Complex Systems. An Introduction

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- ●«A scientist is supposed to have a complete and thorough I of knowledge, at first hand, of some subjects and, therefore, is usually expected not to write on any topic of which he is not a life, master. This is regarded as a matter of *noblesse oblige*. For the present purpose I beg to renounce the noblesse, if any, and to be the freed of the ensuing obligation. My excuse is as follows: We have inherited from our forefathers the keen longing for unified, all-embracing knowledge. The very name given to the highest institutions of learning reminds us, that from antiquity to and throughout many centuries the universal aspect has been the only one to be given full credit. But the spread, both in and width and depth, of the multifarious branches of knowledge by during the last hundred odd years has confronted us with a queer dilemma. We feel clearly that we are only now beginning to acquire reliable material for welding together the sum total of all that is known into a whole; but, on the other hand, it has become next to impossible for a single mind fully to command more than a small specialized portion of it. I can see no other escape from this dilemma (lest our true who aim be lost for ever) than that some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them -and at the risk of making fools of ourselves»**.**
- E.Schrödinger(1887-1961) (Nobel 1933), *What's Life?*, Cambridge University Press, 1944.

Erwin Schrödinger (1887-1961)

- [*Ciò che si suppone di un uomo di scienza è che egli possieda una conoscenza complete e approfondita, di prima mano, solo di "alcuni argomenti; ci si aspetta quindi che egli non scriva di argomenti di cui non è maestro. Se ne fa una questione di* noblesse oblige. *Per lo scopo presente, io chiedo di rinunciare all'eventuale nobiltà, per liberarmi dall'obbligo che ne deriva. La mia giustificazione è la seguente: Noi abbiamo ereditato dai nostri antenati l'acuto desiderio di una conoscenza unificata, che comprenda tutto lo scibile. Lo stesso nome dato al più elevato ordine di scuole, ci ricorda che fin dall'antichità, e per molti secoli, l'aspetto di universalità è stato il solo a cui si è dato pieno credito. Ma il progredire, sia in larghezza che in profondità, dei molteplici rami della conoscenza, nel corso degli ultimi secoli, ci ha posti di fronte a uno strano dilemma. Noi percepiamo chiaramente che soltanto ora incominciamo a raccogliere materiale attendibile per saldare insieme, in un unico complesso, la somma di tutte le nostre conoscenze; ma, d'altro lato, è diventato quasi impossibile, per una sola mente, dominare più di un piccolo settore specializzato di tutto ciò. Io non so vedere altra via d'uscita da questo dilemma (a meno di non rinunciare per sempre al nostro scopo) all'infuori di quella che qualcuno di noi si avventuri a tentare una sintesi di fatti e teorie, pur con una conoscenza di seconda mano e incompleta di alcune di esse, e a correre il rischio di farsi rider dietro*] (trad.it., *Che cos'è la vita? La cellula vivente dal punto di vista fisico*, trad. it. M.Ageno, Adelphi, Milano, 1995)

- «This apology for a physicist venturing into biology will serve for me as well as for Schrödinger, although in my case the risk of the physicist making a fool of himself may be somewhat greater.»

[F.Dyson, *Origins of Life*, Cambridge University Press, Cambridge, ed. 2004, trad.it. *Origini della vita*, Bollati Boringhieri, 2014]

- In my case I can not even get close to the second self-defense, as Dyson (1923-) is for me one of the most acute existing scientists, who despite having about the same age as Feynman (1918-1988) (Nobel 1965), he still lives and he had the extraordinary ability to capture the thoughts, nature, and the characters of his apparently more famous contemporaneous colleagues, also by building bridges and links between them.

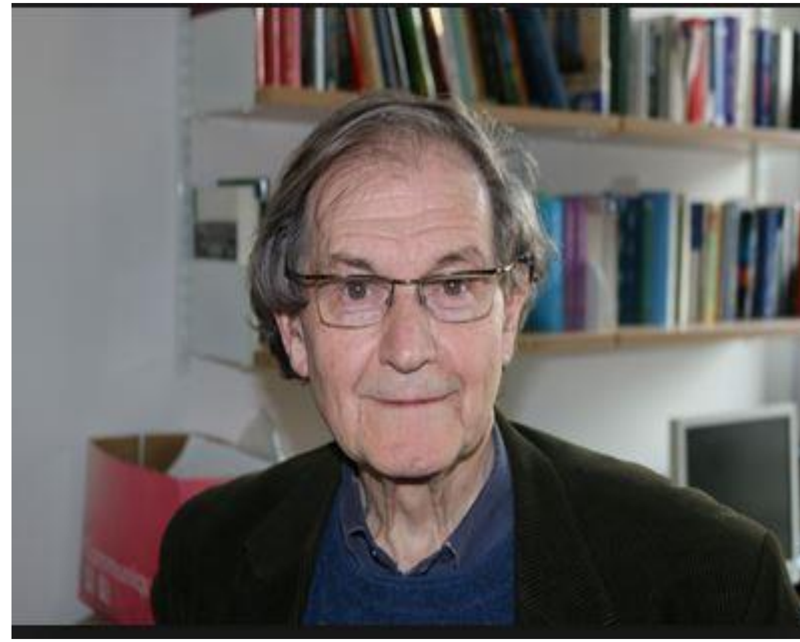
Freeman Dyson (1923-)

«If a theoretical physicist has anything of value to say about the fundamental problems of biology, it can only be through making suggestions for new types of experiment. Half a century ago, Erwin Schrödinger suggested to biologists that they should investigate experimentally the molecular structure of the gene. That suggestion turned out to be timely.

I am now suggesting that biologists investigate experimentally the population structure of homeostatic systems of molecules. If I am lucky, this suggestion may also turn out to be timely.»

[F.Dyson, *Origins of Life*, Cambridge University Press, Cambridge, ed. 2004, trad.it. *Origini della vita*, Bollati Boringhieri, 2014] (p.77)

«… we may think of chemistry as being only rather "weakly" quantum mechanical, where the more puzzling features of quantum mechanics in which distant entanglements and globally coherent behaviour do not seem to feature significantly. Such coherent behaviour is witnessed in the phenomena of superfluidity and superconductivity, and in the mysterious entanglements that one can find between the distantly separated quantum particles of EPR (Einstein-Podolsky-Rosen) situations, where the overall behaviour of the combined system cannot be understood simply in terms of the individual nature of its constituent components. A question of great interest, therefore, is whether or not such "strongly" quantum-mechanical features of Nature might be playing significant roles in the essential processes of life … Foundations of quantum theory no doubt led him [Schrödinger] to be skeptical of the current dogma that the rules of quantum mechanics must hold true at all levels of physical description. (It may be pointed out that three others of the key figures in the development of quantum mechanics, namely Einstein, de Broglie, and Dirac, have also expressed the opinion that existing quantum mechanics must be a provisional theory.) There is, indeed, a distinct possibility that the broadening of our picture of physical reality that may well be demanded by these considerations is something that will play a central role in any successful theory of the physics underlying the phenomenon of consciousness.»



Roger Penrose (1931-)

«… Is it merely the complexity of biology that gives living systems their special qualities and, if so, how does this complexity come about? Or are the special features of strongly quantum-mechanical systems in some way essential?

If the latter, then how is the necessary isolation achieved, so that some modes of large-scale quantum coherence can be maintained without their being fatally corrupted by environmental decoherence? Does life in some way make use of the potentiality for vast quantum superpositions, as would be required for serious quantum computation? How important are the quantum aspects of DNA molecules? Are cellular microtubules performing some essential quantum roles? Are the subtleties of quantum field theory important to biology? Shall we gain needed insights from the study of quantum toy models? Do we really need to move forward to radical new theories of physical reality, as I myself believe, before the more subtle issues of biology - most importantly conscious mentality -can be understood in physical terms? How relevant, indeed, is our present lack of understanding of physics at the quantum/classical boundary? Or is consciousness really "no big deal," as has sometimes been expressed?» [*Penrose, 2008*]

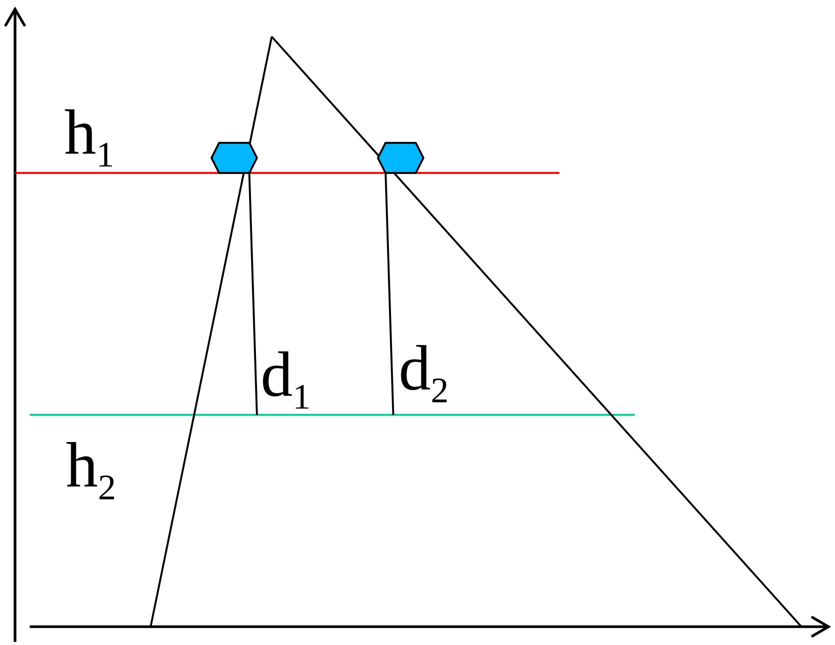
Lectures Program

- Introduction
- Before defining a system: generic chemical-physical vs complex one. Equilibrium and non-equilibrium
- Boundaries and approximation praise.
- More is different! Systems Thinking and Systems Modeling
- What is a complex system? Complex Adaptive Systems (CAS): different approaches (Weaver, Santa Fe Institute, …)
- Feedback idea: positive and negative feedback.
- Complex Systems Structure: auto-organization, hierarchy, coherence.
- Complex System Dynamics: stochastic processes, chaos, non-linear systems, coherent systems having a program, difference between complicated and complex systems.
- Reductionist and systemic view: emergence and de-emergence.
- Physical laws and role of thermodynamics: wrong paradoxes and deviations.
- Applied Systems: physics, chemistry, biology, medicine, ecology.
- Laboratory examples.

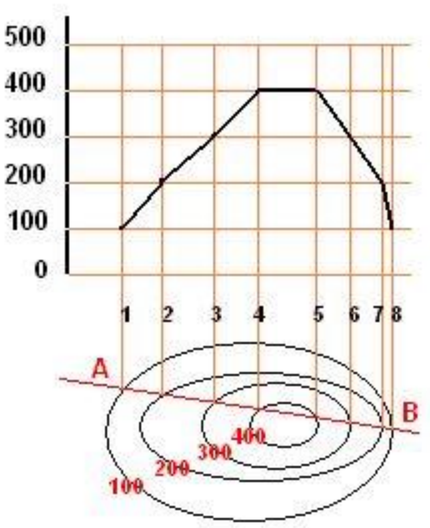
Introduction

- motivations: healthy anarchy and disrespectfulness (Dyson, Feynman)
- *zetetics* (from *zetein* = to seek): method of investigation; research which tends to penetrate the reason of things. In the skeptical philosophy, attitude and spirit of research and investigation of the truth, which can never be achieved, however, definitively.
- right questions (Anassimandro, Schrödinger, Feynman)
- well posed problems, to realize that the problem was misplaced (Anassimandro, Tolomeo, Copernico)
- gratitude for the teachers, but then separation and overcoming
- complexity as a different way of thinking

- Why phenomena happens?
- Why systems evolve?
- Can we predict final state with a certain probability?
- local and “real” causes
- gradient
- time: when and how much?
- thermodynamic and kinetic view
- reversible and irreversible transformations
- equilibrium, local equilibrium thermodynamic (LTE), non-equilibrium



gradient

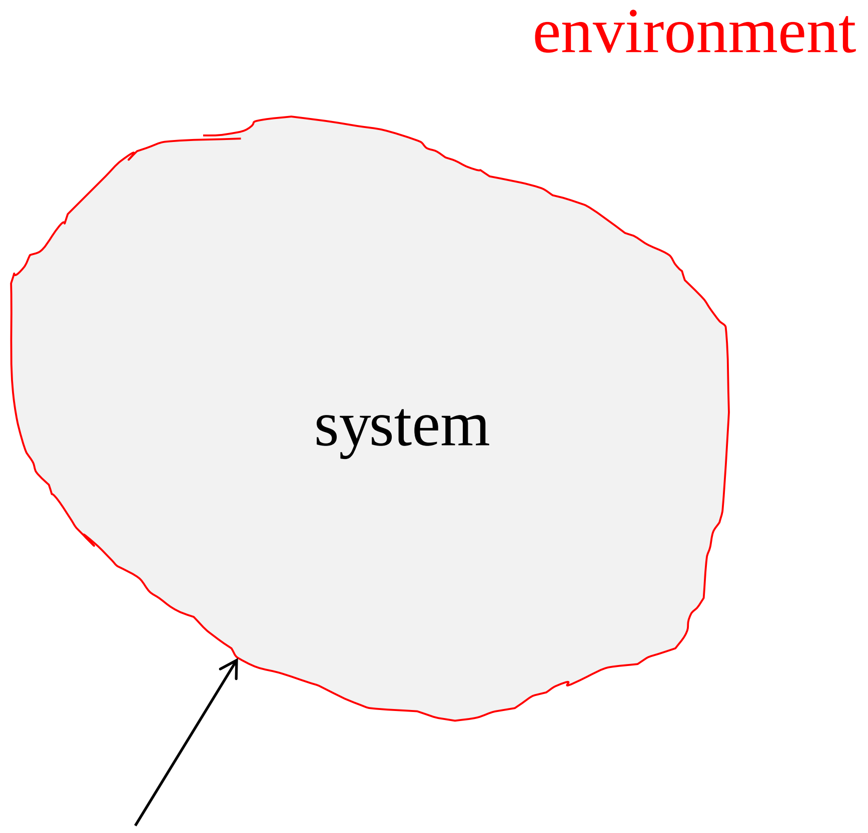


$v_F = \sqrt{(2gh)}$

$t_2 > t_1$

System: definition and choice

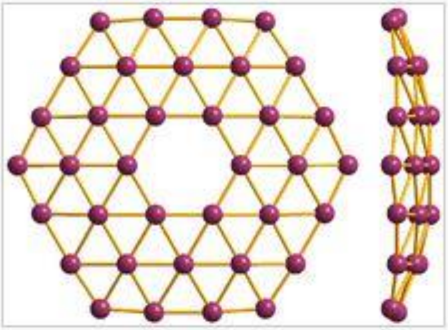
- Generic thermodynamic system: isolated, closed, open; microcanonical, canonical and grand canonical ensemble; intensive and extensive quantities; equilibrium and non-equilibrium
- Boundaries and approximation praise
- Real, ideal and approximate systems: the systems that are typically subject of scientific research are never real systems; they are idealized and schematic systems, result of a complex conceptual processing , by separating it, so to speak, by side phenomena, generally referred as "perturbations".
- Before giving as complete as possible definition of what is a complex system, on which most researchers agree, it may be more useful to ask if the system I'm studying is a complex system. Is it possible the second question without answering the first?



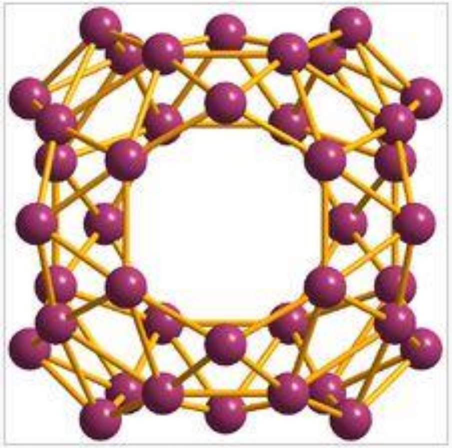
Boundary (open, closed, isolated) – often semi-permeable membrane

- relationship between scaling and boundary (approximation)
- if fields are present?

- «**More is different**». P.W. Anderson (1923-): “More is different. Broken symmetry and the nature of the hierarchical structure of science”, *Science* **177**, 393-397 (1972) (Nobel 1977), «. *The reductionist hypothesis may still a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted without question.(p.393) […] we can see how the whole becomes not only more than but very different from the sum of its parts* (p.395» .
- properties impossible to assign to a single component (water molecule, gold atom, carbon atom, ...): gas, liquid, solid, electrical conduction, thermal conduction (?)
- how many?
- how heavy?
- how big?
- C (diamond, graphite, fullerene, graphene), silicene, germanene, P(white, red, violet, black, phosphorene), B (borophene, borosphorene), ...

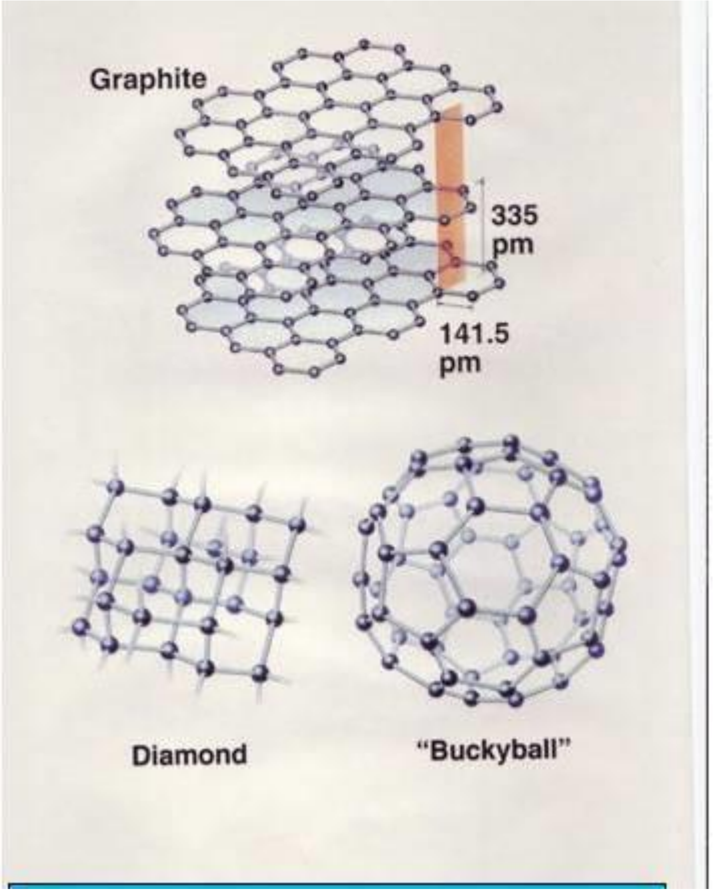


B_{36}° borophene, front and side view



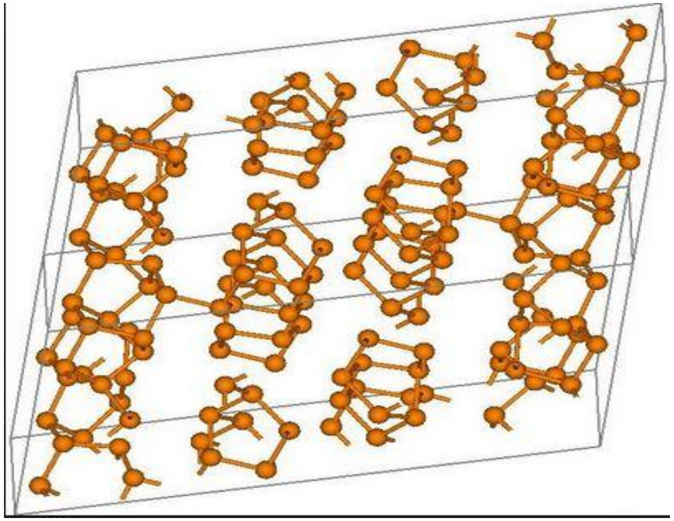
B_{40}° borospherene

Boron

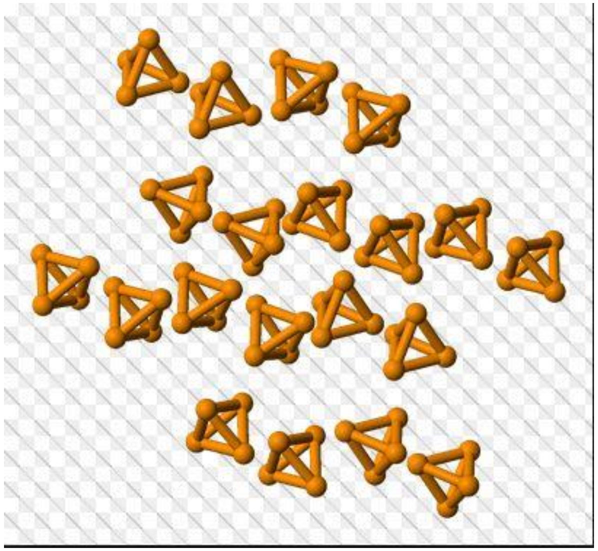


Carbon

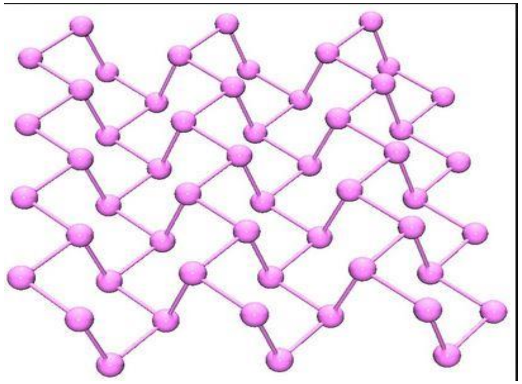
Phosphorous



red

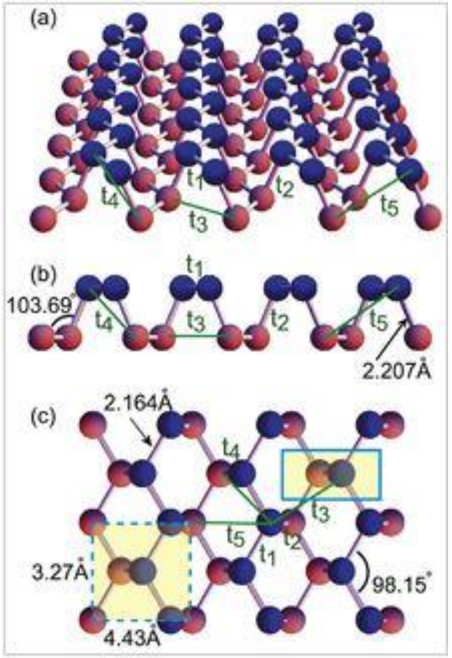


white

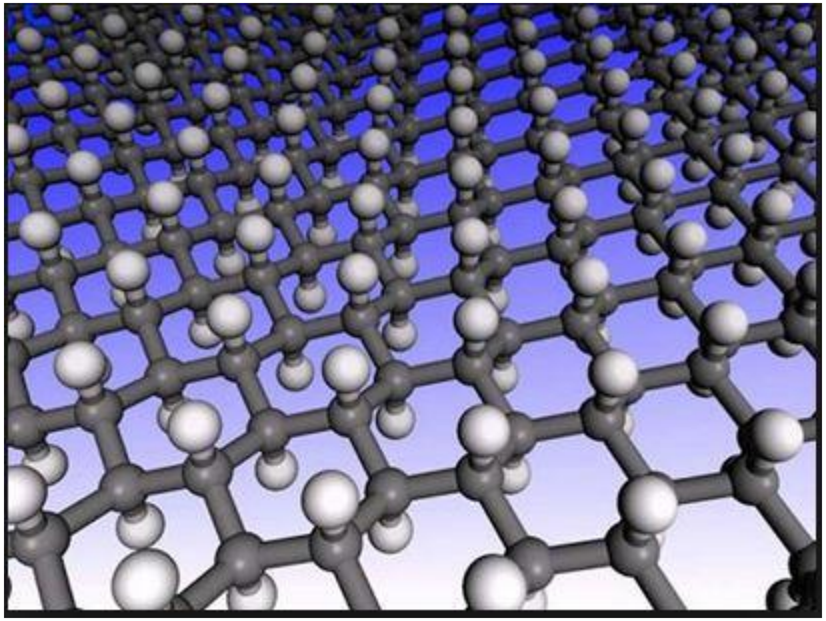


black

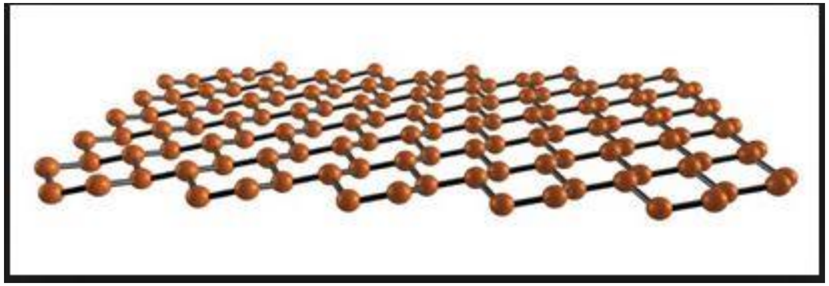
violet



phosphorene



germanene



silicene