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Fundamental Theorists and Condensed Matter Physicists

— What do They Agree and Why do They Argue

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Abstract
Fundamental theorists and condensed matter physicists consist of an important part of the mainstay of physicists. The latter has the largest population and aims at new phenomena at low energy. The former aspires to create a set of rules which everything has to follow. However, their ideas in viewing Physics are dramatically disparate, which causes frequent arguments especially after a group of condensed matter physicists claimed for a unified theory. This article is intended to analyse the accordance and discordance of methodology of these two groups of physicists, including symmetry in Physics, theories in different energy scale, complexity of physical systems and ways to construct a unified theory. No reconciliation is expected, but a review on author's opinion will be given at the end of each section.

Keywords
Fundamental Theory; Condensed Matter Physics

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Motivation

44 years ago, An article *More is Different*[1] by Anderson sparked the physical society. Before that, physicists working on fundamental theory were thought to be more intelligent and creative than those who did research on applied Physics like material science, for people usually thought that applied science is just a manipulation of laws discovered by fundamental theorists. As a result, a set of fundamental laws seems to exhaust all new possible phenomena. However, *More is different* claims that there actually exists a hierarchy of theories classified by the energy scale with each theory in the echelon requiring equal inspiration and creativity. This annihilates the superiority of fundamental theorists, but most of them seemed not to be afflicted by this.

Things changed after Wen Xiao-gang proposed his second quantum revolution.[3] A new framework was introduced to have the capacity to construct a gravitational theory and complete a unified theory through long-established methods in condensed matter Physics. This annoyed the fundamental theorists, since it is improper for them to accept such a applied-method-induced unified theory. Thus, arguments were ignited.

Therefore, this article aims at clarifying the differences of methodology and views towards unified theory held by these two groups of physicist. Nevertheless, it is important to declare that we do not call for a reapproachment, but we do hope to reduce some unnecessary arguments due to misunderstanding of each other.

Clarification

We admit that many of the fundamental theorists and condensed matter physicists respect the work of each other. And we greatly look highly on their contribution to the harmony of academic society. The reason for this article is not to stir up strife. Instead, we hope that this article can increase the communication and understanding of physicists working on different fields, and thus promote the progress of Physics. In this way, the term fundamental theorists and condensed matter physicists appearing in the following context refer to those who are in the center of the storm, not all of them.

Symmetry

Almost all excellent physicists recognise the essential significance of symmetry in physical theory. So do fundamental theorists and condensed matter physicists. However, when talking about symmetry, these two groups of people usually can not understand each other. Condensed matter physicists regard the world as a result of the breaking of symmetry, which is exactly what fundamental theorists are not able to acknowledge. In theorists' view, symmetry forms the foundation of all physical theories they propose. Yet some of the condensed matter scholars infer occasionally their success built on the breaking of the physical foundation that theorists care very much. In this section, we are going to show that the symmetry used most frequently in fundamental theory and condensed matter Physics are in fact not the same thing, for condensed matter Physics concerns more about matter field and fundamental theory deals with rules. [1]

Let's first look at the symmetry in fundamental theory. The symmetry we talk here is not just the identity of certain pattern under rotation or some other transformations. The accurate meaning of symmetry is the invariance of an entity under certain transformation. This symmetry is quite a general one which both fundamental theorists and condensed matter physicists can agree. So what is the difference? The difference is that the symmetry in fundamental theory is just a subset of that general symmetry — **symmetry of theory**. In fundamental Physics, a theory is a continuous real functional (**action**) in the form

$$\mathcal{I}[\psi, \partial_\mu \psi] = \int \mathcal{L}[\psi, \partial_\mu \psi]\varepsilon \tag{1}$$

where $\mathcal{L}[\psi, \partial_\mu \psi]$ is a local continuous function (**Lagrangian**) of matter field ψ. Accordingly, if there is a change of matter field

$$\psi \to \psi + \delta\psi$$

the change of Lagrangian

$$\delta\mathcal{L} = 0$$

this theory is then claimed to have a symmetry of theory under transformation $\delta\psi$.

Next, let's turn to the symmetry breaking stated constantly by condensed matter physicists. In general, there are two types of symmetry breaking. One is called "explicit symmetry breaking" and the other is "spontaneous symmetry breaking". We will talk about the explicit symmetry breaking in the next section. Here we focus on the spontaneous one.

Spontaneous symmetry breaking is a kind of symmetry breaking satisfying at least two conditions:[2]

(i) There are no explicit symmetry breaking terms
(ii) There exists a degenerate ground state

Immediately we notice that the first condition for spontaneous symmetry breaking indicates the preservation of symmetry of theory. Thus, up to the level of physical theory, spontaneous symmetry breaking can not cause any threats.

So what symmetry breaks, now that symmetry of theory preserves? To answer this, we need to invoke a basic conclusion in condensed matter Physics[1]

> The state of system, if it is to be stationary, must always have the same symmetry as the laws of motion which govern it.

Here we find the second kind of symmetry — symmetry of matter state, or **symmetry of system**. Therefore, the second condition infers that the symmetry of system becomes different from that of theory. As a consequence, all physicists should agree that in spontaneous symmetry breaking, no symmetry of theory breaks. What really breaks is the symmetry of system, which is exactly the one that pure theorists pay few attention to.

Remarks. Students major in Physics are always hearing about two sounds from professors: theorists claim that Physics searches for higher and higher symmetry, while materialists insist that the world is constructed upon symmetry breaking. Our previous elucidation aims at indicating the consistency of this two ambiguous statements. However, this does not mean that the problem is solved. Many Physics scholars are not actually able to distinguish these two symmetries quite well, especially when facing internal symmetry. Few fundamental theorists are aware about the common sense on the relationship of these two symmetries in condensed matter Physics, and few condense matter physicists notice that fundamental theorists care little about one of them. Besides, reminiscing the history of science, Physics concerns relatively less about matter field. As a matter of fact, Physics is more like a science that devotes itself into universal laws suitable for all diversity of matter, which is accountable for the absence of matter or state in the precise definition of Physics given by *Nature*. In this circumstance, much work in condensed matter Physics should be classified as *physical science* instead of Physics, and thus, there are definitely no chances for any materialists to break our physical foundation through any means.

Energy Scale

Theoretical Physics has now become an equivocal term. Previously, with the progressive refinement of Relativity, theoretical Physics became closer and closer to the fundamental physical theory. However, the past several decades have witnessed the growing of another strong and strange branch — condensed matter theory. The popping up of such directory brought not only new contents but also new methodology to theoretical Physics — energy scale. This strikes fundamental theorists. Initially, theories are classified through symmetry. Yet *More is Different* claimed a pattern that for all laws there exists a theory parametrized by finite variables in each energy scale. So energy scale was as a consequence proposed to classify theories we have.

Here we have a contradiction again. To analyse this, let us start with fundamental theory first. Here we need to invoke the explicit symmetry breaking. In fundamental theory, we have a hierarchy for symmetry of theory — Galilean, Lorentz, general and internal symmetry, with the latter higher than the former. Thus, if the symmetry of a theory degenerates to a lower one due to certain approximation or symmetry breaking terms, we say the theory is subjected to an explicit symmetry

[1] Yet condensed matter physicists usually obscure these two concepts.[4]

breaking. Explicit symmetry breaking is the major way to apply a fundamental theory. As the symmetry becomes lower, the theory gets simpler but less applicable as well.

But condensed matter physicists do not view things like that. In Quantum Theory, there is a famous uncertainty relation

$$\Delta x \cdot \Delta p \geqslant \frac{\hbar}{2} \tag{2}$$

which indicates that if we want to look into very tiny scale, we will have to create a relatively broader energy range and vice versa. This though is the basis of energy scale classification, since energy becomes a measure of physical range. In the methodology of condensed matter Physics, matter in each energy scale is governed by a theory parametrized with finite variables, which is how science is divided into different subjects.[1]

Until now, fundamental theorists and condensed matter physicists agree with each other. So what do they argue about? The major concentration lie not in the difference of classification standard, but in whether they have a corresponding relation in between. Fundamental theorists believe that as the energy scale drops, the symmetry of theory gets lower, and as a consequence, the theory under lower energy scale must be certain approximation of that of higher energy scale. However, condensed matter physicists contend that a theory under lower energy scale comes not only from approximation. New physical models, concepts, thoughts and innovations that is as brilliant as those which appears in research of fundamental theory are indispensable. This tremendously challenges the strong conviction of theorist that go deeper, and the rest is approximation.

Remarks. The above topic is within one of the most fierce battle, which may be because it not only becomes a academic debate but also touches the value of a large scientific subjects. So what we want to comment here is that the only superiority we want here is solely the predominance status of fundamental theory of Physics. We would like to claim:

First, it has already occurred vast evidences to guarantee the logical approximative relation between theories under different energy scale. At least, we are now able to produce mathematically flawless approximation procedure from the fundamental theory scale into a the scale of Quantum Chemistry. And large number of models (e.g. force) we used in historical physical theory have been weakened due to the discovery of their origin in fundamental theory (e.g. interaction). Therefore, there are no reasons to suspect that after continuous efforts of scientist, the approximation of fundamental theory can unite more and more theories in even lower energy scale.

Second, we do not deny the value of any works by our scientific colleague. Fostering the predominance of fundamental theory does not necessarily infers the dilution of the value of other theories. What we want to defend is the uncontroversial capacity of fundamental theory to discover new Physics. The "new Physics" here refers to something that is beyond any imagination of all current theories we have, and hence the only method to promote this is the amelioration of a fundamental theory.

Complexity

Another center of dispute arises in the disposal of complex systems. Condensed matter physicists usually hold the view (or at least infer) that as the energy scale decreases, the complication of the system increases.[1] However, although this holds for most situations, there does not exist a way to logically linked this two indexes. Thus, we separate this two factors away.

The core of discussion can be summarized as C&C problem (Complexity & Calculation). *More is Different* proposed that it is impossible to use massive calculation to replace the innovative model in a complex system[2]. However, the traditional view of fundamental theorists suggests just as opposite. This problem can be acute enough to raise fierce dispute, since it touches the fundamental value of this two branches — if a complex system can be derived simply through massive calculation, all the problems in condensed matter Physics can be in principle solved through this way and thus the efforts of building models for it becomes useless; on the other hand, if there is no way to calculate the complex system, the utility of the fundamental theory will be severely restricted — at least restricted for the application of our real world due to its great complication. As a consequence, no matter what the answer is, the worth of one side will be impaired.

So for further elaboration, we again analyse respectively. The origin of acquiring information from calculation (so-called constructionism) can date back to the invention of several superposition laws. Conventionally, physicists believed that the behaviour of a many-body system can be calculated through reducing this system into several single bodies and applied fundamental laws into them. This works very well in numerous situations. Notwithstanding, when physicists began to look at condensation under very low energy scale, they found something "interesting" can happen. In solving these situations, ab initio approach results in enormous calculation with which modern computers are not able to handle, and hence new models are involved, which accounts for their denial of constructionism.

But theorists criticize that condensed matter physicists fail to consider the dramatic growing of calculation techniques. As an instance, Anderson claimed that we are not able to depict the ammonia inversion simply through calculation of Quantum Mechanics. However, through Quantum Chemistry technology, we can to some extend. Also, Anderson alleged that it is impossible to derive behaviours of a infinitely many body system and apply them to a finite system merely through fundamental laws and a computer. But theorists believe that this predicate holds only before the invention of a universal quantum computer.

The objective investigation has to end here, since nobody can know at this time what the future will be like. Nonetheless, we are, in fact, able to draw an extrapolating results based on the knowledge, trend and logic we have now.

Review. View from history, the capacity of calculation always surpassed our imagination. As condensed matter physicists realized more is different, contemporary DEC president predicted

[2] The complex system here refers to those with vast number of particles, say for example 10^{20}

it would be no reason for any individuals to have a computer in his home. Therefore, underestimating the development of calculation technology can be catastrophic. About a hundred years ago, people can hardly imagine weather prediction, since even a short time forecast will face a gigantic calculations that far exceeds the ability of human being. And look at what we can do now — we are able to access hourly weather forecast of almost everywhere on earth. As a second example, at the beginning of twentieth century, we need miserable mathematical methods to calculate the wall effect of a falling ball viscometer. Nowadays, this can be resolved automatically by computer simulations. The whole IT history in the past decades exemplifies the superseding of manual work by computation, and we can not see any signs for this trend to stop. The ab initio approach is growing steadily in Quantum Chemistry and how can we concluded that this method can not be generalized to even more complicated systems? Anyway, we still hold the possibility to reach any corners of physical world before any calculation limit of universal quantum computation is found.

Unified Theory

Unified theory is usually the research topic of fundamental theorists and high energy physicists. Yet recently, parts of condensed matter physicists claimed to step into this field. This somehow stuck fundamental theorists. However, we want to make it clear that the unified theory in condensed matter Physics does not have the same goal as the fundamental theory has, and thus no contradiction might appear.

Let's first talk about fundamental theory. Yes, fundamental theory is a kind of unified theory. It unifies all essential laws in nature and has the highest symmetry. This theory mainly contains the most basic laws which all matter in the universe should follow. Usually, the dominance of this theory can only be observed when the energy scale is high enough.

On the other hand, unification in condensed matter Physics can be a much weaker one. It solely unifies behaviours of matter in certain energy scale that we can technically manipulate, including all possible interactions. So actually, this sort of unification has no ambitions to be a fundamental one. And hence we can see such rumours that condensed matter Physics is overwhelming the traditional theoretical Physics can totally be nonsense.

Remarks. There are not much to talk about here, since the "disagreement" does not actually exist. However, we still want to talk more about the new gravity approach with the help of condensed matter theory. Several years ago, certain aspects of string-net condensation was found to have a close connection with Loop Quantum Gravity. This immediately became a big news in physical society. Notwithstanding, this brings no shocks in theoretical Physics. Just as one of the founder of Loop Quantum Gravity Carlo Rovelli said, Loop Quantum Gravity also does not have the ambition to become a final theory.[6]

As a matter of fact, the word "unification" has been overused in many physical theory. However, theoretical physicists will restrict the name of the such theories which only unifies some parts of original theory, such as Grand Unified Theory or Electroweak Unified Theory. So it seems not so appropriate to simply name a possible unified theory of condensed matter Physics *unification*.

Feynman warned very early about clarifying the name and what it really means, but I believe that a dialogue at Diagon Alley sums it up even more clearly:

HARRY POTTER: What's the difference between a stalagmite and a stalactite?

HAGRID: Stalagmite's got an 'm' in it.

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