Re: Several questions about Quantum Mechanics

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- *Date*: Tue, 10 Apr 2007 14:33:48 +0000 (UTC)

On Apr 8, 8:15 am, ZHANG Pu <Lefthanded.Mater...@xxxxxxxxx> wrote:

> 4, Is there a widely accepted quantization program of electromagnetic field? Can you recommend some readings about that?

The free non−interacting electromagnetic field has a well−established quantization as a system that effectively equates to an infinite system of simple harmonic oscillators.

In contrast, there is no known quantization for the electromagnetic field when coupled to other fields; nor (to get technical) even for the free electromagnetic field in the modern context of electroweak theory. That is, more generally, the question of how to quantize a *free* non−Abelian Yang−Mills field is still open (and, essentially, the subject of a $1000000 prize by the Clay foundation). This devolves on the electromagnetic field which, in electroweak theory, is mixed in with the (non−Abelian) field associated with the SU(2) part of the Standard Model.

To put it slightly differently, the modern treatment of electromagnetism (since the advent of electroweak theory) replaces the linear Maxwell equations by non−linear equations that are inhomogeneous both for the electric and magnetic equations. This is generally the case for non−Abelian Yang−Mills fields. Quantum field theory in dimensions greater 2+1 has a difficult time accounting for any kind of non−linear interactions or self−actions. There is no known non−trivial quantum field theory in 3+1 dimensions or more.

Resort is made to a power series expansion approach, in the guise of perturbation theory, for the purpose of trying to account for the non−linear interactions between fields. The series (that is, the S−matrix expansion) is not known to converge to a well−defined value, and is widely believed not to.

Nevertheless, interesting physics arises from what CAN be gleaned. All of this falls under the header of "renormalization theory" and involves such concepts as the "renormalization group", the "running of the couplings", the notions of "bare vs. dressed" charge, etc.

What is NOT as well−known is that what arises shows clearly that the problem is NOT anything that has per se to do with quantum theory, but is generic. The various phenomena that are uncovered (particularly the running of the couplings, which actually manifests in scattering experiments) are essentially classical in nature. The problem which plagues quantum theory, which these devices seek to solve, is a problem that is common to both classical and quantum field theory and is much older than quantum theory, in fact.

The myth that pervades is that the field divergence problem has to do with some kind of Planck level physics and is something that can only be resolved with a theory of quantum gravity. Yet, the phenomena associated with renormalization theory (particularly the running of the couplings) are perfectly well visible at present day levels of resolution −− which is over a dozen orders of magnitude above the Planck scale. This, alone, serves as a clear hint that we're dealing with an essentially classical issue, not anything that has to do with exotic Planck−level or "21st century" Physics.

Indeed, the whole idea (and apparatus) associated with renormalization theory is much older than quantum theory. It originated with Maxwell, himself. It was Maxwell who first posed the idea of charge screening, vacuum polarization, bare vs. dressed charges, setting out to do so specifically to resolve the problem of field infinities.

The source of the infinity that plagues classical and quantum theory is easy enough to describe. However, it is difficult to see in the present−day theoretical literature, because it pertains to an element that is almost always kept out of the discussion: the vacuum permittivity.

Consider the equations
div D = rho; D = epsilon E; F = rho E
describing the relation between the D and E fields and the force density for a charge density rho. Suppose you adopt in place of the second relation the relation posed originally by Lorentz,
D = epsilon_0 E,
who hypothesized that this relation not only holds in the vacuum but even in the spaces between the particles that comprise matter. This, of course, was where the distinction between the "microscopic" vs. "macroscopic" forms of Maxwell's equations arose.

However, it's wrong and is easy to see. What it actually does is reintroduce the very field−theoretic infinity that Maxwell went to great pains to eliminate. It undid the very thesis of the treatise spelled out in article 61 at the end of chapter 1, and it was not until the 1940's that the old elements of Maxwell's theory came to be resurrected (possibly unwittingly) in modern guise as "renormalization theory".

You can see it as follows: a point like or strongly concentrated charge distribution for rho, in virtue of the equation (div D = rho) entails a similarly singular (or near−singular distribution in D). Given the linear relation (D = epsilon_0 E), this property is inherited by E, as well. But in order for (rho E) to be well−defined as a density, E must NOT be singular, wherever rho is.

Check mate.

Hence, the linear relation (D = epsilon_0 E) cannot be valid near point sources or other strong concentrations of charge. Indeed, this was precisely the argument set out by Maxwell in Chapter 1 and 2 of his treatise.

The source of the field infinity is that epsilon was rendered inert (epsilon_0) and then entirely removed from the discussion ("let epsilon_0 = 1" or a similar convention). In the process, you lose some very important physics that it took nearly 50 years after Lorentz to recover. At of the present day, it has not yet been fully recovered. There is a more comprehensive account that will cure the field infinities both classical and quantum theoreitically lurking somewhere that is properly grounded in classical theory, but it has not yet been fully developed.

The true nature of the constant can be seen when going over to the more general context of Yang−Mills theory. Here, the fields (E, B) become indexed (E^a, B^a) with superscripts, while the charge (e) becomes indexed as a (Lie−valued) vector e_a. The space of charges goes from one−dimensional to N−dimensional (e.g. for SU(3) gauge theory, a classical charge is a 8−dimensional quantity, its quantized charge occupies a 2−dimensional representation space). In contrast, the fields (D,H) become indexed with subscripts (D_a, H_a), as the charge and current.

The relation between the two (D = epsilon E) is no longer a trivial linear proportionality; nor is it related merely by a duality transform, as the modern treatment in the language of differential forms renders the Lorentz relation. The two quantities aren't even of the same type, so at the conceptual level a linear relation doesn't even make sense.

Instead, you need to raise and lower indices −− and wherever that happens, you're talking about a metric of some sort. Here, the metric is that associated with the underlying symmetry group, and the relations would be written as D_a = sum (k_ab E^b), where (k_ab) is the components of this metric. For Maxwell's theory, you don't see the extra components, so the metric (k) is (mistakenly) forgotten.

In modern theories, these are called Jordan−Brans−Dicke scalars, but what this actually is is just nothing more than the modern translation of the permittivity! That is, k_ab <−> epsilon c, and for the dual metric k^ab <−> mu c.

This metric, in turn, is subject to a dynamics. The dynamics can be posed by taking the standard geometric formulation of Yang−Mills fields (principal bundles) and allowing the gauge metric to be variable. The result is a additional set of equations governing the dynamics of this set of "dielectric" coefficients.

At the time of Maxwell, epsilon was called K, and Maxwell maMuchde a very specific point of indicating that this is an entirely non−trivial element to the theory that cannot be ignored! It is because epsilon (or Maxwell's K) has been lost that field theory acquired an infinity at the classical level. In turn, it is because of the problem of the infinity in the classical theory, that a similar problem came to be inherited by the quantization of the classical field theories.

Yet, as you can begin to see, the problem is both classical in its nature −− and in its cure! Quantum gravity and Planck−level Physics is nothing more than a red herring, and never was anything more than one here.

Just so there will be no room for questioning Maxwell's (forgotten) role in the development of all the concepts related to renormalization theory, I've included the following discussion. Much of this has been long−forgotten, essentially having been thrown out (like baby with the bathwater) when the so−called ether theory, which the renormalization theory has little to do with, had been discarded.

Though it is not well−known today and nearly forgotten, it was Maxwell who formulated what today is called renormalization theory and the underlying notion of vacuum polarization

From Article 62 of Maxwell's treatise:

"... the energy of electrification resides in the dielectric medium, whether that medium be solid, liquid, or gaseous, dense or rare, or even what is called a vacuum, provided it be still capable of transmitting electrical action."

"That the energy in any part of the medium is stored up in the form of a state of constraint called electric polarization, the amount of which depends on the resultant electromotive intensity at the place."

Which, as per the previous paragraph, includes vacuum polarization.

It is through this theory that the issue of the classical field−theoretic infinity is resolved (via the notion of charge screening). The arguments leading to the theory and the resolution of the infinity transcend the context of the original theory and are not only applicable across the divide between classical and quantum theory, but also to the more general context of Yang−Mills theory.

It is of interest to note that the hypothesis that the vacuum behaves as a dielectric medium not only originates with Maxwell, but is a central thesis of his entire treatment of classical electromagnetism.

Continuing on:
"That electromotive force acting on a dielectric produces what we have called electric displacement, the relation between the intensity and the displacement being in the most general case of a kind to be afterwards investigated in treating the conduction, but in the most important cases the displacement is in the same direction as the intensity, and is numerically equal to the intensity multiplied by K/(4 pi), where K is the specific inductive capacity of the dielectric."

In modern language of Yang−Mills theories, K becomes none other than the gauge metric k_ab, itself, up to a multiple of 4 pi.

From Article 55

"If the electromotive intensity at any point of a dielectric is gradually increased a limit is at length reached at which there is a sudden electrical discharge through the dielectric generally accompanied with light and sound and with a temporary or permanent rupture of the dielectric."

In the context of article 62, "discharge" is also meant to include the breakdown of the vacuum itself. It is interesting that this consequence was never fully spelled out in the treatise. In particular, what would the products of the dielectric breakdown in a vacuum be?

As mentioned above, in the theoretical literature, both the vacuum permeability and vacuum permittivity are disregarded as inert and inessential, and the constants are never seen, their use being relegated instead to "engineering applications". Yet the very physics embodied by the vacuum permittivity is what modern renormalization theory tries to recapture in the guise of quantum field theory!

This is the source of the problem of the field infinity faced not only by quantum field theory, but classical theory, as well − after Lorentz.

The very purpose of Maxwell's hypothesis was to resolve the field theoretic infinity that would otherwise arise, as stated here:

"the dielectric gives way and its insulating power is destroyed, so that a current of electricity takes place through it. It is for this reason that distributions of electricity for which the electromotive intensity becomes anywhere infinite cannot exist."

This argument on the finiteness of E in the presence of point sources is quite general and is precisely the argument that is required to avoid the infinity in the classical theory.

This is how Maxwell avoided the problem that Lorentz reintroduced and which eventually found its way into quantum field theory.

The modern−day solution partly recovers the old formalism, however, the resolution is not properly grounded in classical theory and does not fully embody the Maxwell theory, which requires instead that the vacuum be treated as a non−trivial dielectric with running permittivities instead of running couplings.

The notion of charge screening was developed by Maxwell in the following thought experiment, from Article 55.

"Thus, when a conductor having a sharp point is electrified, the theory, based on the hypothesis that it retains its charge, leads to the conclusion that as we approach the point the superficial density of the electricity increases without limit, so that at the point itself the surface−density, and therefore the resultant electromotive intensity, would be infinite. If the air, or other surrounding dielectric, had an invincible insulating power, this result would actually occur; but the fact is, that as soon as the resultant intensity in the neighborhood of the point has reached a certain limit, the insulating power of the air gives way, so that the air close to the point becomes a conductor. At a certain distance from the point the resultant intensity is not sufficient to break through the insulation of the air, so that the electric current is checked, and the electricity accumulates in the air round the point."

This was spelled out more clearly in the thought experiment of Article 81 ("A Distribution of Electricity on Lines or Points is Physically Impossible"):
"If, while [the linear density of charge] remains finite, [the circumference of a wire] be diminished indefinitely, the intensity at the surface will be increased indefinitely. Now in every dielectric there is a limit beyond which the intensity cannot be increased without a disruptive discharge. Hence a distribution of electricity in which a finite quantity is placed on a finite portion of a line is inconsistent with the conditions existing in nature... In the same way it may be shewn that a point charged with a finite quantity of electricity cannot exist in nature."

This leads directly to the classical notion of charge screening and the distinction between bare vs. dressed charges, as spelled out in Article 83a:
"The apparent charge of electricity within a given region may increase or diminish without any passage of electricity through the bounding

surface of the region. We must therefore distinguish it from the true charge, which satisfies the equation of continuity.In a heterogeneous dielectric in which K varies continuously, if rho' be the apparent volume−density
del^2 V + 4 pi rho' = 0

Comparing this with [the equation div(K grad V) + 4 pi rho = 0], we find
4 pi (rho − K rho') + grad K . grad V = 0.
The true electrification, indicated by rho, in the dielectric whose variable inductive capacity is denoted by K , will produce the same potential at every point as the apparent electrification, denoted by rho', would produce in a dielectric whose inductive capacity is everywhere equal to unity."

This, of course, is nothing less than a description back in the 19th century on the distinction between bare vs. dressed charges.

The distinction is thus grounded firmly at the classical level in the underlying theory of the universal dielectric medium.

It is thus here that one will find the resolution of the field theoretic infinity.

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