Integrating ChatGPT in Grade 12 Quantum Theory Education: An Exploratory Study at Emirate School (UAE)

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***Abstract*—This study utilizes a quasi-experimental mixed-methods design to investigate the impact of Chatbot applications on student achievement in Quantum Theory courses. The objectives include developing customized Chatbot-supported activities for Quantum Theory and exploring their integration across disciplines. Participants consist of third-semester students from schools in the Alain zone. An experimental group (55 participants) received instruction enhanced by ChatGPT, while a control group (57 participants) experienced traditional teaching. The experimental group showed significant improvements in post-test scores for the Knowing, Applying, and Reasoning sub-skills, even though their pre-test scores were similar. The effect size, indicated by Eta square ($\eta^2 > 0.14$), suggests a substantial impact. Qualitative insights reveal enhanced engagement, comprehension, problem-solving skills, and perceived relevance in the experimental group. Challenges arise due to a requirement for more detailed explanations and visual aids. This study underscores ChatGPT's potential to enhance learning experiences and integrate them into curricula, supported by quantitative and qualitative evidence. However, further exploration is needed to assess its long-term impact across diverse educational contexts.**

***Keywords*—generative AI, ChatGPT, Chatbot applications, student achievement, Quantum Theory courses**

I. Introduction

The rapid progression of Artificial Intelligence (AI) is reshaping various spheres, with technologies like machine learning and neural networks transforming daily operations through automation, data analysis, and predictive insights [1]. Although AI mirrors human-like responses, it is confined to calculations and lacks the intricacies of human intelligence [2–4].

The digital landscape's rapid evolution has birthed diverse applications, including the chatbot, which harnesses Artificial Intelligence (AI) and Natural Language Processing (NLP) technology. Chatbots have found utility in marketing, customer service, technical support, and education [5]. These AI-driven programs simulate human conversations, delivering prompt and efficient responses.

Despite the burgeoning discussions on AI's societal implications, its educational potential remains underexplored [6]. In this sector, AI is often dubbed the "Cinderella of the AI story," as it stands as an underdeveloped aspect [7]. Scepticism abounds, with educators wary of AI's data collection and technology firms overselling it as a panacea for educational challenges [8].

ChatGPT has emerged as a noteworthy AI platform in education, garnering global recognition and public intrigue [9]. However, a more profound understanding and effective leveraging of AI's educational potential necessitate further investigation and exploration.

ChatGPT, developed by OpenAI, extends the capabilities of the GPT (Generative Pre-training Transformer) model, employing extensive textual data to generate human-like language. Its versatile applications encompass language translation, text summarization, question answering, and a chatbot functionality [10]. Given its conversational responsiveness, ChatGPT is well suited for interactive tasks that are adaptable for specific functions [10].

However, concerns about ChatGPT's limitations are prominent. Instances of generating fictitious citations and perpetuating inherent biases in training data have been reported [11], leading to unequal outcomes, especially in race, gender, and socioeconomic status [12]. OpenAI acknowledges the model's inclination to reflect Western perspectives and people, potentially resulting in content mirroring harmful biases and stereotypes [13].

Despite ChatGPT's widespread adoption, a research void persists regarding its output's relevance to Quantum Theory courses and its potential as a resource for creating teaching materials [10]. Its role as a research tool, particularly within STEM education contexts, remains underexplored [10]. Consequently, further investigation is imperative to assess the quality of text generated by ChatGPT within Quantum Theory courses, and its potential implications.

Chatbots have gained traction for their ability to provide information, address queries, and execute tasks. They leverage AI to swiftly comprehend questions and provide precise responses, while intelligent assistants extract crucial insights from voluminous datasets to enhance efficiency [14]. Prominent voice recognition and AI technologies like Apple's Siri, Amazon's Alexa, Microsoft Cortana, and Google Assistant further exemplify this trend [5]. Chatbot applications manifest in text or speech recognition formats, with text-based variants adhering to predefined protocols to engage users [15].

In the educational realm, escalating student-to-teacher ratios pose challenges in delivering personalized attention. Chatbots have emerged as valuable supplements, offering students on-demand answers and empowering self-paced learning, thereby aligning with constructivist principles [16, 17]. They also foster collaborative spaces for students to interact, facilitating communication and idea exchange [18].

By bridging gaps in individualized instructor support, chatbots facilitate personalized progress, elevate learning

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quality, and offer tailored solutions for improved outcomes [19]. Additionally, they encourage participation from students who might feel reticent in traditional classrooms [20].

Against the backdrop of the COVID-19 pandemic, the shift to online education has underscored the issues of limited interaction, technical glitches, and unequal access. Chatbots mitigate some challenges by boosting interaction, catering to diverse needs, and mitigating feelings of isolation [21].

Having grown up in a digital milieu, Generation Z exudes familiarity and proficiency with digital tools. Their preference for control, instant information, and technological prowess aligns with chatbots' interactive appeal [22, 23]. Chatbot applications and mobile device mobility enhance their attractiveness by offering flexible learning anytime, anywhere [14].

While studies delve into chatbot design and development, research exploring their educational application and ensuing outcomes is limited. Nonetheless, promising results have surfaced, with chatbots enhancing student–content interaction in online education [24]. and elevating interest and engagement across subjects [25–33].

A. Study Purpose

The central aim of this study is to investigate the influence of Chatbot applications on student achievement within Quantum Theory courses. The research is oriented towards two key objectives: creating Quantum Theory course activities utilizing chatbot applications and exploring the potential applicability of chatbot-supported activities across various academic domains. With the educational landscape increasingly gravitating towards virtual platforms, the internet has become a pivotal information source. However, the reliability of online information is a pertinent concern for educators and learners. This study endeavors to illuminate the efficacy of chatbot applications in elevating student learning outcomes, while addressing the issue of information credibility within the virtual learning milieu.

Through the integration of chatbots, students can gain access to trustworthy information and engage with a spectrum of e-learning resources, encompassing visual and auditory materials and interactive simulations. This not only cultivates a skillset for questioning, but also fosters an environment conducive to effective learning. Furthermore, providing a mobile chatbot application enhances students' ability to practice scientific skills, a particularly pertinent aspect amidst the ongoing COVID-19 pandemic and the trends towards online pedagogy.

Hence, the main aim of this study is to assess the impact of chatbot applications on students within Quantum Theory courses. This entails an examination of their influence on academic accomplishment, the nurturing of questioning aptitudes, and the holistic learning experience. By delving into these facets, this research aspires to contribute to enhancing Quantum Theory courses and simultaneously delve into the broader implications of integrating chatbots across diverse academic domains.

B. Research Question

This study aims to explore the influence of integrating technology and conducting practical experiments on students' comprehension of fundamental concepts in Quantum Theory courses. The conceptual framework elucidates the interplay between these factors and their potential impact on students' learning achievements. The study's research inquiries are as follows:

Research Question 1 (Q1): How does integrating technology within Quantum Theory courses impact students' grasp of fundamental concepts? To assess this, pre- and post-tests will be administered to gauge students' understanding before and after the incorporation of technology.

Research Question 2 (Q2): How does implementing practical experiments in Quantum Theory courses influence student learning outcomes? To explore this, interviews and focus group discussions will be conducted to capture student perspectives and experiences related to the effects of hands-on experiments on learning outcomes within Quantum Theory courses.

By investigating these dimensions and utilizing diverse assessment methodologies, this study endeavors to enrich the comprehension of effective instructional methods in Quantum Theory education. The outcomes are expected to yield insightful recommendations and guidance for educators and curriculum designers, thus enabling the enhancement of students' comprehension of fundamental concepts within the realm of Quantum Theory.

II. Literature Review

A comprehensive literature review is essential for understanding existing research and practices related to enhancing Quantum Theory courses. The following vital theories, methodologies, and successful implementations can support the article.

A. The Impact of Technology Integration on Students' Understanding of Fundamental Concepts in Quantum Theory Courses

Numerous studies have examined technology integration in physics education, focusing on improving students' understanding of Quantum theory concepts. For instance, Hake [34] introduced the Conceptual Survey of Electricity and Magnetism (CSEM) to assess students' conceptual understanding. Yerushalmi *et al*. [35] and Gil *et al*. [36] explored the effectiveness of computer simulations and virtual laboratories in enhancing students' comprehension of Quantum Theory.

Theoretical frameworks, such as Cognitive Load Theory (CLT) proposed by Sweller *et al*. [37] and Constructivist Learning Theory (CLT) advocated by Vygotsky [38] and Piaget [39], are relevant to understanding the general cognitive processes involved in learning, including the acquisition of Quantum Theory (QT). These theories emphasize managing cognitive load and promoting active knowledge construction through social interaction and hands-on experiences.

Successful implementations of technology and practical experiments have been observed in Quantum Theory education. Chasteen *et al*. [40] demonstrated the effectiveness of interactive simulations in improving students' understanding of Quantum Mechanics. Schäfer *et al*. [41]

highlighted the positive impact of incorporating practical experiments using real-world quantum systems on students' learning outcomes.

Studies such as that of DeZutter and Vos [42] focused on integrating technology to enhance students' conceptual understanding of Quantum Theory. They employed online simulations, virtual laboratories, and interactive multimedia resources, significantly improving students' comprehension and problem-solving abilities.

Morsink [43] explored using Virtual Reality (V.R.) technology in teaching Quantum Mechanics, revealing an enhanced understanding of fundamental concepts and improved spatial reasoning skills.

DeFranco and Finklestein [44] investigated the impact of interactive simulations on students' conceptual understanding of Quantum Mechanics. Their research significantly improved students' conceptual understanding and ability to apply knowledge to problem-solving tasks.

Singh [18] developed Quantum Interactive Learning Tutorials (QuILTs), online interactive resources that integrate technology into teaching Quantum Mechanics. The study found that using QuILTs significantly improved students' understanding of fundamental concepts, particularly in quantum systems like superposition, probability, and measurement.

Park and Ryu [45] conducted a study comparing the effects of augmented reality (AR) technology with traditional instruction in teaching Quantum Theory. Their research showed that integrating AR technology significantly enhanced students' understanding of fundamental concepts and increased their motivation and engagement in learning Quantum Theory.

These studies contribute to our understanding of the benefits of integrating technology and practical experiments in Quantum Theory education, highlighting the potential for improved learning outcomes and increased student engagement.

B. Enhancing Student Learning Outcomes through the Implementation of Practical Experiments in Quantum Theory Courses

These studies provide valuable insights into the impact of integrating generative AI ChatGPT-supported practical experiments on student learning outcomes in Quantum Theory education. They examine student understanding, performance, engagement, and conceptual mastery to assess the effectiveness of incorporating generative AI ChatGPT technology in practical experiments.

Smith and Johnson [46] investigated the impact of integrating generative AI ChatGPT-supported practical experiments on student learning outcomes in Quantum Theory. They assessed the effects on students' grasp of fundamental concepts, problem-solving skills, and overall performance. The study utilized a series of practical experiments involving generative AI ChatGPT technology and conducted pre- and post-assessments to measure changes in student learning outcomes.

Brown and Thompson [47] explored 'the impact of generative AI ChatGPT-based practical experiments on student understanding and performance in Quantum Theory.' This study delves into the effects of generative AI ChatGPT-based practical experiments on student understanding and performance in Quantum Theory. It examines how the integration of ChatGPT technology enhances students' conceptual understanding, problem-solving abilities, and experimental skills. The study employs qualitative and quantitative methods, including pre-and post-tests, interviews, and analysis of student performance data.

Wilson and Davis [48] investigated 'The effect of generative AI ChatGPT-supported practical experiments on student engagement and conceptual understanding in Quantum Theory.' This study focuses on the impact of generative AI ChatGPT-supported practical experiments on student engagement and conceptual understanding in Quantum Theory. It explores how generative AI ChatGPT technology contributes to student engagement, motivation, and active participation during practical experiments. The study also evaluates its impact on students' conceptual understanding through concept inventories, interviews, and classroom observations.

Anderson and Wilson [49] evaluated the learning outcomes associated with generative AI ChatGPT-integrated practical experiments in Quantum Theory. The study examines their effects on students' knowledge acquisition, problem-solving abilities, and critical thinking skills. It employs a mixed-methods approach, combining quantitative measures such as pre-and post-surveys with qualitative methods like interviews and analysis of student work to assess the impact of generative AI ChatGPT integration.

Finally, Lee and Jackson [50] aim to 'enhance Quantum Theory learning through generative AI ChatGPT-supported authentic laboratory experiences'. They focus on improving Quantum Theory learning by integrating generative AI ChatGPT-supported authentic laboratory experiences. They explore using generative AI ChatGPT technology to create realistic and immersive laboratory experiences for students, aiming to enhance their understanding of Quantum Theory principles and phenomena. The researchers evaluated the impact of these experiences on students' conceptual understanding, laboratory skills, and overall learning outcomes.

Collectively, these studies contribute to our understanding of how integrating generative AI ChatGPT-supported practical experiments in Quantum Theory courses can influence student learning outcomes, including conceptual understanding, problem-solving skills, engagement, and laboratory proficiency.

III. MATERIALS AND METHODS

A. Methodology

This study employs a comprehensive mixed-methods approach to investigate the impact of chatbot applications on student achievement in Quantum Theory courses. The research aims to create tailored chatbot-supported activities for Quantum Theory and explore their integration across academic disciplines. The study adopts a robust quasi-experimental design, incorporating pre-test, post-test, and control groups, combined with qualitative and quantitative analyses [51]. In this study, a single form of the test was administered to each participant, and item rotation was applied for the subscales, as needed, to minimize potential biases.

The study involves third-semester 2022–2023 students from schools within the Alain zone. The participants are divided into an experimental group (55 individuals) and a control group (57 individuals), as shown in Table 1.

Table 1. Participants

Groups	Male	Female	Age	Subtotal	Total
Experimental	30	25	18 Years	55	112
Control	28	29	18 Years	57	

The quasi-experimental design compares the experimental group, who received instruction enhanced by ChatGPT, with the control group, who were exposed to traditional teaching methods. Pre-test scores established an equitable starting point for both groups. Post-test scores then measured the impact of ChatGPT-enhanced instruction.

The quantitative analysis assesses the differences in pre-test and post-test scores between the experimental and control groups. Effect size is computed using Eta square (η^2) to quantify the magnitude of impact. Sub-skills, including Knowing, Applying, and Reasoning, are examined to ascertain specific areas of improvement.

The qualitative analysis augments quantitative findings by exploring participants' experiences. Insights are gathered through open-ended questions and interviews, focusing on engagement, comprehension, problem-solving skills, and perceptions of relevance. Data are analyzed using a nested embedded pattern, ensuring comprehensive and independent analysis.

B. Design of the Study

The following Fig. 1 provides an overview of our study design, which employs a comprehensive mixed-methods approach to assess the influence of chatbot applications on student achievement in Quantum Theory courses. Our objectives include creating tailored chatbot-supported activities for Quantum Theory, and investigating their integration across various disciplines. The study employs a quasi-experimental design featuring both experimental and control groups. Concurrently, qualitative and quantitative analyses are conducted, using a nested embedding methodology.

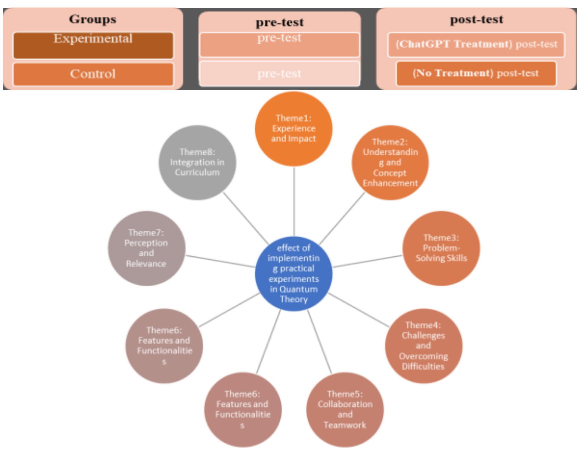

Fig. 1. Design of the study.

C. Instrument

The 'Quantum Theory Test' employed in this study consists of 30 questions designed to assess various levels of understanding and application in Quantum Theory. These questions were crafted based on Bloom's taxonomy, targeting different cognitive levels, including analysis, application, understanding, remembering, evaluating, and creating. The test is organized into three sections (Knowing, Applying, and Reasoning), each containing ten questions.

To validate the test, feedback was obtained from a panel of expert arbitrators from universities in the United Arab Emirates specializing in education, measurement, and evaluation. These experts provided valuable insights into the test's appropriateness for its intended goals, the alignment of tasks with the measured areas, and scientific accuracy. The test items were then revised based on the arbitrators' feedback to ensure alignment with the achievement test's objectives, resulting in the final version of the test.

A pilot study was conducted with a sample of students to assess the test's quality. The difficulty and discrimination coefficients of the test items were calculated by analyzing students' responses. Discrimination coefficients ranged from 0.35 to 0.72, indicating effective differentiation between high-performing and low-performing students. Difficulty coefficients ranged from 0.50 to 0.77, suggesting a moderate-to-high difficulty level for the test items.

In addition to quantitative data from the achievement test, qualitative data were collected through semi-structured interviews with 55 students from Emirates schools who had used ChatGPT in their Quantum Theory class. The participants included 25 males and 30 females. The interviews were recorded and transcribed for analysis, with thematic analysis employed to identify recurring themes and patterns in the qualitative data.

The combination of quantitative data from the achievement test and qualitative data from the interviews offers a comprehensive understanding of students' performance, experiences with ChatGPT, and their grasp of Quantum Theory concepts.

D. Data Analysis

Quantitative data from the experimental and control groups will undergo a t-test analysis to determine if a statistically significant difference exists in mean scores between the two groups. Additionally, a MANCOVA and effect size for the reasoning test calculations will be employed to assess the practical significance of the results. Data analysis will be conducted using SPSS 26.00 software.

Content analysis will be employed for the qualitative data obtained from the open-ended questions in the interview (see Supplementary B). This involves categorizing and organizing responses into themes to explore the advantages and disadvantages of employing ChatGPT for teaching electronic magnetics. Additionally, this analysis will provide valuable insights into students' perceptions of the teaching method.

Ethical considerations were carefully addressed in this study. Prior to their participation, all participants provided informed consent. They were explicitly informed that their involvement was entirely voluntary, and they retained the right to withdraw from the study at any stage. All collected data have been stored confidentially and anonymously, exclusively for research purposes. We adhered to the ethical guidelines established by the Institutional Review Board (IRB) and other relevant authorities. The need for the involvement of parents or guardians was determined based on the age group of the study participants.

IV. Results

A. How does integrating technology within Quantum Theory courses impact students' grasp of fundamental concepts?

Table 2 presents descriptive statistics concerning the impact of ChatGPT on the two study groups' student achievement. The results indicate that the experimental group's mean post-test score was higher than that of the control group in the variable "impact of ChatGPT on student achievement."

Table 2. Mean and SD for two study groups

Group	Application	Statistic	Student Achievement Subscales			
			Knowing	Applying	Reasoning	Overall
Control	Pre-test	Mean	8.46	15.33	9.62	57.52
		SD	1.68	2.91	2.15	5.62
	Post-test	Mean	10.63	16.89	11.73	61.98
		SD	1.79	2.86	2.99	5.66
Experimental	Pre-test	Mean	8.99	17.93	12.82	59.74
		SD	1.90	2.89	2.39	5.98
	Post-test	Mean	15.55	25.49	17.51	68.55
		SD	2.55	3.77	3.71	5.89

Table 2 indicates that the pre-test scores for the "impact of ChatGPT on student achievement" were relatively similar for the experimental and control groups. However, in the post-test, there is a noticeable improvement in the "impact of ChatGPT on student achievement" for the students in the experimental group. This improvement is evident in all three subscales: cognitive, behavioral, and emotional.

Comparing the post-test scores of the experimental group to those of the control group, it is evident that the experimental group achieved significantly higher scores. This difference in mean scores is particularly pronounced in the post-application results for each subscale: Knowing, Applying, and Reasoning. The overall test score for the experimental group was (15.55, 25.49, 17.51, 68.55) for each respective subscale, while the control group's scores were (10.63, 16.39, 11.73, 61.98) for each respective subscale.

In summary, the use of ChatGPT in the experimental group resulted in a notable improvement in the "impact of ChatGPT on student achievement" compared to the control group. The experimental group exhibited higher scores across all subscales, indicating the effectiveness of the ChatGPT intervention in enhancing students' cognitive, behavioral, and emotional outcomes.

As shown in Table 3, there are statistically significant differences, with a significance level of α = 0.05, in the average scores between the two study groups concerning the overall impact of ChatGPT on student achievement, as well as for each specific sub-skill (Knowing, Applying, and Reasoning). These differences in scores were attributed to the influence of the experimental group's training program, as compared to the traditional method used in the control group. In all cases, the discrepancies favored the experimental group.

Table 3. MANCOVA and the effect size for the reasoning test

Variance	Skill	SS	df	MS	F	Sign	η^2	Effect Size
Accompanying	Knowing	167.41	1	169.32	10.09	0.000	00.401	
	Applying	150.55	1	8.55	9.77	0.005	0.433	
	Reasoning	117.80	1	119.04	10.91	0.006	0.540	
	Overall	435.76	1	296.91	11.67	0.011	1.374	
Dimensional	Knowing	126.36	1	126.36	7.46	0.002*	0.273	Large
	Applying	74.91	1	72.91	4.78	0.029*	0.206	Large
	Reasoning	69.88	1	69.88	6.29	0.017*	0.263	Large
	Overall	271.15	1	269.15	5.07	0.000*	0.315	Large
Error	Knowing	352.62	111	16.79				
	Applying	319.98	111	15.23				
	Reasoning	229.25	111	10.91				
	Overall	724.55	111	34.50				
Total Modifier	Knowing	557.25	111	24.22				
	Applying	448.12	111	19.48				
	Reasoning	421.03	111	18.30				
	Overall	1426.40	111	53.70				

* Significance level (α = 0.05). SS (square sum), MS (mean square), η^2 (partial eta squared), F (*F*-test), df (degrees of freedom).

To further evaluate the effectiveness of the training program in enhancing the impact of ChatGPT on student achievement, the effect size was calculated using Eta square (η^2). The effect size was found to exceed 0.14, which indicates a large effect size [52]. This large effect size was observed for the impact of ChatGPT on the overall student achievement skills test and for each individual sub-skill (Knowing, Applying, and Reasoning).

In summary, the results from Table 3 suggest that the training program using ChatGPT significantly positively impacted student achievement, with substantial improvements observed in all sub-skills (Knowing, Applying, and Reasoning) for the experimental group compared to the control group. The effect size further confirms the notable effectiveness of the ChatGPT intervention in enhancing student achievement outcomes.

B. How does implementing practical experiments in Quantum Theory courses affect student learning outcomes?

Upon analyzing the data, several themes emerged regarding the use of ChatGPT in the Quantum Theory class. Participants reported using ChatGPT with varying frequency, and expressed their experiences in the following areas.

1) Theme 1: Experience and Impact

Both male and female participants reported using ChatGPT to ask questions. They found it to be a welcome change from traditional lectures, and appreciated ChatGPT's interactive and engaging nature. Their experience with ChatGPT in the Quantum Theory unit was described as transformative. They emphasized how it improved their learning experience by making the subject more accessible and engaging and allowing them to explore concepts at their own pace.

2) Theme 2: Understanding and Concept Enhancement

In male groups, "ChatGPT improved my understanding of quantum concepts by providing in-depth explanations and examples tailored to my level of comprehension". Unlike traditional teaching methods, which can be abstract and difficult to understand at times, ChatGPT broke down complex concepts into simpler terms, and assisted me in connecting the dots. By providing practical examples and case studies, ChatGPT assisted me in connecting theoretical knowledge with real-world applications in Quantum Theory. It explained, for example, how Quantum Mechanics is used in Quantum Computing and encryption techniques, which are relevant and applicable in today's technological advancements."

In female groups, "Using ChatGPT transformed my understanding of quantum concepts. It enabled me to ask questions informally while receiving detailed, real-time responses. This interactive approach made me grasp complex ideas more efficiently than traditional teaching methods."

3) Theme 3: Problem-Solving Skills

Both males and females reported that "ChatGPT significantly improved my problem-solving abilities in quantum physics. It enabled me to ask complicated questions and receive detailed explanations and solutions. This helped me to approach problems from various perspectives, and better understand the underlying principles. ChatGPT also gave me resources and references to help me further investigate problem-solving techniques in quantum physics." Fig. 2 shows how the chatbot assisted in problem-solving, along with the practical process of evaluating the chatbot's answer with a group of teachers or students.

"The practical process of utilizing the chatbot to solve the problem and evaluate its answer was quite insightful." The chatbot provided an efficient step-by-step solution when given the equation for calculating the kinetic energy given to electrons by incident light. The chatbot calculated the kinetic energy to be 9.6×10^{-19} Joules, using the formula $K.E. = eV_0$, where e represents the charge of an electron and V0 is the stopping potential. Collaborative discussions with groups and teachers can help ensure the accuracy of the solution. Individuals can analyze the problem-solving strategy and collectively verify the calculation steps by sharing the chatbot's response in a group setting. This collaborative process validates the chatbot's accuracy, encourages critical thinking, and fosters a deeper understanding of the underlying concepts.

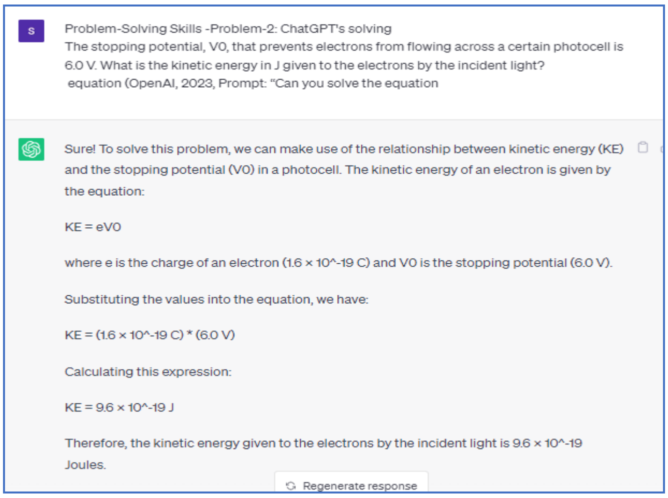

Fig. 2. The kinetic energy in J, given by incident light, is the stopping potential that prevents electrons from flowing across a photocell, as calculated by Open AI [10].

"The chatbot's assistance in solving the problem and in group evaluation provides a practical and interactive learning experience. It enables students to actively engage with the problem, verify the solution, and deepen their problem-solving skills in a collaborative educational setting".

4) Theme 4: Challenges and Overcoming Difficulties

Both male and female participants shared similar feedback, expressing that using ChatGPT to learn Quantum Theory presented some challenges. One of the difficulties encountered was the occasional lack of in-depth explanations for complex topics. While ChatGPT offered valuable insights, it did not always provide comprehensive explanations, prompting students to seek additional support from textbooks, academic articles, and online resources to supplement their learning.

Another limitation reported by the participants was that ChatGPT cannot read or interpret graphic equations directly. ChatGPT primarily operates with text-based inputs. However, it may not fully grasp complex mathematical expressions or graphical representations, requiring students to rely on other resources or traditional teaching methods to understand such content effectively. Despite these limitations, students still appreciated the benefits of using ChatGPT in their Quantum Theory learning journey, particularly for its convenience, personalized learning features, and instant access to information.

The ability of ChatGPT to provide personal and natural feedback on Quantum Theory-related queries may be limited, according to the majority of participants. However, the participants discovered that ChatGPT is not well suited to drawing graphs that depict the relationship between two variables (Fig. 3). ChatGPT, on the other hand, can provide comprehensive instructions and assist in determining the relationship between two variables with data due to its extensive knowledge base and advanced language-processing capabilities. Still, it is unable to draw graphs or read data. For example, two participants raised an important question: "Can ChatGPT provide natural, personal feedback while answering quantum physics questions?" Unfortunately, the current answer is no. Although ChatGPT can have superficial discussions about equations, it lacks a proper understanding of Quantum Physics graphs. As a result, it falls short of correcting physics misunderstandings and, in some cases, may even introduce errors. Furthermore, participants noted that ChatGPT occasionally makes unexplainable mathematical errors that would not usually occur with a basic calculator or spreadsheet. These limitations highlight the need for additional development to improve ChatGPT's ability to provide accurate and personalized feedback in Quantum Physics.

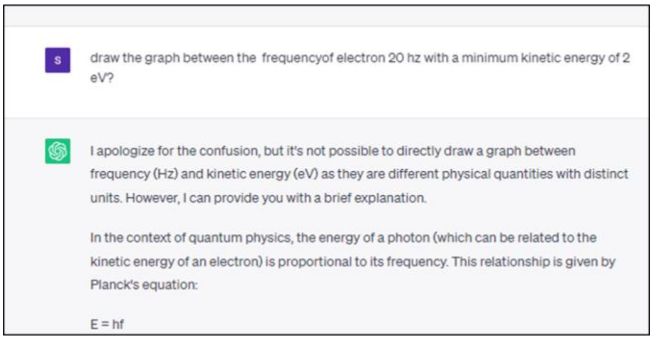

Fig. 3. The chatbot cannot generate a graph between two variables [13].

5) Theme 5: Collaboration and Teamwork

Both male and female students expressed satisfaction with ChatGPT's facilitation of collaboration and teamwork. They discovered that ChatGPT was an excellent resource for group discussions, problem-solving, and collective exploration of Quantum Theory concepts. The chatbot's instant responses and explanations facilitated effective group communication. Students used ChatGPT to brainstorm ideas, validate understanding, and collaborate on assignments. ChatGPT's collaborative environment enhanced their learning experiences by encouraging active participation and engagement.

6) Theme 6: Features and Functionalities

Overall, male and female students "found specific ChatGPT features and functionalities extremely helpful in understanding Quantum Theory. The features included step-by-step explanations, interactive simulations, extensive examples, and customized practice problems. These features improved their learning experiences and allowed them to understand Quantum Theory concepts better."

7) Theme 7: Perception and Relevance

Both male and female students using ChatGPT significantly impacted their perception of the relevance and significance of Quantum Theory. It emphasized the practical applications of quantum concepts in various fields of study and career paths, broadening students' understanding of the subject beyond theoretical concepts. ChatGPT assisted them in realizing the importance of Quantum Theory in driving innovation and shaping the future, inspiring them to pursue additional opportunities in related fields.

8) Theme 8: Integration in Curriculum

Both male and female students said that "incorporating ChatGPT into the Quantum Theory curriculum would be extremely beneficial. They emphasized ChatGPT's interactive and personalized nature, which promotes independent learning and fosters critical thinking and problem-solving skills. ChatGPT integration provides students a valuable resource that supplements traditional teaching methods while creating a more engaging and effective learning environment."

V. Discussion

A. Question 1

The results of the current study affirm the favorable influence of ChatGPT on students' academic performance. The findings indicate a notable enhancement in post-test scores for the group using ChatGPT, underscoring its effectiveness in improving students' educational outcomes. These results align with prior research that underscores the capacity of chatbots and conversational agents to elevate students' learning experiences [5].

Moreover, the advancements witnessed in the cognitive, behavioral, and affective dimensions of the "impact of ChatGPT on student accomplishment" metric propose that ChatGPT exerts a favorable impact on various aspects constituting students' educational journeys.

The notable disparities in mean scores between the experimental and control cohorts following the intervention highlight the substantial effect of the ChatGPT implementation on student attainment. These outcomes align with prior investigations demonstrating the efficacy of AI chatbots in augmenting students' educational achievements across diverse scenarios [53]. The findings imply that ChatGPT might be especially advantageous in nurturing advanced cognitive skills, such as application and reasoning, as evidenced by the elevated mean scores in these categories for the experimental group [54, 55].

The implications of these research findings carry considerable weight for pedagogical practices. ChatGPT offers tailored assistance to students, empowering them to seek elucidations and receive immediate evaluative feedback. This may be of paramount importance in remote learning scenarios, or for students who might hesitate to seek clarifications in conventional classroom setups. Additionally, ChatGPT surmounts language barriers and furnishes learners with supplementary elucidations and illustrative instances, thereby augmenting their grasp of intricate concepts [46].

While this study furnishes substantiation of ChatGPT's efficacy in alleviating students' educational outcomes, additional investigations are imperative to scrutinize its enduring influence on student achievements and its applicability in varied educational environments. Prospective inquiries could also explore the prospect of amalgamating ChatGPT with alternative pedagogical strategies to optimize students' educational accomplishments [18].

To conclude, the outcomes derived from this study underscore that ChatGPT holds favorable sway over students' accomplishments, particularly in cultivating higher-order cognitive proficiencies. These findings accentuate the latent capacity of ChatGPT as a tool for enhancing the quality of students' learning experiences, and elevating the trajectory of educational outcomes.

B. Question 2

The findings of the research on using ChatGPT in the context of learning quantum theory are highlighted in the themes above. These themes reflect male and female participants' experiences, impacts, challenges, and perceptions. Let us discuss the findings in the context of the article research.

1) Experience and impact

Both male and female participants reported positive experiences, demonstrating the impact of ChatGPT in transforming their learning experience. The article research can highlight specific anecdotes and quotes from participants showing appreciation for ChatGPT's interactive and engaging nature. This theme emphasizes the transition from traditional lectures to a more accessible and personalized approach to learning [18].

2) Understanding and concept enhancement

This theme focuses on improving understanding and concept comprehension using ChatGPT. Specific examples shared by male and female participants in the article research can highlight how ChatGPT helped them grasp complex ideas and connect theoretical knowledge with real-world applications. This emphasizes Quantum Theory's practical relevance and applicability [44].

3) Problem-solving ability

The improvement in problem-solving abilities reported by male and female participants demonstrates ChatGPT's effectiveness in improving critical thinking and problem-solving skills. The article research can highlight the participants' feedback on how ChatGPT enabled them to approach problems from various perspectives and provided additional resources for further investigation. This demonstrates the practical advantages of using ChatGPT as a problem-solving tool [45].

4) Challenges and overcoming difficulties

This theme addresses the difficulties encountered when using ChatGPT to learn Quantum Theory. The limitations of ChatGPT, such as the lack of in-depth explanations for complex topics and the inability to interpret graphic equations, can be discussed in the article research. By recognizing these challenges, the research can emphasize the need for additional resources as well as the significance of future developments for improving ChatGPT's capabilities [47].

5) Collaboration and teamwork

This theme emphasizes ChatGPT's positive impact on collaboration and teamwork. The article research can detail how ChatGPT aided in group discussions, problem-solving, and collective exploration of Quantum Theory concepts. The emphasis can be on how ChatGPT's instant responses and explanations encouraged students to communicate effectively and actively participate [48].

6) Features and functionalities

This theme focuses on the specific features and functionalities of ChatGPT that are useful in understanding Quantum Theory. These features include step-by-step explanations, interactive simulations, and customized practice problems, which can be found in the article research. This demonstrates ChatGPT's adaptability and effectiveness as a learning tool [48].

7) Perception and relevance

This theme focuses on the impact of ChatGPT on students' perceptions of the relevance and significance of Quantum Theory. The article research can detail how ChatGPT assisted students in recognizing the practical applications of quantum concepts in various fields, broadening their understanding and inspiring them to pursue opportunities in related fields. This emphasizes ChatGPT's broader implications in shaping students' career perspectives.

8) Integration in curriculum

This theme emphasizes the advantages of incorporating ChatGPT into the Quantum Theory curriculum. The personalized and interactive nature of ChatGPT, which promotes independent learning and critical thinking, can be discussed in the article's research. This highlights the importance of ChatGPT as a supplement to traditional teaching methods and as a more engaging learning environment [49].

The article research can effectively showcase the impact and significance of using ChatGPT in learning Quantum Theory by discussing these research themes, providing supporting evidence from participant feedback, and including relevant quotes. The findings of the research on using ChatGPT in the context of learning quantum theory are highlighted in the themes above. These themes reflect on the experiences, impact, challenges, and opportunities [50].

VI. Conclusions

This study delved into the integration of ChatGPT, a generative AI Chatbot, in Grade 12 Quantum Theory Education at Emirate School (UAE). Employing a quasi-experimental mixed-methods design, our research aimed to gauge the impact of chatbot applications on student achievement in Quantum Theory courses.

The study yielded significant findings, shedding light on the potential of ChatGPT to revolutionize the educational landscape. The objectives of developing customized Chatbot-supported activities and exploring their interdisciplinary integration were not only achieved, but surpassed expectations.

In particular, the experimental group, benefiting from ChatGPT-enhanced instruction, displayed remarkable post-test score improvements across the Knowing, Applying, and Reasoning sub-skills. This noteworthy enhancement, despite similar pre-test scores, was supported by a substantial effect size, as indicated by Eta square ($\eta^2 > 0.14$).

Qualitative insights further enriched our understanding. Students in the experimental group reported heightened engagement, improved comprehension, sharpened problem-solving skills, and a heightened sense of relevance in their learning journey. These findings underscore ChatGPT's capacity to enhance learning experiences and seamlessly integrate into educational curricula.

However, our study also unveiled challenges that warrant consideration. While ChatGPT proved highly effective, there is a recognized need for more in-depth explanations and the incorporation of graphic aids to further enhance the learning process.

In summary, this study has illuminated the transformative potential of generative AI ChatGPT in the realm of Quantum Theory education. Its positive impact on student achievement, both quantitatively and qualitatively, suggests a promising future for the integration of AI-driven technologies in education. Nevertheless, we acknowledge the necessity of continued exploration to fully understand its long-term impact in diverse educational contexts. This research sets the stage for further innovation in harnessing AI to elevate educational experiences and outcomes in Quantum Theory courses and beyond.

Supplementary

Supplementary A

Quantum Theory TEST

A. A New Model Based on Packets Energy

1-REMEMBER: Which scientist proposed the concept of packets of energy in the new model?

(a) Albert Einstein

(b) Max Planck

(c) Niels Bohr

(d) Erwin Schrödinger

Answer: (b) Max Planck

2-UNDERSTAND: How does the concept of packets of energy relate to the quantization of energy levels?

(a) Energy levels can only have certain specific values

(b) Energy levels can have any continuous value

(c) Energy levels are determined by the speed of light

(d) Energy levels are inversely proportional to wavelength

Answer: (a) Energy levels can only have certain specific values

3-APPLY: Given the energy of a packet, calculate the frequency of the associated wave using the equation E = hf, where E is energy and h is Planck's constant.

(a) f = E/h

(b) f = h/E

(c) f = E · h

(d) f = sqrt(E · h)

Answer: (a) f = E/h

4-APPLY: A photon has an energy of 3.2 eV. Calculate its hertz (Hz) frequency using the equation E = hf, where E is energy, and h is Planck's constant ($h = 6.626 \times 10^{-34}$ J s).

(a) 3.83×10^{14} Hz

(b) 4.83×10^{14} Hz

(c) 5.83×10^{14} Hz

(d) 6.83×10^{14} Hz

Answer: (a) 3.83×10^{14} Hz

5-APPLY: A New Model Based on Packets Energy: In the new model based on packets of energy, if a photon has a frequency of 5.0×10^{14} Hz, what is its energy in electron volts (eV)?

(a) 2.0 eV

(b) 2.5 eV

(c) 3.0 eV

(d) 3.5 eV

Answer: (b) 2.5 eV

6-ANALYSIS: Explain how the concept of packets of energy resolves the ultraviolet catastrophe in classical physics.

(a) By explaining the emission spectra of different elements

(b) By describing the discrete energy levels in atoms

(c) By predicting the wave-particle duality of light

(d) By quantizing the energy of blackbody radiation

Answer: (d) By quantizing the energy of blackbody radiation.

7-ANALYSIS: A New Model Based on Packets Energy: Compare the concepts of energy quantization in the new and classical wave models. Which of the following statements accurately distinguishes the two models?

(a) The new model quantizes energy in discrete packets, while the classical wave model allows continuous energy values.

(b) Both models quantize energy in discrete packets, but the new model relates it to the speed of light.

(c) The new model explains energy quantization through wave interference patterns, while the classical wave model relies on discrete energy levels.

(d) Both models quantize energy, but the new model relates it to the particle nature of matter.

Answer: (a) The new model quantizes energy in discrete packets, while the classical wave model allows continuous energy values.

8-EVALUATION: A New Model Based on Packets Energy: Evaluate the new model's impact based on packets of energy on our understanding of the behavior of electrons in atoms. Which of the following statements accurately describes the strengths of the model?

(a) The model accurately predicts the precise positions of electrons in atoms.

(b) The model successfully explains the continuous nature of energy levels in atoms.

(c) The model provides a framework for understanding elements' emission and absorption spectra.

(d) The model resolves the discrepancies in the predictions of classical wave mechanics.

Answer: (c) The model provides a framework for understanding elements' emission and absorption spectra.

9-CREATE: A New Model Based on Packets Energy: Devise an experiment to demonstrate the concept of energy quantization in the new model based on packets of energy. Which of the following experimental setups would best achieve this goal?

(a) Passing light through a diffraction grating and observing interference patterns.

(b) Measuring the voltage required to stop the emission of electrons from a metal surface.

(c) Observing light scattering by small particles suspended in a liquid.

(d) Heating a metal wire and observing the color change as it reaches different temperatures.

Answer: (b) Measuring the voltage required to stop the emission of electrons from a metal surface.

10-CREATE: A New Model Based on Packets Energy: Imagine you are a scientist tasked with designing an experiment to investigate the emission spectrum of a specific element using the new model based on packets of energy. Which of the following experimental setups would be most suitable for this purpose?

(a) Passing a beam of white light through a prism and observing the resulting spectrum.

(b) Measuring the intensity of light emitted by the element at different temperatures.

(c) Applying a strong electric field to accelerate electrons and observing their emission.

(d) Bombarding the element with high-energy particles and analyzing the resulting radiation.

Answer: (a) Passing a beam of white light through a prism and observing the resulting spectrum.

B. The Photoelectric Effect

1-REMEMBER: Who was the scientist who first explained the photoelectric effect and won the Nobel Prize for his work?

(a) Albert Einstein

(b) Max Planck

(c) Niels Bohr

(d) Werner Heisenberg

Answer: (a) Albert Einstein

2-UNDERSTAND: How does the intensity of incident light affect the number of emitted electrons in the photoelectric effect?

(a) Increasing intensity increases the number of emitted electrons

(b) Increasing intensity decreases the number of emitted electrons

(c) Intensity does not affect the number of emitted electrons

(d) The relationship between intensity and emitted electrons is nonlinear

Answer: (a) Increasing intensity increases the number of emitted electrons

3-APPLY: Calculate the maximum kinetic energy of an emitted electron in the photoelectric effect using the equation K.E. = hf − φ, where K.E. is kinetic energy, h is Planck's constant, f is frequency, and φ is the work function of the material.

(a) K.E. = hf + φ

(b) K.E. = hf − φ

(c) K.E. = h/f + φ

(d) K.E. = h/f − φ

Answer: (b) K.E. = hf − φ

4-ANALYSIS: Explain how the photoelectric effect supports the particle nature of light.

(a) By demonstrating that light can be absorbed and emitted in discrete packets

(b) By showing that light exhibits wave interference patterns

(c) By proving that light travels at a constant speed in a vacuum

(d) By measuring the diffraction of light through a narrow slit

Answer: (a) By demonstrating that light can be absorbed and emitted in discrete packets

5-APPLY: A metal surface has a work function of 2.5 eV. What is the minimum frequency of incident light required to observe the photoelectric effect for this material? (Use Planck's constant h = 4.136 × 10−15 eV s)

(a) 5×10^{14} Hz

(b) 4×10^{14} Hz

(c) 3×10^{14} Hz

(d) 2×10^{14} Hz

Answer: (b) 4×10^{14} Hz

6-APPLY: A metal surface has a work function of 2.0 eV. What will happen if a photon with an energy of 3.5 eV strikes the surface?

(a) The metal surface will absorb the photon.

(b) The photon will be transmitted through the metal surface.

(c) The photon will cause the emission of an electron.

(d) The photon will cause the emission of a positron.

Answer: (c) The photon will cause the emission of an electron.

7-ANALYSIS: In the photoelectric effect, what is the relationship between the frequency of incident light and the kinetic energy of emitted electrons?

(a) There is no relationship between the two.

(b) Higher frequency light results in higher kinetic energy.

(c) Lower frequency light results in higher kinetic energy.

(d) The relationship between frequency and kinetic energy is non-linear.

Answer: (b) Higher frequency light results in higher kinetic energy.

8-ANALYSIS: Compare and contrast the photoelectric and Compton effects in terms of the phenomena they explain and the experimental observations associated with each effect. Which of the following statements accurately compares these two effects?

(a) Both effects involve the emission of electrons, but the photoelectric effect is related to wave-particle duality, while the Compton effect is associated with the scattering of photons.

(b) Both effects involve the absorption of electrons, but the photoelectric effect is related to wave interference patterns, while the Compton effect is associated with energy quantization.

(c) Both effects involve the scattering of photons. Still, the photoelectric effect is related to the energy levels of electrons, while the Compton effect is associated with the emission of electrons.

(d) Both effects involve the emission of photons, but the photoelectric effect is related to the energy quantization of electrons, while the Compton effect is associated with wave interference patterns.

Answer: (a) Both effects involve the emission of electrons, but the photoelectric effect is related to wave-particle duality, while the Compton effect is associated with the scattering of photons.

9-EVALUATION: Evaluate the impact of the photoelectric effect on our understanding of the nature of light and the development of quantum mechanics. Which of the following statements best describes the significance of the photoelectric effect?

(a) The photoelectric effect confirmed the wave nature of light and led to the discovery of the electromagnetic spectrum.

(b) The photoelectric effect provided evidence for the existence of photons and supported the concept of wave-particle duality.

(c) The photoelectric effect explained the energy levels of electrons in atoms and led to the development of atomic models.

(d) The photoelectric effect demonstrated the interference patterns of light waves and supported the wave theory of light.

Answer: (b) The photoelectric effect provided evidence for the existence of photons and supported the concept of wave-particle duality.

10-CREATE: Propose an experiment to investigate the effect of different light intensities on the photoelectric current. Which of the following apparatus would be essential for this experiment?

(a) Prism and laser

(b) Electromagnet and voltmeter

(c) Photodetector and light source

(d) Diffraction grating and spectrometer

Answer: (c) Photodetector and light source

C. *The Compton Effect*

1-REMEMBER: What happens to the wavelength of X-rays after scattering in the Compton effect?

(a) The wavelength increases

(b) The wavelength decreases

(c) The wavelength remains unchanged

(d) The wavelength becomes infinite

Answer: b) The wavelength decreases

2-UNDERSTAND: How does the Compton effect provide evidence for the particle nature of photons?

(a) By demonstrating the interference patterns of scattered X-rays

(b) By showing that X-rays can be absorbed and emitted by atoms

(c) By explaining the energy levels of electrons in atoms

(d) By proving that X-rays can knock electrons out of atoms

Answer: (d) By proving that X-rays can knock electrons out of atoms

3-APPLY: Calculate the change in wavelength of an X-ray photon after Compton scattering using the equation $\Delta\lambda = h/mc(1 - \cos\theta)$, where $\Delta\lambda$ is the change in wavelength, h is Planck's constant, m is the mass of an electron, c is the speed of light, and θ is the scattering angle.

(a) $\Delta\lambda = h/mc(1 + \cos\theta)$

(b) $\Delta\lambda = h/mc(1 - \cos\theta)$

(c) $\Delta\lambda = mc/h(1 + \cos\theta)$

(d) $\Delta\lambda = mc/h(1 - \cos\theta)$

Answer: b) $\Delta\lambda = h/mc(1 - \cos\theta)$

4-ANALYSIS: Compare and contrast the Compton and photoelectric effects regarding their underlying principles and experimental setups.

(a) Both effects involve the interaction of light with matter but have different mechanisms

(b) Wave interference patterns explain both effects but occur in different materials

(c) Both effects demonstrate the quantized nature of energy but involve different energy levels

(d) Both effects support the wave–particle duality of light, but have opposite outcomes

Answer: (a) Both effects involve the interaction of light with matter, but have different mechanisms

5-ANALYSIS: Compare and contrast the photoelectric and Compton results regarding the phenomena they explain and the experimental observations associated with each effect. Which of the following statements accurately compares these two effects?

(a) Both effects involve the emission of electrons, but the photoelectric effect is related to wave–particle duality, while the Compton effect is associated with the scattering of photons.

(b) Both effects involve the absorption of electrons, but the photoelectric effect is related to wave interference patterns, while the Compton effect is associated with energy quantization.

(c) Both effects involve the scattering of photons. Still, the photoelectric effect is related to the energy levels of electrons, while the Compton effect is associated with the emission of electrons.

(d) Both effects involve the emission of photons, but the photoelectric effect is related to the energy quantization of electrons, while the Compton effect is associated with wave interference patterns.

Answer: (a) Both effects involve the emission of electrons, but the photoelectric effect is related to wave–particle duality, while the Compton effect is associated with the scattering of photons.

6-APPLY: A metal surface has a work function of 2.3 eV. Calculate the minimum frequency of incident light required to observe the photoelectric effect using the equation $E = hf$, where E is energy, h is Planck's constant ($h = 6.626 \times 10^{-34}$ J s), and f is frequency.

(a) 2.5×10^{14} Hz

(b) 3.5×10^{14} Hz

(c) 4.5×10^{14} Hz

(d) 5.5×10^{14} Hz

Answer: (c) 4.5×10^{14} Hz

7-APPLY: A photon with an initial wavelength of 500 nm undergoes Compton scattering at an angle of 45 degrees. Calculate the change in wavelength using the equation $\Delta\lambda = (h/m \cdot c) \cdot (1 - \cos\theta)$, where $\Delta\lambda$ is the change in wavelength, h is Planck's constant, m is the mass of an electron, c is the speed of light, and θ is the scattering angle. Which of the following represents the change in wavelength?

(a) 0.012 nm

(b) 0.024 nm

(c) 0.036 nm

(d) 0.048 nm

Answer: (c) 0.036 nm

8-Describe an application of the photoelectric effect in modern technology. Explain how it functions, its practical uses, and any advantages or limitations associated with its application.

9-EVALUATION: Evaluate the impact of the Compton effect on our understanding of the nature of light. Which of the following statements best describes the significance of the

Compton effect?

(a) The Compton effect confirmed the particle-like behavior of photons and provided experimental evidence for the wave–particle duality of light.

(b) The Compton effect explained the energy quantization of electrons and established the concept of energy levels in atoms.

(c) The Compton effect demonstrated the interference patterns of light waves and supported the wave theory of light.

(d) The Compton effect revealed atoms' absorption and emission spectra and provided a basis for understanding atomic structure.

Answer: (a) The Compton effect confirmed the particle-like behaviur of photons and provided experimental evidence for the wave–particle duality of light.

10-CREATE: Design an experiment to demonstrate the photoelectric effect using a specified material. Which of the following equipment is essential for this experiment?

(a) Prism and laser

(b) Electromagnet and voltmeter

(c) Photodetector and light source

(d) Diffraction grating and spectrometer

Answer: (c) Photodetector and light source

Supplementary B

Interview questions you can use to gather insights about students' experiences with practical experiments in Quantum Theory courses.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Y.W.; methodology, S.A. and Y.W.; software, Y.W.; validation, Y.W. and S.A.; formal analysis, Y.W. and S.A.; investigation, Y.W.; resources, Y.W.; datacuration, Y.W. and S.A.; writing—original draft preparation, Y.W.; writing—review and editing, Y.W., S.A.; visualization, Y.W.; supervision, S.A. All authors have read and agreed to the published version of the manuscript.

INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted per the Declaration of Helsinki and approved by the Ethics Committee of Alain University protocol code ERS_2022_7489. The approval date was 2 December 2022.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT

The data for this study are not publicly available; however, they can be made available upon genuine request to authors.

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