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Simplicity of Physical Laws: Informational-Theoretical Limits

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ABSTRACT To assess the required simplicity of physical law, it is proposed that the finite information quantity (FIQ)-based approach be used. The approach proved to be reliable and accurate when analyzing the results of measuring physical constants. The method is based on the idea that using a finite amount of information in the model enables one to calculate the smallest preliminary and unremovable comparative uncertainty (respectively, relative uncertainty) depending on a qualitative-quantitative set of variables. The method does not require the usually applied constraints to the input data and works well with numerous statistical assumptions: the normality of the probability distributions of the data, observations, absence of outliers, etc. This paper provides researchers with a tool for analyzing the required level of simplicity of the resulting formulas. The FIQ-based approach is applied to verify the required level of simplicity of different physical laws.

INDEX TERMS Amount of information, Boltzmann's law, finite information quantity, Hubble's law, international system of units, modeling, Newton's law, simplicity of physical law.

I. INTRODUCTION

Galaxies and the smallest particles of matter move, divide, unite, and interact with each other according to laws known only to themselves. These processes occur in a wide range of changes, differing in both temporal and spatial scales, and are characterized by significant complexity and internal dimension. Numerous observations and calculations have highlighted a harsh reality: as incredibly useful and important as the models are, they are imperfect tools, sensitive to the data used and the assumptions on which they are based. Due to this sensitivity, their intended purposes and uses are often misunderstood, which is why, perhaps, one should not overestimate the simplicity of formulas and physical laws as an indicator of their admissibility in physics. Indeed, at present, no criterion for the correlation of the simplicity of the representation of a physical phenomenon with the "true" content of the laws used has been identified.

At the same time, we adhere to the perspective that a physical law is "a theoretical principle derived from specific facts, applicable to a certain group or class of phenomena and expressed by the statement that a specific phenomenon always occurs under certain conditions" [1]. All physical laws are a consequence of empirical observations and are correct with the accuracy that is achieved in the experiment. Therefore, no law is absolute. However, the legality and applicability of the previously agreed frameworks of Archimedes' Law, Ohm's Law, and Stefan-Boltzmann's Law are indisputable. Einstein's formula and Heisenberg's inequality are considered the greatest achievements of the 20th century. Of course, these laws often reflect a degree of luck on behalf of the researchers involved. These laws [2] embody the idea of simplicity and depth of scientific thought. In this case, *the simplicity of the physical law is understood as the choice of the type of relationship*, which, on the one hand, must be established between *a small number of variables* considered, and, on the other hand, ensures *agreement with a set of known experimental results and allows conclusions and predictions about future data to be drawn*.

For several centuries of modern science (since the time of Galileo and Copernicus), scientists have used variables with dimensions that include length (L), mass (M), and time (T) to describe physical objects. It was only in the 19th century that variables with the dimensions of temperature (θ), amount of substance (F), electric current (I), and luminous intensity (J) were proposed in different formulas and theories. The above seven quantities are based on the latest version of the International System of Units (SI), approved in 2019 [3], [4].

Currently, using super powerful computers and well established mathematical methods, scientists and engineers are

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able to formulate and solve physical-mathematical models containing *tens and hundreds of variables* of SI and consider a greater number of potential interaction effects between these variables. Such an approach, however, is a considerable drain on time and financial resources. Moreover, with the current rapid development of science, it is becoming increasingly difficult to identify truly revolutionary discoveries (the idea of incommensurability of scientific theories [5], [6]): supporters of each paradigm see the world in their own way because of their scientific training and previous experience. They use contrasting conceptual frameworks and apply different ideas about scientific standards.

Intuitively or simply from practical wisdom, one might assume that increasing the complexity of the model (more variables considered) increases its accuracy. However, an increase in the value of the total uncertainty of the studied objective function actually reduces the accuracy. Therefore, the supposed important role of simplicity both in assessing the admissibility of a particular formula or law, and the theoretical justification for choosing the most preferable theory (model) of the process under study, raises the question of the possibility of the existence of an optimal number of variables considered for each specific case. We can also assume that there is an optimal trade-off between simplicity (the number of the chosen variables) and the achieved model uncertainty. One of the important consequences of this obvious connection is that the interpretation of experimental data using models containing the optimal number of variables can increase the efficiency of experiments; thus, scientists could conduct expensive experiments fewer times and still form relatively accurate predictions about the behavior of the system under study.

To date, in fact, without exception, all theories and methods of validation and verification of the reliability of the model are focused on the analysis of the uncertainties inherent, from the point of view of the researcher, to the selected variables, due to the chosen structure of the model, the algorithm used, the design of the test bench, and the revealed scatter of experimental data. The analysis of the initial fatal uncertainties of the model caused by the qualitative and quantitative set of variables and the structure of the system of units used to build the model is absent in the modern literature. Therefore, the author considers it his duty, first, to present the starting points and features of the finite information quantity based informational method [7], in accordance with which *the uncertainty of the perception of the object (blurring of the image) is inherent in the mind of the observer*. This philosophical position has not yet received due attention in the scientific community, which is why this uncertainty stands in stark contrast to the widely known and discussed uncertainties resulting from the following [8]–[10]: (1) limited measurement accuracy; (2) the impossibility of observing the object under study; (3) the measurement process introducing perturbations into the system under study; and (4) the interpretation of quantum mechanics causing uncertainty due to the actual structure of the world around us. In fact, this is a new interpretation, which the author includes in the above list and considers to be correct.

II. INFORMATION-BASED APPROACH BACKGROUND

There are five axioms on which the information-based approach is grounded [7]:

1. The observer chooses variables for a model from the specific system of units, such as SI, CGS (centimeter-gram-second), the British-American system of units, or the Planck system of units.

2. The selected base quantities from the system of units used determine the individuality and class of phenomena (CoP) of the model. CoP is a set of physical phenomena and processes described by a finite number of base quantities and derived variables that characterize certain features of the material object with qualitative and quantitative aspects [11]. For example, when modeling an electric arc, variables with a dimension including the base quantities of the SI length L, mass M, time T, current I, and thermodynamic temperature Θ are typically used; that is, the model belongs to the class of $\mathrm{CoP_{SI}} \equiv LMT\Theta I$ phenomena. Each observer determines some special properties of the macroscopic description, selects a qualitative and quantitative set of variables that is not determined a priori, reproduces the observed phenomenon and seeks to eliminate distortions and illusions inherent in his subjective point of view.

3. Variables (finite information quantity—FIQ [12]) include the scalar parameter time, universal constant, one-dimensional component of the position or momentum, and dimensionless number, which acquire values from the set of real numbers, R [12].

4. The model contains a finite amount of information because the number of variables in a model is limited and each variable q (FIQ) contains a bounded portion of information [12], [13].

5. *Any variable is chosen by a conscious observer on an equiprobable basis*. If a system of units is chosen, it is sufficient to estimate the probability of accounting for the variable in the model, provided that no information is known about the phenomenon under study. Accordingly, any variable in the model can appear with the same frequency.

Most readers will possibly agree that the first three axioms are typical of the regular practice of scientists. Considering the modern interest in applications of information theory in different human activities, some researchers will recognize the fourth axiom. The fifth axiom, though, seems controversial. In support of this statement, one can recall the consideration of the electron as a particle or wave. Researchers, based on their intuition, knowledge, and experience, have proposed completely different models. Both approaches are eligible for implementation and both are confirmed by experiments.

Considering the above axioms, it is possible to represent the model as an information channel between the phenomenon under study (P) and the observer (O) [7]. In this case, the uniqueness of this situation lies in the fact that P is introduced by a discrete set of equiprobable random variables, $X \in \{x_1, \ldots, x_j\}$, which are chosen by the will of O. In fact, X is any system of units such as SI, which, in turn, are created by the conscious minds of scientists. It feels highly intuitive that the number of elements of X (criteria, variables) should cover all possible connections that exist in the universe. However, it remains unclear whether a new base quantity will be discovered in the future. Such reasoning, if correct, leads to the idea of *an initially not infinitely accurate description of P, conditioned by human consciousness*.

A step-by-step theoretical analysis of the modelling process, carried out using the concepts and mathematical apparatus of information theory [7], proved the existence of a measurement ultimate limit (the model precedes the construction of any experiment) of an FIQ accuracy

$$\Delta = S \cdot [(z' - \beta')/\mu + (z'' - \beta'')/(z' - \beta')] \tag{1}$$

where

- Δ is the *a priori* model absolute uncertainty (systematic effect [14]) caused by the choice of the CoP and the number of recorded FIQs, S is the interval of observation of the main researched FIQ chosen by the observer, and $\varepsilon = \Delta/S$ is the comparative uncertainty of the model. *ε is a universal indicator to quantitatively assess the proximity of a model to the object under study*. In addition, ε cannot be verified by statistical methods using such tools as consistency, asymptotic normality, weighted estimates, or coefficients;
- z' is the number of FIQs in the selected CoP, β' is the number of base quantities in the selected CoP, z'' is the number of FIQs recorded in a model, and β'' is the number of independent quantities recorded in a model;
- *μ is the number of dimensionless FIQs that can be constructed based on the seven base SI quantities*, $\mu = 38{,}265$ [15]. All the following reasoning and the resulting formulas are applicable to models based on the use of different systems of units containing different numbers of base quantities and derived variables [16].

Hitherto, researchers have not considered the value ε, even though it is vital in information theory [17]. Equation (1)—"*ε–equation*"—applies to models that use both dimensional and non-dimensional FIQs [18].

Summarizing the above and considering the *ε-equation* (1), we can assume that the most accurate scientific theories (the theory of relativity and quantum mechanics) can be based on subjective facts (the philosophical view of the researcher) at the most fundamental level, which raises deep epistemological questions about the fundamental nature of reality. Therefore, the purpose of analyzing the following examples is to identify minute deviations from the generally accepted principles of modeling physical phenomena, which may provide the first indications of new physics.

III. EXAMPLES OF SIMPLE LAWS

Table 1 shows several optimal ε_{opt} values inherent in different CoPs and the recommended number of FIQs corresponding to each CoP [7]. These data are necessary to study the physical laws analysed below, which are well known and widely used, from the standpoint of the FIQ-based approach.

TABLE 1. Comparative uncertainties and optimal number of dimensionless criteria.

$\mathrm{CoP_{SI}}$	*LMT*	*LMTI*	*LMTΘ*	*LMTθF*
Comparative uncertainty, ε_{opt}	0.0048	0.0245	0.0442	0.1331
Number of FIQs inherent in $\mathrm{CoP_{SI}}$, $\gamma_{CoP} = z'-\beta'$	91	468	846	2,546
Optimal number of FIQs inherent in a model, $\gamma_{mod} = z''-\beta''$	$\approx 0.2 < 1$	≈ 6	≈ 19	≈ 169

According to the FIQ-based method, the results of published articles can be analyzed in two ways:

- comparison of the comparative uncertainty ε_{mod} achieved in the model (experiment) with the theoretically substantiated value ε_{opt} (Table 1). The similarity of these two uncertainties proves the applicability of the proposed model to describe the process under study. At the same time, a significant difference between these uncertainties indicates that the proposed model is unreliable;
- comparison of the achieved experimental relative uncertainty r_{exp} with the theoretically substantiated value r_{SI}. The procedure for reformatting comparative uncertainty into relative uncertainty is theoretically substantiated and explained in detail in [15]. The calculation of r_{exp}/r_{SI} is necessary for the following reasons. To calculate the comparative uncertainty using formula (1), it is necessary to know the number of variables in the model. However, it should be noted that specifying the exact number of variables considered is not standard scientific practice and is ignored in most studies. Although it is not difficult, it is not practiced. Therefore, for researchers to better understand the significance of the proposed FIQ-based method and the possibility of using ε_{opt} to test the preferred method for measuring a physical variable, it is necessary to reformulate the concept of "comparative uncertainty" in terms similar to "relative uncertainty", which is understandable to all scientists and is widely used in science and technology. The proximity of these two uncertainties ($r_{exp}/r_{SI} \approx 1$) confirms the plausibility of the proposed model for describing the process under study.

There is no guarantee that this limit (ε_{opt}) will ever be reached, regardless of the achievements of scientists and engineers. The following analysis of the results of the study will identify obstacles that need to be circumvented or overcome before the various goals can be achieved.

A. HUBBLE'S LAW OF COSMIC EXPANSION

The discovery of the linear relationship between redshift and distance, coupled with a supposed *linear relationship*

TABLE 2. **Data for the hubble constant.**

Method	CoP	Comparative uncertainty according to CoP$_{SI}$, ε_{SI}	Relative uncertainty according to CoP$_{SI}$, r_{CoP}	Achieved experimental lowest relative uncertainty, r_{exp}	Ratio of r_{exp}/r_{CoP}
BDL	*LMT*	0.0048	0.00023	0.001	43
CMB	*LMTθ*	0.0442	0.0029	0.007	2.4
BAO	*LMT*	0.0048	0.00018	0.018	100

between recessional velocity and redshift, yields a straightforward mathematical expression for Hubble's law as follows:

$$v = H_0 \cdot \mathrm{D} \tag{2}$$

where v is the recessional velocity (typically expressed in km/s), H_0 is Hubble's constant (the subscript '0' indicates the value of the Hubble constant today), and D is the proper distance (which can change over time, unlike the commoving distance, which is constant) from the galaxy to the observer, measured in mega parsecs (Mpc), in the 3-space defined by given cosmological time.

Hubble's law is considered a fundamental relationship between recessional velocity and distance. However, the relationship between recessional velocity and redshift depends on the cosmological model adopted and is not established except for small redshifts.

To measure H_0, the most widely used methods are the following: Brightness of Distance Ladder (BDL) (which belongs to COP$_{SI}$ $\equiv$ *LMT),* Cosmic Microwave Background (CMB) (which belongs to COP$_{SI}$ $\equiv$ *LMTθ*), and Baryonic Acoustic Oscillations (BAO) (which belongs to CoP$_{SI}$ $\equiv$ *LMT).* In [18], a step-by-step procedure was introduced that calculates the relative uncertainty, $\mathrm{r_{CoP}}$, corresponding to ε_{opt} and to compare this relative uncertainty with the minimum relative uncertainty, $\mathrm{r_{exp}}$, achieved when measuring the Hubble constant by the different research centers using the three mentioned methods. The results of the comparison are summarized in Table 2.

A comparison of the three discussed methods for measuring the Hubble constant, presented in Table 2, indicates the tension in a situation where the true value of H_0 remains unknown. From the data of Table 2, it is apparent that there is a wide range of values between the relative uncertainty calculated in accordance with CoP$_{SI}$, $\mathrm{r_{CoP}}$ and the experimentally achieved relative uncertainty, $\mathrm{r_{exp}}$. The $\mathrm{r_{exp}/r_{CoP}}$ ratio reaches 43 and 100 for BDL and BAO. This situation contradicts the trend observed when measuring the Boltzmann constant and the Planck constant [19], where the ratio $\mathrm{r_{exp}/r_{CoP}}$ is only 0.9–3.0. Only when H_0 is measured using the CMB is this ratio 2.4, which indicates the acceptability and advisability of using the CMB to calculate the true value of the Hubble constant.

Framed within the FIQ-based approach, the explanation of this situation is as follows. Inherent to the process of developing a method for measuring the physical constant, there is an unavoidable uncertainty, called comparative uncertainty, due to the number of variables and a qualitative set of base quantities in the model. The value of comparative uncertainty is not constant and varies with the number of base quantities recorded. Moreover, the implementation of CoP$_{SI}$ $\equiv$ LMT when measuring H_0 is not recommended due to the fact that the achievement of theoretical comparative and relative uncertainties in practice using this method cannot be realized [19]. The fact is that the experimental numerical value of the Hubble constant is determined by the model and the measurement process that implements it, which allows one to establish the relationship between the recorded variables and draw conclusions from the measurement results. In turn, the magnitude of the relative uncertainty is largely determined by the method of measuring H_0 and the experience gained during the experiment. In fact, the experiment is carried out using measuring instruments, depending on the method, which determines the specific relationship between the recorded variables and the Hubble constant, implying the need to introduce the concept of relative uncertainty associated with a set of experimental data for each specific measurement method, which is determined by the class of the phenomenon, selected on the basis of the subjective assessment of the research group. Therefore, the conviction of scientists to consider all possible sources of uncertainty is not a guarantee that the true value of H_0 will be achieved. The informational approach makes it possible to determine whether the subjectivity of the estimation of the magnitude of the uncertainties in calculating the Hubble constant is acceptable.

The use of the information method in combination with a clear analysis of the experimental results achieved, along with a thorough calculation of the comparative and relative uncertainties, suggests an internal reason for the high degree of uncertainty in measuring the Hubble constant associated with CoP and a small number of considered variables compared to the recommended number.

B. STEFAN-BOLTZMANN LAW

A law formulated by the Austrian physicist Josef Stefan (in 1879) and the Austrian physicist Ludwig Boltzmann (in 1884) states that the total radiant heat power emitted by a surface is proportional to the fourth power of its absolute temperature:

$$\mathrm{W} = \sigma \cdot \mathrm{T}^4 \tag{3}$$

$$\sigma = 2 \cdot \pi^5 \cdot k_b^4 / (15 \cdot c^2 \cdot h^3) \tag{4}$$

where W is the radiant thermal energy emitted from a unit area in one second, T is the absolute temperature (in kelvin), σ is a proportionality constant called the Stefan-Boltzmann constant, $\sigma = 5.670367(13) \cdot 10^{-8}$ W/(m^2·K^4) [20], k_b is the Boltzmann constant, $k_b = 1.3806 \cdot 10^{-23}$ m^2·kg·s^{-2}·K^{-1} [21], c is the speed of light, and $c = 2.99792458 \cdot 10^8$ m·s^{-1} [22]. The law applies only to black bodies, theoretical surfaces that absorb all incident thermal radiation.

To confirm the measured value of the physical variable W, the relative uncertainty $\mathrm{r_M}$ is applied as the indicator of accuracy [23], [24]:

$$\begin{aligned} \mathrm{r_W} &= \Delta \mathrm{W}/\mathrm{W} \\ &= 8.07 \cdot 10^{-9}/[2 \cdot \pi^5 \cdot k_b^4 \cdot \mathrm{T}^4/(15 \cdot c^2 \cdot h^3)] \\ &= 1.76 \cdot 10^{-11} \qquad (5) \\ \mathrm{W} &= 2 \cdot \pi^5 \cdot k_b^4 \cdot \mathrm{T}^4/(15 \cdot c^2 \cdot h^3) = 459 \qquad (6) \\ \Delta \mathrm{W} &= \mathrm{A} \cdot (\left|4 \cdot k_b^3 \cdot \mathrm{T}^4 \Delta k_\mathrm{b}/h^3\right| + \left|k_b^4 \cdot 4 \cdot \mathrm{T}^3 \Delta \mathrm{T}/h^3\right| \\ &\quad + \left|k_b^4 \cdot \mathrm{T}^4 \cdot (-3) \cdot \Delta h/h^4\right|), \qquad (7) \\ \mathrm{A} &= 2 \cdot \pi^5/(15 \cdot c^2) = 4.534 \cdot 10^{-16} \qquad (8) \end{aligned}$$

where W and its absolute uncertainty Δ are in units of kg·s^{-3}·K^{-4}, A is calculated in units of c^2·m^{-2}; the relative $\mathrm{r_{kb}}$ and the absolute Δ_{kb} uncertainties of k_b, are 1.06·10^{-6} and 1.5·10^{-29} m^2·kg·s^{-2}·K^{-1}, respectively [21]. We can assume that the value of the temperature T equals 300 K and its measurement uncertainty Δ equals 1.0·10^{-3} K (achieving an uncertainty of 3·10^{-3} K at 300 K requires a measurement time of at least 27 h [25]). The value of h and its relative r_h and the absolute Δ_h uncertainties are 6.6261·10^{-34} kg·m^2·s^{-1}, 13·10^{-9}, and 8.6139·10^{-42} kg·m^2·s^{-1}, respectively [26].

According to Equation (5), $\mathrm{r_W}$ is a very small value and it can indicate the practical universality of the application of the Stefan-Boltzmann law. However, $\mathrm{r_W}$ may only serve to reflect subjective judgment [27]. In addition, $\mathrm{r_W}$ does not imply the need to indicate the measurement results and at the same time consider the measure of confidence in it in the form of an interval within which most of the distribution of the values of the measured variable lies.

Let us calculate the theoretically achieved comparative uncertainty $\varepsilon_{\mathrm{mod}}$. Dimensions of variables used in (3) and (4) belong to $\mathrm{CoP_{SI}} \equiv LMT\theta$. According to the data of Table 1, the number of FIQs inherent in $\mathrm{CoP_{SI}} \equiv LMT\theta$, $\gamma_{\boldsymbol{LMT\theta}} = z'\text{-}\beta' = 846$. Considering two independent variables ($\beta'' = 2$), in accordance with the π-theorem [28], the number of dimensionless criteria in a model, γ_{mod}, equals $\gamma_{\mathrm{mod}} = z''\text{-}\beta'' = 5\text{-}2 = 3$. The achieved comparative uncertainty of a model $\varepsilon_{\mathrm{mod}}$, can be calculated as:

$$\varepsilon_{\mathrm{mod}} = [846/38,265 + 3/846] = 0.0256 \qquad (9)$$

Upon comparing $\varepsilon_{\mathrm{mod}}$ (9) and $\varepsilon_{\mathrm{opt}} = 0.0442$ (Table 1), $\varepsilon_{\mathrm{mod}}/\varepsilon_{\mathrm{opt}} \approx 0.6$ ($\varepsilon_{\mathrm{mod}}$ is far from $\varepsilon_{\mathrm{opt}}$) is obtained due to the difference in the number of criteria considered in the model $\gamma_{\mathrm{mod}} = 3$ and the recommended $\gamma_{\mathrm{opt}} = 19$ [29]. Possible reasons for such a large difference in the magnitude of comparative uncertainties are as follows: Boltzmann did not consider gravity in his thermodynamics [30]; the boundary conditions and assumptions that have been applied to provide a workable solution to similar problems must be considered; the Stefan-Boltzmann equation did not consider emissivity (the ratio of the actual power to the black body power integrated over the entire Planck flux density distribution at a certain temperature), since the black body is a theoretical consideration that does not necessarily apply. In practice, for some materials, emissivity decreases with temperature, while for others emissivity increases with temperature. Thus, *although beautiful and harmonious theories are valued in the exact sciences, the pursuit of simplicity in proof does not always lead to the comprehension of the truth.*

The information approach poses the problem of model uncertainty to researchers not from the position of "which model is the best." The FIQ-method indicates which set of models (class of phenomena and the number of variables considered) is "plausible" and deserves consideration. The purpose of the FIQ-method is to reduce the author's discretion in choosing the preferred model, expanding the range of models and results that are considered by the researcher. The method includes an assessment of all possible combinations of variables in the model, considering the selected class of phenomena, presupposing the calculation of the theoretically optimal comparative uncertainty and its comparison with the one achieved during the experiment (natural or computer). As a result, a scientist or engineer (model developer) can present their preferred model in the context of achieving closeness of the chosen comparative (and accordingly relative) uncertainty with the experimental one.

C. NEWTON'S LAW OF GRAVITATION

Although the gravitational constant G (6,67408 ± 0,00031) ·10^{-11} m^3·kg^{-1}·s^{-2} [31]) was the first physical constant proposed in the history of science, the accuracy of its measurement remains relatively low (high relative uncertainty—4.7·10^{-5}) compared to other physical constants. As readers know, for the first time in the history of modern science (in 2019), the base SI units began to be determined through fixed values of the fundamental physical constants, and for some of them (the speed of light in vacuum c, 299,792,458 m/s; Planck's constant h, 6.62607015·10^{-34} kg·m^2·s^{-1}; Boltzmann's constant k, 1.380649·10^{-23} J/K; Avogadro's constant $\mathrm{N_A}$, 6.02214076·10^{23} mol^{-1}) fixed values are set without indicating the measured uncertainty. At the same time, Newton's law of gravity can be seen as an argument for the simplest explanation of empirical observation. Newton's law of gravity can be expressed as:

$$F = G \cdot (M \cdot m/r^2) \qquad (10)$$

where F is the attractive force between the two masses M and m separated by the distance r.

The key to measuring G is the estimation of uncertainty. Therefore, to identify the best value of the gravitational constant, the comparative study of uncertainties is the central task of the CODATA task force on fundamental constants [32]. The importance of G precision lies in how well gravity is understood: conflicting results may indicate some new physics, or they may demonstrate that we do not understand metrology for measuring weak forces. There is a belief that G is not truly universal and may depend, for example, on the density of matter on an astrophysical scale and the temperature of the medium, or the inverse square law and the universality of free fall are incorrect or the light speed is not constant [33], [34].

We will focus our attention not on speculative theories, however, but on the results achieved by advanced research centers. There are several methods of *G* measurement considered in the latest CODATA-2014 adjustment: time-of-swing, angular acceleration feedback, free deflection, electrostatic compensation, Fabry-Perot cavity, beam balance, and atom interferometry [35]. Furthermore, only those *methods* (mechanical and electromechanical) and the results obtained using them (with data on the relative measurement uncertainty and standard uncertainty), which are presented in the scientific literature and *are consistent with CODATA, will be considered.* Many members of IEEE will hopefully be interested in the following fact. When measuring the gravitational constant, scientists used innovative electromechanical methods ($\mathrm{CoP_{SI}} \equiv LMTI$), which, on the one hand, are unique electrical measuring equipment. On the other hand, these methods make it possible to eliminate (consider) uncertainties in the measurement process, which until now could not be identified and calculated. These methods and their results can be used in various fields of electrical engineering.

Summarized data of measuring *G* published by different research centers during 2000–2018 were analyzed in [36] and are introduced in short form in Table 3.

Looking closer at the data entered, we can make the following comments. In Part A of Table 3, when moving from a model (*LMT*) to a $\mathrm{CoP_{SI}}$ with numerous dimensionless criteria (*LMTI*), the comparative uncertainty increases. This change is due to the potential interaction effects between the increased number of variables, which may or may not be accounted for by the researcher. At the same time, the $\varepsilon_{\mathrm{exp}}/\varepsilon_{\mathrm{SI}}$ ratio decreases ($\varepsilon_{\mathrm{exp}}$ approaches $\varepsilon_{\mathrm{SI}}$), indicating an increase in the likelihood of the model when measuring *G* by means of electromechanical methods.

Following data introduced in Part B of Table 3, the tendency obviously remains similar to the previous case: the ratio $\mathrm{r_{exp}}/\mathrm{r_{SI}}$ decreases when measuring *G* using electromechanical methods compared to mechanistic methods: 1.9 instead of 12.7.

Generalizing the presented results, the author takes the liberty of expressing a nontrivial conclusion: Newton's law ($\mathrm{CoP_{SI}} \equiv LMT$), in its perfect, clear, and simple form, does not consider potential additional effects that are still hidden for scientists associated with other base quantities, such as thermodynamic temperature θ, or current I.

A possible reasonable explanation for the discrepancy of *G* measurements is that there is still some unknown physics including possible sinusoidal changes of G and the sun's dragging effect [37]–[41]. However, it is difficult to confirm or refute such ideas due to the low accuracy of the measurement of *G*. To resolve this problem, additional studies with new approaches and greater accuracy will be required in the future. Indeed, a coordinated international effort is clearly required to carry out the additional number of experiments with models inherent in class of phenomena with an extended list of base quantities, each of which will be tracked in great detail [42].

TABLE 3. Summarized data.

No	Variable/Methods	Mechanical ($\mathrm{CoP_{SI}} \equiv$ *LMT*)	Electro-mechanical ($\mathrm{CoP_{SI}} \equiv$ *LMTI*)
A	Comparative uncertainty inherent in $\mathrm{CoP_{SI}}$, $\varepsilon_{\mathrm{SI}}$	0.0048	0.0245
	Achieved experimental lowest comparative uncertainty, $\varepsilon_{\mathrm{exp}}$	0.4819	0.1930
	$\varepsilon_{\mathrm{exp}}/\varepsilon_{\mathrm{SI}}$	100	7.9
B	Relative uncertainty inherent in $\mathrm{CoP_{SI}}$, $\mathrm{r_{SI}}$	$1.5\cdot10^{-6}$	$6.3\cdot10^{-6}$
	Achieved experimental lowest relative uncertainty, $\mathrm{r_{exp}}$	$1.9\cdot10^{-5}$ [34]	$1.2\cdot10^{-5}$ [35]
	$\mathrm{r_{exp}}/\mathrm{r_{SI}}$	12.7	1.9

IV. DISCUSSION

In this time of uncertainty, it is of great importance to understand the origins of the human "fuzzy" perception of the world around us.

It is common for different scientific experiments to confirm multiple contradictory theories as, until now, no tool has been proposed or implemented that could help to choose the optimal theory out of a given set of possibilities. To be more specific, the author takes the liberty of declaring that the prospect of simple, beautiful, and elegant fundamental laws is "shelved", that is, it cannot be realized. It transpires that in both classical physics and quantum physic, we have limited, imprecise knowledge about the state of the system: there is uncertainty. The exact nature of this uncertainty is revealed through the FIQ-based informational method and lies in the limited accuracy of modeling the object under study: as already noted, any measurement is preceded by the modeling process and the formulation of a specific model, what Heisenberg originally called the metaphysical or epistemological principle. At the same time, the stated axioms of the information method can clearly be challenged. In this article, we would like to emphasize that the informational approach is not a radical departure from measurement theory, which always remains valid, but rather a complementary tool that must be used separately at the later stage of the model implementation. In fact, this is a new interpretation of the interaction of an observer and a physical phenomenon, which can be added to the list of methods for analyzing the likelihood of a model; and we consider it correct.

One of the key features of the information approach is the application of information theory with the concept of complexity to the International System of Units, SI, which does not exist in nature and is the result of the intellectual activity of scientists. The concept of complexity is used to calculate the amount of information contained in a measurement model of a physical variable. The SI with seven base quantities then permits the classification of the classes of phenomena inherent in a particular measurement method (model). The proposed information approach can be considered a universal tool for selecting the optimal model, primarily because it considers both the physical nature of the experiment (a qualitative set of base quantities) and information content due to the specific number of variables considered in the model. In addition, the proposed measure of the closeness of the model to the real object (comparative uncertainty) can be used for any dataset without requiring consistent results.

In this paper, we consider models related to several CoPs: $\text{CoP}_{\text{SI}} \equiv LMT$, $\text{CoP}_{\text{SI}} \equiv LM\theta$, and$\text{CoP}_{\text{SI}} \equiv LMTI$. These models include five base quantities of SI: length (L), mass (M), time (T), electric current (I), and thermodynamic temperature (θ). However, readers may wonder whether the proposed FIQ-based method can be used as a universal tool for studying models of more complex phenomena and processes containing a larger number of base quantities and derived variables. The answer is yes. In [7] this method was used to analyze the data when measuring the Planck constant using the AGT method (acoustic gas thermometer, $\text{CoP}_{\text{SI}} \equiv LMT\theta F$), XRCD method (X-ray crystal density, $\text{CoP}_{\text{SI}} \equiv LMT\theta F$), as well as to calculate the comparative (respectively, relative) uncertainty when measuring the Boltzmann constant with DCGT method (dielectric constant gas thermometer, $\text{CoP}_{\text{SI}} \equiv LMT\theta I$), JNT method (Johnson noise thermometer, $\text{CoP}_{\text{SI}} \equiv LMT\theta I$) and DBT method (Doppler broadening thermometer, $\text{CoP}_{\text{SI}} \equiv LMT\theta F$). The use of complex CoPs should be recognized to require a group of scientists involved in modelling a particular process to have deeper knowledge in various fields of science and technology, significant financial costs and time to develop a model with a large number of variables.

The information approach thus enables the scientific and engineering community to answer several questions faced by researchers in the 21st century: the magnitude of the uncertainty of a model, law, or theory; limited transparency of choice of modeling; and the number of scientific publications is growing, the results of which cannot be reproduced or easily refuted [29], [43], [44]. Authors with different philosophical convictions, methodological approaches, or intuitions should have access to a tool (criterion) that makes it possible to choose, with a high probability, the optimal interpretation of the phenomenon under study.

The presentation of the information approach provides an indication to the scientific community that the simplicity of physical laws, in fact, hides the extraordinary complexity of physical phenomena, which can only be described with finite accuracy. It follows that with a small number of base quantities used in the model (this is typical for most open physical laws), the FIQ-based method acts as a criterion for evaluating which model is best suited to a particular physical system under study. An information-theoretical measure allows one to identify different types of search for patterns. Therefore, such a measure can be applied to any model after a conscientious observer indicates the types of patterns that, in his opinion, should be considered. An additional benefit of this method is to help researchers understand what is important in model specification to achieve high accuracy of the observed object.

For any physical process, it must be recognized that plausible models can be presented that differ from those already well studied and generally accepted. The FIQ-based approach provides researchers with reasonable alternatives for any physical phenomenon, considering the selected class of phenomena and the number of variables. In addition, the use of comparative uncertainty allows one to determine how the experimental results might change if a different model is used.

Ignoring the comparative uncertainty of the model makes it impossible for researchers to objectively present the results of an experimental or theoretical study with a large amount of data that do not meet the criterion of consistency. At the same time, the FIQ-based method, in its essence, can become a routine tool for quantifying the author's influence, from the standpoint of his volitional choice of the class of phenomena and the number of variables in the model. The informational approach allows researchers to show the qualitative and quantitative range of assessments inherent in different plausible models. In an era when the credibility of science is in doubt [29], the application of the FIQ-based approach and accounting for the comparative uncertainty of the model is of great practical importance to making scientific research convincing.

In the measurement, which is always preceded by the formulation of the model by scientists with different philosophical positions, researchers can get different results that will be equally correct [45]. Within the framework of the informational approach, this leads physicists to very interesting conclusions. Conducting an experiment with more complex classes of phenomena by observers will necessarily lead to a new, deeper understanding of the specific phenomenon under study. At the same time, the veracity of the proposed one or another picture of the world (the formulated model) can be established by choosing the most "attractive" class of phenomena for the researcher and choosing the number of considered variables close to optimal. In doing so, readers should accept the possibility of irreconcilable disagreements between various observers as to which class of phenomena is most preferable.

Thus, the ε-equation has theoretical and practical significance for assessing the relative "simplicity" of theories, both in biology and in particle physics or astrophysics. The implementation of the ε-equation confirms the existence of a single concept of simplicity, allowing the formulation of a single choice between competing theories.

V. CONCLUSION

The study of the surrounding Nature, through modeling, should be difficult, but not too difficult. This balance between complexity and simplicity is present in all sciences, both in the micro- and in the macro world. One of the most promising areas of research is the analysis of models through the presented informational approach, because the search for the optimal structure of the model is likely to depend on the ''noise'' introduced by the researcher. This phenomenon manifests itself and affects any intellectual communication (the model is an information channel [7]) everywhere.

The author considers it his duty to note that the main postulates of the proposed informational approach were outlined in previous articles [15], [16], [18]. These articles detail the ideas and evidence for the possibility of: a. application of the mathematical apparatus of information theory to SI for calculating the minimum possible uncertainty of a model of a physical phenomenon; b. calculation of the maximum number of dimensionless FIQs that can be built from seven basic SI values, $\mu = 38{,}265$; c. proof of the applicability of the obtained formulas to models based on the use of different systems of units containing a different number of base quantities and derived variables; d. applying the ''ε-equation'' to models using both dimensional and non-dimensional FIQs. From the author's point of view, the use of previously published articles is a necessary condition for the reproducibility of scientific results. In this article, the reader is given examples of the expediency and practical feasibility of analyzing physical laws in science and technology from the standpoint of calculating comparative (respectively, relative) uncertainties. Therefore, the presented examples make it possible to reveal the smallest deviations from the well-known rules for modeling physical processes, which can give the first signs of a new physics.

In fact, as a result of proving the connection between the uncertainty of the model and the qualitative and quantitative set of variables taken into account, the principles of measurement theory and metrology have not changed; their foundations remain unshakable. The ε-equation only led to an overestimation of the role of knowledge, experience, intuition, creative insights of the researcher in the perception of the observed phenomenon, and, possibly, the limitations of our brain.

One of the consequences of the ε-equation can be, specifically, the conclusion that it is fundamentally impossible to achieve unlimited measurement accuracy based on the use of super powerful computers, unique measuring stands, and advanced mathematical methods, even if the appearance of quantum computers will lead to a tremendous breakthrough in the field of computational technology, because any computer can implement a formal-logical algorithm set by the developer, but the ''noncomputational'' abilities of the intellect are not yet available for it.

The presented results raise the question of a possible paradox, in which the information presented in the model depends on how much the observer knows about the phenomenon under study. The use of the concept ''amount of information in a model'' lays the foundation for the theoretical and experimental demonstration of the existing limit of measurements and, possibly, the limitations of the abilities of researchers in cognition of nature [46], assuming that the accuracy of the laws of physics and the consciousness of the observer should be considered complementary. So the eternal, Buddhist neutrality of the observer is impossible.

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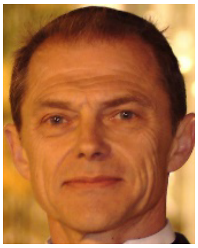

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