The Fourth Industrial Revolution and Beyond

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Abstract: The Fourth Industrial Revolution lies at the heart of major technological advancements we have been witnessing since the inception of the Twenty First Century. Successive industrial revolutions have been built upon well-established scientific theories that open new horizons for numerous potential applications. In human history, translating theoretical scientific ideas or research work into reality always presents a tremendous challenge to the industrial world. Examining the road to development of new technologies provides the humanity with a deeper insight in the working of science. It was found that scientific theories have to wait decades or more until they are translated to practical technologies. This has been the case, for example, of the quantum theory which was introduced in 1900 and developed in the 1920s before becoming the main driver of the third, fourth and possibly the fifth industrial revolution. The motivation of this paper is to highlight the scientific theories that form the cornerstone of the past industrial revolutions with a view to project their impact on the Fourth Industrial revolution and beyond. This paper focuses on the implications of scientific theories, particularly quantum theory, general relativity, and superstring theory, on current and future industrial revolutions. Towards this end, we explore the drivers of previous industrial revolutions and then we analyze the progress of science in various fields as applied to the emergence of new technologies that shape the future of humanity.

Index Terms: Industrial revolutions, technological development, scientific theories, human sustainability.

I. INTRODUCTION

The forth industrial revolution is the outcome of more than two centuries of scientific advancement in a wide range of disciplines. Industrial revolutions have witnessed several periods of development that allowed the transition from farming and feudal society to more advanced society of revolutionized mental and intellectual spirit. This transition allowed contemplating new horizons of prosperity and opulence. Industrial revolutions are characterized by phases and were introduced in the literature as first, second, third, and fourth industrial revolutions. Each phase is dotted with certain characteristics related to the predominance of specific source of energy, technical achievements and their impact on the economic system, but also specifically on the scientific driving framework or theory on which the particular phase is based.

Economy has been always an immanent feature of transforming societies. However, in our time it occurs at a faster and accelerating rate. Industrial revolutions have been always at the heart of major changes that impact severely the society. They also drive the economic system to new horizons of affluence and wealth, and create values that engage people and organizations in a new behavior. Technologies are involved in every aspect of human life, particularly in determining our interactions, smoothing our economies, impacting our environment, and channeling information upon which individuals and institutions are influenced. Therefore, it is essential to control the trend of technologies and their development in a way as to preserve human values.

In this paper we introduce first the outcomes of the first, second, and third revolution, followed by a wider discussion of the forth industrial revolution. In this approach we shall emphasize the impact of scientific theories and development of advanced materials as a major driver that triggers the development of the various industrial revolutions. In the last part of this paper we introduce some new ideas and theories that might shape the next industrial revolution and beyond. Finally, we discuss one of the greatest challenges related to maintaining human values in an exciting era of achievements and the possibility to move from earthly civilization to a more advanced cosmic civilization.

II. SCIENCE AND THE RISE OF INDUSTRIAL REVOLUTIONS

A long history of development of scientific ideas paved the way to the industrial revolutions. In 1656 Robert Boyle, in collaboration with Robert Hook build the first air pump, and they noticed the pressure-volume relation. The invention of the thermometer allowed Gay-Lussac to derive his law, which led shortly latter to the ideal gas law. Later designs conceived the idea of the piston and cylinder engine. This idea was then adopted by the engineer Thomas Savery allowing him to build the first engine. Although these engines are primitive, yet they attracted the attention of the prominent scientists of the time. Among these scientists is Sadi Carnot, who is considered as the father of thermodynamics. He provided a discourse on heat, power, and engine efficiency; and thus he marks the start of thermodynamics as a modern science. By the mid of the 18th century the scientific knowledge has been bountiful to accommodate real life applications, sparking the first industrial revolutions.

III. INDUSTRIAL REVOLUTIONS

Industrial revolutions announced a new era in human history. They impacted heavily the economic systems and promote shift of values toward creativity, trust and enterprise. Britain was the world's leading commercial nation, controlling a global trading supported by colonies in North America and the Caribbean, and reinforced by some political influence on the Indian subcontinent. The first industrial revolution started in Britain as textile and steel

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industry in the mid of the 18th century. It has been sparked by the development of mechanization of spinning and weaving. Coal was the main source of energy that empowers the emerging new technology. Steam engine has been the main technical achievement that promoted trains as a modernized transportation system, but also was a mean to drive the machinery required to energize the textile and steel products. In fact, textiles were the dominant outcome of the first industrial revolution in terms of employment and value of output and capital invested [1]. The first industrial revolution contributed to the spread of colonization and environmental degradation, but also succeeded in making the world wealthier. By 1850, the annual growth rates in Britain and some other European countries has risen to 2-3%, and per capita incomes were rising steadily [2].

The main driver of the first and subsequent industrial revolutions is thermodynamics. It constitutes an essential aspect of the foundation of physics, chemistry, and science in general. It was at the heart of technological developments including steam engine, internal combustion engine, cryogenics, and electricity generation. These are in fact the corner stones on which the early industrial revolutions relied.

The first industrial revolution has led to the emergence of a new wave of interrelated technologies. The second industrial revolution covers the period between 1870 and 1930. During this period, the transformative power of electricity has been materialized in the invention of the telephone, radio, television, home appliances, and electric lighting. On the other hand, the internal combustion engine has led to the invention of the automobile, the airplane, and ultimately building the associated ecosystems-including the laying down of the highway infrastructure. Breakthroughs in chemistry during the same period announced the synthesis of new materials, such as plastics, but also promoted the development of new processes such as the Haber-Bosch process [3], allowing synthesizing ammonia, and consequently leading to the manufacturing of cheap nitrogen fertilizer, a necessary ingredient to the emergence of the "green revolution" of the 1950s. The second industrial revolution allowed human societies to transform to a new era of prosperity benefiting from scientific advancement in a wide range of disciplines from sanitation to international air travel.

The science behind the third industrial revolution was developed slowly and was matured in the 1920s when the structure of quantum theory verge on a completion. In fact quantum theory, unlike most other theories, has been developed by many scientists over a period of many decades. Its implication on technology was crowned by the invention of the transistor in 1947. In fact, in 23 of December of that year William Shockley, John Bardeen, and Walter Brattain were credited with the invention of the first transistor, and thus opening the gate wide open to a new era where digital systems reigned the future of technology. However, digital technologies alone are not at the origin of shaping the third industrial revolution, but rather the way these technologies are embedded in changing the structure of our economic and social systems. The aptitude to store, process, and transmit information in digital form restructured almost every industry, and intensely changed the working and social lives of whole societies. The collective impact of these three revolutions has been at the core of a farfetched increase in wealth and opportunity, but also a drawback on global values when economic systems are endangered.

IV. THE FORTH INDUSTRIAL REVOLUTION

The third industrial revolution is branded by a digital age where general computing, software development, internet, and a widespread digital infrastructure are shaping the rising technologies. The forth industrial revolution, not only addresses new computing systems, but also introduced an innovative new digital based technologies, such as Blockchain and distributed ledger technologies, the internet of things, artificial intelligence and robotics, advanced materials, nanotechnology, virtual and augmented realities, energy capture, storage and transmission, space technologies, and geoengineering. The lines between technologies are becoming blurred. In this paper we shall restrict our discussion to just few disciplines shaping the forth industrial revolution that are expected to have a sweeting and vital impact on human prospect.

A. Digital Computing

Digital computing has been the main technology behind the third industrial revolution. Advances in computing originate from innovation of materials, and the architectures that have been developed to process, store, and manipulate information. Moore's Law is a measure of how fast digital systems are advancing [4]. It is based on the observation that the number of transistors per unit area has doubled every 18 months to two years since mid-1960s. This means that computers, and digital systems in general, have become smaller and faster at an exponential rate. This progress allowed the emergence of significant new technologies such as the mobile phone and other digital systems. The stunning reduction in costs and the associated increase in performance render Moore's Law untenable. Maintaining Moore's Law poses a challenge. For several years, there has been a concern among chip manufacturers and material scientists that the reduction of transistor size has a limit. The increase in speed and decrease in power usage of transistor have already come to an end a decade ago. The size of transistors reaches 14 nanometers, smaller than a virus. 10 nm chips entered in production by 2017 with plans to reach 7 nm chips in the coming few years. In silicon, 5 nm may represent the physical limit for transistor size. Researchers at Berkely have used carbon nanotubes and molybdenum disulfide to create a 1 nm wide gate transistor [5]. As a result, Moore's Law becomes commercially impossible. Pock's Law, a complement to Moore's Law, predicts that realizing smaller chips doubles every four years. The complexity of chip manufacturing has recently extended this period to around 2.5 years [6]. These developments my impact constantly the digital age, and may open new gates for further applications in other disciplines.

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B. Quantum Computing

The quantum theory boosts the progress in digital systems to a new era of development. Quantum computers used the strange laws of quantum mechanics to rethink the process of computing. Instead of using transistors as basic elements for binary logic, quantum computers employ quantum bits, or qubit. Bits are limited to being 0 or 1, whereas qubits exist in superposition, with probability of being in either state until measured, and thus enable them to simultaneously simulate multiple states. Another weird property of the quantum world is entanglement. This allows multiple qubits be connected so that measuring the quantum state of one qubit provides information about other qubits. Therefore, quantum computers can be designed to use quantum algorithms to create probabilistic short cuts, and thus providing suitable answers to difficult mathematical problems that would require much longer time for classical computers to solve. However, quantum computers remain an engineering dilemma. Qubits are difficult to create and maintain in a stable system. To achieve stability, component temperatures may be kept very close to absolute zero. Nevertheless, theoretical aspects shed light on new ideas for developing quantum algorithms and for promoting the emerging field of quantum machine learning.

C. Artificial Intelligence and Robotics

Artificial intelligence (AI) is a device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals [7]. AI will impact the world in profound ways, and will introduce new vision for humans to contemplate the changes impacting the society. However, this is not without risk; since the working of machine-learning algorithms remain opaque to most people, and these issues may reflect socially undesirable biases that require rectification. Modern artificial intelligence techniques are universal and are too numerous to give a full account of their diversity. Frequently, when a particular technique reaches conventional use, it escapes the domain of artificial intelligence; this phenomenon is described as the AI effect. Examples of AI include medical diagnosis, playing games (such as chess), autonomous vehicles (such as self-driving cars), and image recognition in photographs, predicting flight delay, climate modeling, and search engines (such as Google search). Al applications are not restricted only to informing decisions, but also to making them. Future development of AI will allow machines to learn from observation and decipher human values. Robot may learn to teach students, fly aircraft, achieve search and rescue operation, and perform surgery. Following this path, the combination of AI and robotics will constitute a source of power, accountability, responsibility, and will thus require extensive governance. However, it is to be recognized that AI may exhibit disruptive impact on society and economy.

D. The Internet of Things

The internet of things is one of the important pillars of the fourth industrial revolution. This technology involves connecting a range of smart sensors that gather data, and process it into a prescribed form according to need. The data is then communicated to other devices or individuals to meet the objectives of a system or user. It is estimated that the IoT devices will grow from about 15.4 billion devices in 2015 to 75.5 billion in 2025 [8]. This will enhance appreciably the connectivity in every part of life, and will link together global economies in a novel way. It is estimated that the impact will be representing 11% of the world economy [9]. It is estimated that $14 trillion could be added to the global economy by 2030 [10]. The application of IoT requires the development and deployment of several processes: first, use of sensing devices that communicate and perform an action, such as opening a window or moving an object; second building the communication infrastructure that connect these devices together; third implementing a secure data management system that collects and distributes the data generated by the devices for use by the next process; finally, the applications that use the data and provides services to organizations of services.

IoT is not a technology devoid of risks. Several challenges are to be met. These risks may affect not only companies employing the system, but also the users and the public. This may occur when, for example, individuals and firms become reliant on IoT system at the detriment of important skills. In addition, new fragilities may emerge when connectivity and power conditions are not met. One of the most important barriers to integrate IoT in industry is the lack of standards and security. Cybersecurity is a standard risk, and the challenge in IoT requires the management of multiple risks, such as stopping the use of insecure devices to attack third parties, preventing individuals or smart systems from wresting control of IoT devices or systems with the objective of intimidating, steeling, or causing harm to private and public services. Security issues are also associated with worries about data privacy and cross-border data communication. Setting procedure and protocols for storing, using and sharing data is a crucial issue if global data flows are to produce a clear picture of the IoT potential.

E. Nanotechnology

Nanotechnology is the manipulation of matter on an atomic, molecular, or manometer scale. Among the technological goals is the fabrication of macroscale products. The national Nanotechnology Initiative defines nanotechnology as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers. At this dimensions, quantum mechanical effects become important. Nanotechnology as defined by size includes a range of disciplines such as surface science, organic chemistry, biotechnologies, semiconductor physics, microfabrication, energy storage, neurotechnologies, etc. Research and applications in these fields exhibit a wide spectrum ranging from conventional device physics to direct control of matter on the atomic scale. Nanotechnology will certainly shape the future of applied science in the coming decades, with applications in nanomedcine, nanoelectronics, biomaterials and energy production. Nanotechnology may render existing medical applications cheaper and easier to use in places like general practitioner's office and at home [11] In addition cars, for example, can be manufactured with nanomaterials so they may need fewer metals and less fuel to operate [12]. On the other hand, nanotechnology may raise many issues associated with concerns about toxicity and environmental impact of nanomaterials and their impact on global economics. Because of their industrial and military applications, governments have invested billions of dollars in nanotechnology research. Through 2012, the USA has invested $3.7 billion, the European Union has invested $1.2 billion, and Japan has invested $750 million.

Promising applications of nanotechnology include attempting the development of diesel engines with cleaner exhaust fumes, developing the field of tissue engineering, mimicking the nanoscale feature of a cell's microenvironment to direct its differentiation down a suitable lineage [13], and supporting the growth of bone and also osteoclast resorption pits [14]. Researchers were successful in using DNA orgami-based nanobots capable of carrying out logic functions to achieve targeted drug delivery in cockroaches. It is anticipated that the computational power of these nanobots can be scaled to that of Commodore 64 computer [15]. An area of concern is the impact of nanomaterials on human health. Therefore, it is advocated that nanotechnology be regulated by governments. Certain research agencies are conducting research to evaluate the potential health effects arising from exposure to nanoparticles [16] [17]. In addition, nanofibers are extensively used in a variety of products such as aircraft wings and tennis rackets. Health concerns may arise from inhaling airborne particles and nanofibers causing pulmonary diseases [18]. As a conclusion, nanotechnology may shape the future of the forth industrial revolution, and in the same time, addressing its impact on the environment and human beings will constitute a top priority.

F. Advanced Materials

The science of advanced materials will have an important impact on all aspects of the forth industrial revolution. These materials have a wide variety of applications ranging from energy generation to electronic systems. Their impact will affect the supply chain, transform the environment and modify consumption. The world needs these materials to satisfy increasingly demanding performance requirements, particularly in applications such as electric vehicles, drones, smartphones, flexible displays, high speed internet, smarter integrated circuits, etc. Among these materials are metamaterials that exhibit negative refractive index and have a wide range of applications, such as invisibility, medical devices, smart solar power, optical filters, radomes, high frequency battlefield communication, lenses for high gain antennas, improving ultrasonic sensors, and even shielding from earthquakes [19]-[22]. To put things in perspective, material advancements in just one system, semiconductors, have a revolutionized impact on the electronic industry. The advancement of computing and communication technologies stems from improvement in semiconductor technology. One of the challenges facing societies is to make the use of advanced materials ecologically responsible. This approach features low toxicities with minimum damage to the environment. Forcing the manufacturers of new materials to comply with new rules to protect the environment will represent a great challenge.

G. Space Technologies

The space age started with the launch of the satellite Sputnik in 1957. Since then a tremendous progress has been achieved in exploring other planetary systems as well as the planet Earth. The Forth Industrial Revolution will witness an ever expanding applications and data gathering about the working of the Universe. Recently, LIGO and VIRGO detected for the first time gravitational waves, and models were developed to explain the origin of heavy elements in the Universe. On the other hand, commercial companies such as SpaceX and Blue Origin, have been established to reduce appreciably the costs of boosting into orbit. NASA has plans to send people to the Moon and beyond, and SpaceX has been advocating this idea as well. Space tourism and asteroid mining are among the future programs set Space agencies around the world. The next few decades may witness a new era of space exploration and possibly establishing space-based resources for manufacturing and commercialization. One important program using nanotechnology (carbon nanotubes) is the space elevator. It may open a new platform for launching satellites and visiting other bodies in the solar system. The outcome of these endeavors has the potential to reduce the pressure on terrestrial resources.

Despite such potential, the World Economic Forum considered space technologies as benign, and their benefits are limited when compared to technological areas. Certain scientists find this result as surprisingly astonishing given the cutting-edge applications and hardware required for satellites, aeronautics, space exploration, climate modeling, exploration of earth resources, communication systems, and earth science. One has to realize that space technologies are a unification of computing, advanced materials and energy technologies, all of which ranked high in a recent *Global Risk Report* benefit scale.

V. ENVISIONING THE FUTURE

A. Quantum Entanglment

Advances in physics and experimentation have appreciably impacted the humanity and drive towards a new era of prosperity and opulence. At present we have three major theories that describe our perception of the world around us. These are mainly quantum mechanics, special and general theory of relativity, and superstring theory. As we have seen, quantum mechanics shaped the digital age of the third industrial revolution, and still has deep roots in many disciplines of the fourth industrial revolution. However, the quantum theory didn't deliver all its secrets. There remain some gaps in our understanding of the theory. One potential application of the theory may emerge from considering the outcome of proven entanglement experiments. Towards this end, let us consider small particles described by quantum mechanics. For these particles there is no definitive state to settle in. Instead,

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quantum particles exist as a group of probabilities, or in other words they exist in several states at the same time. Thus particles spin up and down until they're measured, where they seem to "choose" a state and stick with it. A particle subject to this process is said to have collapsed wavefunction as if all of its various potential states have fallen away to reveal the one state it settled on. Even weirder, when two particles become "entangled," they will maintain a sort of causal relationship with each other, no matter their distance in space and time. If the spin of one of the particles is up, for example, then its entangled companion would instantly collapse into a spin down state, even if it's on the other side of the universe. That either means that one communicated with the other instantly, or the state of each particle only popped into existence once one was measured. This idea of entangled particles can be exploited to build up an “instantaneous” communication system where the speed of light is no longer considered as a limit for communication. This progress, if realized, may impact the interplanetary communication system and beyond.

B. Nuclear Fusion

Quantum mechanics and special relativity provide us with information about the nature of forces operating at the heart of the atomic nuclei. Nuclear fusion is a source of clean energy mimicking the nuclear processes taking place at the core of the Sun and all main sequence stars. In this process four atoms of hydrogen are fused to produce an atom of helium. The difference of mass between the initial reacting hydrogen atoms and the produced helium atom is liberated in form of energy ($E = mc^2$). Early fusion experiments started in the early 1970s, and appreciable progress has been realized since then. Two approaches were set to realize the nuclear fusion; namely magnetic confinement using toroidal machine (Tokomak) or inertial confinement driven by lasers. It is expected that fusion will be the main source of energy in the coming few decades. This will impact heavily the world’s economic system as well as the environment.

C. Superconductivity

Another important outcome of quantum mechanics is the fabrication of superconducting materials. The first experiment was conducted by the Dutch physicist Heike KamerlinghOnnes in 1911. He found that the resistance of mercury is reduced to zero when cooled to liquid helium temperature. Since then many superconducting materials have been developed. The scientific community has to wait until 1957 to set an adequate theoretical explanation of superconductivity. In fact, in that year, the complete microscopic theory of superconductivity was proposed by John Bardeen, Leon N. Cooper, and Robert Schrieffer (BCS theory). In contrast to normal conductors where conduction is determined by the flow of single electrons, conduction in superconductors is achieved by a coherent flow of pair of electrons (also called Cooper pairs). The next development was in 1986 when J. Georg Bednorz and K. Alex Muller discovered the first high temperature superconductivity in a lanthanum based cuprateperovskite material, which had a transition temperature of 35 K. Ching-Wu Chu replaced lanthanum with yttrium (making YBCO) and found that the critical temperature was raised to 92 K, which is in the domain of refrigeration of liquid nitrogen (77 K). Further research works on a variety of materials resulted in critical temperature of 136 K. The top objective of research on superconductivity is to create a room temperature superconductor. Such an achievement may revolutionize science and technology in many disciplines, particularly in computing and electronic systems. It may have a drastic impact on industry and economy.

VI. PLANET EARTH: TOWARDS A COSMIC CIVILIZATION

It is interesting to ask whether we are the only civilization in this vast universe or there are other technical civilizations flourished over time in our Galaxy and other galaxies. We have to realize that the planet Earth can be compared to just a dust particle floating in this universe. Statistical analysis of recently discovered planets around other stars shows that there are a great number of planets in the habitable zone around certain stars capable of harboring life. In order to appreciate as to where exactly the human civilization stands in the cosmos, and considering hypothetically that other technical civilization exist, Nikolai S. Kardashev- a Russian astrophysicist- set a scale to measure how advanced is a technical civilization, based on the amount of energy they are capable of harnessing. Kardashev came up initially with tree types of cosmic civilizations, which has now been extended to seven types depending on the capability of harnessing energy, communication technology, and other advanced technologies. We shall restrict our discussion to just the first three types of civilization. Type 1 civilization, also called planetary civilization, has the potential to harness all the energy of its home planet, including energy that it receives from its star. Our civilization is far from being able to achieve these criteria. MichioKaku feels that a type 1 civilization should be capable of controlling earthquakes, volcanos, tornados, the weather, and probably building ocean cities. He estimates that humans need 100-200 years to be classified as type 1 civilization.

Type 2 civilization, on the other hand, also known as interplanetary civilization, has the potential to harness the total energy of a star. One idea introduced by the physicist Freeman Dyson suggests that the star is completely enclosed by what is called Dyson Sphere in order to capture all its emitted radiation. It will take human civilization another 1000-2000 years to reach this level.

Type 3 civilization has the potential to harness the energy of the entire galaxy. It will take human race 100000 years to become Type 3 civilization, by then, probably we would never exist.

An important drawback of the above classification of technical civilization in the universe is the neglect of human values. Poverty, inequality of sharing resources, economic system, are just few factors that may have drastic impact on the demarche of civilization.

One of the important questions is whether the human race has acquired enough scientific knowledge to start the cosmic race. The potential application of general relativity may

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have several decades to wait. Basic applied research in this area involves manipulation of spacetime for the purpose of space travel.

Recently, the Mexican theoretical physicist Miguel Alcubierre presented a speculative idea, using the theory of general relativity, to build up a faster than light spaceship [23]. In his proposal, a spacecraft could achieve apparent faster-than-light travel if a configurable energy-density field lower than that of vacuum could be created. A spacecraft would move by contracting space in front of it and expanding space behind it, resulting in effective faster-than-light travel. To test this idea, a researcher team led by Harold White in collaboration with Richard Juday at the NASA Johnson Space Center and Dakota state University, build up a warp-field interferometer experiment to detect a microscopic instance of a wraping of spacetime. The NASA research team has postulated that their findings could reduce the energy requirements for a spaceship moving at ten times the speed of light [23] [24]. By harnessing the physics of cosmic inflation, future spaceships crafted to satisfy the laws of physics might actually be able to get unthinkably fast and without adverse effect [25].

Superstring theory and the more general M-theory are the ultimate theories in physics set by scientists during the past few decades. One particular aspect of these theories is that they evolve in 11 dimensional manifold. The world we perceive consist only of three dimensions of space and one dimension of time, and there are seven missing spacetime dimensions. Certain scientists tried to overcome this problem by reducing the unseen dimensions to Planck scale by a mathematical process known as compactification. However, if we accept that the human mind is limited in its perception, the idea of higher dimensions may reflect a reality beyond our mind. In this case, an advanced civilization capable of manipulating these extra dimensions may master communication systems, interstellar travel, and advanced technologies. The realm of higher dimensions may require centuries before being mastered with unknown impact on human values, technologies, resources, and economic system.

VII. CONCLUSION

The Fourth Industrial Revolution outlined in this paper involves a broad range of disciplines. Emphasis was on the level of technology attained and the expected future development. The potential drawbacks in each of these disciplines, as well as the impact on human values are discussed. Scientific theories such as thermodynamics and quantum mechanics are shown to have decisive impact on shaping the industrial revolutions. It was shown that quantum mechanics didn't deliver all its secrets, and new developments may encompass revolutionized communication system where there is no restriction on the speed limit. It was argued that nuclear fusion may become an ultimate source of energy. Room temperature superconductivity, if realized, may impact heavily a wide range of technologies. In the last section of this paper we discussed the future place of the planet Earth in cosmic perspective. The criteria necessary to become a cosmic civilization were explored.

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