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Quantum Law: the Beginning

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regulation,
risk

Abstract

Objective: to formulate the bases for quantum law as the law of the future, based on the study of quantum phenomena and features of quantum technologies determining the risks and challenges associated with the emergence of these technologies, as well as the analysis of legal regulation of quantum technologies in the Russian Federation and abroad.

Methods: to carry out this research, the authors applied a complex of general scientific methods of systemic analysis and specific methods of engineering and legal sciences. The use of comparative-legal method allowed revealing the main directions of developing legal regulation of quantum technologies in the Russian and foreign law orders based on the analysis of their international and national regulation. The method of legal modeling allowed forming a concept of quantum law, revealing the main vectors of its development and the complex of its ethical-legal principles.

Results: the features and properties of quantum technologies were revealed which can change the development of law with the advent of these technologies; the main risks and challenges were identified which are associated with the development of quantum technologies; the features of quantum technologies regulation in some foreign countries were specified; the trends of developing the quantum technologies regulation in the Russian Federation were identified; the conceptual bases of quantum law were formulated, as well as the vectors of its development.

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Scientific novelty: for the first time in the legal science, a complex analysis of the current national (both Russian and foreign) regulation of quantum technologies was carried out, based on which an attempt was made to substantiate the need to form quantum law and to outline the main vectors of its development.

Practical significance: the research results lay the foundation for forming the concept of quantum law; in this regard, the authors' conclusions and proposals for improving the current regulation of quantum technologies can be used in law-making and law enforcement in this sphere, and may lay the bases for further research in the sphere of quantum technologies.

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Contents

Curiouser and curiouser!
L. Carroll. Alice's Adventures in Wonderland Introduction

Introduction

The results of scientific-technological progress have repeatedly caused our admiration. However, even among digital technological innovations, quantum technologies stand apart. The reason is that the potential of these technologies has not been fully revealed yet, and their properties have not been completely explored. Besides, their introduction and dissemination may have a much larger impact on the future of the humanity than the development of artificial intelligence. However, the most important feature, even a uniqueness, of quantum technologies lies in their physical (natural) essence, based on the laws and phenomena of quantum mechanics (quantum effects) (Arndt et al., 2011; Kholodnaya, 2022).

The key properties of quantum technologies have already changed our usual world. For example, the discovery of quantum mechanics and its main achievements have become one of the reasons for changing the technological paradigm and for the first quantum revolution, which significantly influenced our standard of living. The possibility to control collective quantum phenomena allowed creating particle accelerators, nuclear weapons, lasers, transistor, etc.

Today, we are at the verge of the second quantum revolution, based on three quantum subtechnologies having a large potential: quantum computations, quantum cryptography and quantum sensory and metrology. For example, the possibility to perform quantum computations is one of the expected and predicted events in the academic world. This method of computations will allow performing probability calculations of the complexity unachievable to modern supercomputers.

Development of quantum technologies will facilitate advances in many spheres: from military-industrial complex and automotive industry to medicine and space research. The recognized potential of quantum technologies determined the start of quantum dash of many states towards quantum supremacy.

That is the reason why one of the most important tasks of any state is the adequate and maximally effective coordination of creation, introduction and commercialization of such technologies. Apparently, the search for solution of this task will not be easy. The innovative nature of most digital technologies has already determined the comprehension of the fact that law obsolesces and regulation of social relations requires its transformation and adaptation. Speaking of quantum technologies, their properties can significantly influence the development of social relations, due to which the task faced by law gets even more complicated and formation of a new "quantum" law becomes probable in the future.

Today, quantum technologies are in the focus of attention of the global academic community. A significant number of researches have been published by representatives of engineering sciences both abroad (Belenchia et al., 2022; Ball, 2021; Browne et al., 2017; Chen et al., 2021; Kearney & Perez-Delgado, 2020; Kumar et al., 2022; Mosca, 2018; Taylor, 2020) and in the Russian Federation (Sigov et al., 2020; Petrenko, 2022).

Representatives of jurisprudence also do not avoid quantum technologies. Notably, foreign researchers actively elaborate the concept of quantum computational law (Atik, 2022; Ritter, 2015), ethics of quantum technologies (Atik & Jeutner, 2021; Jeutner, 2021), or research the legal aspects of applying quantum technologies in specific fields of jurisprudence (Yanamadala & Seema, 2022). At the same time, the Russian scientists focus on elaborating the conceptual and categorical framework in the sphere of quantum technologies, as well as on the creation of the bases of legal regulation of these technologies and features of their regulation in modern Russia (Kholodnaya, 2022; Dobrobaba et al., 2022; Naumov & Stankovskiy, 2019).

It should be noted that the research do not comprise a complex analysis of the current international, national (both Russian and foreign) regulation of quantum technologies, as well as defining such features of quantum technologies which cause the necessity to form quantum law.

In this regard, the objective of this research is to formulate the concept of quantum law as the law of the future.

The research tasks are:

1) to study the properties and features of quantum technologies;

2) to determine the threats, risks and challenges associated with the development of quantum technologies;

3) to reveal the features of regulation of these technologies in foreign countries;

4) to analyze regulation of quantum technologies in Russia;

5) to form the main vectors of development of quantum law.

To carry out the research, a complex of general scientific methods was applied, as well as the methods of scientific cognition used in technical and legal sciences.

The methods underlying the technical (engineering) constituent of the research are: the methods of systemic analysis, the methods of quantum mechanics, and models and methods of discrete mathematics and software engineering.

The methods underlying the juridical constituent of the research are: the comparative-legal method and the method of juridical modeling. The use of the comparative-legal method allowed revealing the main directions of development of quantum technologies legal regulation in the Russian and foreign systems of justice, based on international and national regulation of quantum technologies. The method of juridical modeling allowed formulating the concept of quantum law as the law of the future, revealing the main vectors of its development and the complex of its ethical-legal principles.

1. The current level of development of quantum technologies

1.1. Features of quantum phenomena and their main properties

The central term in the sphere of quantum technologies is a quantum bit, or qubit. A qubit is actually any quantum system (possessing at least two states). At that, quantum states are recorded as $|0\rangle$ and $|1\rangle$ (Dirak, 1979) (Fig. 1).

Note that the general state of such system with two states can be presented as a basis set superposition (Fig. 1) (S. A. Petrenko et al., 2021).

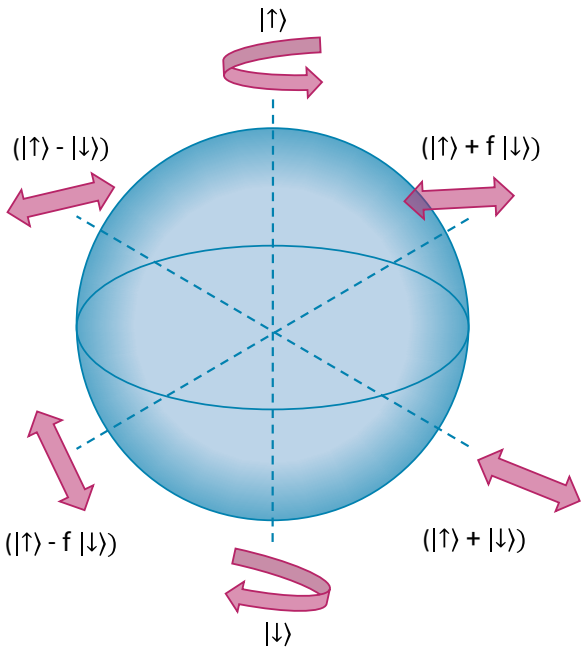


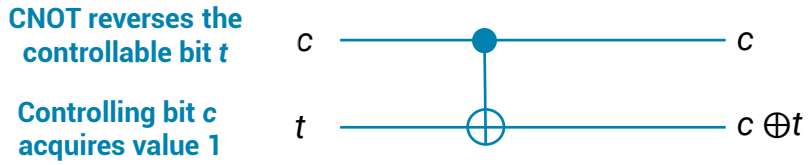
Figure 1. States of a qubit
Source: (S. A. Petrenko et al., 2021).

The register composed of two-level qubits may store simultaneously up to numbers in quantum superposition. Accordingly, if the register is complemented with additional qubits, it will result in an exponential growth of the volume of information stored in the register.

Thus, an example is a 250-qubit register of atomic size, which can store more numbers than there are atoms in the Universe.

This allows formulating another exclusive feature of quantum computation: using the superposition operation only, one may perform a series of mathematical operations, each of which operates all the stored data simultaneously (S. A. Petrenko et al., 2021).

Usually, the quantum computational algorithm is understood as a series of consequential unitary operations. At that, the operations will always be executed according to a previously determined order. This implies the absence of the well-known logical condition "IF…TNEN", the use of which allows us to change the order of calculations. Instead, there are conditional operations realized in gate CNOT (Fig. 2) (Duplij & Shapoval, 2007).



Action of CNOT element

$|00\rangle \mapsto |00\rangle, |01\rangle \mapsto |01\rangle, |10\rangle \mapsto |11\rangle, |11\rangle \mapsto |10\rangle$

Figure 2. Applying CNOT gate (operator)
Source: (S. A. Petrenko et al., 2021).

The above said determined the possibility to formulate a number of basic principles of creating the "Holy Grail" of the quantum theory – a quantum computer: a) a qubit can be initialized in the known state (for example, state $|0\rangle$); b) it can also be measured in the basis $\{|0\rangle,|1\rangle\}$; c) a universal quantum gate can influence any bounded subset of qubits; d) The state of qubits can be changed exclusively by the above said transformations. According to some researchers, quantum computers will be able to solve certain computational tasks a lot more effectively than classical ones (Duplij & Shapoval, 2007).

However, it is still rather hard to maintain qubits in a relatively stable (coherent) state, as any interaction of the system with the external environment leads to the loss of coherency (decoherence), hence, to disorderly closedown of the computer. This effect leads to a violation of quantum steps of computation, which, in turn, makes nonsatisfiable the requirement of inalterability of the quantum system state (Deutsch & Jozsa, 1992), as there is no ideal quantum gate, nor a completely isolated system. It appeared to be a rather difficult engineering task to construct a quantum system in which the loss of coherency would take place less than once per one million uses of XOR gate. According to researchers, we are yet to know whether the physics laws allow finding the lower limit of the coherence loss rate (Deutsch & Jozsa, 1992; Shor, 1994, 1999; A. S. Petrenko et al., 2021).

1.2. Main directions of quantum technologies development

The main directions of quantum technologies development today are the following (Fig. 3).

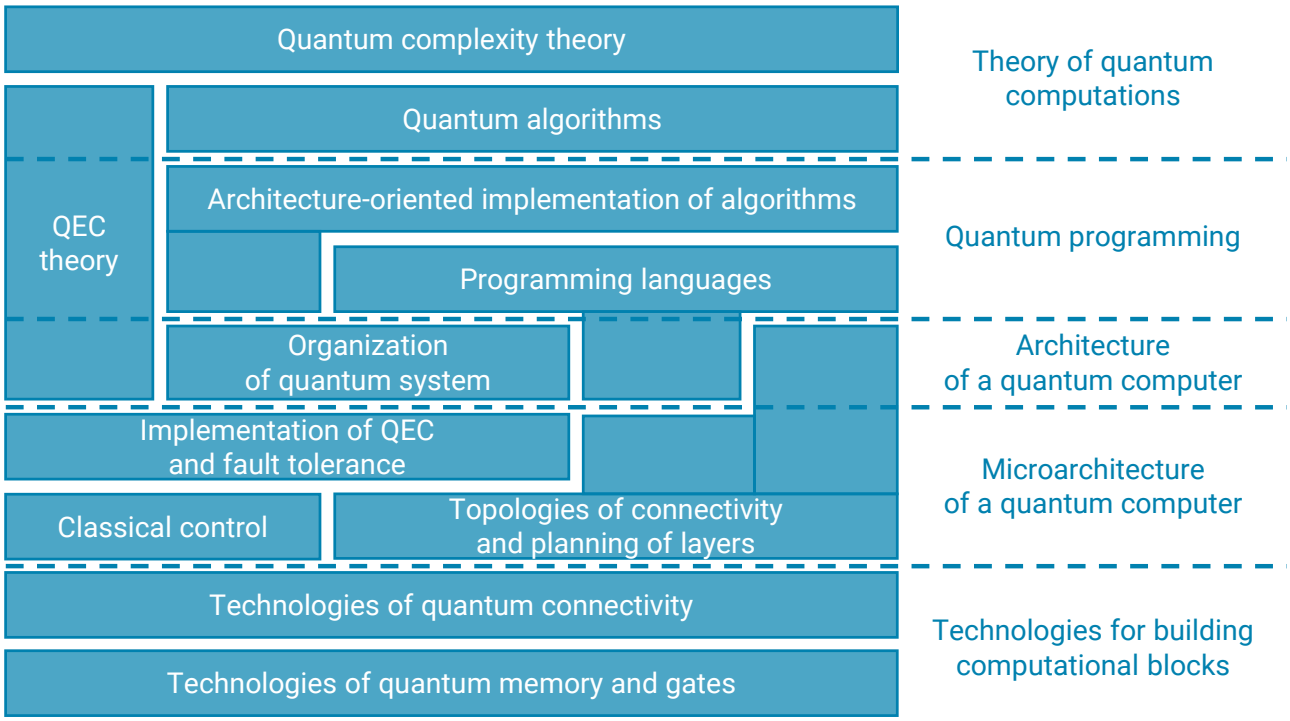


Figure 3. Main directions of quantum technologies development
Source: (S. A. Petrenko et al., 2021).

The most popular are such directions of quantum technologies development as quantum computers, quantum sensory and metrology, and quantum (postquantum) cryptography. As quantum computers were discussed above, we should discuss two other important directions of quantum technologies development.

The development of such direction as quantum sensory and metrology is due to the ability of quantum sensors to perform high-precision, and in future – highly-sensitive measurements. Such sensors will allow achieving breakthroughs in medicine, defense and security, oil-extraction and construction, as well as creating perfect navigation systems.

Postquantum cryptography is one of the most demanded quantum technologies. The idea of making a cipher which cannot be broken has been rather long reigning over scientists' minds. That is why quantum cryptography as the area of research is under the spotlight of most modern states. Researchers conditionally divide quantum cryptography into quantum-secure and quantum-unsecure ones (A. S. Petrenko et al., 2021). Notably, in some countries, like the United States of America (further – US) and the European Union states (further – EU), the transition to sustainable postquantum cryptography is planned for as early as 2025 (A. S. Petrenko et al., 2021).

1.3. Challenges and risks associated with the emergence of quantum technologies

The main challenges posed by quantum technologies before law are the following.

First, these are the challenges to modern economy associated with the availability of financial resources. Thus, the race for quantum supremacy will require from the states to accumulate means for the development of such technologies within a country, which may be problematic under the contemporary economic conditions.

Second, it is a challenge to a national security system of a state. Actually, the emergence of such technologies in one country will become a threat for the national security of others. This, in turn, will require adequate and "symmetrical" responses, which can be provided only if the state possesses quantum technologies of a similar or higher level of development.

Third, the emergence of quantum technologies will entail an increase of digital gaps between those who possess quantum technologies and those who do not, which may result in amplification of inequality. This will also become a global challenge and will require from the states to jointly search for solutions of this problem.

One should also identify the risks which can emerge due to the creation and dissemination of quantum technologies. These are as follows:

1) destabilization of the global financial system;
2) violation of data confidentiality and security;
3) loss of trust in new technologies;
4) dissemination of fake news, disinformation and their influence on democratic processes;
5) increase of legal uncertainty;
6) negative changes in geopolitical relations.

2. Regulation of quantum technologies

As was noted above, quantum technologies are in the focus of attention of modern states. Most of them are actively involved in quantum race and strive to create favorable conditions necessary for effective development of such technologies.

2.1. Regulation of quantum technologies abroad

People's Republic of China. The National Plan "Made in China 2025" (further – National Plan)[1] and the current 14th five-year plan of social-economic development of China (2021–2025)[2] stipulated "large breakthroughs", including in the sphere of quantum technologies. According to the National Plan, it will be possible due to a systematic "build-up of brains", development of numerous national innovative projects, creation of laboratories[3]. State funding will allow achieving significant success in developing quantum technologies, which will make the Chinese technological industry the leader in the global market. Funding is aimed predominantly at commercialization of quantum communication technologies, as well as quantum key distribution and interferometry of cold atoms (Table 1).

European Union. In May 2016, EU announced the launching of a large-scale program – Quantum Flagship Initiative[4]. This document implies both research in the sphere of quantum technologies and organization and implementation of a broad complex of measures aimed at quantum technologies testing. The amount of funding established by the European Commission is 1 billion euro[5].

It is worth noting that the main directions of activity in the sphere of quantum technologies development in EU are described in detail in the Quantum Manifesto of 2016[6]. It is marked that in 2016–2017, over 3400 private companies from various EU countries joined the Manifesto[7]. For such companies, the possibility is stipulated to participate in the creation and development of quantum technologies in the form of public-private partnership, as well as grants, etc.

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1 *Made In China 2025: The Plan to Dominate Manufacturing And High-Tech Industries*. https://www.fdichina.com/blog/made-in-china-2025-plan-to-dominate-manufacturing/

2 *Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035*. t0284_14th_Five_Year_Plan_EN (georgetown.edu)

3 *Made In China 2025: The Plan to Dominate Manufacturing and High-Tech Industries*. https://www.fdichina.com/blog/made-in-china-2025-plan-to-dominate-manufacturing/

4 *Quantum Technologies Flagship*. https://digital-strategy.ec.europa.eu/en/policies/quantum-technologies-flagship

5 *Ibid*.

6 *Quantum Manifesto for Quantum Technologies*. https://ec.europa.eu/futurium/en/content/quantum-manifesto-quantum-technologies.html

7 *Ibid*.

Acts of strategic planning in the sphere of quantum technologies development are adopted in several EU countries (Table 1).

Kingdom of the Netherlands. The National Agenda for Quantum Technology[8] was adopted in the Netherlands in 2019. This act stipulates the creation of a Consortium of regulators, stakeholders and universities which unite their efforts to elaborate quantum technologies[9] (Table 1).

Federal Republic of Germany. The framework program of the German federal government "Quantum technologies – from basics to markets"[10] determined the following objective of the federal government: to consolidate the Germany's strong positions in the sphere of quantum physics research and making way to applications using quantum technologies; to create framework conditions to get prepared for new economic opportunities and markets; to create a solid basis for the leading role of Germany in industrial use of quantum technologies; to develop international cooperation in the sphere of creating quantum technologies; to inform the German population and involve them into promotion of the new key technology[11] (Table 1).

United States of America. The National Quantum Initiative Act[12] of December 13, 2018 poses the task to maintain the US technological leadership in the sphere of quantum technologies middle-term and long-term. This Act contains a 10-year plan of development and promotion of quantum technologies in the country. Among the necessary actions is establishing special agencies and committees to organize research in the sphere of quantum technologies and elaboration of standards in this sphere[13].

Another important document in this sphere is the National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems[14]. It stipulates the key steps needed for maintaining the countries' competitive advantage in the sphere of quantum informatics and simultaneous reduction of risks associated with the emergence of quantum computers for cyber-, economic and national security[15].

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8 *National Agenda for Quantum Technology*. https://qutech.nl/wp-content/uploads/2019/09/NAQT-2019-EN.pdf

9 *Ibid*.

10 *Quantum technologies – from basics to markets*. https://www.bmbf.de/pub/BMBF_Fo__rderprogramm_Quantentechnologie_2018.pdf

11 *Ibid*.

12 Public Law No. 115–368 (12/21/2018) National Quantum Initiative Act. https://www.congress.gov/bill/115th-congress/house-bill/6227

13 *Ibid*.

14 *National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems*. https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/04/national-security-memorandum-on-promoting-united-states-leadership-in-quantum-computing-while-mitigating-risks-to-vulnerable-cryptographic-systems/

15 *Ibid*.

The Memorandum also lists the specific actions to eliminate the vulnerabilities of computer systems for quantum-resistant cryptography. In a secret appendix to this Memorandum, the most "sensitive" issues of national security are considered[16] (Table 1).

United Kingdom of Great Britain and Northern Ireland. In 2014, UK created the National Quantum Technologies Programme[17] (further – NQTP), the aim of which is to turn the country into a global leader in the sphere of elaboration and commercialization of quantum technologies. In 2020, NQTP published a "Strategic intent", establishing a vision for the coming decade for the country's economy with quantum technologies[18] (Table 1).

Canada. For the development of the National Quantum Strategy[19], $360 mln was allocated. The strategy supports the dynamically developing quantum industry of Canada and will help to create the workforce necessary for strengthening the Canada's global leadership in the sphere of quantum technologies[20] (Table 1).

Commonwealth of Australia. National Quantum Strategy[21] contains the plan to help the Australian quantum implement its economic potential. For that, Australia opened a Quantum Commercialization Center which will accompany and support commercialization of quantum research and development of quantum business in the country[22]. Another interesting initiative is the Army Quantum Technology Roadmap[23] (Table 1).

Republic of Singapore. The new National Quantum-Safe Network[24] (NQSN) will deploy commercial technologies for testing in public agencies and private companies, perform an in-depth evaluation of safety systems, and develop guidelines to support companies introducing such technologies. The amount of state funding will achieve 8.5 mln Singapore dollars in three years[25] (Table 1).

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16 *Memorandum on Preparing for Post-Quantum Cryptography*. https://www.dhs.gov/publication/memorandum-preparing-post-quantum-cryptography

17 *UK National Quantum Technologies Programme (NQTP)*. https://uknqt.ukri.org/

18 *Ibid*.

19 *Government of Canada launches public consultations on National Quantum Strategy*. https://www.canada.ca/en/innovation-science-economic-development/news/2021/07/government-of-canada-launches-public-consultations-on-national-quantum-strategy.html

20 *National Quantum Strategy*. https://digitalnovascotia.com/news/government-of-canada-launches-public-consultations-on-national-quantum-strategy/

21 *National Quantum Strategy: proposed framework*. https://consult.industry.gov.au/national-quantum-strategy

22 *Australian National Quantum Strategy*. https://www.insidequantumtechnology.com/news-archive/australias-vision-for-quantum/

23 *Army Quantum Technology Roadmap*. https://researchcentre.army.gov.au/rico/army-quantum-technology-roadmap

24 *CQT researchers join new project to build National Quantum-Safe Network in Singapore*. https://www.science.nus.edu.sg/blog/2022/03/15/cqt-researchers-join-new-project-to-build-national-quantum-safe-network-in-singapore/

25 *National Quantum Security Network*. https://www.eurekalert.org/news-releases/943794

Republic of Korea. In 2019, a Quantum Computing Development Plan was approved[26]. During five years, it is planned to accomplish the development of basic technologies such as hardware provision of quantum computers, and prospective technologies, including new architecture of quantum computations, quantum algorithms, and basic software. The objective of this plan is to design a 5-qubit computer with the 90 % stability index by 2023[27]. For further implementation of the policy in the sphere of quantum technologies development, South Korea adopted a 5-year plan for quantum technologies development in 2022[28] (Table 1).

Table 1. Regulation of quantum technologies abroad

Country	Program	Actors	Actions	Stage	Budget
People's Republic of China	14th five-year plan of social-economic development of China; National Plan "Made in China 2025"	Predominantly the state	Development of national innovative projects, creation of laboratories; training of personnel	Commercialization	15.3 bln dollars
United States of America	National Quantum Initiative Act; National Security Memorandum	The state /private sector	Organization and maintenance of research, elaboration of standards	Commercialization	2.5 bln dollars
European Union	Quantum Flagship Initiative; Quantum Manifesto	The state /private sector	Public-private partnership, grants, consortiums	Commercialization	1 bln dollars
Kingdom of the Netherlands	National Agenda for Quantum Technology	The state and private sector	Creation of a consortium of regulators, stakeholders and universities	Creation	850 mln dollars
Federal Republic of Germany	Framework program of the German federal government "Quantum technologies – from basics to markets"	The state	Support of research, development of cooperation	Creation/commercialization	2.4 bln dollars

26 *Korea Starts Five-year Development Program for Quantum Computing Technology*. https://k-erc.eu/korea-starts-five-year-development-program-for-quantum-computing-technology/

27 *Quantum Computing Development Plan*. http://www.businesskorea.co.kr/news/articleView.html?idxno=28881

28 *5-Years Plan for Quantum Technologies*. https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=&bbsSeqNo=42&nttSeqNo=610&searchOpt=ALL&searchTxt=

United Kingdom of Great Britain and Northern Ireland	National Quantum Technologies Programme	The state /private sector	Support of research, development of cooperation, Public-private partnership, grants, consortiums	Creation	1.23 bln dollars
Republic of Singapore	National Quantum-Safe Network	The state /private sector	Developing guidelines for state support of developer companies	Commercialization	90.9 mln dollars
Canada	National Quantum Strategy	The state /private sector	Support of the quantum industry; training of personnel	Creation/commercialization	650 mln dollars
Commonwealth of Australia	1. National Quantum Strategy. 2. Army Quantum Technology Roadmap	The state /private sector	Support of commercialization of quantum technologies and development of quantum business	Commercialization	94 mln dollars
Republic of Korea	Quantum Computing Development Plan; a 5-year plan for quantum technologies development	The state /private sector	Support of research, development of cooperation, training of personnel	Creation	40.9 mln dollars

2.2. Regulation of quantum technologies in the Russian Federation

Development of high quantum technologies is one of the tasks aimed at achieving scientific and technological progress in Russia in compliance with the Strategy of National Security of the Russian Federation[29]. This said, quantum technologies are in the focus of attention not only as a means to ensure national security. They are also regarded one of the directions of the scientific and technological progress[30]. Moreover, the "Digital Economy" federal target program also emphasizes the need to create and develop such technologies[31].

[29] On adopting the Strategy of National Security of the Russian Federation: Order of the President of the Russian Federation No. 4005 of 02.07.2021. (2021). *Collection of legislation of the Russian Federation*, *27* (Part II). Art. 5351.

[30] On adopting the State Program of the Russian Federation "Scientific and technological development of the Russian Federation": Decree of the Government of the Russian Federation of 29.03.2019 No. 377. (2019). *Collection of legislation of the Russian Federation*, *15* (Part III). Art. 1750.

[31] Passport of the "Digital technologies" Federal project, adopted by the Presidium of the Government Commission on digital development, use of information technologies for improving living standards and conditions for business activity, record of 28.05.2019 No. 9. *SPS KonsultantPlyus*; On adopting the State Program of the Russian Federation "Scientific and technological development of the Russian Federation": Decree of the Government of the Russian Federation of 29.03.2019 No. 377. (2019). *Collection of legislation of the Russian Federation*, *15* (Part III). Art. 1750.

A part of this program is the "Quantum technologies" Roadmap for developing the "end-to-end" digital technology (further – the Roadmap)[32]. It analyzes the existing types of quantum technologies (subtechnologies) – quantum computation, quantum sensors and metrology, quantum cryptography, and defines the necessary steps for developing quantum technologies in Russia. The total budget for the Roadmap implementation (for 2019–2024) is 51.1 billion rubles, including non-state funding of 8.7 billion rubles[33].

It is essential that the support of all three main subtechnologies within quantum technologies is critical for the national security and digital sovereignty of the Russian Federation. One may note that the necessary condition for a breakthrough in quantum technologies is the support of research and launching of national-scale infrastructural projects, as well as implementation of organizational measures to overcome barriers.

The latter include formation of a necessary innovative infrastructure for their development. For example, the "Quantum Valley" innovative scientific-technological center was created[34] in order to stimulate business activity in the sphere of digital technologies.

The Russian Federation also pays attention to elaborating national standards of products and solutions created on the basis of quantum technologies. For example, GOST R 58568-2019 has been elaborated – the "National Standard of the Russian Federation. Optics and photonics. Photonics. Terminology and definitions"[35]. In the nearest future, it is planned to complete elaboration of several other standards in the sphere of digital technologies[36].

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32 *"Quantum technologies" Roadmap for developing the "end-to-end" digital technology*. https://digital.gov.ru/

33 *Ibid*.

34 On creating the "Quantum Valley" innovative scientific-technological center: Decree of the Government of the Russian Federation of 30.11.2021 No. 2133. (2021). *Collection of legislation of the Russian Federation*, *49* (Part II). Art. 8318.

35 *National Standard of the Russian Federation GOST R 57257-2016/ISO/TS 80004-12:2016 "Nanotechnologies. Part 12. Quantum phenomena. Terminology and definitions" (adopted and enacted by the Order of Rosstandart of 10.11.2016 No. 1673-st*). (2016). Moscow: Standartinform.

36 For example, the following standards are currently elaborated: "Quantum communications. Terminology and definitions"; "Quantum communications. General provisions"; "Quantum Internet of Things. Terminology and definitions"; "Quantum Internet of Things. General provisions"; "Quantum Internet of Things. Standard hardware and software complex implementing the functions of the quantum key distribution system. Architecture"; "Quantum Internet of Things. Standard hardware and software complex implementing the functions of the quantum key distribution system. Connection interface" (They started elaborating standards for quantum technologies in Russia. URL: https://habr.com/ru/news/t/684540/).

3. On the way towards the quantum law

> "Don't be sad", said Alice, "Sooner or later everything will become clear, everything will fall into place and line up into a single graceful scheme, like lacework".
>
> **Alice in Wonderland (2010 film)**

3.1. General vectors of forming the quantum law

Researchers have more than once suggested how quantum technologies may cardinally change our life (Arndt, 2011; Browne et al., 2017; Sigov et al., 2020). Many spheres of life will be transformed. Law will not be an exception. Concurrently, we assume that not only legal regulation but law as a whole will be transformed.

Unique features of quantum technologies will not only open new possibilities for us, but will bring new risks and threats, of course. Assumingly, they have a potential of changing certain fundamentals, including legal ones. It implies the possibility to form a quantum law.

As was already noted, foreign researchers actively work over the concept of quantum law. For example, in his article The Birth of Quantum Law: A Concept Paper, J. Ritter puts forward the concept of quantum law – a certain set of universal rules which could be applied regardless of the location or origin of information or technology. At that, according to the researcher, quantum law would allow reviewing our ideas about how the supremacy of law could be maintained (Ritter, 2015).

This viewpoint is echoed by Professor J. Atik who believes that quantum logic, quantum algorithms and quantum computations, together with quantum comprehension of the Universe, may transform law, opening new possibilities for creating quantum norms, quantum judicial decisions, and quantum law order (Atik, 2022).

How can quantum technologies transform law? Analysis of research works in this sphere allowed distinguishing the following vectors of law development under the second quantum revolution.

3.1.1. From determinism to probabilities in law – the change of legal paradigm

One may assume that the new law will develop according to the rules inherent in quantum mechanics, not classical physics. One can already draw some parallels between the existing law and the deterministic approach established in the classical physics, on the one hand, and quantum law as the law of the future, with its probability approach inherent in quantum mechanics, on the other.

According to Professor J. Atik, with the advent of these technologies, "the quantum way of thinking – with information coded in probabilities instead of certainties – will likely affect how we think of complex systems. It has long been understood that true equilibrium can be approached but never achieved in physical systems – and is likely even more so in social systems" (Atik, 2022).

Developing the researcher's idea, we may note that one may say the same about achieving truth in law. The question of what truth is, for example, in criminal law and how to define it is still disputable and it is extremely difficult to find an unambiguous, definite answer to it. Thus, both in quantum mechanics and in certain legal aspects we already think in terms of probabilities, not definitiveness, rejecting determinism.

Moreover, one may note that digitalization literally forces us to reject the previous concept and demands "renovation" of law. In this regard, unorthodox tools are already emerging, which allow creating effective regulation for digital technologies. For example, by allowing to test digital innovations within experimental legal regimes (regulatory sandboxes), we also reject the deterministic approach and think in terms of probabilities. By temporarily not applying certain regulatory requirements, we try to find out the probability of the rule derogation "usefulness" for technological progress and whether this "temporal and specific" should be transferred into the "constant and general" in the future.

3.1.2. Projecting the features of quantum phenomena onto regulation of public relations

How will that be manifested and how can it practically reflect on the law of the future? The fact that a feature of quantum technologies is the probability character of computations will require from the main actors to introduce risk-oriented approaches into many spheres. Today, the risk-oriented approach is being introduced and used for regulating various public relations (Begishev, 2021). For example, in the Russian Federation this is, first of all, the sphere of state and municipal control over the activities of business subjects[37]. Foreign countries use this approach to regulate the artificial intelligence technology[38].

Most probably, with the spreading of quantum technologies, in particular, quantum computations, the concept of lawyers' thinking may also change. In the foreign science, the question is already posed about the transformation of computational law into quantum computational law, which would allow making more objective judicial decisions and finding solutions to seemingly unsolvable legal problems, relying in the properties of quantum phenomena (Atik & Jeutner, 2021).

Turning to the next property of quantum phenomena – quantum entanglement, which is actually a constant interaction of quantum particles and their interdependence upon one another, – one may project it to the future quantum law. Assumingly, this law will not be a "pure" law in its classical sense. It will more and more interact with other spheres of academic knowledge: ethics, economics, and engineering sciences. This process

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37 On state control (supervision) and municipal control in the Russian Federation: Federal law of 31.07.2020 No. 248-FZ. (2020). *Collection of legislation of the Russian Federation*, *31* (Part I). Art. 5007.

38 See, e.g.: EU AI Act, https://artificialintelligenceact.eu/

is already launched. For example, foreign and Russian scientists have been long asserting the need to use the methods of economics in law (economic analysis of law) (Gadzhiev, 2016; Pozner, 2004).

Moreover, at the modern stage, trying to regulate artificial intelligence, we turn not so much to legal norms as to ethical principles. This is due to the fact that the classical legal tools are not sufficient for regulating digital technologies.

3.1.3. Searching for the "quantum" level of law and its consequences

Another question posed in science is: Does law possess a "quantum" level?[39] Professor J. Ritter made an assumption that quantum law does possess a "quantum" level, but did not specify what level that is. Although it is difficult to find any other answer to this question except that such level is the provision of law, we consider it important to focus not on the definition of the quantum level of law but on how the quanta per se may influence regulation. Do any ideas from the quantum theory imply that we must review our assumptions about law or inside law?[40]

We believe that with the advent of these digital technologies the legal regulation per se may become a "quantum" one. In this case that means that it may become more specific, practice-oriented, at the same time moving away from excessive abstraction. Note that this has already become a sort of trend. Regulation in all spheres is now formed not only by legislative bodies. This process has been actively joined by the private sector, mainly by large transnational corporations. For example, law formed by digital platforms has already been spoken about, like the eBay concept of law (eBay Law) (Guadamuz, 2003), while private companies are getting actively involved into elaboration of international and national standards. New regulation will undoubtedly be more practice-oriented, as by forming such rules business builds upon the existing problems they face daily.

3.2. Regulatory sandboxes and other special regimes as quantum law constituents

A large-scale, global and intense digitalization and emergence of new technologies as its consequence have already resulted in the emergence of digital uncertainty and required the search for more flexible approaches to legal regulation. One of such approaches is special regimes and experimental regimes as one of their types.

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39 *Quantum law: an interdisciplinary exploration of quantum theory law and ethics*. https://www.westminster.ac.uk/events/quantum-law-an-interdisciplinary-exploration-of-quantum-theory-law-and-ethics

40 *Ibid*.

Assumingly, the above said is fully applicable to quantum technologies, as their innovative nature also requires transformation of law and adaptation to the realities which would be determined by the spread of quantum technologies.

Experts already speak of the need for certain departures or exceptions from the current legislation. For example, the idea of a special regime in the sphere of patenting quantum technologies was proposed by Prof. V. Jeutner. According to him, the need to reduce digital gaps and inequality as a whole, caused by the emergence of quantum technologies, will require to restrict their patenting (Jeutner, 2021). This is due to the fact that even now a number of countries pursue rather aggressive policy in the sphere of patenting quantum technologies[41], and international stipulation of these rules would facilitate the struggle against inequality. Besides, the researcher proposes to make the quantum technologies transfer obligatory in certain spheres (for example, socially significant ones).

Researchers also propose a special regime for controlling the export of quantum technologies. For example, an idea is put forward about including such technologies into the Wassenaar Arrangement (Jeutner, 2021).

Special regulation is also mentioned in relation to the moment when we will en mass use quantum cloud services. Quantum cloud computations must democratize market, allowing individuals and companies to obtain access to exquisite computational capacities without the need to create and maintain their own infrastructure for quantum computations. Quantum cloud services will be especially important in the nearest three to five years, as they will allow performing experiments before quantum computers become more affordable. However, this will require changes in legislation on personal data. That is why technological leaders should make it clear what data can be transferred across various organizational boundaries, what data are transferred and how.

The Russian researchers also take an active part in creating the bases of quantum technologies regulation and mark the need to elaborate legal regulation of quantum technologies. Besides the above, it is necessary to focus on elaboration of legal regulation of the use of quantum technologies in various spheres of activities (social, cultural, economic, etc.) (Kholodnaya, 2022; Dobrobaba et al., 2022). Specific proposals of the Russian researchers deserve attention in terms of improving particular sectors in order to develop quantum technologies. In particular, it is proposed to endow developers of quantum technologies with a number of tax reliefs and preferences (Dobrobaba et al., 2022). Experts also propose to introduce liability for violating the prohibition to use standard methods of information enciphering (Naumov, 2019).

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41 *Quantum USA vs. Quantum China: The World's Most Important Technology Race*. https://www.forbes.com/sites/moorinsights/2019/10/10/quantum-usa-vs-quantum-china-the-worlds-most-important-technology-race/?sh=311e182372de

Searching for optimal approaches to regulating quantum technologies and forming the law of such technologies, one should apply experimental legal regimes in the sphere of digital innovations (regulatory sandboxes).

Under such regime, certain regulatory requirements are temporarily abandoned in order to check the viability of a digital innovation and to try to create their optimal legal regulation. It allows the subjects of innovative entrepreneurial activity to reduce financial and temporal costs associated with launching the innovation; it also allows the state to determine the optimal model of their legal regulation. It should be noted that the said flexibility of regulatory sandboxes allows creating proactive law, keeping pace with digitalization.

We believe that to create effective legal regulation of quantum technologies, the use of experimental legal regimes will be one of the optimal solutions.

However, one should remember that the properties of quantum technologies and their potential are not comprehensively studied yet, and that requires greater precaution and more effective measures to protect stakeholders. In this regard, it is proposed to take into special account the risks associated with the said features of quantum technologies, and to attempt to minimize them at the level of the experimental legal regime program. It is also proposed to stipulate additional compensations and liability insurance for the subjects of an experimental legal regime (Gromova & Ivanc, 2020). Besides, one should remember that the creation of quantum technologies under experimental legal regimes may also potentially entail violation of antimonopoly legislation. That is because the temporal abandoning of certain regulatory requirements to the activity of a participant of such regime gives them competitive advantages associated with rapid market entry, and sometimes also with reduced costs of performing some actions (certification, licensing, accreditation, etc.) (Gromova, 2022).

4. Ethics of quanta

4.1. Basic ethical principles applied to quantum technologies

Foreign authors propose applying the approach of ethical regulation, which is used in relation to artificial intelligence[42]. Assumingly, quantum technologies will be regulated by general, basic ethical principles, such as safety, reliability, controllability and manageability, transparence, interpretability and predictability.

Considering the principle of safety as applied to quantum technologies, it is important to note that developers of such technologies and other persons involved in their creation and

[42] See, e.g.: *Ethics guidelines for trustworthy AI: Shaping Europe's digital future – European Commission*. https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai; *OECDAI Policy Observatory*. https://oecd.ai/en/; *Code of ethics in the sphere of artificial intelligence*. https://a-ai.ru/ethics/index.html

introduction must ensure the necessary safety of those who will apply such technologies, as well as prevent inflicting harm upon consumers, users and other subjects.

The principle of reliability of quantum technologies implies the need to ensure the ability of such technologies to preserve during a long time the ability to perform the required functions under application, technical servicing, storage and transportation.

Speaking of the principles of controllability and manageability of quantum technologies, it should be noted that their elaboration and application must maximally take into account the risks associated with the use of such technologies; also, the methods of their minimization must be tested.

The principle of transparence of quantum technologies implies the possibility of open, comprehensive, intelligible, clear and understandable representation of information both about the quantum technologies per se, their spheres of application, and the consequences of their application.

Interpretability will imply the need to elaborate comprehensible quantum technologies, the use of which might increase trust in them, providing the society with the opportunity to comprehend their functioning principles, identify cases of discrimination or bias during their application, and to be informed about abuse of rights.

Undoubtedly, quantum technologies must be predictable. Although, taking into account the above said features of quantum technologies and the properties of quantum phenomena, it will be very difficult to ensure the execution of this principle, nevertheless, the elaborators of such technologies must do the utmost for the methods of their application to lead to expected and relevant results.

4.2. Specific ethical principles of developing and applying quantum technologies

At the same time, taking into account the specificity of quantum technologies, one may speak of the need to elaborate special ethical principles. This has been emphasized by both Russian (Yunakovsky et al., 2021; Kabanov et al., 2018; Kitaev et al., 1999; Korolkov, 2015) and foreign representatives of engineering sciences (Arute et al., 2019; Muheidat et al., 2022; Kabanov et al., 2018; Kitaev et al., 1999). For example, a research collective of Lund University elaborated, within their "Quantum Law" project, the so called Quantum imperative. This imperative implies that regulatory bodies and developers must be certain that quantum computers:

– do not create or exacerbate inequlity;

– do not undermine individual autonomy of a personality;

– take into account the opinion of those whose interests may be affected when applying quantum technologies (Jeutner, 2021).

Besides, analysis of foreign sources, in which the issues of quantum technologies ethics are addressed, allowed complementing this Quantum imperative with the following ethical principles:

– ethic-first quantum mind. This principle implies the following constituents: proactivity and proportionality. Proactivity implies the so called anticipation – active, responsible

actions of regulators, business and technology leaders in order to create ethical future for the quantum ecosystem. In the past, the chances to elaborate ethical recommendations in process of new technologies' emergence were lost. This led to serious problems, like racist algorithms of facial recognition. In view of this, actors must take a more proactive position in relation to quantum technologies. Proportionality implies such behavior of regulators and developers, which takes into account the actual necessity to apply quantum technologies and correlates it with the realities. As experts note, it often appears that companies and state agencies use revolutionary technologies for the sake of those technologies, not taking into account the accompanying economic, operational and reputational risks.

– intersectoral and interdisciplinary cooperation to establish clear boundaries for ethical and unethical use of quantum technologies.

In our opinion, adoption of the Code of ethics of regulators and developers of quantum technologies (Quanta code of ethics) will promote the development of ethical, good faith creation and application of these technologies.

Besides, one should consider the possibility of introducing a system of quantum ethical-legal compliance into the activity of developing companies (similar to anti-monopoly compliance), that is, a special internal corporate policy aimed at revealing and preclusion of possible violations of ethical and legal norms.

Conclusions

The research allowed coming to the following conclusions:

Involvement of many countries into the quantum race and their striving not only to create but also to commercialize quantum technologies means that such technologies will, sooner or later, become ingrained in our everyday lives. Taking into account their revolutionary properties and active work of the global academic community for their "harnessing", it becomes apparent that such technologies will not just enter our lives but will significantly change it.

States create a ground for such transformation, including by creating regulation of quantum technologies. So far these are, as a rule, general strategic planning acts, but special documents are already appearing which regulate the features of creation and introduction of quantum technologies in individual spheres.

Having studied regulation of quantum technologies in foreign countries, we can make the following conclusions:

First, most of the countries under study currently regulate quantum technologies through general strategic planning acts. However, sectoral regulation of quantum technologies is starting to appear. Second, the fact is worth noting that in some countries national programs for quantum technologies development emphasize not so much creation of such technologies as their commercialization – that means that their elaboration stage may be almost completed and the countries focus on creating conditions for their application.

Third, these acts stipulate predominantly public funding of creation and commercialization of quantum technologies, though encouraging public-private partnership and private investment into such digital technologies.

Taking into account the described properties of quantum phenomena, as well as the challenges and risks which the application of quantum technologies entails, it becomes obvious that the law itself will be transformed. One of the consequences may be the formation of a new quantum law. Its conceptual bases will be determined by the properties of quantum technologies.

The vectors of the quantum law development will be special, including experimental, legal regimes. Regulatory sandboxes will make it possible to test services, business models and products based on quantum technologies and to elaborate the most optimal regulation for them.

An important role in the quantum law development will be played by ethical principles of regulation and application of such technologies. In this regard and given the need for proactive work, it is already necessary to start elaborating the quantum ethics code and a system of ethical-legal compliance.

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Authors' contributions

Elizaveta A. Gromova performed general supervision and set the research tasks, analyzed the Russian and foreign regulation of quantum technologies.
Sergey A. Petrenko analyzed the current state of Quantum computations science and determined the prospective directions of engineering research in this sphere.

Conflict of interest

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Квантовое право: начало

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Ключевые слова

Квант,
квантовое право,
квантовые вычисления,
квантовые технологии,
право,
регулирование,
риск,
цифровые технологии,
экспериментальные
правовые режимы,
этика

Аннотация

Цель: на основании изучения свойств квантовых явлений и особенностей квантовых технологий, обусловивших риски и вызовы, связанные с появлением данных технологий, а также анализа правового регулирования квантовых технологий в Российской Федерации и зарубежных странах формирование основ квантового права как права будущего.

Методы: для проведения данного исследования применялся комплекс общенаучных методов системного анализа, а также предметных методов технических и юридических наук. Применение сравнительно-правового метода дало возможность выявить основные направления развития регулирования квантовых технологий в российских и зарубежных правопорядках. Метод правового моделирования позволил сформировать концепт квантового права, выявить основные векторы его развития и комплекс его этико-правовых принципов.

Результаты: выявлены особенности и свойства квантовых технологий, которые способны изменить развитие права с приходом таких технологий; определены основные риски и вызовы, связанные с развитием квантовых технологий; выявлены особенности регулирования квантовых технологий в отдельных зарубежных странах; определены тенденции развития регулирования квантовых технологий в Российской Федерации; сформированы концептуальные основы квантового права, а также векторы его развития.

✉ Контактное лицо

Научная новизна: впервые в юридической науке проводится комплексный анализ существующего национального (как российского, так и зарубежного) регулирования квантовых технологий, на основании которого предпринимается попытка обоснования необходимости формирования квантового права и очерчиваются основные векторы его развития.

Практическая значимость: результаты проведенного исследования закладывают основу для формирования концепта квантового права, в связи с чем выводы, к которым пришли авторы, и выдвинутые ими предложения по совершенствованию существующего регулирования квантовых технологий могут быть использованы для правотворчества и правоприменения в данной сфере, а также способны заложить основы дальнейших исследований в области квантовых технологий.

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Е. А. Громова осуществляла общее руководство и постановку задач исследования, анализ отечественного и зарубежного регулирования квантовых технологий.
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