently occupies a component with zero variance and covariance inside the adopted system. Restoring it as an empirical quantity expands both $\boldsymbol{q}$ and $\boldsymbol{\Sigma}$. The resulting change in u_y depends upon sensitivity coefficients and covariance, not merely upon the size of the constant's historical standard uncertainty.

For nonlinear models, bounded distributions, discontinuous processing, or non-Gaussian inputs, first-order propagation may be inadequate. Monte Carlo propagation or a model-specific uncertainty evaluation may then be required. The conceptual distinction nevertheless remains: what is fixed is excluded from the active uncertainty distribution, while what is admitted as empirical must be propagated according to the measurement model.

Appendix B

A Provenance-Bearing Result Template

A compact scientific result may be expanded through the following prose template: within the named metrological system F, whose defining relations include specified exact numerical assignments, and using the stated practical realisations and calibration hierarchy H, the instrument and conversion system registered a finite data trajectory D. Under measurement model M, statistical model S, and admissibility conditions A, that trajectory was represented by the estimate $\hat{X}$ with residual uncertainty u_X. The uncertainty includes the enumerated random, systematic, calibration, and model contributions, excludes quantities fixed by definition and unmodelled alternatives outside the declared hypothesis space, and remains conditional upon the provenance supplied by (F, H, M, S, A).

This template is not proposed as a paragraph to be repeated verbatim in every publication. It identifies the structure that should remain recoverable even when the terminal report is compressed to $X = \hat{X} \pm u_X$. A practical implementation might combine a short human-readable qualification with a structured provenance record capable of preserving dependencies, versions, covariance, exclusions, and calibration ancestry.

Appendix C

Working Vocabulary

Anchor. A defining relation fixed within a symbolic system so that other quantities may be coordinated and compared against it. An anchor supplies determinacy to the frame without making its physical realisation exact.

Definitional exactness. Exactness arising from an adopted rule or identity rather than from an uncertainty-free empirical encounter.

Finite symbolic trajectory. The provenance-bearing path through which an interaction becomes a registration, a sequence of symbols, a calibrated quantity, a statistical result, and a communicated claim.

Generonic boundary. The operational boundary at which a physical interaction is converted into a finite registered distinction capable of entering a symbolic stream.

Residual uncertainty. The uncertainty remaining after the defining frame, admitted inputs, model boundaries, calibration structure, and relevant conventions have been established.

Symbolic determinacy. The stability and exactness of relations inside an adopted symbolic system. Symbolic determinacy must not be assumed to entail increased precision in physical interaction.

Symbolic drag. The supporting work performed by trajectories omitted from a compressed expression but supplied by shared language, institutional memory, convention, or reader expectation.

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