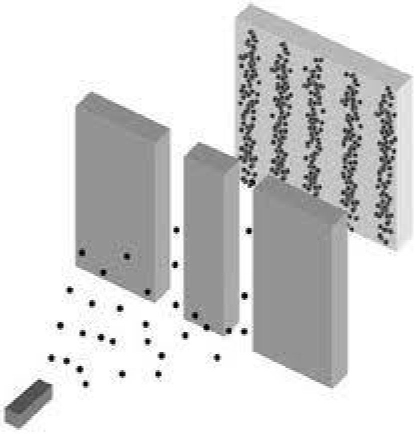
The Double Slit Experiment and the Quantum Measurement Problem

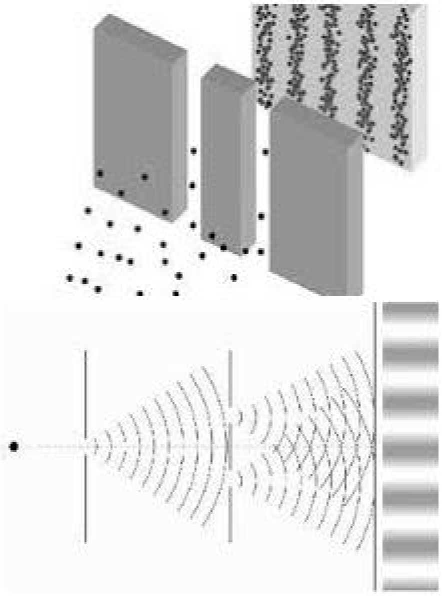
As Feynman frequently pointed out, it's always instructive to examine the measurement problem of quantum theory in the context of the double slit experiment.



Double Slit Experiment

In the above experiment, we're considering photons that are emitted by a laser and are measured on a screen after they pass through the double slit. The photon is a point particle that is measured on the screen at a point of space and time. We literally measure a blip on the screen at a point in space and time when the photon arrives, which is what makes the photon a point particle. The quantum wave-function for the photon is formulated in terms of Maxwell's equations for the electromagnetic field. Maxwell's field equations are the quantum wave equations for the photon and the electromagnetic field is the quantum wave-function. This wave-function only specifies the quantum probability that the photon can be measured at some point in space and time. The quantum wave-function for the photon is always formulated as a sum over or superposition of all possible observable states of the photon. When we actually measure the photon at a particular point in space and time, we're reducing this sum over all possible observable states of the photon to an actual observable state. That reduction of the quantum state is the nature of the quantum measurement problem. The wave-function for the photon is a superposition of all possible observable states of the photon, but with a measurement of the photon at a particular point in space and time, the quantum wave-function is reduced to an actual observable state. Since this superposition of all possible observable states of the photon is quantum entangled, with each observation of the photon, the entangled quantum state is disentangled.

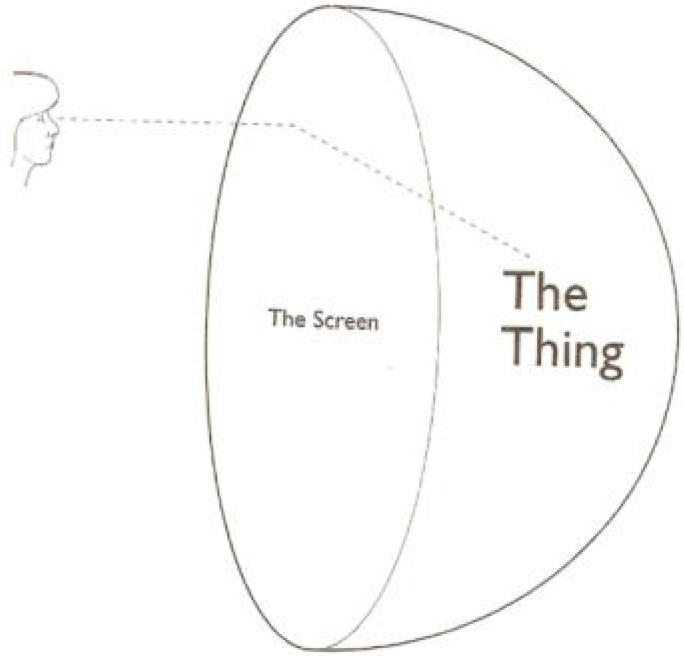
How do we measure a macroscopic electromagnetic field? What constitutes a classical electromagnetic field as described by Maxwell's field equations? The answer is we're measuring many different photon states. We do not directly measure the quantum wave-function for the photon. The quantum wave-function is only a probability amplitude that specifies the quantum probability with which any single photon can be measured as a point particle at some particular point in space and time. However, when we measure many different photons at many different points in space and time, we're sampling that probability amplitude many times, and that repeated sampling of the probability amplitude looks like a macroscopic or classical electromagnetic field. Since the quantum wave-function for the photon is an entangled superposition of all possible observable states of the photon, that probability amplitude displays properties like a quantum interference pattern. When we sample the probability amplitude many times, we generate that quantum interference pattern. That's the only reason the measurement of a macroscopic electromagnetic field displays wave-like behavior like an interference pattern. We have to sample the probability distribution many times with many different photon measurements to recapitulate the quantum interference pattern of the quantum wave-function in a macroscopic electromagnetic field that displays wave-like behavior. The so-called wave-particle duality of quantum theory only reflects the repeated and multiple sampling of the quantum probability distribution.



Interference Pattern of the Double Slit Experiment

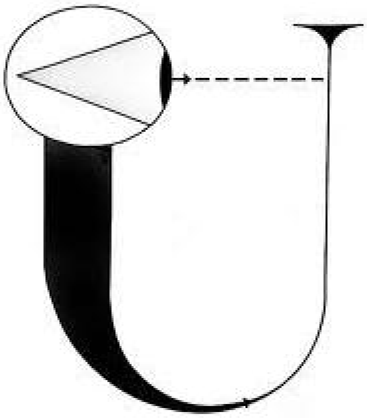
A big problem arises when we try to understand gravity in the same way we understand electromagnetism. Einstein's field equations for the space-time metric are the analogue for gravity of Maxwell's equations for the electromagnetic field, and a graviton is the analogue of a photon. The problem is that if we try to design an experimental apparatus that measures the graviton as a point particle at a point in space and time, we run into a big problem. To measure the graviton as a point particle, we have to concentrate so much energy into such a small region of space that we create a Planck-size black hole in that region of space, and nothing is observable beyond the limits of the event horizon of the black hole. It seems that relativity theory forbids the measurement of the graviton as a point particle. All attempts to do so only create black holes, and then we measure nothing. This is the basic reason why Einstein's field equations for the space-time metric cannot be understood as a quantum field theory in the same way that electromagnetism is understood. Quantum field theory is inherently a point particle description, but it appears that there is no such thing as a graviton description of gravity.

What is the solution for this problem? The answer of course is the holographic principle. The whole freaking thing, which includes the experimenter and his or her experimental apparatus, can be reduced to qubits of information encoded on an accelerating observer's holographic screen. The observer's accelerated motion is what gives rise to its event horizon that becomes its holographic screen when qubits of information are encoded on its horizon. The whole scenario, including experimenter and experimental apparatus, is reducible to qubits of information encoded on the observer's holographic screen. Since the qubits are inherently entangled, this leads to the observation of wave-like behavior, like the interference pattern seen in the double slit experiment. Each observation disentangles the quantum state of the observer's entire holographic world as formulated in terms of qubits of information encoded on its own holographic screen.



The Observer and its Holographic Screen

With a thermodynamic interpretation of the holographic principle, we understand that Einstein's field equations for the gravitational space-time metric and Maxwell's equations for the electromagnetic field are only thermodynamic equations of state that describe events that appear to happen in the observer's holographic world when things are near thermal equilibrium. Each observation of such an event by the observer is like the projection of a holographic image from the observer's holographic screen to its point of view at the center of its own holographic world. All perceivable events can be reduced to qubits of information encoded on the observer's holographic screen. Those events are animated in the flow of energy that arises from the observer's own accelerated motion. Holographic projection is how the holographic principle resolves the measurement problem of quantum theory in the context of quantum gravity.



Universal Observer