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# Gravity, Quantum Mysteries and Einstein's Last Dream

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**Abstract-**
Einstein's General theory of relativity is an excellent theory of gravity but it is still a classical theory. In this paper after giving a broad overview of Gravity, I will use Quantum Field Theory and Graviton to show that some aspects of Gravity can be explained from the Quantum perspective. I will also discuss disturbing aspects of Quantum mechanics like spooky action at a distance and Bell's inequality. Finally I will show how Einstein's failed quest to find a perfect unified theory to achieve space time unification of fundamental forces of nature, continue to inspire physicists in a fruitful way.
Keywords-space time, Gravity, laws of nature, symmetry.

## 1 Introduction

When Isaac Newton discovered the universal law of gravity he could make accurate predictions, but he realized that it was lacking in one important aspect, it offers no insight into what gravity is. After thinking for a long time he finally declared his failure of understanding the real mechanism of gravity. He writes in the second edition of principia [2] "I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses."

The essence of Newton's gravity can be summarized below as

- Gravity is a force.
- Mechanism is unknown.
- Acts at a distance, moves at infinite speed.
- Space and time are two distinct absolute fixed entities.

Einstein realized after completing his special theory of relativity that he could not explain gravity, but as he continued to work in his office he was struck by the fact that if a person falls freely he will not feel his own weight he has described this idea as the happiest thought of his life because it implies that a freely falling reference frame is just like the inertial frame of special relativity. Einstein had found a way to link gravity with uniform motion. During free fall, the acceleration is

$$a=\frac{mg}{mi}\,g, \qquad (1)$$

Only when the gravitational mass $m_g$ is equal to the inertial mass $m_{i,}$

$$a=g \qquad (2)$$

Nothing in special relativity or Newtonian mechanics leads to this conclusion, Einstein saw deeper physics gravity is mysterious and ethereal, but acceleration is concrete and tangible, he had found a powerful principle to guide him, he called it the Equivalence principle which states that

- The laws of physics in a uniform gravitational field are the same as a reference frame undergoing uniform acceleration in free space.

The Equivalence principle worked like magic in the hands of Einstein. One of the most important consequence of the equivalence principle was that gravity affects time, gravity warps space time, Einstein had found the mechanism by which gravity is transmitted it is the warping of space time. In the words of John Wheeler [5] "matter tells space how to curve, and space tells matter how to move". This new theory was a great success.

In General theory of relativity gravity is not a force but it is geometry of four dimensional curved space time. Particle moves in a world line which extremizes the proper time between the points this is the variational principle for general relativity. In curved space time the path taken by matter is given by the equation

$$\delta\int(-g_{\alpha\beta}\, dx^{\alpha}\, dx^{\beta})^{1/2}=0 \qquad (3)$$

This leads to the famous geodesic equation

$$d^2x/d\tau^2+\Gamma_{\beta\gamma}^{\alpha}\, dx^{\beta}/d\tau\, dx^{\gamma}/d\tau=0 \qquad (4)$$

Using the principle of general covariance Einstein was able to write the field equation for gravity as

$$G_{\alpha\beta}=8\pi T_{\alpha\beta} \qquad (5)$$

In Einstein's General relativity the essence of gravity can be summarized as

- Gravity is geometry.
- Mechanism is curvature.
- Acts locally, moves at the speed of light.
- Space time is one entity, it is dynamic

2 Graviton and the origin of force.

Let me use Quantum Field theory to understand why masses attract.

The propagator for spin 2 particle is given by

$$D=(G_{\mu\lambda}\, G_{\nu\sigma}+G_{\mu\sigma}\, G_{\nu\lambda})-\frac{2}{3}\, G_{\mu\nu}\, G_{\lambda\sigma}/k^2-m^2 \qquad (6)$$

The interaction between two lumps of stress energy is described by

W(T)=

$$-1/2\int d^4k/(2\pi)^4 T^{\mu\nu}(k)^* \, (G_{\mu\lambda}\, G_{\nu\sigma} + G_{\mu\sigma}\, G_{\nu\lambda}) - \frac{2}{3}\, G_{\mu\nu}\, G_{\lambda\sigma}/^2\, k^2 - m^2 + i\varepsilon\, T^{\lambda\sigma}(k) \qquad (7)$$

From the conservation of energy and momentum $\partial_\mu T^{\mu\nu}(x)=0$

The interaction between two lumps of energy density $T^{00}$ is given by

$$W(T)=-1/2\int d^4k/(2\pi)^4\, T^{00}(k)^* \frac{1+1-2/3}{k2 - m2 + i\varepsilon}\, T^{00}(k) \qquad (8)$$

Since the path integral is given by $Z=Ce^{iW(J)}$

We can say that the energy is negative this means the potential is negative so two masses attract each other.

This is gravity from the quantum perspective. The exchange of virtual spin 2 particle produces an attractive force. The exchange of particle can produce a force was a profound conceptual advance of twentieth century physics. The main drawback of this model is that graviton has not been discovered but experimentalists are trying to find this important particle in particle accelerator.

3 Quantum Mysteries.

The Central ideas of the Copenhagen model is the Heisenberg’s Uncertainty Principle and the Bohr’s principle of complementarity. The main ideas of the Copenhagen interpretation can be summarized as

- The state of a system is defined by the wave function
- The wave function evolves continuously and deterministically until a measurement is made.
- Prior to experiment the wave function represents a superposition of all possible but as yet unrealized outcomes of the experiment.
- Measurement results in the instantaneous collapse of the wave function into a state representing the actual outcome.
- Collapse of the wave function takes place in a random non-deterministic and unpredictable way.
- Although the precise results of measurements cannot be predicted with certainty, the probability of the outcome can be calculated.

The collapse of the wave function causes a discontinuous change in the wave function from its continuously evolving superposition into one or other definite state. For example before an electron emitted during Beta decay is detected there is a chance of finding the wave function anywhere in space the wave function has a value everywhere in space but as soon as the electron is detected at one place, the wave function at all place where the electron is not detected will instantly be zero. This instant action at a distance, Einstein called it “spooky action at a distance” happens instantly it goes against the philosophy of Einstein’s relativity. This “non-locality “is built in the Copenhagen interpretation and Einstein was against the Philosophy of the Copenhagen school.

Einstein had an abiding faith in what may be called realism: the belief that the universe and its laws exist independently of our ability to observe them, and the goal of science was to discover this underlying reality. Einstein was against the probabilistic interpretation of quantum mechanics, he said how a theory based on chance and uncertainty can be a complete theory of reality. Einstein famously attacked the foundation of quantum mechanics by saying "God does not play dice".

Even as late as 1935 when quantum mechanics was enjoying great success Einstein launched a new subtle attack on quantum mechanics in his famous EPR paper[13] he did not question the correctness of quantum mechanics but its completeness. His said "But on one supposition we should in my opinion hold fast: The real factual situation of the system $S_2$ is independent of what is done with system $S_1$, which is spatially separated from the former." This is called the "Einstein's locality principle".

To resolve the fight between Einstein's locality principle and quantum mechanics J.S Bell [14] pointed out that the alternative theories based on Einstein's locality principle actually predicts a testable inequality relation .He derived an inequality called the Bell's inequality .In quantum mechanics Bell's inequality is violated.

So if experiment violates Bell's inequality quantum mechanics wins. If experiment does not violate Bell's inequality quantum mechanics loses. Bell published his results but sadly no one took interest for more than a decade until an eccentric band of physicists in the 1960's [10] [16] revived interest in the foundational problems of physics. John Clauser [15] was the first scientist to do experiments to test Bell's inequality.

The result of Clauser's experiment conclusively established Bell's inequality was violated in a way that quantum mechanical predictions were fulfilled. In this controversy quantum mechanics has triumphed with flying colors.

But this interesting field of research is not closed many famous physicists like Roger Penrose [8] are studying effects of strong gravity on quantum mechanics.

4 Einstein's last Dream: space time unification of fundamental forces.

When Einstein discovered the field equation for gravity he was guided by the principle of General covariance, which demand that laws of physics preserve their structural form under general coordinate transformation, most equation will not pass this test and must be rejected. General covariance says that an accelerated observer can interpret the difference between the physical reality he experience and the physical reality of a non-accelerated observer as due to gravitational field. The eminent physicist has suggested General covariance to be called dynamical symmetry because it applies only to gravity. So we see the subtle role of symmetry in explaining a fundamental force like gravity. Einstein had grasped the power of symmetry and put to use in developing his theory of gravity.

In his later years Einstein worked very hard to find a complete unified field theory that would explain the fundamental forces of nature as a manifestation of one unified field, he did not succeed in this task because he did not take into account the reality of quantum mechanics, his approach was geometrical, but nevertheless his philosophy was grand and continues to inspire modern physicists.

Einstein had changed the style of doing physics. Earlier when James Clerk Maxwell had discovered the Maxwell equation the two symmetries, Lorentz invariance and Gauge invariance the key to twentieth century physics was hidden inside his equations but he did not see it. But Einstein first saw symmetry like Lorentz invariance and from this symmetry he derived the laws of special relativity, Again by using the power of General covariance which is a special type of symmetry he discovered the law of gravity. This style made a deep impression on younger physicists. Julian Schwinger used Gauge invariance to explain the origin of electromagnetic force and to show that photon mass is zero. C.N Yang was inspired by this work when he used Yang-Mills field to explain the origin of strong Force. So I have shown the indirect influence of Einstein in the development of modern physics. The grand goal of physics today can be summarized in the points below.

- Electromagnetism + quantum theory= QED
- QED + weak interaction = electroweak theory.
- Strong interaction + quantum theory=QCD
- QCD + electroweak theory = GUT
- GUT + gravity=TOE

GUT stands for Grand unified theory and TOE stands for theory of everything. To find the theory of everything is the dream of modern physics [19] but it has eluded many brilliant physicists even after accepting the reality of quantum physics, perhaps quantum mechanics is not complete but we certainly see the influence of Einstein in the creation of Grand unified theory and Theory of everything.

## 5 Conclusions

Einstein's aesthetic motivation animated twentieth century physics. He believed that equations expressing fundamental laws should have a beautiful harmonious structure. He once wrote "I want to know how God created this world. I am not interested in this or that phenomenon, in the spectrum of this and that element. I want to know His thoughts, the rest are details".

Einstein's working style will continue to inspire many students in the future. His attack on the foundation of quantum mechanics is still not resolved; we are still very far from achieving his dream of complete unification of the fundamental laws.

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