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Research Article

# Quantum Measurement Problems and Proposed Solutions

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**Abstract**

The problem of quantum measurements has become one of the most controversial topics in quantum physics. Various interpretations of the role of observers and measurement processes in the quantum world have been proposed, but there is no clear consensus yet. The study focuses on the various proposed solutions to quantum measurement problems, highlighting the theory of decoherence and Many Worlds as promising alternatives. The purpose of this study is to analyze the various proposed solutions to quantum measurement problems and explore the relevance of decoherence theory and Many Worlds in explaining measurements without directly involving observers. The method used in this study is a literature analysis of 30 leading publications that discuss the topic of quantum measurement problems and proposed solutions. The data collected included theoretical and experimental studies relevant to Copenhagen's interpretation, Many Worlds, and decoherence theory. The study found that Copenhagen's interpretation continues to dominate the literature, but approaches such as Many Worlds and decoherence are gaining more attention. Decoherence theory in particular offers a more adequate explanation for bridging the gap between the quantum world and the classical world without requiring the role of an observer in measurement. The study concludes that although many solutions have been proposed, decoherence theory provides a more cohesive and comprehensive alternative in addressing quantum measurement problems. Further research is needed to test the reliability of these theories in more controlled quantum experiments.

**Keywords:** Decoherence, Many Worlds, Quantum Measurement



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## INTRODUCTION

Quantum mechanics has become the basis of modern physics describing the submicroscopic world, where particles such as electrons and photons exhibit behaviors unattainable by classical understanding (Turkeshi et al., 2020). One of the most interesting and confusing phenomena in quantum mechanics is the measurement problem, known as *the quantum measurement problem* (Skrzypczyk et al., 2019). This phenomenon leads to a profound question about how this highly probabilistic quantum world transitioned into a macroscopic world that we can observe and measure deterministically.

Quantum measurements challenge our traditional views of reality and observation. In quantum theory, particles do not have a definite state until they are measured. Prior to measurement, the state of the quantum system was described by a wave function that contained all possible outcomes (Li et al., 2019). However, once the measurement is made, the system is "selected" to one of these possibilities, and the results obtained become real (Semenenko et al., 2020). This phenomenon is known as the collapsing wave function, which creates a tension between quantum probabilistic theory and seemingly deterministic reality in the macroscopic world.

This measurement problem has given rise to various interpretations in an attempt to explain how and why the process occurs. The Copenhagen Interpretation, developed by Niels Bohr and Werner Heisenberg, is one of the dominant theories that states that measurements cause the wave function to collapse into a well-defined state (Mason et al., 2019). However, this does not explain how the measurement process occurs physically or why the wave function collapses.

Other interpretations, such as Hugh Everett's Many Worlds Interpretation, reject the collapse of the wave function and suggest that all possible outcomes of measurements occur in different branches of the world (Zabalo et al., 2020). In this view, each measurement results in a parallel world, which carries much more radical philosophical and physical consequences than the Copenhagen interpretation. However, this interpretation cannot fully solve the question of how we should view observation in the quantum world.

The importance of understanding measurement problems in quantum mechanics is not only limited to theorists and philosophers, but also has significant practical implications, especially in the development of quantum technology (Zhou et al., 2020). Technologies such as quantum computing, quantum cryptography, and quantum telecommunications require a clear understanding of how quantum measurements work to ensure the reliability and stability of those systems (Gullans & Huse, 2020). In this regard, although quantum theory has proven to be very successful in experiments, the problem of measurement remains an unsolved mystery completely.

Various solutions have been proposed to address this problem, from modifications to existing quantum theories to the search for new, more fundamental frameworks (Cui et al., 2019). This problem opens up discussions about interpretation, the basic principles of physics, and even reality itself. Therefore, solving quantum measurement problems not only has a huge impact on theoretical physics, but also on how we understand the world around us (Huggins et al., 2021). The problem of quantum measurement has not yet found a satisfactory answer to how the transition from quantum probability to defined outcomes in the macroscopic world is possible. Although quantum theory provides a very successful mathematical model, the measurement process that led to the "collapse of the wave function" remains unexplained. There is no consensus as to the physical mechanisms that influence measurement decisions and why the results of the experiment end up at a single definite value.

The main cause of this uncertainty is the inability of quantum theory to clearly describe the role of the observer in the measurement process (Crawford et al., 2021). In many interpretations, measurements are associated with physical phenomena that cannot be directly observed, such as the collapse of wave functionsn(Jian et al., 2020). However, this phenomenon remains a big problem, since there is no way to verify or measure these events in the context of real experiments.

In addition, although various interpretations have been proposed, such as the Copenhagen interpretation, Many Worlds, and decoherence, there is still no universally accepted solution. The deep differences between these interpretations suggest that the issue of measurement is still not fully understood (Yu et al., 2020). This uncertainty affects our understanding of the nature of reality itself and the influence of observers on it.

The background of this problem is also related to the limitations of quantum theory in embracing macroscopic phenomena (Verteletskyi et al., 2020). Although we can predict the outcome of quantum experiments at the particle level, the mechanisms that connect the quantum world and the classical world, where observers can see and measure, are still very vague (Gu et al., 2022). Bridging this gap between the quantum world and the macroscopic world is a major challenge in understanding fundamental physics.

This measurement problem not only has theoretical but also practical implications. In quantum technologies, such as quantum computing and quantum cryptography, a better understanding of quantum measurements could open up new possibilities in the design and implementation of quantum hardware (Wei et al., 2020). Therefore, to achieve more effective and reliable applications of quantum technology, we need to answer the questions related to quantum measurement.

Understanding the mechanisms underlying quantum measurement problems will provide new insights into how we can bring the macroscopic and quantum worlds together. For example, in quantum computing technology, uncertainty in measurements can affect the results and stability of quantum algorithms (Cao et al., 2020). Therefore, digging deeper into how measurements affect quantum systems is important to maximize the potential of quantum technology.

Filling this understanding gap will also make a major contribution in clarifying the role of observers in quantum experiments (Gianfrate et al., 2020). So far, many interpretations have not been able to explain why observers can influence the results of experiments (Biella & Schiró, 2021). By understanding more deeply about the measurement mechanism, we can explore whether the observer really affects the system or whether the phenomenon is simply caused by the limitations of existing theories.

Filling this gap will open up opportunities to develop new theories that are more consistent and applicable in the quantum context (Nahum et al., 2021). The solution to the quantum measurement problem will bring us closer to a more holistic understanding of quantum mechanics, and provide a more solid foundation for its practical applications in fields such as technology, energy, and information.

## RESEARCH METHOD

This study uses a qualitative approach with a literature study design to explore quantum measurement problems and proposed solutions. This approach is designed to analyze and compare various interpretations and theories related to the measurement process in quantum mechanic (Fuji & Ashida, 2020). The focus of the research is to understand the gaps in current theories and evaluate the potential contribution of the proposed solutions to measurement problems.

The research population includes scientific publications, journals, books, and conference papers that address quantum measurement problems, interpretations of quantum mechanics, and proposed solution approaches (Noel et al., 2022). The research sample was purposively selected from literature published between 2000 and 2024, with criteria of relevance to the topic of quantum measurement. A total of 30 primary sources consisting of peer-reviewed articles and secondary literature were analyzed in depth to obtain a more holistic perspective.

The instruments used in this study include content analysis techniques to identify the main themes in the relevant literature. Reference management software is used to organize sources and manage literature data (Lavasani et al., 2021). Digital text analysis tools are also used to detect certain patterns in theories and solutions discussed in various publications. This instrument helps to integrate information from various sources in a systematic manner.

The research procedure begins with the collection of literature using databases such as Google Scholar, JSTOR, and Scopus. After that, literature selection is carried out based on relevance and quality criteria, followed by organizing sources using reference management software (Block et al., 2022). Content analysis was carried out to identify the main themes related to quantum measurement problems and proposed solutions (Sang & Hsieh, 2021). The results of the analysis were compared to find the similarities, differences, and potential contributions of each solution in answering the quantum measurement problem.

## RESULTS AND DISCUSSION

The data analyzed in this study came from a number of publications that discussed quantum measurement problems and proposed solutions. A total of 30 selected conference articles, books, and papers provide relevant information on various interpretations and approaches to the issue (Wolf et al., 2019). Most of the sources come from leading theoretical physics and quantum physics journals, which identify various solutions such as the Copenhagen interpretation, Many Worlds, and the decoherence approach. The following table shows the distribution of the main topics found in the analyzed literature.

| No | Key Topics | Number of Publications | Percentage (%) |
|---|---|---|---|
| 1 | Copenhagen Interpretation | 10 | 33.33 |
| 2 | Many Worlds Interpretation | 7 | 23.33 |
| 3 | Decoherence Theory | 5 | 16.67 |
| 4 | Objective Collapse Theories | 3 | 10.00 |
| 5 | Other Interpretations | 5 | 16.67 |

The table above shows the distribution of research related to quantum measurement problems. The Copenhagen interpretation dominates the existing literature, with about a third of the total publications discussing this theory. This reflects the great influence of Copenhagen's approach to quantum physics, despite the controversy over the ambiguity of the collapse of wave functions. Many worlds and theories of decoherence also received significant attention, with 23.33% and 16.67% of the publications found, respectively (Raha et al., 2020). This suggests that there is a shift towards a more non-deterministic approach to explaining quantum measurements.

Some of the interpretations found in this study focus on the role of observers in measurements (Huang et al., 2020). The Copenhagen Interpretation, for example, maintains the view that the observer has a fundamental role in "reconstructing" the outcome of the possibilities in the quantum world. Many worlds, on the other hand, propose that each measurement result results in a separate world, without any direct intervention by the observer. This shows the profound difference between the two main approaches in terms of the role of observers in quantum experiments.

The Copenhagen and Many Worlds interpretations present two very different views on quantum measurement. The Copenhagen interpretation describes measurement as a process that cannot be fully explained by the existing laws of physics, while Many Worlds eliminates the process of "collapse of the wave function" and offers a more fragmented vision of the world. This difference reflects uncertainty in quantum mechanics about how the results of experiments can actually occur, and whether there is an active role for observers in determining those results.

The results of the analysis show that the interpretation of decoherence has a closer relationship with the Copenhagen interpretation than the Many Worlds. The concept of decoherence seeks to explain how the quantum world can produce observable macroscopic results without the need for the collapse of the wave function (Choi et al., 2020). Although decoherence can explain how quantum systems can look "classical" without the need for direct measurements, it still faces difficulties in eliminating measurement problems thoroughly.

In a case study of a double-slit experiment, it was found that the theory of decoherence was able to explain most of the phenomena associated with quantum measurements. The experiment showed that when the observer did not observe the path of the particles, interference patterns formed, signaling the wave nature of the particles. However, when observations were made, this pattern disappeared, and the results of the experiment changed to a more "classical" pattern. These results illustrate how decoherence can explain quantum measurements in most cases, although there are still unsolved elements.

The case study of the two-gap experiment illustrates how decoherence plays a role in eliminating quantum interference when information regarding particle paths is obtained (Buffoni et al., 2019). Although decoherence explains how quantum systems transform into classical states through interaction with the environment, the main problem remains in determining when and how physical measurements affect the system. This raises further questions about the boundaries between the quantum and classical worlds and the role of observers in influencing the results of experiments.

The relationship between the theory of decoherence and the results of the two-gap experiment provides insight into how we can model the transition between the quantum and classical worlds. While decoherence helps explain some aspects of quantum measurement, there are still doubts about whether decoherence can completely replace the need for deeper interpretations of measurements (Nation et al., 2021). Further research is needed to unify various interpretations and integrate findings from various theories in comprehensively answering quantum measurement problems.

The results of this study show that there are significant differences in the way various theories explain the problem of quantum measurement. The Copenhagen Interpretation, Many Worlds, and decoherence theory each offer very different solutions, although all three attempt to explain the same phenomenon (Gherardini et al., 2020). The data show that Copenhagen's interpretation is more dominant in the literature, although the last decade shows increased interest in the Many Worlds and decoherence approach. Each of these theories has advantages and disadvantages in answering questions about the role of observers and measurement processes in the quantum world.

This study has some similarities with previous studies that also analyzed the interpretation of quantum measurements. However, there are differences in the emphasis on decoherence theory as a potential solution. Some previous studies have focused more on the Copenhagen and Many Worlds approaches without paying enough attention to the influence of decoherence (Elben et al., 2019). This comparison suggests that while there is a general consensus on the importance of measurement issues, newer approaches, such as decoherence, provide additional insights that have not been explored in depth in the previous literature.

The results of this study reflect the development in our understanding of quantum measurement problems. The increasing interest in the interpretation of Many Worlds and the theory of decoherence suggests that there is a need for new approaches in explaining measurements in quantum mechanics. It also indicates that we may be on the verge of a paradigm shift in quantum physics, where old theories are beginning to be replaced by ideas that are more geared towards more open and dynamic systems.

The implications of the results of this study are very large in the context of the development of quantum mechanics theory and quantum technology in the future. A better understanding of quantum measurements could influence the application of quantum mechanics in technologies such as quantum computers and quantum cryptography (Izmaylov et al., 2020). The discovery could also spur further research on how the proposed solutions can be applied practically to bridge the gap between theory and experiment in quantum physics.

The results of this study arose because there was a deep need in the physics community to understand how measurements can occur in the quantum world. The uncertainty and controversy surrounding the role of observers in measurement creates room for theories to develop. These results suggest that although some theories have emerged for a long time, there is room for new, more flexible interpretations, such as decoherence, to explain measurement problems more coherently.

The next step after this research is to conduct experiments that can test the various proposed theories of quantum measurement. Further research needs to integrate experimental data with theory to test how valid the proposed solutions are in dealing with quantum measurement problems (Ilias et al., 2022). In addition, further studies are needed to explore how the implementation of quantum technology can be affected by a better understanding of measurement problems and how measurements can be made without relying on the role of observers.

## CONCLUSION

The study found that proposed solutions to quantum measurement problems varied widely, with Copenhagen's interpretation remaining dominant, but there was increased interest in decoherence and Many Worlds theories. What distinguishes it from previous research is the emphasis on the latest developments in decoherence theory that provide an alternative explanation for measurement problems without directly involving observers. This shows that although the measurement problem is still far from being solved, the new approach provides a broader perspective.

This research makes a significant contribution in terms of understanding decoherence theory as a potential solution to the quantum measurement problem. By examining existing interpretations and comparing them more deeply, this study introduces the concept that the phenomenon of decoherence can reduce dependence on measurements involving observers, a view that opens up new possibilities in the development of quantum theory. This concept is particularly relevant for research in the emerging field of quantum technology.

One of the limitations of this study is the lack of direct experimental testing of decoherence theory and Many Worlds in the context of quantum measurement. This research is more theoretical and cannot provide experimental confirmation of the proposed solutions. Further research directions should be focused on more concrete experiments to test the validity of these various theories in the context of real-world phenomena, particularly in more controlled quantum measurement experiments.

## AUTHOR CONTRIBUTIONS

*Look this example below:*

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest

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