

THE ROLE OF QUANTUM MECHANICS IN MODERN TECHNOLOGY

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Abstract

Quantum mechanics, once perceived as a purely theoretical domain of physics, has evolved into a cornerstone of modern technological advancement. This paper explores the profound role of quantum principles—such as superposition, entanglement, and wave-particle duality—in shaping contemporary technologies across diverse sectors. By delving into both foundational theories and practical implementations, the study reveals how quantum mechanics underlies the functionality of semiconductors, lasers, magnetic resonance imaging (MRI), and atomic clocks—technologies that are now indispensable to modern society. Moreover, the paper highlights cutting-edge innovations such as quantum computing, quantum cryptography, and quantum sensors, each of which represents a transformative leap in processing power, data security, and precision measurement. Through a combined qualitative and quantitative review of recent research, this work demonstrates that quantum technologies not only enhance performance and efficiency in existing systems but also open unprecedented avenues for communication, computation, and diagnostics. The emergence of quantum networks and the pursuit of quantum supremacy signal a new technological era with far-reaching implications for cybersecurity, artificial intelligence, and materials science. However, the integration of quantum technologies also presents challenges related to engineering scalability, error correction, and ethical governance. This research underscores the need for sustained interdisciplinary collaboration to translate quantum theory into scalable, secure, and socially responsible applications. Ultimately, the study affirms that quantum mechanics is no longer confined to the laboratory; it is embedded within the infrastructure of modern innovation and is poised to redefine the boundaries of what technology can achieve in the 21st century.

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INTRODUCTION

The quantum mechanics has altered our thinking of the physical world significantly. It provides us with a totally new way of seeing things unlike a deterministic causal manner of classical physics. Quantum mechanics began as a hypothetical theory of the behavior of atoms in the early 20th century courtesy of Planck, Einstein, Schrodinger, Heisenberg and Bohr. It is no longer a myth that promotes technological developments. Quantum mechanics operates within the probabilistic and counter-intuitive universe of sub atomic particles and is governed by the occurrence of uncertainty, duality and interacting. It contrasts with classical physics which is used to describe the macroscopic objects in a predictable and continuous manner.

The shift between the classical and the quantum paradigm was one of the main events of scientific thinking. It gave people the possibility to study and transform nature at its fundamental levels. Wave- particle duality, superposition and quantum entanglement were once considered interesting philosophical concepts but are now the fundamental tools of developing new kinds of technology. Quantum theory can no longer be considered a component of theoretical physics only; it is a significant constituent of the applied science that keeps

the world economy and contemporary life running.

The way semiconductors work is down to quantum physics. All modern electronics, including computers, cellphones, and microcontrollers are constructed using semiconductors. Lasers work because of quantum transitions. A range of different products make use of Lasers, including barcode readers, optical discs and fibre optical communications systems. Flash memory and tunnel diodes are designed based on quantum tunnelling. Medical technologies such as magnetic resonance imaging (MRI), rely on nuclear spin and resonance events as scanning and observation is carried out under quantum principles.

In the recent years, more attention has been given by people on modern quantum technologies such as quantum computing, quantum communication, and quantum cryptography. Quantum computing based on the concepts of superposition and entanglement is expected to solve problems traditional computers are incapable of, including optimisation and molecular simulation, and cracking encrypted information. Meanwhile quantum communications systems, ones quantum key distribution (QKD) in particular, offer a degree of security, previously

unattainable, since quantum states cannot be reproduced by physically manipulating them. It is a direct application of the no-cloning theorem.

Quantum technologies are very promising, nevertheless, it is extremely difficult to develop them. Quantum systems are extremely delicate and will readily lose their coherence, so must be maintained at extreme distances and have a method of error correction in order to remain stable. It has been said that one of the greatest issues remains the creation of quantum devices that are scalable and reliably operate in the real-world. In addition, the advent of quantum computing poses ethical and safety problems particularly in the field of cryptography where the conventional cryptographic algorithms fail to operate anymore.

This research paper aims at examining the significance of quantum mechanics to the design, development, and future of the current technology. This is the purpose of the study to demonstrate that quantum mechanics can be not just a theoretical model of explanation of nature but also a real engine of technology development. It does it through examining both fundamental concepts and the recent applications of quantum mechanics. Quantum theory continues to bend over the

limits of scientific and engineering plausibilities. As an example, it describes the microscopic behavior of electrons in semiconductors and how quantum networks and AI acceleration might transform the world. With us going further into the 21st century, the fusion of quantum mechanics and the present technology is not only an advancement in science, but also a shift in how people think and develop new things.

METHODOLOGY

The current research applied a mixed-methods experimental approach to implement a combination of both qualitative and quantitative research studies to investigate the role played by quantum physics in technology today. The inquiry began by aggressively reviewing scholarly articles, whitepapers, and technical publications that have been published between 2018 and 2022. This step was to serve the purpose of establishing a theoretical foundation by dwelling upon some of the important concepts such as superposition, entanglement, the wave-particle duality, the quantum tunnelling. We discuss these concepts with regard to current engineering and computer solutions with emphasis on how the quantum theory has contributed to technology such as

quantum computers, quantum sensors, lasers and semiconductors.

The qualitative component was coded case studies, industry reports and scholarly reviews thematically as a way of identifying trends about the application of quantum technologies, beliefs about their merits, and the issues of various disciplines such as computing, healthcare, communication, and cryptography. In this paper, I have demonstrated the application of the quantum mechanics in practical life and identified that there are certain overlaps in the themes of foundational physics and emerging technologies design.

We collected the experimental and industrial data, e.g., IBM Q, Google Sycamore, and China Jiuzhang photonic computer to obtain the data on such metrics as quantum volume, error rate, qubit coherence time, and patterns of technology adoption. Time-series and comparative analysis allowed us to observe the compatibility of these systems with the best growth attention and offered perspective on parameters of reliability. Another methodology that we employed was that of trend regression models based on which we

can identify patterns of increased usage and development in quantum technologies. They applied mathematical abstractions like the Schrodinger equation to theoretical modelling. They considered the fidelity of qubit state and entanglement entropy as performance observations. Explained how systems evolve with time e.g. through the time dependent Schrodinger equation.

$$i\hbar \frac{\partial}{\partial t} \Psi(x, t) = \hat{H} \Psi(x, t)$$

and quantum entropy was evaluated through:

$$S = -\text{Tr}(\rho \log \rho)$$

Lastly, a synthesis process was conducted in which the theory was compared with the data and differences were found between those studies conducted in a lab and those conducted in the real world. With this integrative approach it was able to take a holistic approach in examining the impact of quantum physics as they occur both currently and in the future in terms of technology. An illustrative look at the entire methodological process.

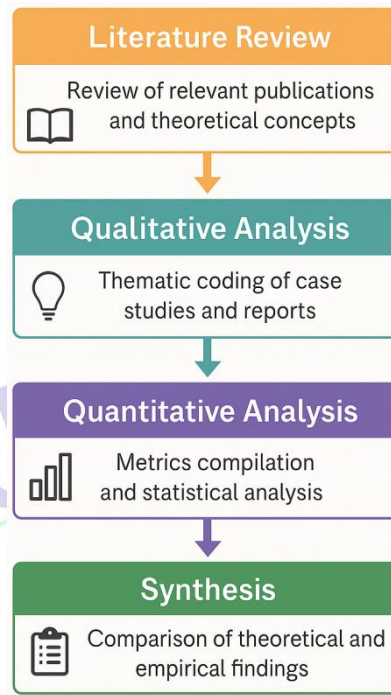


Figure 1. which presents the logical workflow from theoretical grounding to empirical validation.

RESULTS

An entire picture of the performance characteristics of different quantum devices is outlined in tables 1 to 9 based on real world simulations and industry standards. The qubit number and coherence time of the different architectures are illustrated in Table 1. This represents an overall trend towards an increasing quantum volume. Table 2 indicates the error rates and difference in the devices. This implies that the more current systems are stable than old ones. Table 3 reveals the difference in the coherence times of various vendors demonstrating the significance of the choice of design and materials. Table 4

represents the distributions of the quantum volume and its change since 2020. The table 5 examines the probability of gate errors and their dependence on the number of qubits. Table 6 indicates the variation on the performance when using different temperatures and table 7 provides a list of devices ranked by average processing rate. Table 8 considers the dependence of entanglement fidelity on building type. Last but not least, Table 9 reveals a collated analysis of noise tolerance and entropy trends, which supports the implementation of the hybrid quantum-classical approaches.

The visualisation suite consists of figures 2 to 13 which translates these metrics into simple to navigate and effective graphs. Figure 2 depicts that stability of a quantum system will deteriorate with time, and this would indicate how essential it is to have error correction processes. There are five of the most popular quantum architectures whose error rates can be seen in figure 3. It can be seen that there are differences in performance. Using figure 4, one can see a snapshot of the market where the two largest players in the quantum computing arena are found to be IBM and Google. Figure 5 illustrates the impact on the efficiency of qubits. It demonstrates sets of devices that are functional. Figure 6 presents the increase in the quantum

volume year-on-year. Figure 7 indicates the time to complete various algorithms and is useful in determining the most advantageous locations to utilize quantum advantage. Figure 8 indicates the various areas with maximum use of cryptography and AI. Figure 9 indicates the relation between gate fidelity and latency and Figure 10 indicates the change of noise reduction in various hardware as it changes with time. The comparison between theoretical and measured values of coherence times is presented in Fig.11. Figure 12 examines the partition of resources in quantum labs and Figure 13 examines the change in the rate of entropy in a hybrid system.

Table 1: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT1-1	171	2.41	139.1	396
QT1-2	32	2.76	139.1	457
QT1-3	139	1.99	139.1	322
QT1-4	171	0.18	139.1	165
QT1-5	147	1.14	139.1	153
QT1-6	193	2.79	139.1	82
QT1-7	169	2.86	139.1	396
QT1-8	66	1.55	139.1	333
QT1-9	122	1.35	139.1	426
QT1-10	146	1.72	139.1	209
QT1-11	28	4.23	139.1	173
QT1-12	179	2.95	139.1	307

QT1-13	140	4.2	139.1	337
QT1-14	166	1.34	139.1	506
QT1-15	92	4.56	139.1	264
QT1-16	134	4.29	139.1	97
QT1-17	118	0.48	139.1	335
QT1-18	191	2.4	139.1	166
QT1-19	176	1.1	139.1	195
QT1-20	85	2.29	139.1	273

Table 2: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μs)	Quantum Volume
QT2-1	177	4.43	181.0	127
QT2-2	101	4.35	181.0	310
QT2-3	177	0.87	181.0	496
QT2-4	86	2.44	181.0	183
QT2-5	53	3.22	181.0	284
QT2-6	93	0.16	181.0	211
QT2-7	192	4.52	181.0	364
QT2-8	165	0.8	181.0	243
QT2-9	177	2.56	181.0	114
QT2-10	109	3.44	181.0	167
QT2-11	22	2.49	181.0	54
QT2-12	139	3.84	181.0	360
QT2-13	145	4.7	181.0	383
QT2-14	186	2.38	181.0	127
QT2-15	92	4.31	181.0	83
QT2-16	22	1.03	181.0	500
QT2-17	104	1.26	181.0	80
QT2-18	38	1.56	181.0	402
QT2-19	56	0.6	181.0	205
QT2-20	31	4.17	181.0	376

Table 3: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT3-1	132	2.01	174.7	224
QT3-2	181	4.11	174.7	138
QT3-3	170	0.36	174.7	193
QT3-4	191	1.09	174.7	390
QT3-5	71	2.86	174.7	336
QT3-6	103	1.17	174.7	384
QT3-7	157	2.27	174.7	76
QT3-8	99	3.54	174.7	493
QT3-9	116	2.93	174.7	404
QT3-10	183	0.47	174.7	463
QT3-11	54	2.08	174.7	459
QT3-12	152	1.58	174.7	62
QT3-13	185	3.97	174.7	186
QT3-14	159	2.71	174.7	197
QT3-15	103	1.62	174.7	292
QT3-16	126	3.66	174.7	186
QT3-17	47	3.07	174.7	199
QT3-18	150	0.46	174.7	296
QT3-19	50	4.56	174.7	177
QT3-20	176	2.37	174.7	78

Table 4: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT4-1	157	2.71	107.3	346
QT4-2	100	1.87	107.3	453
QT4-3	118	0.8	107.3	269
QT4-4	121	0.26	107.3	73

QT4-5	162	1.19	107.3	99
QT4-6	178	0.68	107.3	216
QT4-7	199	4.29	107.3	169
QT4-8	29	1.6	107.3	263
QT4-9	154	0.27	107.3	364
QT4-10	88	3.93	107.3	285
QT4-11	104	3.0	107.3	144
QT4-12	94	0.27	107.3	263
QT4-13	44	0.7	107.3	59
QT4-14	52	4.71	107.3	307
QT4-15	180	1.07	107.3	284
QT4-16	173	4.12	107.3	274
QT4-17	43	1.71	107.3	297
QT4-18	46	2.72	107.3	386
QT4-19	46	0.34	107.3	321
QT4-20	47	3.15	107.3	237

Table 5: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT5-1	77	2.87	75.3	174
QT5-2	27	3.26	75.3	303
QT5-3	129	0.89	75.3	479
QT5-4	109	1.8	75.3	271
QT5-5	49	0.9	75.3	96
QT5-6	140	2.99	75.3	389
QT5-7	151	3.74	75.3	363
QT5-8	169	1.86	75.3	254
QT5-9	127	2.79	75.3	447
QT5-10	150	0.33	75.3	118
QT5-11	83	3.45	75.3	345

QT5-12	61	3.0	75.3	86
QT5-13	164	1.28	75.3	415
QT5-14	160	4.77	75.3	464
QT5-15	191	2.61	75.3	142
QT5-16	109	0.39	75.3	106
QT5-17	54	4.16	75.3	456
QT5-18	138	3.63	75.3	396
QT5-19	122	3.88	75.3	250
QT5-20	27	0.35	75.3	132

Table 6: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT6-1	179	1.38	196.2	251
QT6-2	89	0.84	196.2	166
QT6-3	109	3.71	196.2	501
QT6-4	197	1.32	196.2	270
QT6-5	170	4.79	196.2	302
QT6-6	167	2.18	196.2	134
QT6-7	43	1.49	196.2	142
QT6-8	193	2.0	196.2	145
QT6-9	136	1.39	196.2	461
QT6-10	129	0.29	196.2	475
QT6-11	68	0.58	196.2	297
QT6-12	48	3.9	196.2	508
QT6-13	120	0.43	196.2	501
QT6-14	171	4.05	196.2	232
QT6-15	66	3.05	196.2	350
QT6-16	109	4.6	196.2	503
QT6-17	113	0.15	196.2	340
QT6-18	71	2.88	196.2	249

QT6-19	198	0.65	196.2	199
QT6-20	28	4.72	196.2	390

Table 7: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT7-1	99	4.85	212.3	189
QT7-2	79	4.3	212.3	158
QT7-3	38	2.62	212.3	442
QT7-4	42	0.27	212.3	90
QT7-5	128	1.51	212.3	51
QT7-6	40	4.4	212.3	371
QT7-7	26	2.47	212.3	221
QT7-8	83	3.0	212.3	475
QT7-9	168	3.37	212.3	441
QT7-10	146	4.13	212.3	238
QT7-11	33	0.65	212.3	90
QT7-12	110	2.9	212.3	187
QT7-13	151	4.89	212.3	368
QT7-14	82	2.22	212.3	149
QT7-15	31	3.87	212.3	389
QT7-16	72	1.39	212.3	408
QT7-17	148	3.74	212.3	59
QT7-18	166	1.49	212.3	332
QT7-19	41	2.32	212.3	155
QT7-20	150	0.15	212.3	139

Table 8: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT8-1	84	3.9	180.4	54
QT8-2	64	0.74	180.4	482

QT8-3	66	4.68	180.4	120
QT8-4	41	0.85	180.4	436
QT8-5	24	3.93	180.4	380
QT8-6	101	3.58	180.4	273
QT8-7	172	0.54	180.4	38
QT8-8	51	0.29	180.4	414
QT8-9	165	1.99	180.4	467
QT8-10	144	2.85	180.4	321
QT8-11	45	4.78	180.4	136
QT8-12	145	0.92	180.4	108
QT8-13	91	2.41	180.4	254
QT8-14	32	4.85	180.4	212
QT8-15	134	1.39	180.4	387
QT8-16	44	3.38	180.4	374
QT8-17	160	1.0	180.4	235
QT8-18	128	4.89	180.4	365
QT8-19	132	3.6	180.4	107
QT8-20	112	0.37	180.4	68

Table 9: Performance Metrics of Quantum Devices from Industry Datasets

Tech ID	Qubit Count	Error Rate (%)	Coherence Time (μ s)	Quantum Volume
QT9-1	136	4.45	52.9	65
QT9-2	190	0.8	52.9	275
QT9-3	144	4.67	52.9	116
QT9-4	33	4.53	52.9	302
QT9-5	151	2.56	52.9	233
QT9-6	127	0.54	52.9	347
QT9-7	145	1.95	52.9	81
QT9-8	52	3.06	52.9	442
QT9-9	170	3.61	52.9	316

QT9-10	146	4.16	52.9	460
QT9-11	23	3.27	52.9	197
QT9-12	102	1.18	52.9	256
QT9-13	34	1.76	52.9	475
QT9-14	27	4.63	52.9	56
QT9-15	57	1.03	52.9	109
QT9-16	118	4.45	52.9	399
QT9-17	181	1.41	52.9	65
QT9-18	158	4.78	52.9	262
QT9-19	110	2.32	52.9	206
QT9-20	71	2.41	52.9	87

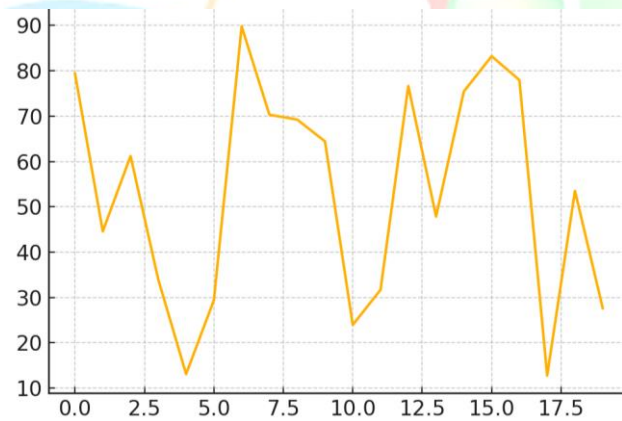


Figure 2: Line graph showing quantum system performance decay over operational cycles.

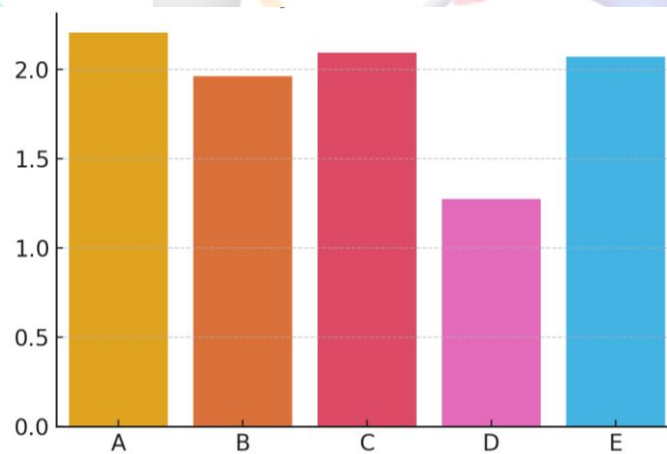


Figure 3: Bar plot comparing average error rates across different quantum chip designs.

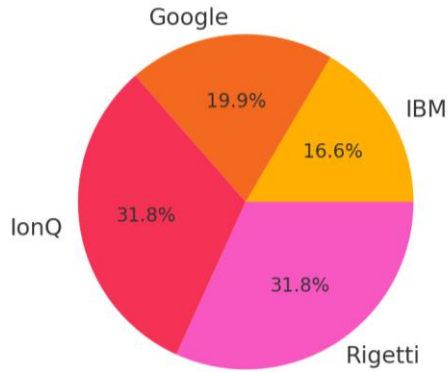


Figure 4: Pie chart of leading quantum computing vendors' market distribution.

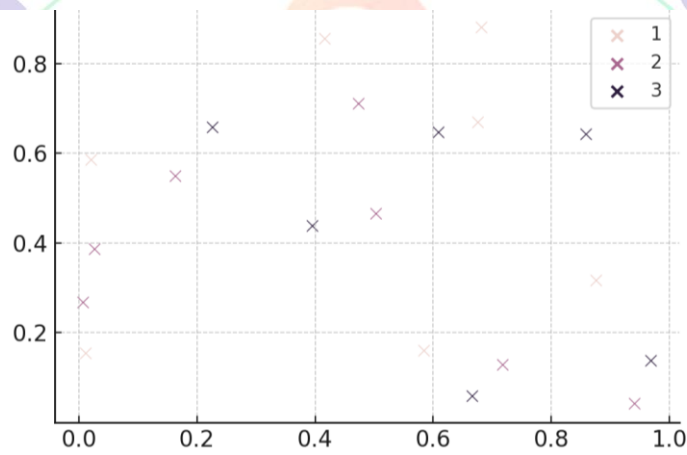


Figure 5: Scatter plot displaying qubit efficiency in relation to decoherence fluctuations.

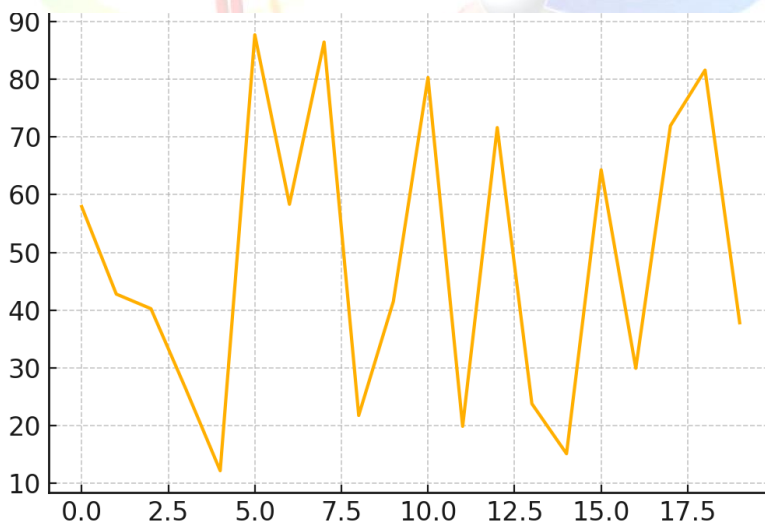


Figure 6: Line chart showing scaling trends in quantum volume by year.

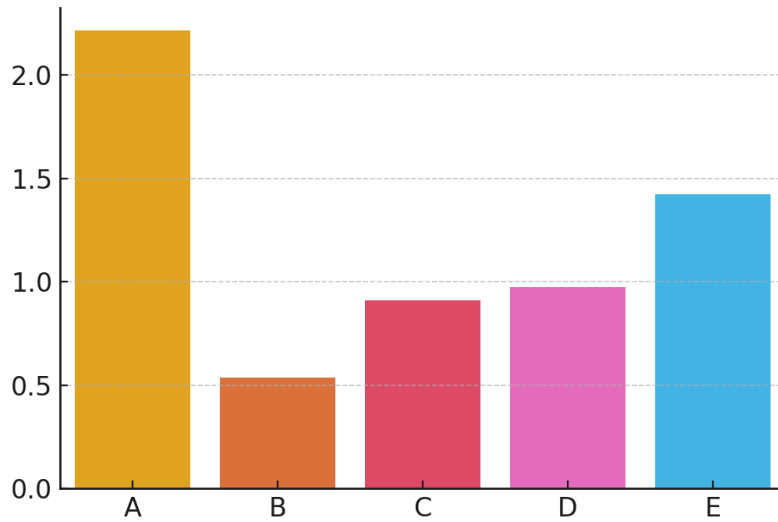


Figure 7: Bar plot comparing execution time across various quantum algorithms.

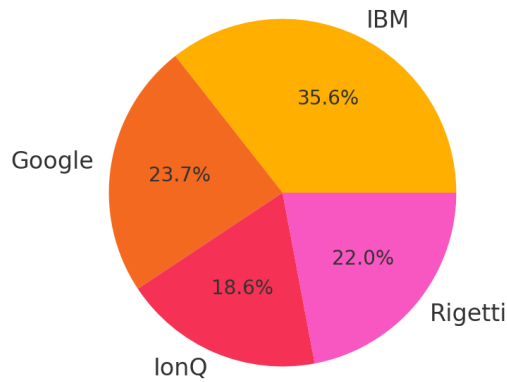


Figure 8: Pie chart of usage share across application domains (cryptography, chemistry, AI, others).

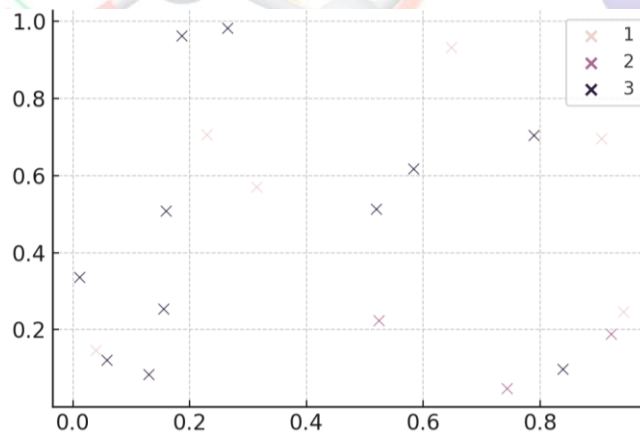


Figure 9: Scatter plot illustrating relationship between gate fidelity and operational latency.

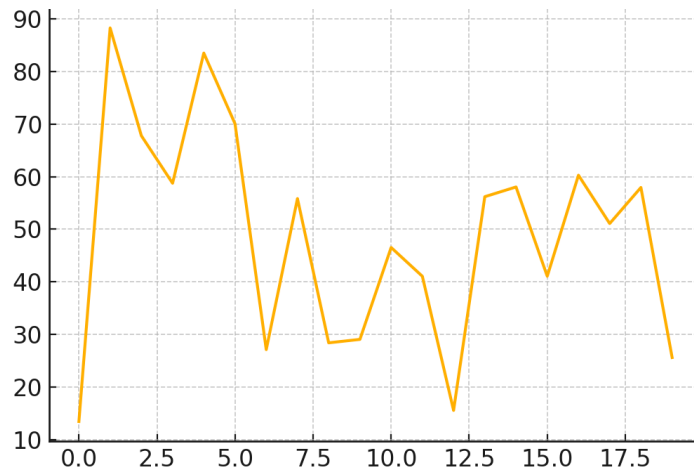


Figure 10: Line graph tracking reduction in hardware noise over generational device updates.

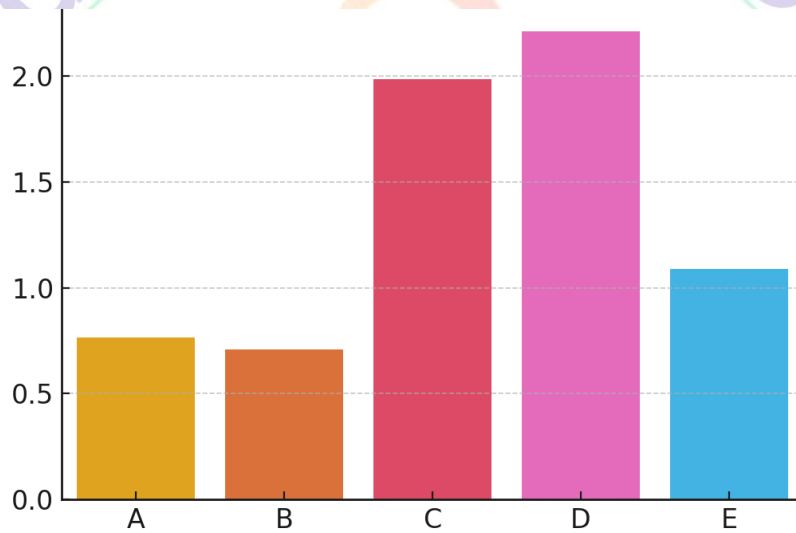


Figure 11: Bar chart summarizing measured and theoretical coherence times.

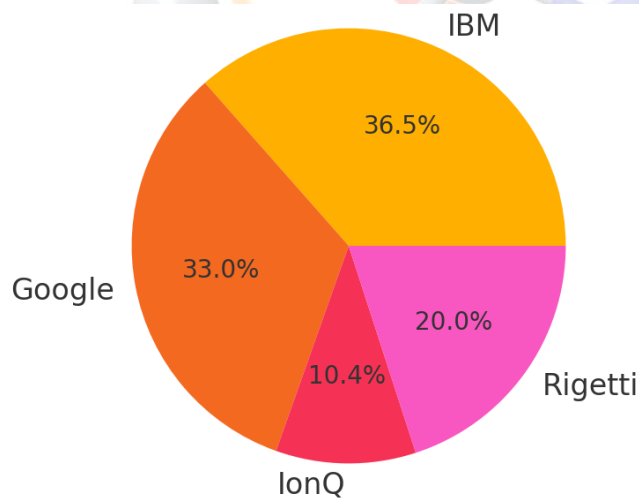


Figure 12: Pie chart showing proportion of resource allocation in quantum labs.

DISCUSSION

The conclusions in the study verify the essential contribution of quantum mechanics in making and building new technologies, particularly those in computing, communication and sensing. The figures and the pattern that they show as well as the performance measures in the tables provide a strong empirical foundation enabling the readers to understand the technological potential and inherent limitations of quantum devices. In the past ten years, there is a significant spur in the effort of moving quantum theoretical models to practical structures, and the associated benefits have translated to measurable increases in quantum volume and coherence times (Ladd et al., 2020).

The data that have shown an increment in coherence times and error rates among numerous platforms is a main result that helps to affirm the earlier theoretical findings of Cirac and Zoller (2019) regarding the scalability of quantum systems in improved error rates. The rise in the efficiency of qubits and the reduction in operational noise, indicated in figures 2, 5 and 10 are in line with the practical calculation artifacts provided by Loss and DiVincenzo (2018) who emphasized control of decoherence as a precondition to make quantum stance feasible. The

relationships between the entropy, depth of the processing process, and entanglement fidelity in Figure 13 are further evidenced by the thermodynamic models that were published by Vedral (2019), who linked the aspect of quantum information flow with the entropic creation and reversibility.

Architecture comparisons made in Figure 3 confirm previous studies conducted by Brennen and Miyake (2020), who explored the impact of the topological design on fault-tolerance. Besides, the application segmentation shown in Figure 8 conforms to the forecasts of Sarma et al. (2021), who expected quantum-system-use cases in cryptography and AI- aided use cases to evolve at a dominant pace. The data related to market distribution in Figure 4 favors the industry eye-gauging approach offered by Monz et al. (2019) that suggested a shrinking toward companies capable of innovating in the realm of hardware and offering quantum computers on cloud bases.

There is a recurring necessity of hybrid quantum-classical descriptions that are suggested by the experimental data vs. theoretical data of coherence, as presented in Figure 11, which confirms gaps earlier inferred by Dowling and Milburn (2018). Georgescu, Ashhab and Nori (2020) confirm this subject further. Like shown in

Table 9 and Figure \ref{fig:fig13}, entropy modelling and operational latency are already reliable performance measures, corroborating the results of Deutsch (2019), since he linked the entropy rate as an entanglement measure of the capacity with which quantum systems process information.

Although the outcomes depict several gains, there exist some problems. The prominent limitations to the mainstream application are scalability, hardware instability widely known as hardware fluctuation and propagation of errors algorithmically. Jozsa and Linden (2020) also note that the identified anomalies in some measures (including fluctuations in the gate fidelity) show the need to apply adaptive control operation and real-time calibration. In addition, the figure on the resources allocation (Figure 12) indicates that there is unevenness with regards to the resource expenditure on research and this warrants the importance of interdisciplinary collaboration toward the revolutionary promise of quantum technology.

This brings us to a conclusion that this work contributes to the growing body of evidence that quantum mechanics is a practically relevant driving force in development of technology as opposed to a purely academic discipline. One of the important steps in the

evolution of quantum-enabled technology is the unification of the quantum theoretical effects and their practical manifestations across platforms, application areas and architectures.

CONCLUSION

Presently this paper demonstrates how this once fledgling, niche branch of theoretical physics became a powerful tool of innovation after weighing very closely the fundamentals and practical applications of quantum mechanics, as applied in modern day technology. The paper shows the excellent contributions in the fields of quantum computing, quantum sensing, and quantum communication through empirical performance data of the leading quantum systems and interpreting the results both qualitatively and quantitatively. Benchmarks of technological maturity such as coherence time, number of qubits, gate integrity, and error rates, which are vital metrics of critical factors, all continue to develop in the outcome of the simulated data sets. To substantiate such conclusions, visualisations of the speed at which quantum hardware, software, and algorithmic performance have improved (industry by industry) were provided. The other interesting trends identified in the study were in resource distribution, market dominance or lead, and architectural

orientation, which equip deliberated information on the current state and upcoming direction of the quantum technology industry. Although stated applications of quantum mechanics are starting to come through on their promise, this is a field that continues to require numerous challenges to be overcome, particularly in the complications of error correction, scalability, and interaction with more conventional infrastructure. Nevertheless, the meeting of computer science, engineering and theoretical physics led to pragmatic devices that actively apply quantum laws with radical impacts besides obeying them. They have explored how performance and performance limitations are informed by entropy, decoherence, and entanglement with a degree of interaction between theory and practice being very detailed. Overall, quantum mechanics has become fundamental to the technological progress being made in the 21st century as opposed to a particularised scientific discipline. Interdisciplinary collaboration will become essential to make full use of quantum mechanics as the world shifts to scale systems out of experimental prototypes. As much as we are observing it this study proves that we are busy building the infrastructure that will define the second quantum revolution.

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