Chapter

Introductory Chapter: The Testimony of Condensed Matter Physics - A Viewpoint on the Achievements and Their Applications

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1. A succinct testimony of advances in condensed matter physics

One of the important topics in the protuberant area of physics is condensed matter physics and it broadly encompasses the microscopic and macroscopic physical properties of materials. In condensed matter physics, the basic laws of general physics include quantum physics laws, electromagnetism, and statistical mechanics. There is a wide variety in the branch of condensed matter physics such as crystallography, metallurgy, elasticity, and magnetism. Again, this condensed matter physics is also known as solid state physics. Thus, basically, condensed matter physics deals with the solid state of substances. The study of condensed matter physics deals with the substances in their obstinate material or solid state by means of crystallography, quantum mechanics, electromagnetism, semiconductors, and metallurgy and looks after the theoretical concepts of materials science and so on. Further, the exploration comprises both crystalline and non-crystalline solids in which the position of atoms is in the form of ordered three-dimensional lattice, such as diamond and sodium chloride, and on the non-crystalline (amorphous) materials in which the position of atoms is more irregular, like in glass, respectively. Studies on condensed matter physics show significant properties in solid materials especially in the atomic scale. The structure and properties of materials in solids are a general subject matter of scientific community for epochs; however, a distinct area moving in the designation of solid state physics and did not materialized in anticipation of the 1940s. One of the largest branches of condensed matter physics is solid state physics. The industrial and solid state physicists developed that and only through the research on solid state materials, the scientific applications and innovations are made conceivable [1–5]. Gargantuan group of people of solid state physicists also transpired in Europe after World War II, more specifically in Germany, England, and the Soviet Union [1–5]. In the Europe and the United States, solid state condensed matter turns out to be a protuberant field based on its systematic explorations into semiconductors, dielectrics, magnetic materials, superconductivity, electron and nuclear magnetic resonance, and its relevant occurrences. However, in the period of Cold War, major researches focused on solid state physics were not limited to only solids, which led some physicists in the 1970s and 1980s to found the field of solid state condensed matter physics, which systematized the universal method used to scrutinize solids, liquids, plasmas, and

Period	Happenings/achievements/folks	Nobel laureates	Ref.
-3000 BC	Stone Age		[1–4]
3000–	Bronze Age		
500 BC	Iron Age		
500 BC-	Demokritos: idea that an “atom” exists		
Early	Aristotle: all metals are a mixture of sulfur and mercury		
Theories	Revival of the idea of an atom by Newton and others		
ca. 1700	Thomas Newcomen builds the first commercial steam		
Eighteenth	engine to pump water out of mines		
century	Musschenbroek and Kleist developed the Leyden jar, an		
1712	early form of capacitor		
1745	Alois Senefelder invents the lithography printing		
1796	technique		
1799	George Medhurst invents the first motorized air		
Nineteenth	compressor		
century	Physics is considered to be “solved” by classical		
1802	mechanics, electromagnetism, and thermodynamics.		
1820	Metallurgy becomes important and is described by		
1839	empirical laws		
1859	Humphry Davy invents the arc lamp		
1853	Classification of crystal symmetries (Brillouin)		
1879	Edmond Becquerel invents a method for the photovoltaic		
1897	effect, effectively producing the first solar cell		
	Gaston Planté invents the first rechargeable (lead acid)		
	battery		
	Wiedemann-Franz Law (for thermal and electrical		
	conductivity)		
	Hall effect		
	Thomson discovered the electron using a cathode ray tube		
1900	Drude (and Lorentz): classical electron gas in metals	Onnes 1913	
1911	Onnes (and Holst) discover superconductivity in mercury	Van Laue 1914	
1912	Van Laue discovers diffraction of X-rays by crystals	H&L. Bragg 1915	
1913	W.H. & W.L. Bragg use X-rays to analyze crystals	Einstein 1921	
1905	Fundamentals of photoemission (Einstein)	Raman 1930	
1907–1913	Specific heat of solids (Einstein, Debye, and Born)	D., T. 1937	
1920s	Raman scattering	Anderson, Mott, Van	
1925–1928	Electron diffraction (Davisson, Thomson)	Vleck 1977	
1926–1928	Quantum mechanics (Schrödinger, Heisenberg, Pauli, and	Alvén, Néel 1970	
1928–1933	Dirac)	S., B., B. 1956	
1947	Sommerfeld, Pauli: the electron gas with Dirac statistics		
	The quantum theory of an electron in a solid.		
	Band structure (Bloch, Peierls, Brillouin, Van Vleck)		
	Magnetism (Pauli, Landau, Heisenberg, Bethe)		
	Transistor effect (Shockley, Bardeen, Brattain)		
1950s	Development of quantum field theory (Feynman, etc.)	Ginzburg, Leggett,	
1950	Ginzburg-Landau: phenomenological theory of	Abrikosov, 2003	
Late 1950s	superconductors	Landau 1962	
1956	Theory of interacting electrons in solids (Landau, Migdal)	B.,S., 1994	
1957	Neutron scattering and diffraction (Brockhouse, Shull)	W. Shockley, J.	
1958	Invention of the transistor	Bardeen, and W.	
1960s	Bardeen, Cooper, Schriefer: theory of superconductivity	Brattain	
1970s	Josephson effect of electron tunneling in superconductors	B.,C.,S. 1972	
1972	The understanding of the resistance minimum in metals:	Esaki, Giaever,	
1980	the Kondo effect (Kondo, Anderson 1969)	Josephson 1973	
1982	Density functional theory (Kohn, Pople)	Anderson, Mott, Van	
1985	Theory of liquid crystals	Vleck 1977	
1986	The renormalization group	1998 (Chemistry)	
1988	Superfluid He3 (Lee, Osheroff, Richardson)	de Gennes 1991	
1988	The integer quantum hall effect	Wilson 1982	
1991	The fractional quantum hall effect (Tsui, Störmer,	L.,O.,R. 1996	
1995	Laughlin)	von Klitzing 1985	

Period	Happenings/achievements/folks	Nobel laureates	Ref.
	Fullerenes C60 (Curl, Kroto, Smalley) Discovery of high-temperature superconductivity Discovery of the muon neutrino Giant magnetoresistance Carbon nanotubes (Iijima) Experimental Bose-Einstein condensation (Ketterle, Cornell, Wieman)	T, S., L. 1998 1996 (Chemistry) Müller, Bednorz 1987 Lederman, Schwartz & Steinberger, 1988 Fert, Grünberg 2007 K., C.,. W. 2001	
2003 2007 2008 2009 2010 2012 2013 2014 2015 2016 2017 2018 2019	Single graphene sheets discovered Discovery of giant magnetoresistance (GMR) Discovery of the mechanism of spontaneous broken symmetry in subatomic physics Invention of an imaging semiconductor circuit-the CCD sensor Two-dimensional material graphene Measuring and manipulation of individual quantum systems Discovery-understanding the origin of mass of subatomic particles Invention of efficient blue light-emitting diode Discovery of neutrino (have mass) oscillations Theoretical discoveries of topological phase transitions and phases of matter Decisive contributions to the LIGO detector and the observation of gravitational waves Invention-laser physics: optical tweezers and their application to biological systems Invention-laser physics: generating high-intensity, ultra-short optical pulses Theoretical discoveries in physical cosmology Discovery of an exoplanet orbiting a solar-type star	Geim, Novoselov 2010 Fert, Grünberg 2007 Yoichiro Nambu, 2008 Boyle, Smith, 2009 Geim, Novoselov, 2010 Haroche, Wineland, 2012 Englert, Higgs, 2013 Akasaki, Amano, Nakamura, 2014 Kajita, McDonald, 2015 Haldane, Kosterlitz, 2016 Thorne, Barish, 2017 Ashkin, 2018 Mourou, Strickland, 2018 Peebles, 2019 Mayor, Queloz, 2019	

**Courtesy:*
[1]Ref. [1].
[2]Ref. [3].
[3]Ref. [4].
[4]Ref. [5].

Table 1.
Squat historical achievements of condensed matter physics.

additional complex matter [1–5]. Thus, solid state physics forms a theoretical basis of materials science. The main theme of solid state condensed matter physics is the exertion to interpret the well-established microscopic interactions, in many-body systems, into higher-level descriptions containing a smaller number of degrees of freedom. In the recent decades, the sophisticated nature of these protuberant fields has shown interesting properties and concomitant phenomena that frequently insinuate into a bonanza of fundamental physics. Though the viewpoint is mutable persistently with innovative discoveries, the elementary defies in condensed matter physics are to forecast and perceive novel phenomena and its materials properties are frequently assertive at the frontlines of quantum mechanics [2]. Today, condensed matter experiments are mainly deliberated on the nature and structure of condensed state of compact materials where relations between adjacent electrons, molecules, and atoms regulate the solid properties with crystal systems and so on. Also, in physics, condensed matter physics has got a unique niche. Progresses in this field of solid state condensed matter are ever so often important for scientific achievements and for enlightening our ultimate understanding about the nature of materials. A strong revolution instigated its rapid growth in condensed matter physics with strong investigation in physics of scattering, photonics, advanced materials physics, surface analysis, low-temperature physics, low-dimensional electronic systems, structure of biological chemistry, and high-temperature superconductors. However, most discoveries and inventions concern the goings-on of short historical achievements of condensed matter physics, as abridged in **Table 1**, with some additional literatures in condensed matter physics, on the basis of historical accomplishments in different eras.

2. Topical advancements in recent advancements in the field of condensed matter and materials physics

The recent advancements in the field of condensed matter and aterials physics through fabrication of electronic devices such as computers and mobiles, opto-electronic devices such as fiber optics and lasers with different types, magnetic devices such as magnetic resonance imaging (MRI) and vibrating magneto devices, silicon-based logic and memory bits. The entire perception of contemporary technology is established upon the ideologies of condensed matter and materials physics. Routine things like the building that is made up of electrical wiring, the windowpane, and a refrigerator door equipped with the magnet, are all reliant on the principles resultant from condensed matter and materials physics. Further,

Field	Studies/application	Experiments (examples)
Superconductors	• *Iron pnictide* superconductor family	• F-doped LaOFeAs [6]
	• *Majorana fermions* (particles that are their own antiparticle)	• Gauge bosons and Higgs bosons [7]
	• *Plutonium*-based heavy-fermion systems	• Plutonium, owing to strong electron-electron interactions [8]
	• *Superconducting qubits* allow arbitrary rotations in the Bloch sphere with pulsed microwave signals, thus implementing arbitrary single qubit gates	• *Superconducting qubits* are leading candidates in the reach of modern supercomputers [9]
Topological materials	• First example of a conducting material with a nontrivial electronic structure topology	• Weyl metal [10]
	• Isolated quantum many-body systems (statistical and quantum physics)	• Ultra cold quantum gases [11]
	• Symmetry-protected topological (SPT) phases	• Topological defects [12]
	• Anyon condensation is the inverse process of passing from C/G to C	• Bose condensation is central to our understanding of quantum phases of matter [13]
Spin liquids	• Nematic Fermi fluids Correlated electron fluids can exhibit a startling array of complex phases, among which one of the more surprising is the electron nematic, a translationally invariant metallic phase with a spontaneously generated spatial anisotropy	• $Sr_3Ru_2O_7$ [14]

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Field	Studies/application	Experiments (examples)
	• Non-Fermi liquids are unconventional metals whose physical properties deviate qualitatively from those of noninteracting fermions due to strong quantum fluctuations near Fermi surfaces	• *Non-Fermi liquid,* also known as *"strange metal,"* also called the *Luttinger liquid* [15]
Water science	• Fouling resistant *oil–water* separation	• Superhydrophilic lithium exchanged vermiculite as a thin coating layer on microfiltration membranes to resist fouling [16]
	• *Swimming droplets* are artificial microswimmers based on liquid droplets that show self-propelled motion when immersed in a second liquid	• Mechanisms involve self-propulsion, microswimmers, Marangoni stress in the biological systems [17]
	• *Wave turbulence on water surface*-gravity waves on the surface of an infinitely deep fluid	• Nonlinear Hamiltonian equations govern the water-wave system and describe the premises of the weak wave turbulence theory [18]
Quantum materials & spintronics	• *Fracton* phases constitute a new class of quantum state of matter	• Emergent topological quasiparticle excitation [19]
	• Quantum spin Hall effect It is a state of matter proposed to exist in special, two-dimensional, semiconductors that have a quantized spin-Hall conductance and a vanishing charge-Hall conductance	• Crystalline solids, and ferromagnets [20]
	• *Quantum anomalous Hall effect* Quantized Hall effect realized in a system without an external magnetic field	• Topological structure in many-electron systems and may have potential applications in future electronic devices [21]
	• *Quantum Monte Carlo simulations* encompass a large family of computational methods whose common aim is the study of complex quantum systems	• Quantum criticality, quantum spin liquid [22]
	• *Quantum turbulence*-the chaotic motion of a fluid at high flow rates (cooled to temperatures close to absolute zero)	• ^{4}He (He II) & ^{3}He-B (Type-II SC) [23]
	• *Quantum-thermal fluctuations* of electromagnetic waves are the cornerstone of quantum statistics and inherent to phenomena such as thermal radiation and van der Waals forces	• Three manifestations: (a) the Stefan-Boltzmann law, (b) the heat transfer between two bodies, (c) Casimir forces [24]
	• Spintronics encompasses the ever-evolving field of magnetic electronics	• Switching magnetic moments by spin-polarized currents, and photonic fields [25]
Magnetoelectric (ME)	• Multiferroics are materials that combine coupled electric and magnetic dipoles	• Magnetoelectric effect, spiral magnetic order [26]

Field	Studies/application	Experiments (examples)
Physics with atoms in an optical lattice and some theorems	• The *Fermi-Hubbard model* is a key concept in condensed matter physics and provides crucial insights into electronic and magnetic properties of materials	• Key experiments in the metallic, band-insulating, superfluid, and Mott-insulating regimes [27]
	• *Nambu-Goldstone modes* (NGMs) that govern the low-energy property of the system	• This theorem ranges from high-energy, particle physics to condensed matter and atomic physics [28]
Medical	• *Arrhythmogenesis* was one of the first biomarkers of particulate matter (PM) cardiovascular toxicity observed in controlled animal studies	• Cardiac arrhythmias, excitable media, spiral & scroll waves, turbulence, nonlinear dynamics [29]
	• *Viral Shells*-studied the condensed matter physics to the assembly and maturation of viral capsids [30]	• Three-dimensional morphological subunits in a protein shell of a virus
	• Apiece *organism* follows its own evolutionary course and it also obeys a set of common (*Newton's law to Neuron*s) laws	• Insect flight-physics of behavior (fly must sense its orientation in order to balance in air) [31]
	• Intracellular oscillations and waves-dynamic processes in living cells are highly organized in space and time	• At the interface between physics and biology, the underlying molecular mechanism of spatiotemporal formation remains owing defies [32]

Table 2.
List of recent advancements in the field of condensed matter physics and materials physics.

Table 2 shows the list of recent advancements in the field of condensed matter and materials physics.

3. Conclusion

In summary, condensed matter physics is living in the form of several technical and high-tech challenges in our everyday life. The field of condensed matter and materials physics finds major developments and brings out the rudimentary comprehending toward the concepts, phenomena, and materials that facilitate scientific improvements and leads to entering into a new-fangled epoch, motivated by new competences in the research related to neutron, cyclotron, and synchrotron, probing and imagining in the atomic scale, nano—/micro-fabrication, and supercomputing, etc. These competencies offer prospects to scrutinize the nature of materials at complex levels with degrees of microscopic control that are exceptional. The modern era providing assurances to revolutionize the systematic technological advancements in preparing materials which leads in developing the knowledge elsewhere and through the physics of impeccable coordination the tangible solid materials that develop day-to-day environment. Understanding the basic concepts and techniques in the opto-electronic process provides information about the assemblies of multifaceted atoms and multicomponent materials and phenomena of non-equilibrium, and biological ideologies will stimulate improvements in technological scale from micro-/nano-electronics to structure of materials to the field of medicine. The new era retains the possibilities of ground-breaking advancements in condensed matter physics that will subsidize the national security, economic growth, and the excellence of life.

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Conflict of interest

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