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Quantum Gravity

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ABSTRACT *Quantum gravity is a field of theoretical physics that seeks to describe the force of gravity according to the principles of quantum mechanics, and where quantum effects cannot be ignored. Quantizing matter fields on a black hole background teaches us a lot about black holes. However, we need a quantum theory of gravity to understand the fundamental principles underlying black hole thermodynamics. We also need a quantum theory to tell us what happens near the singularity. However, quantizing gravity is extremely difficult. One theory which offers some hope, particularly for understanding black holes, is string theory. the branch of mechanics that deals with the mathematical description of the motion and interaction of subatomic particles, incorporating the concepts of quantization of energy, wave–particle duality, the uncertainty principle, and the correspondence principle.*

Introduction:

The aim of quantum gravity is only to describe the quantum behavior of the gravitational field and should not be confused with the objective of unifying all fundamental interactions into a single mathematical framework. While any substantial improvement into the present understanding of gravity would aid further work towards unification, study of quantum gravity is a field in its own right with various branches having different approaches to unification. Although some quantum gravity theories, such as string theory, try to unify gravity with the other fundamental forces, others, such as loop quantum gravity, make no such attempt; instead, they make an effort to quantize the gravitational field while it is kept separate from the other forces. A theory of quantum gravity that is also a grand unification of all known interactions is sometimes referred to as a theory of everything (TOE).

Gravity:

Our modern understanding of gravity is based on Einstein's general theory of relativity, but Einstein himself realized that it was incomplete. Shortly after publishing his most famous theory, he remarked that gravitational effects would cause electrons to spiral in on atomic nuclei. To stop that would take a quantum revision of general relativity. In 1916 he wrote: "Due to the intra-atomic movement of electrons, atoms would have to radiate not only electromagnetic but also gravitational energy, if only in tiny amounts. As this is hardly true in nature, it appears that quantum theory would have to modify not only Maxwellian electrodynamics, but also the new theory of gravitation." (To be sure, the implosion of atoms would take 10^{30} years to complete. At the time, Einstein assumed the universe was infinitely old. If he had known it was only just a dozen billion years young, his argument would be less compelling.)

Quantized properties:

Certain properties, such as position, speed and color, can sometimes only occur in specific, set amounts, much like a dial that "clicks" from number to number. This challenged a fundamental assumption of classical mechanics, which said that such properties should exist on a smooth, continuous

Quantum gravity is the branch of physics relating to the very small:

In 1900, German physicist Max Planck sought to explain the distribution of colors emitted over the spectrum in the glow of red-hot and white-hot objects, such as light-bulb filaments. When making physical sense of the equation he had derived to describe this distribution, Planck realized it implied that combinations of only certain colors (albeit a great number of them) were emitted, specifically those that were whole-number multiples of some base value. Somehow, colors were quantized! This was unexpected because light was understood to act as a wave, meaning that values of color should be a continuous spectrum.

In quantum theories, these physical quantities do not in general *have* definite values. For example, in quantum mechanics, the position of an electron may be specified with arbitrarily high accuracy only at the cost of a loss of specificity in the description of its momentum, hence its velocity. At the same time, in the quantum theory of the electromagnetic field known as quantum electrodynamics (QED), the electric and magnetic fields associated with the electron suffer an associated uncertainty. In general, physical quantities are described by a quantum state which gives a probability distribution over many different values, and increased specificity (narrowing of the distribution) of one property (e.g., position, electric field) gives rise to decreased specificity of its canonically conjugate property (e.g., momentum, magnetic field). This is an expression of Heisenberg's Uncertainty Principle. In the context of quantum gravity the fluctuating geometry is known as "spacetime foam". Likewise, if one focuses in on the spatial geometry, it will not have a definite trajectory.

What is it about quantum mechanics that is incompatible with general relativity?

As I understand the basic problem, 'Classical' general relativity, which is the theory developed by Einstein in 1915, is a theory where gravitational fields are continuous entities in nature. They also represent the geometric properties of 4-dimensional spacetime. In quantum mechanics, fields are discontinuous and are defined by 'quanta'. So, there is no analog in conventional quantum mechanics for the gravitational field, even though the other three fundamental forces have now been described as 'quantum fields' after considerable work in the 1960-1980s. Quantum mechanics is incompatible with general relativity because in quantum field theory, forces act locally through the exchange of well-defined quanta.

"Problems in quantum gravity:

Loop quantum gravity is a way to quantise space time while keeping what General Relativity taught us. It is independent of a background gravitational field or metric. So it should be if we are dealing with gravity. Also, it is formulated in 4 dimensions. The main problem is that the other forces in nature, electromagnetic, strong and weak cannot be included in the formulation. Nor it is clear how loop quantum gravity is related to general relativity.

Conclusion:

Research on quantum gravity is beset by a combination of formal, experimental, and conceptual difficulties. It is inevitable that the quest for a quantum theory of gravity will continue – whether for reasons of necessity or not – and it seems that the resolution of the problem will require an equivalent combination of formal, experimental, and conceptual expertise. Given this, and given the central position quantum gravity research occupies in theoretical physics, it makes good sense for philosophers of physics (and general philosophers of science) to do their best to acquaint themselves with the central details of the problem of quantum gravity and the main approaches that are seeking to crack the problem. Beyond this, quantum gravity research has the potential to invigorate several standard areas of philosophical inquiry, including our standard notions of theory construction, selection and justification; the nature of space, time, matter, and causality, and it also introduces a new case study in emergence, with entirely novel features.

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