STRUCTURAL COMPLEXITY OF THE MATERIALS AND SUPERCONDUCTIVITY: HOW FUNDAMENTAL IS THE MECHANISM INDUCING THIS PHENOMENON OF NATURE

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The structural complexity aspect of the materials reveals itself in the superconductivity of the metals. A complex, multisided behavior of the superconducting materials is analyzed in this work. It is shown that there is a subtle balance between superconductivity property of materials and their latent heat of fusion. This feature of superconducting materials manifests itself sharply especially in the case of the so called conventional superconductors, for the indium, lead, tin and mercury. The Cooper pairs analogue formation possibility of the atomic nuclei of the superconducting metals is also considered This analysis strongly supports the idea that electroweak gauge boson masses are manifestation of the fundamental level structural complexity inherent to our universe.

Keywords: dependence of the structural complexity on the energy, the connection between the charges and masses of the elementary particles, structural complexity - latent heat of fusion connection of the substances, the latent heat of fusion and critical temperature dependence for the metals.
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INTRODUCTION

As it was discussed in the previous works ([1], [2])

$$M_W/g = M_B/g' \tag{1}$$

type of connection between the masses and coupling constants of the electroweak gauge bosons leads to the emergence of the W boson and Z boson in a succinct, natural form. Eq. (1) can also be interpreted as a connection between the energy and structural complexity of the system. It was indicated that this kind of relation holds for all the known elementary particles, but only in an approximate form. This equation can also be interpreted as a connection between the energy and the structural complexity of the system, their direct proportionality relation. Energy and structural complexity manifest themselves in the form of the mass and coupling constants in this equation. We can observe a similar behavior in the case of superconductors too, at least in the form of the inverse proportionality of the molecular mass of the particular substance and Bose – Einstein condensate critical temperature for this substance [7]. One can also observe trends between the superconductivity temperature of metals and their main physical properties in the wide range, such as latent heat of fusion, crystal structure and nuclear binding energy per nucleon.

METHODS

A. The connection between masses and the structural complexity of the system

Charm quark has a bigger charge (coupling constant) and bigger mass than strange quark has these parameters. Similar relations hold for the top quark – bottom quark, charged lepton – corresponding neutrino relations. Let's pay attention that here what is important is the particle's charge (coupling constant) after the shift in the symmetry, but not its place isospin wise, heavier leptons have the original isospin number $I_W = -1/2$ and heavier quarks have $I_W = ½$.

Charge conjugation operator aspect of the electron wave function also confirms this interpretation of the equation above. Charge conjugation operator changes a negative - energy solution for the electron with the certain momentum p_i and polarization S_i to a positive - energy solution with the same p_i and S_i:

$$\Psi_C = C\gamma_0\Psi^* = C\gamma_0((\varepsilon\gamma_i p^i + m)/(2m))^*(1 + \gamma^5(p_i S^i)/2)^*\Psi^* \rightarrow (-\varepsilon\gamma_i p^i + m)/(2m)(1 + \gamma^5(p_i S^i)2)\Psi_C \tag{2}$$

Here ε = 1 for positive energy states and ε = -1 for negative energy states.

When applied to Eq.(1), we can say that both numerator and denominator change sign which has no impact on the equation. Only the magnitude of the coupling constant, in this particular case the electric charge, is important for the energy – structural complexity relations. The exact nature of Eq.(1) indicates that the electroweak gauge bosons are indeed the fundamental level of particles, the intermediaries of the fundamental level of interactions.

The Bose – Einstein condensate critical temperature, the temperature playing vital role in superconductivity [8],

$$T_c = {2\pi\hbar^2}/{mk_B\lambda_c^2} \tag{3}$$

is inversely proportional to the molecular mass of the substance. Here k_B is the Boltzmann constant and λ_c is the thermal wavelength at the critical temperature.

We can interpret this formula as follows: the bigger the mass the stronger coupling between the molecules of the substance, structural complexity wise, and the breakdown of this complexity occurs at lower temperature. We can treat the superconductivity as a manifestation of the breakdown of the structural complexity of the system also. Eq. (2) is derived for the non interacting gas. Eq. (1) is a key to understanding the W boson, B boson mixing, meanwhile its approximate form is valid when applied to the lepton and quark masses. Similarly, approximate form of Eq. (2) could be valid when applied to metal atoms, latent heat of fusion instead of atomic mass would be more suitable in this case (see next section).

This approach to understanding of the rise of superconducting state is also supported by the isotope mass dependence of this phenomenon. There is a well – known relation [7]

$$T_c = \frac{C}{M^{\frac{1}{2}}} \tag{4}$$

between the isotope mass and temperature of superconductivity of metals. C is constant here.

B. Trends between the physical properties of the superconducting materials and their critical temperature.

In the table below we show the certain physical properties of some metals which are likely to play significant role in the superconductivity of the metals. Most of these metals exhibit superconductivity at temperatures significantly distant from the absolute zero temperature.

Physical properties of the superconducting materials

Metal	Atomic number - Atomic Weight (g/mol)	Crystal Structure	Latent heat of fusion		Temperature of superconductivity, K	Nuclear Binding Energy per Nucleon, MeV
			KJ/mol	J/g		
Aluminum, Al	13 - 27	fc cubic	10.7	396	1.2	8.33
Beryllium, Be	4 - 9.1	hexagonal	12.2	1356	0.026	6.3
Cadmium, Cd	64 - 112	hexagonal	6.3	56	0.5	8.5
Indium, In	49 - 115	bc tetragonal, fc cubic	3.26	28.3	3.41	8.5
Iron, Fe	26 - 55.8	bc cubic, fc cubic	13.8	247	0.0	8.8
Lanthanum, La	57 - 138.9	hexagonal	6.2	44.6	5.0	8.38
Lead, Pb	82 - 207	fc cubic	4.77	23	7.2	7.67
Mercury, Hg	80 - 201	rhombohedral, tetragonal	2.29	11.4	α - 4.15 β – 3.95	7.89
Nickel, Ni	28 - 58.7	fc cubic	17.2	293	0.0	8.73
Niobium, Nb	41 - 92.9	fc cubic	26.4	288	9.3	8.66
Tantalum, Ta	73 - 181	bc cubic	36	199	4.48	8.02
Technetium, Tc	43 - 99	hexagonal	24	244.9	7.77	8.61
Thallium, Tl	81 - 204.4	hexagonal	4.14	20.25	2.39	7.88
Tin, Sn	50 - 118.7	bc tetragonal	7.0	59	3.7	8.5
Titanium, Ti	22 - 48	hexagonal	18.7	390	0.39	8.79
Tungsten, W	74 - 183.8	bc cubic	35	190	0.015	8.0
Vanadium, V	23 - 50.95	bc cubic	22.8	448	5.48	8.74

A quick look at this table tells us that all four conventional superconductors, indium, tin, lead and mercury have the specific latent heat of fusion at the lower end values for the specific latent heat of fusion in J/g. One would say that they have noticeably small value for the latent heat of fusion per nucleon. Their structural complexity gets altered by smaller value of energy: according to Eq. (1) the bond holding the structural complexity is weaker and this complexity breaks down at temperatures significantly distant from the absolute zero temperature. Atoms and molecules are not like flamboyant objects moving chaotically in our world, they are more likely follow the certain pattern in their thermal motion: under extreme conditions the whole structure of this pattern breaks down.

Schematically we can depict the above discussed connection between the latent heat of fusion and superconductivity of metals the following way:

Small value of the latent of fusion → low level of the structural complexity → weaker bond between the atoms of the substance → smaller value of the analogue of the coupling constant in Eq. (1) → smaller value of the analogue of the mass in Eq. (1) or Eq. (2) → superconductivity at the temperature significantly distant from the absolute zero temperature.

It catches one’s attention that metals (isotopes) with the sizable critical temperature tend to have an odd number of nucleons, that is their nuclei are fermions and can induce their own specific Cooper pairs analogue. The distance between the atomic nuclei of crystals is three – four orders less than the typical distance between the electrons of the Cooper pairs. Vanadium, the superconducting metal, has high value for the latent heat of fusion, but it also has at the higher end value for its nuclear binding energy per nucleon. Vanadium is not considered as a conventional superconductor, high value of the nuclear binding energy per nucleon might be another venue for the transition of the metal into the superconducting state [2]. The naturally occurring isotopes of iron, Fe^{57}, and nickel, Ni^{61}, have high value of nuclear binding energy per nucleon and fermionic statistics nuclei. These isotopes might also exhibit superconductivity under certain conditions. Iron and nickel have relatively simple crystal structures, face centered cubic and body centered cubic crystal structures. Chances are slim that these isotopes have their own, noticeably low value latent heat of fusion, because the melting point of these metals is not in the region of temperature we usually call extreme conditions (He^3 isotope of helium has significantly smaller values for both the specific heat of vaporization and latent heat of fusion than He^4 isotope has). Nevertheless, if these isotopes exhibit superconductivity, it would be another confirmation of the structural complexity – superconductivity connection scheme. This would also imply that the substances exhibit the structural complexity in different forms. The high value of the nuclear binding energy per nucleon for nickel Ni^{62} could also be another clue to determining the complexity level inherent to our universe.

DISCUSSION AND CONCLUSIONS

The connection between the energy and structural complexity of the quantum mechanical systems reveal itself distinctly in many physical systems, such as the connection of the electroweak interactions coupling constants and electroweak boson masses, latent heat of fusion related properties of the crystals. Superconductivity of metals, this tantalizing phenomenon is analyzed in the frame of the structural complexity of the substances. It is shown that like electroweak gauge boson masses, this phenomenon is the manifestation of the most fundamental feature of nature, its structural complexity. The latent heat of fusion of metals – superconducting temperature connection emerges as a result of this analysis. It is emphasized that not just conducting electrons but also the atomic nuclei of the superconducting metals may generate they own Cooper pairs analogue, since they often tend to be fermions.

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