Quantum Astrophysics

Quantum Physics and Astrophysics
A New Paradigm For Human Habitation

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Here I present 'Quantum Astrophysics', a simple contraction of quantum physics and astrophysics, as they apply to the concept of human habitation within a classical biological world interfaced between these two extreme environments - whether they be on the surface of the planet Earth, or in deep space.

Over the last centuries we have mapped out our local mesoscopic world, in terms of the structures and objects within it, the natural and physical laws under which they were formed, evolved and operate, and as they now still exist, the materials they are composed of, and the industrial and manufacturing processes which may be applied to them to produce the functioning chemical and electronic machines and devices we use to carry out the tasks of our everyday biological human lives on a terrestrial planet. In recent years the field of astrobiology, along with that of extrasolar planetary astrophysics and stellar and terrestrial planetary evolution, have greatly altered our views of the laws of nature and physics as to what they permit and demand in terms of the widespread existence of biological life in the universe. We have also recently witnessed the convergence of complex cosmological theories based upon arcane abstract mathematical formalisms into condensed matter physics and quantum many body theories that can be implemented, simulated and tested in small spectroscopy laboratories, with many participants, using a wide variety of experimental spectroscopic and analytical instruments, devices and techniques.

In this remarkable and discernible but slowly evolving cosmos, universe, solar system and world which we now find ourselves trapped within, we are also confronted with the constant crises and horrors that always accompany the wild diversity and change inherent in all dynamical, thermodynamic, quantum mechanical and indeed, chemical, electronic and mechanical lives that we live. Biology still rules us. It's the intent of this essay to discern a path forward in our astrobiological lives on this terrestrial planet, that will address these everyday crises of global planetary fate and destiny, within the greater internal quantum physical and external astrophysical forces we cannot change, which control all of our actions. Although we cannot change these forces, we can manipulate them, and thus the universe continually provides us with emerging phenomena that we may further manipulate and exploit to sustain our lives.

Mathematical incompleteness dictates the cosmos will always provide us with the unknown to discover. Here I outline the various options that quantum and condensed matter physics offers us to work with, in terms of the astrobiological and astrophysical constraints set by our evolution into this state of 'being'.[1] The path forward for humanity is in the use of quantum physics and astrophysics for human habitation. This NASA NIAC proposal is for the identification and synthesis of a ZT=3-4 thermoelectric device, which is the single most important development necessary for the wide scale colonization of space, and for solving severe atmospheric problems on earth; CFC/HFC pollution and industrial carbon emissions.

The Idea

We are approaching an incipient emerging revolution in quantum nanostructured thermoelectric devices and high temperature superconductivity. Temperature scales of these two phenomena are converging as a result of unexpected new breakthroughs in topological states of matter and quantum critical behavior. The immediate benefactor of any hypothetical new ZT = 3-4 room temperature thermoelectric devices would be astronautics, in the form of the improved solar powered production and storage of cryogens.

Extremely efficient refrigeration, and humidity control through water condensation, becomes trivially possible with the use of thermoelectric devices and technologies. This includes completely eliminating compressor driven CFC and HFC loops and replacing them with static systems, production of distilled water, refrigeration and freezing of water and food goods, heat into electricity and waste heat rejection. Products like low voltage efficient refrigerators and reflective solar ovens alone have the potential of completely revolutionizing the lives of billions of people living in the remote areas of the third world and greatly facilitating and accelerating the transition from fossil fuels to alternative energy production.

Furthermore, once high temperature superconductivity is realized through this improved thermoelectric device efficiency, sustained magnetic fields, spin, vortices and fluxes may be added to the mix of new quantum many body effects which may be physically demonstrated and then implemented, opening up a much larger quantum phase space of new solid state systems, which can then be driven into far from equilibrium metastable states or conditions - functioning as high efficiency quantum energy converters.

Thermoelectricity at elevated ZT efficiencies is the first necessary step towards realizing a low voltage DC powered future, where devices such as solar cells, batteries, fuel cells, electric motors and other electronic devices, condensers and evaporators, heating, cooling and air conditioning systems operate at moderately high Carnot cycle efficiencies, with cleverly designed thermal congeneration pathways leading to efficient heat utilization through energy conversion, useful work and thermal dissipation.[2]

Flat, buckled and puckered two dimensional hexagonal atomic monolayers of Group IV and Group V elements are now considered to be at the very low density limit for atomic and molecular structures. These systems now include graphene, silicene, germanene and stanene in Group IV elements, and also phosphorene, arsenene, antimonene and bismuthene in the Group V elements. Nitrogen is the outlier here, but comes into play again in the high density limit in the form of alkali metal ammonia solutions. These systems in their loose and relaxed form essentially create novel atomic and molecular simulators, where atomic species may be adhered or absorbed onto their surfaces at various densities and observed. Adsorbed and terminating species include hydrogen at low atomic mass, alkali metals such as lithium, sodium and potassium, iodine at high atomic mass, and chalcogenides such as oxygen, sulfur, selenium and tellurium, which in the case of bismuthene, comprise the classical n- and p- doped thermoelectrics. Selective oxidation of the atomene surfaces has already yielded insight into potentially useful devices.

Multilayers may be laser ablated, and monolayers may be snipped and cut up into any desired shapes. Various new allotropes and polymorphs may be created by selective modification of bonding orbitals. Sheet curvature may be induced by the addition or removal of atomic nodes in the monolayer sheets. In this manner structural balls, spheres, tubes and eventually highly complex nanostructures in the lattice may be created by simple geometric analysis, and creative snipping, cutting and atomic modifications. In the case of bismuth iodide, the heaviest form of doped bismuthene, atomically thin wires are formed which can transform continuously into two dimensional sheets of iodine terminated bismuthene lattice, and then ultimately wrapped up into a tubular bilayer bismuthene, entirely free of terminating species. In carbon, the graphene can be reversibly transformed into carbon onions and diamond with pressure.

In the high density, high pressure regime, where materials are for all practical purposes crushed into three dimensionality, and eventually into simple cubic phases, hydrogenated Group IV and V elements ultimately become moderately good classical BCS superconductors, due to the small atomic mass of the hydrogen and the moderately high optical phonon frequencies. In these compounds the hydrogen tends to disassociate and decouple from the host atoms and form a variety of new high pressure phases. This is to be distinguished from ambient bulk phases where the electronic and lattice properties change rather abruptly as the two dimensional, loosely coupled, and often hexagonal lattice limit is approched. The transition is from the *ines to the *enes and back again, and is well represented across the periodic table in Group V with ammonia, presenting unique bright blue to gold alkali metal ammonia solutions, phosphine, bismuthine, and at high atomic mass, the unique and distinctive bismuth iodide solutions.[3] The hydrides of nearly every element are ubiquitous, but not nearly so as the oxides, and this naturally leads to the question of just where does electron and proton solvated water fit into this new paradigm?

The Problem

The problem at hand is how to extract a new, non-toxic, relatively inexpensive ZT = 3-4 thermoelectric device from this now much better understood and greatly reduced phase space of nanostructured atoms. The options include quantum atomic simulation on hexagonal platforms, functionalization of the two dimensional hexagonal sheets, physical nanostructuring of the atoms into three dimensional shapes and nanostructuring of the three dimensional bulk multilayer materials, as well as traditional processes of impurity implantation, inhomogeneity engineering and chemical doping of the materials into devices. The problem is complex since the effects are also wave vector and stacking layer orientation dependent within the 'atomenes' and will certainly require the intercalation of other unusual impurity structures, as well as a great deal of three dimensional engineering of added functionality groups and inhomogeneity. The problems of boosting Seebeck coefficient and thermopower seems to have been solved, but the phonon spectrum is wide and complex. Building the necessary filters and barriers in order to reduce lattice thermal conductivity while maintaining decent electronic transport properties will be difficult. There is most likely no magic bullet for ZT=4 thermoelectricity, but if it exists, it will show up shortly given the recent dramatic advances in spectroscopic resolution, theoretical analysis, and computation.

The Solution

Hydrogenated and iodated bismuthene and iodobismuthine appear to have the best near term prospects for a ZT=4 thermolectric energy conversion medium. It will be interesting to see if bismuthine can be stabilized long enough to load into the diamond anvil cell and tested for hydrogen superconductivity. The transition from two dimensional bismuthene into high pressure iodobismuthine is one of the last uncharted areas of exotic quantum matter left to explore, although it appears now that almost any metal can be paired with a Group V or chalcogenide and their electronic properties tuned into exotic physics. What is found in bismuthene can then be tested in phosphorene to discern any differences in behavior. Carbon is cheap, ubiquitous and relatively non-toxic, and can be brute force nanoengineered into the electronic transport and thermal phonon filtering structures necessary for ZT efficiencies up to ZT=3. Stanene is radically different than graphene, and has a very low lattice thermal conductivity for a metal. Tin selenide in the crystallographic *a* axis has an estimated ZT of 2.7 in the electron n-doping regime.

References

1. cosmic.lifeform.org, T. L. Elifritz, Blog (2015)
2. The Quantum Initiative, T. L. Elifritz, Essay (2015)
3. On the Nature of Bismuth (I) Iodide in the Solid State, T. L. Elifritz, Spec. Sci. Tech., 17, 85 (1994)

Proposal Summary

Quantum astrophysics is defined as a new domain of science - bridging quantum and condensed matter physics with the astrobiological requirements of humanity and its cohabitating species, living together sustainably in the astrophysical universe, whether that be on earth or in deep space.

I point out that an enormous paradigmatic shift and technological revolution is now occurring in condensed matter physics, where modern computational and atomic and molecular simulations are converging to immediate spectroscopic verification of quantum theories of matter, which has suddenly revealed the rich and mathematically precise realm of novel topological physics and quantum critical behavior of matter, that apparently is now immediately available for technological exploitation.

I further point out that the single most valuable result coming out of this new perspective of quantum matter would be a ZT=3-4 room temperature thermoelectric device, since all quantum behavior of matter is temperature dependent, and cooling quantum devices will require lowering their temperature. A simple electrical device of this efficiency would also solve a number of pressing human habitability problems such as the boiling and freezing of water, humidity control of air, and the rejection and dissipation of waste heat. Cascading such devices down to cryogenic temperatures will solve a variety of astronautical problems in the area of cryogenic fuel and oxidizer storage in deep space and on planetary surfaces.

A new paradigmatic perspective of condensed matter systems is presented where the 'atomenes' of the Group IV elements, graphene, silicene, germanene and stanene, and the Group V elements, phosphorene, arsenene, antimonene and bismuthene, are considered to be at the low dimensional, weakly coupled, hexagonal limit of molecular matter, and the high pressure hydride phases of ammonia, phosphine, arsine, stibine and bismuthine are considered to be at the three dimensional, pseudo cubic limit of what is achievable in this realm of novel quantum physics.

Since the surfaces of the atomenes in their various polymorphic and allotropic forms are, for all practical purposes, essentially two dimensional atomic and molecular simulators, it is proposed that the thermodynamic, electrochemical and electronic transport properties and behaviors of various elemental configurations of atomic and molecular species can be quickly sorted through using them to produce and then host the most likely combination of elements and nanostructures necessary for high ZT thermoelectric effects.

Finally I point out that the most promising candidate for a ZT=4 room temperature thermoelectric energy conversion device would be bismuthene in the form of hydrogenated and/or iodated bismuthene at the low dimensional limit, and iodobismuthine under pressure at the high density limit, with any phosphorene based anolog of this system running a close second. Nanoengineered and nanostructured graphene appears to be viable up to about ZT=3, and doped stanene related compounds up to ZT=2.7.

Obviously this NASA NIAC submission refers to a ninth month continuation of the effort to identify a suitable ZT=3 room temperature thermoelectric device, and the application of such a device to other more actively driven approaches to ZT efficiency enhancement using thermoelectrically cooled quantum physics, whatever those microscopic quantum processes turn out to be.

Note: After the formal submission of this research proposal an indication of ZT=6.4 in the distorted Bismuth (110) crystallographic face was reported. See http://arxiv.org/abs/1509.08002 for details.