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Interaction Free Bomb Testing using Quantum Mechanics

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ABSTRACT

The following paper describes the wierdness of quantum mechanics and discusses the peculiar properties of quantum sized particles. The dual nature of quantum particles is very useful aspect in many of the practical situations. The dual nature of photon is used to test the bombs very effectively without any explosion. This will be a major breakthrough in the field of explosive testing. The great advantage of using quantum mechanics to test the bomb is it is completely interaction free procedure. So by using this method one can reduce the loss to a great extent. Moreover this method is ecofriendly.

Keyword : Contingency

1. INTRODUCTION

Atoms and the particles that compose them are unimaginably small. Electrons have a mass of less than a trillionth of a trillionth of a gram, and a size so small that it is immeasurable. Electrons are small in the absolute sense of the word—they are among the smallest particles that make upmatter.And yet, as we have seen, an atom's electrons determine manyof its chemical and physical properties. If we are to understand these properties,we must try to understand electrons.

In the early 20th century, scientists discovered that the absolutely small (or quantum) world of the electron behaves differently than the large (or macroscopic) world that we are used to observing. Chief among these differences is the idea that, when unobserved,absolutely small particles like electrons can simultaneously be in two different states at the same time . For example, through a process called radioactive decay an atom can emit small (that is, absolutely small) energetic particles from its nucleus. In the macroscopic world, something either emits an energetic particle or it doesn't. In the quantum world, however, the unobserved atom can be in a state in which it is doing both—emitting the particle and not emitting the particle—simultaneously. At first, this seems absurd. The absurdity resolves itself, however, upon observation. When we set out to measure the emitted particle, the act of measurement actually forces the atom into one state or other. Early 20th century physicists struggled with this idea. Austrian physicist Erwin Schrödinger, in an attempt to demonstrate that this quantum strangeness could never transfer alive, not both. However, while unobserved, the cat is both dead and alive. The absurdity of the both dead and dead cat in Schrödinger's thought experiment was meant to demonstrate how quantum strangeness does not transfer to the itself to the macroscopic world, published a paper in 1935 that contained a thought experiment about a cat, now known as Schrödinger's cat. In the thought experiment, the cat is put into a steel chamber that contains radioactive atoms such as the one described in the previous paragraph. The chamber is equipped with a mechanism that, upon the emission of an energetic particle by one of the radioactive atoms, causes a hammer to break a flask of hydrocyanic acid, a poison. If the flask breaks, the poison is released and the cat dies. Now here comes the absurdity: if the steel chamber is closed, the whole system remains unobserved, and the radioactive atom is in a state in which it has emitted the particle and not emitted the particle (with equal probability). Therefore the cat is both dead and undead.Schrödinger put it this way: "[the steel chamber would have] in it the living and dead cat mixed or smeared out in equal parts." When the chamber is opened,act of observation forces the entire system into one state or the other: the cat is either dead or macroscopic world.we examine the quantum-mechanical model of the atom, a model that explains the strange behavior of electrons. In particular, we focus on how the model describes electrons as they exist within atoms, and how those electrons determine the chemical and physical properties of elements. We have already learned much about those properties. We know, for example, that some elements are metals and that others are nonmetals.

2.The Wave Nature of Matter

The heart of the quantum-mechanical theory that replaced Bohr's model is the wave nature of the electron, first proposed by Louis de Broglie (1892–1987) in 1924 and confirmed by experiments in 1927. It seemed incredible at the time, but electrons—which were thought of as particles and known to have mass—also have a wave nature. The wave nature of the electron is seen most clearly in its diffraction. If an electron beam is aimed at two closely spaced slits, and a series (or array) of detectors is arranged to detect the electrons after they pass through the slits, an interference pattern similar to that observed for light is recorded behind the slits . The detectors at the center of the array (midway between the two slits) detect a large number of electrons—exactly the opposite of what you would expect for particles. Moving outward from this center spot, the detectors alternately detect small numbers of electrons and then large numbers again and so on, forming an interference pattern characteristic of waves. It is critical to understand that the interference pattern described here is not caused by pairs of electrons interfering with each other, but rather by single electrons interfering with themselves . If the electron source is turned down to a very low level, so that electrons come out only one at a time, the interference pattern remains . In other words, we can design an experiment in which electrons come out of the source singly. We can then record where each electron strikes the detector after it has passed through the slits. If we record the positions of thousands of electrons over a long period of time, we find the same interference pattern . This leads us to an important conclusion: The wave nature of the electron is an inherent property of individual electrons.Recall that unobserved electrons can simultaneously occupy two different states. In this case, the unobserved electron goes through both slits—it exists in two states simultaneously, just like Schrödinger's cat—and interferes with itself. As it turns out,this wave nature is what explains the existence of stationary states and prevents the electrons in an atom from crashing into the nucleus as they are predicted to do according to classical physics. We now turn to three important manifestations of the electron's wave nature: the de Broglie wavelength, the uncertainty principle and indeterminacy.

3.The Uncertainty Principle

The wave nature of the electron is difficult to reconcile with its particle nature. We can begin to answer this question by returning to the single-electron diffraction experiment. Specifically, we can ask the question: how does a single electron aimed at a double slit produce an interference pattern? We saw previously that the electron travels through both slits and interferes with itself. This idea is testable. We simply have to observe the single electron as it travels through both of the slits. If it travels through both slits simultaneously, our hypothesis is correct. But here is where nature gets tricky. Any experiment designed to observe the electron as it travels through the slits results in the detection of an electron "particle" traveling through a single slit and no interference pattern. Recall that an unobserved electron can occupy two different states; however, the act of observation forces it into one state or the other. Similarly, the act of observing the electron as it travels through both slits forces it go through only one slit. The following electron diffraction experiment is designed to "watch" which slit the electron travels through by using a laser beam placed directly behind the slits. An electron that crosses a laser beam produces a tiny "flash"—a single photon is scattered at the point of crossing. A flash behind a particular slit indicates an electron. passing through that slit. However, when the experiment is performed, the flashalways originates either from one slit or the other, but never from both at once.Futhermore, the interference pattern, which was present without the laser, is nowabsent. With the laser on, the electrons hit positions directly behind each slit, as ifthey were ordinary particles.As it turns out, no matter how hard we try, or whatever method we set up, we can never see the interference pattern and simultaneously determine which hole the electron goes through . It has never been done, and most scientists agree that it never will. In thewords of P. A. M. Dirac (1902–1984),There is a limit to the fineness of our powers of observation and the smallness of the accompanying disturbance—a limit which is inherent in the nature of things and can never be surpassed by improved technique or increased skill on the part of the observer. The single electron diffraction experiment demonstrates that you cannot simultaneously observe both the wave nature and the particle nature of the electron. When you try to observe which hole the electron goes through (associated with the particle nature of the electron) you lose the interference pattern (associated with the wave nature of the electron). When you try to observe the interference pattern, you cannot determine which hole the electron goes through. The wave nature and particle nature of the electron are said to be complementary properties .Complementary properties exclude one another—the more you know about one, the less you know about the other. Which of two complementary properties you observe depends on the experiment you perform—in quantum mechanics, the observation of an event affects its outcome. As we just saw in the de Broglie relation, the velocity of an electron is related to its wave nature . The position of an electron, however, is related to its particle nature . (Particles have well-defined positions, but waves do not.) Consequently, our inability to observe the electron simultaneously as both a particle and a wave means that we cannot simultaneously measure its position and its velocity.

4. Indeterminacy and Probability Distribution Maps

According to classical physics, and in particular Newton's laws of motion, particles movein a trajectory (or path) that isdetermined by the particle's velocity (the speed and directionof travel), its position, and the forces acting on it.Even if you are not familiar with Newton's laws, you probably have an intuitive sense of them. For example, when you chase a baseballin the outfield, you visually predict where the ball will land by observing its path. You dothis by noting its initial position and velocity, watching how these are affected by the forces acting on it (gravity, air resistance, wind), and then inferring its trajectory, as shown in If you knew only the ball's velocity, or only its position you could not predict its landing spot. In classical mechanics, both position and velocity are required to predict a trajectory. Newton's laws of motion are deterministic —the present determines the future. This means that if two baseballs are hit consecutively with the same velocity from the same position under identical conditions, they will land in exactly the same place. The same is not true of electrons. We have just seen that we cannot simultaneously know the position and velocity of an electron; therefore, we cannot know its trajectory. In quantum mechanics,trajectories are replaced with probability distribution maps In quantum mechanics, we cannot calculate deterministic trajectories. Instead, it is necessary to think in terms of the probability maps: statistical pictures of where a quantum-mechanical particle, such as an electron, is most likely to be found. In this hypothetical map, darker shading indicates greater probability. to be found under a given set of conditions.To understand the concept of a probability distribution map, let us return to baseball.Imagine a baseball thrown from the pitcher's mound to a catcher behind home plateThe catcher can watch the baseball's path, predict exactly where it will crosshome plate, and place his mitt in the correct place to catch it. As we have seen, this wouldbe impossible for an electron. If an electron were thrown from the pitcher's mound to homeplate, it would generally land in a different place every time, even if it were thrown inexactly the same way. This behavior is called indeterminacy . Unlike a baseball, whosefuture path is determined by its position and velocity when it leaves the pitcher's hand, thefuture path of an electron is indeterminate, and can only be described statistically.In the quantum-mechanical world of the electron, the catcher could not know exactlywhere the electron will cross the plate for any given throw. However, if he kept track ofhundreds of identical electron throws, the catcher could observe a reproducible statisticalpattern of where the electron crosses the plate. He could even draw a map of the strike zone showing the probability of an electron crossing a certain area, as shown in This would be a probability distribution map. In the sections that follow, we discuss quantummechanical electron orbitals , which are essentially probability distribution maps for electrons as they exist within atoms. An electron does not have a well-defined trajectory. However, we can construct a probability distribution map to show the relative probability of it crossing home plate at different points.

5.Schrodingers Wave Equation

As we have seen, the position and velocity of the electron are complementary properties—if we know one accurately, the other becomes indeterminate. Since velocity is directly related to energy (we have seen that kinetic energy equa position and energy are also complementary properties—the more you know about one, the less you know about the other. Many of the properties of an element, however, depend on the energies of its electrons. For example, whether an electron is transferred from one atom to another to form an ionic bond depends in part on the relative energies of the electron in the two atoms. In the following paragraphs, we describe the probability distribution maps for electron states in which the electron has well-defined energy, but not well-defined position. In other words, for each state, we can specify the energy of the electron precisely, but not its location at a given instant. Instead, the electron's position is described in terms of an orbital , a probability distribution map showing where the electron is likely to be found. Since chemical bonding often involves the sharing of electrons between atoms to form covalent bonds, the spatial distribution of atomic electrons is important to bonding. The mathematical derivation of energies and orbitals for electrons in atoms comes from solving the Schrödinger equation for the atom of interest. The general form of the Schrödinger equation is:

$$\mathbf{H\Psi = E\Psi}$$

The symbol H stands for the Hamiltonian operator, a set of mathematical operations that represent the total energy (kinetic and potential) of the electron within the atom. The symbol E is the actual energy of the electron. The symbol c is the wave function , a mathematical function that describes the wavelike nature of the electron. A plot of the wave function squared (c2) represents an orbital, a position probability distribution map of the electron.

6.Bomb Testing Using Quantum Mechanics

The bomb-testing problem can be described as follows. Say, in a collection of bombs some are duds. The bombs can be detonated by a single photon. Dud bombs will not absorb the photon but good ones will absorb and explode. We can use the counterfactual phenomenon of QM to separate the usable bombs from the duds. If we try to test by detonating the usable ones, then it will destroy all the usable bombs. (The alternate version of the problem would be to detect a bomb without detonating at least some of them). A very sensitive mirror attached to the plunger activates the detonator when a photon that impinges on it is pushing the plunger. The plungers of the duds are stuck, so that they do not get pushed and therefore no detonation occurs. It means a dud one effectively reflects the photons. The fact that the photon did not actually hit the bomb's mirror is enough to know that the photon went through the other path (a "null" measurement). The light source is of very low intensity that itemits only single photon at a time. A photon reaching the beam splitter BS1 has equal chances of passing through or of getting reflected by it. Say, on path 1, a bomb is placed with the triggering mechanism by photon as described above. If the bomb is usable, then the photon is absorbed triggering the bomb. If the bomb is dud one, the photon will pass through unaffected. Let us consider the two cases

Case 1 - The bomb is a dud one:

The photon either gets reflected by the first beam splitter, BS1 and takes path-2 or after passing through BS1, is reflected by the mirror on the trigger of the bomb along path-1. The plunger will not get pushed as it is dud. The system is now like the basic apparatus in which constructive interference occurs along the horizontal path along D1 and destructive along the vertical path towards D2. Therefore, the detector D1 will click, and the detector at D2 will not.

Case 2-The bomb is usable:

As in the above case the two different possibilities are that the photon can take either path-1 or path-2 after encountering the beam splitter BS1. If it takes path-1 it surely gets reflected and by the plunger mirror and the bomb will definitely explode. Since the bomb acts like a detector, the wave function 'collapses' and therefore cannot be in superposition. If the photon takes the upper route path-2 the bomb will not explode yet there will be no interference effect. The photon now either passes through the BS2 or is reflected. The photon must be in either of the detectors D1 or D2. Hence, on the whole, there are only three outcomes: a) The bomb explodes, b) The bomb does not explode and only detector D2 detects the photon. In this case we are sure that the bomb is live though it has not exploded and the photon has not interacted with it, c) The bomb does not explode and only detector D1 detects photon. It is possible that the bomb is usable or that it is a dud. In the last case, the test has to be repeated to see if the bomb will explode or if D2 will click. Usually this is sufficient to recognize all of the dud ones. The tests will identify the one third of the usable bombs without detonating but detonate two thirds of the remaining good ones. Kwiat et al in 1996 devised a technique, using a series of polarizing devices to yield a rate arbitrarily close to one. Here the answer to the query ‘what would happen’ is determined without the bomb going off. Thisprovides an example of an experimental method to answer a counterfactual question.

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