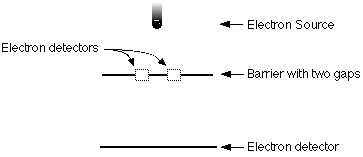
if light consisted of particles, it would travel in straight lines from a source, through two slits in a barrier, and on to a screen placed at the back of the apparatus; at the screen, it would appear as two stripes of light. On the other hand, if light consisted of waves, it would radiate outward from the source toward the two slits, pass through the two slits, and begin radiating anew from each of the two slits as it travels toward the back screen; at the screen, it would appear as a series of stripes of light, representing the interference pattern typical of overlapping, symmetrical waves both emanating from a "stripe" in the barrier, i.e., one of the slits.

if there is a wave, there must be a medium. This is the very nature and essence of a wave. Without a medium, there can be no wave. We don't care what the medium is -- air or water or dominoes or sports fans will do -- but a medium there must be. It had already been firmly established that light can and does travel through a vacuum with complete ease; and a vacuum, by definition, is a space where we have removed absolutely everything that is capable of being removed. Therefore, it appeared that the medium through which light traveled was something so all-pervasive that it filled even a "vacuum." In 1881, the American scientist Albert Michelson invented a device so exquisitely sensitive that it was thought to be capable of detecting the aether. His invention, called an interferometer. If the aether pervades the entire universe, then anything that moves will be in motion relative to the aether. That is to say, we can think of the aether as a large ocean of a medium; we can then think of everything in the universe as being like a fish or a buoy or a scrap of algae -- floating or moving through the ocean of aether. Light waves traveling upstream in this aether current should appear to proceed more slowly than light waves traveling across the current or downstream. Vice versa, light waves traveling downstream should appear to proceed more quickly than light waves traveling across the current or upstream. The full implications of this experimental result are truly astonishing. As an aside, I will note that Einstein's special theory of relativity (1905) was prompted, in significant part, by the need to explain the results of the Michelson-Morley experiment. But, even apart from its leading to the revolutionary ideas of relativity, the Michelson-Morley experiment forced a confounded scientific community to conclude, very reluctantly, that there was no aether. None. Aether did not exist. And I hope that the reader can now appreciate the consequences which this conclusion had for the wave theory of light: light, apparently, was a wave without a medium



1.**Turn off the electron detectors at the slits**. Suppose we take our modified double slit set up -- with electron detectors at the slits -- and leave everything intact. But, we will conduct the experiment with the electron detectors at the slits turned off, so that we will not actually detect any electrons at the slits.

The result upon analysis: an interference pattern at the back wall. So it seems that the electron detectors located at the slits do not themselves affect the electron, even when the equipment is fully functioning and detecting (in a mechanical sense) the electrons, so long as we don't obtain the results of these measurements.

**2.  Leave the electron detectors on, but don't gather the information.** Suppose we take our modified double slit set up -- with electron detectors at the slits -- and still leave everything intact. And we will keep the electron detectors at the slits turned on, so that they will be doing whatever they do to detect electrons at the slits. But, we will not actually look at the count of electrons at the slits, nor will we record the count at the slits in any way, so that we will not be able to obtain any results from these fully-functioning electron detectors.

The result upon analysis: an interference pattern at the back wall. So it seems that the electron detectors located at the slits do not themselves affect the electron, even when the equipment is fully functioning and detecting (in a mechanical sense) the electrons, so long as we don't obtain the results of these measurements.

**3.  Record the measurements at the slits, but then erase it before analyzing the results at the back wall.** Suppose we take our modified double slit set up -- with electron detectors at the slits -- and still leave everything intact. And we will still keep the electron detectors at the slits turned on, so that they will be doing whatever they do to detect electrons at the slits. And we will record the count at the slits, so that we will be able to obtain the results. But, we will erase the data obtained from the electron detectors at the slits before we analyze the data from the back wall.

    The result upon analysis: an interference pattern at the back wall. Notice that, in this variation, the double slit experiment with detectors at the slits is *completed in every respect* by the time we choose to erase the recorded data. Up to that point, there is no difference in our procedure here and in our initial procedure ([pp. 15-17]), which yielded the puzzling clumping pattern. Yet, it seems that if we, in a sense, *retroactively* remove the electron detectors at the slits (not by going back in time to physically remove them, but only by removing the information they have gathered so that it is not available from the time of the erasure going forward into the future), we can "change" the results of what we presume is a mechanically *complete* experiment, so far as those results are determined by a *later* analysis, to produce an interference pattern instead of a clumping pattern. This is mind-boggling.

**.  Arrange the experiment so that we can make an arbitrary choice at some later time, after the experiment is "complete," whether or not to use the information gathered by the electron detectors at the slits.**  Suppose we take our modified double slit set up -- with electron detectors at the slits -- and still leave everything intact. And we will still keep the electron detectors at the slits turned on, so that they will be doing whatever they do to detect electrons at the slits. And we will record the count at the slits, so that we will be able to obtain the results. But (this gets a little complicated), we will   
(1) mix the data from the slits with additional, irrelevant garbage data, and record the combined (and incomprehensible) data;   
(2) design a program to analyze data coming from the slits in one of two ways, either   
    (a) filtering out the garbage data so that we will be able to obtain clean results of electrons going through the slits, or   
    (b) analyzing the mixed-up data so that we will *not* be able to obtain the results of electrons going through the slits; and   
(3) leave it up to a visiting politician which way we actually analyze the data from the slits.

    The result upon final analysis by method (2)(a): a particle clumping pattern appears from the data.   
    The result upon final analysis by method (2)(b): an interference pattern appears from the data.

And, by changing the result, we mean that this arbitrary, delayed choice will affect the actual location of the electron hits as recorded by the electron detector at the back wall, representing an event that was supposed to have happened days, months, or even years in the past.  An event that we suppose has taken place in the past (impingement of the electron on the detector) will turn out to be correlated to a choice that we make in the present.

The proverbial tree has already fallen in the forest, and we can later choose whether or not to listen. And if we choose to listen then the falling tree will have made a noise, and if we choose not to listen then the falling tree will not have made a noise.

 the difference is not whether electrons were run through an electron detector at the slits. It turns out that, so far as experimentalists have been able to determine, the difference is whether the analysis of the results at the back wall is conducted when information about the electrons' positions at the slits is available, or not.

**QKD**Quantum key distribution (QKD) uses individual photons for the exchange of cryptographic key data between two users, where each photon represents a single bit of data. The value of the bit, a 1 or a 0, is determined by states of the photon such as polarization or spin.  
At the sender’s end, a laser generates a series of single photons, each in one of two polarizations: horizontal or vertical. The polarization of the photon is measured at the receiver’s end. If an eavesdropper intercepts the photon to determine its polarization, the photon is destroyed in the process, and the eavesdropper would have to generate a new, duplicate photon to pass on to the receiver.

“That’s fine, as long as there is only a single property or state being sent,” said Don Hayford, director of research at Battelle Memorial Institute, which has implemented a QKD system at its Columbus, Ohio, headquarters. But a second state, such as spin, is also part of the photon. The [uncertainty principle of quantum physics](http://en.wikipedia.org/wiki/Uncertainty_principle) makes it impossible for the eavesdropper to determine both properties of the photon, so it would be impossible for him to send along an accurate duplicate.