International Journal of Formal Sciences: Current and Future Research Trends (IJFSCFRT)
ISSN: 2790-7945

https://ijfscfrtjournal.isrra.org/index.php/Formal_Sciences_Journal/index

"*Materionics*"—A New Term for the World of Science, Engineering, and Technology

M. Hossein Siadati[a*], Mohsen Mirzaee-Sisan[b]

[a,b]*Materials Science and Engineering Faculty, K. N. Toosi University of Technology, Tehran, Iran*
[a]*Email: siadati@kntu.ac.ir*
[b]*Email: sisan.materionics@gmail.com*

Abstract

The advent of functional materials yielding electro-ceramics, electro-polymers, piezo-electrics, semi-conductors, nano-biomaterials, and other electro-material concepts has undergone the focus of many scientific and creative endeavors. In favor of creating and defining a term covering under its *umbrella* all of these concepts, we propose the designation **"*Materionics*"** taken from the first and second halves of the two words "***materi***als" and "electr***onics***," respectively. The ever-growing trend of overlapping activities in the two engineering fields of Materials Science and Electronics accentuates this necessity. With the introduction of *Materionics*, once it has flourished, we expect that a new wave of understanding will engulf and overtake the scholars of this new field and that their contributions in the disciplines having overlaps will be most synergistic. Inevitably, goods and services that *Materionics* could yield will expeditiously become ubiquitous in modern life and civilization.

Keywords: Materionics; electronic materials; functional materials.

1. Introduction

1.1 Definition of Materionics

Today's technologies involve many functional materials and their related components and systems which are mostly the results of modern Materials Science and Electronics [1-3]. During the past decades, scientists have used various names to delineate these functional materials, such as electro-ceramics [4], electro-polymers [5], piezo-electrics [6], semi-conductors [7], and nano-biomaterials [8]. Encouraging a common dialogue to consolidate the research activities in the two engineering fields of Materials Science and Electronics, we propose a new interdisciplinary field to be called *Materionic* Engineering, or "*Materionics*" for short, composed of the first and second halves of the words "***materi***als" and "electr***onics***," respectively. We firmly believe that all the above concepts can come under this umbrella term.

----

* Corresponding author.

The main idea of introducing and encouraging *Materionics* revolves around training and inspiring a new generation of engineers and scientists whose gathered knowledge will consist of the overlapping features of both Materials Science and Electronic Engineering, working in synergy as a team rather than independently, creating and flourishing an interdisciplinary field called *Materionics*. Indeed, our proposal has been adopted from the circumstances that led to the introduction and widespread use of the term Mechatronics [9-11], an interdisciplinary field of Mechanical and Electronic Engineering whereby wonderful and remarkable breakthroughs have hitherto emerged in the world of the pertinent fields. Once taught at universities, similar to Mechatronics, the emerging scholars of *Materionics* will soon manifest their achievements surpassing well beyond those of either of the two engineering fields.

Nonetheless, a word composed of the two existing English words may convey quite a restrictive meaning of the term *Materionics* as a whole. Nowadays, scientists and engineers would have to dissect matter for a deeper understanding of its behaviors at the quantum level and beyond. Therefore, *Materionics* can be broadly defined as the field of understanding elementary particles at the microscopic scale for applications in the macroscopic world. This definition readily reveals the two main perspectives of science and engineering. The former, inclusive of sciences of materials, physics, chemistry, mathematics, computer, and even psychology, constitutes the core of the latter. Fig. 1 illustrates some disciplines that currently participate very actively in *Materionics*. The question mark left in Fig. 1 will perhaps be specified by specialists of other fields to be accommodated, in the near or ever future, under this umbrella.

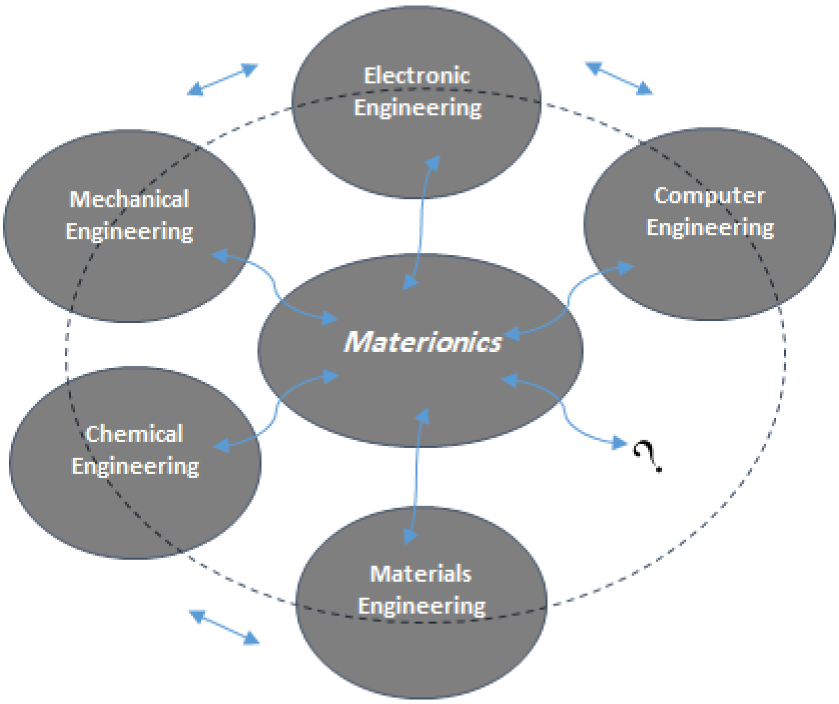

Figure 1: The inherent multidisciplinary nature of *Materionics*.

One should notice that nearly fifty years have elapsed during which academia and industry have paved the path toward the development of Mechatronics. The term was coined in 1969, however, the first conference promoting it was held over 20 years later in 1990, and ever since, in the course of the last 30 years, the term Mechatronics and the engineering design philosophy that it encompasses began to develop a really clear definition and scope. Today, after over 50 years, its impact has been so far-reaching that currently, some highly prestigious universities are offering Mechatronics at both undergraduate and graduate levels. Consequently, it is indisputable that, with the road paved from the Mechatronics trend, *Materionics* shall realize and flourish its potentials in a much shorter time.

2. Discussion

2.1 The art of manipulating materials

Since 1929 when Hubble discovered that the universe is expanding [9], scientists have been endeavoring to figure out the nature of this phenomenon. They have found out that, some 13.7 billion years ago, the matter came into existence all of a sudden, which has become known as the Big Bang Theory [10], albeit some criticisms have been leveled at this theory [11]. Albert Einstein's most famous equation ($E = mc^2$) has proven that energy (massless) and matter are of the same nature; matter is a condensed form of energy. And, it is also well known that material is any type of matter. Materials behave differently as a result of variation in the movement of electrons, which inherently depends on the interatomic bonding. Atoms provide housing and residence to the electrons, and upon interactions with each other, interatomic bondings form. For instance, sea of electrons forms metallic bonding, providing free electrons for ease of electronic conductivity, while sharing of electrons constitutes the covalent bonding, whereby the electrons are bound from free movement and thus dielectric/insulative properties emerge, such as in electro-ceramics. Small addition of nanomaterials such as graphene to some polymers produces nano-biomaterials which possess adequate conductivity for biomedical applications such as tissue engineering and regenerative medicine. The electronic properties of nano-biomaterials is also related to the movement of electrons that ultimately determines their behavior. Biologists often look for electronic transfers and configurations at the subatomic level that provide many aspects of the cells' behaviors [12-17].

Interestingly enough, the idea behind the introduction of *Materionics* revolves around educating and training professionals who understand the behavior of materials and the movement of electrons simultaneously. Materials scientists have been involved with the structure-property relationship of materials, and electronic engineers have been eager in learning how the electrons move and control their movements for various applications. With the advent of *Materionics,* the scientific community will soon have professionals possessing a deep understanding of both the structure-property relationship as well as the mechanism of electronic movements that cause the various properties to develop and manifested in different materials. Pursuing such deep understanding, the materials and devices produced and made available for the convenience of mankind will be glorious.

Furthermore, scientists have postulated that the gigantic but invisible part of our universe consists of dark matter. By and large, there are two approaches to the concept of dark matter. The first approach assumes that dark matter is made up of the familiar particles as described in the standard model of particle physics [18] but behaves unlike those of normal matter in terms of emanating/reflecting light. Nonetheless, in the second approach, likely some as-yet-undiscovered subatomic particles other than the ordinary atoms, protons, neutrons, and electrons form the dark matter and thus require a new comprehension above and beyond what the current standard model presents [19, 20]. There have been periods mankind used materials without knowing the mechanism of their operation, or breathed the air without knowing he was surrounded by it for a long time. What if we have always been surrounded by dark matter and we are still ignorant about it? Consequently, the more we learn about materials and the way their electrons move and behave in them, the better we can manipulate and control them to our advantage. In either case, it is hoped that our proposed field, *Materionics,* would lead to a transparent understating of the dark matter in that it, in addition to describing the nature of its constituents, clearly manifests the motion of the fundamental particles such as the electrons.

In what follows, we shall present an overview of some of the more important instances involving *Materionics*.

2.2 Catalysts

In the age of modern technology, catalysts play a pivotal role in both academia and industry and have enormous potential in our daily lives. Some of the applications of these materials include fine chemicals, pharmaceuticals, petroleum, polymers, electronics, and environmental purposes [21]. Besides having chemical aspects, catalysts lower environmental pollution as well as manufacturing costs and are also the most important items in the processing and manufacturing of electronic components. These advantages have escalated worldwide demand for these materials [22].

In catalysts, the movement of electrons is a vital parameter determining their activity and selectivity, and the arrangement of electrons indicates how they perform [23]. Every catalytic process, like any other chemical process, is inherently contingent on the operating mechanism of the electrons involved [24], whose clear definition can be sought in *Materionics*. For instance, Sun and his colleagues [25] simulated the influence of catalytic parameters used in the cathode of a fuel cell. Their simulation results have shown that the electron conduction and proton migration parameters are as important as the oxygen penetration to determine the rate of electrode reaction in the fuel cell. Also, Reference [26] found that, in the structure of metals, a direct relationship exists between catalytic activities and low-energy local electronic fluctuations.

Another key point in catalysis may be realized by the Heisenberg's uncertainty principle [27] which expresses the movement of electrons. Perhaps in the near future, by using it, we can justify the attitude of electrons in catalysis and thus further optimize the efficiency of catalysts. We believe that it will be viable in light of *Materionics,* the apt field providing a level of insight that the elementary particles and their properties and reactions, as well as the attitude of the elements composing the catalysts, are considered at once.

The objectives of *Materionics* in catalysts are never confined to the aforementioned. *Materionics* can also express the relationship between catalytic and electronic properties of semiconductors, and of course the chemical and electronic properties of matter in general. As a result, we can say that two areas take part in the design and performance of catalysts: one is the movement of electrons and their properties, and the next is the knowledge of materials and the strategy to choose them. Considering the many valuable research works performed in both areas [28], in the not-too-distant future, the field of *Materionics* could definitely broaden their scope further.

2.3 Quantum computers

The design and manufacture of quantum computers are more important than you might think. The idea of quantum computers dates back to the 1980s, when Richard Feynman [29] suggested that computational methods should be transformed from the digital concept to a new world called quantum.

It was from 1994 onwards that information theory and quantum mechanics [30] have entered a new phase currently known as the quantum computing age [31]. Quantum computing is one remedy for redesigning transistors and electronic devices based on the quantum theory. More specifically, it implies that the transistor can be in smaller sizes, i.e., nanometer scale [32, 33]. Within this age, the term "qubit" (quantum bit) was first coined [34]. As it is typical and standard, in a binary system, a bit is the smallest and most basic unit of data storage on a computer. In an instant, a bit can take only one of the two values, zero or one, whereas in the quantum logic, a qubit can be zero, one, or both simultaneously [33]. In other words, in the case that a conventional computer can evaluate one process, a quantum system affords many processes [35]. As a matter of fact, particles such as electrons have the ability to spin in all directions in an instant [36], and this is one of the wonderful features taken into account in quantum mechanics from which one may discern again the footprints of *Materionics*. If an electron can spin in all directions and we can subsequently measure it, it means that we can perform numerous calculations at the same time, an approach the mechanism of quantum computers is predicated on [37].

2.4 Disease treatment

Even if we glance at the medical sciences, we can also appreciate the significance of *Materionics*. There is an innovative method for cancer treatment presented by Yoram Palti and his colleagues [38, 39]. This therapy employs an electric field that interferes with the proliferation of cancerous cells, on account of its influence on the objects that have an electric charge. As another example, a dependable method to quickly get rid of virus-infected cells is to utilize electron beam irradiation (EBI), which can destroy virus species [40]. Luchsinger and his colleagues showed that the EBI technique can eliminate the E. coli and Salmonella found in pigs and serve in the health of the food industry [41]. Also, the results obtained by Feng and his colleagues have demonstrated the effect of EBI on deactivating the recently identified coronavirus (COVID-19), although its exact mechanism of action is still unknown [42]. It seems that, by exploiting *Materionics* to investigate how the electron movements engage in the treatment, we may find how to treat a variety of serious diseases.

The above compelling examples suggest that wherever in the world of science and technology the elementary particles (e.g., electrons) and the properties of various elements and materials appear, *Materionics* will be present. In fact, *Materionics* will provide us with the simultaneous knowledge of the attitude of the elementary particles and of the identification and selection of the best materials for our desired applications.

2.5 Educational and industrial expectations

Considering the significance of the above-discussed examples and potentials, the academic-industrial programs covering topics in *Materionics* will definitely inspire a new generation of engineers and scientists in the coming years. In this regard, the K. N. Toosi University of Technology (KNTU) is in the process of executing a program in *Materionics* leading to a master's degree. In this program, students will be taught to more profoundly understand the overlapping features of the two engineering fields, Materials Science and Electronics, thereby becoming inherently qualified in both as prospective scholars of *Materionics*. With respect to the well-established record and successful experience of the KNTU in the multidisciplinary field of engineering, we highly expect that this forthcoming program will turn out to be very fruitful.

As per data from the U.S. Census Bureau [43], Table I lists the share of people employed as materials engineers in various industries over recent years. We readily notice that the largest share each year contributes to electronic component and product manufacturing. These staggering statistics, even more, necessitate establishing the field of *Materionics* and no doubt it will soon become an essential ingredient in enhancing the living standards of nations around the world. If materials engineers have caused such staggering statistics without much knowledge of electronics, the advent of *Materionics* will give birth to new scientists and scholars

Table 1: The share (%) of materials engineers employed by various industries in the U.S.A.[a].

Industry	2015	2016	2017	2018
Electronic component & product	20.9	23.5	18.1	20
Motor vehicles & motor vehicle equipment	14.7	12.4	11.8	12.6
Aircraft & parts	11.2	14.9	16.3	12
Machine shops; turned product; screw; nut & bolt	7.09	7.22	7.77	8.9
Iron & steel mills & steel product	6.87	4.87	6.31	6.85
Machinery	2.32	6.04	5.96	5.33
Railroad rolling stock	3.72	4.23	2.85	4.85
Navigational, measuring, electromedical & control instruments	4	3.48	4.05	4.47
Plastics product	5.07	3.57	3.16	2.65
Others	24.13	19.79	23.7	22.35

[a] Data from the Census Bureau ACS PUMS 1-Year Estimate [43].

capable of introducing and producing many novel materials and devices as a result of their combined grasp of both Materials and Electronics.

3. Conclusions

In a nutshell, we have proposed the umbrella term *Materionics* to provide and develop a common intellectual framework for the overlapping research activities in the two engineering fields of Materials Science and Electronics as well as the pertinent subjects. We discussed the contribution that this term will have toward some crucial cases such as catalysts, quantum computers, and disease treatment. In the world of catalysts, *Materionics* can describe their microscopic mechanism to improve their performance or, by combining their electronic and chemical properties, can develop much more efficient catalysts. In quantum computers, *Materionics* can further their feasibility and thus expand their applications by facilitating deeper insights into the movement of electrons in more advanced materials. In the realm of medicine, since most human cells are made of proteins, and the electric and magnetic fields affect their structure, *Materionics* can shed light on discovering and ovdercoming many dangerous diseases, even cancer or COVID-19. We conclude that no boundaries can be imagined for *Materionics*, particularly when the elementary particles such as electrons and the properties of various elements and materials are involved in the problem. Throughout history, it has been observed that wherever a synergy emerges between two or more disciplines—as the idea *Materionics* conveys—enormous inventions and achievements have materialized. Therefore, we hope that our suggested field will stimulate joint research studies in materials and electronics and introduce new horizons for functional materials at play in human lives. Future work will entail presenting expertise and experience that are expected of those who wish to be *Materionics* specialists.

Acknowledgment

This work was non-financially supported by K. N. Toosi University of Technology, the Materionics Group.

4. List of Figures

5. Conflict of Interest

The authors declare that they have no conflict of interest, or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] P. M. Vilarinho, “Functional Materials: Properties, Processing and Applications,” *Scanning Probe Microscopy: Characterization, Nanofabrication and Device Application of Functional Materials*, pp. 3–33, Jul. 2005, doi: 10.1007/1-4020-3019-3_1.

[2] R. Dorey, *Ceramic thick films for MEMS and microdevices*. 2011. Accessed: Dec. 19, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=J4eqjGWxEPMC&oi=fnd&pg=PP1&dq=2.%09R.+Dorey,+Ceramic+Thick+Films+for+MEMS+and+Microdevices+&ots=GbuqyunTeP&sig=u34tJyfQ1mnhibXS8fC2kfUSmfE

[3] S. Banerjee and A. Tyagi, “Functional materials: preparation, processing and applications,” 2011, Accessed: Dec. 19, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=FVvU6QhAt3YC&oi=fnd&pg=PP1&dq=Functional+Materials:+Preparation,+Processing+and+Applications+&ots=Q_NDxKItoy&sig=_Ew0t6ddTwn0CvvyCpXACaH9P3I

[4] R. Pandey, *Fundamentals of electroceramics: materials, devices, and applications*. 2019. Accessed: Dec. 19, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=LfF5DwAAQBAJ&oi=fnd&pg=PR13&dq=Fundamentals+of+Electroceramics:+Materials,+Devices,+and+Applications+&ots=p20CDgy1nO&sig=pjLjy04Rin4HPAtMPl6rc25DikM

[5] V. F.-A. microbiology and biotechnology and undefined 2005, "Natural polysaccharides as electroactive polymers," *Springer*, vol. 67, no. 6, pp. 735–745, Jun. 2005, doi: 10.1007/s00253-005-1931-4.

[6] M. C. Sekhar, E. Veena, N. S. Kumar, K. C. B. Naidu, A. Mallikarjuna, and D. B. Basha, "A Review on Piezoelectric Materials and Their Applications," *Crystal Research and Technology*, 2022, doi: 10.1002/CRAT.202200130.

[7] A. Behera, "Advanced Semiconductor/Conductor Materials," *Advanced Materials*, pp. 557–596, 2022, doi: 10.1007/978-3-030-80359-9_16.

[8] S. Ramakrishna, M. Ramalingam, and T. Kumar, *Biomaterials: a nano approach*. 2016. Accessed: Dec. 19, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=mobLBQAAQBAJ&oi=fnd&pg=PP1&dq=8.%09S.+Ramakrishna,+M.+Ramalingam,+T.+S.+S.+Kumar,+W.+O.+Soboyejo,+Biomaterials:+a+nano+approach.&ots=WlVVm0hnDE&sig=dcjeRfhCvTekZepBJgGfqDoWIEw

[9] M. M.-C. and Q. Gravity and undefined 2015, "Milestones of general relativity: Hubble's law (1929) and the expansion of the universe," *iopscience.iop.org*, Accessed: Dec. 19, 2022. [Online]. Available: https://iopscience.iop.org/article/10.1088/0264-9381/32/12/124002/meta

[10] S. Singh, S. K. Modak, and T. Padmanabhan, "Evolution of quantum field, particle content, and classicality in the three stage universe," *Physical Review D - Particles, Fields, Gravitation and Cosmology*, vol. 88, no. 12, Dec. 2013, doi: 10.1103/PHYSREVD.88.125020.

[11] J. C. S. Neves, "Bouncing cosmology inspired by regular black holes," *Gen Relativ Gravit*, vol. 49, no. 9, Sep. 2017, doi: 10.1007/S10714-017-2288-6.

[12] A. S.-G.-P. chemistry and physics and undefined 1980, "The living state and cancer.," *europepmc.org*, Accessed: Dec. 19, 2022. [Online]. Available: https://europepmc.org/article/med/6254102

[13] T. S.-I. J. of Yoga and undefined 2017, "Electrons in biology," *ncbi.nlm.nih.gov*, Accessed: Dec. 19, 2022. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5793004/

[14] T. Nezakati, A. Seifalian, A. Tan, and A. M. Seifalian, "Conductive Polymers: Opportunities and Challenges in Biomedical Applications," *Chem Rev*, vol. 118, no. 14, pp. 6766–6843, Jul. 2018, doi:

10.1021/ACS.CHEMREV.6B00275.

[15] R. J. P. Williams, "Electron transfer in biology," *Mol Phys*, vol. 68, no. 1, pp. 1–23, 1989, doi: 10.1080/00268978900101931.

[16] W. Zakrzewski, M. Dobrzyński, A. Z.-K.- Materials, and undefined 2021, "Nanomaterials application in endodontics," *mdpi.com*, Accessed: Dec. 20, 2022. [Online]. Available: https://www.mdpi.com/1270760

[17] Y. Engel, J. D. Schiffman, J. M. Goddard, and V. M. Rotello, "Nanomanufacturing of biomaterials," *Materials Today*, vol. 15, no. 11, pp. 478–485, Nov. 2012, doi: 10.1016/S1369-7021(12)70217-1.

[18] W. Cottingham and D. Greenwood, *An introduction to the standard model of particle physics*. 2007. Accessed: Dec. 20, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=Dm36BYq9iu0C&oi=fnd&pg=PA1&dq=18.%09W.+N.+Cottingham,+D.+A.+Greenwood,+An+Introduction+to+the+Standard+Model+of+Particle+Physics+(Cambridge+University+Press,+Cambridge,+ed.+2,+2007(.&ots=boDf171sPC&sig=5xG6iRa2xOIdgwotoCLpRUi1xL8

[19] A. Pontzen, F. G.- Nature, and undefined 2014, "Cold dark matter heats up," *nature.com*, 2014, Accessed: Dec. 20, 2022. [Online]. Available: https://www.nature.com/articles/nature12953

[20] E. Papantonopoulos, *The invisible universe: dark matter and dark energy*. 2007. Accessed: Dec. 20, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=hTOZfGqriikC&oi=fnd&pg=PA2&dq=+Dark+Matter+and+Dark+Energy+book&ots=T4paLlpZ5O&sig=tUmv11Pn5aa6zUyEycttXgo-E2I

[21] V. v. Ranade and S. S. Joshi, "Catalysis and Catalytic Processes," *Industrial Catalytic Processes for Fine and Specialty Chemicals*, pp. 1–14, Jan. 2016, doi: 10.1016/B978-0-12-801457-8.00001-X.

[22] R. S.-A. C. A. General and undefined 2004, "Future trends in the refining catalyst market," *Elsevier*, Accessed: Dec. 20, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0926860X03010007

[23] J. Richardson, *Principles of catalyst development*. 2013. Accessed: Dec. 20, 2022. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=GTIBCAAAQBAJ&oi=fnd&pg=PA1&dq=Principles+of+Catalyst+Development+book&ots=Oeh96HpVBL&sig=VdU_81Id4rVV60gO5_mL1ZAmkL8

[24] T. W.-A. in Catalysis and undefined 1960, "The electron theory of catalysis on semiconductors," *Elsevier*, Accessed: Dec. 20, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360056408606033

[25] W. Sun, B. Peppley, K. K.-E. acta, and undefined 2005, “An improved two-dimensional agglomerate cathode model to study the influence of catalyst layer structural parameters,” *Elsevier*, Accessed: Dec. 20, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0013468604012228

[26] L. Falicov, G. S.-P. of the National, and undefined 1985, “Correlation between catalytic activity and bonding and coordination number of atoms and molecules on transition metal surfaces: Theory and experimental evidence,” *National Acad Sciences*, vol. 82, pp. 2207–2211, 2022, Accessed: Dec. 20, 2022. [Online]. Available: https://www.pnas.org/doi/abs/10.1073/pnas.82.8.2207

[27] J. Vigoureux, D. C.-A. Optics, and undefined 1992, “Detection of nonradiative fields in light of the Heisenberg uncertainty principle and the Rayleigh criterion,” *opg.optica.org*, Accessed: Dec. 20, 2022. [Online]. Available: https://opg.optica.org/abstract.cfm?uri=ao-31-16-3170

[28] W. Yao, X. Xu, H. Wang, J. Zhou, … X. Y.-A. C. B., and undefined 2004, “Photocatalytic property of perovskite bismuth titanate,” *Elsevier*, Accessed: Dec. 20, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0926337304002516

[29] R. F.-Found. Phys. and undefined 1986, “Quantum mechanical computers.,” *cs.princeton.edu*, Accessed: Dec. 20, 2022. [Online]. Available: http://www.cs.princeton.edu/courses/archive/fall05/frs119/papers/feynman85_optics_letters.pdf

[30] … P. S.-35th annual symposium on foundations of computer and undefined 1994, “Algorithms for quantum computation: discrete logarithms and factoring,” *ieeexplore.ieee.org*, Accessed: Dec. 20, 2022. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/365700/

[31] P. W. Shor, “Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer,” *SIAM Review*, vol. 41, no. 2, pp. 303–332, 1999, doi: 10.1137/S0036144598347011.

[32] M. Zalba, J. Haigh, T. Yang, L. I.-H. Review, and undefined 2019, “Quantum Computing Using Silicon Transistors,” *vitacastle.com*, Accessed: Dec. 20, 2022. [Online]. Available: https://www.vitacastle.com/rev/archive/2019/r2019_04/pdf/P138-142_R4c03.pdf

[33] M. Horowitz and E. Grumbling, *Quantum computing: progress and prospects*. 2019. Accessed: Dec. 20, 2022. [Online]. Available: https://catalog.lib.kyushu-u.ac.jp/ja/recordID/5010239/

[34] B. Schumacher, “Quantum coding,” *Phys Rev A (Coll Park)*, vol. 51, no. 4, pp. 2738–2747, 1995, doi: 10.1103/PHYSREVA.51.2738.

[35] S. Akama, *Elements of quantum computing*. 2015. Accessed: Dec. 20, 2022. [Online]. Available: https://link.springer.com/content/pdf/10.1007/978-3-319-08284-4.pdf

[36] A. Khalid, “A Gentle Introduction to Quantum Computing,” 2012, Accessed: Dec. 20, 2022. [Online].

Available: https://www.physlab.org/wp-content/uploads/2016/03/Abdullah-Khalid.pdf

[37] R. Vrijen *et al.*, "Electron-spin-resonance transistors for quantum computing in silicon-germanium heterostructures," *Phys Rev A*, vol. 62, no. 1, p. 10, 2000, doi: 10.1103/PHYSREVA.62.012306.

[38] E. D. Kirson *et al.*, "Alternating electric fields arrest cell proliferation in animal tumor models and human brain tumors," *Proc Natl Acad Sci U S A*, vol. 104, no. 24, pp. 10152–10157, Jun. 2007, doi: 10.1073/PNAS.0702916104.

[39] E. Kirson, Z. Gurvich, R. Schneiderman, E. D.-C. research, and undefined 2004, "Disruption of cancer cell replication by alternating electric fields," *AACR*, Accessed: Dec. 20, 2022. [Online]. Available: https://aacrjournals.org/cancerres/article-abstract/64/9/3288/517864

[40] D. F. Mollenkopf, K. E. Kleinhenz, J. A. Funk, W. A. Gebreyes, and T. E. Wittum, "Salmonella enterica and Escherichia coli harboring bla CMY in retail beef and pork products," *Foodborne Pathog Dis*, vol. 8, no. 2, pp. 333–336, Feb. 2011, doi: 10.1089/FPD.2010.0701.

[41] S. Luchsinger, D. Kropf, … C. Z.-J. of F., and undefined 1996, "Color and oxidative rancidity of gamma and electron beam-irradiated boneless pork chops," *Wiley Online Library*, Accessed: Dec. 20, 2022. [Online]. Available: https://ift.onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2621.1996.tb10920.x

[42] G. Feng, L. Liu, W. Cui, F. W.-C. P. B, and undefined 2020, "Electron beam irradiation on novel coronavirus (COVID-19): A Monte–Carlo simulation," *iopscience.iop.org*, Accessed: Dec. 20, 2022. [Online]. Available: https://iopscience.iop.org/article/10.1088/1674-1056/ab7dac/meta

[43] Data USA: Materials Engineers, https://datausa.io/profile/soc/materials-engineers (2018).