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ARTS

CONSTRUCTING 'CULTURAL IDENTITY' IN MUSIC EDUCATION: FUNCTIONS, PATHWAYS, AND REFLECTIONS

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Abstract

This paper aims to systematically explore the core concepts and practical pathways for constructing "cultural identity" in music education. The article first elucidates the three core functions of music education from a functionalist perspective. Subsequently, based on a pathway approach, it proposes systematic innovations across three levels. Finally, the paper introduces critical reflections, pointing out the need to guard against the potential tendencies of essentialization and labeling in cultural identity construction, as well as the power relations implicit within them. It advocates for an open, dialogic, and reflective music education practice that respects cultural hybridity, with the goal of enabling music education to truly become an important pathway for promoting deep cultural understanding and cultivating a healthy cultural subjectivity.

Keywords: music education; Cultural identity; Function; route; reflection

I. Functionalism: The Core Functions of Music Education in Constructing Cultural Identity

(I) Emotional Foundation Function: Shaping Cultural Belonging and Emotional Bonds

Within the various functions of music education in constructing cultural identity, the emotional foundation function occupies a central and primary position. It operates not through rational knowledge indoctrination but by leveraging music's direct, affective power to establish a profound and enduring emotional bond between the individual and their culture, ultimately fostering a sense of cultural belonging that is "prior to reflection." The realization of this function is rooted in the nature of music as an "emotional symbol" and its inherent connection to human memory and experience.

The primary pathway lies in the early immersion in and emotional awakening of one's "musical mother tongue." The lullabies, nursery rhymes, and festive ritual music encountered in early life, particularly within informal educational spheres like family and community, constitute an individual's initial "sonic home." These melodies, rhythms, and timbres, intricately intertwined with the tones of a specific dialect, the presence of loved ones, and the essence of the native land, become cultural codes etched into bodily and emotional memory. For instance, an ancient folk song sung in dialect carries meaning far beyond its pitch and lyrics; it conveys the warmth of ancestors, the character of a region, and the historical echoes of a community. Through repeated listening, imitation, and internalization of these sounds, individuals unconsciously complete the initial emotional anchoring to their cultural roots. This sense of familiarity and security triggered by sound forms the most primordial, rationally irreplaceable cornerstone of cultural identity.

Furthermore, collective musical practice serves as a key mechanism for strengthening this emotional bond. When people sing, play, or dance together in a

shared time and space—such as in a choir, a folk band, or community festival dances—music transcends individual expression, transforming into a powerful social adhesive. Within unified rhythms and harmonious sounds, individual breath, heartbeat, and emotional rhythms become synchronized, producing what psychology terms a "communitas" experience. This highly coordinated collective practice not only creates intense immediate emotional resonance and pleasure but also deeply inscribes a sense of "we are one" within participants. Activities like class choir performances, rehearsals of traditional music ensembles in schools, or ritual dances in villages repeatedly enact this process, translating abstract cultural identity into tangible collective emotional energy, allowing individuals to affirm their cultural position within the sound of "us."

(II) Cognitive Construction Function: Providing Cultural Knowledge and Frameworks of Meaning

If the emotional foundation function of music education awakens the sense of "who we are," its cognitive construction function strives to answer the rational question of "why we are this way." Transcending emotional resonance, it treats music as a unique cognitive symbol and system of meaning, systematically transmitting specific cultural knowledge, worldviews, and modes of thinking to learners, thereby providing them with a structured cognitive framework for understanding their own culture. This function elevates cultural identity from a spontaneous emotional attachment to a conscious cultural understanding and identify with of meaning.

Music to start with functions as a "living cultural encyclopedia," carrying information far beyond its acoustic form. When students learn a folk song, they encounter more than just melody and lyrics. A work song depicting labor encodes a specific ethnic group's mode of production and relationship with nature; the strictly structured musical patterns of Beijing opera

contain the philosophical dialectic of "formula" and "adaptation" in traditional Chinese aesthetics; the complex rhythms of African drum music mapping the precise time concepts and social collaboration logic within a community. By analyzing musical forms, interpreting lyrical texts, and investigating performance contexts and taboos, music education guides learners in decoding a complete cultural grammar. In this process, abstract cultural knowledge—historical memory, ethical concepts, social structures, cosmology—is perceived, understood, and remembered through embodied musical experience.

At a deeper level, the cognitive construction function of music lies in shaping a distinctive cultural "perception-thinking" mode. Different musical systems represent different ways of perceiving the world and organizing experience. The highly developed harmonic logic and thematic development techniques in Western classical music unconsciously convey a linear, analytical mode of thinking that seeks conflict and resolution. Conversely, the emphasis on "linear fluidity" in melodic aesthetics, the pursuit of "interplay between substantial and insubstantial" in timbre, and the tradition of improvisational variation in Chinese traditional music are deeply rooted in a holistic, relational, and dialectical cultural way of thinking. Learning the vibrato techniques of the guqin is not merely acquiring a skill but experiencing what constitutes "vivid rhythmic vitality." Analyzing the strict correspondence between "ragas" in Indian classical music and specific times of day or emotions allows students a glimpse into a worldview that deeply integrates art, nature, and spirit. Thus, the process of music education is also one of guiding learners "to listen and think like a member of that culture," cultivating a aesthetic perception and meaning-interpretation ability inherent to a specific culture.

Ultimately, this cognitive construction leads to the acquisition of cultural interpretive authority. When an individual can use the musical vocabulary and meaning frameworks of their culture to understand, evaluate, and even create music, they cease to be a passive cultural recipient and become an active participant and interpreter of cultural meaning. They can comprehend the historical hardship and emotional tension carried by the "bitter tone" in Shanbei's Xintianyou folk songs, appreciate the melancholy and resistance expressed by the flattened third and seventh degrees in Blues, and discern how specific musical forms are adapted and reinterpreted in the process of modernization. This deep cognitive understanding frees cultural identity from superficial symbolization, establishing a solid foundation of rationality.

(III) Identity Negotiation Function: Facilitating the Integration of Individual and Collective Identities

The identity negotiation function of music education occupies the most complex and dynamic level in the process of constructing cultural identity. It transcends the foundational emotional belonging and the construction of knowledge systems, face the inevitable issues of identity plurality and fluidity encountered by individuals in the context of globalization and modern-

ization. The core of this function lies in providing learners with a safe, creative "third space" within music education, allowing them to explore, adapt, and integrate their individual selves with various collective cultural identities, ultimately forming a dialectically unified identity that possesses both subjectivity and sociality.

In this process, music to begin with serves as a symbolic resource for individuals to express and experiment with identity. The musical preferences of adolescents—whether enthusiasm for Chinese-style rock, indie folk, immersion in K-pop, or classical music—are not merely aesthetic choices but symbolic practices for self-definition, peer differentiation, and seeking group belonging. If music education can provide students with a sufficiently broad musical vision and equitable value judgment, it can support them in attempt to play different "cultural roles" through exposure to diverse musical-cultural symbols, thereby exploring the multiple possibilities of "who I am" and "who I want to be." This exploration is active and experimental, providing rich material for identity integration.

Furthermore, music education guides individuals in achieving the "creative suturing of personal and collective narratives" through diverse musical practices. When a Chinese student practices Western violin repertoire, they are internalizing a cross-cultural artistic expressive skill. When they attempt to interpret the charm of "Er Quan Ying Yue" on the violin or participate in composing contemporary works incorporating pentatonic modes, they are engaged in a deeper identity negotiation: being an individual performer, a learner of the global classical tradition, and a contemporary inheritor and innovator of local culture. Activities like musical composition, improvisation, and arrangement particularly encourage learners to fuse personal experiences, emotions, and multiple cultural influences into a unique musical expression. This process is precisely the integrative act of "personalizing" collective cultural identity and "culturalizing" individual experience.

Ultimately, effective identity negotiation leads to a hybrid, situational cultural identity. It is not a choice between pure, mutually exclusive identities but cultivates an inclusive "both/and" capacity for identification. Individuals become able to flexibly and confidently mobilize their multi-layered musical literacy and identity awareness in different cultural contexts: singing local folk songs at family gatherings, interpreting works by national composers in international exchanges, fusing global elements in personal creation. By affirming the legitimacy of such hybridity and fluidity, music education helps learners move beyond essentialist identity anxiety, constructing a healthy, modern cultural subjectivity that is rooted locally, oriented globally, and capable of evolving throughout one's life.

II. Path Theory: Multiple Pathways for Constructing Cultural Identity in Music Education Practice

(I) Curriculum Content Level: From "Singular Canon" to "Polyphonic Plurality" in Text Selection

The evolution of music education at the curriculum content level profound reflection the shift in socio-cultural idea from static closure to dynamic openness. The traditional model often adhered to a "singular canon"

principle, its core consisting of a highly canonized, authoritative set of musical works and knowledge systems. This selection served to establish aesthetic standards and consolidate national identity in specific historical periods, but it invisibly constructed an invisible cultural wall, excluding a vast array of vibrant local, marginalized, and cross-cultural musical practices from the palace of formal education, essentially transmitting a singular, hierarchical cultural value system.

With the deepening of cultural globalization and postmodern thought, the limitations of this "singular canon" paradigm have become increasingly apparent. The core direction of contemporary music education curriculum reform is precisely towards a practice of "polyphonic plurality" in text selection. "Plurality" manifests in geographical, historical, and social breadth: the curriculum includes not only Western classical and Chinese traditional masterpieces but also systematically incorporates traditional music of world peoples, regional folk music, urban popular music, and contemporary experimental music, forming an equitable juxtaposition of a "world music map." "Polyphony," however, emphasizes a deeper pedagogical philosophy—it is not merely a simple accumulation of repertoire but intentionally creates a "dialogue" among musics of different cultural backgrounds, aesthetic concepts, and social functions within the curriculum. For example, juxtaposing an Italian opera aria, a Beijing opera aria, and Javanese gamelan vocal chanting to discuss "vocal expressiveness"; or connecting African drumming, Chopin's mazurkas, and electronic music beat design from the perspective of rhythm. This "polyphonic" arrangement aims to break aesthetic hegemony, guiding students to recognize the diversity and relativity of musical cultures, and to understand that every music is a product of its specific cultural context, possessing its own unique system of meaning and value logic.

Achieving the shift from "singular" to "polyphonic" involves far more than expanding a repertoire list. It requires educators to fundamentally rethink the cultural politics of the curriculum, transitioning from the authoritative role of "transmitting the canon" to the facilitator role of "building a platform for dialogue." This means balancing local and global, traditional and modern, artistic and everyday elements when selecting texts. The ultimate goal is for students, through listening to and understanding this rich "polyphony," to deepen their "depth" of cognition regarding their own cultural traditions while simultaneously developing a "breadth" of sincere respect and understanding for other cultures. Within this framework, students gain access to diverse musical "texts" in a safe, open educational space, thereby providing the most fertile ground for their individual cultural negotiation and creative integration in broader life. The music curriculum itself thus transforms from a repository transmitting fixed knowledge into a vibrant "polyphonic" field that stimulates cultural understanding and critical thinking.

(II) Teaching Methodology Level: Paradigm Shift from "Knowledge Transmission" to "Cultural Experience"

In traditional music teaching, "knowledge transmission" occupies the central position. Classes often revolve around the one-way instill of systematic knowledge such as music theory, sight-reading, and technique, placing students in a passive receive role. While this paradigm consolidates foundations, it tends to reduce music to decontextualized techniques and symbols, difficult to reach its deeper cultural significance and emotional resonance.

Contemporary educational concept are driving a profound paradigm shift—from "knowledge transmission" towards "cultural experience." The teaching focus is no longer merely on "knowing what," but on "experiencing what" and "understanding why." This means the classroom becomes a field for cultural practice: students feel music as a living cultural force by exploring the local customs and practices behind folk songs, listening to classics within historical contexts, comparing musical expressions across cultures, and even participating in improvisation and community music activities. Teaching methods subsequently diversified, with strategies like project-based learning, scenario simulation, and interdisciplinary mix being widely employed, aiming to guide students in constructing a holistic understanding of musical style, social function, and cultural value through personal participation and aesthetic immersion.

This shift builds a bridge for students from skill acquisition to cultural understanding, ensuring that music learning ceases to be an isolated skill drill and becomes a vital pathway for cultivating aesthetic judgment, cultural empathy, and creative literacy, ultimately point to the cultivation of a complete personality.

(III) Practical Field Level: Field Expansion from "Classroom" to "Lifeworld"

Traditional music teaching's practical field is largely confined to the physically speaking "classroom" space. Here, instruction is preset and procedural, with knowledge and skill training occurring in a relatively closed and controlled environment. An invisible boundary seem exists between music and the outside world, with students' learning experiences often ending at the classroom walls.

Modern educational concept vigorously promote the expansion of the practical field from the "classroom" to the vast "lifeworld." The core of this transformation lies in recognizing that the essence of music is vivid socio-cultural life practice, not static knowledge confined to textbooks. The reach of teaching therefore extends to concert halls, museums, community squares, folk festivals, digital networks, and even daily family life. Students are no longer merely listeners in the classroom but become explorers, participants, and creators in life's scenes: they might record and study the musical elements in street vendor calls, experience the function of ritual music in traditional festivals, create their own city sound maps using mobile technology, or interact with distant fan communities via social media.

The significance of this field expansion is profound. It breaks down the barrier between art and life, allowing music learning to occur through interaction with the complex, plural realities of the real world. Students can understand music's social functions, cultural meanings,

and emotional power in concrete contexts, thereby transforming knowledge into lived experience and genuine competence, ultimately achieve the educational goal of "unifying knowledge and action" in music education.

III. Reflection Theory: A Critical Examination of Cultural Identity Construction in Music Education

In the process of music education promoting "cultural experience," the construction of cultural identity is often viewed as a natural and positive outcome. However, the perspective of reflection theory subjects this to critical examination, warning us to be vigilant against potential essentialist narratives and power discourses within it.

If mishandled, cultural identity construction in music education can easily slide into a simplified "cultural tagism." That is, solidifying rich, fluid musical traditions into static symbols representing a particular nation or group, complete the designation and indoctrination of a culture by teaching a few "representative" pieces or styles. This mode of construction may complete cultural boundaries, shape stereotypes, and even place and other cultures within a binary oppositional framework, overlooking the complex reality of internal cultural plurality and mutual penetration.

A deeper critique lies in the power relations often implicit within this construction process. Which musics are selected for the curriculum, from which perspective

they are interpreted, and who decides what is "orthodox" or "canonical"—these questions involve struggles of cultural authority, political ideology, and educational policy. It may amplify certain voices while obscuring or co-opting others from marginalized, folk, or subcultural musical practices, thereby constructing a filtered, "official" cultural identity that serves a specific narrative.

Therefore, reflection theory calls for a self-conscious, critical practice of music education. It demands that educators and learners jointly examine the cultural presuppositions and power structures latent in teaching content and methods, maintain openness and dialogicality in identity construction, respect cultural hybridity and individual experiential diversity, making music education truly a reflective space that promotes cultural understanding rather than solidifying cultural barriers.

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ECONOMIC SCIENCES

APPLICATION OF FUZZY LOGIC AND ARTIFICIAL INTELLIGENCE IN ECONOMIC DECISION-MAKING PROCESSES

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QEYRI-SƏLİS MƏNTİQ VƏ SÜNİ INTELLEKTİN İQTİSADI QƏRAR QƏBULETMƏ PROSESLƏRİNƏ TƏTBİQİ

Hüseynzadə G.

Dissertant

Tədris texnologiyaları üzrə işçi

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Abstract

The application of fuzzy logic and artificial intelligence in economic decision-making processes has become increasingly relevant, particularly in conditions of uncertainty and incomplete information, where it contributes to more effective decision outcomes. Traditional methods demonstrate limitations when addressing the complexity of multi-criteria economic systems, conflicting objectives, and imprecise data. Fuzzy logic allows the incorporation of subjective assessments and linguistic variables into mathematical models, enhancing the flexibility and reliability of decision-making. This paper analyzes the combined application of fuzzy logic and artificial intelligence in optimizing resource allocation, evaluating alternatives, and supporting strategic planning processes. Empirical studies from recent decades indicate that these approaches improve decision quality, reduce associated risks, and facilitate the data-driven and adaptive implementation of economic strategies. At the same time, challenges such as computational complexity, algorithmic bias, and data accuracy remain pertinent issues. The study emphasizes the necessity of integrating expert knowledge and ethical principles into AI-driven decision-making frameworks. The findings suggest that the use of fuzzy logic and artificial intelligence enhances the transparency, agility, and reliability of economic decision-making, enabling organizations to adapt more efficiently to dynamic market conditions.

Abstrakt

Qeyri-səlis məntiq və süni intellektin iqtisadi qərar qəbulətmə proseslərində tətbiqi getdikcə aktuallaşır, xüsusilə qeyri-müəyyənlik və məlumat çatışmazlığı şəraitində effektiv qərar qəbuluna töhfə verir. Ənənəvi metodlar çoxmeyarlı iqtisadi sistemlərin mürəkkəbliyi, ziddiyyətli məqsədlər və qeyri-dəqiq məlumatlarla işləməkdə məhdudiyyətlər göstərir. Qeyri-səlis məntiq, subyektiv qiymətləndirmələr və dil dəyişənləri kimi qeyri-dəqiqlikləri riyazi modelə daxil etməyə imkan verərək qərar qəbulətmənin çevikliyini və etibarlılığını artırır. Bu məqalədə qeyri-səlis məntiq və süni intellektin birgə tətbiqi vasitəsilə resurs bölgüsü, alternativlərin qiymətləndirilməsi və strateji planlaşdırma proseslərinin optimallaşdırılması analiz edilmişdir. Son onilliklərin empirik tədqiqatları göstərir ki, bu yanaşmalar qərarların keyfiyyətini yüksəldir, riskləri azaldır və iqtisadi strategiyaların məlumat-əsaslı və adaptiv şəkildə icrasına şərait yaradır. Eyni zamanda, hesablama mürəkkəbliyi, alqoritmik qərəz və məlumatların doğruluğu kimi məsələlər hələ də aktual problemlər kimi qalmaqdadır. Məqalədə vurğulanır ekspert biliklərinin və etik prinsiplərin inteqrasiyası süni intellektin qərar qəbulətmə çərçivəsinə daxil edilməli olduğu vurğulanır. Nəticələr göstərir ki, qeyri-səlis məntiq və süni intellektin tətbiqi iqtisadi qərar qəbulətmənin şəffaflığını, çevikliyini və etibarlılığını artıraraq müəssisələrin dinamik bazar şəraitinə daha səmərəli uyğunlaşmasına imkan yaradır.

Keywords: Fuzzy logic, Artificial intelligence, Economic decision-making, Multi-criteria decision analysis, Uncertainty management, Resource allocation, Strategic planning

Açar sözlər: *Qeyri-səlis məntiq, Süni intellekt, İqtisadi qərar qəbulətmə, Çoxmeyarlı qərar analizi, Qeyri-müəyyənliyin idarə olunması, Resurs bölgüsü, Strateji planlaşdırma*

Qeyri-səlis məntiq (fuzzy logic) və süni intellekt (AI) qərar qəbulətmə sahəsində son illərdə həm akademik, həm də praktik marağın mərkəzinə çevrilmişdir. Klassik qərar qəbulətmə yanaşmaları ənənəvi iqtisadi modellərdə məhdudiyyətlərlə qarşılaşır, çünki realıqda qərarlar çox vaxt qeyri-dəqiq, subyektiv və qeyri-

müəyyən biliklərlə verilir. Qeyri-səlis məntiq bu problemləri həll etmək üçün nəzəri və praktiki alət təmin edir, çünki o, “tam doğru” və “tam səhv” kimi kəskin qütblər əvəzinə “qismən doğru”, “çox gümanla deyil” və “orta dərəcədə” kimi qeyri-səlis qiymətləndirmələrlə işləməyə imkan verir. Bu

yanaşma, süni intellektin hesablama gücü ilə birləşərək sənaye, maliyyə və iqtisadi idarəetmədə mürəkkəb qərar qəbulətmənin daha dəqiq və etibarlı olmasına şərait yaradır [1].

Qeyri-səlis məntiqin əsasını ABS-da Kaliforniya Universitetinin professoru Lütfi Zadə qoymuşdur və bu nəzəriyyə çoxlu şərtlər üçün qeyri-müəyyənliyin riyazi modelinin qurulmasını təmin edir. Qeyri-səlis sistemlər klassik məntiqin "0 və 1" yanaşmasından fərqli olaraq müxtəlif səviyyəli doğruluqlar arasındakı əlaqələri analiz etməyə imkan verir və bu, iqtisadi qərar qəbulətmədə subyektiv və qeyri dəqiq məlumatların nəzərə alınmasını mümkün edir [2].

Bu məqalədə qeyri-səlis məntiq və süni intellektin iqtisadi qərar qəbulətmə proseslərinə tətbiqi nəzəri, metodoloji və tətbiqi aspektlərdə ətraflı araşdırılır.

Qeyri-səlis məntiq, müxtəlif dərəcəli doğru və səhv anlayışlarını riyazi modelə daxil etmək üçün yaradılmışdır və bu, ənənəvi məntiqin hər iki ekstremini birləşdirən genişlənmiş bir çərçivə təmin edir. Ənənəvi mexanizmlər bəzi real iqtisadi qərarlarda qeyri-dəqiqlik və subyektiv seçimlər qarşısında çətinliklərlə üzləşir. Qeyri-səlis məntiq bu boşluğu doldurur və çoxsaylı kriteriyalar əsasında qərar qəbulətmənin fleksibil və güclü modelini yaradır.

Beynəlxalq ədəbiyyat qeyri-səlis məntiq və süni intellekt alətlərinin birgə tətbiqinin optimallaşdırılmış qərar qəbulətmədə mühüm rolunu vurğulayır. Mövcud bibliometrik analizlərə görə, bu yanaşmalar iqtisadi idarəetmə institutlarında qərar qəbulətmənin mürəkkəbliyini aradan qaldırmaq üçün geniş potensiala malikdir, lakin tətbiq sahəsi hələ də tam şəkildə araşdırılmayıb [1].

Müasir tədqiqatlarda süni intellektlə gücləndirilmiş qeyri-səlis çoxmeyarlı qərar qəbulətmə (MCDM) yanaşmaları müxtəlif sahələrdə, o cümlədən planlaşdırma, resursların optimallaşdırılması və strateji qərarlar üçün nəzərdən keçirilmişdir. Bu metodologiyalar çoxsaylı kriteriyaların olduğu iqtisadi problemlərdə alternativlərin sistemli qiymətləndirilməsinə imkan verir [3].

Bu məqalə, qeyri-səlis məntiq və süni intellektin iqtisadi qərar qəbulətmədə tətbiqi üçün nəzəri və tətbiqi araşdırma metodlarını birləşdirir. Əsas metodoloji yanaşma aşağıdakılardır:

- Ədəbiyyatın sisteməlik təhlili – müasir elmi nəşrlərdən qeyri-səlis məntiq və AI inteqrasiyası üçün statistika və nümunə tədqiqatlar toplanır;
- Qeyri-səlis qərar dəstək modelləri – Fuzzy Decision Support Systems (FDSS) konsepsiyası çərçivəsində meta-alqoritmlər izah edilir;
- Empirik yanaşma – real iqtisadi vəziyyət nümunələri və modelləri əsasında təhlil edilir;
- Tətbiq nümunələri – qeyri-səlis MCDM və AI alqoritmlərinin optimal resurs bölgüsü və investisiya qərarlarında tətbiqi göstərilir.

Qeyri-səlis çoxluqlar qeyri-dəqiq məlumatların riyazi modelləşdirilməsini təmin edir [12]. Belə modellər, məsələn, qərar kriteriyalarının "yüksək", "orta" və "aşağı" kimi qeyri-kəskin kateqoriyalara bölünməsi ilə tətbiq olunur. Bu yanaşma, müxtəlif iqtisadi dəyişənləri daha realist şəkildə təsvir etməyə imkan verir və klassik

modeli genişləndirir [4]. FİS (Fuzzy Inference Systems) qeyri-səlis qaydalar əsasında çıxış qərarlarını və qiymətləndirmələri yaradır. Belə sistemlər, məsələn TOPSIS və digər MCDM metodlarının qeyri-səlis variantları ilə birləşdirilərək optimal seçimləri tapmağa xidmət edir [5].

Müasir elmi tədqiqatlar qeyri-səlis məntiq ilə süni intellektin maliyyə proqnozlaşdırılması və risk idarəetməsi proseslərinə uğurla tətbiq olunduğunu göstərir. Bu yanaşma makroiqtisadi göstəricilərlə birləşdirilmiş halda daha dəqiq proqnozlar və risk profilləri yaradır [6].

Qeyri-səlis MCDM modelləri müxtəlif iqtisadi kriteriyalar arasında balanslaşdırılmış qərar qəbulətmə üçün geniş şəkildə tətbiq edilir. Məsələn, şəhər iqtisadiyyatının digital təsirini analiz edən tədqiqatlarda qeyri-səlis MCDM metodları bazarın inkişafını ölçmək üçün istifadə olunmuşdur [7].

AI-nin qərar qəbulətmə sistemlərinə inteqrasiyası yeni riskləri də ortaya çıxarır. Bu risklər arasında alqoritmik qərəz və məlumatların düzgünlüyü məsələləri xüsusilə vacibdir. Qeyri-səlis modellər subyektiv kriteriyaları nəzərə alsa da, bu yanaşma etibar səviyyəsini düzgün qurmaq üçün əlavə nəzarətlər tələb edir [8].

AI-əsaslı qərar qəbulətmə modellərinin **şəffaf olması və etika prinsiplərinə uyğunluğu** prioritet olaraq qalır. Əks halda, bu sistemlərin tətbiqi iqtisadi qərarların qəbulunda səhv nəticələrə yol açabilir [9].

Qeyri-səlis məntiq və süni intellekt modellərinin birgə tətbiqi iqtisadi qərar qəbulətmənin:

- qeyri-müəyyənliklərlə effektiv işləmə,
- çox kriteriyalı problemlərin riyazi modelləşdirilməsi,
- optimal qərarların tapılması kimi üstünlüklərini təmin edir [10].

Bu yanaşma real dünya iqtisadi problemlərində qərar keyfiyyətini artırır və riskləri minimuma endirməyə kömək edir. Buna baxmayaraq, hesablama mürəkkəbliyi, alqoritmik qərəz və məlumatların doğruluğunu təmin etmə məsələləri hələ də aktual qalmışdır. Beləliklə, süni intellekt və qeyri-səlis məntiq modellərinin tətbiqi üçün güclü etik və normativ rəqəmsal çərçivələr zəruridir [10].

NƏTİCƏ

Bu tədqiqat göstərir ki, qeyri-səlis məntiq və süni intellektin birgə tətbiqi iqtisadi qərar qəbulətmə proseslərinin effektivliyini əhəmiyyətli dərəcədə artırır. Qeyri-dəqiqlik, subyektiv qiymətləndirmələr və qeyri-müəyyənlik kimi problemlər ənənəvi qərar qəbulətmə modellərində ciddi məhdudiyyətlər yaradır. Lakin qeyri-səlis məntiq bu qeyri-dəqiqlikləri riyazi modelə daxil etməyə imkan verərək qərarların çevikliyini və etibarlılığını yüksəldir. Süni intellekt isə məlumatların böyük həcmli təhlili, nümunələrin aşkar edilməsi və adaptiv optimallaşdırma vasitəsilə qərar qəbulətmə prosesinə əlavə üstünlüklər gətirir.

Empirik və nəzəri tədqiqatlar göstərir ki, AI ilə inteqrasiya edilmiş qeyri-səlis MCDM yanaşmaları resurs bölgüsü, strateji planlaşdırma və risklərin idarə edilməsində daha səmərəli nəticələr təmin edir. Eyni zamanda, hesablama mürəkkəbliyi, məlumatların

doğruluğu və algoritmik qərar kimi risklər hələ də aktualdır və diqqət tələb edir. Bu səbəbdən qərar qəbul etmə sistemlərinin tətbiqində ekspert biliklərinin integrasiyası, etik prinsiplərin qorunması və normativ çərçivələrin formalaşdırılması vacibdir.

Nəticə olaraq, qeyri-səlis məntiq və süni intellektin sinergetik istifadəsi iqtisadi qərar qəbul etməni daha şəffaf, çevik və məlumat-əsaslı edir. Bu yanaşma müəssisələrin dinamik bazar şəraitinə adaptasiyasını asanlaşdırır və riskləri minimuma endirərək strateji qərarların keyfiyyətini artırır. Gələcək tədqiqatlar bu yanaşmaların daha geniş sektorlarda tətbiqini və mövcud metodların optimallaşdırılmasını əhatə edə bilər.

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BRIDGING THE GAP: PHYSICIANS' AND NURSES' PERSPECTIVES ON HEALTH TECHNOLOGY IMPLEMENTATION IN ALMATY CITY HOSPITALS**Tolegenova S.**

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Abstract

A cross-sectional study was conducted from January to March 2025 using a structured, expert-validated questionnaire, pilot tested in Kazakh and Russian. The survey was distributed anonymously via Google Forms to all doctors and nurses in a medical organization, with 136 doctors and 225 nurses participating. Consent was obtained electronically. The questionnaire covered demographics, innovation, collaboration, and reflective practices. Data analysis was performed using SPSS and Excel, applying chi-square tests to compare responses between doctors and nurses, with significance set at $p < 0.05$.

Doctors were generally younger and had slightly less experience than nurses, though only age differences were statistically significant. Nurses reported higher engagement in innovation, including introducing new ideas, using alternative methods, and promoting team creativity. In contrast, doctors more often described strong collaboration, knowledge sharing, and reflective team practices. They reported more frequent discussions on effectiveness, problem-solving, and peer feedback. Doctors also more often recognized platforms for interdepartmental and patient interactions.

This study revealed key differences between doctors and nurses in innovation, collaboration, and team reflection. Doctors were more engaged in critical discussion and reflection, while nurses showed stronger tendencies toward innovation. Future strategies should focus on fostering interdisciplinary collaboration, expanding innovation opportunities for nurses, and promoting team-based learning to enhance overall healthcare quality.

Keywords: Healthcare professionals, interdisciplinary collaboration, team reflection, knowledge sharing, organizational culture.

Introduction. Universal Health Coverage (UHC) is a global health priority, aiming to ensure that everyone, everywhere has access to quality health services without facing financial hardship. UHC is one of the central components of the United Nations' Sustainable Development Goals (SDGs), particularly Goal 3, which focuses on ensuring healthy lives and promoting well-being for all, at all ages. Achieving UHC requires a healthcare system that is accessible, efficient, and capable of delivering high-quality care to all individuals [1].

A critical factor in achieving UHC is the effective collaboration between healthcare professionals, especially doctors and nurses, as this directly impacts the quality and accessibility of services provided to patients [2].

Effective collaboration between doctors and nurses is essential for delivering patient-centered care. Doctors and nurses bring unique perspectives and expertise to the table, with doctors focusing on diagnosis and medical treatment, and nurses providing continuous, hands-on patient care. Their collaboration fosters

an environment of shared knowledge, skills, and decision-making, which is crucial for improving patient outcomes [3].

Team-based care allows for a more holistic approach to treatment, where both medical and supportive needs of patients are addressed [4].

Moreover, effective collaboration leads to improved communication, reduced medical errors, and more efficient care delivery, all of which are vital for achieving UHC. In a collaborative setting, doctors and nurses can work together to make informed decisions, leading to better resource allocation, reduced costs, and more effective health interventions [5].

For healthcare managers, addressing the dynamics of collaboration between doctors and nurses is of paramount importance. Strong teamwork is directly tied to improved organizational performance, which has implications for both clinical outcomes and financial sustainability [6].

Managers need to ensure that healthcare teams function smoothly and that effective communication channels are in place. This is not only critical for im-

proving patient safety and care quality but also for optimizing the use of resources, reducing waste, and improving the efficiency of healthcare delivery. From an economic perspective, better collaboration leads to fewer medical errors, reduced duplication of effort, and more efficient workflows, all of which contribute to cost savings. Furthermore, effective collaboration enhances employee satisfaction and retention, which can further reduce turnover costs and promote a more stable and effective workforce.

Almaty is the largest city in Kazakhstan, and its medical facilities are often at the forefront of the country's healthcare delivery. The hospital in question plays a vital role in serving a diverse population with varying health needs. By improving collaboration within the hospital, we can ensure that both doctors and nurses are aligned in their efforts to provide comprehensive, efficient, and compassionate care. Effective collaboration in this context will not only improve patient satisfaction but also contribute to the hospital's reputation, operational efficiency, and overall quality of care. As Almaty continues to grow and its healthcare system evolves, fostering a culture of teamwork will be essential for meeting the healthcare demands of the city's residents while working towards UHC and the SDGs. The aim of the article is to compare doctors and nurses perceptions of innovation, collaboration, and reflective practices in healthcare teams, and to identify differences that may influence organizational performance and patient safety improvement in medical organization "X" of the Almaty city.

While leadership, organizational culture, and digital tools are acknowledged contributors to resilience, multiple recent studies underscore the role of resilience and innovation across industries [7]. However, in healthcare, more research is needed to fully understand the mechanisms through which resilience supports innovation and improves outcomes.

2. Literature review. Innovation in service organizations such as hospitals is a multifaceted and evolving process. It extends beyond individual adoption to encompass an organization's capacity to assimilate new practices, processes, or technologies. Successful adoption depends on factors including the perceived relative advantage of an innovation, its compatibility with existing workflows, complexity, trialability, and observability. Psychological readiness, supportive context, and opportunities for adaptation further influence the innovation process. Continuous support, system readiness, and well-managed stages of implementation and feedback are essential for healthcare organizations to effectively embed innovation. According to Greenhalgh *et al.*, for example, diffusion of innovations in service organizations can be facilitated by ensuring these factors align with organizational needs. Nonetheless, healthcare innovation initiatives often remain complex; one recent study even questioned whether certain HTA processes help or hinder innovation in practice.

Innovation readiness – an organization's ability to adopt and implement impactful changes – is particularly crucial in healthcare. Greenhalgh *et al.* described innovation as coordinated actions intentionally departing from established routines to drive improvement.

Yet despite growing attention to healthcare innovation, comprehensive research on what constitutes innovation readiness remains limited. Recent research has highlighted four key factors contributing to innovation readiness in healthcare organizations: strategic direction, organizational climate, leadership, and individual commitment, with *climate for innovation* receiving the most attention [8]. However, many studies overlook the interplay between these factors and tend to focus narrowly on the implementation phase, neglecting the broader innovation lifecycle. Other studies in various contexts similarly emphasize structured pathways and supportive environments as determinants of successful innovation [9].

Professional roles also influence innovation dynamics. Physicians often play a pivotal role in the innovation lifecycle by identifying unmet clinical needs, shaping device design through user input, ensuring safety and performance via assessment, and contributing to the economic and ethical evaluation of new technologies. Their clinical insight and contextual understanding are essential in early stages of innovation, making them indispensable for aligning health innovations with real-world patient care. For instance, a systematic review by Smith *et al.* showed how clinicians drive early health technology assessment in medical device innovation. Process frameworks such as stage-gate models and discussions on value-based decision making in HTA further contextualize how leadership and clinical input contribute to successful healthcare innovation.

In Kazakhstan, Health Technology Assessment (HTA) was introduced in 2009 as a tool to support evidence-based healthcare decision-making. Overseen by the National Scientific Center for Health Development and the Joint Commission on Quality under the Ministry of Health, HTA is used to assess the safety, clinical effectiveness, and cost-effectiveness of medical technologies. For example, Kulembekova *et al.* document how Kazakhstan's HTA framework involves stakeholders in evaluating new interventions. Between 2015 and 2017, HTA efforts in one Kazakhstani hospital led to the rejection of 17 ineffective technologies – saving over \$1 million – and supported the adoption of 24 effective interventions. Kazakhstan has also adopted evidence-informed deliberative processes and multi-criteria decision analysis to improve transparency and stakeholder involvement in prioritizing health technologies as part of its push toward Universal Health Coverage [10].

3. Research methods. To carry out this study, we developed a comprehensive questionnaire tailored to assess perceptions of innovation, collaboration, and reflective team practices among healthcare professionals. The questionnaire was constructed based on relevant literature and validated by experts in healthcare management and medical education to ensure content validity.

It comprised three main components: (1) Perceptions of Innovation and Idea Generation, focusing on the extent to which individuals and teams propose and implement new ideas; (2) Collaboration, Knowledge Sharing, and Patient Engagement Structures, assessing

communication across departments and with patients; and (3) Team-Based Reflective Practices and Problem-Solving Approaches, exploring teamwork dynamics, critical reflection, and performance evaluation. A demographic (passport) section included age, experience, and leadership training.

The instrument was pilot tested with 10 staff members from a medical organization, using both Kazakh and Russian versions to ensure clarity and linguistic appropriateness. Based on feedback, wording and layout adjustments were made.

The study employed a cross-sectional design. Data were collected anonymously via an online Google Form from January to March 2025. Participation was voluntary, with informed consent obtained electronically at the start of the survey through a dedicated consent button. All doctors and nurses employed at the organization were invited to participate. While the facility employed 50 doctors and 50 nurses, a total of 361 participants responded, including 136 doctors and 225

nurses, reflecting a high level of engagement and ensuring representativeness.

Quantitative data analysis was conducted using SPSS (Statistical Package for the Social Sciences) and Microsoft Excel. Descriptive statistics were used to summarize demographic variables. Group comparisons between doctors and nurses were carried out using the chi-square test to assess statistically significant differences in categorical variables. A p-value of less than 0.05 was considered statistically significant.

4. Results. Doctors were significantly younger than nurses ($p = 0.014$), with more in the 20–30 age group, while nurses were more represented in older age brackets. Although doctors had slightly less experience, the difference was not statistically significant ($p = 0.066$). Leadership training rates were similar between groups, with no significant difference ($p = 0.286$), table 1.

Table 1.

Demographic and Professional Characteristics of Doctors and Nurses

		Doctor n (%)	Nurse n (%)	Total n (%)	p
Age	20-30	52(38.2)	77(34.2%)	129(35.7%)	0,014
	31-45	39(28.7)	71(31.6%)	110(30.5%)	
	46-60	35(25.7%)	74(32.9%)	109(30.2%)	
	over 60	10(7.4%)	3(1.3%)	13(3.6%)	
	Total	136(100,0%)	225(100,0%)	361(100,0%)	
Working experience	up to 5 years	57(41.9%)	76(33.8%)	133(36.8%)	0,066
	6-10	20(14.7%)	46(20.4%)	66(18.3%)	
	11-20	19(14.0%)	50(22.2%)	69(19.1%)	
	over 20	40(29.4%)	53(23.6%)	93(25.8%)	
Leadership training	No	91(66.9%)	138(61.3%)	229(63.4%)	0.286
	Yes	45(33.1%)	87(38.7%)	132(36.6%)	

Source: Compiled by the authors.

Statistically significant differences were observed between doctors and nurses in their responses to questions related to innovation and idea generation in the workplace. Nurses consistently reported higher levels of agreement with statements regarding the introduction of new ideas, the use of alternative methods, and personal and team innovation. A higher percentage of nurses than doctors agreed that team members frequently introduce new ideas to improve quality (31.1% vs. 25.0%, $p = 0.023$), consider alternative procedures ($p = 0.014$), and create new services or methods (31.6% vs. 13.2%, $p < 0.001$). Nurses were also more likely to perceive their teams as innovative ($p = 0.001$) and to generate new ideas ($p = 0.004$). Furthermore, nurses more frequently agreed that they actively seek out new working methods ($p = 0.007$), promote and support innovative thinking among colleagues ($p = 0.012$), and

engage in research or fundraising to implement new ideas ($p = 0.033$). They also reported higher agreement in developing plans for implementing innovations ($p = 0.006$) and considered themselves more innovative overall ($p = 0.004$), table 2.

The survey revealed significant differences between doctors and nurses regarding collaboration, communication, and knowledge-sharing practices within the organization. A higher proportion of doctors (69.1%) than nurses (57.3%) reported that their organization has departments where colleagues from different departments can meet and learn from each other ($p = 0.026$). Similarly, 66.2% of doctors and 54.7% of nurses affirmed that there are spaces where patients and their representatives can meet with medical staff to receive necessary information ($p = 0.031$).

Table 2.

Perceptions of Innovation and Idea Generation Among Doctors and Nurses

		Doctor n (%)	Nurse n (%)	Total n (%)	p
Team members frequently introduce new ideas to improve the quality of our products and services	Disagree	34(25,0%)	34(15,1%)	68(18,8%)	0,023
	Somewhat disagree	14(10,3%)	48(21,3%)	62(17,2%)	
	Neither agree nor disagree	34(25,0%)	49(21,8%)	83(23,0%)	
	Somewhat agree	11(8,1%)	24(10,7%)	35(9,7%)	
	Agree	43(31,6%)	70(31,1%)	113(31,3%)	
The team considers new and alternative methods and procedures for doing their work.	Disagree	35(25,7%)	34(15,1%)	69(19,1%)	0,014
	Somewhat disagree	12(8,8%)	45(20,0%)	57(15,8%)	
	Neither agree nor disagree	35(25,7%)	50(22,2%)	85(23,5%)	
	Somewhat agree	13(9,6%)	26(11,6%)	39(10,8%)	
	Agree	41(30,1%)	70(31,1%)	111(30,7%)	
Team members often create new services, methods or procedures.	Disagree	49(36,0%)	44(19,6%)	93(25,8%)	<0,001
	Somewhat disagree	24(17,6%)	39(17,3%)	63(17,5%)	
	Neither agree nor disagree	34(25,0%)	49(21,8%)	83(23,0%)	
	Somewhat agree	11(8,1%)	22(9,8%)	33(9,1%)	
	Agree	18(13,2%)	71(31,6%)	89(24,7%)	
Our team is innovative.	Disagree	52(38,2%)	45(20,0%)	97(26,9%)	0,001
	Somewhat disagree	21(15,4%)	38(16,9%)	59(16,3%)	
	Neither agree nor disagree	29(21,3%)	45(20,0%)	74(20,5%)	
	Somewhat agree	11(8,1%)	27(12,0%)	38(10,5%)	
	Agree	23(16,9%)	70(31,1%)	93(25,8%)	
Generate new ideas.	Disagree	43(31,6%)	41(18,2%)	84(23,3%)	0,004
	Somewhat disagree	28(20,6%)	45(20,0%)	73(20,2%)	
	Neither agree nor disagree	33(24,3%)	51(22,7%)	84(23,3%)	
	Somewhat agree	13(9,6%)	21(9,3%)	34(9,4%)	
	Agree	19(14,0%)	67(29,8%)	86(23,8%)	
Seek out new ways of working, techniques and ideas.	Disagree	38(27,9%)	36(16,0%)	74(20,5%)	0,007
	Somewhat disagree	26(19,1%)	42(18,7%)	68(18,8%)	
	Neither agree nor disagree	38(27,9%)	56(24,9%)	94(26,0%)	
	Somewhat agree	12(8,8%)	20(8,9%)	32(8,9%)	
	Agree	22(16,2%)	71(31,6%)	93(25,8%)	
Promote and support ideas, inspiring other hospital staff to come up with new ideas.	Disagree	41(30,1%)	46(20,4%)	87(24,1%)	0,012
	Somewhat disagree	27(19,9%)	39(17,3%)	66(18,3%)	
	Neither agree nor disagree	37(27,2%)	51(22,7%)	88(24,4%)	
	Somewhat agree	11(8,1%)	21(9,3%)	32(8,9%)	
	Agree	20(14,7%)	68(30,2%)	88(24,4%)	
Research and raise funds to implement new ideas.	Disagree	34(25,0%)	37(16,4%)	71(19,7%)	0,033
	Somewhat disagree	31(22,8%)	42(18,7%)	73(20,2%)	
	Neither agree nor disagree	35(25,7%)	51(22,7%)	86(23,8%)	
	Somewhat agree	11(8,1%)	23(10,2%)	34(9,4%)	
	Agree	25(18,4%)	72(32,0%)	97(26,9%)	
Develop adequate plans and schedules for the implementation of new ideas.	Disagree	55(40,4%)	56(24,9%)	111(30,7%)	0,006
	Somewhat disagree	31(22,8%)	51(22,7%)	82(22,7%)	
	Neither agree nor disagree	24(17,6%)	47(20,9%)	71(19,7%)	

Are innovative employees.	Somewhat agree	3(2,2%)	20(8,9%)	23(6,4%)	0.004
	Agree	23(16,9%)	51(22,7%)	74(20,5%)	
	Disagree	54(39,7%)	53(23,6%)	107(29,6%)	
	Somewhat disagree	33(24,3%)	51(22,7%)	84(23,3%)	
	Neither agree nor disagree	25(18,4%)	52(23,1%)	77(21,3%)	
	Somewhat agree	4(2,9%)	21(9,3%)	25(6,9%)	
	Agree	20(14,7%)	48(21,3%)	68(18,8%)	

Source: Compiled by the authors.

More notably, 76.5% of doctors stated that the organization offers patient forums or peer-support spaces where patients can exchange experiences and information, compared to only 53.8% of nurses ($p < 0.001$). Doctors also reported more frequent knowledge sharing with colleagues (69.1% vs. 53.8%, $p = 0.004$) and more consistent discussions with team members about important work-related topics (70.6% vs. 59.1%, $p = 0.028$).

When examining team dynamics, a greater proportion of doctors (79.4%) than nurses (63.6%) reported

that their teams discuss criteria for effective functioning ($p = 0.002$). Furthermore, 88.2% of doctors compared to 64.0% of nurses indicated that their teams regularly discuss problems to improve ($p < 0.001$). Discussions about individual developments were also more common among doctors (79.4%) than nurses (59.1%, $p < 0.001$). These findings highlight the need to strengthen interdisciplinary communication and knowledge-sharing culture among nursing staff to foster a more collaborative environment, table 3.

Table 3.

Collaboration, Knowledge Sharing and Patient Engagement Structures in Healthcare Settings: Perceptions by Doctors and Nurses

		Doctor n (%)	Nurse n (%)	Total n (%)	p
Our organization has departments where colleagues from other departments and divisions can meet and learn from each other	Yes	94(69,1%)	129(57,3%)	223(61,8%)	0,026
	No	42(30,9%)	96(42,7%)	138(38,2%)	
Our organization has departments where patients and their representatives can meet and get the necessary information between medical staff	Yes	90(66,2%)	123(54,7%)	213(59,0%)	0.031
	No	46(33,8%)	102(45,3%)	148(41,0%)	
Our organization has departments or patient forums or where patients and their representatives can meet and get the necessary information from other patients (their treatment experience and other)	Yes	104(76,5%)	121(53,8%)	225(62,3%)	<0.001
	No	32(23,5%)	104(46,2%)	136(37,7%)	
I regularly share my knowledge and experience with my team members/colleagues	Yes	94(69,1%)	121(53,8%)	215(59,6%)	0.004
	No	42(30,9%)	104(46,2%)	146(40,4%)	
I discuss with my team members/colleagues what I think is important in my work	Yes	96(70,6%)	133(59,1%)	229(63,4%)	0.028
	No	40(29,4%)	92(40,9%)	132(36,6%)	
As a team, we discuss our criteria for effective functioning.	Yes	108(79,4%)	143(63,6%)	251(69,5%)	0.002
	No	28(20,6%)	82(36,4%)	110(30,5%)	
We discuss problems in our team to learn and improve.	Yes	120(88,2%)	144(64,0%)	264(73,1%)	<0.001
	No	16(11,8%)	81(36,0%)	97(26,9%)	
I discuss my developments with my team members/colleagues	Yes	108(79,4%)	133(59,1%)	241(66,8%)	<0.001
	No	28(20,6%)	92(40,9%)	120(33,2%)	

Source: Compiled by the authors.

The analysis revealed notable differences between doctors and nurses regarding team-based reflective practices and problem-solving behaviors. A significantly higher proportion of doctors (71.3%) compared to nurses (56.9%) reported that their teams consistently seek different interpretations and points of view to solve problems ($p = 0.006$). Likewise, more doctors (75.0%) than nurses (64.0%) indicated that team members regularly critique each other's work to improve performance ($p = 0.030$).

Reflection on team behavior was also more frequently reported by doctors, with 77.9% affirming that

their teams are willing to reflect on how they act, compared to 65.3% of nurses ($p = 0.011$). A significant gap was observed in the evaluation of team weaknesses, where 82.4% of doctors and only 56.9% of nurses reported engaging in this practice ($p < 0.001$). Additionally, 84.6% of doctors said that they openly challenge each other's opinions during teamwork, as opposed to 64.9% of nurses ($p < 0.001$). Finally, the tendency to reconsider proposed solutions was more common among doctors (75.7%) than nurses (64.0%), with the difference being statistically significant ($p = 0.020$), table 4.

Table 4.

Team-Based Reflective Practices and Problem-Solving Approaches Among Doctors and Nurses

		Doctor n (%)	Nurse n (%)		
In a team, we always look for different interpretations and points of view to solve a problem	Yes	97(71,3%)	128(56,9%)	225(62,3%)	0.006
	No	39(28,7%)	97(43,1%)	136(37,7%)	
In a team, we criticize each other's work to improve the team's performance.	Yes	102(75,0%)	144(64,0%)	246(68,1%)	0.030
	No	34(25,0%)	81(36,0%)	115(31,9%)	
In a team, we are willing to reflect on how we act	Yes	106(77,9%)	147(65,3%)	253(70,1%)	0.011
	No	30(22,1%)	78(34,7%)	108(29,9%)	
In a team, we evaluate our weaknesses to achieve effectiveness	Yes	112(82,4%)	128(56,9%)	240(66,5%)	<0.001
	No	24(17,6%)	97(43,1%)	121(33,5%)	
In a team, we openly challenge each other's opinions	Yes	115(84,6%)	146(64,9%)	261(72,3%)	<0.001
	No	21(15,4%)	79(35,1%)	100(27,7%)	
In a team, we reconsider any proposed solution	Yes	103(75,7%)	144(64,0%)	247(68,4%)	0.020
	No	33(24,3%)	81(36,0%)	114(31,6%)	

Source: Compiled by the authors.

5. Discussion. Our findings support existing research on the link between diversity climate, job crafting, and innovation, particularly in healthcare. Nurses exhibited a stronger orientation toward innovation than doctors, potentially due to a more supportive and equitable diversity climate. This aligns with previous studies, which found that nurses are more innovative when they feel valued in a diverse environment [11]. The role of job crafting and knowledge sharing on the effect of transformational leadership on innovative work behavior. Other researches shows that the Integrated Innovation & Entrepreneurship Certificate in Nursing Program aims to empower nurses to lead the design and development of health care innovations by fostering interdisciplinary collaboration, hands-on experience, and a focus on diversity, inclusion, and equity. The Elaine Marieb Center for Nursing and Engineering Innovation plays a pivotal role in supporting this initiative by providing infrastructure for students to collaborate across disciplines, designing and testing new health care products, services, and delivery systems [12].

Overall, our results emphasize that fostering an inclusive work culture can drive innovation, particularly among nursing teams who are closely involved with patient care. A strong positive correlation was found between nurse-physician collaboration and perceived healthcare service quality. Promoting interprofessional collaboration can enhance the overall quality of patient care [13]. Additionally, systematic review synthesizes over 20 years of empirical research on the role of teamwork in implementing new practices in health and human services, examining both qualitative and quantitative studies. The review highlights key factors such as staffing shortages, adaptive team functioning, and effective communication that significantly impact implementation outcomes. Teams with positive affective states, shared cognitive states, and effective behavior processes facilitate successful implementation, while negative team dynamics serve as barriers. It was found that job demands, control, and social support significantly influence physicians' orientation toward lifelong learning, our study similarly found that doctors are

more likely to engage in critical evaluation, open dialogue, and reflective team practices - all essential components of effective team learning and continuous improvement. Doctors in our sample also reported more opportunities for interdepartmental collaboration and knowledge sharing, underscoring their active role in shaping a culture of continuous professional development. In contrast, nurses in our study perceived fewer structured spaces for interdepartmental interaction or avenues for patient feedback, indicating a gap in support for collaborative learning and feedback-based improvement in nursing practice. Three types of interventions were identified in the broader literature to enhance team functioning: Training, including principle-based programs simulation-based methods, and general team training; Tools, such as SBAR protocols, checklists, debriefings, and communication technologies to structure and facilitate teamwork; and Organizational (re)design, involving structural changes that stimulate effective team processes. Comprehensive programs that combine these strategies show the greatest potential, especially in acute care settings, where improving non-technical skills—such as communication, leadership, and coordination - is critical.

These findings align with our study, which highlights the importance of creating systems and supports that promote reflective practices and open dialogue, particularly among physicians. Additionally, while a review of literature on team-based healthcare revealed that critical reflection is rarely labeled as such, many studies exhibit its elements—especially through challenging power hierarchies and questioning practice norms via open dialogue. This kind of reflection enables collaborative practice and innovation, pushing boundaries through shared knowledge and purpose. However, to be truly effective, such practices require a deliberate environment where reflection and dialogue are encouraged and structurally supported.

Our study supports this need for purposefully designed reflective spaces, as we observed that physicians are more likely than nurses to engage in team-based dialogue and challenge one another's perspectives to improve outcomes. Therefore, to support equitable care and foster high-functioning teams, we recommend intentionally integrating opportunities for critical reflection and interprofessional dialogue across all levels of health care teams, especially by including nurses more actively in these spaces.

6. Implications. For healthcare administrators and policymakers, several practical implications arise from this study. First, there is a clear need to develop inclusive, accessible, and relevant training programs for all healthcare professionals – especially nurses – to ensure equitable access to continuing professional development. Strengthening training will enhance competencies in the use of new medical technologies across the workforce. Second, hospital managers should foster interdisciplinary collaboration and communication. Our findings showed that nurses are open to task-sharing in technology use, indicating that teamwork between physicians, nurses, and mid-level providers can facilitate smoother implementation of innovations. Third, addressing systemic integration challenges is crucial. This

includes allocating resources to alleviate equipment shortages and ensuring sufficient technical support and training during technology rollouts. By proactively mitigating these barriers, healthcare organizations can improve the success rate of new technology adoption. Additionally, emphasizing evidence-based practice (EBP) training for nurses and mid-level staff will help standardize patient care and ensure that technological innovations are used optimally and safely across all roles. In summary, investing in human capital (through training and education) and promoting a collaborative culture are key steps to translating technological advancements into improved clinical practice.

7. Limitation and future steps. While this study offers valuable insights into the differences in innovation, collaboration, and reflective team practices between doctors and nurses, several limitations must be acknowledged. First, the cross-sectional design captures perceptions at a single point in time, limiting the ability to infer causality. Longitudinal studies would be better suited to assess how organizational changes or targeted training interventions influence these perceptions over time. Second, although the sample size was large and demonstrated strong engagement, the self-reported nature of the data may introduce social desirability bias—particularly in questions concerning teamwork and reflective behaviors. Future research should consider complementing quantitative methods with cognitive interviews or qualitative approaches to gain deeper insights into how innovation, collaboration, and reflection are understood and enacted across different healthcare roles.

From a policy perspective, the findings highlight the need for targeted support and structural interventions, particularly to enhance innovation and collaboration among nursing teams. Although nurses demonstrated high innovation potential, they reported fewer opportunities for interdepartmental collaboration, patient feedback, and team-based reflection - all of which are essential for fostering sustainable innovation and continuous learning. To address these gaps, healthcare organizations should: Expand cross-disciplinary forums and patient engagement platforms, ensuring equitable access for all professional groups; Implement structured reflective practices, such as regular debriefings and interprofessional team rounds, with particular focus on nursing teams; Provide tailored leadership and innovation training, cultivating a culture of inquiry, experimentation, and shared problem-solving; Adopt validated tools like SBAR, Team STEPPS, and simulation-based training to strengthen non-technical skills and enhance team performance.

Finally, critical reflection should be embedded as a foundational component of collaborative healthcare practice - not just as a learning tool, but as part of routine operations and team performance evaluation. Achieving this will require cultural change, supportive policies, and sustained leadership commitment to ensure psychological safety across all levels of the organization. Only in such an environment can all healthcare professionals—regardless of role or hierarchy - fully engage in open dialogue, challenge assumptions, and innovate together.

8. Conclusion. The significant differences between doctors and nurses in areas of innovation, collaboration, and team dynamics were identified. Doctors tend to engage more in reflective practices, critical discussions, and problem-solving within their teams, while nurses report higher levels of innovation and idea generation. The findings suggest a need for enhanced interdisciplinary communication and knowledge-sharing, particularly among nursing staff, to foster a more collaborative work environment. Moreover, nurses may benefit from increased opportunities for innovation and critical reflection, as these practices are linked to improved patient safety and service quality. Future efforts should focus on creating more collaborative platforms for all healthcare professionals, encouraging innovation across roles, and strengthening reflective team practices. Training programs aimed at enhancing these skills, alongside strategies for improving interdepartmental interactions, could help bridge the gaps between doctors and nurses, ultimately leading to improved patient care and organizational performance.

In sum, promoting innovation in healthcare through these targeted strategies will not only improve service quality and streamline operations but also foster greater patient satisfaction. In the long run, successfully integrating new health technologies can lead to better healthcare outcomes for patients and more sustainable performance for hospitals in Kazakhstan.

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PHILOLOGICAL SCIENCES

ANALYZING MAJOR LINGUISTIC THEORIES RELATED TO SYNTAX AND COMMUNICATION

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Abstract

This article provides a comprehensive and in-depth analysis of major linguistic theories related to syntax and communication. It traces the historical development of syntactic thought from early structuralist approaches to contemporary functional, pragmatic, and cognitive models. Particular attention is paid to the ways in which syntactic structures function within communicative contexts and how different theoretical paradigms conceptualize the interaction between form, meaning, and use. The study also discusses the implications of these theories for applied linguistics, discourse analysis, and language teaching, emphasizing the necessity of an integrative approach to syntax and communication.

Keywords: syntax, communication, linguistic theories, discourse, pragmatics

Introduction

Syntax and communication represent two closely interconnected domains within linguistic research [1, p.15]. Syntax traditionally focuses on the formal organization of sentences, examining how words combine to form grammatical structures. Communication, on the other hand, is concerned with meaning, interaction, and the effective transmission of messages in context. For much of the history of linguistics, these domains were treated separately; however, modern linguistic theory increasingly recognizes that syntactic structures cannot be fully understood without reference to their communicative functions.

The purpose of this article is to analyze major linguistic theories related to syntax and communication, highlighting their theoretical foundations and evaluating their contributions to understanding language as a communicative system. By examining structuralist, generative, functional, pragmatic, and cognitive approaches, the study aims to demonstrate how syntactic theory has evolved toward a more communicatively oriented perspective.

Structuralist Approaches to Syntax

Structuralist linguistics, rooted in the work of Ferdinand de Saussure, conceptualizes language as a system of signs defined by internal relations rather than by reference to external reality [1, p.42]. Syntax, within this framework, is studied through the distributional relationships among linguistic elements. Leonard Bloomfield and other American structuralists further emphasized empirical observation and formal description, focusing on surface patterns of sentence construction.

Although structuralism largely excluded considerations of meaning, speaker intention, and context, it played a crucial role in establishing rigorous methods for syntactic analysis. Structuralist approaches provided linguistics with systematic tools for identifying syntactic categories and patterns, which later theories would build upon. From a communicative perspective, however, the main limitation of structuralism lies in its neglect of how syntactic forms function in actual language use.

Generative Grammar and Communicative Competence

The emergence of generative grammar in the mid-twentieth century marked a significant shift in syntactic theory. Noam Chomsky's generative approach introduced the idea that humans possess an innate capacity for language, referred to as Universal Grammar. Syntax was viewed as a mental system governed by abstract rules capable of generating an infinite number of sentences.

Early generative models prioritized grammatical competence—the speaker's knowledge of syntactic rules—while downplaying performance and communicative use. This narrow focus led to criticism from scholars who argued that syntactic knowledge cannot be separated from social and communicative contexts. Dell Hymes' concept of communicative competence expanded the notion of linguistic competence to include sociolinguistic, pragmatic, and discourse-related dimensions [3, p.269]. This development significantly strengthened the link between syntax and communication, highlighting that grammatical correctness alone is insufficient for effective communication.

Functional and Communicative Approaches to Syntax

Functional linguistics emerged as a response to formalist models, emphasizing that syntactic structures are shaped by communicative needs. M.A.K. Halliday's Systemic Functional Linguistics (SFL) proposes that language serves multiple metafunctions: ideational, interpersonal, and textual [2, p.27]. From this perspective, syntax is not an autonomous system but a resource for meaning-making in social interaction.

Functional approaches argue that grammatical choices reflect speakers' intentions, attitudes, and communicative goals. Sentence structure varies depending on factors such as information focus, discourse context, and the relationship between interlocutors. By integrating syntax with semantics and pragmatics, functional linguistics provides a more comprehensive account of how language operates in real communicative situations.

Pragmatics, Discourse, and Syntax

Pragmatic and discourse-oriented theories further emphasize the contextual nature of syntax. Scholars such as Stephen Levinson and Teun van Dijk argue that

syntactic structures are influenced by discourse organization, information structure, and communicative intention [4, p.112]. Word order variation, ellipsis, and syntactic complexity often serve pragmatic functions, such as highlighting new information or maintaining coherence in discourse.

From this viewpoint, syntax is dynamic rather than fixed. Speakers adapt grammatical structures to suit communicative contexts, audience expectations, and interactional goals. Discourse analysis thus reveals that syntactic patterns cannot be adequately explained without considering broader communicative frameworks.

Cognitive Linguistics and Usage-Based Models

Cognitive linguistics challenges the strict separation between syntax, meaning, and use by emphasizing mental representation and embodied cognition. Usage-based models propose that syntactic structures emerge from repeated communicative experiences rather than from abstract rules alone. Ronald Langacker's Cognitive Grammar and Adele Goldberg's Construction Grammar treat syntactic constructions as form-meaning pairings shaped by cognitive processes [5, p.89].

This approach reinforces the idea that syntax is inherently communicative. Grammatical patterns reflect how speakers conceptualize events and experiences, making syntax an integral part of human cognition and interaction. Cognitive models thus provide valuable insights into the relationship between syntax, communication, and conceptualization.

Syntax in Cross-Linguistic and Applied Perspectives

Cross-linguistic studies reveal that syntactic variation reflects different communicative strategies across languages. Applied linguistics draws on syntactic theories to improve language teaching, translation, and discourse analysis. Communicative language teaching, in particular, integrates syntactic accuracy with functional use, demonstrating the practical relevance of theoretical insights.

Implications for Language Teaching and Research

The integration of syntactic theory and communication has significant implications for applied linguistics. In language teaching, communicative approaches emphasize the use of grammar as a tool for meaningful

interaction rather than as an end in itself. Understanding how syntax functions in discourse enables teachers to design more effective instructional strategies that promote both grammatical accuracy and communicative competence.

In addition, syntactic theories inform areas such as translation studies, discourse analysis, and language assessment. An awareness of communicative syntax allows practitioners to account for contextual and pragmatic factors that influence grammatical choices

Conclusion

The analysis presented in this article demonstrates that syntax and communication are inseparable components of language. While early linguistic theories such as structuralism and generative grammar prioritized formal structure and abstract rule systems, subsequent developments have increasingly emphasized the communicative, functional, and cognitive dimensions of syntax. Functional, pragmatic, and cognitive approaches reveal that syntactic structures are shaped by meaning, context, and interaction rather than by formal constraints alone.

An integrative view of syntax that incorporates communicative principles provides a more comprehensive understanding of language as a dynamic system. Such a perspective not only advances theoretical linguistics but also offers practical benefits for applied fields, including language teaching and discourse analysis. Future research should continue to explore interdisciplinary approaches that unify syntax, pragmatics, cognition, and social interaction, thereby deepening our understanding of how grammatical structures function in real communicative contexts.

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S. S. KUNANBAEVA'S COGNITIVE-LINGUACULTURAL APPROACH TO THE THEORY AND PRACTICE OF FOREIGN LANGUAGE TEACHING**Kismetova G.
Dzhunusova N.****КОГНИТИВНО-ЛИНГВОКУЛЬТУРОЛОГИЧЕСКИЙ ПОДХОД С. С. КУНАНБАЕВОЙ В ТЕОРИИ И ПРАКТИКЕ ОБУЧЕНИЯ ИНОСТРАННЫМ ЯЗЫКАМ****Кисметова Г.
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Современная парадигма языкового образования всё чаще опирается на идеи глубокой интеграции языка, культуры и сознания обучающегося [1], [2]. В условиях глобализации изучение иностранного языка перестало быть процессом простого усвоения грамматики и лексики: основной акцент делается на погружение в инокультурную среду и развитие межкультурной и лингвокультурной компетенций [3].

Это продиктовано требованиями рынка труда, так как обществу необходим специалист, способный гибко менять формы деятельности и успешно самореализовываться в условиях позитивной коммуникации и социальной ответственности [11], [5].

Среди наиболее перспективных направлений особое место занимает когнитивно-лингвокультурологическая методология, разработанная казахстанским учёным С. С. Кунанбаевой [1], [2]. Данный подход представляет собой концептуальную модель, направленную на формирование билингвального сознания и воспитание личности, готовой к эффективному диалогу культур [7], [8].

В последние десятилетия роль этого подхода значительно усилилась, что подтверждается многочисленными исследованиями казахстанских и российских учёных [6], [9]. Методология С. С. Кунанбаевой позволяет переосмыслить традиционные методики обучения: в условиях растущей мобильности населения владение языком превращается в комплексную культурно-коммуникативную компетентность, включающую не только знание слов и грамматики, но и умение анализировать языковую картину мира и понимать культурные концепты [1], [15].

Когнитивно-лингвокультурологический подход, разработанный С. С. Кунанбаевой, представляет собой современную методологическую платформу иноязычного образования, ориентированную на формирование вторичной языковой личности [1], [2]. В центре внимания этой концепции находится обучающийся, который должен не просто освоить иностранный язык как формальную систему знаков, но овладеть им как средством познания мира, культурного взаимодействия и личностной самореализации [2], [7].

Согласно С. С. Кунанбаевой, ключевая цель обучения сегодня заключается в формировании личности, способной функционировать в условиях многоязычия и многокультурности, для которой освоение языка становится путём к расширению

когнитивного пространства и развитию межкультурной чуткости [1], [7]. В основе данного подхода лежит идея формирования билингвального сознания как важнейшего результата образования; оно означает способность мыслить средствами двух культурных систем, свободно переходить между концептуальными мирами и интерпретировать события, исходя из иной картины мира [6], [5].

Другим фундаментальным принципом является единство языка, сознания и культуры: язык выступает формой существования культурного опыта, через него человек не просто описывает реальность, а организует её, опираясь на культурно закреплённые значения [1], [8]. Следовательно, освоение языка предполагает проникновение в систему ценностей и образов изучаемого этноса, что подчёркивают Утебалиева и Каскабасова, рассматривая вторичную языковую личность как результат вхождения в иную культурную систему [4], [10].

Важное место занимает принцип антропоцентризма, согласно которому главной целью образовательного процесса является развитие человека как носителя культурных характеристик, а обучение понимается как процесс личностного роста, формирования толерантности и открытости [2], [11]. Дополнительно выделяется принцип культуросообразности, требующий строить обучение на основе национальной специфики языка и опоры на этнокультурные ценности Казахстана [9], [13].

Наконец, важнейшим принципом является диалог культур, предполагающий взаимодействие равноправных систем на основе взаимного уважения, где язык выступает инструментом активного участия личности в глобальном пространстве [1], [15]. Таким образом, все перечисленные принципы образуют целостную систему, отвечающую задачам подготовки конкурентоспособного специалиста в условиях глобализации [2], [5].

Переходя от теории к практике, следует отметить, что в условиях компетентностного подхода основой обучения становится создание учебных ситуаций, моделирующих реальные коммуникативные и профессиональные задачи [2], [3]. Ключевой единицей содержания выступает профессиональный концепт, который задаёт основу формирования профессионального мышления, мотивов и ценностных установок будущего специалиста [1], [9].

Освоение профессионального концепта предполагает не только получение знаний, но и развитие

эмоционально-волевой готовности к профессиональной деятельности; профессиональный концепт рассматривается как функционально ориентированный фрагмент обучения, реализуемый через специальную технологию [2]. Его компонентами являются учебная цель и информационный блок, методическое руководство, исполнительский блок (система типовых и ситуационных задач) и контролирующий блок, что обеспечивает целостность образовательного цикла [1].

Особое место в этой системе занимают когнитивно-лингвокультурологические комплексы (КЛК), которые, по определению С. С. Кунабаевой, обеспечивают реконцептуализацию мира обучающегося и интеграцию когнитивного, языкового и культурного компонентов [1], [9]. КЛК функционируют как интегрированные единицы, выделенные в рамках различных сфер общения – от профессиональной до социально-бытовой; в их структуру входит тематико-текстовое единство (ТТЕ), представляющее собой комплекс аутентичных текстов, раскрывающих культурный и социальный контекст изучаемых понятий [8], [4].

Практическая реализация подхода предполагает использование разнообразных форм и методов работы: проблемных заданий, проектной деятельности, ролевых игр, анализа сценариев межкультурного общения, а также интеграции цифровых технологий и онлайн-проектов [14], [15]. Это позволяет моделировать реальные ситуации межкультурного взаимодействия и развивать у студентов способность к адекватной интерпретации иноязычных коммуникативных норм и стратегий [15].

Языковая и культурная картина мира занимает центральное место в когнитивно-лингвокультурологическом подходе, поскольку именно через эти картины личность интерпретирует реальность и выстраивает коммуникативное поведение [1], [8]. Языковая картина мира фиксирует способы осмысления действительности средствами языка, а культурная картина мира отражает национальные нормы, ценности и этнокультурные стереотипы [11], [12].

Процесс формирования этих картин предполагает «когнитивную реконцептуализацию», когда студент переходит от одномерного, этноцентрического восприятия мира к многомерному, включающему элементы другой культурной и языковой системы [4], [10]. В исследованиях Утебалиевой и Каскабасовой подчёркивается, что вторичная языковая личность формируется именно при вхождении в иную культурную систему через языковые и культурные практики [4].

В рамках КЛК языковая картина мира раскрывается через тематико-текстовые единства и систему заданий, направленных на выявление и интерпретацию культурно маркированных единиц, что обеспечивает связь между языковыми формами и профессиональным контекстом [9], [8]. Таким образом, формируется способность студентов соотносить языковые средства с определёнными фрагментами культурной картины мира и корректно действовать в межкультурной коммуникации [5], [15].

Понятие культурного концепта выступает фундаментом лингвокультурологии и является одной из ключевых категорий рассматриваемого подхода [12], [11]. Культурный концепт определяется как ментальная единица, в которой отражён коллективный опыт народа, объединяющий понятийный (рациональный), образный (ассоциативный) и ценностный (эмоционально-оценочный) уровни [12].

Концепт выполняет функцию «моста» между коллективным сознанием народа и индивидуальным восприятием студента, что подчёркивается как казахстанскими, так и российскими исследователями [11], [8]. Для казахстанского контекста особую значимость имеют концепты, связанные с национальной культурой, традициями и ментальностью, которые могут быть сопоставлены через казахский, русский и иностранные языки [13], [4].

Логическим продолжением данной системы является кросс-культурное взаимодействие, которое в современном мире рассматривается как ключевая профессиональная и жизненная компетенция [15]. В его основе лежит понимание того, что при контакте культур происходит обмен концептуальными системами, и для продуктивности такого обмена необходимы эмпатия, толерантность и готовность видеть «чужое» как «возможное» [5].

Образовательные программы, построенные в русле когнитивно-лингвокультурологического подхода, должны предоставлять обучающимся возможность «примерить» другой культурный контекст через ролевые ситуации, анализ сценариев, участие в онлайн-проектах и межкультурных дискуссиях [14], [5]. Это позволяет формировать способность к адекватному взаимодействию на уровне ментальных моделей, не ограничиваясь только языковыми формами [6], [11].

Подводя итог, можно утверждать, что когнитивно-лингвокультурологический подход С. С. Кунабаевой представляет собой комплексную концепцию, направленную на формирование вторичной языковой личности, способной эффективно действовать в двух и более культурных системах [1], [2]. Интеграция языка, сознания и культуры через аутентичные тексты, тематико-текстовые единства, профессиональные концепты и когнитивно-лингвокультурологические комплексы (КЛК) обеспечивает не только усвоение лингвистических структур, но и глубокое понимание культурных реалий [9], [8].

Практическая значимость подхода заключается в возможности его внедрения в образовательный процесс подготовки учителей иностранных языков, что позволяет формировать у студентов лингвокультурную и межкультурную компетенции, гибкость поведения и эмпатию в различных социокультурных контекстах [4], [13], [14]. Предложенные теоретические положения и методические решения могут быть использованы при разработке учебных программ и методических пособий, обеспечивая подготовку профессионально конкурентоспособных выпускников, готовых к полноценному участию в глобальном кросс-культурном взаимодействии.

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PHYSICAL SCIENCES

HOW TO CALL YOURSELF TO YESTERDAY?

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Abstract

The article explains that it will probably soon be possible to travel through time on Earth and make a telephone call to anyone people (even yourself) who located into yesterday or tomorrow. And such a possibility is created by the corrected version of the special theory of relativity (SRT). But the version of SRT studied in all physics textbooks states that time travel on Earth will never be available to people. Nevertheless, ignoring this opinion of the generally recognized service station, currently millions of air passengers already travel through time every day, which is confirmed by the translation of their watches to local time after landing the plane.

Keywords: special relativity theory, relativistic formulas, Multiverse, anti-universe, antimatter, anti-time, internal time, external time, time zones of Earth, time travels

1. Preface

The author published his three “top secret” articles in which the physical reality of imaginary numbers was proved, during the existence of the USSR. And after this, the Library of the US Congress contacted the author’s place of work with a request to send an unclassified his publications. And at this time the author, having learned about the secret resolution of the Presidium of the USSR Academy of Sciences prohibiting any criticism of the works of Albert Einstein, not wanting to be repressed, stopped his research and left the Moscow region for Ukraine. And he resumed his research only after the collapse of the USSR, as a result of which Ukraine became independent. Later, already living in Ukraine, the author in 2008-2010. published five unclassified articles in English, in which he also proved the physical reality of imaginary numbers. And thus, with his publications, he made the unsuccessful ORERA experiment in 2011 unnecessary. However, participants in the ORERA experiment ignored these publications. And the incorrect version of the SRT still continues to be studied in all physics textbooks. And these textbooks are used in the educational process of all universities, even the most prestigious ones.

2. Introduction

The article explains that the special theory of relativity (SRT), studied in all physics textbooks, rightly recognized as an outstanding scientific achievement due to the principle of relativism proposed in it, nevertheless, due to the lack of necessary experimental knowledge in the 20th century, turned out to be largely incorrect¹. Therefore, she could not explain the phenomena of dark matter and dark energy, the problem of baryon asymmetry, denied the existence of tachyons and antimatter, and incorrectly solved other problems of astrophysics. And due to the inability to explain the relativistic formulas obtained by the creators of this theory in the hyperluminal speed range, the incorrect principle of not exceeding the speed of light was introduced into the SRT, from which incorrect conclusions were

drawn about the existence in nature of our only visible universe and about the physical unreality of imaginary numbers. But by denying the physical reality of imaginary numbers, this incorrect SRT denied the existence of radio technology and computer technology, resonance and bell ringing, tsunamis, piano music, swaying children's

swings and much more. Therefore, due to the complete lack of experimental proof of its truth of this version of SRT, Albert Einstein for its creation, even despite the fact that he was nominated for the Nobel Prize 66 times, never received it.

3. The version of SRT taught in all physics textbooks is incorrect

However, while being brilliant in its concept, the version of SRT taught in all physics textbooks is nevertheless largely incorrect, since::

- the relativistic formulas obtained in this SRT are incorrect, because it is ignored the fact that the argument ‘velocity’ in them, in accordance with Newton’s first law, is the fourth spatial dimension² [1]-[5];
- the formula for the relativistic mass $m(v)$ in the hyperluminal $v > c$ speed range corresponds to a physically unstable process that cannot exist in nature;
- being unable to explain the physical meaning of the imaginary values of the quantities $m(v)$, (v) , $l(v)$ in the hyperluminal $v > c$ speed range, the authors of the SRT, in order not to explain their relativistic formulas in this range, introduced an incorrect postulate into it, called the principle of not exceeding the speed of light, which is incompatible with the fourth spatial dimension.
- in the 21st century, despite the fact that the attempt to refute SRT with the OPERA experiment [6] at the Large Hadron Collider was unsuccessful, it was still experimentally proven that imaginary numbers are physically real [7]-[24]. And, therefore, the principle of not exceeding the speed of light in the generally accepted SRT and this version of SRT itself, which is studied in textbooks, are incorrect [25]-[57].

¹ Which is not a big drawback for the new theory

² Not to be confused with the fourth dimension in four-dimensional space-time (Minkowski space).

In addition, the conclusions drawn from incorrect relativistic formulas using the incorrect principle of not exceeding the speed of light are also incorrect:

- about the existence in nature of our only visible universe;
- about the physical unreality of imaginary numbers.

4. Proof of the physical reality of imaginary numbers

But by now, numerous [7]-[24] experimental evidence of the physical reality of imaginary numbers have already been published. All of them are quite simple and can be completed by one radio engineer in less than one day. They can therefore always be repeated and checked in any other radio engineering laboratory. In contrast to these simple radio engineering experiments, the unsuccessful OPERA physics experiment at the Large Hadron Collider was carried out for a total of almost 15 years (2003-2018).

And so that the reader can convince himself of the truth of the mentioned radio engineering experiments, let us consider one of them as an example. The rest are also quite simple experiments mentioned in the list of references.

From the well-known Ohm's law in the interpretation of Steinmetz [58], the validity of which is daily confirmed by millions of radio engineers throughout the world through their practical activities, it follows that in addition to the electrical resistance R of resistors, measured by real numbers, there are also electrical resistances $-j/\omega C$ of capacitors and $+j\omega L$ of inductors, which are measured by imaginary numbers.

Consequently, if these imaginary numbers $-j/\omega C$ and $+j\omega L$, in accordance with the generally accepted version of SRT are physically unreal, then the electrical resistance of any electrical LCR -circuit will always be measured in real numbers and will not depend on frequency. Therefore, when the frequency ω of the applied voltage changes, the amount of current flowing through such an electrical circuit will not change.

And vice versa, if the imaginary resistances $-j/\omega C$ and $+j\omega L$ are physically real, then the electrical resistance of any electrical LCR -circuit will be measured

in complex numbers and when the frequency ω of the applied voltage changes, its resistance will change. Therefore, in accordance with Ohm's law, the magnitude of the current flowing through this electrical LCR -circuit will also change.

Consequently, an experiment proving the physical reality of imaginary numbers is extremely simple. You just need to change the frequency ω of the voltage applied to any electrical LCR -circuit and measure the value of electric current flowing through it. And all radio engineers know that in this case its value will change. Thus proving the physical reality of imaginary numbers.

However physicists did not do such an experiment, since in fact, as shown below, on the contrary, they need evidence of the physical unreality of imaginary numbers. Which do not exist in nature.

5. Corrected version of SRT

And since the physical reality of imaginary numbers has just been proven in the most indisputable way, it remains to fully and correctly explain (which no one has done over the past hundred years) the relativistic formulas of SRT [59]-[67].

$$m = \frac{m_0}{\sqrt{1 - (v/c)^2}} \quad (1)$$

$$\Delta t = \Delta t_0 \sqrt{1 - (v/c)^2} \quad (2)$$

$$l = l_0 \sqrt{1 - (v/c)^2} \quad (3)$$

in which m_0 is the rest mass of a moving body;

m is the relativistic mass of a moving body;

Δt_0 is the rest time of a moving body;

Δt is the relativistic time of a moving body;

l_0 is the rest length of a moving body;

l is the relativistic length of a moving body.

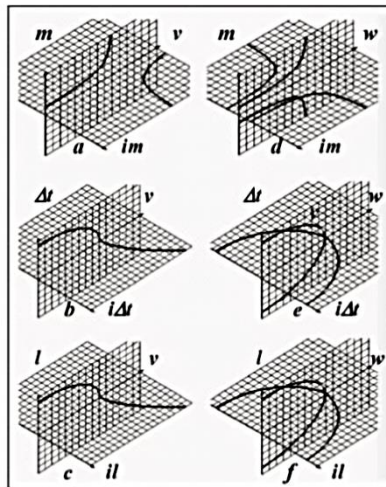


Fig 1. Graphs of functions $m(v)$, $\Delta t(v)$, $l(v)$, corresponding to the existing and revised versions of SRT in the subluminal $v < c$ and hyperluminal $v > c$ ranges

These formulas correspond to the graphs in Fig. 1a,b,c. And they show that these graphs in the subluminal $v < c$ and hyperluminal $v > c$ ranges of the argument v have different appearances. Therefore, the same

processes cannot occur in these ranges. And in order for the same processes to occur in these ranges, the graphs of the corrected relativistic formulas should

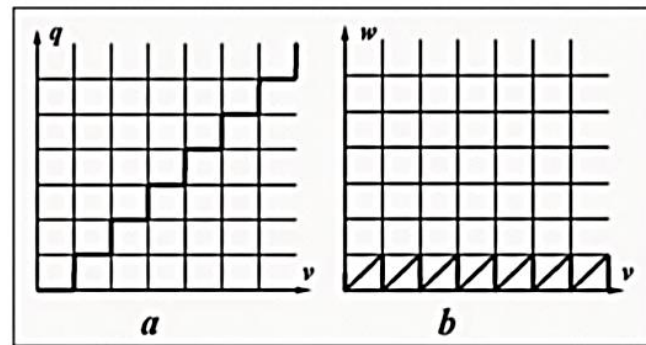


Fig. 2. Graphs of functions $q(v)$ and $w(v)$, illustrating the meaning of the "floor" function of discrete mathematics

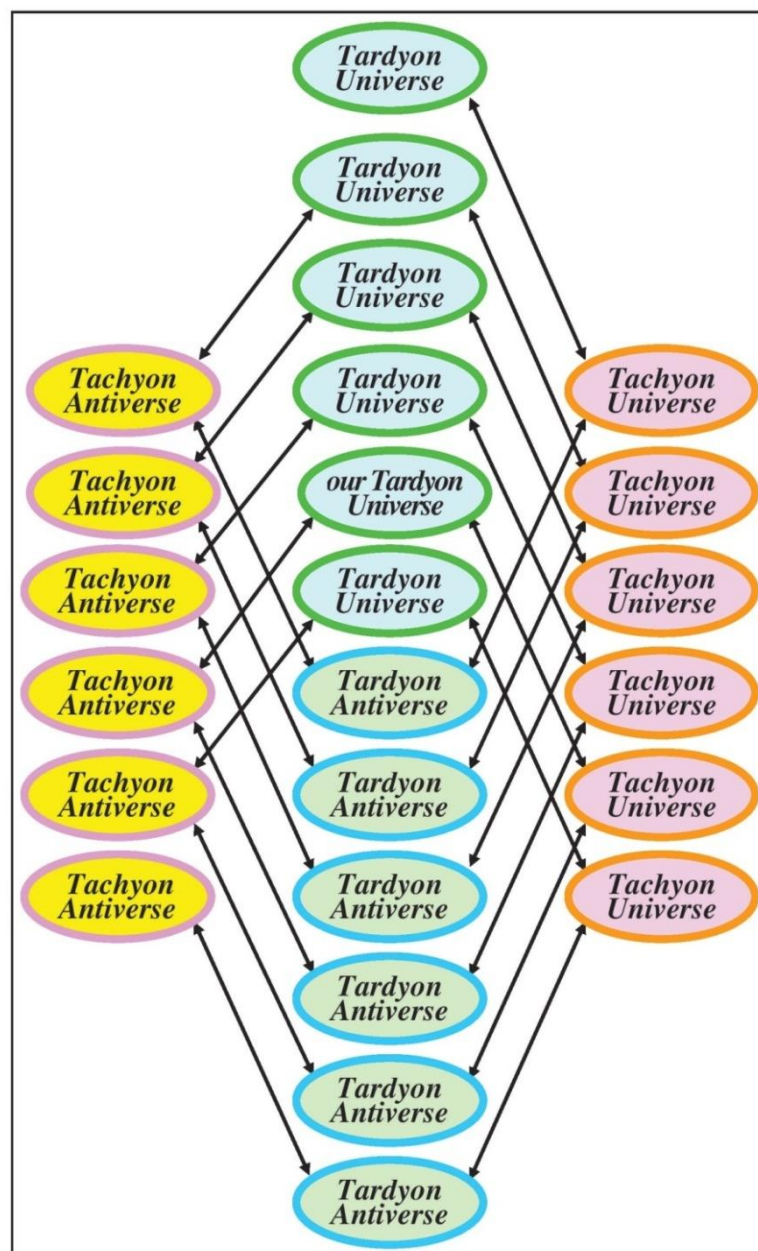


Fig. 3. Structure of the hidden Multiverse corresponding to the principle of physical reality of complex numbers

look the same, as shown in Fig. 1d,e,f. And for this, in formulas (1)-(3), since the speed v in them is the

fourth spatial dimension, the factor i^q must be introduced

$$m(q) = \frac{m_0 i^q}{\sqrt{1 - (v/c - q)^2}} = \frac{m_0 i^q}{\sqrt{1 - (w/c)^2}} \quad (4)$$

$$\Delta t(q) = \Delta t_0 i^q \sqrt{1 - (v/c - q)^2} = \Delta t_0 i^q \sqrt{1 - (w/c)^2} \quad (5)$$

$$l(q) = l_0 i^q \sqrt{1 - (v/c - q)^2} = l_0 i^q \sqrt{1 - (w/c)^2} \quad (6)$$

where $q(v) = [v_q/c]$ is the “floor” function of discrete mathematics from the argument v_q/c

(its graph shown in Fig. 2a), which is the fourth spatial dimension;

$w = v - qc$ – is the local speed in all universes (its graph is shown in Fig. 2b).

At that, this function i^q in formulas (4)–(6), which determines the essence of each universe, for integer values of the argument $q(v)$ equal to ... 0, 1, 2, 3, 4, 5, ..., takes the values +1, +i, -1, -i, +1, +i, ... etc. And the value $q(v) = 0^4$ in formulas (4)–(6) for the range of sublight speeds $v < c$ corresponds (since $i^0 = 1$) to our visible universe, which for definiteness we will call the tardyon universe⁵ (see Fig. 3). The value $q(v) = 1$ in the hyperluminal speed range $2c > v > c$ corresponds (since $i^1 = i$) to some other invisible universe, since it is located beyond the event horizon. For definiteness, we will therefore call it the tachyon universe⁶. Then the value $q(v) = 2$ in the speed range $3c > v > 2c$ will correspond (since $i^2 = -1$) to an invisible tardion antiverse. The value $q(v) = 3$, in the speed range $4c > v > 3c$ will correspond (since $i^3 = -i$) to an invisible tachyon anti-universe. The value $q(v) = 4$ in the speed range $5c > v > 4c$ will correspond (since $i^4 = +1$) to another (and therefore also invisible) tardyon universe. The value $q(v) = 5$ in the speed range $6c > v > 5c$ will correspond (since $i^5 = +i$) to another tachyon universe. Etc.

Consequently, in nature there is not only, as stated in the generally accepted version of SRT, our visible universe corresponding to formulas (1)–(3), but also many other mutually invisible⁷ universes and antiuniverses corresponding to formulas (4)–(6). And these mutually invisible universes and antiuniverses, together with our visible universe, form the Multiverse, which we therefore called hidden. Such a hidden Multiverse, the structure of which is helical, is shown in Fig. 3.

6. Analysis of data obtained by the WMAP and Planck spacecraft

However, in this structure it is still necessary to take into account and explain the phenomena of dark

matter and dark energy, so named because of their incomprehensibility, since not a single chemical element has been found in them, and also because they do not emit, absorb, reflect or refract electromagnetic radiation and, therefore, are invisible. Finally, it is not clear why dark matter and dark energy, which accounts for more than 95%⁸ of all mass-energy contained in nature, are being persistently searched for at the Large Hadron Collider in the microcosm. Therefore, it is quite acceptable to make an assumption that is impossible when explaining these phenomena in the only generally accepted version of the SRT of our visible universe. Namely, let us assume that dark matter and dark energy are all other mutually invisible universes and antiuniverses⁹ of the hidden Multiverse. Then the phenomena of dark matter and dark energy will be a gravitational shadow¹⁰ on our visible universe from the remaining mutually invisible universes and antiuniverses included in the hidden Multiverse. This assumption explains all the incomprehensibility of phenomena simply and clearly. That's why we will use it.

Then, assuming that over the billions of years of its existence, the mass-energy of all universes and antiuniverses of the hidden Multiverse, due to the presence of a huge number of portals between them according to the law of communicating vessels, has been largely averaged, it becomes possible, using the data obtained by the WMAP and Planck spacecraft, to determine the structure of the hidden Multiverse. And according to data obtained by the WMAP spacecraft [68], the mass-energy of our visible universe (in fact, our hidden Multiverse) consists of 4.6% baryonic matter, 22.4% dark matter and 73.0% dark energy. And according to more recent data obtained by the Planck spacecraft [69], the mass-energy of our visible universe (again, actually our hidden Multiverse) consists of 4.9% baryonic matter, 26.8% dark matter and 68.3% dark energy. As you can see, these data differ little from each other, which proves their truth. Therefore:

- the entire hidden Multiverse, according to experimental data obtained by the WMAP spacecraft, consists of $100\% / 4.6\% = 21.8$ parallel universes, and according to data obtained by the Planck spacecraft, it consists of $100\% / 4.9\% = 20.4$ parallel universes;

- dark matter, according to experimental data obtained by the WMAP spacecraft, consists of $22.4\% / 4.6\% = 4.9$ parallel universes, and according to data obtained by the Planck spacecraft, it consists of $26.8\% / 4.9\% = 5.5$ parallel universes;

³ In the theory of functions of a complex variable, the function i^q is defined only for integer values of the argument q . However, it can be further defined as follows. For integer values of the argument ... -2, -1, 0, +1, +2, +3, +4, +5, ... the function i^q is equal to ... -1, -i, +1, +i, -1, -i, +1, +i, ... But for the same integer values of the argument ... -2, -1, 0, +1, +2, +3, +4, +5, ... to the same values ... -1, -i, +1, +i, -1, -i, +1, +i, ... is also equal to the function $e^{iq\pi/2}$, which, in accordance with Euler's formula $e^{iq\pi/2} = \cos(q\pi/2) + i\sin(q\pi/2)$, is also defined for non-integer values of the argument q . Therefore, the function i^q can be further defined for any values of the argument q by the formula $i^q = \cos(q\pi/2) + i\sin(q\pi/2)$, similar to Euler's formula. The resulting formula will be needed in astro-geophysical studies of portals, which will be discussed further.

⁴ Those, if we take our visible universe as the origin of coordinates q .

⁵ Tardyon universe is a term used by Isaak Asimov in his short story 'Take a Match'.

⁶ Tachyon universe is a term used by Isaak Asimov in his short story 'Take a Match'.

⁷ Since they are all beyond the event horizon

⁸ That is, approximately twenty times more than in our entire visible Universe.

⁹ Which, as shown below, there are just about twenty

¹⁰ And therefore, like our shadow on a sunny day, they do not contain a single chemical element.

- dark energy, according to experimental data obtained by the WMAP spacecraft, consists of 73.0% / 4.6% = 15.9 parallel universes, and according to data obtained by the Planck spacecraft, it consists of 8.3% / 4.9% = 13.9 parallel universes;

- and our visible universe, naturally, is only one.

7. Corrected version of SRT (continued)

As can be seen, received by the WMAP and Planck spacecraft experimental data did not confirm the above conclusions about the structure of the hidden Multiverse, since our visible universe actually has not two neighboring invisible parallel universes - one tachyon universe and one tachyon antiuniverse - but five or six¹¹.

Consequently, there was some error in the previous reasoning. And we, it turns out, were wrong in assuming that in the hidden Multiverse there is only one additional dimension q . And therefore, when describing it, they used complex numbers containing only one imaginary unit. And now, in order for six other parallel universes to coexist with our visible universe in the really existing hidden Multiverse - three tachyon universes and three tachyon antiuniverses - it is necessary to have three additional dimensions q, r, s . At the same time relativistic formulas must be corrected again as follows [70]-[77]

$$m(q, r, s) = \frac{m_0 i_1^q i_2^r i_3^s}{\sqrt{1 - [\frac{v}{c} - (q + r + s)]^2}} \quad (7)$$

$$\Delta t(q, r, s) = \Delta t_0 i_1^q i_2^r i_3^s \sqrt{1 - [\frac{v}{c} - (q + r + s)]^2} \quad (8)$$

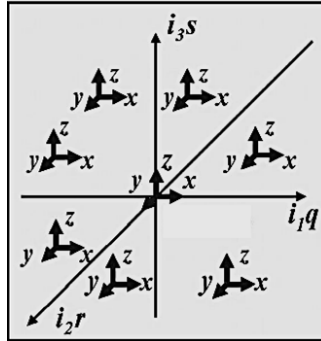


Fig. 4. Six-dimensional space of the hidden Multiverse, where q, r, s are the coordinates of invisible parallel universes, and x, y, z are the coordinates of the matter content in each parallel universe

In such a quaternion structure of the hidden Multiverse [79], in contrast to its structure considered earlier (in Fig. 3), the distribution of material content in each three-dimensional parallel universe will be determined by a certain function $f_{q,r,s}(x, y, z)$, and the coordinates of these universes will be determined by the values $i_1 q, i_2 r, i_3 s$. Those. the hidden Multiverse (see Fig. 4) will be described by the formula $f_{q,r,s}(x, y, z) + i_1 q + i_2 r + i_3 s$. This is exactly what Lisa Randall predicted: “Perhaps we live in a three-dimensional pocket of higher dimensional space”.

From formulas (7)-(9) it follows that such a hidden Multiverse still has a helical structure, and its mutually

$$l(q, r, s) = l_0 i_1^q i_2^r i_3^s \sqrt{1 - [\frac{v}{c} - (q + r + s)]^2} \quad (9)$$

where $q(v) = \lfloor v_q/c \rfloor$ is the “floor” function of discrete mathematics from the argument v_q/c

which is one of the orthogonal coordinates q of the fourth spatial dimension v ;

$r(v) = \lfloor v_r/c \rfloor$ is the “floor” function of discrete mathematics from the argument v_r/c which is another orthogonal coordinate r of the fourth spatial dimension v ;

$s(v) = \lfloor v_s/c \rfloor$ is the “floor” function of discrete mathematics from the argument v_s/c which is another orthogonal coordinate s of the fourth spatial dimension v ;

v_q, v_r, v_s is projections of the velocity vector v onto the orthogonal coordinates q, r, s (see Fig. 4).

The space of such a hidden Multiverse will already be six-dimensional (see Fig. 4). And its structure will correspond to the quaternions $\sigma + i_1 \omega_1 + i_2 \omega_2 + i_3 \omega_3$, i.e. hypercomplex numbers [78] containing exactly three imaginary units i_1, i_2, i_3 , which are related to each other by the relations

$$i_1^2 = i_2^2 = i_3^2 = -1 \quad (10)$$

$$i_1 i_2 i_3 = i_2 i_3 i_1 = i_3 i_1 i_2 = -1 \quad (11)$$

$$i_1 i_3 i_2 = i_2 i_1 i_3 = i_3 i_2 i_1 = 1 \quad (12)$$

invisible universes and antiuniverses (in addition to our visible universe) form dark matter and dark energy. In this case, it is possible to move into the tardion antiuniverse from the tardion universe and into the tardion universe from the tardion antiuniverse in various, but not arbitrary, ways, but only in such a way (see Fig. 6), in which the value of i^q will successively take on the values $+1, +i_1 \oplus +i_2 \oplus +i_3, -1, -i_1 \oplus -i_2 \oplus -i_3, +1, \dots$ and etc., where $\oplus$ is the symbol of the logical operation of discrete mathematics ‘exclusive OR’. In this case, different trajectories of movement from one universe (or antiuniverse) to another can differ only due to the replacement of some tachyon universes from i_1, i_2, i_3 with others and some tachyon anti-universes from i_1, i_2, i_3

¹¹ According to WMAP data 4.9 universes and Planck data 5.5 universes

with others. Consequently, tachyon universes i_1, i_2, i_3 in the hidden Multiverse are located parallel to each other. Tachyon antiuniverses i_1, i_2, i_3 are also located parallel to each other for the same reasons. And therefore, in the hidden Multiverse, when transitioning from any tardion universe to a tardion anti-universe and then to another tardion universe, parallel universes and antiverses must alternate in the following sequence - 'tardion universe', 'one of the tachyon universes', 'tardion anti-universe', 'one of the tachyon anti-universes', 'tardion universe', 'one of tachyon universes', etc.

One of the easiest to explain such possible quaternions structures of the hidden Multiverse is shown in Fig. 5. Its difference from the structure shown in Fig. 3 is the presence in it of several different tachyon universes and antiuniverses located in parallel, corresponding to three imaginary units i_1, i_2, i_3 . Another difference is the presence in such a structure of the Multiverse of not only bidirectional portals corresponding to formula (7) and indicated by two-way arrows, but also unidirectional portals corresponding to formulas (8), (9) and indicated by one-way arrows.

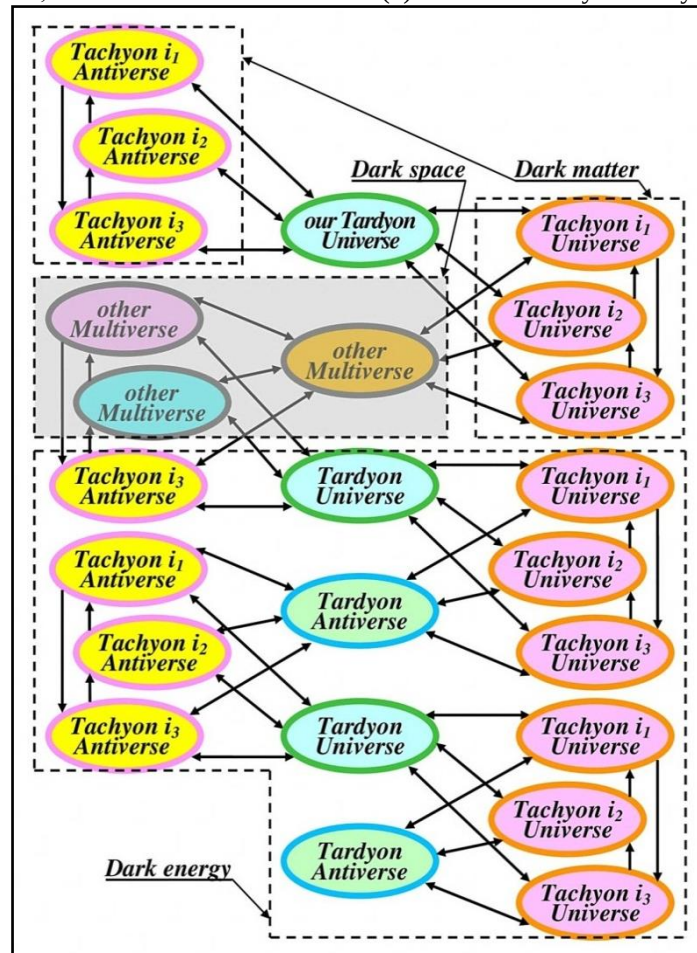


Fig. 5. Structure of the hidden Multiverse corresponding to the principle of physical reality of hyper-complex numbers

In Fig. 5 all these transitions are shown. Moreover, since the data obtained by the WMAP and Planck spacecraft correspond to the open screw structures of our hidden Multiverse, united through the corresponding portals with other Multiverses, then all together they form the Hyperuniverse.

8. How to see invisible universes and anti-universes?

But in order to believe in the existence of the Multiverse mentioned in the article instead of the Monoverse mentioned in the textbooks, experimental confirmation of the above is necessary [80]-[97]. Those. it is necessary to prove that in addition to our visible universe, there are other universes and antiuniverses in nature. And there is no need to prove that they are invisible, since we do not see them without any experiments.

And it is possible to do this. After all, invisible universes and antiuniverses in outer space, continuously drifting, touch each other in many places and even submerge slightly into each other, forming transitions called portals between the touching universes and anti-universes. And since the constellations in the starry sky in neighboring universes and antiuniverses are always different¹², when moving through portals, the map of the starry sky in them will change, which will prove the existence of invisible universes neighboring the

¹² Like all people, everything that is in their apartments

Earth. On Earth there are more than two hundred thousand anomalous zones¹³ [98]-[101], which are entrances to portals. Moreover, in some of them observatories are already located. For example, the Main Astronomical Observatory of the Academy of Sciences of Ukraine is 12 km away from the center of the capital of Ukraine, Kyiv, in the Goloseevsky forest. Therefore, by comparing maps of the starry sky on a computer in portals (or even in anomalous zones) and outside portals, universes neighboring the Earth can be discovered. And as a result of astro-geophysical studies of portals, it will be possible to determine the main parameters of neighboring tachyon universes and antiuniverses. Which will ultimately allow us to determine the structure of our hidden Multiverse.

9. Where are antimatter and anti-time located?

And this structure of the hidden Multiverse allows us to explain another problem that is currently inexplicable within the framework of all physics textbooks - where antimatter is located [102]-[112]. It is clear that it cannot be in our visible universe¹⁴, since due to its annihilation with matter, our universe would then cease to exist. But the fact that antimatter exists has been proven experimentally. In 1995, a sensational result was obtained at CERN - scientists managed to obtain nine antihydrogen atoms, which lasted for about forty billionths of a second. And just one gram of such antihydrogen would cost 662.5 trillion dollars.

Consequently, this experiment can be considered proof that, in accordance with formulas (7)-(9), antimatter can exist in nature in the invisible tardyon and tachyon antiuniverses of the hidden Multiverse and Hyperuniverse. (see Fig. 5). Moreover, in these invisible tardyon and tachyon anti-universes, anti-time and anti-space also exist.

10. Time travels

And the discovery of anti-time already allows us to assert that due to the choice of one or another route of travel in space, time travel also becomes possible [113]-[123], since from formulas (8), (9) it follows that time Δt in universes and antiuniverses during such travel will always change simultaneously with the change in distance l . But since neither the portals, much less the universes and anti-universes of the hidden Multiverse, are still unexplored, time travel in space is now inaccessible to us. And that's why we're interested in time travel on Earth now.

However, although official modern science admits the possibility of time travel in some exotic situations

in the special¹⁵ and general¹⁶ theories of relativity, as well as in quantum physics¹⁷, it still claims that time travel of people on Earth, neither now nor in the distant future, will never be possible.

Nevertheless, these time travels on Earth are now already carried out by airplane flights. And millions of people take part in these flights every day, since upon landing at any airport, air passengers always change their watches to a local time other than at the airport of departure. Thus, they confirm their time travel. Indeed, due to the rotation of the Earth and the presence of time zones on it, movement in space on Earth, as in space, is always accompanied by movement in time.

And when explaining this situation, we must take into account the existence in nature of two different types of time that we will use - internal human time, which we have always used until now, and external time, which, on the contrary, we have never used before. These two times are generated by different processes that exist independently of each other and have different features. Internal time is determined by processes occurring in human bodies. One second is one contraction of the human heart. Therefore, internal time is the biological time of people. External time is determined by processes occurring in the external environment. Namely, the rotation of the Earth and the existence of time zones. These features of it are reflected in formula, absent from physics textbooks, derived from the relativistic SRT formulas (5), (6) and (8), (9)

$$\Delta t = \Delta t_0 l / l_0 \quad (13)$$

in which Δt is external time in hours;

Δt_0 – 24 hours;

l – path length in the direction perpendicular to time zones;

l_0 – the length of a circle that intersects 24 time zones at a given latitude.

These two different times also have different properties. Human biological time cannot flow backwards. A person cannot return to his youth or childhood. And external time, when changing the direction of movement, can change its sign - the plane can fly across time zones both to the west and to the east. When the speed of movement of the aircraft changes, the value of external time will also change. Therefore, in the external environment it is possible to move both into the past and into the future. Moreover, even short-term movements in external time can

¹³ Which in itself confidently – more than two hundred thousand times – also confirms the existence of neighboring universes and anti-universes.

¹⁴ But the textbooks state that there are no other universes in nature besides it. And this, naturally, gives reason to doubt the truth of this version of SRT.

¹⁵ For example, in the 'twin paradox'

¹⁶ For example, in a region of ultra-high gravity near the event horizon of a black hole

¹⁷ For example, as a result of teleportation not of information, but of physical objects

Table 1.

Examples of business jet performance flight performance characteristic that could be used for time travels

Aircrafts	Maximum range	Cruising speed	Hourly rates	Seats
Citation Latitude	5 300 km	815 km/h	3 500 €/hour	8
Citation Longitude	7 400 km	910 km/h	5 000 €/hour	12
Challenger 300	5 700 km	850 km/h	4 900 €/hour	8
Challenger 350	5 926 km	850 km/h	4 000 €/hour	9
Challenger 600	5 500 km	850 km/h	4 600 €/hour	12
Challenger 3500	6 297 km	985 km/h	5 500 €/hour	10
Falcon 20	4 200 km	987 km/h	3 900 €/hour	8
Falcon 50/50EX	5 600 km	850 km/h	4 900 €/hour	8-10
Global 5500	10 927 km	900 km/h	8 000 €/hour	16
Gulfstream G150	5 200 km	850 km/h	3 900 €/hour	6-8
Gulfstream G200	5 000 km	870 km/h	6 200 €/hour	8
Hawker 850 XP	4 800 km	750 km/h	3 400 €/hour	6-8
Hawker 900XP	5 400 km	865 km/h	3 700 €/hour	6-8
Hawker 4000	5 280 km	890 km/h	5 400 €/hour	10
Learjet 70	3 815 km	967 km/h	3 500 €/hour	7
Legacy 450	5 370 km	860 km/h	3 300 €/hour	8
Praetor 600	7 400 km	850 km/h	6 000 €/hour	12

Table 2.

The value of external time at different latitudes

Location of departure and arrival airfields	Geographic coordinates of the airfield	Size of 24 time zones for a round-the-world flight	Size of one time zone.
Santiago de Chile	33,45° S.	33422 km	1393 km
Buenos Aires	34,60° S.	33021 km	1375 km
Melbourne	37,82° S.	31339 km	1306 km
New York City	40,72° N.	30456 km	1269 km
Reykjavík	64,15° N.	17616 km	734 km
Murmansk	69,58° N.	14424 km	601 km
Kirkenes	69,73° N.	14376 km	599 km
Longyearbyen (Spitsbergen, Norway)	78,13° N.	8184 km	341 km
Alert, (Canada)	82,5° N.	5230 km	218 km

sometimes be very useful. This is known to everyone, although it has not yet been used in any way in human activity. But this is a resource given to us by nature for solving the problem of people traveling through time, which would even seem easy to use (you just need to fly on an airplane).

The only difficulty with this is that such time travel on Earth necessarily involves unnecessary travel over long distances, which is why it is not used. However, this problem can be solved. Aircraft flights must be carried out in compliance with two mandatory conditions:

- the flight of the aircraft must be around the world, i.e. all the time from take-off to landing at the same airfield¹⁸ from which the plane took off, it must

be carried out in the same direction - to the West or to the East;

- the aircraft must fly at a high enough speed that it will cross each time zone in less than one hour of domestic time

Moreover, there are a great many aircraft models suitable for time travel. They are called business jets¹⁹. Table 1 illustrates the performance characteristics of some of these business jets. Table 2 lists airfields close enough to the North Pole to provide the shortest possible round-the-world flight route.

Therefore, time travels to the present is already physically and technically feasible.

¹⁸ And therefore, ultimately, as a result of such a journey we will not move anywhere.

¹⁹ A business jet is a small private aircraft designed for comfortable, tailor-made, unscheduled flights for businessmen, officials, and VIPs. It offers a higher level of comfort

than standard airliners, advanced technology, the ability to take off from small airfields, and high speed, allowing for quick travel to any point in the world

Conclusion

From the above it follows that for Albert Einstein in his version of SRT, it turns out that the most important thing was to prove not physical reality, but, on the contrary, the physical unreality of imaginary numbers. Otherwise, his theory would fall apart. This is why relativistic physicists have been so stubbornly resisting understanding for more than a hundred years why, contrary to their version of SRT, children's swings still swing.

But the physical reality of imaginary numbers in radio engineering was essentially proven by Charles Proteus Steinmetz in his proposed interpretation of Ohm's law back in 1893. That is. before the creation by Albert Einstein and Jules Henri Poincaré in 1905 of the version of SRT that is now studied in all physics textbooks. And since then, radio engineers have never had the slightest reason to doubt this, since always when the frequency of the sinusoidal voltage applied to any electrical LCR circuit changes, the amount of current flowing through it changes. This well-known fact, which occurs in the practical activities of radio engineers literally at every step, is an extremely simple, absolutely understandable and irrefutable proof of the physical reality of imaginary numbers.

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Nevertheless, Albert Einstein still needed to doubt²¹. this without evidence in his proposed version of SRT. And for this reason, a postulate²² was introduced into the SRT, called the principle of not exceeding the speed of light, from which a conclusion was

made about the physical unreality of imaginary numbers,²³ which was not confirmed by any experiments. And only the Nobel Committee - and this causes the greatest respect for it - remained faithful to common sense and scientific integrity. Due to the lack of any experimental evidence of the truth of the proposed version of SRT, despite the fact that Albert Einstein was nominated for the Nobel Prize 66 times, he never received it for this theory.

And in order to preserve the denial of the physical reality of imaginary numbers in SRT, relativistic physicists had to make great sacrifices. In particular, in order to create the impression that it is impossible to refute the statement of SRT about the physical unreality of imaginary numbers, at the Large Hadron Collider (worth ten billion dollars), the OPERA collaboration, which includes more than one hundred of the most authoritative physics professors, carried out the unsuccessful OPERA experiment for almost 15 years²⁴ (2003-2018), which allegedly had as its goal proving the physical reality of imaginary numbers, but not managed to do it. And thereby allegedly proving the impossibility of refuting the statement about the physical unreality of imaginary numbers. In 2011, its sensationally successful completion was even announced, but six months later in 2012 it was announced that it had been refuted at the same Large Hadron Collider by the ICARUS experiment.

For this reason, numerous publications were ignored, citing simple and easily understood radio engineering experiments that successfully demonstrated the physical reality of imaginary numbers and explained that if imaginary numbers were truly, as claimed in the SRT, physically unreal, then all radio engineering devices and computers would not exist, tsunamis, bells, piano music would not exist, children's swings would not swing after a parent's push, and much more.

Furthermore, because of the assertion of the physical unreality of imaginary numbers and, therefore, the existence of our only visible universe in nature, it turned out that antimatter and tachyons had no place in this single visible universe. The corrected version of the SRT, however, explains where they are located;

For this reason, numerous publications were ignored, which presented simple and understandable radio engineering experiments, successfully proving the physical reality of imaginary numbers and explaining that if imaginary numbers were really, as claimed in the SRT, physically unreal, then all radio engineering products and computers should not exist and should not exist, tsunamis, bell ringing, piano music would not exist, children's swings would not swing after a push from parents, and should not exist much more.

In addition, due to the statement about the physical unreality of imaginary numbers and therefore about the

²⁰ Which is explained in this article above

²¹ Unable to explain in any other way the incorrect relativistic formulas of SRT in the hyperlight range of speeds

²² As it turned out later, it turned out to be incorrect and refuted by all published experimental evidence of the physical reality of imaginary numbers.

²³ At the beginning of the 20th century, this assumption saved special relativity, as it allowed it to be explained somehow.

Otherwise, a theory that its creators couldn't explain would have been of no use to anyone. Therefore, back then, such an assumption, as a temporary measure, was acceptable. But now, in the process of knowledge, it's time to move on.

²⁴ Let's remember - one day is more than enough for a radio engineering experiment proving the physical reality of imaginary numbers.

existence in nature of our only visible universe, it turned out that there was no place for antimatter and tachyons in this only our visible universe. The corrected version of the STO explains where they are located;

It also turned out that due to the statement about the physical unreality of imaginary numbers and therefore about the existence in nature of our only visible universe, the phenomena of dark matter and dark energy have not been and will never be explained, since dark matter and dark energy are actually, according to the corrected version of STR, mutually invisible universes and antiuniverses of the really existing hidden Multiverse;

More than two hundred thousand anomalous zones have also been discovered on Earth, which are entrances to portals to the invisible universes and anti-universes neighboring our visible universe. And even this alone already proves their existence. Moreover, these universes and antiuniverses, invisible outside the portals, can also be seen²⁵ by astronomical observations of the starry sky in anomalous zones. But these low-cost astronomical observations, which would allow sensational scientific discoveries of other universes, are still not carried out due to fears that these invisible neighboring universes and antiuniverses can actually be seen. And then the version of SRT studied in textbooks will undoubtedly have to be recognized as incorrect.

Due to the statement of the version of STR studied in physics textbooks about the physical unreality of imaginary numbers and therefore about the existence in nature of our only visible universe, a conclusion was also made about the impossibility of time travel for people. Although in fact, millions of air passengers on Earth already make such time travel every day, which is confirmed by the translation of their watches to local time after landing.

But since such time travel by airline passengers occurs simultaneously with space travel, it is not used. The article explains how it is physically and technically possible to travel through time by plane without ultimately traveling through space. Less expensive time travel by telephone is also possible and, if proven feasible and in demand, could be implemented quickly and inexpensively. This would even make telephone conversations and other forms of information exchange with people (including oneself) located in the past or future widely available.

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THE LAST STOP BEFORE THE COSMIC DEFECT: NEUTRON STARS

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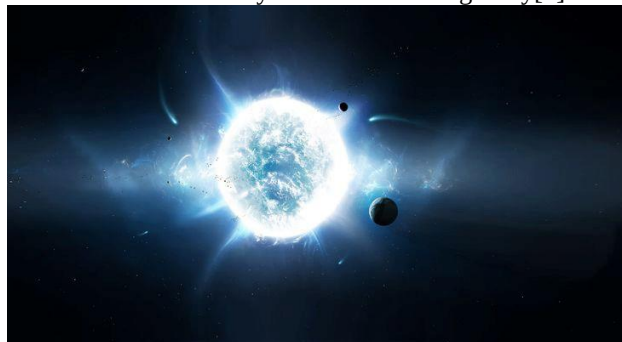
Abstract

Neutron stars are natural laboratories of exotic forms of dense matter. Neutron stars constitute the final stage of stellar evolution, providing an opportunity to empirically test both mathematical models and quantum gravity theories. A thorough study of the structure and properties of these objects is of great importance for both astrophysics and nuclear physics. In this article, neutron stars are presented as one of the most mysterious objects in astrophysics, and their structure, extreme physical conditions, and possible connections with cosmic defects are investigated. It analyzes various neutron stars not only as massively condensed stellar remnants, but also as high-energy structures approaching defects on a cosmic scale. The article takes an in-depth look at topics such as baryon degeneracy, superfluidity, thermal evolution, mass vacuum, the nature of magnetars, etc. In particular, it aims to connect the evolutionary stages of neutron stars over time in space with the theories of quantum gravity, high-density matter, and topological defects. This approach analyzes neutron stars as the "last barrier" in the topological continuum of the Universe. While traditional astrophysical models describe neutron stars as relatively static objects, this paper views them in a new context—as topological objects approaching cosmic defects on a cosmic scale. The paper takes a step toward a broader and more unifying cosmological model, taking its place at the intersection of modern theoretical physics and astrophysics.

Keywords: Neutron stars, magnetar, thermal evolution, mass gap, black holes, quark matter, cosmic defect.

Introduction. The dynamics of the Universe are not limited only to expansion, gravity and the interactions of matter, but the Universe also introduces us to the boundaries of space-time and matter through extreme objects within it[1]. One of these objects is neutron stars. Neutron stars are one of the most extreme and interesting objects in the Universe. Neutron stars are dense stellar remnants formed after the supernova explosion of very massive stars and consist mainly of

neutrons[2]. Neutron stars form in the final stages of the evolution of ordinary stars, providing us with living evidence not only of dead stars but also of fundamental physics. Although these objects have small radii, their masses can be as large as or larger than the Sun. Understanding the behavior of matter in such dense conditions is of great importance not only for astrophysics, but also for nuclear physics, quantum field theory, and theories of gravity[3].



Neutron star

The study of neutron stars provides us with fundamental information about the nature of high-density matter, quark matter, gravitational waves, the boundary values of magnetic fields, and even the structure of space-time. In particular, these objects are natural laboratories for modeling processes occurring in the early moments of the Universe or in high-energy regimes[4]. Therefore, the study of neutron stars is not limited to theoretical physics, but rather plays a key role in forming a deeper understanding of the origin, evolution, and possible fate of the Universe[5]. Let us first look at the discovery and development of neutron stars. In 1931,

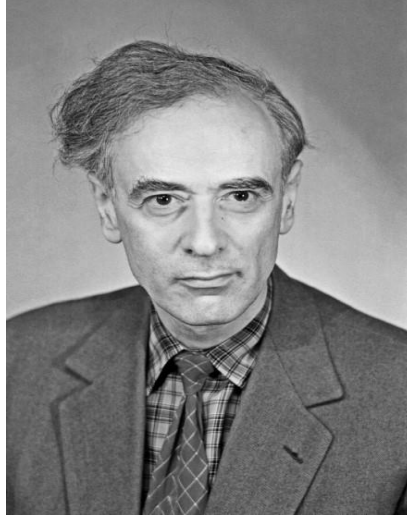
the Indian physicist Subrahmanyan Chandrasekhar calculated that the maximum mass of white dwarf stars is about 1.4 solar masses. This result showed that stars exceeding this limit must take on another exotic form[6]. This limit, proposed by S. Chandrasekhar, is considered the first theoretical basis for neutron stars. In 1932, the Soviet physicist Lev Landau proposed the idea that very dense stars could exist even before the discovery of the neutron particle. L. Landau wrote that the collapse of massive stars could lead to matter becoming denser than the atomic level. L. Landau discussed this idea with Niels Bohr, and predicted that electrons in

stars would combine with protons to form neutron-like matter[7]. In the same year, the English physicist James Chadwick discovered a particle called the neutron,

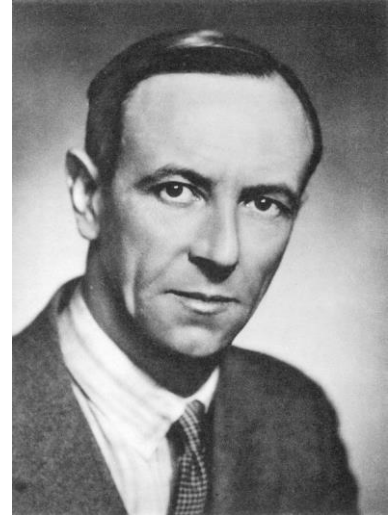
which led to the conclusion that this idea was possible[8].



Subrahmanyan
Chandrasekhar



Lev
Landau



James
Chadwick

In 1933, physicists Walter Baade and Fritz Zwicky proposed that supernova explosions could produce "very dense stars made of neutrons". They first called

these objects "neutron stars"[9]. This event was theoretically the birth of neutron stars. However, these objects had not yet been observed.

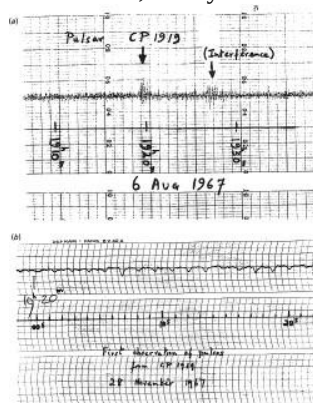


Fritz Zwicky

Walter Baade

The years 1965–1967 were the years of the first observations of neutron stars. In 1967, Jocelyn Bell

Burnell and Antony Hewish detected regular radio signals during radio telescope observations[10].



Surveillance signal;



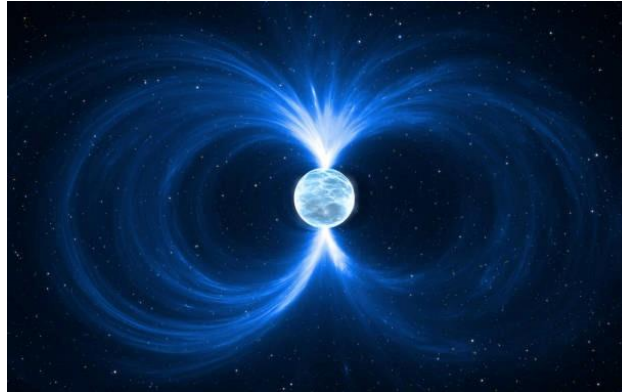
Jocelyn Bell Burnell

They initially called these signals "Little green men" (aliens)[11]. It was soon discovered that these signals came from rapidly rotating neutron stars. These radio signals were called "pulsars" because they resembled a regular heartbeat, and the existence of neutron

stars was confirmed by observation. For this discovery, A. Hewish was awarded the Nobel Prize in 1974[12]. In the 1970s, the first X-ray-emitting pulsars were observed by NASA's Uhuru satellite. These observations showed that some neutron stars were emitting energetic

X-rays as they absorbed matter in a binary star system[13]. Most pulsars had a rotation rate measured in seconds. However, in 1982, the first millisecond pulsar was discovered: PSR B1937+21. This pulsar was rotating 641 times per second. This discovery proved that neutron stars are extremely stable and dense[14]. Since

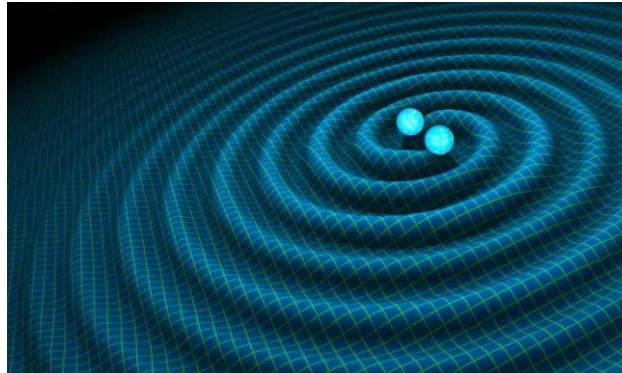
the 1990s, neutron stars with very strong magnetic fields, called magnetars, have been discovered. Magnetars are distinguished by their gamma-ray and X-ray bursts. Magnetars have magnetic fields of the order of 10^{15} – 10^{16} Gauss, making them among the strongest in the Universe[15].



Magnetar

In 2003, the first confirmation of the merger of two neutron stars in gravitationally bound binary star systems was observed. These objects were considered potential sources of gravitational waves and kilonova

explosions[16]. 2017 was marked by the event GW170817. The LIGO and Virgo detectors first observed gravitational fluctuations from the merger of two neutron stars[17].

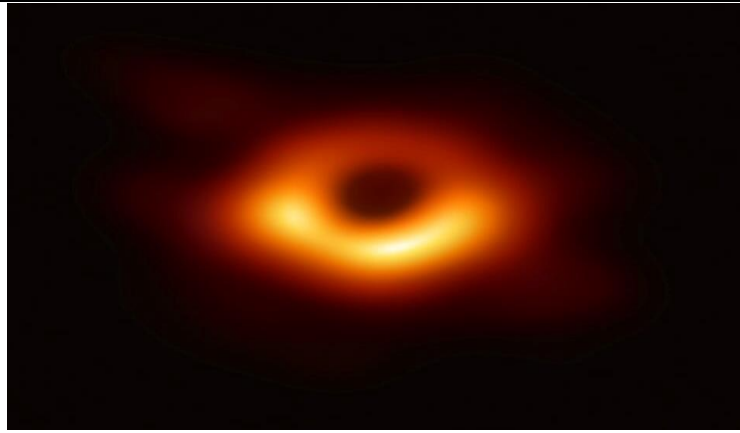


Gravitational waves

This observation paved the way for the era of multidimensional astronomy in the history of astronomy. The discovery and study of neutron stars stands at the intersection of nuclear physics, quantum field theory, cosmology, and astronomy. Neutron stars represent the densest matter, the strongest magnetic fields, and the fastest rotating objects in the Universe. Thanks to these objects, real observational material is obtained towards the unification of gravitational and quantum theories[18]. A neutron star is one way that stars end their lives. Neutron stars have a mass of at least 1.1 solar masses

($M_{\odot}$). The upper limit on the mass of a neutron star is called the Tolman–Oppenheimer–Volkoff limit and is generally considered to be around $2.1 M_{\odot}$ [19]. However, recent studies suggest that this

limit is $2.16 M_{\odot}$. As of September 2019, the most massive neutron star discovered was PSR J0740+6620, with a mass of $2.14 M_{\odot}$ [20]. There are approximately 2,000 neutron stars known to exist within the Milky Way galaxy. The closest neutron stars to the Solar System are RXJ1856.5-3754, about 400 light-years away, and PSR J0108-1431, about 424 light-years away[21]. Stars with masses below the Chandrasekhar limit of $1.39 M_{\odot}$ are generally white dwarfs. Compact stars with masses between $1.4 M_{\odot}$ and $2.16 M_{\odot}$ are expected to be neutron stars. However, there is a small mass range, a tenth of the mass of the Sun, within which the lowest-mass neutron stars and the most massive white dwarfs can coexist[22]. Above a mass of $2.16 M_{\odot}$, the gravity of a compact star, theoretically the remnant of a dead star, is thought to overcome the degenerate neutron pressure and form a black hole.



Black hole photographer

However, the smallest observed black hole has a mass of $5 M_{\odot}$ [23]. Despite their enormous masses, neutron stars have very small volumes. For example, a neutron star with a mass about 1.5 times that of the Sun would have a diameter of only 10 kilometers. The smallest neutron stars have a radius of about 10 kilometers, while the largest have a radius of 14–16 km. In very rare cases, this figure can approach 22 kilometers, but this can only happen for unusually massive

stars[24]. Density of neutron stars $\rho \approx 10^{17} \text{ kg/m}^3$, gravitational field approximately 10^{11} g , while the magnetic field 10^8 - 10^{15} It is in the Gaussian range (especially in magnetar-type neutral stars). From this perspective, the volume of an average neutron star is:

$$V = \frac{4\pi R^3}{3} = \frac{4 \cdot 3,14 \cdot (10^4)^3}{3} \approx 4,2 \cdot 10^{12} \text{ m}^3$$

[25]. It is said that a spoonful of neutron star matter would be equivalent to 100 million tons on Earth. This mass is about the same as Mount Everest[26]. In fact, when we calculate with the given quantities,



$$m_s = \rho \cdot V_s = 10^{17} \cdot 10^{-6} = 10^{11} \text{ kg/m}^3$$

we will get it.

Neutron stars are very hot, with surface temperatures reaching 600,000 K. The internal temperature of a newly formed neutron star is. 10^{11} - 10^{12} K is between. However, the neutrinos it emits are so energetic that within a few years the temperature drops to 10^6 K. Most of the radiation emitted by a neutron star at this temperature is X-rays[27]. The reason why neutron stars do not shrink further under the influence of gravity is the Pauli exclusion principle. This principle states that no two fermionic particles, such as protons, electrons, and neutrons, can occupy the same location and quantum state. Therefore, stars with a mass greater than 5 times that of the Sun are unstable and will continue to collapse. These stars will become black holes. The reason why neutron stars do not collapse further is neutron pressure[28].

Neutron stars rotate at very high speeds because, according to the law of conservation of angular momentum, the rotation speed increases as the star's volume decreases[29]. However, according to the law of conservation of angular momentum, we can also obtain the following result:

$$L = J \cdot \omega = \text{const}$$

Therefore, as J decreases, ω will increase. In short, as the radius decreases, the rotational speed increases sharply. Here, L is the torque, J is the moment of inertia (related to mass and radius), and ω is the angular velocity of rotation[22].

The fastest known neutron star to rotate on its axis is PSR J1748-244bad, which rotates 716 times per second, or 43,000 times per minute. At its equator, its rotation speed is about 24 percent of the speed of light[30].

Now let's look at the process of neutron star formation. A neutron star is formed when a massive star explodes as a Type II, Type Ib, or Type Ic supernova and the rest collapses in on itself. Although these stars are composed almost entirely of neutrons, they also contain small amounts of protons and electrons. Without these protons and electrons, neutron stars would not survive for long[31]. This is because neutrons are unstable in their free state and quickly decay into protons and electrons, emitting beta radiation. However, due to the high pressures inside the star, protons and electrons combine to form neutrons, making neutron stars more stable[22]. An average neutron star contains about

$$N = M/m_n = 2,8 \cdot 10^{30} / 1,675 \cdot 10^{-27} \approx 1,7 \cdot 10^{57}$$

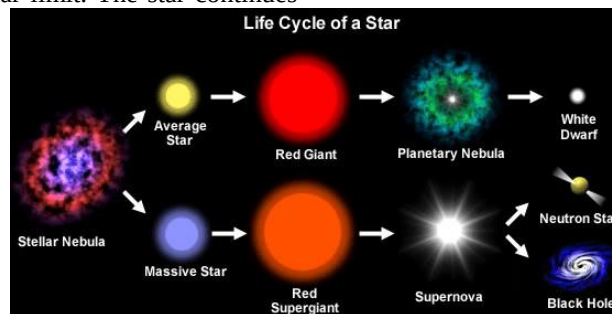
There are neutrons in the number. Here M is the mass of the neutron star, and m_n is the mass of the neutron. Although this number is huge compared to the existing number of baryons in the Universe (about 10^{80}), this is how many quantum particles are contained in a single star.

As a result of the burning reactions of the star, all light elements are synthesized up to iron. Iron is the element that produces energy in nuclear fusion, because when heavier elements are synthesized, energy is consumed, not produced. This transformation process occurs in the following:

1. The iron core begins to collapse (because it no longer produces energy);
2. Due to the high gravitational force, electrons combine with protons and become neutrons;
3. At this time, a large number of neutrons are formed[31].

Neutron stars are formed by stars with masses close to the Chandrasekhar limit. The star continues

its life by fusing hydrogen into helium. Under normal conditions, this fusion process is sufficient to maintain the star's size. In other words, the energy generated by the external fusion reaction counteracts the internal gravitational force, keeping the star's size constant. However, as the star nears the end of its hydrogen supply, it begins to shrink due to the gravitational pull at its center. In this state, it continues to emit faint light due to the reaction of the remaining hydrogen in its center. Then, when its fuel is completely exhausted, another reaction begins: the fusion of helium atoms into carbon atoms. Compared to hydrogen fusion, helium fusion releases an incredible amount of energy. Therefore, centrifugal force cannot withstand this energy and the star begins to grow at an incredible rate[32]. So much so that if the Sun were to enter this space, its diameter would expand to swallow Mars. This red giant continues to expand in this way for a while until it even uses up the helium in its structure.



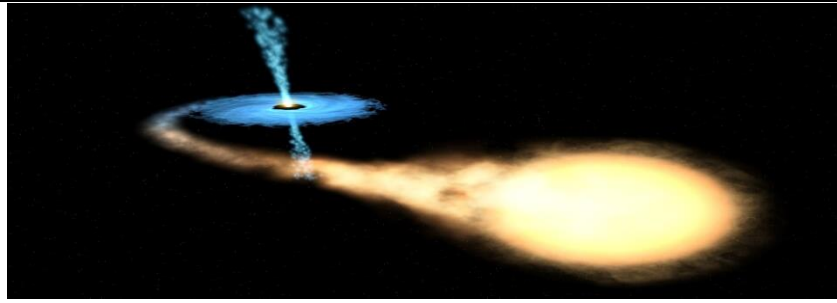
Stages of stellar evolution

Once the helium is exhausted, the star's energy production pathways are exhausted and it begins to collapse again under the influence of its unbalanced gravity[6]. In the compression phase, the fate of the star is determined by its mass. The greater the mass of the star, the greater its central gravitational force. The smaller its mass, the weaker its central gravitational force. For example, stars smaller than the Sun collapse to form brown or black dwarfs[33]. Neutron stars are classified into different types based on their mass and internal structure. The types of neutron stars are described differently in different literatures. We can generally divide neutron stars into the following groups:

- Pulsars (radio, optical, X-ray radiation);
- Magnetars (super strong magnetic field);
- X-ray binaries[34].

Magnetars are neutron stars with extremely strong magnetic fields. These magnetic fields are the strongest known in the Universe: $B \approx 10^{14} - 10^{15}$ Gauss. Magnetars are formed by a supernova explosion of a rapidly rotating protoneutron star with a highly convective zone.

The supernova explosion creates an extremely strong magnetic field inside the star. As a result, the star emits energy, explodes, and emits X-rays and gamma rays. Magnetars provide unique information about the evolution of neutron stars and the mechanism of magnetic field formation[35]. About 5% of known neutron stars are members of binary star systems. In these systems, the neutron star's companions may be normal stars, white dwarfs, or other neutron stars. X-ray binaries are a class of binary stars that are bright in X-rays. A typical low-mass X-ray binary emits about 10^{41} positrons per second. General relativity predicts that binary star systems emit gravitational waves and that the distance between the stars decreases over time. The first evidence for the existence of gravitational waves was obtained by observing a binary star system containing a neutron star and finding that the distance between the stars varied according to the predictions of general relativity[36]. This much information about the types of neutron stars will suffice.



X-ray binaries

Scientists first modeled how matter would behave in density by making calculations based on Einstein's general theory of relativity and quantum statistics. At that time, observational evidence proved that neutron stars have layers[37]. When various pressure-energy relationship models were compared with these observations, only the layered structure models were consistent[18]. The fact that the shell vibrates and breaks also suggests that these events occur as a result of compression and tension due to the difference in stiffness between the shell and the core[38]. According to scientific sources, we can roughly express the structure of these layers as follows:

1. Inner Core:

- Content: ~99% neutrons, protons, electrons, muons, hyperons and/or quark matter.

- Density: $> 1.5 \times 10^{15}$ qr/sm³ (2-3 times the nuclear density)

- Note: The composition of this region is not fully known and various theories (hyperons, pion/condensate, quark-gluon plasma) have been proposed.

2. Outer Core:

- Content: ~90-95% neutrons, ~5-10% protons, electrons and muons.

- Density: 4.3×10^{14} - 1.5×10^{15} qr/sm³ (close to or higher than the nuclear density)

- Characteristics: Superconducting liquid neutron-proton mixture. Free electrons and muons provide high conductivity.

Inner Shell:

- Composition: Atomic nuclei that are extremely rich in neutrons ($Z=30-40$) + free neutron superfluid + electron gas.

- Density: 1.4×10^{14} - 4.3×10^{14} qr/sm³ (up to about half the core density)

- Note: The "neutron droplet matter" phase is observed here (lattice, cylinder, sheet shapes).

Outer Shell:

- Composition: Crystal lattice of iron-56 (⁵⁶Fe) and heavier elements ($Z=26-38$) + free electron gas.

- Density: 10^6 - 1.4×10^{14} qr/sm³

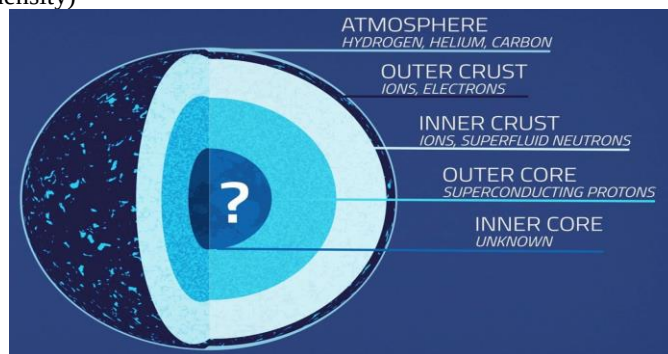
- Characteristics: Perfect crystalline structure. As the density increases, the nuclei begin to become extremely enriched with neutrons by capturing electrons.

The atmosphere

- Composition: A thin layer of hydrogen or helium (about 1-10 m thick).

- Density: $< 10^6$ qr/sm³

- Significance: Determines the emission properties of a neutron star[39].



The internal structure of a neutron star

However, many scientists believe that there is a substance with different properties in the core of a neutron star. In 1984, the American theoretical physicist Edward Witten suggested that "strange" quark matter (consisting of u, d, and s quarks) may be a more stable form in the center of neutron stars. E. Witten even claimed that quark stars may exist in the Universe. According to E. Witten, this matter is one of the densest and most stable types of matter known to mankind[40]. Canadian-American writer Norman Glendennig suggested that neutron stars may contain high-density hybrid stars. That is, the outer part of the star may consist

of neutron matter, and the center of quark matter. N. Glendennig suggested that this transition may not occur abruptly, but rather in the form of a "mixed phase"[41]. American theoretical physicist Fridolin Weber has worked extensively on the internal structure of neutron stars and has investigated the observable astrophysical results. F. Weber showed that quark matter affects parameters such as the radius, rotation frequency, and temperature of the star. F. Weber also tried to theoretically justify the existence of quark stars[42]. All these ideas argue that neutron stars may be a new type of hybrid stars. It should be noted that in some

sources the term "nuclear fluid" is used inside neutron stars. However, this fluid is not a classical fluid. Because, at such a high density, a liquid state cannot exist. Here, the word "liquid" only denotes collective quantum behavior[43]. Inside neutron stars, the density is no longer only the possibility of the formation of quark matter, but also collective effects arising from the quantum nature of baryons - degeneracy and superfluidity - begin to play an important role. These processes are the main factors determining the internal structure of the star and the dynamics of rotation[44]. Baryon degeneracy is an effect that arises as a result of the inability of baryons to simultaneously occupy certain quantum states due to quantum statistics. We have noted that neutron stars have a very high density. This value indicates that they are denser than the atomic nucleus. At this density, baryons, which are fermions according to the Pauli principle, can only exist in their own quantum state. This constraint creates a very large "degeneracy pressure" inside the star. The resulting pressure balances the collapsing force of gravity[22]. Superfluidity is the resistance-free, frictionless flow of particles in a fluid state. In neutron stars, this occurs when neutrons or protons form pairs. Neutrons pair up depending on density and temperature conditions. These pairs exhibit superfluidity behavior, which alters the internal heat transfer and heat balance of the star. Neutron superfluidity alters the thermal conductivity and rotational dynamics. Sudden jumps in the rotational frequency of pulsars in particular are considered evidence of neutron superfluidity. Neutron superfluidity occurs at temperatures below $\sim 10^9$ K[45]. Protons also become superconducting under the same conditions. This leads to quantization of the magnetic field. Proton superconductivity can begin around $\sim 10^{10}$ K. As a result, superfluidity changes thermal diffusion and neutrino emission. Superconductivity plays an important role in explaining the field structures and stability of magnetars[46]. Thus, it has a strong influence on thermal evolution. Thermal evolution is the field that studies how the internal temperature of neutron stars changes over the millions of years after their birth. The neutron star formed as a result of the collapse of the star becomes extremely hot (10^{11} - 10^{12} K). At this time, very strong neutron emission occurs. During the first 10^5 years, a neutrino cooling period occurs. The main cooling occurs by neutrino emission. At this stage, the temperature decreases very rapidly. After 10^5 years, the photon cooling phase begins. Now the main energy loss is radiation from the surface by photons. The internal temperature of the star stabilizes, and the surface cools down[27]. Thermal evolution graphs also show that there are different thermally conductive zones inside the star[47]. This fact is further evidence confirming the existence of layers. One of the problems that arise during the evolution of neutron stars is the mass problem. The mass gap is the gap observed between the neutron star and the black hole and is related to objects that do not have mass in nature. So, the mass of neutron stars 1.1 - $2.16 M_{\odot}$, and black holes $5 M_{\odot}$ but no objects are observed in the mass range of these two objects, i.e., between 2.5 and $5 M_{\odot}$. This phenomenon is known as the "mass gap"[48].

The exact cause of this problem is still unknown, but some hypotheses have been proposed. According to the supernova explosion mechanism, the material in the explosion at the end of the star's life is either very compressed or the compression stops, but in the intermediate state the explosion may be unstable. That is, objects in this mass range cannot form[49]. If a neutron star becomes too compressed, its center can become a quark-gluon plasma, and this transition can define an "instability zone." When the star explodes, most of the matter is thrown out, and what remains becomes either a neutron star or, if it is large enough, a black hole. Sometimes this transition can be abrupt[41]. Some scientists, however, suggest that this mass gap may actually be due to limitations in our observational methods. It is possible that objects in this mass range do exist, but because black holes are so small that they emit so little radiation that telescopes cannot observe them[50].

Neutron stars are considered a bridge to the quantum theory of gravity. Because their internal structure is subject to quantum effects, and gravity is subject to the theory of general relativity. General relativity is the main theoretical framework that explains the existence and behavior of these objects[51]. New discoveries have been made in 2020-2025 regarding pulsars and magnetars. It is almost certain that a "sea of gluons" is present in the composition of neutron stars. New theories show that some electron stars contain not only neutrons in their cores, but also partially free gluons and quarks. This discovery also brings them closer to quark stars. These studies help us understand the behavior of matter at high densities in the context of quantum chromodynamics[52]. In late 2024, the LIGO-Virgo-KAGRA collaboration observed gravitational waves from the merger of two neutron stars with higher precision. This observation confirmed the formation of heavy elements (gold and platinum) in kilonova events[53]. Another novelty is that "unbreakable crystalline matter" may exist on the surface of neutron stars. New simulations show that a substance called nuclear paste forms on the surface of neutron stars. This substance is considered the strongest substance that can exist in the Universe. This substance is called spaghetti or lasagna due to its structure in nuclear paste forms[54]. Another novelty is related to neutron star-black hole hybrids. Some theoretical models suggest that a neutron star may contain a micro-black hole. This claim provides an important test for the unification of gravitational and quantum theories[55]. At the same time, new discoveries have been made about magnetars. In 2020, the Chinese FAST telescope and the Canadian CHIME telescope observed a magnetar associated with a radio burst. The burst came from a magnetar called SGR 1935+2154. This was the first evidence that fast radio bursts sometimes originate from magnetars[56]. The magnetic field of magnetars consists not only of dipoles, but also of theoretical and complex fields. These fields are unstable and can cause explosions. Some magnetars, if massive enough, can even become black holes in a very short time. Recent observations show that some magnetars can deform the surrounding space with their magnetic field[57]. After 2022, it was ob-

served that the rotation rate of some magnetars suddenly decreased. This phenomenon is thought to be due to the restructuring of the magnetic field by internal stresses[58].

Problem statement: It turns out that neutron stars, the remnants of massive stars that have collapsed under the influence of gravity, are one of the most extreme and at the same time the most mysterious objects in astrophysics. The small size of neutron stars and their density, which exceeds other stars many times, allow us to study the behavior of matter in regimes that are not possible in laboratory conditions. However, despite all the observational and theoretical advances, fundamental questions about the internal structure of neutron stars remain open. One of the main difficulties is related to the equation of state of matter, which determines the stability of the objects. Different nuclear models give different predictions for the radius, maximum mass, and density profile of neutron stars. This highlights the need to reconcile observations with theoretical models[59]. Another important problem is the relationship between general relativity and quantum physics in neutron stars. On the one hand, Einstein's equations determine the gravitational constant of these objects. On the other hand, the behavior of nucleons or quarks at high densities is still not fully understood[60]. Thus, given the above contradictions, the main problems about neutron stars will be the following questions:

- What is at the very center of a neutron star?
- How is the magnetic field of magnetars created?
- Is neutron star matter superconductive?
- What causes thermal evolution?
- What causes mass void?
- What theoretical model can fully explain all the properties of neutron stars? Etc.

Solving these problems not only sheds light on the nature of neutron stars, but also creates a bridge between nuclear physics, gravitational theories, and astrophysics. That is, the theoretical model put forward must first answer these questions.

Solution to the problem: Based on the above information, it is possible to propose a new model that eliminates the questions raised about neutron stars. Based on many factual evidences, we see that neutron stars have layers. We can say that in neutron stars, the lower shell consists mainly of neutrons and this matter will be compressed as it goes towards the center. From this point of view, we can conclude that the very center is a denser medium than neutrons. Therefore, the probability of quark matter being present in the very center of neutron stars is very high. Since the surface of a neutron star consists mainly of neutrons, it can be considered the hardest substance in the Universe, and this hardness increases further towards the center. A neutron star can be thought of as a dual quantum fluid: a superfluid consisting of neutrons and a superconductor consisting of protons. That is, the proton component of neutron stars is a superconductor. Since neutron stars are composed primarily of neutrons, they can only exist in a superfluid phase. These quantum phases determine the magnetic field, spin rate, and rotational behavior of

neutron stars. Astronomical observations show that the cooling rate of neutron stars cannot be explained without considering the superfluid and superconducting phases. In particular, the cooling of a young neutron star in a supernova galaxy is considered strong evidence for neutron superfluidity[61]. The superfluidity and superconductivity phases are essential components to explain the course of these processes. These processes create possible conditions for thermal evolution in neutron stars. In magnetars, the star does not lose its magnetic field during the collapse as a result of a supernova. Since the radius is reduced by a factor of 10^5 as a result of the collapse, the magnetic flux is conserved and the field is strengthened by the $B \sim 1/R^2$ law. That is, the $\sim 10^3$ Gauss field of a typical massive star can reach $\sim 10^{12}$ Gauss after the collapse. This value corresponds to the field of normal pulsars. However, in magnetars this value reaches 10^{15} Gauss[22]. Therefore, the mechanism of magnetar formation cannot be explained simply by the freezing of magnetic flux. Therefore, a second mechanism must be involved. After the collapse, the young neutron star rotates at a very high speed. Its interior has a very high conductivity. In this situation, the " α - ω dynamo" mechanism plays a role: rotation and convection combine to create electric currents inside, and as a result, the magnetic field becomes incredibly strong. Simulations show that if the initial rotation period is < 3 ms, the field can grow to 10^{15} Gauss. This strong field that is created deforms the front of the neutron star over time[62]. On the other hand, as we know, our space is built on a certain energy. If we have an energy higher than the boundary energy of the space in a certain part, it is possible to transition to other spaces. Our 3-dimensional space has its own unique properties like other spaces. That is, every object that exists in this space must exist in a way that corresponds to these properties[63]. When we look at space, we observe a number of unusual properties in black holes. It can be said that black holes exhibit a number of abnormal behaviors that are different from the properties of space itself. Black holes are objects that can be compared to topological defects in space-time[64]. They may be related to the distribution of dark matter in space, and this relationship may shed light on the observed inconsistencies in the mass distribution. Black holes are formed after the collapse of massive stars. As we mentioned above, the greater the mass of a star, the greater its centripetal force. That is, in this case, the energy of the impact exerted by the star on the central part is very high. Therefore, when massive stars collapse, the energy of the star's impact on the central space is higher, and a defect is formed in that part. The reason why black holes exhibit this type of defective behavior is precisely because it is a defect in cosmic space[64]. If the mass of the star is not large enough, the energy of its impact on a point in space will also be small. In this case, no defect is created in space. In this regard, when neutron stars are formed, a defect is not created in space, but something close to it is formed. Therefore, since neutron stars are not defects created in 3-dimensional space, their behavior can be determined by the laws of physics. For this reason, neutron stars can be considered as the last stop before a

cosmic defect. When we look at the properties of dark matter and 3-dimensional space, we observe a similar discrepancy. This fact also leads us to view dark matter as a complex structure existing in higher-dimensional space[65]. Dark matter exerts its influence more in galaxies, or rather, in the centers of galaxies[63]. Interestingly, it is thought that at the center of every galaxy there are cosmic defects, that is, black holes[66]. When we combine these facts, we understand that dark matter exists in high-dimensional space and exerts its influence mainly in galaxies due to black holes. In short, there is an important connection between these two concepts. This approach put forward also allows us to answer the problem of mass gap. Since neutron stars are not cosmic defects, their masses are determined only by the sum of the masses of the particles in their composition. Since the mass of black holes is strongly affected by dark matter, its mass will be large relative to its size, and thus there will be a large mass difference between the two objects. Therefore, if a neutron star collides with a black hole, the black hole will prevail, and there are observations that support this[67].

Result: As can be seen, on the basis of the new theoretical model proposed above, it was possible to give substantial answers to many problematic questions about neutron stars. Thus, new scientific directions emerge in astrophysics and other fields. The matter of neutron stars is the hardest matter in the Universe, and it is highly probable that there is a matter consisting of quarks in their core. Due to the amount and interaction of neutrons and protons in the composition of neutron stars, important processes (superconductivity, superfluidity, baryon degeneracy, etc.) occur for these objects. The exchange between these two particles plays a possible role in the formation of thermal evolution. Depending on the parameters of the star, different types of neutron stars can be formed during a supernova explosion. It is clear that black holes are cosmic defects and due to their significant interaction with dark matter, the mass difference compared to neutron stars is sharp. From this point of view, it is more correct to consider neutron stars as the final state before the cosmic defect. Because, as we have mentioned, if the mass of the star is small, the impact energy of its center on space is small and this energy is not enough to create a defect in the space lattice. However, neutron stars are extremely important objects for research. The study of the properties of both black holes and neutron stars plays an important role in studying the properties of the Universe in which we live and in experimental confirmation of theories. As a result of the study, it is clear that the scattering of these two objects into the Universe is not accidental, but rather follows a certain purpose and regularity.

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SOCIAL SCIENCES

QUANTUM PHYSICS: A NARRATIVE OF FUTURE TECHNOLOGY

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Abstract

Quantum physics represents one of the most significant intellectual achievements of modern science, reshaping humanity's understanding of nature at its most fundamental level. It provides the conceptual and mathematical foundations for explaining atomic structure, radiation, and the behavior of particles, forces, and materials, while underpinning many contemporary technologies. Yet its development was marked by profound conceptual disruption. From its earliest formulations, quantum theory challenged classical assumptions about determinism, causality, and certainty, generating paradoxes and disagreements even among its founders. In exploring the universe, quantum physics focuses on the smallest constituents of matter such as quarks, electrons, and photons, revealing a domain that consistently defies everyday intuition. Within this realm, particles exhibit wave-particle duality, physical outcomes are described probabilistically, and measurement plays a constitutive role in determining observable reality. Although such phenomena may appear extraordinary, physicists have rendered them intelligible through rigorous theoretical frameworks and precise mathematical formalism. Within a scientific context, the "truth" of quantum mechanics does not imply metaphysical finality, but rather its exceptional capacity to describe, explain, and predict experimental results with remarkable accuracy. Importantly, this scientific account need not contradict spiritual or religious perspectives. Instead, by unveiling the coherence and complexity of the universe, quantum physics can complement scriptural narratives that emphasize meaning and purpose. This study investigates the scientific truth and narrates the story of universe on the basis of quantum physics and explores its influences on technological development and reshaping the civilization.

Keywords: Quantum physics, dark energy, QM, Big Bang, cosmic inflation,

1. Introduction

Quantum physics is the study of matter and energy at the most fundamental level. Knowledge of quantum principles transformed our conceptualization of the atom, which consists of a nucleus surrounded by electrons.²⁶ On the other hand, Quantum mechanics (QM) is an extraordinarily successful and rigorously verified scientific theory that describes the behavior of matter and energy at the atomic and subatomic scales. Its purpose is to provide a fundamental framework for understanding the microscopic world, enabling the development of most modern technology.²⁷ Quantum mechanics is the foundational physical theory that explains how matter and light behave, with its unusual properties usually manifesting at or below a certain scale of atoms.²⁸ This area of mechanics focuses on using mathematics to explain how subatomic particles move and interact. combining the ideas of wave-particle du-

ality, quantization of energy, and the uncertainty principle²⁹, and the principle of correspondence. Numerous systems that classical physics is unable to describe can be described by it.³⁰ Many aspects of nature can be described at an ordinary (as macroscopic) scale by classical physics, but at very small submicroscopic scales, it is insufficient.³¹ (as atomic and subatomic) scales.³² However, the quantum physics principle known as "quantization of energy" asserts that a physical system can only have specific discrete, permitted energy values, not any value within a continuous range.³³ Once again, a basic concept of quantum physics is wave-particle duality, which states that all fundamental things, including matter and light, may display both particle-like and wave-like qualities, depending on the experiment. For example, light may behave as discrete energy packets called photons, which have been seen in the photoelectric effect, or as a wave that exhibits interference, diffraction, etc. Similar to this, matter, such as

²⁶ <https://scienceexchange.caltech.edu/topics/quantum-science-explained/quantum-physics>, accessed on 23 Dec 2025

²⁷ <https://plato.stanford.edu/entries/qt-issues/>, accessed on 23 Dec 2025

²⁸ Feynman, Richard; Leighton, Robert; Sands, Matthew (1964). *The Feynman Lectures on Physics*. Vol. 3. California Institute of Technology. Retrieved 19 December 2020. Reprinted, Addison-Wesley, 1989, ISBN 978-0-201-50064-6, accessed on 11 Dec 2025

²⁹ Ayene, M., Kriek, J. & Damtie, B. (2011). Wave-particle duality and uncertainty principle: Phenomenographic categories of description of tertiary physics students' depictions. *Physical Review Special Topics Physics Education Research*, 7, 020113, accessed on 11 Dec 2025

³⁰ Morin, David (2008). *Introduction to Classical Mechanics*. New York: Cambridge University Press. ISBN 9780521876223, accessed on 11 Dec 2025

³¹ Nemiroff, R.; Bonnell, J., eds. (18 October 2006). "NGC 7635: The Bubble". *Astronomy Picture of the Day*. NASA, accessed on 11 Dec 2025

³² Jaeger, Gregg (September 2014). "What in the (quantum) world is macroscopic?". *American Journal of Physics*. 82 (9): 896–905. Bibcode:2014AmJPh..82..896J. doi:10.1119/1.4878358, accessed on 11 Dec 2025

³³ Davisson, C. J.; Germer, L. H. (1928). "Reflection and Refraction of Electrons by a Crystal of Nickel". *Proceedings of the National Academy of Sciences*. 14 (8): 619–627, accessed on 11 Dec 2025

electrons, may display wave-like characteristics like diffraction in addition to particle-like behavior.^{34, 35} It was Werner Heisenberg who developed the Uncertainty Principle.³⁶ is a key idea in quantum mechanics that states that there is an intrinsic limit to the accuracy with which certain pairs of physical attributes, like a particle's location and momentum, may be simultaneously known.³⁷

One of the most well-known outcomes of quantum mechanics is Heisenberg's Uncertainty Principle, which asserts that one cannot simultaneously know all detail about a particle as specified by its wave function. Non-commuting operators are a mathematical representation of this idea.³⁸ QM is the foundation of all quantum physics, which includes quantum chemistry³⁹, quantum biology⁴⁰, quantum field theory⁴¹, quantum technology⁴², and quantum information science⁴³. The incapacity of classical physics to explain phenomena like blackbody radiation, the photoelectric effect, and atomic stability gave rise to one of the most revolutionary scientific discoveries of the 20th century: quantum mechanics. Max Planck's quantum hypothesis (1900) introduced the idea of energy quanta, while Einstein's explanation of the photoelectric effect (1905) revealed the particle nature of light. Niels Bohr's atomic model (1913) established quantized electron orbits, and subsequent advances by de Broglie, Heisenberg, Schrödinger, and Born laid the mathematical and conceptual foundations of modern quantum theory. Further developments, including Dirac's relativistic formulation, Feynman's quantum electrodynamics, and Bell's theorem, expanded the scope of QM, confirming entanglement and ruling out hidden variables. By the 1970s, quantum field theory culminated in the Standard Model, successfully describing fundamental particles and forces, except gravity. Beyond theory, QM underpins modern technology, from semiconductors and lasers to medical imaging and quantum tunneling devices. Today, frontiers such as quantum computing (QC), communication, and sensing promise to revolutionize fields from cryptography to medicine, while unresolved questions on quantum gravity and the nature of reality continue to drive physics forward.

QM to explain phenomena at the smallest scales like atoms, electrons, photons, and subatomic particles and where classical theories failed. In this realm, matter and energy behave in ways that defy intuition; even atoms, the building blocks of matter, appear massive compared to the subtler quantum entities that govern their interactions. Over time, the field expanded and deepened. Quantum electrodynamics (QED) unified the behavior of light and electrons, achieving remarkably precise predictions and forming the basis for the Standard Model of particle physics. Later, John Bell's theorem and experimental evidence confirmed the non-local nature of quantum systems, validating the concept of entanglement and ruling out hidden variable theories. The evolution of quantum theory has also inspired new philosophical and scientific debates. Some scholars question whether QM represents the ultimate framework of physics or merely a gateway to deeper, undiscovered laws. Thinkers such as Roger Penrose have linked quantum processes to consciousness and quantum gravity, while modern advancements in quantum computing hint at transformative applications for technology and science. To understand why quantum physics became necessary, it is essential to revisit the state of science at the dawn of the 20th century. At that time, physics was considered nearly complete. Newton's laws of motion, Maxwell's equations of electromagnetism, and the principles of thermodynamics appeared to explain virtually all natural phenomena. Many physicists believed that only minor refinements were needed. However, as experimental techniques improved, inconsistencies began to emerge. One of the earliest and most significant challenges arose from the study of black body radiation.

A black body is an idealized object that absorbs all incoming radiation and emits energy solely based on its temperature. According to classical predictions, the emitted energy should increase without limit at shorter wavelengths, a problem famously known as the 'ultra-violet catastrophe.' But experiments revealed otherwise: the emission peaked at a certain wavelength before tapering off something classical physics could not explain. The relationship between the temperature of a filament and the color of the light it emits held crucial

³⁴ Feynman, Richard P.; Leighton, Robert B.; Sands, Matthew L. (2007). Quantum Mechanics. The Feynman Lectures on Physics. Vol. 3. Reading/Mass.: Addison-Wesley. ISBN 978-0-201-02118-9, accessed on 11 Dec 2025

³⁵ Wheaton, Bruce R. (1978). "Philipp Lenard and the Photoelectric Effect, 1889-1911". *Historical Studies in the Physical Sciences*. 9: 299–322. doi:10.2307/27757381, accessed on 11 Dec 2025

³⁶ <https://www.britannica.com/topic/philosophy-of-science/Underdetermination>, accessed on 11 Dec 2025

³⁷ Chang, Raymond. *Physical Chemistry for the Biosciences*. Sausalito California: University Science Books, 2005, accessed on 11 Dec 2025

³⁸ [https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_\(Physical_and_Theoretical_Chemistry\)/Quantum_Mechanics/02._Fundamental_Concepts_of_Quantum_Mechanics/Heisenberg's_Uncertainty_Principle](https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Quantum_Mechanics/02._Fundamental_Concepts_of_Quantum_Mechanics/Heisenberg's_Uncertainty_Principle), accessed on 11 Dec 2025

³⁹ McQuarrie, Donald A. (2007). *Quantum Chemistry* (2nd ed.). University Science Books. ISBN 978-1891389504, accessed on 11 Dec 2025

⁴⁰ Brookes, J. C. (May 2017). "Quantum effects in biology: golden rule in enzymes, olfaction, photosynthesis and magnetodetection". *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 473 (2201): 20160822. Bibcode:2017RSPSA.47360822B. doi:10.1098/rspa.2016.0822, accessed on 11 Dec 2025

⁴¹ Weinberg, Steven (1977). "The Search for Unity: Notes for a History of Quantum Field Theory". *Daedalus*. 106 (4): 17–35. JSTOR 20024506, accessed on 11 Dec 2025

⁴² Ladd, T. D.; Jelezko, F.; Laflamme, R.; Nakamura, Y.; Monroe, C.; O'Brien, J. L. (2010). "Quantum computers". *Nature*. 464 (7285): 45–53. arXiv:1009.2267. Bibcode:2010Natur.464...45L. doi:10.1038/nature08812, accessed on 11 Dec 2025

⁴³ Watrous, John (2018-04-26). The Theory of Quantum Information. Cambridge University Press. ISBN 978-1-316-85312-2, accessed on 13 Dec 2025

clues about the fundamental nature of the universe.⁴⁴ Solving this mystery was not just a step forward in technology. But it was a quest to unlock the deepest secrets of nature. Driven by this goal, the German government established a research center in Berlin named the Imperial Physical and Technical Institute.⁴⁵ In 1900, a brilliant mind, Max Planck, was appointed to lead the Institute's work. When Planck pursued what seemed like a simple question, he found that the laws of classical physics were inadequate to explain this phenomenon. A new paradigm was needed to understand the nature of light and energy. This quest led to the revolutionary idea that energy is emitted in discrete packets – quanta. Planck's groundbreaking concept laid the foundation for QM, radically transforming our understanding of the universe. The light bulb was no longer just a device that illuminated darkness; it became a gateway to the mysterious world of atoms and particles.

By explaining the behavior of matter and energy at the most basic levels, quantum theory offers a framework for comprehending the world, especially in the early stages of the universe and in extreme conditions like black holes where conventional classical physics is ineffective⁴⁶ and that, depending on the context, refers to scientific ideas in the realm of physics that are either non-quantum or both non-quantum and non-relativistic.⁴⁷ But a black hole is an astronomical entity so dense that nothing, not even light, can escape due to its gravity. According to Albert Einstein's general theory of relativity, a sufficiently compact mass will eventually become a black hole.^{48, 49} The event horizon is the

point at which there is no way out.⁵⁰ According to general relativity, an object's destiny is sealed by a black hole's event horizon, although crossing it results in no locally perceptible change.⁵¹ Because it doesn't reflect any light, a black hole often behaves like an ideal black body.⁵² Hawking radiation is predicted by quantum field theory in curved spacetime to be emitted at event horizons⁵³, having a temperature that is inversely proportional to its mass and the same spectrum as a black body. For stellar black holes, this temperature is on the order of billionths of a kelvin, making direct observation almost impossible.⁵⁴ Before theoretical research revealed that black holes were a general relativity prediction in the 1960s, they were thought of as mathematical curiosity.⁵⁵ Cygnus X-1 was the first known black hole, discovered in 1971 by a number of separate researchers.⁵⁶

Quantum cosmology applies these principles to the universe as a whole, treating it as a quantum system governed by a wave function,⁵⁷ and aims to explain phenomena like the Big Bang, the origin of cosmic structure, and the mysteries of dark matter and dark energy.⁵⁸ However, dark matter is an invisible substance that has a gravitational pull, holding galaxies and cosmic structures together.⁵⁹ Dark matter is a hypothesized, unseen kind of stuff that does not interact with light or other electromagnetic waves in astronomy and cosmology.⁶⁰ The cosmos is expanding more quickly due to a repulsive force called dark energy.⁶¹ Dark energy, therefore, is a theory of energy that has the biggest effects on the cosmos. Its main impact is to accelerate the universe's expansion.⁶² Their existence is deduced

⁴⁴ Landau, Lev Davidovich; Lifshitz, Evgeny Mikhailovich (1977). *Quantum Mechanics: Non-Relativistic Theory*. Vol. 3 (3rd ed.). Pergamon Press. ISBN 978-0-08-020940-1, accessed on 13 Dec 2025

⁴⁵ Robertson, H. P. (1929), "The Uncertainty Principle", *Phys. Rev.*, 34 (1): 163–164, Bibcode:1929PhRv...34..163R, doi:10.1103/PhysRev.34.163, accessed on 13 Dec 2025

⁴⁶ Morin, David (2008). *Introduction to Classical Mechanics*. New York: Cambridge University Press. ISBN 9780521876223, accessed on 13 Dec 2025

⁴⁷ Herbert, Friedman (2002). "From the ionosphere to high energy astronomy – a personal experience". *The Century of Space Science*. Springer. ISBN 0-7923-7196-8, accessed on 13 Dec 2025

⁴⁸ Overbye, Dennis (8 June 2015). "Black Hole Hunters". *NASA*. Archived from the original on 9 June 2015, accessed on 13 Dec 2025

⁴⁹ O'Riartaigh, C.; O'Keeffe, M.; Nahm, W.; Mitton, S. (2017). 'Einstein's 1917 Static Model of the Universe: A Centennial Review'. *Eur. Phys. J. (H)* 42: 431–474, accessed on 13 Dec 2025

⁵⁰ Rindler, Wolfgang (1956-12-01). "Visual Horizons in World Models". *Monthly Notices of the Royal Astronomical Society*. 116 (6). [Also reprinted in *General Relativity and Gravitation*, 34, 133–153 (2002), doi: 10.1023/A:1015347106729]: 662–677. doi:10.1093/mnras/116.6.662, accessed on 13 Dec 2025

⁵¹ Hamilton, A. "Journey into a Schwarzschild black hole". *jila.colorado.edu*. Archived from the original on 3 September 2019, accessed on 13 Dec 2025

⁵² Schutz, Bernard F. (2003). *Gravity from the ground up*. Cambridge University Press. p. 110. ISBN 978-0-521-

45506-0. Archived from the original on 2 December 2016, accessed on 13 Dec 2025

⁵³ Rose, Charlie. "A conversation with Dr. Stephen Hawking & Lucy Hawking". *charlierose.com*. Archived from the original on March 29, 2013, accessed on 13 Dec 2025

⁵⁴ Davies, P. C. W. (1978). "Thermodynamics of Black Holes" (PDF). *Reports on Progress in Physics*. 41 (8): 1313–1355. Bibcode:1978RPPh...41.1313D. doi:10.1088/0034-4885/41/8/004, accessed on 13 Dec 2025

⁵⁵ Webster, B. Louise; Murdin, Paul (1972), "Cygnus X-1—a Spectroscopic Binary with a Heavy Companion?", *Nature*, 235 (5332): 37–38, Bibcode:1972Natur.235...37W, doi:10.1038/235037a0, accessed on 13 Dec 2025

⁵⁶ Bolton, C. T. (1972), "Identification of Cygnus X-1 with HDE 226868", *Nature*, 235 (5336): 271–273, Bibcode:1972Natur.235..271B, doi:10.1038/235271b0, accessed on 13 Dec 2025

⁵⁷ <https://arxiv.org/html/2502.03075v1>, accessed on 13 Dec 2025

⁵⁸ Ferris, Timothy (January 2015). "Dark matter". *Hidden cosmos*. *National Geographic Magazine*. Archived from the original on 25 December 2014, accessed on 13 Dec 2025

⁵⁹ <https://physics.ucdavis.edu/~kaloper/siegfr.txt>, accessed on 13 Dec 2025

⁶⁰ Stapelberg, Sebastian (5 December 2022). "The Cosmic Web of Galaxies, Dark Matter and How It Emerged". *Structures Blog*, accessed on 13 Dec 2025

⁶¹ Carr, Bernard; Kühnel, Florian (2 May 2022). "Primordial black holes as dark matter candidates". *SciPost Physics Lecture Notes* 48, doi:10.21468/SciPostPhysLectNotes.48, accessed on 13 Dec 2025

⁶² Idicherian Lonappan, Anto; Kumar, Sumit; R, Ruchika; Dinda, Bikash R.; Ananda Sen, Anjan (21 February 2018).

from their effects on visible matter and the large-scale structure of the cosmos, despite the fact that both are dark since they do not produce light and cannot be directly detected.⁶³ Dark matter has an attractive or positive gravity, pulling cosmic structures together. Dark energy has a repulsive or negative gravity, pushing them apart.⁶⁴ Again, dark matter creates structure by holding things together, while dark energy drives expansion by pushing things apart.⁶⁵ Dark matter and dark energy are considered opposing forces that have shaped the history and evolution of the universe since the Big Bang.⁶⁶

Understanding this cosmic struggle and the nature of dark matter and dark energy is crucial for comprehending the universe's fate and structure, requiring new breakthroughs in observation and theory.^{67,68} Quantization, which is the process of converting continuous infinite values to a smaller set of discrete finite values of energy and time, is one of the key ideas.⁶⁹ The phenomenon known as quantum entanglement occurs when each particle in a group has a quantum state that cannot be explained apart from the states of the other particles.⁷⁰ Furthermore, the creation of quantum gravity theories aims to bring general relativity and quantum mechanics together.⁷¹ Sometimes it is possible to find a perfect correlation between measurements of entangled particles' location, momentum, spin, and polarization.⁷² The quantum state of an isolated quantum system is mathematically defined by the universe as a wave function.⁷³ where its past and future states are governed by quantum probabilities, offering a more

complete picture than classical models.^{74,75} The scientific community has long been fascinated by and studied QM, and its distinctive concepts and phenomena continue to influence how we see the world.⁷⁶ Entanglement, a phenomena where two or more particles become correlated to the point that their states are reliant on one another even when they are separated by great distances, is at the core of this area.⁷⁷ Measurements that would not be feasible otherwise have been made using this correlation as a kind of "quantum probe."⁷⁸

Researchers have successfully employed entangled particles to assess the characteristics of small systems, such as superconducting qubits, with previously unheard-of accuracy. The evolution of QC, which mostly depends on these concepts to carry out computations, will be significantly impacted by these tests. Understanding quantum systems also helps us understand how atomic and subatomic particles behave, revealing the basic essence of reality. In recent years, the idea of wave function collapse has been reexamined, and some scholars have put out other theories, such as the Many-Worlds Interpretation. This theory has significant ramifications for our comprehension of quantum mechanics as it implies that the cosmos divides into many branches upon measurement.⁷⁹ Researchers are still trying to figure out what drove inflation and what the early cosmos looked like. Our knowledge of this important early stage of cosmic history is still being improved by ongoing study. Again, QC can process larger and more complex datasets, leading to more efficient

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⁶³ Steinhart, Paul J.; Turok, Neil (2006). "Why the cosmological constant is small and positive". *Science*. 312 (5777): 1180–1183, doi:10.1126/science.1126231, accessed on 13 Dec 2025

⁶⁴ Overbye, Dennis (20 February 2017). "Cosmos Controversy: The Universe Is Expanding, but How Fast?". *The New York Times*. Archived from the original on 4 April 2019, accessed on 13 Dec 2025

⁶⁵ Bird, Simeon; Albert, Andrea; Dawson, Will; Ali-Haïmoud, Yacine; Coogan, Adam; Drlaca-Wagner, Alex; Feng, Qi; Inman, Derek; Inomata, Keisuke; Kovetz, Ely; Kusenko, Alexander; Lehmann, Benjamin V.; Muñoz, Julian B.; Singh, Rajeev; Takhistov, Volodymyr; Tsai, Yu-Dai (1 August 2023). "Primordial black hole dark matter". *Physics of the Dark Universe*. 41: 101231, doi:10.1016/j.dark.2023.101231. ISSN 2212-6864, accessed on 13 Dec 2025

⁶⁶ O'Riadaigh, C.; O'Keeffe, M.; Nahm, W.; Mitton, S. (2017). 'Einstein's 1917 Static Model of the Universe: A Centennial Review'. *Eur. Phys. J. (H)* 42: 431–474, accessed on 13 Dec 2025

⁶⁷ Hossenfelder, Sabine; McGaugh, Stacy S. (August 2018). "Is dark matter real?". *Scientific American*. 319 (2): 36–43. Bibcode:2018SciAm.319b..36H. doi:10.1038/scientificamerican0818-36, accessed on 13 Dec 2025

⁶⁸ I. P. C. Heard, D. Wands, Cosmology with positive and negative exponential potentials, *Class. Quant. Grav.* 19 (2002) 5435–5448, arXiv:gr-qc/0206085, doi:10.1088/0264-9381/19/21/309, accessed on 13 Dec 2025

⁶⁹ <https://www.mathworks.com/discovery/quantization.html>, accessed on 13 Dec 2025

⁷⁰ https://www.reddit.com/r/explainlikeimfive/comments/1ihv2q7/eli5_what_is_quantum_entanglement/,

⁷¹ <https://science.nasa.gov/what-is-the-spooky-science-of-quantum-entanglement/>, accessed on 13 Dec 2025

⁷² Dietrich, Cornelius Frank (1991) *Uncertainty, Calibration and Probability: The Statistics of Scientific and Industrial Measurement* 2nd Edition, A. Higler. ISBN 9780750300605, accessed on 13 Dec 2025

⁷³ Murdoch, D. (1987). *Niels Bohr's Philosophy of Physics*. Cambridge UK: Cambridge University Press. ISBN 978-0-521-33320-7, accessed on 13 Dec 2025

⁷⁴ Hanle, P.A. (1977), "Erwin Schrodinger's Reaction to Louis de Broglie's Thesis on the Quantum Theory", *Isis*, 68 (4): 606–609, doi:10.1086/351880, S2CID 121913205, accessed on 13 Dec 2025

⁷⁵ J.-L. Lehnars, Wave function of simple universes analytically continued from negative to positive potentials, *Phys. Rev. D* 104 (6) (2021) 063527, arXiv:2105.12075, doi:10.1103/PhysRevD.104.063527, accessed on 13 Dec 2025

⁷⁶ Aharonov, Y., & Bohm, D. (1959). Significance of Electromagnetic Potentials in Quantum Theory. *Physical Review*, 115, 485-491, accessed on 13 Dec 2025

⁷⁷ Bub, J., & Clifton, R. K. (1996). Understanding Uncertainty: What's Wrong with Copenhagen? *Foundations of Physics*, 26, 1407-1425, accessed on 03 Jan 2026

⁷⁸ Ansmann, M., et al. (2010). Entanglement-based Quantum Measurement with a Superconducting Qubit. *Nature Physics*, 7, 894-898, accessed on 03 Jan 2026

⁷⁹ Woolnough et al., 2023), A.P. Woolnough, L.C.L. Hollenberg, P. Cassey, T.A.A. Prowse, Quantum computing: A new paradigm for ecology, *Trends in Ecology & Evolution*, 38 (8) (2023), pp. 727-735, 10.1016/j.tree.2023.04.001, accessed on 03 Jan 2026

and faster training of machine learning models. Quantum computers can help financial institutions create more effective investment portfolios and develop better trading simulators. QC can optimize complex supply chains, including route planning, cargo loading, and manufacturing processes. It can also be applied to traffic optimization and logistics for more efficient planning. They can be used for advanced financial risk analysis and improved fraud detection. Quantum Key Distribution (QKD) uses QM to create unbreakable encryption keys that can detect eavesdropping attempts.⁸⁰ While posing a threat to current encryption methods, quantum computers also enable the development of stronger, post-quantum cryptographic algorithms that are resistant to quantum attacks.⁸¹ Potential uses include developing advanced sensors for clean water monitoring and understanding chemical processes for environmental benefit.

However, when quantum physics challenges our traditional understanding of how the universe functions, it often seems like a string of little miracles.⁸² The quantum realm is defined by uncertainty, superposition, and entanglement, in contrast to the macroscopic world, where things follow predictable routes and behaviors.⁸³ According to quantum physics, particles may affect one another across great distances, exist in numerous states simultaneously, and behave in ways that seem illogical.⁸⁴ These phenomena are not only enthralling but also indicate at a deeper and more complicated structure of reality. Authors like Carlo Rovelli in his book 'Reality Is Not What It Seems'⁸⁵ and Brian Greene in his book 'The Elegant Universe' use quantum physics and string theory to explore reality, bridging science and philosophy by revealing the universe's profound interconnectedness and challenging our intuitive notions of space, time, and existence, fostering wonder about creation through unifying theories and highlighting limits of human knowledge. Rovelli explores how our perception of time like sunrise/sunset is an illusion, pointing to the fundamental, relational nature of physics and the quantum world.⁸⁶ On the other hand, Greene introduces string theory, and suggesting reality is composed of tiny vibrating strings, revealing hidden dimensions and a universe far grander and more complex than we perceive.⁸⁷ They aim for a 'Theory of Everything (ToE)' demonstrating how seemingly disparate phenomena from quarks to galaxies arise from unified principles, see-through a deeply unified cosmos.⁸⁸ By revealing the sublime complexity and beauty

of physics, they suggest a profound sense of wonder, transforming scientific concepts into deeply human missions and searches for understanding. Both authors push beyond everyday experience to describe a universe far stranger than it appears, showing how our "common sense" view of reality breaks down at fundamental levels.

One of the most fascinating aspects of the Biblical or Quranic creation story in Bible or Quran is the concept that spoken words brought the universe into existence.⁸⁹ A few problems are raised by this concept, such as whether science can explain how sound or words may affect how things are formed. There are similar ideas that emphasize the power of sound and vibration, even if contemporary scientific theories do not support the assumption that words alone may produce physical things. The story of creation of universe and life found in the Bible and the Quran emphasizes how God's spoken word was instrumental in creating the cosmos. Thus, quantum physics highlights the complimentary nature of spirituality and science and improves our comprehension of creation. The scientific elucidation of creation through quantum physics need not be understood as a refutation of spiritual or religious narratives. On the contrary, for many, it deepens a sense of wonder and gratitude toward the complexity and coherence of the universe and, ultimately, toward the Almighty or Creator. Scriptural accounts found in the Qur'an offer spiritual and philosophical perspectives that emphasize meaning, purpose, and intentionality in creation. Quantum physics, by contrast, offers precise descriptions of particle behavior and cosmic formation grounded in observation and experiment. Together, these perspectives can be seen not as rivals, but as complementary lenses—one addressing empirical mechanisms, the other addressing existential significance. Against this backdrop, the present analytical study seeks to investigate the scientific truth of quantum physics and to explore how this understanding can influence technological development and contribute to the improvement of civilization. By clarifying what quantum theory genuinely claims—and what it does not—the study aims to situate quantum physics as both a cornerstone of modern science and a catalyst for deeper reflection on humanity's place within an intricately ordered universe. This analytical study narrates the story of universe in the eye of quantum physics and evaluate the influence of future technology by QM.

⁸⁰ <https://www.spinquanta.com/news-detail/benefits-of-quantum-computing>, accessed on 03 Jan 2026

⁸¹ <https://www.investopedia.com/terms/q/quantum-computing.asp#>, accessed on 03 Jan 2026

⁸² Brian Greene, "The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory", Vintage Series, Random House Inc., February 2000 ISBN 0-375-70811-1, accessed on 03 Jan 2026

⁸³ Brown, Laurie M. (June 2004). "Reviewed Work: The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory by Brian Greene". *Isis*. 95 (2): 327. doi:10.1086/426259, accessed on 03 Jan 2026

⁸⁴ Thomson, Ian (January 21, 2017). "Reality Is Not What It Seems by Carlo Rovelli review – physics versus certainty". *The Guardian*, accessed on 03 Jan 2026

⁸⁵ Banville, John (August 5, 2017). "Reality Is Not What It Seems review: Carlo Rovelli's journey to quantum gravity". *The Irish Times*, accessed on 03 Jan 2026

⁸⁶ <https://www.amazon.com/Reality-Not-What-Seems-Journey/dp/0735213933>, accessed on 03 Jan 2026

⁸⁷ Johnson, George (February 21, 1999). "Space-Time: The Final Frontier (Review of The Elegant Universe by Brian Greene)". *The New York Times*.

⁸⁸ Schwarz, J. H. (2000). "Review of The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory by Brian Greene". *American Journal of Physics*. 68 (2): 199–200. doi:10.1119/1.19379.

⁸⁹ <https://www.worldcertification.org/quantum-miracles-how-science-unveils-the-secrets-of-the-universe/#>, accessed on 03 Jan 2026

2. Literature Review: Basic Theory of Quantum Physics

This paper primarily aims to provide a broad interdisciplinary overview of quantum mechanics and its implications for modern technology and civilization, rather than a detailed technical treatment. The captivating journey of quantum physics began unexpectedly in the 1890s with a seemingly ordinary invention like light bulb. Edison's innovation quickly captured global attention, and several engineering firms invested millions to acquire the European patent. Among from many, the light bulb was the very essence of modern technology, a radiant symbol of progress that promised to transform urban life by illuminating the streets of the German Empire. Yet, beneath this simple innovation lay a profound scientific puzzle. While it was known that the filament glowed when heated by electricity, the underlying physical mechanism of how light was produced remained a mystery. This question would ultimately spark a revolution in physics and lay the foundation for what later became known as quantum mechanics. Few big names like Einstein, Bohr, Heisenberg, Neumann, David Bohm, John Steward Bell, Hugh Everret, Schrodinger, etc. are discussed and lay the foundations of Quantum Mechanics⁹⁰

Sir Isaac Newton argued that light was corpuscular (particulate) in the late 17th century, whereas Christiaan Huygens argued for a wave description.⁹¹ Newton anticipated the current wave-particle duality by becoming the first to try to reconcile the wave and particle theories of light, even though he had preferred a particle approach.⁹² Thomas Young's⁹³ interference experiments in 1801, and François Arago's⁹⁴ detection of the Poisson spot in 1819, validated Huygens' wave models.⁹⁵ However, Planck's equation for black-body radiation presented a challenge to the wave model in

1901.⁹⁶ By assuming that a hypothetical electrically charged oscillator in a cavity containing black-body radiation could change its energy only in minimal increments, E , proportional to the frequency of its associated electromagnetic wave, Max Planck heuristically derived a formula for the observed spectrum.⁹⁷ Albert Einstein also used discrete photon energies to understand the photoelectric phenomenon in 1905.⁹⁸ Both of these shows how particles behave. The photon hypothesis was debatable until Arthur Compton, although several experimental findings supported it.⁹⁹ Conducted several tests between 1922 and 1924 to show how light has momentum.¹⁰⁰ The prior work showing wave-like interference of light seemed to be at odds with the experimental evidence of particle-like momentum and energy.

Electrons' contradicting evidence came in the opposite sequence. Prominent physicists J. J. Thomson, Robert Millikan, and Charles Wilson, among others, demonstrated in several experiments that free electrons have particle characteristics. For example, Thomson measured the mass of free electrons in 1897.¹⁰¹ In 1924, Louis de Broglie presented his theory of electron waves in his doctoral dissertation, *Recherches sur la "orie des quanta*.¹⁰² He proposed that electrons and all matter might be seen as waves, and that an electron around a nucleus could be thought of as a standing wave.¹⁰³ He combined the concepts of considering them as waves and particles. According to his theory, particles are collections of waves, or wave packets, with an effective mass and a group velocity. Both of these rely on energy, which is linked to the wavevector and to Albert Einstein's relativistic theory from a few years earlier.¹⁰⁴ Erwin Schrödinger created the wave equation of motion for electrons in 1925 and 1926 after de Broglie proposed the wave-particle duality of electrons. This

⁹⁰ https://olshansky.info/book/what_is_real, accessed on 22 Dec 2025

⁹¹ Aldersey-Williams, H. (2020). *Dutch Light: Christiaan Huygens and the Making of Science in Europe*. Pan Macmillan. ISBN 978-1-5098-9332-4, accessed on 03 Jan 2026

⁹² Finkelstein, David Ritz (1996). *Quantum Relativity*. Springer Berlin Heidelberg. pp. 156, 169–170. doi:10.1007/978-3-642-60936-7. ISBN 978-3-642-64612-6, accessed on 03 Jan 2026

⁹³ Nolte, David D. (2023). *Interference: The History of Optical Interferometry and the Scientists Who Tamed Light* (Oxford University Press, 2023). Oxford University Press. ISBN 978-0192869760, accessed on 03 Jan 2026

⁹⁴ F. Arago (1859), *The history of my youth*, Boston: Ticknor and Fields, doi:10.5962/BHL.TITLE.19132, accessed on 03 Jan 2026

⁹⁵ Arianrhod, Robyn (2012). *Seduced by Logic: Émilie Du Châtelet, Mary Somerville and the Newtonian Revolution*. New York: Oxford University Press. p. 232. ISBN 978-0-19-993161-3, accessed on 13 Dec 2025

⁹⁶ Planck, Max (1901). "Ueber das Gesetz der Energieverteilung im Normalspectrum". *Annalen der Physik* (in German). 309 (3): 553–563. doi:10.1002/andp.19013090310, accessed on 13 Dec 2025

⁹⁷ Fraenkel, Abraham (2016). *Recollections of a Jewish Mathematician in Germany*. Basel, Switzerland: Birkhäuser. p. 96. ISBN 978-3-319-30845-6, accessed on 03 Jan 2026

⁹⁸ Einstein, Albert (1993). *The collected papers of Albert Einstein*. 3: The Swiss years: writings, 1909 - 1911: (English

translation), Princeton, NJ: Princeton Univ. Pr., ISBN 978-0-691-10250-4, accessed on 17 Dec 2025

⁹⁹ Hockey, Thomas (2007). *The Biographical Encyclopedia of Astronomers*. Springer Publishing. ISBN 978-0-387-31022-0, accessed on 03 Jan 2026

¹⁰⁰ Ma, Xiao-song; Kofler, Johannes; Zeilinger, Anton (2016-03-03). "Delayed-choice gedanken experiments and their realizations". *Reviews of Modern Physics*. 88 (1): 015005. doi:10.1103/RevModPhys.88.015005, accessed on 17 Dec 2025

¹⁰¹ Thomson, J. J. (1897). "XL. Cathode Rays". *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*. 44 (269): 293–316. doi:10.1080/14786449708621070, accessed on 17 Dec 2025

¹⁰² de Broglie, Louis Victor. "On the Theory of Quanta" (PDF). *Foundation of Louis de Broglie* (English translation by A.F. Kracklauer, 2004. ed.), accessed on 17 Dec 2025

¹⁰³ Bridgman, P. W.; de Broglie, Louis; Knodel, Arthur J.; Miller, Jack C. (1960). "Review of Non-Linear Wave Mechanics: A Causal Interpretation, de Broglie-Louis, Knodel-Arthur J., Miller-Jack C." *Scientific American*. 203 (4): 201–206. doi:10.1038/scientificamerican1060-201, accessed on 22 Dec 2025

¹⁰⁴ Crystallography example: Vainshtein (1994). *Modern Crystallography*. p. 259. ISBN 978-3-540-56558-1, accessed on 22 Dec 2025

quickly became a component of what Schrödinger dubbed "undulatory mechanics."¹⁰⁵ It is sometimes referred to as "wave mechanics" and the Schrödinger equation.¹⁰⁶

Max Born presented a discussion at an Oxford gathering in 1926 about the use of electron diffraction measurements to verify the electrons' wave-particle duality.¹⁰⁷ But Born also referenced 1923 experimental results from Clinton Davisson. Davisson was there during that discussion as well. Davisson went back to his lab in the United States to refocus his experiments on testing the electron's wave property.¹⁰⁸ Once again, two tests in 1927 provided empirical evidence for the electrons' wave character. Electrons dispersed from Ni metal surfaces were detected in the Davisson-Germer experiment at Bell Laboratories.¹⁰⁹ At Cambridge University, George Paget Thomson and Alexander Reid observed concentric diffraction rings after electrons were scattered through thin nickel sheets.¹¹⁰ Thomson's graduate student Alexander Reid carried out the first trials,¹¹¹ however he was killed in a motorbike accident shortly after,¹¹² and is seldom ever brought up. Hans Bethe's initial non-relativistic diffraction model for electrons quickly followed these results.¹¹³ based on the Schrödinger equation, which is quite similar to the current description of electron diffraction. Notably, Davisson and Germer observed that since the locations were consistently varied, their findings could not be understood using a Bragg's law approach; Bethe's method,¹¹⁴ It produced more accurate findings by accounting for the refraction caused by the average potential. In 1937, Davisson and Thomson received the Nobel Prize for using diffraction tests to confirm that electrons are waves experimentally.¹¹⁵ Otto Stern conducted similar

crystal diffraction studies using beams of hydrogen molecules and helium atoms in the 1930s. These investigations further confirmed that wave behavior is a universal characteristic of matter at the microscopic level and is not specific to electrons.

We must provide some definitions of particles and waves from both quantum mechanics and classical theory. Each of the two models for physical systems—waves and particles—has an extensive range of applications. Classical waves have continuous values at several locations in space that change over time, and they follow the wave equation. They also exhibit wave interference, and their spatial extent may change over time due to diffraction.¹¹⁶ Water waves, seismic waves, sound waves, radio waves, and other physical systems that exhibit wave behavior are all described by wave equations. Once again, classical mechanics governs classical particles. They follow trajectories with locations and velocities that change over time, and in the absence of forces, their trajectories are straight lines. They also have some center of mass and extension. Particle models of stars, planets, spaceships, tennis balls, bullets, and grains of sand operate on a huge scale. Particles do not interact as waves do.¹¹⁷ Particle probability distributions are predicted by quantum systems' adherence to wave equations. For characteristics like spin, electric charge, and magnetic moment, these particles are linked to discrete values called quanta.¹¹⁸ These particles accumulate a pattern despite arriving randomly and one at a time. The square of a complex-number wave is the likelihood that investigations will detect particles at a certain location in space. Diffraction and interference of the probability amplitude may be shown in experiments.¹¹⁹ Wave-like characteristics may thus

¹⁰⁵ Schrödinger, E. (1926). "An Undulatory Theory of the Mechanics of Atoms and Molecules". *Physical Review*. 28 (6): 1049–

1070. Bibcode:1926PhRv...28.1049S. doi:10.1103/PhysRev.28.1049, accessed on 17 Dec 2025

¹⁰⁶ Schrödinger, E. (1926). "An Undulatory Theory of the Mechanics of Atoms and Molecules" (PDF). *Physical Review*. 28 (6): 1049–70, doi:10.1103/PhysRev.28.1049, accessed on 22 Dec 2025

¹⁰⁷ Greenspan, Nancy Thorndike (2005). *The End of the Certain World: The Life and Science of Max Born*. New York: Basic Books. ISBN 978-0-7382-0693-6, accessed on 22 Dec 2025

¹⁰⁸ Gehrenbeck, Richard K. (1978-01-01). "Electron diffraction: fifty years ago". *Physics Today*. 31 (1): 34–41. doi:10.1063/1.3001830. ISSN 0031-9228, accessed on 17 Dec 2025

¹⁰⁹ Davisson, C. J.; Germer, L. H. (1928). "Reflection of Electrons by a Crystal of Nickel". *Proceedings of the National Academy of Sciences*. 14 (4): 317–322, doi:10.1073/pnas.14.4.317, accessed on 17 Dec 2025

¹¹⁰ Thomson, G. P.; Reid, A. (1927). "Diffraction of Cathode Rays by a Thin Film". *Nature*. 119 (3007): 890. Bibcode:1927Natur.119Q.890T. doi:10.1038/119890a0, accessed on 17 Dec 2025

¹¹¹ Reid, Alexander (1928). "The diffraction of cathode rays by thin celluloid films". *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*. 119 (783): 663–667,

¹¹² Navarro, Jaume (2010). "Electron diffraction chez Thomson: early responses to quantum physics in Britain". *The British Journal for the History of Science*. 43 (2): 245–275, accessed on 17 Dec 2025

¹¹³ Bethe, H. (1928). "Theorie der Beugung von Elektronen an Kristallen". *Annalen der Physik* (in German). 392 (17): 55–129. Bibcode:1928AnP...392...55B. doi:10.1002/andp.19283921704, accessed on 17 Dec 2025

¹¹⁴ Bach, Roger; Pope, Damian; Liou, Sy-Hwang; Batelaan, Herman (2013-03-13). "Controlled double-slit electron diffraction". *New Journal of Physics*. 15 (3). IOP Publishing: 033018, accessed on 17 Dec 2025

¹¹⁵ "The Nobel Prize in Physics 1937". NobelPrize.org, accessed on 17 Dec 2025

¹¹⁶ Whittaker, E. T. (1910). *A History of the Theories of Aether and Electricity: From the Age of Descartes to the Close of the Nineteenth Century*. Longman, Green and Co, accessed on 17 Dec 2025

¹¹⁷ Davisson, C. J.; Germer, L. H. (1928). "Reflection and Refraction of Electrons by a Crystal of Nickel". *Proceedings of the National Academy of Sciences*. 14 (8): 619–627. Bibcode:1928PNAS...14..619D. doi:10.1073/pnas.14.8.619, accessed on 17 Dec 2025

¹¹⁸ Baggott, J. E. (2013). *The quantum story: a history in 40 moments* (Pbk ed.). Oxford [England]: Oxford University Press. ISBN 978-0-19-965597-7, accessed on 22 Dec 2025

¹¹⁹ Wheaton, Bruce R. (1978). "Philipp Lenard and the Photoelectric Effect, 1889-1911". *Historical Studies in the Physical Sciences*. 9: 299–322. doi:10.2307/27757381. JSTOR 27757381, accessed on 17 Dec 2025

be seen in statistically significant numbers of random particle occurrences. Quasiparticles are collective excitations governed by similar equations.

In 1887, Heinrich Hertz made the observation that a metallic surface generates cathode rays, or what are now known as electrons, when light strikes it at a high enough frequency.¹²⁰ Once again, Philipp Lenard found in 1902 that the intensity of an expelled electron has no bearing on its maximal energy.¹²¹ The energy of the electron should be proportional to the intensity of the incoming radiation, according to classical electromagnetism, which contradicts this result.¹²² In 1905, Albert Einstein proposed that there must be a limited amount of energy quanta in order for light to have energy.¹²³ He proposed that electrons can only absorb energy from an electromagnetic field in discrete units, such as quanta or photons, and that the energy E could be correlated with the light's frequency f using the formula $E=hf$. The Planck constant, or h in this case, is equal to 6.626×10^{-34} J·s. For instance, red light photons lacked the energy necessary to liberate an electron from the metal he used, but blue light photons did. Only one electron could be released by a single photon of light above the threshold frequency; the greater the photon's frequency, the more electrons it could release. Therefore, no quantity of light below the threshold frequency could release an electron, regardless matter how much kinetic energy the expelled electron had. The photon idea remained disputed until Arthur Compton conducted a series of tests from 1922 to 1924 proving the momentum of light, despite corroboration by several experimental data.¹²⁴ Classically, momentum and discrete (quantized) energy are both characteristics of particles.

There are several more instances where photons exhibit particle-like characteristics, such as in laser cooling, where the momentum is used to slow down (cool) atoms, and solar sails, where sunlight might power a spacecraft.¹²⁵ These represent a distinct facet of the duality between waves and particles. Energy is transferred in "quanta," or fixed packets, like the photons that make up light. This idea underlies quantum mechanics and explains phenomena like atomic spectra. It was first proposed by Max Planck to explain

blackbody radiation and was subsequently applied to atomic structure by researchers like Niels Bohr.¹²⁶ Figure 1 below displays graphs of blackbody radiation from an ideal radiator at three different radiator temperatures. The peak of the spectrum moves toward the visible and ultraviolet portions of the spectrum, and the intensity or rate of radiation emission rises sharply with temperature. Classical physics is unable to explain the spectrum's form.¹²⁷ The theory that atoms and molecules in a body function as oscillators to absorb and release radiation was used by the German physicist Max Planck (1858–1947).¹²⁸ To accurately represent the blackbody spectrum's form, the oscillating atoms' and molecules' energies have to be quantized. Planck concluded that $E=(n+1/2) hf$ gives the energy of an oscillator with frequency f .

Where n may be any nonnegative number between 0 and 3. Additionally, h represents Planck's constant, which is 6.626×10^{-34} J·s. According to this equation, the energy of an oscillator with frequency f (emitting and absorbing electromagnetic radiation of frequency f) may only rise or decrease in discrete steps of size $\Delta E = hf$. Additionally, the Planck's constant, h , is a very tiny value. For instance, the difference in energy levels for a blackbody emitting an infrared frequency of 1014 Hz is merely $\Delta E = hf = (6.63 \times 10^{-34} \text{ J·s}) \times (1014 \text{ Hz}) = 6.626 \times 10^{-20} \text{ J}$, or around 0.4 eV. Compared to usual atomic energies, which are on the order of an electron volt, or thermal energies, this 0.4 eV energy is considerable. Once again, they are usually fractions of an electron volt. However, energies are usually measured in joules on a macroscopic or classical scale. The quantum steps are too tiny to be perceptible, even if macroscopic energies are quantized. An illustration of the correspondence principle is this. QM yields answers that are identical to those of classical physics for a huge object. parallels of this quantization of energy phenomenon at the macroscopic level. This is comparable to a pendulum that can swing with just certain amplitudes but has a distinctive oscillation frequency. Additionally, quantization of energy is similar to a standing wave on a string that only permits certain harmonics represented by numbers.¹²⁹ Instead of being able to go up and down a continuous slope, it is comparable to

¹²⁰ Whittaker, E. T. (1910). *A History of the Theories of Aether and Electricity: From the Age of Descartes to the Close of the Nineteenth Century*. Longman, Green and Co, accessed on 17 Dec 2025

¹²¹ Wheaton, Bruce R. (1978). "Philipp Lenard and the Photoelectric Effect, 1889-1911". *Historical Studies in the Physical Sciences*. 9: 299–322. doi:10.2307/27757381, accessed on 17 Dec 2025

¹²² Hawking, Stephen (November 6, 2001) [November 5, 2001]. "The Universe in a Nutshell". *Physics Today*. 55 (4). Impey, C.D. Bantam Spectra (published April 2002): 80~. doi:10.1063/1.1480788. ISBN 978-0553802023, accessed on 17 Dec 2025

¹²³ Einstein, Albert (1905). "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt". *Annalen der Physik*. 17 (6): 132–48, doi:10.1002/andp.19053220607, accessed on 17 Dec 2025

¹²⁴ Whittaker, Edmund T. (1989). *A history of the theories of aether & electricity*. 2: The modern theories, 1900 -

1926 (Repr ed.). New York: Dover Publ. ISBN 978-0-486-26126-3, accessed on 17 Dec 2025

¹²⁵ Hänsch, T. W.; Schawlow, A. L. (January 1975). "Cooling of gases by laser radiation". *Optics Communications*. 13 (1): 68–69. Bibcode:1975OptCo..13..68H. doi:10.1016/0030-4018(75)90159-5, accessed on 22 Dec 2025

¹²⁶ Landsberg, P. T. (1990). *Thermodynamics and statistical mechanics* (Reprint ed.). Courier Dover Publications. ISBN 0-486-66493-7, accessed on 22 Dec 2025

¹²⁷ Arianrhod, Robyn (2012). *Seduced by Logic: Émilie Du Châtelet, Mary Somerville and the Newtonian Revolution*. New York: Oxford University Press. p. 232. ISBN 978-0-19-993161-3, accessed on 17 Dec 2025

¹²⁸ Weir, Jane (2009). *Max Planck: Revolutionary Physicist*. Capstone. ISBN 978-0-7565-4073-9, accessed on 22 Dec 2025

¹²⁹ PhET Interactive, Simulations. available at: University of Colorado Boulder. Located at: <http://phet.colorado.edu>, accessed on 20 Sep 2025

taking individual stair steps to climb and descend a hill. As we go step by step, our potential energy takes on distinct values.

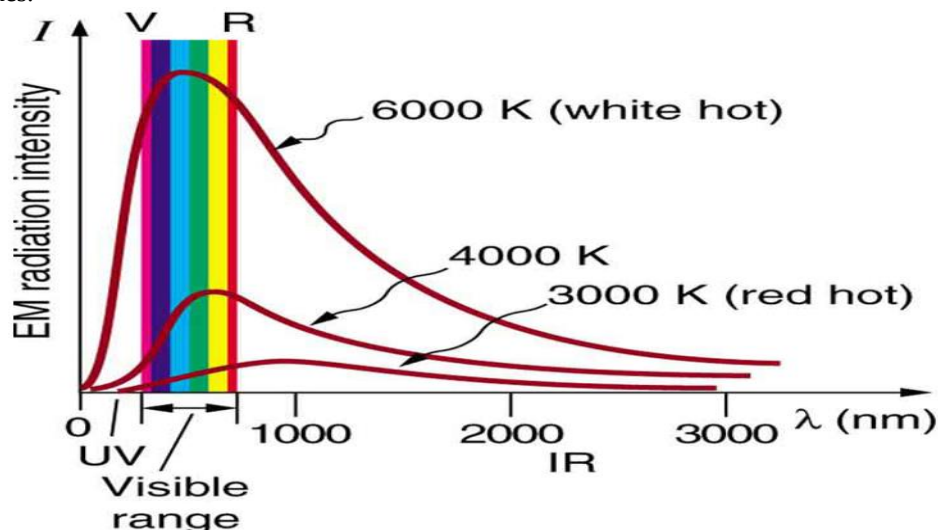
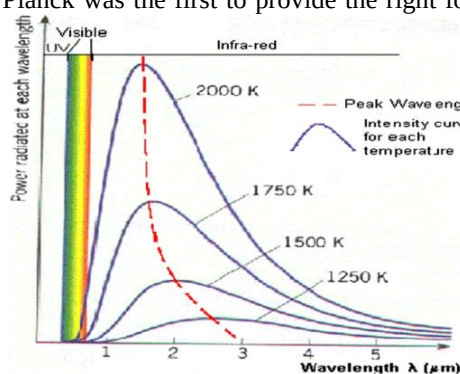


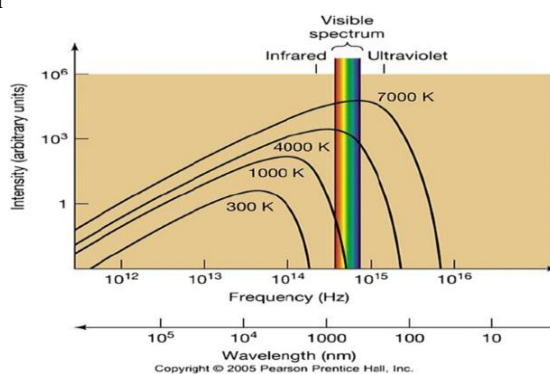
Figure 1: Graphs of blackbody radiation at three different radiator temperatures from an ideal radiator.¹³⁰

The empirically known form of the blackbody spectrum was accurately described by Planck using the quantization of oscillators. He was awarded the 1918 Nobel Prize in Physics for this first proof that energy may sometimes be quantized on a small scale. Despite being founded on observations of a macroscopic item, Planck's hypothesis is analyzed using atoms and molecules. Planck himself was hesitant to embrace his own theory that energy levels are not continuous since it represented such a radical break from traditional physics. Einstein's explanation of the photoelectric phenomenon (covered in the following section) advanced energy quantization and significantly increased the widespread acceptance of Planck's energy quantization. Planck actively participated in the creation of relativity and early QM. Planck was the first to provide the right formula

for relativistic momentum, $p = \gamma mu$, in 1906. He swiftly accepted Einstein's special relativity, which was published in 1905. As is well known, gases emit and absorb electromagnetic radiation. The most well-known example of a gaseous entity that emits visible light in its electromagnetic spectrum is the Sun. Examples of this include neon signs and candle flames. These investigations of hot gas emissions started almost 200 years ago, and it was quickly discovered that these emission spectra held a wealth of information. It is possible to identify the kind of gas and its temperature. These electromagnetic emissions are now caused by electrons in individual atoms and molecules changing their energy levels. They also characterize it as atomic spectra, which are still a crucial analytical tool today.¹³¹



(a)



(b)

Figure 2: Conceptions of quantum phenomena¹³²

Understanding the fundamental ideas and developing applications that characterize quantum boundaries is crucial as we stand in the front of this quantum revolution. This scholar delves into the mysterious

world of QM, clarifying its core ideas like as decoherence, entanglement, and superposition.¹³³ It traverses the wave of the future via a multidisciplinary lens, re-

¹³⁰ <https://courses.lumenlearning.com/suny-physics/chapter/29-1-quantization-of-energy/>, accessed on 17 Dec 2025

¹³¹ College Physics. Authored by: OpenStax College, available at: http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a/College_Physics, accessed on 17 Sep 2025

¹³² Abhang, R. Y. (2005). Making introductory quantum physics understandable and interesting. *Resonance Journal of Science Education*, 10, 63–73, accessed on 17 Dec 2025

¹³³ https://www.researchgate.net/publication/380949628_Quantum_frontiers_navigating_the_wave_of_the_future, accessed on 17 Dec 2025

vealing the revolutionary possibilities of quantum frontiers as well as the difficulties that lie ahead in using its power for the benefit of humanity. Thus, quantum mechanics (QM) is a theory that describes the behavior of the tiniest objects in our surroundings, ranging from individual atoms to dust particles. Furthermore, quantum technologies—which are based on the ideas of QM—are poised to revolutionize how we communicate, compute, and measure, bringing about innovations that

were previously only found in science fiction. QM, a fundamental theory of physics that explains the physical characteristics at the atomic and subatomic levels, lies at the center of these new technologies. Even though everything in our macroscopic world is made up of quantum particles, the behavior of this tiny world differs significantly from what we see in our daily lives.

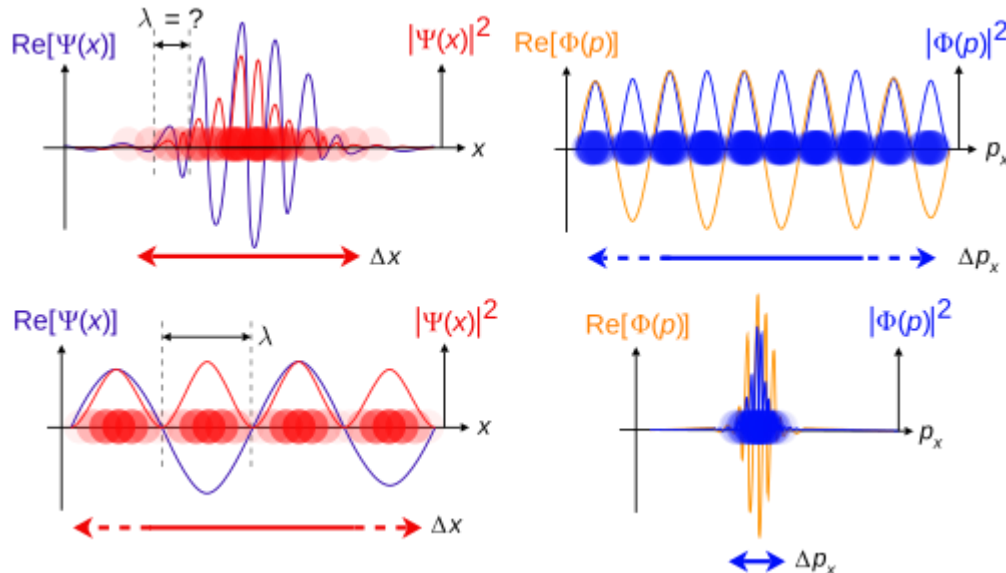


Figure 3. Depicts elements of quantum physics, including uncertainty in particle position and wave-particle duality.¹³⁴

According to QM, basic phenomena such as photons and electrons have characteristics of both waves and particles. A single electron can behave as a particle or a wave. Momentum, energy, and other physical attributes only exist in discrete packets known as quanta; they are not continuous. This suggests that the cosmos has a granular base, with smooth, steady evolution being an illusion at the most basic level. A quantum system exists in every conceivable state at the same time before measurement. A particle may simultaneously have many spins or be in several places. The measuring process "collapses" the wave function into a single, unambiguous result. This implies that observation is essential to the manifestation of reality and that "potentiality" is just as real as actuality at the quantum level. Specific pairings of attributes, like the precise location and momentum of a particle, cannot be known simultaneously with absolute precision. One attribute may be known more accurately than the other. This suggests that the cosmos is inherently fuzzy or indeterminate, not a limitation of our measuring instruments but a fundamental feature of reality itself. Two or more quantum particles can become intrinsically linked, sharing a unified existence regardless of the distance separating them. At a speed greater than the speed of light, measuring one instantly affects the other's condition. This "spooky activity at a distance" (as Einstein put it) sug-

gests a deep, interwoven fabric to the cosmos and undermines the traditional understanding of a distinct, local reality.

The collapse of the wave function has led to various interpretations of quantum physics (e.g., the Copenhagen interpretation and the Many-Worlds interpretation). Some interpretations imply that consciousness or the act of observation is necessary to resolve potentiality into reality. Others suggest that the interaction with any macroscopic environment causes the collapse (decoherence). Regardless, the boundary between the "observed system" and the "observer" becomes blurred. This suggests that "reality" isn't a fixed property but depends on how it's observed or interacts with its environment. Quantum physics fundamentally challenges classical notions of reality, offering a view of the universe based on probabilities, non-locality, and the profound role of observation. We can use the QM concept to understand the truth of the universe. This is an analytical study to understand the truth of the universe in the eyes of QM by using QM concepts, and to evaluate the purpose and beneficial applications in technology and the development of contemporary civilization. The authors will try to investigate and narrate the scientific story of universe on the basis of quantum physics and also try to discover its influences on technological development in future. This paper highlights the historical de-

¹³⁴ Heisenberg, W. (1927) [1927-03-01]. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik". Zeitschrift für Physik (in German). 43 (3): 172–

198, doi:10.1007/BF01397280. ISSN 0044-3328, accessed on 17 Dec 2025

velopment, technological impact, and broader interpretative significance of quantum physics within modern civilization and narrative of universe.

3. Chronology of Evolution of Quantum Physics and Relevant Hypotheses

Planck's Quantum Hypothesis (1900).

In 1900, Max Planck introduced a revolutionary idea while addressing the problem of blackbody radiation—the distribution of energy emitted by a perfect heat source. Classical physics predicted that energy at higher frequencies would diverge to infinity, a contradiction known as the “ultraviolet catastrophe.” Planck suggested that energy is released and absorbed in discrete packets, which he named quanta, to address this.¹³⁵ He introduced a fundamental constant, later called Planck's constant, linking the energy of each quantum to the frequency of radiation.¹³⁶ This bold departure from classical theory marked the birth of quantum physics.

Einstein and the Photoelectric Effect (1905).

Albert Einstein expanded on Planck's discovery by applying the idea of quantization to light. He claimed that light itself is made up of discrete energy packets, subsequently referred to as photons, in order to explain the photoelectric effect.¹³⁷ When light strikes a metal surface, electrons are ejected only if the light's frequency exceeds a threshold value—something classical wave theory failed to explain. Einstein's photon theory not only matched experimental evidence but also provided the first clear demonstration of light's particle-like behavior, laying the groundwork for the principle of wave-particle duality.

Bohr's Atomic Model (1913).

In 1913, Niels Bohr applied quantum concepts to the structure of the atom. Observations of hydrogen's spectral lines revealed discrete frequencies of emitted light that classical models could not explain. According to Bohr's theory, electrons can move between distinct, quantized orbits around the nucleus by either absorbing or emitting photons of varying energies.¹³⁸ While his model combined classical and quantum ideas, it successfully explained hydrogen's spectrum and introduced the concept of quantized atomic structure.

The Copenhagen Interpretation (1920s).

The 1920s witnessed the rise of the Copenhagen Interpretation, chiefly developed by Niels Bohr and Werner Heisenberg. This interpretation suggested that quantum systems exist in superpositions of states until observed, at which point the wavefunction collapses into a definite outcome.¹³⁹ It emphasized the observer's

central role. It introduced profound questions about the nature of reality, the boundary between the quantum and classical worlds, and whether physical properties exist independently of measurement.

De Broglie's Matter Waves (1924). In 1924, Louis de Broglie proposed that particles such as electrons behave like waves, thereby extending wave-particle duality to matter. He derived a relation between a particle's momentum and its associated wavelength. This radical idea was soon confirmed by electron diffraction experiments, in which electrons produced interference patterns similar to those of light waves.¹⁴⁰ De Broglie's insight unified the concepts of waves and particles, suggesting that all matter has a dual nature.

Heisenberg's Matrix Mechanics (1925).

In 1925, Werner Heisenberg developed matrix mechanics, the first comprehensive formulation of quantum mechanics. Rejecting the notion of particles following definite paths, he represented physical quantities such as position and momentum as matrices that describe transitions and probabilities between states.¹⁴¹ Though abstract and mathematically demanding, this framework provided accurate predictions without relying on classical visualization.

Schrödinger's Wave Mechanics (1926).

To explain how quantum states change over time, Erwin Schrödinger developed wave mechanics in 1926 and formulated the Schrödinger equation. In his view, particles were not points moving through space but waves of probability, represented by a *wavefunction*. The likelihood of finding a particle in a given location was determined by the square of the wavefunction's amplitude.¹⁴² Schrödinger's approach provided a more intuitive picture of quantum systems and was later shown to be mathematically equivalent to Heisenberg's matrix mechanics.

Born's Probability Interpretation (1926).

Max Born added a crucial conceptual breakthrough by interpreting the wavefunction as a *probability amplitude*. He proposed that the square of the wavefunction gives the probability density of locating a particle at a particular position. This interpretation introduced inherent randomness into physics, shifting the view of nature from deterministic to probabilistic, and firmly established probability as the core of quantum theory.¹⁴³

Heisenberg's Uncertainty Principle (1927).

Heisenberg presented his Uncertainty Principle in 1927. It asserts that certain combinations of attributes, like momentum and position, cannot be measured with

¹³⁵ Planck, M. (1900). On the Theory of the Law of Energy Distribution in the Normal Spectrum. *Annalen der Physik*, 1, 553-563, accessed on 4 Jan 2026

¹³⁶ Bohr, N. (1913). On the Constitution of Atoms and Molecules. *Philosophical Magazine*, 26, 473-485, accessed on 4 Jan 2026

¹³⁷ Einstein, A. (1905). On a Heuristic Point of View Concerning the Production and Transformation of Light. *Annalen der Physik*, 17, 132-148,

¹³⁸ Bohr, N. (1928). The Quantum Postulate and the Recent Development of Atomic Theory. *Nature*, 121, 580-584, accessed on 4 Jan 2026

¹³⁹ De Broglie, L. (1926). The Wave Theory of Light, Electrons, and Matter. *Annales de Physique*, 10, 347-414,

¹⁴⁰ De Broglie, L. (1928). The Wave Theory of Light: A Treatise on the Theory of Light. Longmans, Green and Co, accessed on 27 Dec 2025

¹⁴¹ Herbert S. Green (1965). *Matrix mechanics* (P. Noordhoff Ltd, Groningen, Netherlands) ASIN : B0006BMIP8, accessed on 27 Dec 2025

¹⁴² Schrödinger, E. (1935). Die gegenwärtige Situation in der Quantenmechanik. *Die Naturwissenschaften*, 23, 807-812, accessed on 17 Dec 2025

¹⁴³ Mermin, N. David (1993-07-01). "Hidden variables and the two theorems of John Bell", *Reviews of Modern Physics*. 65 (3): 803–815, doi:10.1103/RevModPhys.65.803, accessed on 29 Dec 2025

infinite accuracy. It is harder to discern the other the more precisely one is known.¹⁴⁴ This was not a flaw in measurement but a fundamental feature of nature, highlighting intrinsic limits of knowledge in the quantum realm and challenging the deterministic outlook of classical physics.

Dirac's Relativistic Quantum Theory (1928).

Paul Dirac advanced quantum theory by integrating it with special relativity. His *Dirac Equation* described the behavior of electrons moving at relativistic speeds and predicted the existence of antimatter—the positron—later confirmed experimentally.¹⁴⁵ Dirac's theory reinforced the predictive power of quantum mechanics and laid the foundation for quantum field theory, which describes particles and forces within a unified framework.

The EPR Paradox (1935).

Despite these advances, Albert Einstein remained skeptical of quantum mechanics' probabilistic nature. In 1935, Einstein, Boris Podolsky, and Nathan Rosen proposed the EPR paradox, arguing that the theory was incomplete. They highlighted the puzzling phenomenon of entanglement, in which two particles appear to influence each other instantaneously across distance, a phenomenon Einstein famously dismissed as "spooky action at a distance." The paradox questioned whether hidden variables might exist to restore determinism.¹⁴⁶

Quantum Electrodynamics (QED) (1940s–50s).

In the mid-20th century, Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga developed *Quantum Electrodynamics* (QED), the quantum theory of electromagnetic interactions. QED provided exact predictions of how light and matter interact and introduced innovative tools, such as Feynman diagrams, to simplify complex calculations.¹⁴⁷ It became the first entirely consistent quantum field theory and earned its creators the Nobel Prize, setting the stage for later advances in particle physics.

Bell's Theorem and Experimental Tests (1964).

John Bell addressed the EPR paradox in 1964 by formulating *Bell's Theorem*, which established testable inequalities distinguishing quantum mechanics from hidden-variable theories. Experiments in the following decades, particularly Alain Aspect's work in the 1980s, confirmed violations of these inequalities, thereby validating quantum entanglement and ruling out local hidden variables.¹⁴⁸ These results demonstrated the fundamentally nonlocal nature of quantum reality.

The Standard Model and Quantum Field Theories (1970s).

The Standard Model of particle physics was developed from quantum field theory in the 1970s. This paradigm, based on electroweak theory and quantum chromodynamics, unified quantum electrodynamics, the weak nuclear force, and the strong nuclear force (QCD). Except for gravity, all known fundamental particles and their interactions are described by the Standard Model, which remains one of the most successful scientific theories.¹⁴⁹ The search for a theory that unites quantum mechanics with general relativity, often referred to as quantum gravity, continues to drive modern physics. Bohr and Heisenberg developed many of the foundational ideas of QM in Copenhagen during the 1920s. They derived a wave function that describes the probabilistic nature of a wave-particle. And, Heisenberg's uncertainty principle further added that if a particle-wave's location is measured, it's meaningless to speak of its momentum and vice versa. Most importantly, this was the first time the measurement paradox was introduced, whereby a measurement causes the wave function to collapse, and which begs the question of what is allowed to make a measurement? A human? A cat? A machine? An ant?¹⁵⁰ Max Born, Neumann, and several other physicists helped support and formalize the Copenhagen interpretation. But it was very loosely defined between the 1920s and 1950s until Heisenberg published his book. A fun fact about Heisenberg is that he was the youngest tenured professor at the time. He was afraid Schrödinger was going to outpace, because of how neck-and-neck both of them were.

The great scientist Albert Einstein was a fantastic character. In addition to his contributions to relativity and Quantum Mechanics, he also wrote about Brownian motion, the photoelectric effect, and much more. This is simply Amazing! Einstein discovered the existence of photons 20 years before anyone else believed him. In 1935, Einstein, Podolsky, and Rosen showed that "spooky action at a distance" (now known as Quantum Entanglement) proved that the Copenhagen Interpretation is incomplete. David Bohm made various contributions to physics and mathematics, but his most famous is the pilot-wave theory, also known as Bohmian mechanics.¹⁵¹ This was the first example of the hidden variable theory. By introducing nonlocality, his theory solves the problems of wave-particle duality, wave function collapse, and Schrödinger's cat. In this theory, each particle "lives" on a pilot wave, which introduces deterministic behavior to Quantum Mechanics. I haven't had time to delve into the details of how this really works. Unfortunately, most of Bohm's work

¹⁴⁴ Shor, P. W. (1994). Algorithms for Quantum Computation: Discrete Logarithms and Factoring. Proceedings of the 35th Annual Symposium on Foundations of Computer Science, 124-134, accessed on 29 Dec 2025

¹⁴⁵ Zichichi Antonino, (2 March 2000), "Dirac, Einstein and physics". *Physics World*, accessed on 29 Dec 2025

¹⁴⁶ Peres Asher, (2002), *Quantum Theory: Concepts and Methods*. Kluwer. p. 149-152, accessed on 05 Jan 2026

¹⁴⁷ Lamb Willis, Retherford Robert, (1947), "Fine Structure of the Hydrogen Atom by a Microwave Method". *Physical Review*, 72 (3): 241–43, doi:10.1103/PhysRev.72.241, accessed on 05 Jan 2026

¹⁴⁸ Nielsen Michael A., Chuang Isaac L. (2010), *Quantum Computation and Quantum Information* (2nd ed.). Cambridge: Cambridge University Press, ISBN 978-1-107-00217-3, accessed on 05 Jan 2026

¹⁴⁹ Bailly, C., & Finkelstein, N. D. (2010). Teaching and understanding of quantum interpretations in modern physics courses. *Physical Review Special Topics-Physics Education Research*, 6, 010101, accessed on 17 Dec 2025

¹⁵⁰ <https://hachette.imgix.net/books/9781473661363.jpg?auto=compress&w=440>, accessed on 04 Jan 2026

¹⁵¹ <https://ui.adsabs.harvard.edu/abs/2019eurs.book.S/abstract>, accessed on 4 Jan 2026

was rejected throughout his life. He challenges the status quo, and paid the price... Due to his Marxist activities, he was exiled several times. He lived in America, Brazil, and Britain at various points through his life. This made it difficult for him to present and promote his work, which most Copenhagen Interpretation supporters had already shut down.¹⁵²

John Stewart Bell is famously known for iterating on the work of the famous EPR paper, as well as finding a mistake in one of Von Neumann's proofs. Bell's theorem proved the nonlocal nature of Quantum Physics, thereby proving the incompleteness of the Copenhagen Interpretation. This further supports the concept of "spooky action at a distance". Bell knew that his ideas were not widely accepted and he always looked out for other physicists. On several occasions, he would ask other physicist if they were tenured before they start researching his work so as not to risk tenure-ship in the future. In 1957, Hugh Everett proposed an alternative to the Copenhagen interpretation, known as the many-worlds interpretation. Many science fiction films have adopted this idea, implying that there is an infinite number of Universes covering all possible outcomes. This resolves Schrödinger's cat paradox by positing two Universes: one in which the cat lives and another in which the cat dies. A couple of decades after Everett published his work, DeWitt published his work on quantum decoherence. Rather than having wave functions collapse, the wave function of a particle "merges" with its outer world. This, in a way, supports the many-worlds interpretation. Everett's work was met with widespread skepticism, and he never returned to academia after completing his PhD. Instead, he started a company that consulted with the US government on war strategies, making him quite wealthy.

4. The Quantum Theory and Conceptual Framework

The light bulb as a gateway to quantum theory.

In the 1890s, Edison's invention of the light bulb attracted widespread attention, with engineering firms investing millions to secure European patents. Entrepreneurs envisioned immense profits from illuminating the streets of the German Empire, but the invention's significance extended far beyond commerce. While it was understood that the filament glowed when heated by electricity, the precise mechanism of light emission remained a mystery. This puzzle led scientists to confront the limitations of classical physics. Investigations revealed that heated filaments emitted specific colors at different temperatures, a phenomenon classical theory could not explain.¹⁵³ In 1900, Max Planck introduced the revolutionary idea that energy is quantized, existing in discrete packets rather than continuous waves. This paradigm shift marked the birth of quantum mechanics.

What began as a practical innovation in lighting ultimately ignited a scientific revolution, reshaping our understanding of nature and laying the foundation for modern physics.

Wave-particle duality is a cornerstone of quantum mechanics.

In 1905, Albert Einstein revolutionized physics with his explanation of the photoelectric effect, challenging the prevailing belief that light was purely a wave. He proposed that light could also be understood as a stream of discrete energy packets, later known as quanta. Each quantum carried a specific amount of energy, a concept that seemed radical and challenging to accept at the time. Einstein's idea not only clarified the photoelectric effect but also laid the groundwork for a deeper understanding of light's dual wave-particle nature. Building on this, Louis de Broglie extended the principle of duality to matter, suggesting that particles also exhibit wave-like properties.¹⁵⁴ This breakthrough forced physicists to reconsider classical divisions, revealing a profound interconnection between matter and energy and establishing a cornerstone of quantum theory.

Atomic structure and quantum stability.

Rutherford's discovery of the nucleus overturned the notion of a uniform atom but left unanswered why electrons remained stable. Niels Bohr resolved this by proposing quantized orbits with discrete energy levels. His model explained atomic spectra and successfully merged experimental findings with emerging quantum principles, transforming nuclear physics.¹⁵⁵ The Davisson-Germer experiment confirmed de Broglie's hypothesis by showing electron diffraction patterns, proving particles can behave like waves. This groundbreaking result established the probabilistic nature of quantum mechanics and laid the foundation for the wavefunction, reshaping our understanding of matter.

Observer-dependent reality and quantum uncertainty.

The Copenhagen interpretation reshaped physics by presenting reality as probabilistic and observer-dependent, with wavefunctions collapsing upon measurement. Heisenberg's uncertainty principle further revealed fundamental limits to knowledge, demonstrating that at quantum scales reality is not predetermined but influenced by observation, challenging classical determinism. Building on this, Paul Dirac's relativistic equation unified quantum mechanics with special relativity, predicting antimatter long before its discovery. This breakthrough highlighted the predictive power of mathematics and expanded our understanding of cosmic symmetry, raising questions about the matter-antimatter imbalance in the universe. Later, John Bell's inequalities distinguished quantum theory from hidden-

¹⁵² <https://pegasusbookstore.com/event/2018-03-22/adam-becker-discusses-what-real-unfinished-quest-meaning-quantum-physics>, accessed on 4 Jan 2026

¹⁵³ Didiş, N., Eryilmaz, A., & Erkoç, S. (2014). Investigating students' mental models about the quantization of light, energy, and angular momentum. *Physical Review—Special Topics Physics Education Research*, 10, 020127, accessed on 17 Dec 2025

¹⁵⁴ Pauli, W. (1927). Über die Quantentheorie der Elektronen in Kristallen und ihre Anwendung auf die Eigenschaften von Festkörpern. *Zeitschrift für Physik*, 36, 765-783, accessed on 17 Dec 2025

¹⁵⁵ <https://www.sciencedirect.com/science/article/pii/S0303264725000772>, accessed on 17 Dec 2025

variable alternatives. Experimental violations confirmed nonlocal entanglement, revealing that nature permits instantaneous correlations across distances and compelling physicists to abandon classical assumptions of locality and fixed reality.

5. Quantum Theory: From Fundamental Forces to Transformative Technology

Quantum field theory advanced physics by describing particles as excitations of underlying fields, integrating quantum mechanics with special relativity, and providing a framework for all fundamental forces except gravity. It illuminated the dynamic creation and annihilation of particles, deepening our understanding of the universe's structure and guiding efforts toward a unified theory. Building on principles such as superposition and entanglement, quantum computing demonstrates how foundational theory can drive transformative technology. Yet philosophical reflections, such as those of Roger Penrose, caution that the ultimate nature of quantum reality may remain elusive.¹⁵⁶ The ongoing debate considers whether quantum mechanics represents a final theory or a stepping stone toward deeper laws that may involve gravity and consciousness, highlighting scientific inquiry as a continuous, evolving journey.

Photoelectric Effect and Quantum Electrodynamics.

The Photoelectric Effect: A Challenge to Classical Physics.

At the turn of the 20th century, Max Planck initiated a revolutionary shift in physics while addressing the ultraviolet catastrophe. He discovered a precise relationship between the frequency of light and its energy, a mathematical connection that hinted at the particle-like nature of light. However, Planck himself did not fully grasp its profound implications. Meanwhile, scientists exploring radio waves sought to understand their transmission, often using spark-gap apparatuses that generated electric discharges between metal spheres. Unexpectedly, they observed that shining an intense light on the spheres made sparks easier to produce, suggesting a mysterious link between light and electricity. To investigate further, researchers developed the gold leaf electroscope, a sensitive device with two thin gold leaves attached to a metal rod. When negatively charged, the leaves repelled each other. Experiments with this apparatus revealed a striking phenomenon.¹⁵⁷ Red light, regardless of brightness, did not affect the separation of the leaves, indicating insufficient energy to influence electrons. In contrast, blue or ultraviolet light caused the leaves to collapse immediately, showing that high-frequency light could release electrons from the metal surface.

This discovery, known as the photoelectric effect, demonstrated that light's energy depends not only on intensity but also on frequency. Low-frequency red light lacked sufficient energy to mobilize electrons, whereas higher-frequency blue and ultraviolet light could. The effect provided critical evidence that light exhibits both wave-like and particle-like properties,

carrying discrete energy packets called quanta. The photoelectric effect thus laid the foundation for quantum mechanics, challenging classical physics and revealing that energy is quantized at microscopic scales. By linking light's frequency to its energy and demonstrating particle-like behavior, this phenomenon transformed our understanding of electromagnetic radiation. It set the stage for a new era in theoretical and experimental physics, ultimately reshaping our view of the universe's fundamental workings.

Planck, Blackbody Radiation, and the Ultraviolet Catastrophe.

The question of why a heated filament changes color puzzled scientists at the turn of the 20th century. A metal rod, when gradually heated, glows red at first, then shifts to orange and yellow as its temperature rises, but never emits blue light. To investigate this phenomenon, Max Planck and his colleagues developed the blackbody radiator, a specialized furnace designed to measure light frequencies emitted at controlled temperatures. Experiments revealed that at 841°C, the furnace glows orange-red, while at around 2000°C, it emits bright whitish light. Even so, blue and ultraviolet components remain weak, highlighting the difficulty of producing high-frequency light. This observation contradicted classical physics, which predicted that objects at high temperatures should emit an infinite amount of high-energy light, particularly in the ultraviolet. In reality, even the sun, with a surface temperature of 5,500°C, emits primarily white light and very little ultraviolet radiation. This glaring discrepancy, later termed the ultraviolet catastrophe, exposed a fundamental failure of classical theory and demanded a new approach. Planck's work on blackbody radiation ultimately led to the revolutionary concept that energy is quantized, introducing discrete energy packets linked to light frequency. This breakthrough not only resolved the ultraviolet catastrophe but also laid the foundation for quantum mechanics, reshaping our understanding of light, heat, and the behavior of matter at microscopic scales.

The Double-Slit Experiment and Wave-Particle Duality.

The Davisson-Germer experiment excited the physics community by confirming de Broglie's hypothesis that electrons exhibit wave-like behavior. Around the same time, the double-slit experiment further demonstrated this wave-particle duality. When electrons passed through two slits, they produced interference patterns similar to light. Remarkably, even sending electrons one at a time resulted in cumulative interference patterns, indicating that each electron's wavefunction traveled through both slits and interfered with itself. These experiments provided compelling evidence that particles like electrons can behave simultaneously as particles and waves, fundamentally challenging classical notions and laying a cornerstone for quantum mechanics.

Quantum Electrodynamics: Uniting Electrons and Light.

¹⁵⁶D. Chalmers, (1995), Facing up to the problem of consciousness, *Journal of Consciousness Studies*, 2 (3) (1995), pp. 200-219, accessed on 17 Dec 2025

¹⁵⁷<https://www.scientificamerican.com/article/physicists-divided-on-what-quantum-mechanics-says-about-reality/>, accessed on 17 Dec 2025

In the 1940s, Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga revolutionized physics with quantum electrodynamics (QED). This theory describes the electromagnetic force governing interactions between light and electrons at the quantum level. Classical electromagnetism failed to explain these subatomic behaviors, necessitating a new framework. QED successfully integrated quantum mechanics with electromagnetic theory, providing precise predictions and deep insights into the behavior of particles and light, marking a significant milestone in modern physics.

Quantum Electrodynamics: Mapping the Dance of Light and Matter.

Quantum electrodynamics (QED) revealed the intricate interactions between electrons and photons, showing that light and matter are connected through profound symmetry and harmony. Richard Feynman revolutionized the field with Feynman diagrams, a visual tool that represents how electrons and photons are created and annihilated and how they exchange energy. These diagrams transformed complex quantum calculations into intuitive maps, enhancing understanding of the subatomic world. QED made exact predictions, such as the electron's magnetic moment and its interactions with photons, demonstrating remarkable agreement between theory and experiment. This precision established QED as one of the most accurate and successful theories in physics. Beyond explaining electromagnetic interactions, QED laid the groundwork for understanding the strong and weak nuclear forces. Its success ultimately contributed to the development of the Standard Model, the foundational framework describing the fundamental particles and forces of the universe, cementing QED's role as a cornerstone of modern particle physics.

6. Quantum Mechanics Theoretical Approach The Limits of Classical Light Theory.

For early 20th-century physicists, the ultraviolet catastrophe and the photoelectric effect presented unsolvable mysteries. At the time, light was firmly understood as a wave. Everyday observations seemed to confirm this: diffraction caused the blur at shadow edges, and rainbows formed as sunlight refracted and reflected through water droplets, separating into vivid colors.¹⁵⁸ These phenomena, easily explained by wave behavior, reinforced the wave theory of light. Yet despite its elegance in describing visible effects, the wave theory faltered when confronted with high-energy phenomena. The ultraviolet catastrophe predicted infinite energy emission at high frequencies, clearly contradicting experimental results. Similarly, the photoelectric effect showed that light could eject electrons from a metal surface in ways

that were unexplained by classical wave theory. These inconsistencies exposed the limits of conventional understanding. While light's wave nature explained the observable world, it failed to account for behavior at microscopic and high-frequency scales.¹⁵⁹ The ultraviolet catastrophe and the photoelectric effect, therefore, served as critical clues, signaling the need for a new framework—one that would eventually lead to the birth of quantum mechanics.

Heisenberg and the Birth of Matrix Mechanics.

Classical physics, relying on differential equations and continuous functions, struggled to describe phenomena at the subatomic level. Werner Heisenberg revolutionized this understanding by introducing matrices to represent physical quantities and their interactions. These matrices encoded transitions between energy levels and probability amplitudes, allowing Heisenberg to formulate a theory based entirely on observable phenomena.¹⁶⁰ This approach replaced the deterministic framework of classical physics with a probabilistic, statistical understanding, focusing on likelihoods rather than precise positions or velocities. In Heisenberg's model, an electron's behavior was described through probabilities instead of fixed orbits, marking a radical departure from traditional concepts. Collaborating with Max Born and Pascual Jordan, he developed a robust mathematical foundation for matrix mechanics, establishing the core principles of quantum mechanics.¹⁶¹ This theory accurately predicted atomic spectra and aligned closely with experimental observations, demonstrating its effectiveness. Matrix mechanics transformed the comprehension of the subatomic world, making its uncertain and probabilistic nature intelligible.¹⁶² The deterministic vision of the universe gave way to a reality governed by probabilities and uncertainties, reshaping our fundamental understanding of matter and energy at microscopic scales.

Schrödinger and the Development of Wave Mechanics.

While Heisenberg's matrix mechanics provided a robust mathematical framework for quantum phenomena, its abstract nature made it unintuitive for many physicists. Seeking a more visual and wave-based understanding of the quantum world, Austrian physicist Erwin Schrödinger developed wave mechanics in 1926. Schrödinger proposed that particles, such as electrons, do not exist solely at a single point but spread across space like real waves. This perspective allowed the behavior of subatomic particles to be described by the wave function, a mathematical construct representing their spatial distribution and time evolution.¹⁶³ Unlike purely probabilistic interpretations, Schrödinger's

¹⁵⁸ Arute, Frank; Arya, Kunal; Babbush, Ryan; Bacon, Dave; Bardin, Joseph C.; Barends, Rami; Biswas, Rupak; Boixo, Sergio; Brandao, Fernando G. S. L.; Buell, David A.; Burkett, Brian (2019). "Quantum supremacy using a programmable superconducting processor". *Nature*. 574 (7779): 505–510, doi:10.1038/s41586-019-1666-5, accessed on 17 Dec 2025

¹⁵⁹ Georgescu, Iulia (2020). "Trapped ion quantum computing turns 25". *Nature Reviews Physics*. 2 (6): 278, doi:10.1038/s42254-020-0189-1. ISSN 2522-5820, accessed on 17 Dec 2025

¹⁶⁰ <https://www.epsrc.ac.uk/newsevents/pubs/dstl-uk-quantum-technology-landscape-2014/>, accessed on 17 Dec 2025

¹⁶¹ MacQuarrie, Evan R.; Simon, Christoph; Simmons, Stephanie; Maine, Elicia (2020). "The emerging commercial landscape of quantum computing". *Nature Reviews Physics*. 2 (11): 596–598, doi:10.1038/s42254-020-00247-5, accessed on 17 Dec 2025

¹⁶² Dowling, J. P.; Milburn, G. J. (2003). "Quantum Technology: The Second Quantum Revolution". *Phil. Trans. R. Soc. A*. 361 (1809): 1655–1674, doi:10.1098/rsta.2003.1227, accessed on 17 Dec 2025

¹⁶³ Greenspan, Nancy Thorndike (2005). *The End of the Certain World: The Life and Science of Max Born*. New York:

wave function carried physical reality, depicting particles as extended waves rather than isolated points. His approach provided an intuitive, visualizable alternative to matrix mechanics, enriching the understanding of quantum behavior and complementing Heisenberg's formalism.¹⁶⁴ Wave mechanics became a cornerstone of quantum theory, demonstrating the dual wave-particle nature of matter and profoundly shaping modern physics.

Born, Schrödinger, and the Probabilistic Nature of Quantum Mechanics.

In 1926, Max Born proposed a groundbreaking interpretation of the wave function, suggesting it represents a probability amplitude rather than a physical wave. According to Born, the absolute square of the wave function determines the likelihood of finding a particle at a particular location. This concept became a cornerstone of the Copenhagen interpretation, which embraces the inherently probabilistic and observer-dependent nature of quantum mechanics.¹⁶⁵ Erwin Schrödinger, however, strongly opposed this view. He argued that the wave function should depict real physical waves, with particles existing as extended waves in space governed by precise energy and momentum.¹⁶⁶ Schrödinger's deterministic approach aligned more closely with classical intuition, offering a vision of a universe ruled by definite physical laws. Despite its appeal, the Copenhagen interpretation gained wider acceptance, asserting that quantum phenomena cannot be fully predicted and that observation fundamentally influences outcomes, highlighting a deep philosophical divide between determinism and probability in understanding the quantum world.

Schrödinger's Cat and Quantum Paradoxes.

Schrödinger's cat thought experiment highlights the paradoxes of the Copenhagen interpretation. A cat, placed in a superposition of being simultaneously alive and dead, illustrates how applying probabilistic quantum rules to macroscopic objects can lead to seemingly absurd conclusions, questioning the limits of quantum mechanics' probabilistic framework.

The Copenhagen Interpretation: Observation Shapes Reality.

In 1927, Copenhagen became the stage for one of the most profound debates in physics, as Niels Bohr and

Werner Heisenberg sought to unravel the mysteries of the quantum world. Their discussions led to the development of the Copenhagen interpretation, a revolutionary framework that challenged classical notions of definite reality. According to this interpretation, a particle's wave function represents the probabilities of it occupying particular locations or energy levels, rather than a single predetermined state. Particles exist in a superposition of potential states and do not possess definite properties until measured. Observation plays a central role: it causes the wave function to collapse, transforming a particle from a range of possibilities into a specific, observable state. In this view, reality at the quantum level is inherently probabilistic, and the act of observation shapes outcomes.¹⁶⁷ When unobserved, the quantum universe exists as a dynamic field of potentialities, highlighting the fundamental interplay between measurement and reality and fundamentally redefining our understanding of the subatomic world.

Heisenberg, Bohr, and the Dual Nature of Quantum Reality.

A central feature of quantum mechanics is Heisenberg's uncertainty principle, which asserts that a particle's exact position and momentum cannot be simultaneously known with perfect accuracy. The more precisely one property is measured, the greater the uncertainty in the other.¹⁶⁸ This limitation is intrinsic to nature, not a flaw in measurement tools, highlighting the fundamentally probabilistic and indeterministic character of the quantum world.¹⁶⁹ Building on this, Niels Bohr introduced the principle of complementarity to explain the dual behavior of quantum particles. Particles can exhibit both wave and particle characteristics, but these properties cannot be observed simultaneously. Measuring one aspect inevitably obscures the other.¹⁷⁰ For instance, when electrons form interference patterns, their wave-like nature is evident, but their precise positions remain indeterminate.¹⁷¹ Conversely, pinpointing their positions conceals their wave behavior. Bohr argued that both perspectives are essential for a complete understanding of quantum phenomena. Together, the uncertainty principle and complementarity reveal that absolute certainties do not govern quantum reality but emerge from the interplay of complementary

Basic Books. ISBN 978-0-7382-0693-6, accessed on 17 Dec 2025

¹⁶⁴ Zhong, Han-Sen; Wang, Hui; Deng, Yu-Hao; Chen, Ming-Cheng; Peng, Li-Chao; Luo, Yi-Han; Qin, Jian; Wu, Dian; Ding, Xing; Hu, Yi; Hu, Peng (2020). "Quantum computational advantage using photons". *Science*. 370 (6523): 1460–1463, doi:10.1126/science.abe8770. ISSN 0036-8075, accessed on 17 Dec 2025

¹⁶⁵ Born, G. V. R. (May 2002). "The Wide-Ranging Family History of Max Born". *Notes and Records of the Royal Society of London*. 56 (2): 219–262. doi:10.1098/rsnr.2002.0180, accessed on 17 Dec 2025

¹⁶⁶ Thew, Rob; Jennewein, Thomas; Sasaki, Masahide (2019). "Focus on quantum science and technology initiatives around the world". *Quantum Science and Technology*. 5: 010201. doi:10.1088/2058-9565/ab5992, accessed on 17 Dec 2025

¹⁶⁷ Raymer, Michael G.; Monroe, Christopher (2019). "The US National Quantum Initiative". *Quantum Science and*

Technology. 4 (2): 020504, doi:10.1088/2058-9565/ab0441, accessed on 17 Dec 2025

¹⁶⁸ Born, M.; Heisenberg, W.; Jordan, P. (1925). "Zur Quantenmechanik II". *Zeitschrift für Physik*. 35 (557–615): 557, doi:10.1007/BF01379806, accessed on 17 Dec 2025

¹⁶⁹ De Haro, Sebastian (2020). "Science and Philosophy: A Love–Hate Relationship". *Foundations of Science*. 25 (2): 297–314, doi:10.1007/s10699-019-09619-2, accessed on 17 Dec 2025

¹⁷⁰ Rademacher, Markus; Millen, James; Li, Ying Lia (2020-10-01). "Quantum sensing with nanoparticles for gravimetry: when bigger is better". *Advanced Optical Technologies*. 9 (5): 227–239, doi:10.1515/aot-2020-0019, accessed on 17 Dec 2025

¹⁷¹ Heisenberg, W. (1944). "Die beobachtbaren Grössen in der Theorie der Elementarteilchen. III". *Z. Phys.* 123 (1–2): 93–112, doi:10.1007/BF01375146, accessed on 17 Dec 2025

observations, reshaping our understanding of nature at its most fundamental level.¹⁷²

7. The Profound Insight of QM

Einstein and the Birth of Quantum Mechanics.

Einstein proposed that light consists of discrete quanta, or particles, with energy directly proportional to their frequency. Low-frequency red light carries little energy per quantum, while high-frequency ultraviolet light carries significantly more. This insight elegantly explained the photoelectric effect, where only high-frequency light can eject electrons from a metal surface.¹⁷³ It also resolved Planck's dilemma regarding blackbody radiation: ultraviolet light is less abundant because producing its energetic quanta requires far more energy than generating red light quanta. This revolutionary idea marked a profound turning point in physics, demonstrating that classical approaches were insufficient to describe nature at microscopic scales. Einstein's work introduced the concept of light's duality: exhibiting both wave-like and particle-like properties.¹⁷⁴ This paradox challenged intuition but laid the foundation for quantum mechanics, opening a new era of scientific inquiry. Physics, long dominated by deterministic laws, now embraces a probabilistic, counterintuitive understanding of the fundamental behavior of matter and energy.

Rutherford and the Discovery of the Atomic Nucleus.

In 1911, Ernest Rutherford conducted an experiment that revolutionized the understanding of atomic structure. By directing positively charged alpha particles at a thin sheet of gold foil, he tested the prevailing notion that atoms were homogeneous. While most particles passed through the foil, some were unexpectedly deflected, as if striking a dense, impenetrable core. This surprising result revealed that atoms are far more complex than previously thought. Rutherford concluded that at the heart of every atom lies a tiny, extremely dense concentration of positive charge—the nucleus.¹⁷⁵ This discovery not only overturned classical models of the atom but also laid the foundation for modern atomic physics, reshaping scientific understanding of matter and its internal structure.

Bohr's Atomic Model and Quantized Electron Orbits.

In 1913, Niels Bohr sought to solve fundamental questions about atomic structure by integrating the emerging quantum ideas of Planck and Einstein. Planck had proposed that energy is emitted in discrete packets, or quanta, and Einstein applied this concept to explain the photoelectric effect. Building on these insights,

Bohr developed a revolutionary atomic model describing electron behavior. He proposed that electrons do not occupy arbitrary orbits but exist in specific, quantized energy levels, maintaining stability without radiating energy while in these orbits.¹⁷⁶ Electrons could transition between these energy levels by absorbing or emitting precise amounts of energy, providing a theoretical explanation for the discrete lines observed in atomic spectra. Each energy level corresponded to a distinct spectral line, as exemplified by hydrogen, whose electrons produced characteristic spectral emissions. Bohr's model marked a critical innovation in atomic theory, introducing the concept of quantized electron orbits and linking energy transitions to observable spectral phenomena, thereby laying the foundation for modern quantum mechanics and deepening understanding of atomic structure.

De Broglie and the Wave Nature of Matter.

Louis de Broglie proposed a revolutionary idea: matter, like light, could exhibit wave-like behavior. He suggested that the wavelength of a particle could be calculated by dividing Planck's constant by its momentum. This concept, initially applied to electrons, was built on earlier work relating the wavelength of light to its momentum, despite photons having zero rest mass. Einstein's theory of relativity had shown that light, though massless, carries momentum, enabling such calculations. De Broglie extended this principle to all material particles, including electrons, protons, and neutrons, hypothesizing that they too possess a wavelength. While some critics viewed this as merely applying existing equations to matter, de Broglie's insight had profound implications. His hypothesis provided a theoretical foundation for the quantized electron orbits in Bohr's atomic model and explained phenomena that classical physics could not.¹⁷⁷ By introducing the concept of matter waves, de Broglie bridged the gap between particle and wave behavior, laying the groundwork for modern quantum mechanics and offering a deeper understanding of the dual nature of matter.

The EPR Paradox and the Debate over Quantum Reality.

In 1935, Albert Einstein, Nathan Rosen, and Boris Podolsky formulated the Einstein-Podolsky-Rosen (EPR) paradox to challenge the completeness of quantum mechanics. Central to the paradox was quantum entanglement, a phenomenon in which two particles created together remain interconnected, such that measuring one instantly influences the state of the other, regardless of distance. Einstein famously called this

¹⁷² Kemmer, N.; Schlapp, R. (1971). "Max Born 1882–1970". *Biographical Memoirs of Fellows of the Royal Society*. 17: 17–52. doi:10.1098/rsbm.1971.000, accessed on 17 Dec 2025

¹⁷³ Henriksen, E. K., Bungum, B., Angell, C., Tellefsen, C. W., Frågât, T., & Vetleseter Bøe, M. (2014). Relativity, quantum physics and philosophy in the upper secondary curriculum: challenges, opportunities and proposed approaches. *Physics Education*, 49(6), 678–684, accessed on 17 Dec 2025

¹⁷⁴ Fox, Michael F. J.; Zwickl, Benjamin M.; Lewandowski, H. J. (2020). "Preparing for the quantum revolution: What is

the role of higher education?". *Physical Review Physics Education Research*. 16 (2): 020131, doi:10.1103/PhysRevPhysEducRes.16.020131. ISSN N 2469-9896, accessed on 17 Dec 2025

¹⁷⁵ <https://uwaterloo.ca/institute-for-quantum-computing/graduate-studies/programs>,

¹⁷⁶ Pais, Abraham (1991). *Niels Bohr's Times, In Physics, Philosophy and Polity*. Oxford: Clarendon Press. ISBN 978-0-19-852049-8, accessed on 17 Dec 2025

¹⁷⁷ Zhang, Qiang; Xu, Feihu; Li, Li; Liu, Nai-Le; Pan, Jian-Wei (2019). "Quantum information research in China". *Quantum Science and Technology*. 4 (4): 040503, doi:10.1088/2058-9565/ab4bea, accessed on 17 Dec 2025

“spooky action at a distance,” arguing that it conflicted with relativity and violated the principle that nothing can travel faster than light. Einstein proposed that entangled particles must possess definite properties before measurement, illustrating the idea with the analogy of gloves in separate boxes: opening one box reveals the state of the other without altering it. Niels Bohr, in contrast, contended that particle states are only determined upon observation, existing otherwise as probabilities. This debate highlighted a profound philosophical divide: Einstein favored an observer-independent reality, while Bohr embraced a probabilistic, measurement-dependent framework. Although the onset of World War II temporarily shifted focus to urgent human needs, the EPR paradox set the stage for future explorations of entanglement and quantum foundations, influencing both theory and technological innovation.

Dirac's Equation and the Impact of Antimatter.

Dirac's equation revolutionized the understanding of electron behavior, extending beyond its prediction of antimatter. It provided a comprehensive framework for atomic and subatomic processes, naturally explaining electron spin and magnetic moments, which deepened insights into atomic structure and chemical bonding.¹⁷⁸ The concept of antimatter, emerging from Dirac's work, has significant modern applications. In medicine, positron emission tomography (PET) utilizes antimatter by detecting gamma rays produced when positrons interact with electrons, enabling detailed imaging of the human body.¹⁷⁹ Antimatter also plays a crucial role in experimental particle physics, produced in high-energy particle accelerators to probe fundamental properties of matter. Dirac's contributions thus bridge theoretical physics and practical technology, illustrating how abstract quantum concepts can yield transformative scientific and technological advancements.

8. Quantum Field Theory and Technological Approach

Quantum Field Theory: Unifying Particles and Fields.

By the 1930s, physics faced a challenge: while quantum mechanics accurately described subatomic particles and special relativity governed high-speed phenomena, no unified framework existed to combine the two. This gap was addressed through the development of Quantum Field Theory (QFT), which revealed that particles and fields are inseparable. In QFT, particles are viewed as excitations of underlying fields rather than isolated entities. These quantum fields govern processes such as particle creation and annihilation, showing that energy and matter are continuously interacting at the subatomic level. A particle can only

emerge where a field exists, and the quantization of these fields dictates its behavior. This framework provides deep insights into the fundamental forces of nature. For example, the electromagnetic force is mediated by quantized excitations of fields called photons. By extending this approach, physicists could also explain strong and weak nuclear forces, paving the way for the Standard Model. QFT thus established a comprehensive understanding of how particles like electrons, protons, and neutrons interact, reshaping our grasp of the universe's microscopic structure.

Quantum Field Theory and the Dance of Particles.

Quantum Field Theory (QFT) provides a profound understanding of particle creation and annihilation and naturally incorporates the existence of antiparticles predicted by Dirac. In QFT, particle-antiparticle pairs emerge from the quantized excitations of fields, reflecting a deep symmetry between matter and antimatter. This continuous interplay resembles a cosmic dance, where fields govern the birth and death of particles throughout the universe. Beyond theoretical insights, QFT has driven experimental physics. Particle accelerators and colliders were developed to test their predictions, leading to the discovery of fundamental particles such as quarks, gluons, and the carriers of the weak force. These findings revealed the intricate structure of matter and the mechanisms by which particles interact, exchange energy, and transmit information. By connecting theory and experiment, QFT not only reshaped our understanding of the microscopic universe but also provided a framework to explore the fundamental forces and the elegant symmetries governing the cosmos.

Quantum Field Theory: From Subatomic Particles to the Cosmos.

Quantum Field Theory (QFT) has profoundly impacted both microscopic physics and cosmology. By applying QFT principles, scientists have gained insight into the earliest moments of the universe, including the Big Bang, cosmic microwave background radiation, and the behavior of black holes and dense stars.¹⁸⁰ The theory explains how galaxies, stars, and planets are interconnected, how space curves around massive objects, and how matter moves on cosmic scales.¹⁸¹ QFT also provides a unifying framework for understanding the four fundamental forces—electromagnetic, weak, strong, and gravitational—showing they arise from interactions between particles and fields that weave the universe's fabric.¹⁸² Beyond theoretical insights, QFT has driven numerous technological advancements. Modern devices such as semiconductors, transistors,

¹⁷⁸ Dirac, P. A. M. (1928). *The Principles of Quantum Mechanics*. Oxford University Press, accessed on 17 Dec 2025

¹⁷⁹ Dirac, P. A. M. (1928). *The Quantum Theory of Radiation*. Proceedings of the Royal Society of London A: Mathematical and Physical Sciences, 117, 610-624, accessed on 17 Dec 2025

¹⁸⁰ Lindgren. *The Heisenberg Uncertainty Principle as an Endogenous Equilibrium Property of Stochastic Optimal Control Systems in Quantum Mechanics*. Symmetries Quantum Mech. 2020; available at:

<https://doi.org/10.3390/sym12091533>, accessed on 17 Dec 2025

¹⁸¹ Brukner, Caslav; Zukowski, Marek (2009). "Bell's Inequalities: Foundations and Quantum Communication", accessed on 17 Dec 2025

¹⁸² Klebanov, Igor & Maldacena, Juan (2009). "*Solving Quantum Field Theories via Curved Spacetimes*". *Physics Today*. 62 (1): 28, doi:10.1063/1.3074260, accessed on 17 Dec 2025

and medical imaging tools—including MRI and radiation therapy—rely on quantum principles. Through the concept of second quantization, QFT reveals that all particles emerge from the excitations of underlying fields.¹⁸³ This understanding demonstrates that the universe, from subatomic particles to galaxies, is shaped by dynamic fields in continuous motion, highlighting the profound unity of nature across scales.

9. Quantum Theory and Its Application in the Real World

QM can explain many aspects of our world with great success. All subatomic particles, including electrons, protons, neutrons, photons, and others, make up matter, and their unique behaviors are often best explained by quantum mechanics. String theory, a contender for a theory of everything, has been dramatically influenced by quantum physics. Statistical mechanics is also connected to it. Grasping how individual atoms join together covalently to create compounds or molecules requires an understanding of quantum mechanics. Quantum chemistry is the application of quantum mechanics to chemistry. In theory, most chemistry can be described by (relativistic) quantum mechanics. By clearly demonstrating which molecules are energetically favorable to which ones, and by about how much, quantum mechanics may provide quantitative insight into ionic and covalent bonding processes. Quantum mechanics is used in the majority of computations in computational chemistry—a large portion of contemporary technology operates at scales where quantum effects are essential. The laser, transistor, electron microscope, and magnetic resonance imaging are a few examples. The diode and transistor, which are critical to contemporary electronics, were developed through research into semiconductors.¹⁸⁴ Strong techniques for directly modifying quantum states are now being sought after by researchers. To ensure secure information transfer, efforts are underway to develop quantum cryptography. The creation of quantum computers, which are anticipated to do specific computational tasks tenfold faster than conventional computers, is a more distant objective. Quantum teleportation, which deals with methods for transferring quantum states over arbitrary distances, is another current area of study.¹⁸⁵

There has long been discussion among physicists about measuring the unmeasurable in quantum systems. It is generally acknowledged that the Heisenberg Uncertainty Principle, which asserts that it is impossible to determine a particle's location and momentum with infinite accuracy, is a fundamental restriction on our capacity to quantify specific particle attributes.¹⁸⁶ However, new measurement methods that seem to con-

tradict this idea have emerged from recent developments in quantum technology. Quantum measurements using entangled particles are one such method. The phenomenon known as entanglement occurs when two or more particles become so coupled that, even when separated by large distances, the state of one particle depends on the state of the other. As a kind of "quantum probe," entangled particles have enabled observations that would not be feasible otherwise.

For instance, scientists recently measured the characteristics of a superconducting qubit with previously unheard-of accuracy using entangled photons.¹⁸⁷ A method known as "quantum tomography" was used to measure the state of the qubit, a small circuit composed of a few billion atoms. To determine the qubit's characteristics, the entangled photons had to be directed onto it, and their interactions measured. The experiment produced startling results: the scientists measured the qubit's energy levels with a precision previously believed unattainable. This has significant ramifications for the advancement of quantum computing as it raises the possibility that these novel measurement methods may be used to create a dependable and scalable quantum computer. Not everyone, however, is persuaded that this experiment really calls into question the Heisenberg Uncertainty Principle. According to some scientists, the experiment's measurements were simply the result of astute statistical analysis and did not significantly advance our knowledge of quantum physics.¹⁸⁸ This discussion brings to light the ongoing dispute over how to interpret the findings of quantum measurements.

In recent years, the idea of wave function collapse has also been reexamined. It is still often believed that a wave function collapses from a superposition of states to a single definite state during the measuring process itself. Nevertheless, other scholars have put forward different theories, such as the Many-Worlds Interpretation, which contends that the world branches into many worlds as it is measured. The idea of the multiverse has provoked considerable discussion among philosophers and physicists, casting doubt on the coherence of formal theories and on our understanding of reality. In his work, Ivan Karpenko explores this subject, examining how using multiverse models as the foundation may alter mathematical theory and logic. Karpenko's work creates new opportunities for investigating the nature of reality by analyzing the role of consistency in formal theories and its consequences for intellectual intuition.¹⁸⁹

These concepts have significant ramifications for our understanding of quantum physics. What does it in-

¹⁸³ Fischler, H., & Lichtfeldt, M. (1992). Modern physics and students' conceptions. *International Journal of Science Education*, 14(2), 181–190, accessed on 17 Dec 2025

¹⁸⁴ https://www.the-ochem.ru.nl/~pwormer/Knowino/knowino.org/wiki/Quantum_mechanics/Advanced.html#,

¹⁸⁵ Nancy Thorndike Greenspan, "The End of the Certain World: The Life and Science of Max Born (Basic Books, 2005), pp. 124-128, and 285-286,

¹⁸⁶ <https://www.aps.org/archives/publications/apsnews/200802/physics/history.cfm>, accessed on 17 Dec 2025

¹⁸⁷ Ansmann, M., et al. (2010). Entanglement-based Quantum Measurement with a Superconducting Qubit. *Nature Physics*, 7, 894–898, accessed on 17 Dec 2025

¹⁸⁸ Holevo, A. S. (1982). Probabilistic and Statistical Aspects of Quantum Theory. *American Journal of Physics*, 80, 931–938, accessed on 17 Dec 2025

¹⁸⁹ https://quantumzeitgeist.com/formal-theories-face-uncertainty-in-a-multiverse-reality/#google_vignette,

dicates about the nature of reality itself if entangled particles can be used to quantify particle attributes with infinite precision? Is it only the product of astute statistical analysis, or does it indicate that the act of measuring has a fundamental effect on the universe? Numerous disciplines are still investigating the ideas of superposition and entanglement. These ideas are crucial to quantum computing.¹⁹⁰ Understanding the behavior of particles at the atomic and subatomic levels is another benefit of studying quantum systems. In several fields, including chemistry and materials science, quantum mechanics has been thoroughly investigated and used. Creating new materials and technologies requires a grasp of chemical processes and molecular interactions.¹⁹¹

Understanding the behavior of particles at the atomic and subatomic levels is another benefit of studying quantum systems. These ideas are crucial to quantum computing. In several fields, including chemistry and materials science, quantum mechanics has been thoroughly investigated and used. Creating new materials and technologies requires a grasp of chemical processes and molecular interactions. What does it indicate about the nature of reality itself if entangled particles can be used to quantify particle attributes with infinite precision? Therefore, quantum mechanics is more than simply a fascinating theory. It serves as the basis for much of the technology that shapes our daily lives, ranging from energy systems and secure communications to cellphones and medical imaging.

Quantum Chemistry and Material Science.

Quantum chemistry applies quantum mechanics to predict and understand molecular behavior, providing a powerful alternative to traditional experimentation. By simulating interactions between atoms and molecules at the electronic level, researchers can anticipate chemical reactions and optimize molecular designs. This predictive capability is critical in drug discovery, enabling the rational design of pharmaceuticals that precisely target biological systems.¹⁹² In material science, quantum chemistry guides the creation of advanced materials with tailored properties, such as stronger alloys, lighter composites, and high-performance batteries. At the nanoscale, it supports the design of novel nanostructures and devices with unprecedented functionalities.¹⁹³ Across these domains, quantum chemistry accelerates scientific discovery, reduces experimental costs, and

enables the precise engineering of materials and compounds, transforming research methodologies.

Quantum Mechanics in Energy Technologies.

In the energy sector, quantum mechanics is driving transformative technologies. Understanding electron behavior in semiconductors has led to more efficient solar cells by optimizing photon absorption and electron excitation for maximal energy conversion.¹⁹⁴ Superconductivity, explained by quantum phenomena such as Cooper pairs, promises zero-resistance power transmission, potentially revolutionizing energy infrastructure. Superconductors also enable the generation of strong magnetic fields for applications such as maglev trains and advanced quantum computing.¹⁹⁵ By harnessing the unique properties of quantum materials, scientists are laying the foundation for a more sustainable, efficient, and technologically advanced energy future.

Quantum Biology: Life Through a Quantum Lens. The advent of quantum biology was made possible by the emergence of quantum physics. Its significance to biological things was not acknowledged, but as experimental research and scientific understanding have advanced, new connections and recognitions of quantum phenomena in biology are emerging. It is envisaged that the quantum effect will be applied to molecules, which are composed of atoms and subatomic particles, as they form any organic cellular structure. It's intriguing that nature has benefited from quantum biology and has a billion-year head start on our current understanding of how it functions. So, quantum biology is emerging as a frontier in life sciences, exploring how quantum phenomena may influence biological processes.¹⁹⁶ For example, the extraordinary efficiency of photosynthesis may rely on quantum coherence, allowing energy to traverse multiple pathways simultaneously. Quantum tunneling appears to enhance enzyme catalysis, enabling reactions faster than classical physics would predict. Additionally, the navigational abilities of migratory birds may exploit quantum effects in detecting Earth's magnetic field.¹⁹⁷ Although still in its early stages of development, this field suggests that life may have evolved to utilize quantum principles, offering a new perspective on fundamental biological mechanisms and potentially inspiring bio-inspired technologies.

¹⁹⁰ Nielsen, M. A., & Chuang, I. L. (2000). *Quantum Computation and Quantum Information*. Cambridge University Press, accessed on 22 Dec 2025

¹⁹¹ Feynman, R. P. (1985). *QED: The Strange Theory of Light and Matter*. Princeton University Press

¹⁹² Bub, Jeffrey (2023), "[Quantum Entanglement and Information](#)", in Zalta, Edward N.; Nodelman, Uri (eds.), *The Stanford Encyclopedia of Philosophy* (Summer 2023 ed.), Metaphysics Research Lab, Stanford University, retrieved 2025-08-06, accessed on 22 Dec 2025

¹⁹³ Niaz M. Reconstruction of the history of the photoelectric effect and its implications for general physics textbooks. *Sci Educ*. 2010; <https://doi.org/10.1002/sce.20389>, accessed on 22 Dec 2025

¹⁹⁴ Schlosshauer, Maximilian (2019-10-25). "[Quantum decoherence](#)". *Physics Reports*. 831: 1–

57. [arXiv:1911.06282](#). [Bibcode:2019PhR...831....1S](#). [doi:10.1016/j.physrep.2019.10.001](#). ISSN 0370-1573, accessed on 22 Dec 2025

¹⁹⁵ Kalkanis, G., Hadzidaki, P., & Stavrou, D. (2003). An instructional model for a radical conceptual change towards quantum mechanics concepts. *Science Education*, 87(2), 257–280, accessed on 22 Dec 2025

¹⁹⁶ Schreiner. Quantum mechanical tunneling is essential to understanding chemical reactivity. *Inst Organ Chem*. 2020; <https://doi.org/10.1016/j.trechm.2020.08.006>, accessed on 22 Dec 2025

¹⁹⁷ Sandev. Effective potential from the generalized time-dependent schrödinger equation. *Mathematics*. 2016; <https://doi.org/10.3390/math4040059>, accessed on 22 Dec 2025

Quantum Theory and the Cosmos.

The universe is described as a wave function, where its past and future states are governed by quantum probabilities, offering a more complete picture than classical models.¹⁹⁸ Entangled particles, no matter how far apart, remain connected, a concept that may play a role in the universe's initial formation and large-scale structure. To describe the universe in its earliest moments or near-extreme objects like black holes, a theory of quantum gravity is needed to reconcile general relativity with quantum mechanics, as classical laws fail in these extreme conditions. Quantum theory helps in understanding phenomena such as the nature of dark matter and dark energy, which are critical components of the universe but are not fully explained by current models.

Quantum mechanics also informs our understanding of the universe at the largest scales. Cosmologists propose that microscopic quantum fluctuations during the Big Bang were magnified by cosmic inflation, seeding the formation of galaxies and large-scale structures. These ideas bridge the most minor and largest scales of reality, connecting subatomic phenomena to cosmic evolution. One of the central challenges in modern physics is unifying quantum mechanics with general relativity. Theoretical frameworks like quantum gravity and string theory aim to provide a consistent description of spacetime, black holes, and the universe's ultimate fate, promising to illuminate fundamental questions about the cosmos.

Quantum Mechanics in Everyday Technology.

Beyond research, quantum mechanics underpins numerous technologies integral to daily life. Semiconductors in transistors, which form the foundation of modern processors and memory, operate based on quantum principles. Solar panels harness photon-electron interactions to generate electricity efficiently. Medical imaging technologies, such as MRI, rely on quantum alignment of atomic nuclei in magnetic fields to produce detailed internal images. From communication and computation to energy and healthcare, quantum mechanics has transitioned from an abstract theoretical framework to an indispensable practical tool, shaping the technological landscape of the 21st century.

Quantum Mechanics in Technology.

Modern technology operates at scales where quantum effects are essential in many ways.¹⁹⁹ Quantum

chemistry and quantum optics—a subfield of atomic, molecular, and optical physics that examines photon behavior—are significant uses of quantum theory.²⁰⁰ Quantum computing (is a computer that essentially uses quantum mechanical phenomena)²⁰¹, superconducting magnets (is an electromagnet made from coils of superconducting wire)²⁰², LEDs, or light-emitting diodes (is a semiconductor device that emits light when current flows through it) Magnets that are superconducting (is an electromagnet made from coils of superconducting wire)²⁰³, the optical amplifier (is a device that amplifies an optical signal directly, without the need first to convert it to an electrical signal)²⁰⁴ and the transistor, a semiconductor device that amplifies or switches electrical signals and power, and the laser, a device that produces light via an optical amplification process based on the stimulated emission of electromagnetic radiation. It is among the fundamental components of contemporary electronics.²⁰⁵ as well as semiconductors (is a material with electrical conductivity between that of a conductor and an insulator)²⁰⁶ such as electron microscopy (a microscope that uses an electron beam as a source of illumination), medical and research imaging (such as magnetic resonance imaging, or MRI, a medical imaging technique used in radiology to generate pictures of the anatomy and physiological processes inside the body), and microprocessor (a computer processor for which the data processing logic and control is included on an IC or ICs). The nature of chemical bonds, particularly those seen in the macromolecule DNA, provides explanations for a wide range of physical and biological phenomena. Beyond its theoretical and philosophical significance, quantum mechanics underpins contemporary technology. Quantum principles underlie the operation of hospital MRI scanners, the operation of semiconductors in smartphones, and the operation of lasers in business and medicine. Nuclear fusion in the Sun is explained by quantum tunneling, which also drives devices like scanning tunneling microscopes. Quantum physics directly led to the development of semiconductors and the transistor, an essential part of all contemporary electronics. Quantum effects are responsible for the operation of today's semiconductor chips, which are the foundation of modern computing. The diode and transistor, which are essen-

¹⁹⁸ Murdoch, D. (1987). *Niels Bohr's Philosophy of Physics*. Cambridge UK: Cambridge University Press. ISBN 978-0-521-33320-7, accessed on 22 Dec 2025

¹⁹⁹ <https://builtin.com/hardware/quantum-computing-applications>, accessed on 22 Dec 2025

²⁰⁰ Nielsen, Michael A.; Chuang, Isaac L. (2010). *Quantum computation and quantum information* (10th anniversary ed.). Cambridge: Cambridge University Press. ISBN 978-1107002173, accessed on 22 Dec 2025

²⁰¹ Mermin, N. David (2007). *Quantum Computer Science: An Introduction*. doi:10.1017/CBO9780511813870. ISBN 978-0-511-34258-5, accessed on 22 Dec 2025

²⁰² Yntema, G.B. (1955). "Superconducting winding for electromagnets". *Physical Review*. 98 (4). APS: 1197, doi:10.1103/PhysRev.98.1144, accessed on 22 Dec 2025

²⁰³ Edwards, Kimberly D. "Light Emitting Diodes" (PDF). *University of California, Irvine*. p. 2. Archived from the original (PDF) on February 14, 2019, accessed on 22 Dec 2025

²⁰⁴ Pearsall, Thomas (2010). *Photonics Essentials, 2nd edition*. McGraw-Hill. ISBN 978-0-07-162935-5. Archived from the original on 2021-08-17, accessed on 22 Dec 2025

²⁰⁵ "A History of the Invention of the Transistor and Where It Will Lead Us" (PDF). *IEEE JOURNAL OF SOLID-STATE CIRCUITS* Vol 32 No 12. December 1997, accessed on 22 Dec 2025

²⁰⁶ Worzyk, Thomas (11 August 2009). *Submarine Power Cables: Design, Installation, Repair, Environmental Aspects*. Springer. ISBN 978-3-642-01270-9, accessed on 22 Dec 2025

tial components of modern electronics systems, computers, and telecommunications equipment, were developed through research on semiconductors.²⁰⁷

Many electronic devices operate using quantum tunneling.²⁰⁸ Flash memory chips found in USB drives²⁰⁹ use quantum tunneling to erase their memory cells.²¹⁰ Another application is the manufacture of laser diodes and light-emitting diodes, which are high-efficiency light sources. The global positioning system (GPS)²¹¹ uses atomic clocks to measure precise time differences and therefore determine a user's location. Quantum mechanics forms the basis of modern electronics, computing, and telecommunications. It's also crucial for precise measurements (such as atomic clocks for GPS) and energy applications (such as solar cells)²¹². Emerging quantum technologies, such as quantum computing, quantum communication, and quantum sensing, promise future advancements in medicine, cybersecurity, material science, and artificial intelligence by harnessing the unique properties of quantum systems.²¹³ In this sense, quantum mechanics is not only a scientific triumph but also the invisible engine of contemporary civilization.

The Quantum Future: Computing, Communication, and Sensing.

While the successes of quantum theory are undeniable, its story is far from complete. Today, scientists are only beginning to unlock its full potential. One of the most promising frontiers is **quantum computing**, which harnesses superposition and entanglement to

perform calculations unimaginable for classical computers.²¹⁴ Unlike a traditional bit, which can be either 0 or 1, a quantum bit (qubit) can exist in both states simultaneously, enabling massive parallel computation.²¹⁵ If fully developed, quantum computers could revolutionize cryptography, drug design, climate modeling, artificial intelligence, and other areas of technology. Closely related, quantum communication transmits information using the principles of quantum mechanics, such as entanglement and superposition, to achieve ultra-secure communication networks and uses quantum key distribution (QKD) to guarantee ultra-secure data transfer, with security rooted not in human ingenuity but in the fundamental laws of physics.²¹⁶ QKD is useful for industries such as banking, government, and healthcare, enabling the development of quantum networks for distributed quantum computing and enhancing precision in scientific measurements and metrology.²¹⁷ It also contributes to the advancement of telecommunications by improving security and efficiency in 5G/6G networks and potentially enabling advanced quantum sensing and future applications such as quantum internet and quantum computing.²¹⁸ It also generates secure, unhackable encryption keys, protecting financial transactions, online banking, and sensitive government and military information.²¹⁹ Quantum communication can enhance 5G/6G networks by improving security and energy efficiency.²²⁰ It also supports the development of a quantum internet for global quantum computing and communication networks.²²¹ In real-world situations, it is often used with

²⁰⁷ Cyphers, Bennett (16 October 2019). "The Case for Fiber to the Home, Today: Why Fiber is a Superior Medium for 21st Century Broadband". Electronic Frontier Foundation. Archived from the original on 3 June 2021, accessed on 22 Dec 2025

²⁰⁸ Davies, P C W (6 May 2004). "Quantum mechanics and the equivalence principle". Classical and Quantum Gravity. 21 (11): 2761–2772. [arXiv:quant-ph/0403027](https://arxiv.org/abs/quant-ph/0403027). Bibcode:2004CQGra..21.2761D. doi:10.1088/0264-9381/21/11/017. ISSN 0264-9381, accessed on 22 Dec 2025

²⁰⁹ Bauer, Roderick (6 March 2018). "HDD vs SSD: What Does the Future for Storage Hold?". Backblaze. Archived from the original on 22 December 2022, accessed on 22 Dec 2025

²¹⁰ Schneier, Bruce (1993). Applied Cryptography (2nd ed.). Wiley. p. 554. ISBN 978-0471117094, accessed on 22 Dec 2025

²¹¹ National Coordination Office for Space-Based Positioning, Navigation, and Timing (March 3, 2022). "GPS Accuracy". GPS.gov. Archived from the original on April 12, 2022, accessed on 22 Dec 2025

²¹² Al-Ezzi, Athil S.; Ansari, Mohamed Nainar M. (8 July 2022). "Photovoltaic Solar Cells: A Review". Applied System Innovation. 5 (4): 67. doi:10.3390/asi5040067. ISSN 2571-5577, accessed on 22 Dec 2025

²¹³ <https://www.oecd.org/en/blogs/2025/02/a-policy-makers-guide-to-quantum-technologies-in-2025.html>,

²¹⁴ Nielsen, Michael A.; Chuang, Isaac L. (2010-12-09). Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press. ISBN 978-1-139-49548-6, accessed on 22 Dec 2025

²¹⁵ Love, Dylan (July 31, 2017). "'Quantum' technology is the future, and it's already here — here's what that means for

you". Business Insider. Retrieved 2019-11-12, accessed on 22 Dec 2025

²¹⁶ Zollman, D., Rebello, S., & Hogg, K. (2002). Quantum physics for everyone: Hands-on activities integrated with technology. American Journal of Physics, 70, 252–259, accessed on 22 Dec 2025

²¹⁷ Scarani, Valerio; Bechmann-Pasquinucci, Helle; Cerf, Nicolas J.; Dušek, Miloslav; Lütkenhaus, Norbert; Peev, Momtchil (29 September 2009). "The security of practical quantum key distribution". Reviews of Modern Physics. 81 (3): 1301–1350, doi:10.1103/RevModPhys.81.1301, accessed on 22 Dec 2025

²¹⁸ Shannon, C. E. (1949). "Communication Theory of Secrecy Systems". Bell System Technical Journal. 28 (4). Institute of Electrical and Electronics Engineers (IEEE): 656–715. doi:10.1002/j.1538-7305.1949.tb00928.x. hdl:10338.dmlcz/119717. ISSN 0005-8580, accessed on 22 Dec 2025

²¹⁹ Wang, Shuang; Yin, Zhen-Qiang; He, De-Yong; Chen, Wei; Wang, Rui-Qiang; Ye, Peng; Zhou, Yao; Fan-Yuan, Guan-Jie; Wang, Fang-Xiang; Chen, Wei; Zhu, Yong-Gang; Morozov, Pavel V.; Divochiy, Alexander V.; Zhou, Zheng; Guo, Guang-Can (February 2022). "Twin-field quantum key distribution over 830-km fibre". Nature Photonics. 16 (2): 154–161, doi:10.1038/s41566-021-00928-2, ISSN 1749-4893, accessed on 22 Dec 2025

²²⁰ Ekert, Artur K. (5 August 1991). "Quantum cryptography based on Bell's theorem". Physical Review Letters. 67 (6): 661–663, doi:10.1103/PhysRevLett.67.661, accessed on 22 Dec 2025

²²¹ Tomamichel, Marco; Leverrier, Anthony (2017). "A largely self-contained and complete security proof for quantum key distribution". Quantum. 1 14, doi:10.22331/q-2017-07-14-14, accessed on 22 Dec 2025

encryption, employing symmetric-key algorithms such as the Advanced Encryption Standard.²²²

On the other hand, **quantum sensing** uses the principles of quantum mechanics to enable ultra-sensitive measurements of physical quantities like magnetic fields (is the magnetic influence on moving electric charges, electric currents)²²³, gravity (is the effect of a field that is generated by a gravitational source such as mass)²²⁴, or motion (is the change in position of the body relative to that frame with a shift in time)²²⁵, and is poised to redefine precision in navigation, medical diagnostics, and geological exploration, opening possibilities well beyond current technological limits.²²⁶ It is enabling high-accuracy applications in navigation, healthcare, resource exploration, environmental monitoring, and scientific research. These sensors provide unprecedented sensitivity and stability, enabling significant advancements across various fields by measuring changes that current technologies cannot detect.²²⁷ Quantum sensors are used to measure fundamental physical quantities, such as gravity and magnetic fields, with unparalleled precision, thereby aiding scientific research and industrial applications. It can also be utilized in non-photonics areas such as spin qubits, trapped ions²²⁸, flux qubits, and nanoparticles.²²⁹

Gravitational wave sensing is a real-world application of quantum sensing. Gravitational wave detectors, such as the Laser Interferometer Gravitational-Wave Observatory (LIGO), measure the minuscule spacetime distortions known as gravitational waves.²³⁰ Squeezed light is used to measure signals below the conventional quantum limit in this large-scale physics experiment and observatory, which aims to detect cosmic gravitational waves and develop gravitational-wave observations as an astronomical instrument.

²³¹ Additionally, signals below the conventional quantum limit have been detected using squeezed light in atomic force microscopy and plasmonic sensors. Squeezed laser light has been used by the gravitational-wave observatories LIGO and Virgo since 2019, significantly increasing the frequency of detected gravitational-wave events.²³² Furthermore, enhanced quantum sensing, which has applications in basic research, navigation, and healthcare, employs quantum mechanics to provide highly accurate and flexible measurements of time, temperature, gravity, and electromagnetic fields.²³³ Unlike classical sensors, quantum sensors operate at the atomic level, enabling higher accuracy and new capabilities²³⁴, such as GPS-independent navigation and improved medical imaging, like enhanced Magnetic Resonance Imaging (MRI).²³⁵ Because advanced quantum sensing may provide more precise information about the body's molecular architecture and functions, it can improve medical imaging methods such as MRI.²³⁶

The development of practical applications will be essential to realizing the full promise of quantum sensing, which has reached a critical phase. Significant advancements were made in the sector in 2024 and early 2025, particularly in semiconductor and military use cases. Now that quantum sensing technology has advanced beyond basic research, manufacturing and deployment are the main priorities. Over the past year, notable developments have included Sandbox-launch AQ's of AQNav, a real-time, AI-driven quantum navigation system; Quantum Diamonds' launch of a diamond-based microscopy tool for semiconductor failure analysis; Q-use CTRL's of quantum magnetometers to navigate GPS-denied environments; and NASA's first

²²² Daemen, Joan; Rijmen, Vincent (March 9, 2003). "AES Proposal: Rijndael" (PDF). National Institute of Standards and Technology. p. 1. Archived (PDF) from the original on 5 March 2013, accessed on 22 Dec 2025

²²³ Young, Hugh D.; Freedman, Roger A.; Ford, A. Lewis (2008). *Sears and Zemansky's university physics : with modern physics*. Vol. 2. Pearson Addison-Wesley. pp. 918–919. ISBN 9780321501219, accessed on 22 Dec 2025

²²⁴ Krebs, Robert E. (1999). Scientific Development and Misconceptions Through the Ages: A Reference Guide (illustrated ed.). Greenwood Publishing Group. p. 133. ISBN 978-0-313-30226-8, accessed on 22 Dec 2025

²²⁵ Wahlen, Lars (1997). "9.1 Relative and absolute motion" (PDF). The Deadbeat Universe. Boulder, CO: Coultron Research. pp. 121–129. ISBN 978-0-933407-03-9, accessed on 22 Dec 2025

²²⁶ <https://q-ctrl.com/topics/introduction-to-quantum-sensing#>, accessed on 22 Dec 2025

²²⁷ <https://www.gao.gov/products/gao-25-107876#>, accessed on 22 Dec 2025

²²⁸ Campbell, W (February 23, 2017). "Rotation sensing with trapped ions". *Journal of Physics B*. 50 (6): 064002. arXiv:1609.00659. Bibcode:2017JPhB...50f4002C. doi:10.1088/1361-6455/aa5a8f, accessed on 22 Dec 2025

²²⁹ Kustura, K.; Gonzalez-Ballester, C.; De los Rios Sommer, A.; Meyer, N.; Quidant, R.; Romero-Isart, O. (April 7, 2022). "Mechanical Squeezing via Unstable Dynamics in a Microcavity". *Physical Review Letters*. 128 (14): 143601, doi:10.1103/PhysRevLett.128.143601, accessed on 22 Dec 2025

²³⁰ Shoemaker, David (2012). "The evolution of Advanced LIGO" (PDF). LIGO Magazine (1): 8. Archived from the original (PDF) on 16 November 2017, accessed on 22 Dec 2025

²³¹ Yu, Haocun; McCuller, L.; Tse, M.; Kijbunchoo, N.; Barsotti, L.; Mavalvala, N. (July 2020). "Quantum correlations between light and the kilogram-mass mirrors of LIGO". *Nature*. 583 (7814): 43–47, doi:10.1038/s41586-020-2420-8, accessed on 22 Dec 2025

²³² Tse, M.; Yu, Haocun; Kijbunchoo, N.; Fernandez-Galiana, A.; Dupej, P.; Barsotti, L.; Blair, C. D.; Brown, D. D.; Dwyer, S. E.; Effler, A.; Evans, M. (December 5, 2019). "Quantum-Enhanced Advanced LIGO Detectors in the Era of Gravitational-Wave Astronomy". *Physical Review Letters*. 123 (23): 231107, doi:10.1103/physrevlett.123.231107, accessed on 22 Dec 2025

²³³ Degen, C. L.; Reinhard, F.; Cappellaro, P. (2017). "Quantum sensing". *Reviews of Modern Physics*. 89 (3): 035002, doi:10.1103/RevModPhys.89.035002, accessed on 22 Dec 2025

²³⁴ Tan, Si-Hui; Erkmen, Baris I.; Giovannetti, Vittorio; Guha, Saikat; Lloyd, Seth; Maccone, Lorenzo; Pirandola, Stefano; Shapiro, Jeffrey H. (December 18, 2008). "Quantum Illumination with Gaussian States". *Physical Review Letters*. 101 (25): 253601, doi:10.1103/PhysRevLett.101.253601, accessed on 22 Dec 2025

²³⁵ <https://www.advanced-quantum.de/products/education/quantum-sensing>, accessed on 22 Dec 2025

²³⁶ <https://cast.desu.edu/research/centers/advanced-quantum-sensing-center>, accessed on 22 Dec 2025

demonstration of an ultracold quantum sensor in space.
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10. Quantum Market Analysis

A significant turning point was reached in 2024 when the quantum technology (QT) sector moved from expanding quantum bits (qubits) to stabilizing them. It lets mission-critical businesses know that QT has the potential to become a dependable, secure part of their technological infrastructure soon. To this end, this year's paper offers a unique, in-depth look into the rapidly expanding field of quantum communication, which may provide the security required for the broad adoption of QT. According to a recent study, by 2035, the three main pillars of QT—quantum computing, quantum communication, and quantum sensing could together provide up to \$97 billion in global income. The majority of the income will come from quantum computing, which is expected to increase from \$4 billion in 2024 to as much as \$72 billion in 2035.²³⁸ The industries most impacted by QT include the chemicals, life sciences, finance, and mobility sectors.²³⁹ Another survey has found that the quantum market is attracting substantial investment, with projections for dramatic growth, particularly in quantum computing, which could reach \$28 billion to \$72 billion by 2035.²⁴⁰ The industry features major tech giants like Google, Microsoft, and IBM, alongside a rapidly growing number of startups specializing in hardware, software, and services. On a country level, China and the United States filed the most QT patent applications in 2024, with China leading in quantum computing patents. Despite rapid progress, the industry faces hurdles such as technological immaturity, high costs, scaling difficulties, and a critical talent gap.²⁴¹ While widespread adoption for large-scale applications may take another 15-20 years, practical applications for specific problems are expected to emerge sooner, promising to revolutionize various industries.²⁴²

Significant investment flows are occurring in the quantum market. Although overall investments in QT companies suffered a 27% year-over-year decline in

2023, private investments in QT startups reached \$6.7 billion for quantum computing, \$1.2 billion for quantum communication, and \$0.7 billion for quantum sensing. Investors are nevertheless hopeful about the long run despite these swings. However, public financing remained robust; as of 2023, governments all around the globe have announced a total of almost \$42 billion in public support for QT development. The market for quantum computing is expected to increase rapidly. Fortune Business Insights projects that by 2030, the market will have grown from \$928.8 million to \$6.5 billion, or a compound annual growth rate of 32.1 percent.²⁴³ Further market size scenarios, including analysis by McKinsey, suggest the quantum computing market alone could reach between \$28 billion and \$72 billion by 2035, and \$45 billion to \$131 billion by 2040. This growth is part of a broader trend, with quantum technology potentially unlocking up to \$2 trillion in economic value across key industries like chemicals, life sciences, finance, and mobility by 2035.²⁴⁴

11. Leading Players and Quantum Tech Industry

There are several startups as well as big, established businesses in the quantum technology sector. Google, Microsoft, IBM, and Pascal are notable companies that are actively creating platforms, software, and hardware. In only quantum computing hardware, software, and services, there are more than 261 businesses; hardware makers continue to draw the most startup capital. These industry leaders are making noteworthy progress.²⁴⁵ For example, the newest cutting-edge quantum processor from Google Quantum AI, Willow, exhibits "exponential quantum error correction—below threshold!" and completed a benchmark calculation that would have taken a supercomputer ten septillion years in less than five minutes (1025 years). According to Google Quantum AI founder and lead Hartmut Neven, Willow is a "strong evidence that practical, extremely big quantum computers may actually be developed."²⁴⁶ IBM Quantum is also a major force,

²³⁷ "NASA demonstrates 'ultra-cool' quantum sensor for first time in space," NASA Jet Propulsion Laboratory, August 13, 2024; "Q-CTRL overcomes GPS-denial with quantum sensing, achieves quantum advantage," Q-CTRL, April 14, 2025; "Launch of the world's first commercial quantum device for semiconductor failure analysis," QuantumDiamonds, September 26, 2024, accessed on 22 Dec 2025

²³⁸ John Timmer, "Microsoft and Atom Computing combine for quantum error correction demo," Ars Technica, November 19, 2024, accessed on 22 Dec 2025

²³⁹ <https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025>, accessed on 22 Dec 2025

²⁴⁰ <https://blog.colobridge.net/en/2025/05/state-of-the-quantum-technology-industry-en/>, accessed on 22 Dec 2025

²⁴¹ S.L. Wu, J. Chan, W. Guan, S. Sun, A. Wang, C. Zhou, M. Livny, F. Carminati, A. Di

Meglio, A.C.Y. Li, J. Lykken, P. Spentzouris, S.Y.C. Chen, S. Yoo, T.C. Wei, (2021), Application of quantum machine learning using the quantum variational classifier method to high energy physics analysis at the LHC on IBM quantum computer simulator and hardware with 10

qubits, Journal of Physics G: Nuclear and Particle Physics (12) (2021), p. 48, [10.1088/1361-6471/ac1391](https://doi.org/10.1088/1361-6471/ac1391), accessed on 22 Dec 2025

²⁴² A. Wichert, (2016), Artificial intelligence and a universal quantum computer, AI Communications, 29 (4) (2016), pp. 537-543, [10.3233/AIC-160699](https://doi.org/10.3233/AIC-160699), accessed on 22 Dec 2025

²⁴³ <https://www.mckinsey.com/about-us/overview/mckinsey-insights-app>, accessed on 22 Dec 2025

²⁴⁴ <https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-computing-just-jumped-the-wall-of-the-physics-lab>, accessed on 22 Dec 2025

²⁴⁵ J. Schuhmacher, G. Mazzola, F. Tacchino, O. Dmitriyeva, T. Bui, S. Huang, I. Tavernelli, (2022), Extending the reach of quantum computing for materials science with machine learning potentials, AIP Advances, 12 (11) (2022), [10.1063/5.0099469](https://doi.org/10.1063/5.0099469), accessed on 22 Dec 2025

²⁴⁶ K. Si Mohammed, V. Serret, S. Ben Jabeur, H. Nobanee, (2024), The role of artificial intelligence and fintech in promoting eco-friendly investments and non-greenwashing practices in the US market, Journal of Environmental Management, 359 (2024), Article 120977, [10.1016/j.jenvman.2024.120977](https://doi.org/10.1016/j.jenvman.2024.120977), accessed on 22 Dec 2025

with a mission to build quantum computing for otherwise unsolvable problems.²⁴⁷ They have developed a powerful quantum computing stack and set an ambitious roadmap to achieve quantum advantage by 2026, targeting a large-scale fault-tolerant quantum computer, Starling, capable of 100 million quantum gates on 200 logical qubits by 2029.²⁴⁸ Matthias Troyer, IBM Technical Fellow, notes their commitment: “From the start we wanted to make a quantum computer for commercial impact, not just thought leadership”. IBM also operates 15+ utility-scale quantum systems worldwide and their Heron chip features 156 qubits.

Microsoft has carved a new path with its Majorana 1 chip, powered by a Topological Core architecture. This breakthrough leverages topo-conductors to produce more reliable and scalable qubits, with a clear path to fit a million qubits on a single chip. As Chetan Nayak, Microsoft Technical Fellow, states, “Whatever you’re doing in the quantum space needs to have a path to a million qubits. If it doesn’t, you’re going to hit a wall before you get to the scale at which you can solve the really important problems that motivate us”. Microsoft’s approach aims for error resistance at the hardware level, simplifying quantum computing through digital control. In addition to delivering Quantum as a Service (QaaS), which enables enterprises and academics to access quantum computing power in the cloud without developing their own hardware, several organizations are researching numerous quantum technologies at the same time.²⁴⁹ Quantum technology development is happening globally, with vibrant regional ecosystems emerging in North America, Asia, and Europe. These innovation clusters are critical for facilitating close collaboration between government, academia, and industry, which is essential for advancing technology and key use cases.

When it comes to the amount of quantum computing firms, private finance, and QT patents awarded, the US tops all other nations. The Mid-Atlantic Quantum Alliance, the Chicago Quantum Exchange, and the Boston Area Quantum Network are important centers of innovation. China demonstrates significant public

investment (over \$15 billion), dedicated research institutions, and increasing patent activity, particularly in quantum communication. Hefei is noted as a key innovation cluster. India has launched a National Quantum Mission with \$730 million in funding and plans to create 21 quantum hubs and four quantum research parks. Israel has a quantum computing consortium exploring various qubit technologies, supported by \$368 million in public funding. There are also major public financing and research centers in European nations including France, Germany, the United Kingdom, and the Netherlands. The largest concentration of QT graduates is found in the UK and the European Union.²⁵⁰ Paris (France), Delft (Netherlands), and Munich Quantum Valley are notable clusters (Germany).

In order to reach its full potential, quantum technology is now undergoing active research and substantial investment, with a clear emphasis on overcoming technical obstacles. Large-scale applications could not become popular for another 15 to 20 years, according to experts, although practical solutions for certain issues might appear sooner. The sustained increase in job listings for tech trends and increased interest in using these technologies for future development reinforce the optimistic long-term forecast.²⁵¹ Quantum computing is predicted to revolutionize various industries, including medicine, finance, automotive, engineering, and cybersecurity, over the next two decades. Initiatives like DARPA’s US2QC program are actively working to deliver utility-scale fault-tolerant quantum computers, emphasizing that the horizon for transformative, real-world solutions is within years, not decades.²⁵²

Quantum AI (QAI) integrates quantum computing to enhance machine learning algorithms, allowing for more powerful AI models that can achieve results beyond classical computers’ capabilities. This is due to QAI leveraging qubits, which can approximate multiple computations simultaneously (massive parallelism), unlike classical AI that relies on binary bits.²⁵³ While scientists are striving for quantum advantage—the ability of quantum computers to solve problems beyond classical computers—estimates vary. Some companies are projected to reach quantum advantage by

²⁴⁷ S.H. Sureshbabu, M. Sajjan, S. Oh, S. Kais, (2021), Implementation of quantum machine learning for electronic structure calculations of periodic systems on Quantum computing devices, *Journal of Chemical Information and Modeling* (2021), [10.1021/acs.jcim.1c00294](https://doi.org/10.1021/acs.jcim.1c00294), accessed on 22 Dec 2025

²⁴⁸ D. Solenov, J. Brieler, J.F. Scherrer, (2018), The potential of quantum computing and machine learning to advance clinical research and change the practice of medicine, *Missouri Medicine*, 115 (5) (2018), pp. 463–467, accessed on 22 Dec 2025

²⁴⁹ A. Shrivastava, A. Badhoutiya, M.S. Jeyalakshmi, A. Asif, Sayad, A. Deepak, A. Kakoli, Rao, I.S. Chakrapani, N. Kumar, (2024), Quantum Computing and Healthcare: Drug Discovery and Molecular Simulation with Machine Learning 1 *International Journal of INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING Quantum Computing and Healthcare: Drug Discovery and Molecular Simulation with Machine Learning*, *ijisae*, 2024 (2024), Issue 14s, www.ijisae.org, accessed on 22 Dec 2025

²⁵⁰

V. Rishiw, U. Agarwal, M. Yadav, S. Tanwar, D. Garg, M. Guizani, (2025), A new alliance of Machine Learning and Quantum Computing: Concepts, attacks, and challenges in IoT networks, *IEEE Internet of Things Journal* (2025), [10.1109/JIOT.2025.3535414](https://doi.org/10.1109/JIOT.2025.3535414), accessed on 22 Dec 2025

²⁵¹ Pathak, S., Arora, K., & Quraishi, S.J. (2024), Strategic challenges of Human resources management in the industry 6.0 (pp. 169–190). [doi:10.4018/978-1-6684-9596-4.ch009](https://doi.org/10.4018/978-1-6684-9596-4.ch009), accessed on 22 Dec 2025

²⁵² R.M. Pujahari, R. Khan, S.P. Yadav, (2025), Integration of quantum artificial intelligence in healthcare system, *Quantum computing for healthcare data*, Elsevier (2025), pp. 139–166, [10.1016/B978-0-443-29297-2.00005-8](https://doi.org/10.1016/B978-0-443-29297-2.00005-8), accessed on 22 Dec 2025

²⁵³ Y. Mahmoudi, N. Zioui, H. Belbachir, (2025), An improved quantum-inspired particle swarm optimisation approach to reduce energy consumption in IoT networks, *International Journal of Cognitive Computing in Engineering*, 6 (2025), pp. 313–322, [10.1016/j.ijcce.2025.01.010](https://doi.org/10.1016/j.ijcce.2025.01.010), accessed on 22 Dec 2025

2030. However, the hardware and software for handling the most complex problems might not be available until 2035 or later.²⁵⁴ Quantum AI is expected to revolutionize industries by accelerating drug discovery, optimizing supply chains and logistics, transforming financial modeling, and enabling advancements in materials science.²⁵⁵ It also holds promise for cybersecurity through quantum cryptographic protocols and could lead to breakthroughs in weather forecasting and automotive industries.²⁵⁶ Quantum Neural Networks (QNNs) and Quantum Support Vector Machines (QSVMs) are examples of specialized quantum algorithms that are being created to outperform their classical equivalents in tasks including pattern recognition, optimization, and reinforcement learning.^{257,258}

12. Very Recent and Future Use of Quantum Mechanics

For generations, humanity has been captivated and perplexed by the universe's origin, development, and nature. Cosmology was revolutionized by new concepts and significant findings in the 20th century, which changed how we think about and investigate the cosmos. But it is reality that much remains unknown to us. QC can accurately simulate the behavior of molecules, aiding in the design of new drugs, understanding protein interactions, and developing new chemical fertilizers. This technology can accelerate the discovery of new materials, like energy-efficient batteries, superconductors, and stronger alloys, by simulating their properties and interactions. QC uses the principles of QM to solve complex problems that are intractable for classical computers, with key applications including drug discovery, materials science, financial modeling, artificial intelligence, and cybersecurity. These systems are particularly effective at simulating quantum systems for new chemical and material development, accelerating machine learning by processing vast datasets, optimizing complex logistical and financial processes, and creating more secure cryptographic methods.²⁵⁹ Quantum algorithms can improve optimization tasks, such as feature selection and pattern recognition in AI systems, leading to better performance in areas like fraud detection. QC can improve weather

forecasting and climate modeling by processing complex environmental data.

Quantum Mechanics: The Science that Redefined Reality. One of the most astounding and revolutionary discoveries in scientific history is quantum mechanics. It emerged in the early 20th century as a reaction to the inability of classical physics to explain new experimental findings rather than as the result of abstract conjecture. Phenomena such as electrons jumping between discrete energy levels, particles behaving like waves, and measurements yielding probabilities instead of certainties demanded a complete rethinking of the natural world. What followed was not a minor refinement of existing laws but the creation of an entirely new worldview—one where reality is governed by probabilities, interconnectedness, and fundamental limits to knowledge. The pioneers of this revolution—Werner Heisenberg, Erwin Schrödinger, Niels Bohr, Max Born, Paul Dirac, and others—did more than write equations. They reshaped humanity's understanding of matter, energy, and the very fabric of reality. Dirac, in particular, expanded the theory by reconciling quantum mechanics with Einstein's special relativity, paving the way for quantum field theory and the prediction of antimatter.

Quantum AI.

QC may be able to complete jobs much more quickly than traditional computing, which might lead to more effective training of AI systems. This is particularly crucial as AI models get increasingly intricate and data-intensive.²⁶⁰ Complex issues that are beyond the capacity of traditional computers might be resolved by quantum AI. This covers activities like as forecasting protein folding in biology, resolving intricate logistical issues in real time, or improving forecasting accuracy in financial markets.²⁶¹ Training and inference periods for machine learning models, which form the basis of contemporary AI systems, might be greatly accelerated. More sophisticated AI models and speedier decision-

²⁵⁴ Moret-Bonillo, (2015), V. Moret-Bonillo, Can artificial intelligence benefit from quantum computing?

Progress in Artificial Intelligence, 3 (2) (2015), pp. 89-105, [10.1007/s13748-014-0059-0](https://doi.org/10.1007/s13748-014-0059-0), accessed on 25 Dec 2025

²⁵⁵ M. Murugan, M.N. Prabadevi, (2025), Artificial intelligence, Quantum computing, autonomous operation, emotional intelligence: Key drivers of industry 6.0 and sustainable development goals (SDG-8,9,12,17) for business sustainability in the oil and gas industry, Journal of Lifestyle and SDGs Review, 5 (2) (2025), Article e04549, [10.47172/2965-730X.SDGsReview.v5.n02.pe04549](https://doi.org/10.47172/2965-730X.SDGsReview.v5.n02.pe04549), accessed on 25 Dec 2025

²⁵⁶ A. Omar, T. and Abd El-Hafeez, (2023), Quantum computing and machine learning for arabic language sentiment classification in social media, Scientific Reports, 13 (1) (2023), [10.1038/s41598-023-44113-7](https://doi.org/10.1038/s41598-023-44113-7),

²⁵⁷ <https://www.geeksforgeeks.org/artificial-intelligence/what-is-quantum-ai/>, accessed on 25 Dec 2025

²⁵⁸ M. Sang-eetha, P. Senthil, A.H. Alshehri, S. Qamar, H. El-shafie, V.P. Kavitha, (2024), Neuro quantum computing

based optoelectronic artificial intelligence in electroencephalogram signal analysis, Optical and Quantum Electronics, 56 (4) (2024), p. 544, [10.1007/s11082-023-06187-5](https://doi.org/10.1007/s11082-023-06187-5), accessed on 25 Dec 2025

²⁵⁹ B. Zhang, J. Wu, L. Fan, Q. Zhuang, (2022), Hybrid entanglement distribution between remote microwave quantum computers empowered by machine learning, Physical Review Applied, 18 (6) (2022), [10.1103/PhysRevApplied.18.064016](https://doi.org/10.1103/PhysRevApplied.18.064016), accessed on 25 Dec 2025

²⁶⁰ Bel Hadj Miled, (2024), Dynamic connectedness of quantum computing, artificial intelligence, and big data stocks on renewable and sustainable energy Energy Economics, 140 (2024),

Article 108017, [10.1016/j.eneco.2024.108017](https://doi.org/10.1016/j.eneco.2024.108017), accessed on 25 Dec 2025

²⁶¹ A.S. Duggal, P.K. Malik, A. Gehlot, R. Singh, G.S. Gaba, M. Masud, J.F. Al-Amri (2022), A sequential roadmap to industry 6.0: Exploring future manufacturing trends

IET Communications, 16 (5) (2022), pp. 521-531, [10.1049/cmu2.12284](https://doi.org/10.1049/cmu2.12284), accessed on 25 Dec 2025

making result from QC's far faster processing and analysis of massive datasets than traditional computers.²⁶² Despite the enormous promise of quantum AI, there are a number of obstacles that must be addressed. The development of quantum computers is still in its infancy. One of the biggest challenges is creating reliable quantum computers with sufficient qubits and low error rates. The great susceptibility of quantum systems to noise can lead to computational errors. Researchers are developing strong error-correcting methods for quantum computers.²⁶³ Research is still being done to create quantum algorithms that can perform better than conventional ones in real-world situations. It will be challenging for broad adoption in the near future since only a small number of companies, like IBM, Google, and D-Wave, now have access to quantum computers.

As QC technology develops, Quantum AI might transform industries such as engineering, banking, health, and climate modeling by making it feasible to tackle complicated problems that are now unsolvable by traditional computers.²⁶⁴ AI and QC working together might result in innovations in autonomous systems and illness diagnostics. A few probable future developments include exponential improvements in the training times of machine learning models.²⁶⁵ Sophisticated pattern recognition that has the potential to revolutionize industries like fraud detection and cybersecurity, real-time supply chain, production, and logistics optimization, more precise financial simulations and projections.²⁶⁶ Thus, quantum artificial intelligence is the nexus of two of the most revolutionary technologies available today.²⁶⁷ Even though it is still in its early stages, it has the potential to combine the intelligence of AI with the processing capacity of quantum computing to solve some of the most challenging issues facing humanity. Driven by the amazing potential of quantum AI, we are expected to see advances in domains including healthcare, logistics, finance, marine, transportation, agriculture, industry, and more as both continue to advance.²⁶⁸

The Unfinished Quest. Despite its successes, quantum mechanics leaves profound mysteries unsolved. Physicists continue to seek a grand unified theory that merges quantum mechanics with Einstein's

general relativity. The unfinished quest of quantum physics is focusing on debates since Niels Bohr's Copenhagen interpretation. Key unresolved issues include the measurement problem (why collapses happen), the role of consciousness, hidden variables, and whether quantum rules apply universally, with thinkers like David Bohm and Hugh Everett proposing alternatives like pilot waves and many-worlds to reconcile quantum weirdness with a coherent picture of reality, a quest still ongoing today. Questions about quantum gravity, the nature of dark matter and dark energy, and the deeper connections between entanglement and spacetime remain at the forefront of research. Yet even within its mysteries lies its strength. Richard Feynman famously noted that one need not fully understand quantum mechanics to appreciate its power—the crucial fact is that it works, and it works with astonishing precision. The theory not only explains the unseen world of atoms and particles but also continues to shape the technologies and philosophies of the future.

13. Story of Universe and Fascinating Thinking of Human

Physics ruled the twentieth century, and neurology will rule the twenty-first. One way to look at this is that, whereas a large portion of the most renowned science of the previous century focused on comprehending the motion of bodies in space, from the smallest subatomic particles to superclusters of galaxies, a significant portion of the science of the present century appears to be focused on the workings of the mind and the resulting complexity of human behavior. While the twin cornerstones of general relativity and quantum mechanics helped physics paint a picture of the outside world in the 20th century, an increasing amount of scientific study in the present day attempts to describe the interior world of human perception and experience. Einstein was a brilliant scientist, and his ideas of mass-energy equivalency and special relativity are outstanding. Due of his high status, he casually described "spacetime curvature," which led to the incorrect philosophical paradigm of general relativity. Despite having a vague meaning in human philosophy, space and time each created a scientific philosophical framework for physics, but no philosopher ever questioned it. This raises a very

²⁶² Cherbal et al., (2024), S. Cherbal, A. Zier, S. Hebal, L. Louail, B. Annane, Security in internet of things: A review on approaches based on blockchain, machine learning, cryptography, and quantum computing, *The Journal of Supercomputing*, 80 (3) (2024), pp. 3738-3816, [10.1007/s11227-023-05616-2](https://doi.org/10.1007/s11227-023-05616-2), accessed on 25 Dec 2025

²⁶³ G. Hellstern, V. Dehn, and M. Zaefferer, (2024), Quantum computer based feature selection in machine learning, *IET Quantum Communication* (2024), [10.1049/qtc2.12086](https://doi.org/10.1049/qtc2.12086), accessed on 25 Dec 2025

²⁶⁴ L.T. Duarte, and Y. Deville, (2024), Quantum-assisted machine learning by means of adiabatic Quantum computing 2024, *IEEE Mediterranean and Middle-East Geoscience and Remote Sensing Symposium (M2GARSS)* (2024), pp. 371-375, [10.1109/M2GARSS57310.2024.10537323](https://doi.org/10.1109/M2GARSS57310.2024.10537323), accessed on 25 Dec 2025

²⁶⁵ R. Iyer, and A. Bakshi, (2024), Artificial intelligence and quantum computing techniques for stock market predictions,

Deep learning tools for predicting stock market movements, *Wiley* (2024), pp. 123-146, [10.1002/9781394214334.ch5](https://doi.org/10.1002/9781394214334.ch5), accessed on 25 Dec 2025

²⁶⁶ A. K, L.H. R, N.H. K, S. K, and Y.C L, (2024), Machine learning approach for Parkinson's disease prediction through Quantum computing techniques, *2024 S International Conference on Advances in Information Technology (ICAIT)* (2024), pp. 1-6, [10.1109/ICAIT61638.2024.10690380](https://doi.org/10.1109/ICAIT61638.2024.10690380), accessed on 25 Dec 2025

²⁶⁷ S. Liu, (2024), Harvesting chemical understanding with machine learning and quantum computers *ACS physical chemistry au*, Vol. 4, American Chemical Society (2024), pp. 135-142, [10.1021/acspchemau.3c00067](https://doi.org/10.1021/acspchemau.3c00067), accessed on 25 Dec 2025

²⁶⁸ A. Lappala, (2024), The next revolution in computational simulations: Harnessing AI and quantum computing in molecular dynamics, *Current Opinion in Structural Biology*, 89 (2024), Article 102919, [10.1016/j.sbi.2024.102919](https://doi.org/10.1016/j.sbi.2024.102919), accessed on 27 Dec 2025

important question: are people smart or stupid? The fact that our scientific community has actually shown the accuracy of spacetime's curvature is even more absurd. There must have been many tests, real-world circumstances, and findings to substantiate the curvature of spacetime. However, what precisely is the curvature of spacetime that has been shown by science? Spacetime curvature itself is a philosophical conundrum, time and space are part of the morphological category of three-dimensional material positional notions, and curvature itself is part of the unknown category of cosmic truths. Spacetime cannot be explained by the "gravitational lensing effect" idea, but it can explain the form of photon existence. The genesis of space and time is genuinely unknown from the standpoint of the universe's fundamental principles. Time and space forms can be used to explain matter, but the non-material time and space forms cannot be adequately articulated.

Mathematical miracle for the physical universe. The four-dimensional Einstein spacetime model contains three dimensions and a time dimension. Only four-dimensional spacetime mathematical-philosophical study improves material universe research. Einstein disregarded time and space. In "Mathematical Principles of Natural Philosophy," he focused on relative space and location. Considering time's appearance, not its essence. Instead of studying space and time philosophically, Einstein devised a mathematical model called "four-dimensional spacetime." Relativity, along with quantum mechanics, complements classical physics' universal gravity, electromagnetic force, optics, thermodynamics, and statistical mechanics. Conservation of energy states that energy, not matter, inhabits the material universe where humans exist. Relativity and quantum mechanics work well with classical physics' universal gravity, electromagnetic force, optics, and natural philosophy thermodynamics and statistical mechanics.

Energy, not matter, occupies space in the material cosmos where people live, according to the rule of conservation of energy. Physics has formally announced to mankind that persons and materials arise from information and energy, but the true difficulty is that they are substances. The natural God of the cosmos created these natural facts, not 'The God of Personification'. Cosmic Origin Philosophy might be humanity's next philosophy. Aristotle condensed this pre-axial thinking into material philosophy and science. Material philosophy has guided physics to its apex after 2000 years of growth in material science and philosophy. It has also confirmed the trustworthiness of the Cosmic Origin Philosophy, which may help resolve current physics'

conflicts. Through a paradox, science has again allowed Cosmic Origin Philosophy. This resolves contemporary physics' inconsistencies and raises science to the apex of human intellectual reasoning, calling into question human existence and survival.

13.1 Quantum cosmology.

In order to derive quantum theories that seek to apply to the whole universe at cosmic scales—particularly at very early periods, when quantum effects are thought to be significant—it uses the methods created by the community of quantum gravity to basic cosmological models.²⁶⁹ The cosmos grew from an initial condition of great density and temperature, according to a scientific hypothesis known as the Big Bang.²⁷⁰ A wide variety of phenomena are explained by several cosmological theories based on the Big Bang theory,²⁷¹ such as the cosmic microwave background (CMB) radiation and the quantity of light elements²⁷², and structure on a huge scale. Cosmic inflation, a period of rapid expansion in the early cosmos, provides an explanation for the uniformity of the universe, sometimes referred to as the horizon and flatness issues. Intriguing concepts like time being discrete or substituting a Big Bounce for the Big Bang are suggested by works in quantum cosmology. However, quantum cosmology likewise suffers from its conceptual flaws by embracing the formal structures of complete quantum gravity.²⁷³

The study of quantum cosmology looks at the cosmos as a single quantum system and tries to apply quantum theory to it. However, the No-Boundary Proposal is a quantum cosmology hypothesis that aims to define the beginning circumstances of the universe without a prior instant and avoid the Big Bang singularity. Thus, a cosmological explanation for the beginning of the known universe is the Big Bounce hypothesis. It was initially proposed as a phase of the oscillatory universe or cycle model interpretation of the Big Bang, in which the first cosmic event was caused by the collapse of an earlier universe. A cyclic model, often known as an oscillating model, is any of a number of cosmological theories in which the cosmos has self-sustaining cycles that are endless or indefinite. For instance, the oscillating universe theory, which Albert Einstein briefly considered in 1930, postulated that the universe would expand for a while before collapsing back in and undergoing a bounce due to the gravitational pull of matter.

²⁶⁹ Carroll, Sean (2001). "The cosmological constant". *Living Reviews in Relativity*. 4 (1) 1, doi:10.12942/lrr-2001-1. PMC 5256042. PMID 28179856. Archived from the original on 13 October 2006, accessed on 27 Dec 2025

²⁷⁰ Overbye, Dennis (20 February 2017). "Cosmos Controversy: The Universe Is Expanding, but How Fast?". *The New York Times*, accessed on 27 Dec 2025

²⁷¹ Singh, Simon (2004), *Big Bang: The Origin of the Universe* (1st U.S. ed.). New York: *Fourth Estate*, ISBN 978-0-00-716220-8, accessed on 27 Dec 2025

²⁷² the Planck Collaboration (2014), "Planck 2013 results. XXVII. Doppler boosting of the CMB: Eppur si muove", *Astronomy*, 571 (27): A27, doi:10.1051/0004-6361/201321556, accessed on 27 Dec 2025

²⁷³ Landau, L.D.; Lifshitz, E. M. (1977). *Quantum Mechanics: Non-Relativistic Theory*. Vol. 3 (3rd ed.). *Pergamon Press*. ISBN 978-0-08-020940-1, accessed on 27 Dec 2025

Each oscillation would start with a Big Bang and end with a Big Crunch.^{274,275}

Again, Cosmic Inflation is a period of rapid expansion in the early universe, which quantum fluctuations are thought to have initiated and which is crucial for the formation of cosmic structures like galaxies. Several theoretical physicists, notably Alexei Starobinsky at the Landau Institute for Theoretical Physics, Alan Guth at Cornell University, and Andrei Linde at the Lebedev Physical Institute, made significant contributions to the development of inflation theory in the late 1970s and early 1980s.²⁷⁶ Starobinsky, Guth, and Linde won the 2014 Kavli Prize "for pioneering the theory of cosmic inflation".²⁷⁷ Hawking Radiation is the quantum mechanical process by which black holes are predicted to emit particles, eventually leading to

their evaporation.²⁷⁸ It is black-body radiation²⁷⁹ released outside a black hole's event horizon due to quantum effects according to a model developed by Stephen Hawking in 1974.²⁸⁰ However, the Loop Quantum Cosmology is an approach that uses quantum mechanics to describe spacetime, aiming to resolve the problem of the Big Bang singularity.²⁸¹ It is a finite, symmetry-reduced model of loop quantum gravity or LQG²⁸² that predicts a "quantum bridge" between contracting and expanding cosmological branches.^{283,284} Modern theoretical physics attempts to unify theories and explain phenomena in further attempts to understand the Universe, from the cosmological to the elementary particle scale.²⁸⁵ Where experimentation cannot be done, theoretical physics still tries to advance through the use of mathematical models.²⁸⁶

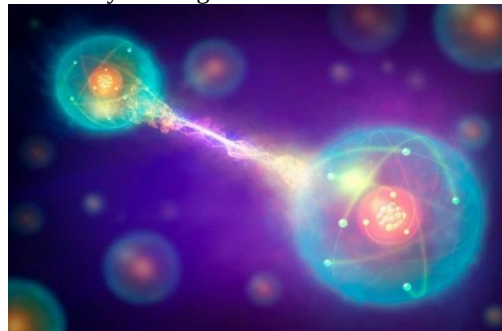


Figure 4: The fascinating science of quantum entanglement proposes that particles of the same origin are always connected²⁸⁷

13.2 Cosmic Inflation.

In order to explain a few aspects of the cosmos that are very difficult to explain without it, inflation was created. The first is that mass notoriously bends space and time in Einstein's general theory of relativity.²⁸⁸ Therefore, a universe like ours that has mass must be generally curved, either out on itself like a saddle or in

on itself like a ball (positive curvature) (as negative curvature). These issues are immediately resolved by cosmic inflation. The universe grew faster than light in its early moments (the speed limit of light only applies to objects within the cosmos).²⁸⁹ This smoothed out the creases in its early chaotic nature and meant that distant

²⁷⁴ McKee, Maggie (25 September 2014). "Ingenious: Paul J. Steinhardt – The Princeton physicist on what's wrong with inflation theory and his view of the Big Bang". Nautilus. No. 17. NautilusThink Inc. Archived from the original on 23 January 2017,

²⁷⁵ Steinhardt, Paul J.; Turok, Neil (2005). "The cyclic model simplified". *New Astronomy Reviews*. 49 (2–6): 43–57, doi:10.1016/j.newar.2005.01.003. ISSN 1387-6473, accessed on 27 Dec 2025

²⁷⁶ <https://esotericka.org/cmc/tth.html>, accessed on 27 Dec 2025

²⁷⁷ "2014 Astrophysics Citation", The Kavli Foundation. Archived from the original on 14 July 2014, accessed on 27 Dec 2025

²⁷⁸ Aldering; Goldhaber; Knop; Nugent; Castro; Deustua; Fabbro; Goobar; Groom; Hook; Kim; Kim; Lee; Nunes; Pain; Pennypacker; Quimby; Lidman; Ellis; Irwin; McMahon; Ruiz-Lapuente; Walton; Schaefer; Boyle; Filippenko; Matheson; Fruchter; et al. (1999). "Measurements of Omega and Lambda from 42 high redshift supernovae". *Astrophysical Journal*. 517 (2): 565–586, doi:10.1086/307221, accessed on 25 Dec 2025

²⁷⁹ Gubser, Steven S.; Pretorius, Frans (2017), *The little book of Black Holes*. Princeton, New Jersey: Princeton University Press. pp. 154–162. ISBN 978-0691163727, accessed on 25 Dec 2025

²⁸⁰ Rose, Charlie, (2025), "A conversation with Dr. Stephen Hawking & Lucy Hawking". charlierose.com. Archived from the original, accessed on 25 Dec 2025

²⁸¹ ohnson, George (27 February 2005), "The Road to Reality: A Really Long History of Time". *The New York Times*, accessed on 25 Dec 2025

²⁸² Struyve, Ward (2017), "Loop quantum cosmology and singularities". *Scientific Reports*. 7 (1) 8161, doi:10.1038/s41598-017-06616-y, accessed on 25 Dec 2025

²⁸³ Agullo, Ivan; Singh, Parampreet (2016). "[1612.01236] Loop Quantum Cosmology: A brief review". *arXiv:1612.01236*, accessed on 27 Dec 2025

²⁸⁴ Bojowald, Martin (2020). "Critical Evaluation of Common Claims in Loop Quantum Cosmology". *Universe*. 6 (3):36, doi:10.3390/universe6030036, accessed on 27 Dec 2025

²⁸⁵ Wilczek, Frank (11 February 2005). "Treks of Imagination (review of The Road to Reality)". *Science*. 307 (5711): 852–853. doi:10.1126/science.1106081, accessed on 27 Dec 2025

²⁸⁶ *The Road to Reality: A Complete Guide to the Laws of the Universe by Roger Penrose*, Goodreads. 9 January 2007. ISBN 978-0-679-77631-4, accessed on 27 Dec 2025

²⁸⁷ <https://science.nasa.gov/what-is-the-spooky-science-of-quantum-entanglement/>, accessed on 27 Dec 2025

²⁸⁸ <https://www.newscientist.com/definition/general-relativity/>, accessed on 27 Dec 2025

²⁸⁹ https://www.newscientist.com/article/2106321-reality-guide-the-essential-laws-of-cosmology/#LAW_1:_The_speed_of_light_is_a_constant, accessed on 27 Dec 2025

sections could still exchange heat since they were formerly in close proximity. Our conventional narrative of

cosmic development now includes inflation. It is still debatable, however.

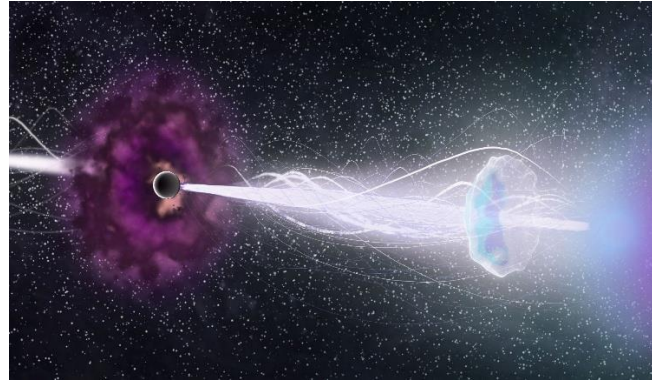


Figure 5: Singularity bursts- creating space-time in their path: Goodbye Big Bang²⁹⁰

Because distant sections were formerly in close proximity to one another, heat could be exchanged, ironing out creases in its early chaotic nature. These days, inflation is a fundamental component of the accepted theory of cosmic evolution. It is still controversial, however. However, this turned out to be incorrect, and it's unclear what exactly would have caused the early cosmos to expand. Worse, inflation is very difficult to stop, creating a multiverse of causally disconnected universes that eternally bud off from one another. Weakening the steady speed of light might be one solution. If the speed of light was faster in the early universe, that would also explain the temperature problem. Maybe light is still slowing down now, but not as much as our most sensitive detectors can detect. Cosmic inflation is the term for the brief period of time about 13.8 billion years ago when the cosmos expanded faster than the speed of light. Scientists don't know what caused inflation or what preceded it. During this epoch, energy could have just been a component of space-time. Cosmologists think inflation explains many aspects of the universe we observe today, like its flatness, or lack of curvature, on the largest scales. Additionally, density disparities that naturally exist on the tiniest, quantum-level scales in space may have been amplified by inflation, ultimately contributing to the formation of the universe's large-scale features.

13.3 Big Bang and Nucleosynthesis. The big bang occurred when the energy behind cosmic inflation

shifted to matter and light. The cosmos was a primordial soup of light and particles that was very hot—18 billion degrees Fahrenheit or 10 billion degrees Celsius—one second after the big bang. The initial elements, hydrogen, helium, and traces of lithium and beryllium, were created over the next few minutes of a process known as nucleosynthesis, in which protons and neutrons collided. The majority of the helium that exists today was generated after five minutes, and the cosmos had cooled and expanded to the point where the creation of new elements ceased. However, the cosmos was still too hot at this time for these elements' atomic nuclei to absorb electrons and become whole atoms.²⁹¹ Because so many electrons generated a kind of fog that dispersed light, the universe was opaque. Astronomers refer to this time as the epoch of recombination because it occurred around 380,000 years after the big bang, when the cosmos cooled sufficiently for atomic nuclei to absorb electrons. This affected the universe in two significant ways. First the cosmic fog cleared since there were no longer enough free electrons to scatter light entirely because the majority of them were already bonded into atoms. For the first time, light could move freely across long distances, and the cosmos became transparent. Second, light was created by the creation of these first atoms. This light is known as the cosmic microwave background, and it may still be seen today. It is the earliest light in the cosmos that we can see.²⁹²

²⁹⁰ <https://www.ecoportal.net/en/big-bang-experts-singularity-bursts/7451/>, accessed on 27 Dec 2025

²⁹¹ Stephen Hawking wrote 1999: So what the singularity theorems are really telling us, is that the universe had a quantum origin, and that we need a theory of quantum cosmology, if we are to predict the present state of the universe."Quantum

Cosmology, M-theory and the Anthropic Principle – Stephen Hawking". Archived from the original on 2015-02-14, accessed on 27 Dec 2025

²⁹² <https://science.nasa.gov/universe/overview/#>, accessed on 30 Dec 2025

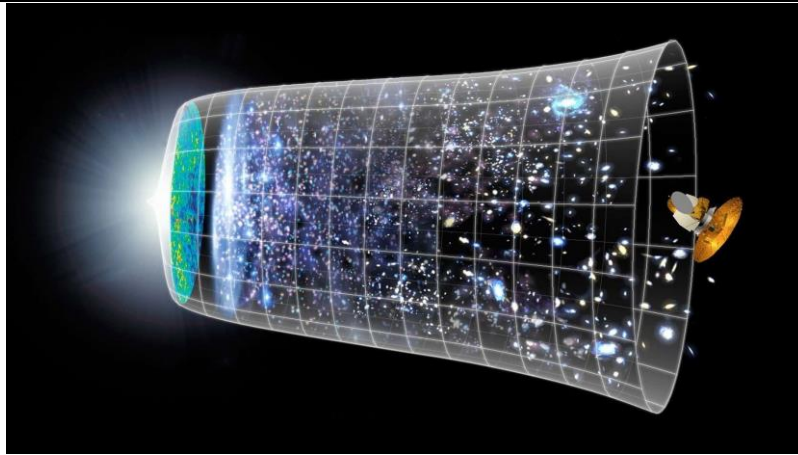


Figure 6: Cosmic inflation is a faster-than-light expansion of the universe that spawned many others²⁹³

We now accept the big bang, but without a theory that unites general relativity with quantum theory, we can't explain why it occurred. The proof came by accident in 1964. Telecoms engineers Arno Penzias and Robert Wilson were developing an early mobile-phone technology when they found an unexplained, persistent noise in a huge microwave receiver. This is the earliest

light in the universe, transmitted 380,000 years after the big bang, when the cosmos cooled enough for the first atoms to form and photons to travel freely. ESA's Planck mission has meticulously mapped this light, revealing its origins and current composition, supporting the standard model of cosmology, which includes dark matter and dark energy.²⁹⁴

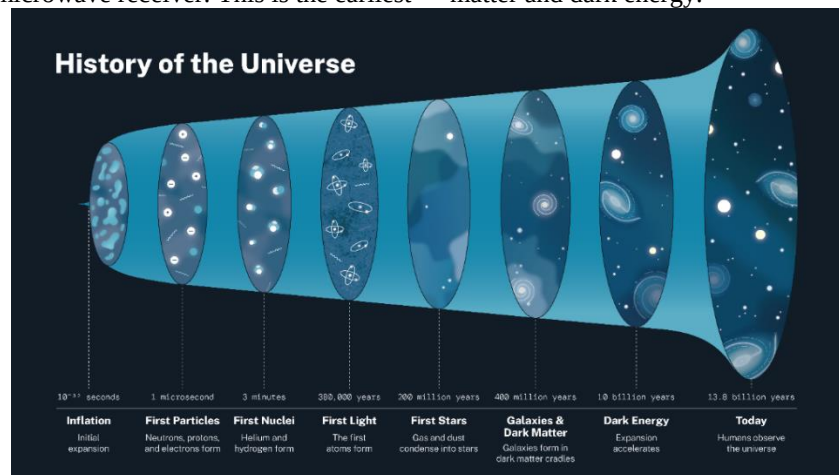


Figure 7: History of creation and universe (by NASA)

The age of the universe is defined in Big Bang theories of physical cosmology as the cosmic time back to the moment at which the cosmos's scale factor extrapolates to zero. According to current models, the age is 13.79 billion years.²⁹⁵ There are two methods used by astronomers to estimate the universe's age. One is based on the Lambda-CDM particle physics model of the early cosmos, which is matched to observations of properties that are far away and hence ancient, such as the cosmic microwave background.²⁹⁶ Two methods are available to astronomers for estimating the uni-

verse's age. The first is based on the Lambda-CDM particle physics model of the early cosmos, which is matched to observations of the cosmic microwave background and other far-off, hence ancient characteristics.²⁹⁷ The age of the cosmos may be ascertained by astronomers using two distinct methods. One relies on the Lambda-CDM particle physics model of the early cosmos, which is matched to observations of properties

²⁹³ <https://www.newscientist.com/definition/cosmic-inflation/>, accessed on 27 Dec 2025

²⁹⁴ Richard Webb, (2025), A sea of radiation that's clinching evidence for the big bang, available at: <https://www.newscientist.com/definition/cosmic-microwave-background/>, accessed on 27 Dec 2025

²⁹⁵ Hubble, E. (1929). "A relation between distance and radial velocity among extra-galactic nebulae". *Proceedings of the National Academy of Sciences*. 15 (3): 168–173. Bibcode:1929PNAS...15...168H. doi:10.1073/pnas.15.3.168, accessed on 27 Dec 2025

²⁹⁶ Planck Collaboration (2020). "Planck 2018 results. VI. Cosmological parameters". *Astronomy & Astrophysics*. 641. page A6 (see PDF page 15, Table 2: "Age/Gyr", last column). arXiv:1807.06209. Bibcode:2020A&A...641A...6P. doi:10.1051/0004-6361/201833910, accessed on 27 Dec 2025

²⁹⁷ Verde, Licia; Schöneberg, Nils; Gil-Marín, Héctor (13 September 2024). "A Tale of Many H₀". *Annual Review of Astronomy and Astrophysics*. 62: 287–331. doi:10.1146/annurev-astro-052622-033813. ISSN 0066-4146, accessed on 28 Dec 2025

that are far away and hence ancient, such as the cosmic microwave background.²⁹⁸

13.4 Dark Ages. The absorbing actions of all those hydrogen atoms caused the cosmos to once again become opaque at shorter wavelengths after the cosmic microwave background. The cosmos remained black for the following 200 million years. The stars weren't shining. At this moment, the universe was made up of a sea of hydrogen atoms, helium, and trace quantities of heavier elements. Astronomers will be able to unravel the puzzle of what the universe was like during the Cosmic Dark Ages if they comprehend the earliest stars and their predecessors. Dark matter is a hypothesized, unseen kind of stuff that does not interact with light or

other electromagnetic waves in astronomy and cosmology.²⁹⁹ Gravitational events that general relativity cannot explain unless there is more matter than can be seen imply the existence of dark matter. These impacts take place during the creation and development of galaxies.³⁰⁰ gravitational lensing,³⁰¹ the mass location in galaxy collisions and the present structure of the visible cosmos,³⁰² the cosmic microwave background anisotropies and the migration of galaxies inside galaxy clusters. It is believed that dark matter provides cosmic structures with gravitational scaffolding.³⁰³ At sizes where whole galaxies seem as small particles, dark matter clumped into blobs along thin filaments with superclusters of galaxies to create a cosmic web after the Big Bang.³⁰⁴

²⁹⁸ Vagnozzi, Sunny; Pacucci, Fabio; Loeb, Abraham (1 November 2022). "Implications for the Hubble tension from the ages of the oldest astrophysical objects". *Journal of High Energy Astrophysics*. 36: 27–35. [arXiv:2105.10421](https://arxiv.org/abs/2105.10421). [Bibcode:2022JHEAp...36...27V](https://ui.adsabs.org/abs/2022JHEAp...36...27V). [doi:10.1016/j.jheap.2022.07.004](https://doi.org/10.1016/j.jheap.2022.07.004), accessed on 27 Dec 2025

²⁹⁹ https://structures.uni-heidelberg.de/blog/posts/2022_12_cw/, accessed on 27 Dec 2025

³⁰⁰ Siegfried, T. (5 July 1999). "Hidden space dimensions may permit parallel universes, explain cosmic mysteries". *The Dallas Morning News*, accessed on 27 Dec 2025

³⁰¹ Trimble, V. (1987). "Existence and nature of dark matter in the universe" (PDF). *Annual Review of Astronomy and Astrophysics*. 25: 425–472, [doi:10.1146/annurev.aa.25.090187.002233](https://doi.org/10.1146/annurev.aa.25.090187.002233). ISSN 0066-4146, accessed on 27 Dec 2025

³⁰² <https://arstechnica.com/science/2017/02/a-history-of-dark-matter/>, accessed on 27 Dec 2025

³⁰³ <https://www.scientificamerican.com/article/the-milky-way-may-be-missing-a-trillion-suns-worth-of-mass/>, accessed on 27 Dec 2025

³⁰⁴ <https://www.science.org/content/article/filaments-early-universe>, accessed on 27 Dec 2025

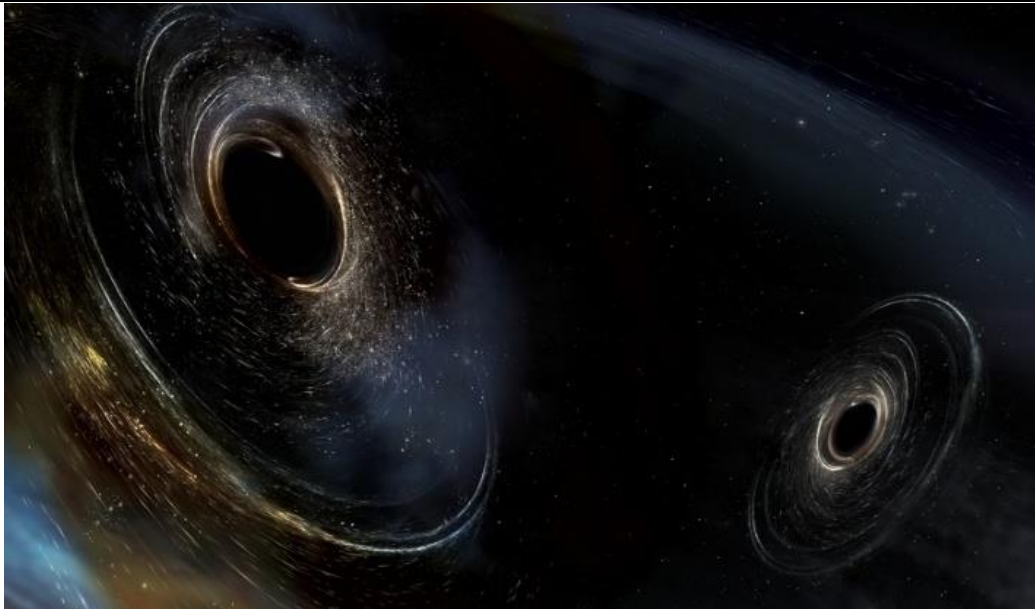


Figure 8: This artist's conception shows two merging black holes, like those detected by the LIGO and Virgo facilities on several occasions in 2018^{305, 306}

The universe's mass-energy composition in the classic Lambda-CDM cosmological model is composed of 68.2 percent dark energy, 26.8 percent dark matter, and 5 percent ordinary matter.^{307,308,309,310} Therefore, dark energy and dark matter make up 95% of the overall mass-energy content, while dark matter makes up 85% of the total mass.^{311,312,313} The local density of dark matter in the Solar System is far lower than that of normal matter, even though it is large in the halo around a galaxy. All of the dark matter that reaches Neptune's orbit would weigh around 1017 kg, which is equivalent to a big asteroid. Since dark

matter is only known to interact with radiation and regular baryonic matter via gravity, it is challenging to detect in a lab setting. The most common idea is that dark matter is an unidentified subatomic particle, such as axions or weakly interacting massive particles (WIMPs).³¹⁴ Another major idea is that primordial black holes make up dark matter.^{315, 316} Depending on its velocity, dark matter is categorized as "cold," "warm," or "hot" (more precisely, its free streaming length).³¹⁷ A cold dark matter scenario, in which structures form via the slow accretion of particles, has been supported by recent simulations.³¹⁸

³⁰⁵ <https://physics.aps.org/articles/v11/99>, accessed on 27 Dec 2025

³⁰⁷ "Planck Mission Brings Universe into Sharp Focus". NASA Mission Pages. 21 March 2013. Archived from [the original](#) on 12 November 2020, accessed on 27 Dec 2025

³⁰⁸ <https://science.nasa.gov/dark-matter/>, accessed on 27 Dec 2025

³⁰⁹ Ade, P. A. R.; Aghanim, N.; Armitage-Caplan, C.; et al. (Planck Collaboration) (22 March 2013). "Planck 2013 results. I. Overview of products and scientific results – Table 9". *Astronomy and Astrophysics*. 1303: 5062. [arXiv:1303.5062](#). [Bibcode:2014A&A...571A...1P](#). [doi:10.1051/0004-6361/201321529](#), accessed on 27 Dec 2025

³¹⁰ <https://arstechnica.com/science/2013/03/first-planck-results-the-universe-is-still-weird-and-interesting/>, accessed on 04 Jan 2025

³¹¹ Carroll, Sean (2007). *Dark Matter, Dark Energy: The dark side of the universe*. The Teaching Company. Guidebook Part 2 p. 46, accessed on 07 Jan 2025

³¹² Ferris, Timothy (January 2015). "Dark matter". *Hidden cosmos*. National Geographic Magazine. Archived from [the original](#) on 25 December 2014, accessed on 05 Jan 2025

³¹³ Jarosik, N.; et al. (2011). "Seven-year Wilson microwave anisotropy probe (WMAP) observations: Sky maps, systematic errors, and basic results". *Astrophysical Journal Supplement*. 192 (2): 14. [doi:10.1088/0067-0049/192/2/14](#), accessed on 07 Jan 2025

³¹⁴ Timmer, John (21 April 2023). "No WIMPS! Heavy particles don't explain gravitational lensing oddities". *Ars Technica*, accessed on 07 Jan 2025

³¹⁵ Carr, B. J.; Clesse, S.; García-Bellido, J.; Hawkins, M. R. S.; Kühnel, F. (26 February 2024). "Observational evidence for primordial black holes: A positivist perspective". *Physics Reports*. 1054: 1–68. [arXiv:2306.03903](#). [Bibcode:2024PhR.1054....1C](#). [doi:10.1016/j.physrep.2023.11.005](#), accessed on 07 Jan 2025

³¹⁶ Bird, Simeon; Albert, Andrea; Dawson, Will; Ali-Haïmoud, Yacine; Coogan, Adam; Drlica-Wagner, Alex; Feng, Qi; Inman, Derek; Inomata, Keisuke; Kovetz, Ely; Kusenko, Alexander; Lehmann, Benjamin V.; Muñoz, Julian B.; Singh, Rajeev; Takhistov, Volodymyr; Tsai, Yu-Dai (1 August 2023). "Primordial black hole dark matter". *Physics of the Dark Universe*. 41: 101231. [doi:10.1016/j.dark.2023.101231](#), accessed on 06 Jan 2025

³¹⁷ Carr, Bernard; Kühnel, Florian (2 May 2022). "Primordial black holes as dark matter candidates". *SciPost Physics Lecture Notes* 48. [doi:10.21468/SciPostPhysLectNotes.48](#), accessed on 06 Jan 2025

³¹⁸ Hossenfelder, Sabine; McGaugh, Stacy S. (August 2018). "Is dark matter real?". *Scientific American*. 319 (2): 36–43. [doi:10.1038/scientificamerican0818-36](#), accessed on 06 Jan 2025

13.5 First Stars and Galaxies. When observing distant objects, we look back in time, so in theory, if we look far enough into the Universe, we should be able to see the very first stars. The farthest galaxies and quasars we've found are about 13 billion years old. What we see then is a Universe that resembles today in many ways, with supernovae and gamma-ray bursts occurring. We cannot confirm whether a Universe existed before the Big Bang, but we can look back to roughly 300,000 years after it, when the Cosmic Microwave Background (CMB) was emitted. At that epoch, we do not see galaxies, only a uniform glow of radiation across the sky, originating from the era when protons and electrons first combined to form hydrogen atoms.³¹⁹ We are interested in the conditions of the Universe prior to the formation of the first stars. What we observe in the CMB is the sole hint. But what would you look for if there were no stars and galaxies to shine? Perhaps, initially, the universe was entirely smooth, with only tiny bumps forming over time. Without stars and galaxies, what would you search for? The universe must have started out as a smooth, uniform expanse before developing the small bumps we observe today. Stars formed when gas densities reached a certain density due to gravity. The universe initially had uneven gas distribution. The gas clouds in cooler space were denser and lumpier. Gravity drew stuff as these clusters became larger. These aggregates got denser and more compact, heating their cores to the point of nuclear fusion. First-ever stars. Their mass was 30–300 times that of the Sun and millions of times brighter. The earliest

galaxies formed from stars over several hundred million years.

Gravity holds stars, planets, and enormous gas and dust clouds together in galaxies. The biggest have trillions of stars and are over a million light-years wide. The smallest may have thousands of stars and cover a few hundred light-years. Some big galaxies feature supermassive black holes with billions of times the Sun's mass at their cores. Galaxies are generally spirals and ellipticals, although some are irregular. Most galaxies are 10–13.6 billion years old. Some are almost as ancient as the cosmos, which originated 13.8 billion years ago. Astronomers estimate the youngest galaxy emerged 500 million years ago.³²⁰ Our home galaxy is the Milky Way. It's a spiral galaxy with a 100,000-light-year star disk. One of the galaxy's spiral arms holds Earth halfway from the center. Our solar system orbits the Milky Way once every 240 million years. From Earth, the Milky Way appears as a thin, milky bar of light arcing across the sky, thus its name. This feature is our home galaxy's edge-on core disk. The Milky Way is part of the Local Group, a neighborhood of roughly 50 galaxies. Its members include dwarf galaxies with a few billion stars and Andromeda, our closest giant galactic neighbor. Galaxies may form gravity-held clusters of 100 or fewer individuals. Clusters may contain thousands of galaxies. Non-gravitational superclusters may hold groups and clusters. The cosmic web of matter includes superclusters, empty voids, galaxies' "walls" and other large-scale formations.

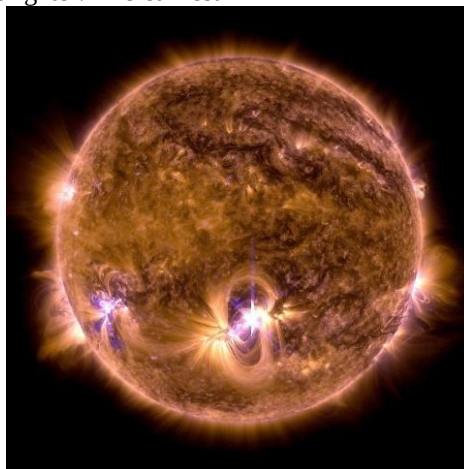


Figure 9: Sun a main sequence star, emits a strong solar flare flashes in this image captured by NASA's Solar Dynamics Observatory³²¹

13.6 Reionization and Future.

The thick gas around the earliest stars dispersed starlight, preventing it from traveling far. The ultraviolet radiation from these stars gradually ionized hydrogen atoms in the atmosphere into electrons and protons. Starlight went further, breaking up more hydrogen atoms during reionization. At 1 billion years old, stars

and galaxies had changed practically all this gas, making the cosmos transparent to light. Over time, astronomers believed the cosmos was expanding slower. In reality, cosmic expansion is accelerating. Supernovae, dazzling star explosions, were fainter than predicted in 1998. This could only happen if the supernovae traveled quicker and further away than planned. A strange material called dark energy may accelerate growth, say

³¹⁹ Bertone, Gianfranco; Hooper, Dan (15 October 2018). "History of dark matter". *Reviews of Modern Physics*. 90 (4): 045002, doi:10.1103/RevModPhys.90.045002, accessed on 07 Jan 2025

³²⁰ <https://science.nasa.gov/universe/galaxies/>, accessed on 05 Jan 2026

³²¹ <https://science.nasa.gov/universe/stars/>, Jaspers, K. (2019). *The Origin and Goal of History* (Translated by Li Xuetao). East China Normal University Press, accessed on 07 Jan 2025

scientists. Future study may reveal new discoveries, but cosmologists believe the cosmos will likely expand forever.

13.7 Ruliad or Rulial Universe. According to Stephen Wolfram's theory of a computational cosmos, basic computational operations are the source of the universe's complexity. According to Wolfram's book "A New Kind of Science," these processes may simulate everything from plant development to financial market activity since they resemble cellular automata. A novel perspective on the complexity of the cosmos is presented in Stephen Wolfram's "A New Kind of Science," which contends that the huge array of phenomena we see is supported by simple computational principles. The intricate mathematical frameworks and actual data supporting modern physics, however, pose serious obstacles to this viewpoint. His concept/criticism, proposition's which is based on complex mathematical formulas and concepts, encourages a more in-depth examination of the fundamental structure of reality.³²² It sheds light on the wide range of scientific knowledge that must be included in a thorough account of the cosmos. Although Wolfram's theories are innovative and thought-provoking, they must be reconciled with these sophisticated mathematical principles and empirical data in order to be accepted as part of contemporary scientific beliefs.

The Ruliad or rulial universe is a concept from Stephen Wolfram's Physics Project, representing the ultimate totality of all possible computations, including every mathematical structure, physical law, and potential universe, all arising from a universal, simple, computational substrate. It's an abstract, hyperdimensional space containing every rule and its applications, from which our perceived universe emerges as a specific 'point of view' or branch of computation, explaining the fundamental nature of reality as a vast computational process.³²³ Time experience is a fundamental manifestation of becoming through our experience in our part of the Ruliad. The ruliad's theoretical investigation will be a protracted and challenging process. However, because of the ruliad's extraordinary universality and generality, any advancement is expected to have very potent effects. The study of the ruliad might be seen as a type of ultimate abstract boundary of theoretical research and more, since it encapsulates everything that it means to conduct theoretical inquiry. The notion of space as 'emes' is intriguing. The term "emes" in relation to space likely refers to memes and the theoretical concept of a 'memescape' and that is a

digital, non-physical environment where ideas, representations, and meanings proliferate rapidly. The "notion of space as memes" suggests an intriguing perspective on how online spaces function and evolve, distinct from traditional physical locations.³²⁴

However, we have yet to achieve new predictions associated with concepts or find "unification" at a mathematical level between, say, QFT and GR, from Stephen's work. Wolfram's work is simply opening new doors of perception as a work of 'poetic naturalism', or will lend itself towards deeper objective understanding that can be practically applied in science, physics, and engineering. Again, this contemporary, digital notion of space contrasts with classical philosophical and physical interpretations of space, which debate whether space is an absolute, objective reality (Newton), a relative relation between objects (Leibniz), or a fundamental, a priori mode of human perception (Kant).³²⁵ The "memescape" concept offers a new, abstract lens through which to view how social and cultural "spaces" are formed in the digital age.³²⁶ The Ruliad is a comprehensive and ambitious conceptual framework that seeks to use computational rules to explain the whole world and its phenomena in the framework of Stephen Wolfram's work on computational irreducibility and the computational universe.³²⁷ The Ruliad notion has significant ramifications for theoretical physics and other fields. It suggests a new framework for comprehending the basic principles of the world via the prism of computing rather than conventional equations and physical laws. This viewpoint offers fresh opportunities for investigating the nature of space and time, the origins of complexity, and the ultimate laws governing reality.³²⁸

13.8 Reflecting on Divine Mystery. Reflecting on divine mystery in the Quran is a highly encouraged spiritual and intellectual pursuit in Islam, seen as a path to deeper faith, humility, and inner peace. The Quran itself prompts believers to use their reason and ponder its verses and the signs of God in creation. In monotheistic worldview of the Quran, it is crystal clear that who God is and who He is not. There is no room left for doubt that God is One, He is the only Creator, Sustainer and Owner of the Universe. He has no partners (Quran: 59: 22-24) He has no relatives; wives, children or offspring. (Quran, 23: 91) He is not like His creation (Quran 42: 11) and He does not need the creation for His existence, while all the time the creation is totally dependent on Him. He is for instance, the All-Knowing; the All-Hearing; the All-Seeing; the All-Forgiving;

³²²<https://medium.com/mathematical-musings/a-mathematical-exploration-of-the-computational-universe-a-critique-of-wolframs-framework-9e673e5dd665>, accessed on 07 Jan 2025

³²³ <https://writings.stephenwolfram.com/2021/11/the-concept-of-the-ruliad/>, Jaspers, K. (2019). *The Origin and Goal of History* (Translated by Li Xuetao). East China Normal University Press, accessed on 07 Jan 2025

³²⁴https://www.degruyterbrill.com/document/doi/10.1515/9783110219166.1.1/html?lang=en&srsltid=AfmBOopMS9cn_iH7qzAaLjAKYP6QiWxGL8OwBt-fglnLTkymnudeKY9u, Jaspers, K. (2019). *The Origin and Goal of History* (Translated by Li Xuetao). East China Normal University Press, accessed on 07 Jan 2025

³²⁵ <https://thephilosophyforum.com/discussion/14473/kants-notions-of-space-and-time>, Jaspers, K. (2019). *The Origin and Goal of History* (Translated by Li Xuetao). East China Normal University Press, accessed on 07 Jan 2025

³²⁶ <https://philosophypublics.medium.com/the-concept-of-space-where-from-f5d898a39373>, Jaspers, K. (2019). *The Origin and Goal of History* (Translated by Li Xuetao). East China Normal University Press, accessed on 07 Jan 2025

³²⁷ <https://www.chadly.net/Ruliad>, Jaspers, K. (2019). *The Origin and Goal of History* (Translated by Li Xuetao). East China Normal University Press, accessed on 07 Jan 2025

³²⁸<https://writings.stephenwolfram.com/2020/04/finally-we-may-have-a-path-to-the-fundamental-theory-of-physics-and-its-beautiful/>, accessed on 07 Jan 2025

the All- Loving; the All-Merciful; the Only One God. There is never a contradiction to this found anywhere in the Quran.³²⁹ In Quran verse 57:3, the Creator Allah announced that, “He is the First and the Last, the Outer and the Inner, and He has knowledge of all things.” This verse presents a fourfold description of Divine reality—temporal, spatial, ontological, and epistemic. While revealed in a pre-scientific era, its language invites contemplation across time. Modern quantum physics, though methodologically distinct from theology, offers conceptual tools that can deepen our appreciation of the verse’s philosophical depth.

➤ “He is the First and the Last” — Beyond Linear Time: Classical physics treats time as linear: a clear past to present to future. Quantum physics, especially when combined with relativity and cosmology, destabilizes this simplicity. At the quantum level, time symmetry exists: many fundamental equations work equally well forwards and backwards in time. In quantum cosmology, time itself may emerge from deeper physical laws, rather than exist as a fundamental entity. When the Qur’an describes God as *al-Awwal* (The First) and *al-Akhir* (The Last), it points to a reality not confined within time, but rather the ground from which time itself arises and to which it returns. Quantum physics similarly suggests that time may not be ultimate - resonating with the idea of a Creator who precedes and transcends temporal succession.

➤ “The Outer and the Inner” - Visible Phenomena and Hidden Reality: Quantum physics reveals that what we perceive as “solid reality” is mostly empty space, governed by invisible wavefunctions and probability amplitudes. The outer world (particles, matter, radiation) is only the *manifestation*. The inner reality consists of non-observable mathematical structures (wavefunctions, quantum fields) that determine what can appear. The Qur’anic pairing of *al-Zāhir* (The Manifest) and *al-Bāṭin* (The Hidden) aligns remarkably with this structure of reality. What we observe is real—but not complete. The deeper truth lies beneath appearances, beyond direct sensory access. This does not mean the Qur’an predicts quantum theory, but that quantum discoveries echo a metaphysical intuition already embedded in the verse: reality has layers, and the deepest layer is unseen.

➤ Unity Without Distance: Quantum Nonlocality:

➤ One of the most counterintuitive features of quantum mechanics is entanglement. Two particles, once connected, remain correlated regardless of spatial separation. Information about the system exists non-locally, defying classical notions of distance. When the verse declares God as both “Outer” and “Inner” simultaneously, it challenges spatial separation. Divine presence is not distributed *across* space but independent of spatial limitation. Quantum nonlocality does not explain God - but it breaks our assumption that influence must be local, sequential, or spatially bound. This prepares the modern mind to better grasp Qur’anic descriptions that transcend physical geometry.

➤ “And He has knowledge of all things” - Information as the Fabric of Reality:

➤ In contemporary physics, information is increasingly viewed as fundamental are Quantum states encode information, observation is not passive; it participates in defining outcomes, some physicists describe reality as “information-theoretic” at its core. Divine knowledge in the Qur’an is not reactive or observational - it is constitutive. God does not *learn* reality; reality unfolds within Divine knowledge. Quantum physics suggests that information precedes form, echoing the theological claim that creation unfolds according to pre-existing knowledge and order.

➤ So, a single verse in the holy Qur’an (57:3) articulates a vision of reality where time, space, visibility, and knowledge are not ultimate categories, but contingent dimensions rooted in a deeper unity. Quantum physics, by dismantling naive realism and classical certainty, makes such a vision intellectually less alien to the modern mind. Rather than conflict, we observe complementarity like Quantum physics explains *how* reality behaves and the Qur’an speaks to *what it means* and *why it matters*. In this convergence, scientific discovery does not diminish faith; it refines awe.

The Bible involves understanding that a "mystery" in scripture is a truth once hidden but now revealed by God for our benefit. These mysteries are not puzzles to be solved by human intellect alone, but profound realities that invite deeper faith, humility, and trust in God's nature and redemptive plan. Unlike a secular mystery, a biblical mystery is a truth that God chooses to disclose through His Word and the Holy Spirit. Deuteronomy 29:29 encapsulates this balance: "The secret things belong to the LORD our God, but the things revealed belong to us and to our children forever". Jesus often spoke in parables, explaining that the mysteries of the Kingdom were given to His disciples to know, but not to the crowds, until the time of their full revelation. The New Testament emphasizes that the Holy Spirit plays a crucial role in guiding believers into all truth, as seen in John 16:13: "However, when the Spirit of truth comes, He will guide you into all truth. For He will not speak on His own, but He will speak what He hears, and He will declare to you what is to come."³³⁰ The interplay between mystery and revelation underscores the dynamic relationship between God and humanity. While certain aspects of God's nature and plans remain beyond human comprehension, He graciously reveals what is necessary for faith and obedience. Deuteronomy 29:29 encapsulates this balance: "The secret things belong to the LORD our God, but the things revealed belong to us and to our children forever, so that we may follow all the words of this law."

14. Conclusion

From the structure of atoms and the behavior of radiation to the dynamics of particles, forces, and materials, quantum mechanics provides the conceptual and mathematical foundation upon which much of contemporary physics and technology rests. Yet its ascent has never been straightforward. Again, from its earliest development, quantum theory unsettled even its own

³²⁹ <https://www.quora.com/How-does-the-Quran-reflect-our-divine-nature>, accessed on 07 Jan 2025

³³⁰ https://biblehub.com/topical/d/divine_mystery_and_revelation.htm, accessed on 07 Jan 2025

pioneers, provoking deep disagreements, conceptual tensions, and paradoxes that challenged long-standing assumptions about reality, causality, and certainty. In its effort to comprehend the universe, quantum physics turns its attention to the smallest constituents of matter - quarks, electrons, photons - revealing a domain that consistently defies everyday intuition. In this realm, particles behave like waves, outcomes are described probabilistically rather than deterministically, and observation itself plays a constitutive role. To the uninitiated, such phenomena can appear almost miraculous. Nevertheless, physicists have labored to render these "cosmic miracles" intelligible through rigorously defined principles and mathematically precise frameworks, transforming strangeness into systematic knowledge. Within a scientific context, the "truth" of quantum mechanics does not imply an absolute or metaphysical finality. Rather, it refers to the theory's extraordinary capacity to describe, explain, and predict experimental outcomes with remarkable accuracy. Its success lies not in offering ultimate answers to philosophical questions, but in providing a reliable and empirically grounded account of physical phenomena across an immense range of scales.

Quantum field theory and Quantum physics by itself are insufficient. New, sophisticated civilizations are continuously developed as a result of human cognition. A scientific approach to nature, including consciousness, is based on quantum theory. Rethinking the underpinnings of quantum theory has helped to address some of the mysteries surrounding consciousness. The information we take in from our body and surroundings is processed by our consciousness, which is an information structure. We get this information in the form of characteristics of tangible things and photons, the massless units of light. Kinetic energy, or motion, is one of the characteristics of matter. Motion may be transformed into matter, as shown by Einstein's $E = mc^2$. So, one of its qualities is equal to matter. A thorough understanding of how complex systems are built from simpler structures has been made possible by the mathematical-physical framework of quantum theory. The most basic quantum structure, a quantum bit, may and ought to be the starting point for such a creation. In the end, matter and photons may be seen as expressions of abstract quantum information. Deterministic devices that follow only logical input and output rules are not what living things are. This brings us to the vast realm of emotions. Emotion provides creatures of all complexity levels with an active, adaptive role in evolution and fulfills the age-old function of sensory-motor self-regulation.

An intriguing discussion between science and spirituality is made possible by the idea that quantum physics seems to be a collection of miracles. The biblical or Quranic creation account, which recounts the universe's creation over seven days by the spoken word of a higher force or Almighty, is one of the most significant crossings of these domains (or period of time). By portraying creation as a methodical and intentional process by the Almighty or Creator, this narrative evokes a feeling of purpose and order. On the other hand, quantum physics describes how basic particles and forces

interacted over billions of years to generate the cosmos. These scientific ideas are explored by writers like as Brian Greene in "The Elegant Universe" and Carlo Rovelli in "Reality Is Not What It Seems," who make connections between philosophical questions about existence and the intricacies of the quantum universe. These pieces demonstrate the ways in which spiritual and scientific viewpoints may enhance one another and provide a variety of views on the mysteries of creation. Like spiritual traditions, their work invites readers to reflect on life, awareness, and our role in the wide world by combining scientific precision with philosophical reflection.

There would appear to be no reason why there shouldn't be various worlds based on other rules if the universe were founded on a certain fundamental law. However, our method has the first startling result that the universe is in fact founded on all formally feasible laws. This leads to the conclusion that there can only be one universe, which is, as we have demonstrated, rather inevitable. However, humans only perceive a little portion of this vast "rulial cosmos," which is predicated on all imaginable laws. We are used to living on a certain planet at the edge of a specific galaxy in physical space. However, we now understand that we are merely sampling a small portion of the rulial space of all conceivable universe descriptions. We would characterize the cosmos extremely differently if our cerebral development or sensory equipment were different. The cosmos produced humans, who employ language, writing, numbers, science, and coordinate systems to construct all "man-made existences," including philosophy, religion, and science. Humans act in this way because it is essential to their life and survival. With their senses, perception, and subjective awareness, as well as their ability to write, speak, and use knowledge to create existence, humans are the universe's ambassadors. This is the purpose of human life and the natural capacity of people to learn, create, find inconsistencies, and resolve them. Understanding oneself and the world around one is the primary goal of human life.

According to quantum physics, the universe's reality may be summed up as follows: probabilities, not certainties, are used to forecast the outcomes of events at the quantum level. Entanglement depicts a cosmos in which everything is inextricably intertwined in ways that are beyond the realm of traditional physics. Reality is modified by encounters and measurements rather than existing as a static backdrop. According to Fuzzy and Granular, the cosmos consists in discrete packets of matter and energy and is fundamentally dominated by uncertainty. According to QM, the reality we see in our daily, macroscopic world arises from a much weirder, counterintuitive substratum where connections defy spatial separation and possibilities are actual. The lines between science and spirituality may blur and change as we go further into the quantum world and uncover the depths of our consciousness, revealing a more cohesive and inclusive view of the world. This musical exchange encourages us to be receptive to the secrets that both disciplines want to unravel, resulting in a conversation that not only enlightens but also motivates us to investigate the limitless potential of life. Therefore,

we appreciate the universe's complexity and wonder by embracing both the scientific and the spiritual, and we acknowledge that our quest for knowledge and wisdom is just as much a part of our path of discovery as the search for meaning. The tapestry of creation continues to reveal itself as we stand on the brink of new scientific

discoveries and more profound spiritual understanding. This appeals to brilliance at the quantum wonders that characterize our existence and provide a clear image of the universe's uncertainty.

TECHNICAL SCIENCES

HIGH TECHNOLOGY IN E-BIKE POWER SYSTEM USING MODELING DEVELOPMENT

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Abstract

The following work consists of the mechanical Computes Assisted Design (CAD) for an electric bicycle, which involves a detailed and structured process ranging from the creation of individual components to the integration of complete systems. A comprehensive global review of current e-bike technologies was conducted, focusing on the selection of lightweight and strong materials to optimize the energy efficiency and maneuverability of the bicycle. The chassis was designed primarily from carbon fiber. The selected electric motor has a capacity of 2000 W, providing an optimal balance between power and efficiency, enabling the bike to reach an autonomy of 90 km and a significant range. This project brings an innovative solution to the e-bike market using advanced design and careful selection of materials, resulting in a lightweight, durable and efficient vehicle. The novelty lies in the integration of advanced design technologies and high-quality materials, which not only improve the user experience, but also promote sustainability in urban transportation.

Keywords: E-bike, power system, modeling development, high technology in materials, CAD.

1.0 INTRODUCTION

In recent years the world has developed new means of transportation, the most used in these times in the electric bicycle or also called E-BIKE, it is economical and avoids contamination with gases dangerous [1,2]. In this way an electric bicycle is different to a regular bicycle, the electric bicycles are becoming more popular due to their convenient mode of transportation. Various nations of the world, including China, the United States of America, Switzerland, México, Colombia, Cuba the Netherlands, and Japan, use electric bicycles for daily transportation. The electric bicycle has been demonstrated that the greenhouse gas emissions of electric vehicles were significantly influenced by the chosen system boundary for analysis, whether it encompassed the well-to-wheel perspective or the entire vehicle lifecycle. The study showed that emissions assessed on a well-to-wheel basis were lower compared to those calculated over the vehicle's commercial [3,4]. One of the first patents for an electric system in a bicycle was filed by Ogden Bolton Jr, in 1895. Its design included an electric motor mounted on the bicycle frame. Later S. Argyris in 1948 also developed an electric bicycle. From there the famous E-BIKE for electric mobility began, for more years later this project added more things in the E-BIKES that had more impact towards the means of transporting people[5]. The use of E-BIKES benefits the development of different persons such as, police or law enforcement, tourists, delivery workers, boys, tenders, students, teachers, purchasers of different products, and people with health issues. It is a way of representing sustainable eco-friendly transport solutions for cities and towns. Advantages clearly observed are strengthened accelerations from stand still, allowing different loads, improved hill climbing, increased ride distances and higher average speeds [6, 7].

Electric mobility has long been considered a technological solution to the environmental problems caused by current transportation patterns (especially

their impact on climate change), characterized by a high proportion of car trips powered by fuel injection [9, 10]. The electrification of mobility marks this change by being part of the means of transportation that does not require fossil fuels. Furthermore, electric transportation will be the future that is gradually being accepted and must be realized because it is the way out of environmental changes and has the technology to solve all transportation problems [2, 7, 10].

The design of the E-BIKE in the software CAD includes the next steps.

a) Planning and conceptualization. Before starting the design in software CAD, it is crucial to define the requirements and specifications of the e-bike, is necessary the type of e-bike (e-mountain bike, e-cargo bike, e-folding bike, and others), the specifications help to determinate the features such as frame size, motor type, battery capacity, drive system and other key components, in the last decade the research took wide application on the existing designs and perform analysis to understand functionality and aesthetic requirements [11].

b) Creation of the frame and main components. The frame modeling starts with an initial sketch with the profile of the structural part to the frame, the sketching tools are used in software CAD, to create the basic shapes of the product, in the actual systems are necessary tools as extrusion, revolve and others, it let apply extrusion and revolution operations to shape the frame, when the parts are modeled is possibly make a component assembly, also the design allow have the mounting points for the motors, battery, wheels and suspension and other components [11, 12].

c) Assemblies and adjustments of components, it is possible using the software CAD assembly tool to design the frame, motor, battery, rim and other components with precision, in this point the positioning adjustments allow sure all components fit correctly and make adjustments if necessary [11, 13].

d) Simulation and analysis. The CAD software allows the stress analysis, the perform simulations to evaluate the resistance of the frame and other components, with the tools in motion simulation that checks the range of motion of moving parts and ensures there are no interferences [11, 13].

e) Documentation and technical drawing. The software lets you generate detailed drawings for manufacturing, including plan views, elevations, cross sections, dimensions, tolerances, configuration to assembly and materials in technical drawings. Create assembly and maintenance manuals to facilitate the construction and maintenance of the e-bike [13].

f) Prototyping and testing. If it is possible, use 3D printing or manufacturing prototype, the 3D printing or rapid manufacturing techniques to prototype components and test the design, with the prototype the evaluation is possible and let make adjustments based on prototype testing and return to software CAD, to modify the design if necessary. The real field tests are necessary to evaluate the performance of the e-bike in real conditions and adjust the design according to the results obtained [12, 13].

1.1 E-BIKE power system modeling development

The power system of the E-BIKE, this term consists of several operations, both design and manufacturing, applicable as mentioned, electric bicycles are a means of transportation for people who want a better path without having to go through a series of already known problems, the E-BIKE power system consists of important parts which will be mentioned.

The battery is the heart of the power system. It stores the electrical energy necessary to power the motor. The most common batteries in e-bikes are lithium (Li-ion) due to their high energy density, low weight and long life. The battery capacity, measured in watt-hours (Wh), determines the range of the bicycle, while the motor is the component that converts the electrical energy from the battery into mechanical energy to propel the bicycle. The motors can be located in the front, rear wheel hub or bottom bracket axle. Motor power is measured in watts (W) and may vary depending on the e-bike model. Another element is the controller, it is the brain of the power system. It regulates the amount of power the motor receives from the battery and manages the interaction between the battery, motor and sensors. The controller also allows you to adjust different assistance modes and manage additional functions such as regenerative braking. The charger allows you to recharge the battery when it runs out. Chargers are designed to provide the correct amount of voltage and current to the battery for safe and efficient charging. Today it is necessary to use a display and control panel. It provides the rider with information on battery status, speed, motor assist level and other relevant data. Control panels can be integrated into the handlebars or a separate unit. The sensors include torque (force) and speed sensors that adjust motor assistance based on the power the rider applies to the pedals and the speed of the bike. These parts are very important because it is the function of the entire E-BIKE power system, there-

fore the quality that the part contains must be considered and in order to better understand what is being explained, the software CAD, will be used, but I will detail more in the next part [14].

1.2 Model in software CAD

In the software CAD all the parts of the E-BIKE were designed respecting the measurements under the standard but with different modeling and function in the power system. Here the CAD was used to develop a functional product and have less mistakes, this came to the assembly part and exploded, however there was complexity in the part of the sprockets and chain mechanism, a good material was applied to each piece and different from that of the other models that already exist, these materials will be listed in an orderly manner and with their different properties, in the part of CAE the electrical analysis tool was used [10-13].

2.0 Method and materials

The achievement of an electric bicycle, the so-called E-BIKE, as a solution for sustainable mobility in cities requires a series of planned tasks and a multidisciplinary approach, such as those that have been carried out within the framework of this work where has developed an efficient and accessible electric bicycle, with the application of new design and simulation tools. The design using CAD allows the use of appropriate materials and components, as well as the use of lightweight materials, as a point of reference when proposing a solution that meets the expectations of current and future users. The different materials that have been used and the different methodologies used when carrying out this project are detailed below [15].

2.1 Materials

The development of the electric bicycle model was carried out using CAD software. The program was chosen for the possibility of generating an accurate three-dimensional model and performing finite element analysis. The latter is crucial to evaluate the structure's strength and aerodynamic capabilities.

Tools and equipment used

In this development a software CAD was used for its versatility and power in the area of mechanical design and simulation using original license version 2022. The software allowed each component of the e-bike to be modeled with the greatest precision. In this case the computer needs a wide memory in RAM, and the process recommended by the software. The hardware all-in-one computer was used. This computer was equipped with a high-performance processor I5, 16GB in RAM and an advanced graphics card. This setup was critical to being able to work with complex 3D models and perform detailed simulations without losing speed and efficiency.

The combination of CAD software with computer equipment allowed not only to develop a detailed and functional model, but also to carry out simulations that anticipate and reduce problems before physical manufacturing. As a result, the final design is ensured to be optimized for manufacturing, resulting in lower cost and production time, without compromising quality.

Materials used in design

In this project were reviewed different options of materials and products of high technology and were

found to the E-BIKE the aluminum 606 being one of the most used aluminum alloys in the industry due to its combination of mechanical properties, corrosion resistance and ease of manufacturing. It contains magnesium and silicon as the main alloying elements, which gives it good mechanical properties and resistance to corrosion. It has a tensile strength of approximately 290 MPa (42,000 psi) and a yield strength of 240 MPa (35,000 psi). The density is approximately 2.7 g/cm³, making it a lightweight material. Other material found was carbon fiber. It is an advanced composite material known for its high strength and lightness. It is widely used in high-performance applications, including bicycles, due to its excellent physical and mechanical properties [15]. It is composed of extremely fine carbon filaments that are intertwined and combined with an epoxy resin matrix to form a composite material. It has a tensile strength that can exceed 6000 MPa (870,000 psi), and its modulus of elasticity (stiffness) can be greater than 230 GPa. This makes it extremely strong and rigid compared to metals. The density is approximately 1.6 g/cm³.

2.2 Methodology

The development of the electric bicycle was carried out in different phases, all of them planned in order to guarantee an effective and functional design.

The first phase of the project was an investigation into the market and technology that existed at that time for e-bikes. This included an analysis of existing technology trends, user demand, and available component capabilities. From this research, the technical specifications of the project were defined, for example, battery capacity, motor power, chassis materials and control systems. These parameters established the design and performance objectives that were to be achieved.

With the established specifications, the 3D model of the e-bike was designed using a commercial CAD software in the field of design. Aerodynamics and structural integrity of the chassis were especially considered. Once the 3D design was completed, stress simulations and aerodynamics analysis were carried out in order to detect and optimize the critical areas of the design. These simulations allowed us to calculate the resistance of the chassis to different types of loads and reduce wind resistance, an aspect of utmost relevance at the level of energy efficiency and autonomy.

The choice of materials was a very important point of the project. The design of the electric bike was made with materials such as aluminum and carbon fiber. The

predominant material of the chassis structure was aluminum. It was chosen for its high strength-to-weight ratio and corrosion resistance. Carbon fiber was used for critical components to decrease the overall weight of the bike, improving maneuverability without compromising structural strength.

Finally, once the design was adjusted, a meticulous validation of both the design itself and the entire e-bike was carried out, so that all elements of the bicycle met the technical and safety requirements of the regulations. This validation included a final series of simulations and tests that ensured that the electronic bicycle was correctly sized for subsequent production and use by users.

In this way, it has been possible to create an electric bicycle that not only meets the needs of current urban users, but also promotes sustainable mobility and the reduction of the carbon footprint of the entire e-bike.

3.0 Results and discussion

The work presents the results of the modeling of the electric bicycle with high technology (Figure 1) and the characteristics that it must present. Likewise, in this work the shape, the mass of the E-BIKE and the energy system that must accompany it were developed.

The modeling of the electric bicycle was a widely detailed procedure, from a process of creating the drawing in a CAD software, two additional characteristics of the e-bike have been expected to be taken into account: structural resistance and aerodynamics. The electric bicycle frame is made up of a high-strength carbon fiber frame. It has been made of this material not only because it is among the strongest unthinkably light frames, but also because its function is to provide a robust platform for all the components. remaining part of the design [14].

The design has an adjustable seat, a support frame for the battery and motor, and a rear space for the high-capacity battery. A protection system has been chosen for the engine and internal components, keeping the main part of the system safe from breakdowns regardless of what is used.

The main parts of the model are detailed below:

1. Battery
2. Electric motor
3. Body or structure
4. Rim
5. Tires (Figure 2)
6. Control of the velocity
7. Adjustable seat features
8. Battery charger independent

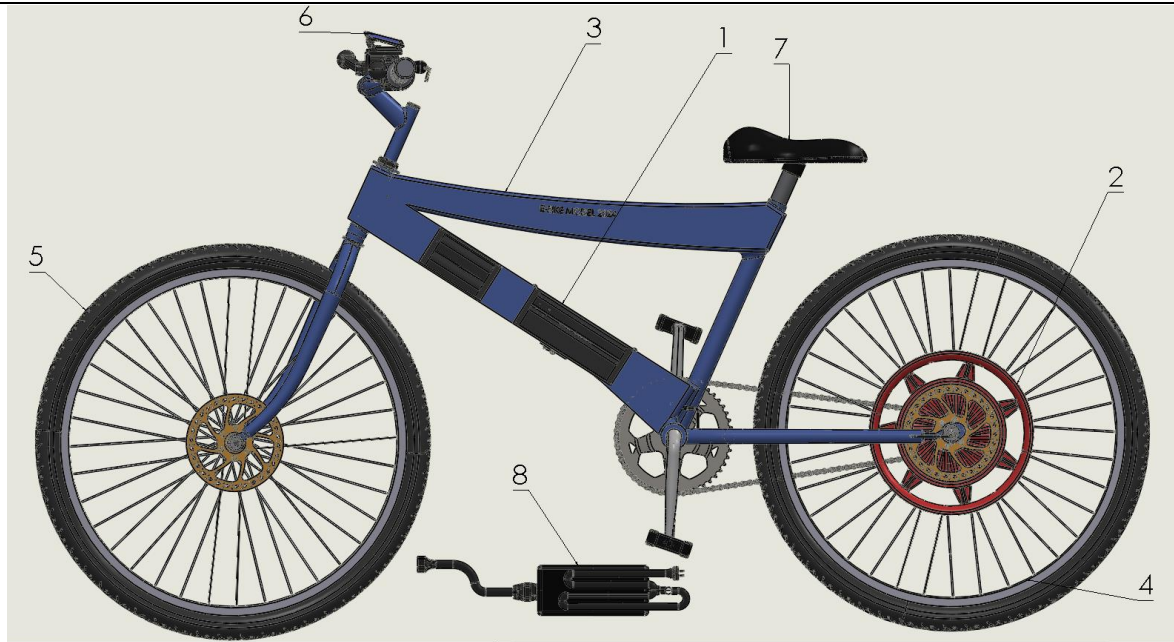


Figure 1. Diagram of the E-BIKE in the software CAD.



Figure 2. Assembly of the parts of E-BIKE in the software CAD

The final results of the design of the E-BIKE are those that have the most impact both on electric mobility and on the CAD software. Each component of this vehicle has its own characteristics and properties of materials, mainly the body or structure of the E-BIKE. It was modified to alloy aluminum, it is a light and resistant material because the objective is for it to be lighter than the other materials seen in these vehicles. The electric bicycle lithium-ion battery can work at a temperature between -20 and 60C, and the discharge efficiency can reach 95%. Make full use of the battery,

and the riding distance is longer. When the battery is not used, the self-discharge rate does not exceed 3%. It can save battery power.

The project was amazing and use many time and other resources, was modified again and again, the design of every with detail, the analysis of the elements, the shapes of design, the selection of configuration, found different batteries, motors, wheels, materials and functional configuration was a work widely analyzed (Figure 3).

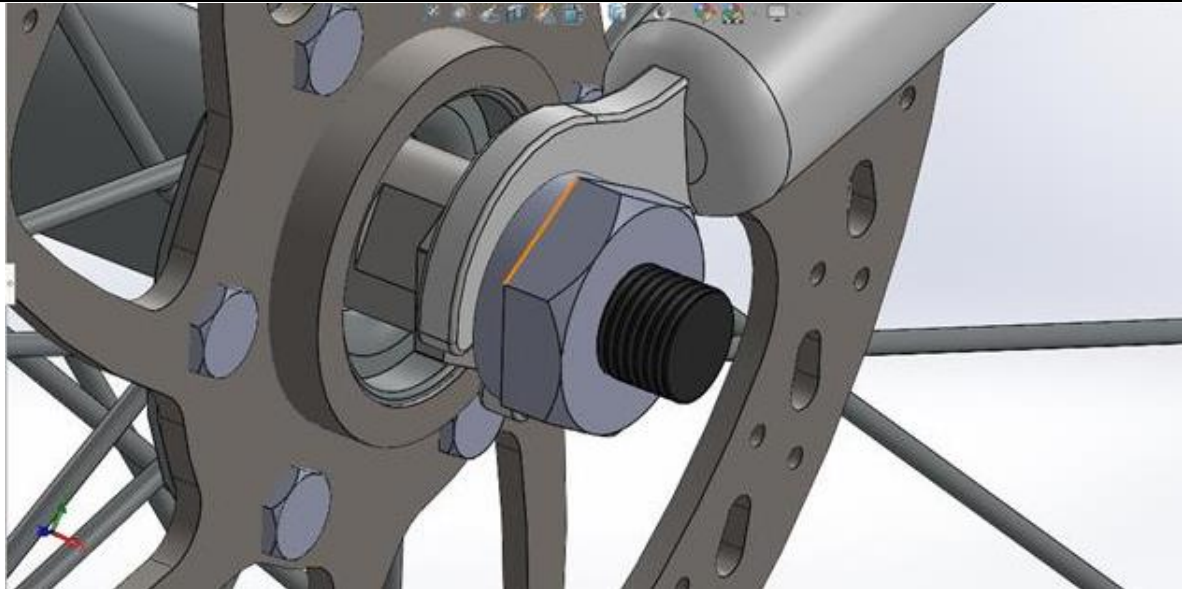


Figure 3. Detail of the parts to E-BIKE in the software CAD

Figure 4 was shown the stress analysis with the software having a value that allows verifying the mechanical resistance is over the values of stress obtained

under load and it. In the figures 5 y 6 are shown the steps used in the development of the models.

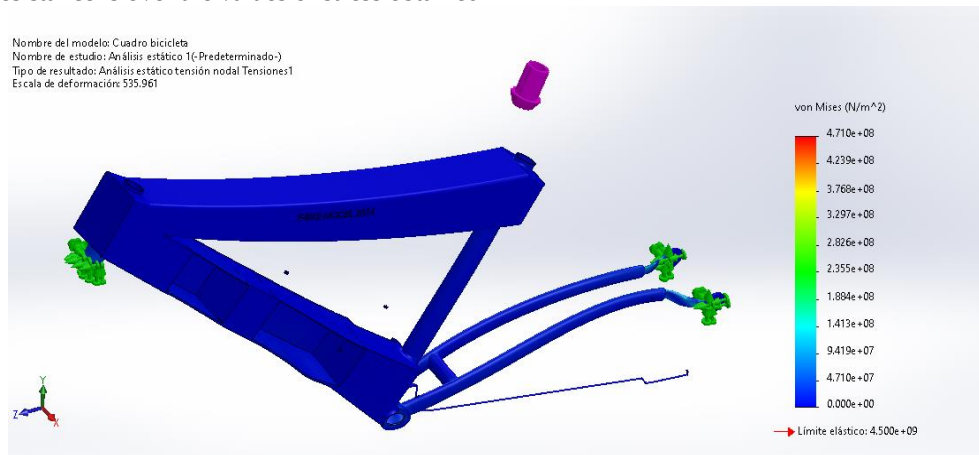


Figure 4. Stress analysis with the software CAD.

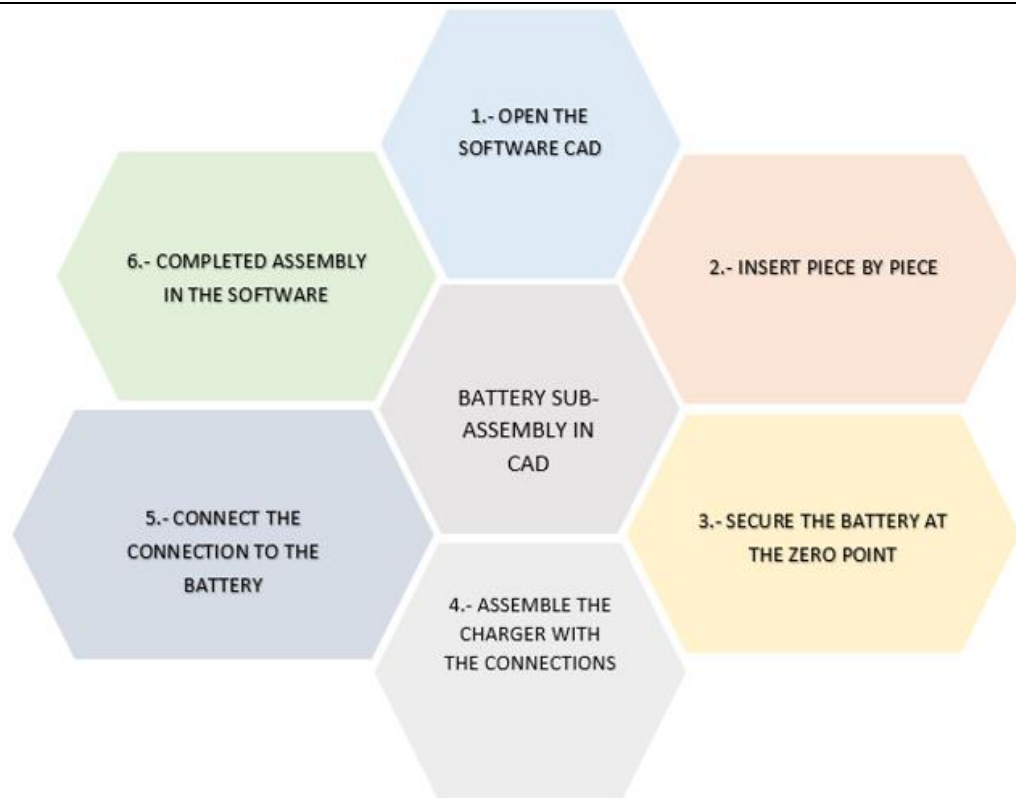


Figure 5. Steps in the modeling of parts with the software CAD.

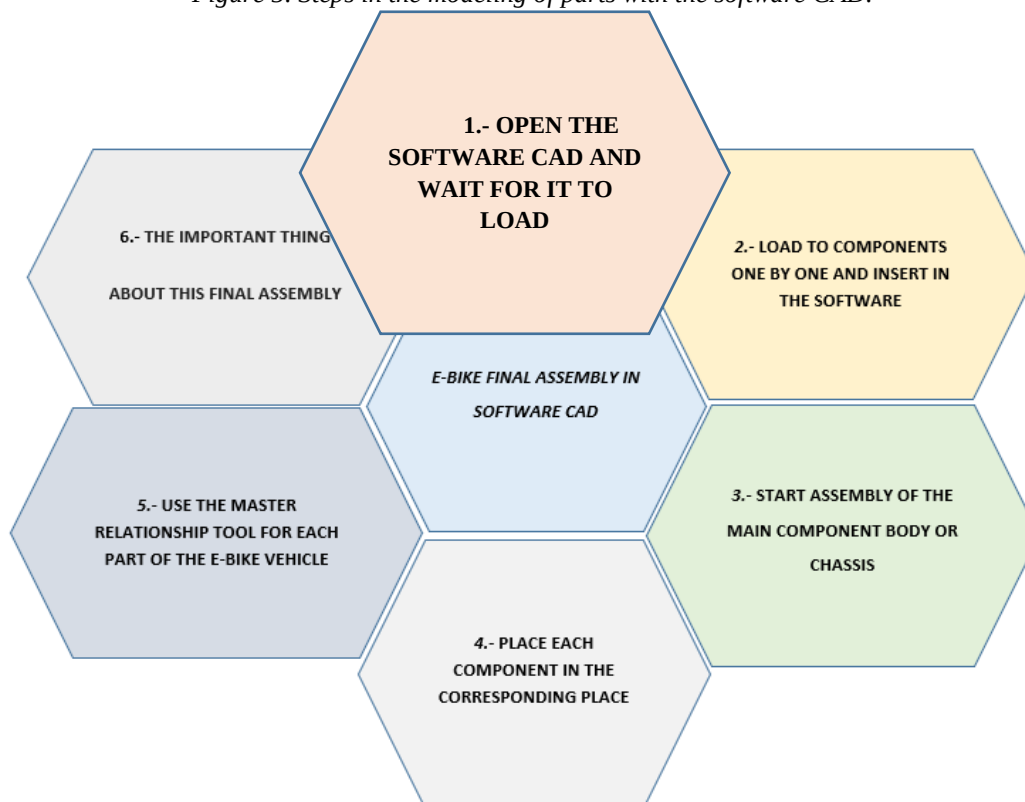


Figure 6. Steps in the modeled of assembly with the software CAD.

The autonomy of the E-BIKE is obtained of the next equation:

$$\text{Autonomy (km)} = \text{Battery (Ah)} \times \frac{\text{Efficiency of system}}{3600} \times \frac{1}{\text{Power Consumption}}$$

$$\text{Autonomy} = 60 \text{ Ah} \times 0.85 \times \frac{3600}{2000 \text{ W}} = 91.8 \text{ Km}$$

The parts modeled on electric elements are shown in the figures 7 and 8.
Characteristics of the elements of E-BIKE

Characteristics of elemental parts of the power system

Component	Detail
Battery	72 volt lithium ion 60Ah
Motor	2000W
Wheel	Ultra-light
Structure	Aluminum / Carbon fiber
Time of recharge	4 hours
Autonomy with the maximum capacity	90 Km

This is the subassembly of the electric battery and the independent charger with its connections connected to the battery, this system must be assembled separately

so that it can be seen how it is connected and at the end the final rendering is applied so that it is displayed with more quality in the CAD software.

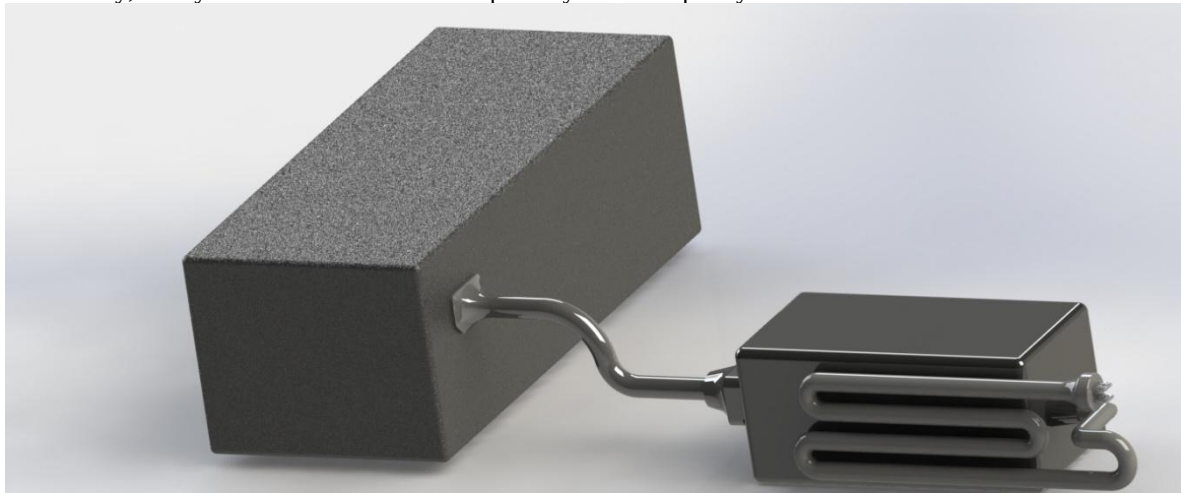


Figure 7. Battery and charger connection in CAD software.

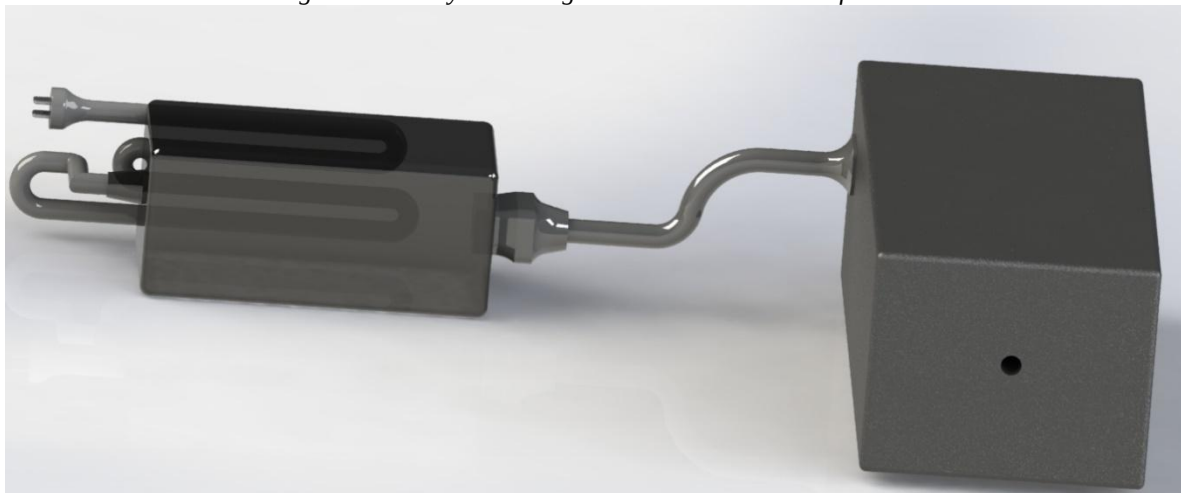


Figure 8. Battery and charger connection in CAD software.

The development of the E-BIKE model in the CAD software was detailed in every component, the colors and texturization were evaluated with different

options, the need of components were integrated as the design was developed, each step was analyzed and implemented (Figure 9).



Figure 9. Assembly of the E-BIKE

In this part of the assembly, the handlebar is the one that has the speed controller integrated and also includes the display so that the numbers can be clearly

seen, and at the end a rendering was applied so that the assembly could be seen realistically as is shown in figure 10.



Figure 10. Handlebar and their realistically

In this figure 11, the view of the handlebar is from the front and shows the components that were added, such as the speed controller, and in that same piece is the display, which is the mirror so that the mileage

numbers and the time between can be displayed. Other details, the rendering that was applied was realistic, and royal blue automotive paint was applied to make it look more original than the other e-bikes.



Figure 11. Handlebar and their realistically

In this view you can see the brake disc with the front tire. Here in figure 12 the disc was assembled but with specific shapes of geometry and position and the

paint that was applied was yellow so that it looked more original and with the most realistic rendering.



Figure 12. Brake Disk.

The design of the mechanism of the motor and the rear tire of the e-bike, this idea was analyzed and implemented in the CAD software and several steps were

carried out so that this system was united and both components moved on the same circumference and the rendered so that the difference in changes could be noticed (Figure 13).

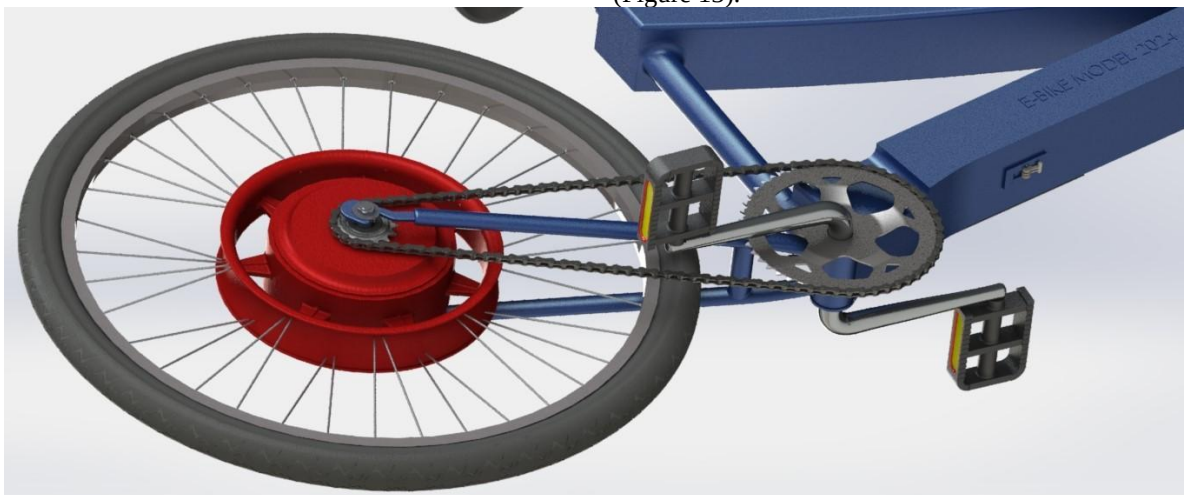


Figure 13. The engine and rear tire system were assembled.

The same mechanism is only in the 3D isometric view in the final rendering. In this part you can see the rear brake disc that is coupled with the engine and for

greater support, special screws were designed for both components (Figure 14).



Figure 14. The engine system was assembled

In this view (Figure 15) you can see the transparent appearance of the e-bike casing where the following components were placed; electric battery and the

charger with the connections for the battery and these were inserted into the housing or trunk of the e-bike.

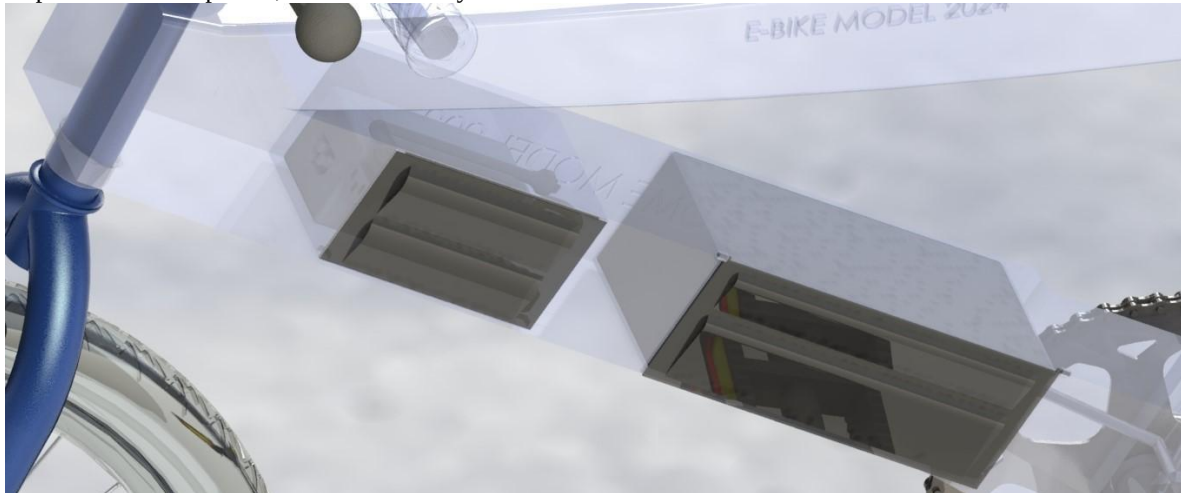


Figure 15. Trunk or casing of the e-bike where the battery and charger with their connections are stored.

In the view of figure 16, the transparent appearance was implemented in the CAD software, this in order for all the components of the e-bike to be displayed

since after having assembled the design, the rendering must be done in two parts, the first is with appearance with materials and the second is with transparency.



Figure 16. View the transparent appearance of the e-bike.

Table 2.

Advantages of electro mobility.

<i>Advantages of the e-bike in the world of electric mobility</i>	
1	Energy Efficiency and Low Consumption
2	Environmental Benefits
3	Mobility and Accessibility
4	Health Benefits
5	Low Operational and Maintenance Costs
6	Noise Reduction
7	Ease of Parking and Storage
8	Technological Innovations and Personalization
9	Promotion of Sustainable Mobility
10	Government Incentives and Support

Conclusions

In this final E-BIKE, quite a few operations were carried out in the CAD software, first were investigated advanced components of an electric bicycle, how it works and how they were assembled both in design and in the real process. This took time to analyze and implement in the CAD software, which is to carry out this type of complex projects. The objective of the new E-

BIKE design is for people in general to see the new improved E-BIKE modeling with high technology.

In addition to the development of sustainable mobility solutions, this project highlights the need for innovation in product manufacturing. Given the recent global interest in the environment and the all-too-common problem of road congestion, e-bikes have become

an affordable and efficient alternative to the car for millions of people. Some of the improvements, such as increasing battery life, reducing costs, and creating more advanced features, will only solidify the position of these solutions in modern urban transportation.

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Declaration of Competing Interest

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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