# BIOETHICAL PROBLEMS OF QUANTUM COMPUTING

Khokhlov AL[1], Pavlov AV[1], Kotlovsky MYu[1,2] ✉, Potapov MP[1], Gabidullina LF[1]

[1] Yaroslavl State Medical University, Yaroslavl, Russia

[2] National Research Institute of Public Health named after NA Semashko, Moscow, Russia

Today, quantum computing is one of the most promising areas of modern science that can solve the problems which are too hard to handle for classical computers. However, a huge potential accompanied by a rapid progress in this area creates significant ethical risks, including threat of hacking existing cryptographic systems and the problem of non-transparent decisions made using quantum computing. The article highlights the need for timely ethical analysis, development of a regulatory framework, and interdisciplinary collaboration to ensure sustainable and socially acceptable technology development. Main ethical, bioethical challenges, in particular, that arise against the background of quantum computing, and identification of possible ways to regulate them captivate special attention.

**Keywords:** quantum computing, bioethics

**Author contribution:** A. L. Khokhlov — formulation of the problem, discussion of key ethical issues, planning and discussion of the article; A. V. Pavlov — study of the literature on the topic, systematization and generalization of data, participation in the discussion of the results, writing and design of the article; M. Yu. Kotlovsky, M. P. Potapov, L. F. Gabidullina — study of the literature on the topic, participation in the discussion of the results and writing of the article.

✉ **Correspondence should be addressed**: Mikhail Yu. Kotlovsky
Revolutsionnaya str., 5, Yaroslavl, 150000, Russia; m.u.kotlovskiy@mail.ru

**Received:** 05.05.2025 **Accepted:** 19.05.2025 **Published online:** 23.06.2025

**DOI:** 10.24075/medet.2025.007

# БИОЭТИЧЕСКИЕ ПРОБЛЕМЫ КВАНТОВЫХ ВЫЧИСЛЕНИЙ

А. Л. Хохлов[1], А. В. Павлов[1], М. Ю. Котловский[1,2] ✉, М. П. Потапов[1], Л. Ф. Габидуллина[1]

[1] Ярославский государственный медицинский университет, Ярославль, Россия

[2] Национальный НИИ общественного здоровья имени Н. А. Семашко, Москва, Россия

На сегодняшний день квантовые вычисления представляют собой одно из наиболее перспективных направлений развития современной науки, способное решать задачи, не доступные классическим системам. Однако, наряду с огромным потенциалом, стремительный прогресс в этой области порождает существенные этические риски, включая угрозу взлома существующих криптографических систем и проблему непрозрачности принимаемых с помощью квантовых вычислений решений. В статье подчеркивается необходимость своевременного этического анализа, разработки нормативно-правовой базы и междисциплинарного сотрудничества для обеспечения устойчивого и общественно приемлемого развития технологии. Особое внимание уделяется рассмотрению основных этических, в частности биоэтических, вызовов, возникающих на фоне развития квантовых вычислений, и определению возможных путей их регулирования.

**Ключевые слова:** квантовые вычисления, биоэтика

**Вклад авторов:** А. Л. Хохлов — постановка проблемы, обсуждение ключевых этических вопросов, планирование и обсуждение статьи; А. В. Павлов — изучение литературы по теме, систематизация и обобщение данных, участие в обсуждении результатов, написание и оформление статьи; М. Ю. Котловский, М. П. Потапов, Л. Ф. Габидуллина — изучение литературы по теме, участие в обсуждении результатов и написание статьи.

✉ **Для корреспонденции**: Михаил Юрьевич Котловский
ул. Революционная, д. 5, г. Ярославль, 150000, Россия; m.u.kotlovskiy@mail.ru

**Статья поступила:** 05.05.2025 **Статья принята к печати:** 19.05.2025 **Опубликована онлайн:** 23.06.2025

**DOI:** 10.24075/medet.2025.007

## INTRODUCTION

Today, quantum computing is one of the most promising areas of modern science. They are developed using fundamental quantum properties of matter such as superpositions, entanglements and interference for information processing. Owing to that, quantum computers are able to perform tasks that are either extremely difficult or completely impossible for classical systems of today. This applies, in particular, to complex chemical process modeling, accelerated search in big data, as well as cryptographic analysis.

The current stage in quantum computing development represents a transition to a new technological order, especially in cryptography, artificial intelligence, and biomedical research. Potential advantages of the new approach are also accompanied by significant risks, many of which are of ethical origin. The history of information technology shows that ignoring moral and social consequences of scientific discoveries can lead to massive issues such as privacy violations, spread of misinformation, or growth of digital inequality in society.

Currently, possible use of quantum algorithms to crack existing cryptographic information security systems is one of the most significant threats. We are also concerned about transparency of decisions made using quantum computing. This is especially important in areas related to human life and health, such as medicine or forensic science. All this greatly increases the need for timely and adequate ethical analysis.

Ethical issues related to quantum computing cover a variety of aspects, from principles of equity and accountability to implications for global security. To solve the issues, a clear regulatory framework and ethical guidelines that can ensure sustainable and socially acceptable technology development are required.

Thus, ethics of quantum computing is becoming an integral part of scientific and engineering thinking of the 21st century. Cooperation between specialists from various fields is necessary for its development. The specialists are physicists, computer scientists, lawyers, and philosophers. Active involvement of civil society institutions is required. In this chapter, it is proposed to consider the main bioethical challenges that arise during rapid progress of this field of science, and identify possible ways to regulate them.

## 1. FUNDAMENTALS OF QUANTUM COMPUTING: KEY DIFFERENCES AND OPPORTUNITIES

Quantum computing is a special approach to information processing based on the principles of quantum mechanics [1]. Unlike standard classical machines that use bits, which can represent values of 0 or 1, quantum computers operate with qubits, which can exist in multiple states at once due to superposition. It provides quantum systems with a unique opportunity to perform parallel calculations. Traditional processors cannot do that.

### 1.1. The main differences of quantum calculations

*Origin of data representation.* Classical computers use bits to encode information. Quantum systems use qubits, which can take not only the values 0 or 1, but also their linear combinations. This is how their computing capabilities can be numerously increased.

*Parallelism.* Quantum systems can simultaneously analyze numerous options owing to superimposition. Due to that, certain types of problems such as iteration or optimization can be solved faster.

*Entanglement.* Quantum entanglement allows you to connect qubits in such a way that changing one instantly leads to a change in the other. This powerful tool allows to build complex algorithms.

*Algorithmic advantage.* Shor's and Grover's algorithms show that quantum computers can significantly outperform classical ones [2]. They are especially efficient in factorization, search, and modeling of chemical processes.

*Physical instability.* Qubits are extremely sensitive to external influences and lead to decoherence. It is difficult to maintain quantum states as ultra-low temperatures and error correction systems are required. This makes quantum computing technically complex and cost-effective.

### 1.2. Types of quantum devices

At the present stage of development, quantum devices are mainly represented by quantum computers and quantum simulators:

- universal quantum computers can perform a wide range of tasks and simulate any quantum system. They have a flexible architecture and implement a universal set of quantum logic operations;
- quantum simulators are often tailored to model specific physical systems such as modeling molecular interactions. In these areas, they are often more efficient than universal machines.

### 1.3. Potential and limitations

Quantum computing is highly potential in solving the problems that cannot be solved by classical systems, such as modeling molecular interactions, cryptographic analysis, optimization, and machine learning. Quantum parallelism, entanglement, and the possibility of exponential acceleration when executing certain algorithms are key advantages of quantum computers. However, implementation of this potential is limited by a number of factors.

First, significant difficulties can be seen at the level of hardware: qubits are extremely unstable, subject to decoherence, and operate at ultra-low temperatures and in the presence of complex technical infrastructure. Existing quantum devices are still laboratory prototypes with limitations in qubit count and error rates, which makes it necessary to use complex correction systems.

Second, there are significant limitations associated with development of quantum algorithms. To date, there exist only a limited number of algorithms with proven quantum superiority (for example, Shor's and Grover's algorithms), and their use is limited to a narrow class of tasks. Designing new algorithms requires a strong foundation in quantum physics and mathematics, as well as mastering new programming languages and computational models that are under active development [3]. Meanwhile, most of the known algorithms show practical efficiency primarily with a large number of qubits, which cannot be achieved with the current level of technology. It is expected that they will appear in future.

Since universal quantum computers are still far from practical application, **hybrid quantum-classical approaches** (for example, Variational Quantum Algorithms) have the greatest prospects. However, their implementation requires deep integration of two types of systems and novel engineering solutions [4].

Thus, despite their outstanding potential, quantum technologies are still at the stage of scientific and engineering testing, and their practical application requires overcoming both technical and methodological barriers.

## 2. POTENTIAL THREATS AND RISKS

### 2.1. Digital security threats

Quantum technologies can solve problems which cannot be overcome by classical processors. This, however, poses serious threats to existing data encryption systems. Modern cryptographic methods (for example, RSA) are based on complex big number factorization, but the advent of scalable quantum computers using Shor's algorithm makes the task solvable in polynomial time [5].

The strategy of individuals trying to gain unauthorized access to 'store now, decrypt later' information is of particular concern. Meanwhile, the encrypted data is intercepted and deposited for subsequent decryption, at a time when quantum computing reaches the required power. This is especially critical for information with long-term confidentiality, such as documents containing information classified as a state secret, medical archives, and personal correspondence.

In this regard, transition to post-quantum cryptography based on principles resistant to quantum attacks is required to protect digital infrastructure. The solutions can be effective only with international cooperation and timely revision of cryptographic standards.

### 2.2. Military and political risks

Quantum technologies can reshape global power dynamics significantly. Countries with access to quantum computing will gain significant advantages in intelligence, data analysis, information security, and defense system development. The capabilities of these future systems will involve modeling tactical scenarios, optimization of combat operations, and developing cyber-warfare capabilities.

Similar to nuclear development, the quantum arms race can significantly heighten international instability. Possible militarization of technology will be accompanied by growth of closed projects, reducing their transparency and hampering control. Concentration of all quantum powers in a limited number of countries can increase inequality and disturb the balance in the global security system.

The risks can be struggled by implementing international agreements aimed at prevention of uncontrolled proliferation and use of quantum systems for purely militaristic purposes.

### 2.3. Risk of social inequality

Development of quantum computing can exacerbate existing digital and economic inequalities [6]. Access to advanced technologies is most often limited by large scientific centers, corporations, and economically developed superpower states. This threatens to widen the global gap between the "technological center" and the developing periphery.

To exclude the threat, an inclusive scientific policy is necessary. It means expansion of educational programs, provision of open access to research results, and support of infrastructure in countries with limited resources. Patent regulation is also expected to be important, as excessive monopolization of quantum developments may hinder equal access to new knowledge and achievements.

Functioning patent systems should facilitate distribution of useful technologies without creating artificial barriers. Meanwhile, transparency in developments and publications is also critical. It will reduce the risks of manipulation, increase trust, and turn quantum technologies into the subject of public control.

Modern international norms, including agreements on intellectual property rights and open data, need to be adapted to new challenges of the quantum era. Ethical and legal support is necessary to create a fair technological environment where innovation serves the interests of all countries and communities around the world.

## 3. RESPONSIBLE DEVELOPMENT AND USE

Development of quantum computing requires ethical and legal support to ensure a balance between scientific progress and interests of the society. For ethical development of quantum technologies, it is necessary to rely on the principles of precaution, transparency, accessibility and open cooperation. These provisions will serve as an ethical guideline and allow integration of quantum technologies into public and scientific processes without loss of trust and fairness.

***The precautionary principle.*** If the technology poses potential threats, it should be used along with a preliminary assessment of all possible risks during its implementation. In terms of quantum computing, this is especially important in the fields of security, international relations, and civil rights. Prior to mass implementation of such solutions, it is necessary to perform a comprehensive ethical and legal examination.

***Transparency.*** Effective and responsible use of quantum technologies will require an open and understandable description of algorithms, development goals, and possible consequences of using these technologies. Transparency is especially important when quantum solutions are used in critical areas such as medicine, defense, and digital security. Availability of information will help increase trust and reduce the risks of abuse from individual players.

***Inclusivity.*** When technologies are developed, the interests of a wide range of participants, states, research institutes, small research teams, and developing countries should be taken into account. Access to resources, education, knowledge, and research results should not be limited only to economically developed regions or multinational corporations.

***Openness.*** Access to scientific publications, source codes, and research protocols is an important condition for progress in ethics. Modern open platforms such as Qiskit (IBM) or PennyLane (Xanadu) demonstrate that collaboration and knowledge sharing are possible. This will reduce barriers of entry into this scientific field and contribute to a more even development of quantum technologies.

## 4. THE ROLE OF ORGANIZATIONS IN SHAPING THE ETHICAL AGENDA

***Universities and research centers.*** Higher educational institutions all over the world are not only developing technologies, but also shaping the worldview of future specialists working with them. Educational programs in ethics of technology, interdisciplinary research and introduction of standards of scientific integrity are the most important elements of sustainable technological development of society. Besides, Universities are actively initiating research on the ethical aspects of artificial intelligence, quantum computing, and other breakthrough fields.

***The private sector.*** Companies, especially leading technology corporations, are increasingly integrating ethical standards into their daily operations through corporate and social responsibility (CSR) mechanisms. It means establishment of internal ethics committees, publication of codes of ethics, and participation in international initiatives aimed at ethical regulation. The leading market players also play a key role in standardization of new technologies becoming drivers of ethics implementation in practice.

***International initiatives and a consortium.*** To ensure safe development of quantum computing, these structures form the basis for an international dialogue and a regulatory framework. They monitor compliance with ethical principles, develop accountability mechanisms, and assess the risks of exploiting these technologies.

- **Institute of Electrical and Electronics Engineers (IEEE)**: an international organization that develops technical and ethical standards. The *IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems* also addresses quantum computing.
- **Quantum Ethics Consortium**: an interdisciplinary platform for developing ethical approaches to application of quantum technologies. It ensures cooperation of scientists, engineers, and policy makers in this area.
- **AI Ethics Guidelines Global Initiative**: an international movement whose activities are aimed at developing universal standards for breakthrough technologies. It includes participation of the United Nations, the WIPO (World Intellectual Property Organization) and other private organizations [7].

Thanks to cooperation between universities, businesses and interstate structures, it is possible to form global standards that are selectively adapted to particular regional peculiarities and needs.

## 5. THE NEED FOR REGULATION AND INTERNATIONAL COOPERATION

Quantum computing has a high modernization potential that can affect key areas of public life, from national security and economics to medicine and sensitive data management.

This progress affects not only scientific, but also geopolitical interests, and requires well-thought-out regulatory mechanisms, global interaction, and creation of an adequate system of checks and balances.

The need for international regulation of quantum technology development in this regard is due to:

- threat of destroying the existing global cryptographic infrastructure and undermining cybersecurity;
- risk of monopolization of technology by individual states (superpowers) or multinational corporations;
- increasing the likelihood of technological inequality between countries;
- possibility of militarization and entering a new round of the arms race using the established foundation of quantum developments;
- lack of developed ethical guidelines and global norms necessary for protection of human rights and individual freedom.

In this case, **geopolitical competition** and desire for technological leadership can act as a barrier to global regulation, which is reflected in **secrecy of defense developments**, which hinders transparency and control. This is driven by **uneven development** of quantum technologies in different countries around the globe [8]. **Differences in legal systems** and limited sovereignty of individual states are essential as well.

Activity of the international organizations below is given as an example of international initiatives in this field:

- **WEF (World Economic Forum)** builds a "quantum economy" with an emphasis on sustainability and global ethics;
- **UNESCO** is discussing formation of an international code of ethics for quantum technologies based on rich bioethical developments;
- **OECD** forms recommendations on responsible implementation of breakthrough technologies and stimulates intersectoral dialogue;
- **Quantum Flagship (EU)** supports standardization, ethical control and cross-border cooperation within the European research policy [9].
- It seems the above barriers can be cleared with the following methods:
- **soft law** [10] — creation of codes, declarations and framework agreements that form a culture of responsibility between the leading players working in this field;
- **scientific diplomacy** — development of international research consortia and open networks;
- **inclusivity in technology** — ensuring equal access to education and infrastructure for people from all countries;
- **open standards platform** — use of publicly available quantum instruments under international jurisdiction [11];
- **interdisciplinary approach** — involving lawyers, philosophers, engineers and representatives of civil society in discussion of ethical issues of quantum technology development.

Thus, international cooperation in quantum technologies is not an optional, but a vital condition for preventing future global conflicts, building trust and fairly distributing the results of scientific progress within society. Development of ethically sound global regulatory mechanisms should go hand in hand with scientific advances and include both initiatives from states, international institutions, research centers, and individual citizens.

## CONCLUSION

Quantum computing promises a qualitative breakthrough in science, medicine, industry, communications and many sectors of national economy. This opens up new horizons for solving problems that have long been considered inaccessible to classical computing systems. Meanwhile, such a large-scale human progress is accompanied by serious challenges to society [12]. These threats range from information security to the risks of increasing global strategic inequality and, as a result, global military and political instability.

Ethical aspects of quantum technology development and application hold a specific place in modern scientific discourse [13]. It requires a systematic approach that unites the efforts of physicists, engineers, lawyers, philosophers and politicians. Meanwhile, the principles of precaution, transparency, inclusivity and openness should form the basis for ethically sustainable development in this field.

Formation of an ethical culture among specialists working with quantum technologies is becoming one of the key tasks of modern scientific training. Ethical literacy, as part of professional training, is necessary to ensure a balance between technological progress and public interests.

The future of quantum technologies should be based on the principles of international partnership, trust and equal access to these technologies. Safe, fair and benefit-oriented development of such systems is possible only with joint efforts.

**References**


1. Kitaev AYu, Shen` AN, Vyaly`j MN. Klassicheskie i kvantovy`e vy`chisleniya. M. MCzNMO. 1999; 320 s. Russian.
2. Valiev KA. Kvantovy`e komp`yutery`: nadezhdy` i real`nost`. M. Nauka. 2001; 256 s. Russian.
3. Antipenko LG. Ponyatie kvantovoj logiki: matematicheskie i filosofskie aspekty`. Vestnik Moskovskogo universiteta. Seriya 7: Filosofiya. 2015; (3): 3–15. Russian.
4. Nil`sen MA, Chuang IL. Kvantovy`e vy`chisleniya i kvantovaya informaciya. M. Vil`yams. 2020; 800 s. Russian.
5. Aaronson S. Kvantovy`e vy`chisleniya so vremyon Demokrita. Per. s angl. N. Lisovoj. Nauch. red. A. L`vovskij. M. Al`pina non-fikshn. 2018; 494 s. Russian.
6. Kaku M. Kvantovoe prevosxodstvo: revolyuciya v vy`chisleniyax, kotoraya izmenit vsyo: per. s angl. M. Al`pina non-fikshn. 2021; 352 s. Russian.
7. Borzunov SV, Kurgalin SD. Osnovy` kvantovy`x vy`chislenij i kvantovoj teorii informacii: uchebnoe posobie. SPb. BXV-Peterburg. 2022; 144 s. Russian.
8. Xidari Dzh. Kvantovy`e vy`chisleniya. Prikladnoj podxod: per. s angl. M. DMK Press. 2021; 352 s. Russian.
9. Perrier E. Ethical Quantum Computing: A Roadmap. arXiv preprint arXiv: 2102.00759. 2021.
10. Schumacher B, Westmoreland MD. Quantum Processes, Systems, and Information. Cambridge: Cambridge University Press. 2010; 500 p.
11. Wilde MM. Quantum Information Theory. Cambridge: Cambridge University Press. 2013; 685 p.
12. EITC/QI/QIF Osnovy` kvantovoj informacii. Akademiya EITCA. 2021.
13. Kvantovaya i prikladnaya e`tika. SystemsWorld Club. 2022. Available from URL: https://systemsworld.club/t/topic/3029?ysclid=ma2tqu2wx1885516128 (accessed: 15.04.2025). Russian.

**Литература**

1. Китаев А. Ю., Шень А. Н., Вялый М. Н. Классические и квантовые вычисления. М. МЦНМО. 1999; 320 с.
2. Валиев К. А. Квантовые компьютеры: надежды и реальность. М. Наука. 2001; 256 с.
3. Антипенко Л. Г. Понятие квантовой логики: математические и философские аспекты. Вестник Московского университета. Серия 7: Философия. 2015; (3): 3–15.
4. Нильсен М. А., Чуанг И. Л. Квантовые вычисления и квантовая информация. М. Вильямс. 2020; 800 с.
5. Ааронсон С. Квантовые вычисления со времен Демокрита. Пер. с англ. Н. Лисовой. Науч. ред. А. Львовский. М. Альпина нон-фикшн. 2018; 494 с.
6. Каку М. Квантовое превосходство: революция в вычислениях, которая изменит все: пер. с англ. М. Альпина нон-фикшн. 2021; 352 с.
7. Борзунов С. В., Кургалин С. Д. Основы квантовых вычислений и квантовой теории информации: учебное пособие. СПб. БХВ-Петербург. 2022; 144 с.
8. Хидари Дж. Квантовые вычисления. Прикладной подход: пер. с англ. М. ДМК Пресс. 2021; 352 с.
9. Perrier E. Ethical Quantum Computing: A Roadmap. arXiv preprint arXiv: 2102.00759. 2021.
10. Schumacher B, Westmoreland MD. Quantum Processes, Systems, and Information. Cambridge: Cambridge University Press. 2010; 500 p.
11. Wilde MM. Quantum Information Theory. Cambridge: Cambridge University Press. 2013; 685 p.
12. EITC/QI/QIF Основы квантовой информации. Академия EITCA. 2021.
13. Квантовая и прикладная этика. SystemsWorld Club. 2022. Режим доступа: [Электронный ресурс] URL: https://systemsworld.club/t/topic/3029?ysclid=ma2tqu2wx1885516128 (дата обращения: 15.04.2025).