

A Simple Proof That Finite Mathematics Is More Fundamental Than Classical One

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Abstract

Classical mathematics (involving such notions as infinitely small/large and continuity) is usually treated as fundamental while finite mathematics is treated as inferior which is used only in special applications. In our previous publications we argue that the situation is the opposite: classical mathematics is only a special degenerate case of finite one in the formal limit when the characteristic of the ring or field in finite mathematics goes to infinity. In the present paper we give a simple and rigorous proof of this fundamental fact. In general, introducing infinity automatically implies transition to a degenerate theory because in this case all operations modulo a number are lost. So, *even from the pure mathematical point of view*, the the very notion of infinity cannot be fundamental, and theories involving infinities can be only approximations to more general theories. We also prove that standard quantum theory based on classical mathematics is a special degenerate case of quantum theory based on finite mathematics. Motivation and implications are discussed.

Keywords: classical mathematics, finite mathematics, quantum theory

1 Motivation

A belief of the overwhelming majority of scientists is that classical mathematics (involving the notions of infinitely small/large and continuity) is fundamental while finite mathematics is something inferior what is used only in special applications. This belief is based on the fact that the history of mankind undoubtedly shows that classical mathematics has demonstrated its power in many areas of science.

The notions of of infinitely small/large, continuity etc. were proposed by Newton and Leibniz more than 300 years ago. At that time people did not know about existence of atoms and elementary particles and believed that any body can be divided by an arbitrarily large number of arbitrarily small parts. However, now it is clear that standard division has only a limited applicability because when we reach the level of atoms and elementary particle the division operation loses its meaning. In nature there are no infinitely small objects and no continuity because on the very fundamental level nature is discrete. So, as far as applications of mathematics to physics is concerned, classical mathematics is only an approximation which in many

cases works with very high accuracy but the ultimate quantum theory cannot be based on classical mathematics.

A typical situation in physics can be described by the following

Definition: *Let theory A contain a finite parameter and theory B be obtained from theory A in the formal limit when this parameter goes to zero or infinity. Suppose that with any desired accuracy theory A can reproduce any result of theory B by choosing a value of the parameter. On the contrary, when the limit is already taken then one cannot return back to theory A and theory B cannot reproduce all results of theory A. Then theory A is more general than theory B and theory B is a special degenerate case of theory A.*

Probably the most known example is that nonrelativistic theory (NT) can be obtained from relativistic theory (RT) in the formal limit $c \rightarrow \infty$ where c is the velocity of light. RT can reproduce any result of NT with any desired accuracy if c is chosen to be sufficiently large. On the contrary, when the limit is already taken then one cannot return back from NT to RT, and NT can reproduce results of RT only in relatively small amount of cases when velocities are much less than c . Therefore RT is more general than NT and NT is the special degenerate case of RT. Other known examples are that classical theory is a special degenerate case of quantum one in the formal limit $\hbar \rightarrow 0$ where \hbar is the Planck constant, and Poincare invariant theory is a special degenerate case of de Sitter invariant theories in the formal limit $R \rightarrow \infty$ where R is the parameter defining contraction from the de Sitter Lie algebras to the Poincare Lie algebra.

In our publications (see e.g. Refs. [1, 2]) we discussed an approach called Finite Quantum Theory (FQT) where quantum theory is based not on classical but on finite mathematics. It has been shown that FQT is more general than standard quantum theory and the latter is a special degenerate case of the former in the formal limit when the characteristic of the field or ring in FQT goes to infinity. In Sec. 2 we describe a proof of this statement and also prove

Main Statement: Even classical mathematics itself is a special degenerate case of finite mathematics in the formal limit when the characteristic of the field or ring in the latter goes to infinity.

2 Proof of the main statement

Classical mathematics starts from natural numbers but here only addition and multiplication are always possible. In order to make addition invertible we introduce negative integers and get the ring of integers Z . However, if instead of all natural numbers we consider only a set R_p of p numbers $0, 1, 2, \dots, p-1$ where addition and multiplication are defined as usual but modulo p then we get a ring without adding new elements. In our opinion the notation Z/p for R_p is not quite adequate because it may give a wrong impression that finite mathematics starts from the infinite set Z and that Z is more general than R_p . However, although Z has more elements than R_p , Z cannot be more general than R_p because Z does not contain operations modulo

a number.

We assume for definiteness that p is odd; the case of even p can be considered analogously. Since operations in R_p are modulo p , one can represent R_p as a set of elements $\{0, \pm i\}$ ($i = 1, \dots, (p-1)/2$). Let f be a function from R_p to Z such that $f(a)$ has the same notation in Z as a in R_p .

If elements of Z are depicted as integer points on the x axis of the xy plane then the elements of R_p can be depicted as points of the circumference in Fig. 1. This picture is natural since R_p has a property that if we take any element $a \in R_p$

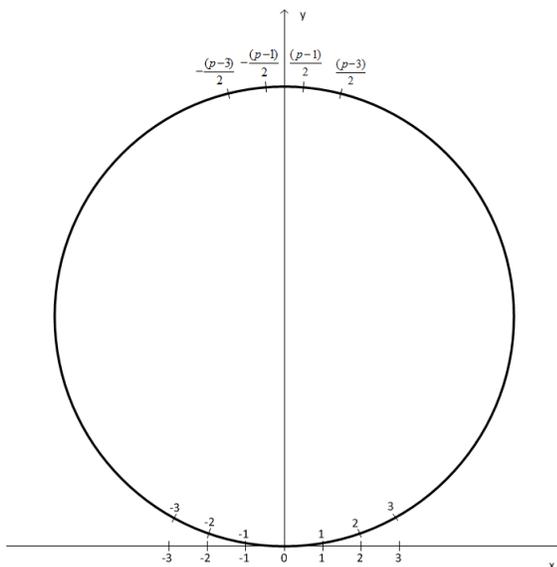


Figure 1: Relation between R_p and Z

and successively add 1 to this element then after p steps we will exhaust the whole set R_p by analogy with the property that if we move along a circumference in the same direction then sooner or later we will arrive at the initial point.

Let m be a natural number and $U(m)$ be a set of elements $a \in R_p$ such that $|f(a)| \leq [(p-1)/2]^{1/m}$. Then for any $n \leq m$ the result of any n operations of addition, subtraction or multiplication of elements $a \in U(m)$ is the same as for the corresponding elements $f(a)$ in Z , i.e. in this case operations modulo p are not explicitly manifested.

Let us now choose m as $m = g(p) = \text{int}(\{\ln[(p-1)/2]\}^{1/2})$ where $\text{int}(x)$ is the integer part of x . Since $[(p-1)/2]^{1/g(p)}$ becomes infinitely large when $p \rightarrow \infty$ then in the formal limit $p \rightarrow \infty$ the set $U(g(p))$ becomes Z and for the infinite number of additions, subtractions and multiplications of the elements of $a \in U(g(p))$ the result is the same as for the corresponding elements $f(a)$ in Z .

We have proved the following

Statement 1: The result of any finite combination of additions, subtractions and multiplications in Z can be reproduced in R_p if p is chosen to be sufficiently large. On the contrary, when the limit $p \rightarrow \infty$ is already taken then one cannot

return back from Z to R_p , and in Z it is not possible to reproduce all results in R_p because in Z there are no operations modulo a number. According to the **Definition** in Sec. 1 this means that *the ring R_p is more general than Z , and Z is the special degenerate case of R_p .*

The problem of actual infinity is discussed in a vast literature. The *technique* of classical mathematics does not involve actual infinities and here infinities are understood only as limits. However, the *basis* of classical mathematics does involve actual infinities. For example, Z is treated as actual and not potential infinity and, in particular, there is no rigorous definition of Z as a limit of R_p when $p \rightarrow \infty$.

When p is very large then $U(g(p))$ is a relatively small part of R_p , and in general the results in Z and R_p are the same only in $U(g(p))$. This is analogous to the fact mentioned in Sec. 1 that the results of NT and RT are the same only in relatively small cases when velocities are much less than c . However, when the radius of the circumference in Fig. 1 becomes infinitely large then a relatively small vicinity of zero in R_p becomes the infinite set Z when $p \rightarrow \infty$. *This example demonstrates that once we involve infinity and replace R_p by Z then we automatically obtain a degenerate theory because in Z there are no operations modulo a number.*

In classical mathematics the ring Z is the starting point for introducing the notions of rational and real numbers. Therefore those notions arise from a degenerate set. Then a question arises whether the fact that R_p is more general than Z implies that finite mathematics is more general than classical one. In particular, a problem arises whether finite mathematics can reproduce the results obtained by applications of classical mathematics. For example, if p is prime then R_p becomes the Galois field F_p , and the results in F_p considerably differ from those in the set Q of rational numbers. In particular, $1/2$ in F_p is a very large number $(p+1)/2$. Since quantum theory is the most general physical theory, the answer to this question depends on whether standard quantum theory based on classical mathematics is most general or is a special degenerate case of a more general quantum theory.

As noted in Sec. 1, de Sitter invariant quantum theory is more general than Poincare invariant quantum theory. As shown in Refs. [1, 2]

Statement 2: In standard de Sitter invariant quantum theory it is always possible to find a basis where the spectrum of all operators is purely discrete and the eigenvalues of those operators are elements of Z . Therefore the remaining problem is whether or not quantum theory based on finite mathematics can be a generalization of standard quantum theory where states are described by elements of separable complex Hilbert spaces H .

Let x be an element of H and (e_1, e_2, \dots) be a basis of H normalized such that the norm of each e_j is an integer. Then *with any desired accuracy each element of H can be approximated by a finite linear combination*

$$x = \sum_{j=1}^n c_j e_j \tag{1}$$

where $c_j = a_j + ib_j$ and all the numbers a_j and b_j ($j = 1, 2, \dots, n$) are rational. This follows from the known fact that the set of such sums is dense in H .

The next observation is that spaces in quantum theory are projective, i.e. for any complex number c the elements x and cx describe the same state. This follows from the physical fact that not the probability itself but only ratios of probabilities have a physical meaning. In view of this property, both parts of Eq. (1) can be multiplied by a common denominator of all the numbers a_j and b_j . As a result, we have

Statement 3: Each element of H can be approximated by a finite linear combination (1) where now all the numbers a_j and b_j are integers, i.e. belong to Z .

We conclude that Hilbert spaces in standard quantum theory contain a big redundancy of elements. Indeed, although formally the description of states in standard quantum theory involves rational and real numbers, such numbers play only an auxiliary role because with any desirable accuracy each state can be described by using only integers. Therefore, as follows from **Definition** in Sec. 1 and *Statements 1-3*,

- Standard quantum theory based on classical mathematics is a special degenerate case of quantum theory based on finite mathematics.
- **Main Statement** formulated in Sec. 1 is valid.

3 Discussion

The above construction has a well-known historical analogy. For many years people believed that the Earth was flat and infinite, and only after a long period of time they realized that it was finite and curved. It is difficult to notice the curvature when we deal only with distances much less than the radius of the curvature. Analogously one might think that the set of numbers describing physics in our Universe has a "curvature" defined by a very large number p but we do not notice it when we deal only with numbers much less than p .

As noted in the preceding section, introducing infinity automatically implies transition to a degenerate theory because in this case operations modulo a number are lost. We will not discuss whether or not infinities exist in nature but *even from the pure mathematical point of view* the notion of infinity cannot be fundamental, and therefore theories involving infinities can be only approximations of more general theories.

In the preceding sections we have proved that classical mathematics is a degenerate case of finite one in the formal limit $p \rightarrow \infty$ and that quantum theory based on finite mathematics is more fundamental than standard quantum theory. The fact that at the present stage of the Universe p is a huge number explains why in many cases classical mathematics describes natural phenomena with a very high accuracy. At the same time, as shown in our publications in Ref. [2], the explanation of several phenomena can be given only in the theory where p is finite.

One of the examples is that in our approach gravity is a manifestation of the fact that p is finite. Our estimation is that p is a huge number of the order of

$\exp(10^{80})$ or more. However, since the effective gravitational constant is proportional to $1/lnp$, the existence of p is observable while in the formal limit $p \rightarrow \infty$ gravity disappears.

Although classical mathematics is a degenerate case of finite one, a problem arises whether classical mathematics can be substantiated as an abstract science. It is well-known that, in spite of great efforts of many great mathematicians, the problem of foundation of classical mathematics has not been solved. For example, Gödel's incompleteness theorems state that no system of axioms can ensure that all facts about natural numbers can be proven and the system of axioms in classical mathematics cannot demonstrate its own consistency.

The philosophy of Cantor, Fraenkel, Gödel, Hilbert, Kronecker, Russell, Zermelo and other great mathematicians was based on macroscopic experience in which the notions of infinitely small, infinitely large, continuity and standard division are natural. However, as noted above, those notions contradict the existence of elementary particles and are not natural in quantum theory. The illusion of continuity arises when one neglects the discrete structure of matter.

However, since classical mathematics is a special degenerate case of finite one, foundational problems in this mathematics do not have a fundamental role, and classical mathematics can be treated only as a technique which in many cases (but not all of them) describes reality with a high accuracy.

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