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JAHN TELLER METAL:THE BASIS OF NEXT GENERATION MAGLEV

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ABSTRACT : Indeed, everyone can press the spacebar and come out of their cocoon to resurrect something innovative out of the dent. An international team of researchers at TOKOHU UNIVERSITY at Japan studying a superconductor made from Bucky balls or C_{60} molecules discovered a new type of metallic state of matter named as, Jahn Teller Metal. It's a combination of insulating, magnetic, metallic and superconducting phases having the potential to achieve superconductivity at a relatively high T_c (high) as in -135 degree Celsius as opposed to -243.2 degree Celsius, where normally superconductivity is observed. We now aim to deploy this concept in maglev vehicles, as superconductivity allows a material to conduct electricity without resistance which gives an inception to the next generation maglev. Here, a major observation of high temperature superconductors, which has the potential of Jahn Teller Metal, is also further taken into consideration for high speed maglevs. Based on the reality check, Japan has again demonstrated its prowess in high-speed rail travel with its state-of-the-art maglev train setting a world record of just over 603km/h (375mph), i.e. approx. 1.8 km could be covered in just 11 seconds. This paper emphasizes on the fact that this efficiency could be further escalated by Jahn Teller Metal possibly breaking the present boundaries.

Index Terms—Maglev, Levitation System, Guidance System, Propulsion and braking System, Jahn Teller Metal, Jahn Teller Effect, Crystal Field Theory, BCS Theory, High Temp. Superconductors

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1 INTRODUCTION

our planet can be a crowded, polluted and crazy place, but a new design concept proposes that we rise above it all, by moving to a magnetically levitated island in the sky, complete with green forests, mountains, and urban centres. The concept, called Heaven and Earth proposes that the massive donut-shaped platform can hold magnets on its underside that would repulse the earth's magnetic field to hold the island aloft. The Maglev Train which uses the same concept is one of the fastest transport media in the whole world. The Maglev uses magnets to reach a really high velocity. It doesn't touch the floor because it levitates due to the magnets.Magnetic levitation, maglev, or magnetic suspension is a method by which an object is suspended with no support other than magnetic fields. For decades competing transportation technologies have seen dramatic changes that make it more efficient and cost effective. Operational maglev designs are both fast and efficient, but have not seen this same level of development. There is now a unique opportunity to invest in next-generation maglev where JAHN TELLER METAL is of great insight.

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2 THROWBACK

A Brief History of Maglev Trains and Superconductivity Superconductivity was discovered in 1911 by Dutch physicist H. Kammerlingh Onnes[1]. Maglev trains are not a new concept. Thomas Bachelet and Robert Goddard both came up with ideas for maglev in the early twentieth century, but had no way to actually create them. In 1934, Hermann Kemper received a patent for magnetically levitated trains, but maglev was not practical for transport until some decades later. In 1966, a maglev system consisting of superconducting magnets that induced a current in a conductor was proposed by James Powell and Gordon Danby[2,3]. This concept was explored further with working scale models built that functioned at speeds of 97 km/hr. This type of levitation is called Inductrack. Maglev can be used for both low and high speed transportation.

3 BASIC PLATFORM

3.1 WORKING PRINCIPLE:

They work on the basic principle of magnetism."LIKE POLE REPEL EACH OTHER AND UNLIKE POLE ATTRACT EACH OTHER", i.e. a system in which the vehicle runs levitated from the guideway (corresponding to the rail tracks of conventional railways) by using electromagnetic forces between superconducting magnets on board the vehicle and coils on the ground.[4,5]

LEVIATION SYSTEM:

Levitation means rise or cause to a rise. The "8" figured levitation coils are installed on the sidewalls of the guideway. When the on-board superconducting magnets pass at a high

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speed about several centimetres below the center of these coils, an electric current is induced within the coil, which push the superconducting magnet upwards and ones which pull them upwards simultaneously, thereby levitating the maglev vehicle. Both the track and train exert a magnetic field and the train is levitated by the repulsive force between the magnetic fields.

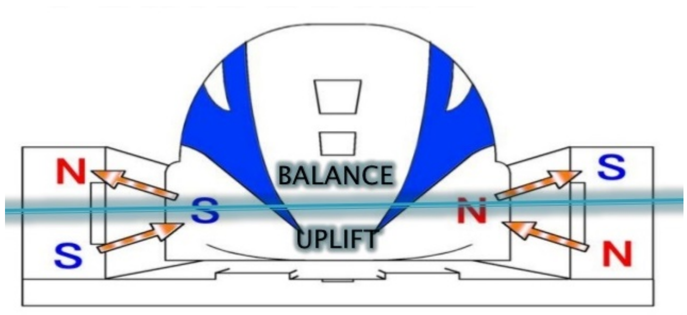

Fig.1. Levitation System

GUIDANCE SYSTEM:

The levitation coils facing each other are connected under the guideway, constituting a loop. When a running Maglev vehicle, that is superconducting magnet, displaces laterally, an electric current is induced in the loop, resulting in repulsive force acting on the levitation coils of the side farther apart from the car. Thus, a running car is always located at the center of the guideway.

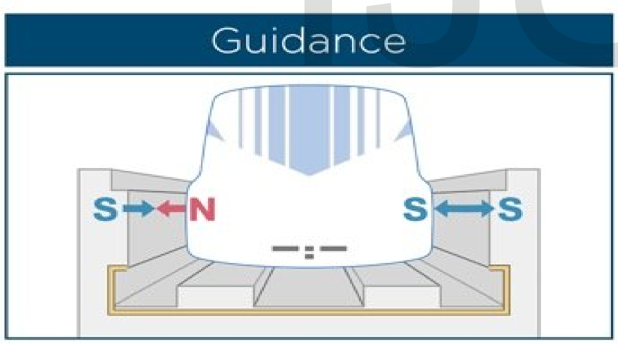

Fig.2, Guidance System

PROPULSION AND BRAKING SYSTEM:

A repulsive force and an attractive force induced between the magnets are used to propel the vehicle(superconducting magnet).The propulsion coils located on the sidewalls on both sides of the guideway are energized by a three-phase alternating current from a substation, creating a shifting magnetic field on the guideway. The on-board superconducting magnets are attracted and pushed by the shifting field, propelling the Maglev vehicle. The magnetic force between the stators and the supporting magnets can either propel or brake the train depending on the phase difference between the magnetic poles of the stators and the support magnets of the train.

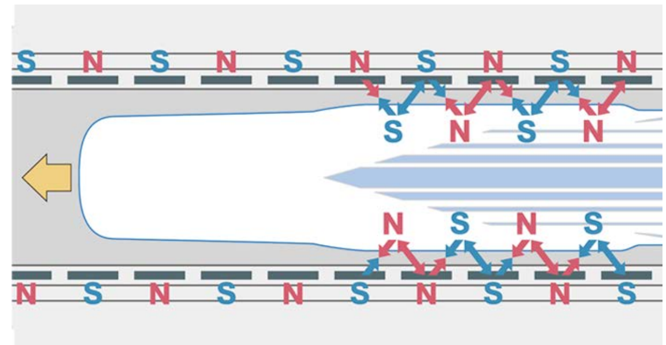

Fig.3, Propulsion and braking System

3.2 PRESS THE SPACEBAR! In maglev trains, regular conductors like copper and aluminium are used which lose energy to resistance when they transport electricity. But contrary to the conductors, superconductors have this ability that they make almost perfect magnets and thus, can be used to make powerful electromagnets. It is a phenomenon of nearly zero electrical resistance and expulsion of magnetic fields occurring in certain materials when cooled below a characteristic critical temperature. The drawback at the moment is that they have to be cooled to extremely low temperature approaching *-243.2 degree Celsius.* **Here comes the Game Changer, "THE JAHN TELLER METAL"[6,7]** which allows superconductivity to occur at *-135 degree Celsius*. It was very difficult and expensive to attain -243 *degree Celsius* but comparatively easy to get -135 *degree Celsius.* An entirely new state of matter has been discovered named Jahn- Teller-Metal which allows superconductivity to occur at low temperature which when put through an array of tests, displayed an unusual combination of properties—insulator, metal, superconductor, magnet.

proposed work

Here comes the newest state of matter, "the Jahn teller metal" that appears to be insulator, magnetic, metal and superconductor - including the otherwise unknown properties all rolled into one.[8] The surprising thing about this metal is that it involves an intermediate state never seen before. And it is this intermediate state that we are interested, as it seems that just applying pressure can turn the material from an insulator into a conductor. The research provides important clues about how the interplay between the electronic structure of the molecules and their spacing within the lattice can strengthen interactions between electrons that cause superconductivity.

What happens in Jahn Teller Metal is that as pressure is applied, and as what was previously an insulator –due to the electrically-distorting Jahn teller effect –becomes a metal, the effect persists for a while. The molecules hang on to their old shapes. So, there is an overlap of sorts, where the material still looks an awful lot like an insulator, but the electrons also manage to hop around as freely as if the material were a conductor. Jahn-Teller effect, is used in chemistry to describe how at low pressures, the geometric arrangement of

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molecules and ions in an electronic state can become distorted, this new state of matter allows scientists to transform an insulator - into a conductor.

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3.3 MAKING OF JAHN TELLER METAL:

Alkali-Fulleride superconductors were discovered in the early 90s and they consist of C60 molecules (a.k.a. buckeyballs, a.k.a fullerene, a.k.a buckminsterfullerene) forming a body-centered-cubic or face-centered cubic lattice with 3 Alkali atoms (Cs, Rb, K) for each buckeyball. The superconducting transition temperature can be tuned by hydrostatic pressure or by chemical pressure, i.e. substituting one Alkali atom with another one which has a different ionic radius.[9,10]

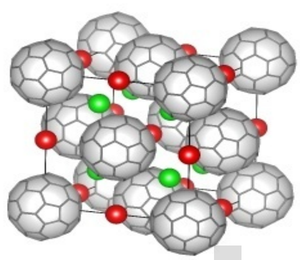

Fig.4, Crystal Structure of A3C60 where A=Cs, Rb, K, face centered cubic version.

Introduction of *rubidium* to carbon-60 molecules arranged as *fullerenes,* apply pressure forcing its molecule closer together by brute force tweaking the distance between the molecules by adding or subtracting some sort of barriers between them. When put through an array of tests, this structure displayed a combination of insulating, metallic, superconducting, and magnetic phases, including a brand new one, which the researchers have named 'Jahn-Teller metals'. And it's this transition phase between insulator and conductor that, until now, scientists have never seen before, and hints at the possibility of transforming insulating materials into super-valuable superconducting materials. And this buckyball crystalline structure appears to be able to do it at a relatively high TC. This opens up an array of possibilities to transform the insulator into superconducting material, a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain

UNDERSTANDING THE JAHN TELLER EFFECT

In the electronically degenerate state, the orbitals are said to be asymmetrically occupied and get more energy. Therefore the system tries to get rid of this extra energy by lowering the overall symmetry of the molecule i.e., undergoing distortion, which is otherwise known as **Jahn Teller distortion**.[11]

The Jahn-Teller effect/distortion is best explained by considering a different system: a d-electron metal ion in an octahedral bonding environment. The starting point is crystal field theory.[12] We know that all five *d*-orbitals of, say, copper atom, have the same energy. However, when this atom is put into a crystal with other atoms, the energy of some of these orbitals will be lowered relative to others because of electrostatic repulsion from electrons in other orbitals. In the image below, this is illustrated for a d-electron ion surrounded by 8 oxygens (octahedral environment), among the in-plane d-orbitals, the ones whose lobes point along the crystallographic directions (the so-called eg orbitals) suffer a Coulomb-repulsion energy penalty as compared to the ones which point along the diagonals (the t_{2g} orbitals) because of increased overlap with oxygen p_x and p_y orbitals. Other bonding configurations (e.g. tetrahedral) will put an energy penalty on different orbitals. This crystal-field-induced energy splitting has implications for how electrons are placed into the d-orbitals (with crystal-field effects, the lower energy orbitals are populated first, whereas without crystal field effects, one just uses Hund's rules) which has implications for magnetism and metallicity.

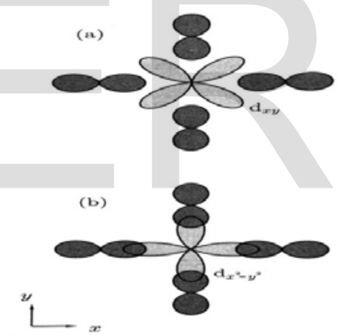

Fig.5, E.g. In case of octahedral d^9 configuration, the last electron may occupy either d_{z^2} or $d_{x^2-y^2}$ orbitals of e_g set. If it occupies d_{z^2} orbital, most of the electron density will be concentrated between the metal and the two ligands on the z axis. Thus, there will be greater electrostatic repulsion associated with these ligands than with the other four on xy plane. This asymmetric distribution of the electron density may increase the overall energy of the system. To get rid of this, the complex suffers elongation of bonds on z-axis and thus lowers the symmetry.

Conversely, occupation of the $d_{x^2-y^2}$ orbital would lead to elongation of bonds along the x and y axes.

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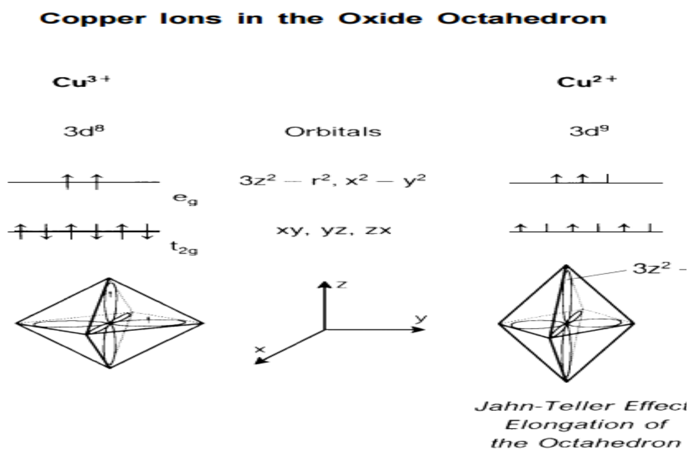

Fig.6, Schematic representation of electron orbitals for octahedrally coordinated copper ions in oxides. For Cu^{3+} with $3d^8$ configuration, the orbitals transforming as base functions of the cubic e_g group are half-filled, thus a singlet ground state is formed. In the presence of Cu^{2+} with $3d^9$ configuration, the ground state is degenerate, and a spontaneous distortion of the octahedron occurs to remove this degeneracy known as the Jahn-Teller effect.

The Jahn Teller distortion is mostly observed in octahedral environments. Theoretically the electronic degeneracy in octahedral symmetry is possible in all the configurations except d^3, d^8, d^{10}, high spin d^5 and low spin d^6 configurations.[13]

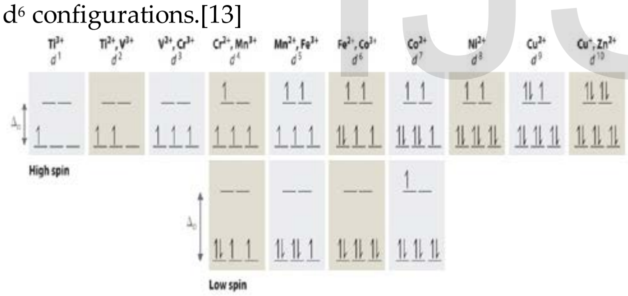

Fig.7, Configuration showing significant and weak J-T distortion.

A complex can be classified as high spin or low spin by comparing the crystal field splitting energy (Δ) and the pairing energy (P). When the crystal field splitting energy is greater than the pairing energy, electrons will fill up all the lower energy orbitals first and only then pair with electrons in these orbitals before moving to the higher energy orbitals. Electrons tend to fall in the lowest possible energy state, and since the pairing energy is lower than the crystal field splitting energy, it is more energetically favourable for the electrons to pair up and completely fill up the low energy orbitals until there is no room left at all, and only then begin to fill the high energy orbitals. On the other hand, when the pairing energy is greater than the crystal field energy, the electrons will occupy all the orbitals first and then pair up, without regard to the energy of the orbitals. If every orbital of a lower energy had one electron, and the orbitals of the next higher energy had none, an electron in this case would occupy the higher energy orbital. This follows Hund's rule that says all orbitals must be occupied before pairing begins. Remember, this situation only occurs when the pairing energy is greater than the crystal field energy. These phenomena occur because of the electron's tendency to fall into the lowest available energy state.
However considerable distortions are usually observed in **high spin d^4, low spin d^7 and d^9** configurations in the octahedral environment. It is because the Jahn Teller distortion is usually significant for asymmetrically occupied e_g orbitals since they are directed towards the ligands and the energy gain is considerably more.
In case of unevenly occupied t_{2g} orbitals, the Jahn Teller distortion is very weak since the t_{2g} set does not point directly at the ligands and therefore the energy gain is much less. E.g. d^1; d^2; low spin d^4 & d^5; high spin d^7 & d^7 configurations. Because of same reason, the *tetrahedral complexes also do not exhibit Jahn-Teller distortion*. Again, in this case also the ligands are not pointing towards the orbitals directly and hence there is less stabilization to be gained upon distortion. The Jahn-Teller effect is a secondary crystal field effect caused by *spontaneous* distortion of the unit cell. There is an elastic energy penalty for doing stretching and compressing, but Jahn-Teller distortion happens spontaneously if there is an electronic energy savings. This has further implications for bonding and magnetism.

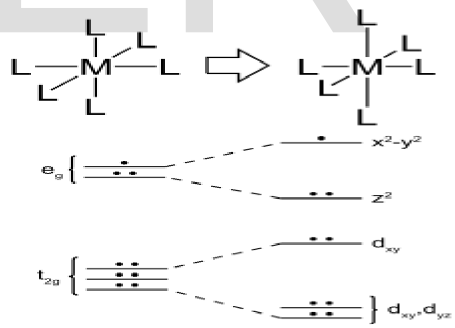

Fig.8, Crystal field effects and Jahn-Teller distortion for 3d ion in octahedral crystal field environment. The octahedral environment makes t_{2g} orbitals (d_{xy}, d_{xz}, d_{yz}) have lower energy than e_g orbitals ($d_{x^2-y^2}$, $d_{3z^2-r^2}$) orbitals. Jahn-Teller distortion (stretching of the octahedron) further splits the energies of the orbitals.

Originally, electrons can sit in one of three degenerate molecular orbitals, but compression (or stretching) of the entire buckeyball can lift the degeneracy, change the spin state, and change the orbital overlap with adjacent molecules (i.e. the metallicity).

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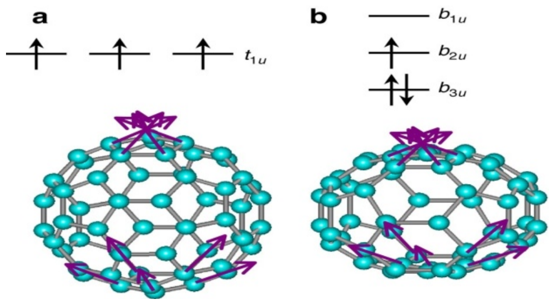

Fig.9, Distortion at molecular level occurring due to Jahn Teller Effect. Jahn-Teller effect in the parent insulating state of the molecular superconductor Cs_3C60.

One of the most exciting things about Jahn Teller Metal is that on the one hand, they behave like conventional superconductors, superconductors explained by BCS theory [14,15] for instance, buckeyball phonon modes appear to play a role in superconductivity, but on the other hand, the fact that their superconducting properties are tuneable by pressure implicates electron-electron interactions as seen above , which lend them similarity to unconventional superconductors, such as high-T_c cuprates.`

This is all pretty important because this transition from insulator to metal is also a transition from insulator to *potential superconductor. The resulting metal* just needs low enough temperatures and all of a sudden its electrons start pairing up and skipping around, with the result being a sudden drop to exactly zero electrical resistance.

It's this pairing up of electons, which are together known as Cooper pairs, that's crucial for superconductivity. Now, BCS theory is the microscopic theory of superconductivity caused by a condensation of cooper pairs. In normal state, the force between the electrons is repulsive. In superconducting state, the force between the two electrons becomes attracted due to the formation of cooper pair. When current flows to superconductor, and electron comes near the positive ion core of the lattice, then the electrons experiences the attractive force. Due to the interaction between the electrons and the ion core, the ion core is slightly displaced. This is known as LATTICE DISTORTION, which travels as a mechanical wave, phonon (quantized lattice vibrational energy).Now if another electron comes near the distorted lattice then phonon interacts with second electron and hence there is a force of attraction between the second electron and phonon. In this way two electrons interact with each other through the lattice vibration. This process is called electron-lattice-electron interaction via a phonon field.

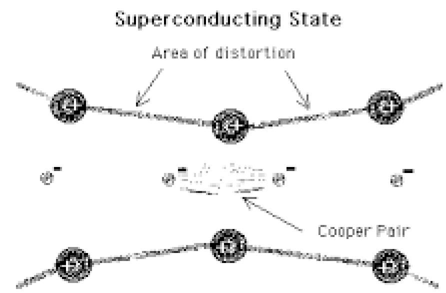

Fig.10, The two elstrons, called Cooper Pairs, become locked together and will travel through the lattice.

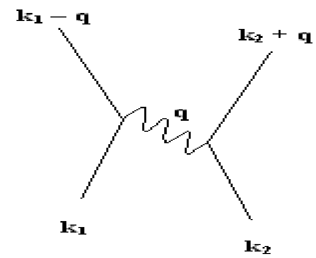

Fig.11. When electron vector k_1 distorts the lattice, the lattice gains momentum. As the result, the momentum of electron decreases. So, a phonon of wave vector q is emitted. When another electron with wave k_2 absorbs the energy from phonon, it gains momentum. Therefore, due to interaction we have two electrons with wave vector k_1-q and k_2+q. These two electrons form the cooper pair and know as cooper electron. The main important point is that the pair of electrons does not transfer any energy to the lattice. So, when the pair of electrons flow in the form of cooper pair, they don't encounter any scattering and the resistance factor vanishes, i.e., conductivity becomes infinity which is named as superconductivity.

"The surprising thing about this metal–insulator transition is that it involves an intermediate state never seen. This is pretty important because this transition from insulator to metal is also a transition from insulator to potential superconductor. In Jahn–Teller metal as pressure is applied, that which previously was an insulator , due to the electrically-distorting Jahn-Teller effect becomes a metal and the effect persists for a while. The molecules hang on to their old shapes. So, there is an overlap of sorts, where the material still looks like an insulator, but the electrons also manage to hop around as freely as if the material were a conductor.

When distortion of the buckeyballs favors an insulating electronic structure, Mott-jahn teller insulator occurs. When the material is studied using infrared spectroscopy, the fulleride molecules clearly show rugby-ball distortions, which were only known to occur in insulators. However, nuclear magnetic resonance measurements clearly show that electrons are able to "hop" from one molecule to the next--which is the signature of a conducting metal."[16,17]

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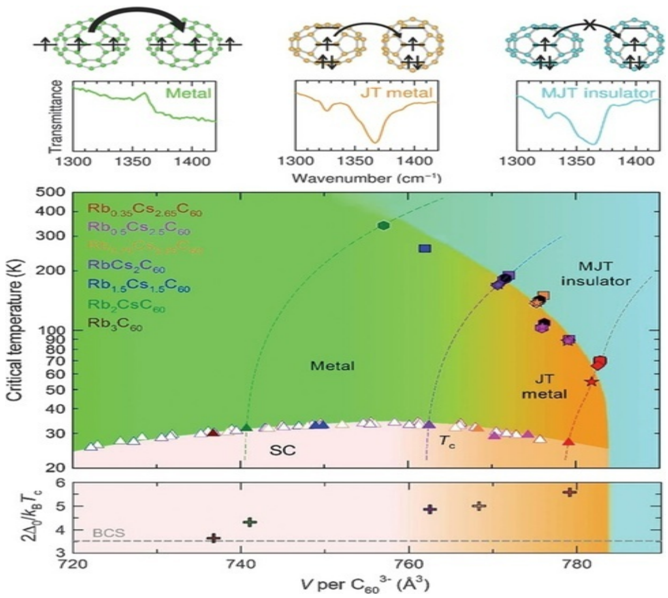

Fig.12,. Phase diagram of FCC A3C60, where the axis is the unit-cell volume, tuned by either chemical or hydrostatic pressure. The diagrams at the top illustrate Jahn-Teller distortion and the resulting molecular-orbital energy splitting, but they do not explain why conduction is permitted in the middle sketch but not in the right sketch.

A well documented example includes complexes of the type $M_2PbCu(NO_2)_6$.
For M=Cs, below 285K the molecule shows tetragonal symmetry, for M=K this occurs at below 273K, for M=Rb at less than 276K and for M=Tl at temperatures less than 245K. Above these temperatures the molecules appear octahedral due to the dynamic Jahn-Teller effect.

$CuBr_2$	4 Br at 240pm 2 Br at 318pm
$CuCl_2$	4 Cl at 230pm 2 Cl at 295pm
$CuCl_2.2H_2O$	2 O at 193pm 2 Cl at 228pm 2 Cl at 295pm
$CsCuCl_3$	4 Cl at 230pm 2 Cl at 265pm
CuF_2	4 F at 193pm 2 F at 227pm
$CuSO_4.4NH_3.H_2O$	4 N at 205pm 1 O at 259pm 1 O at 337pm
K_2CuF_4	4 F at 191pm 2 F at 237pm
$KCuAlF_6$	2 F at 188pm 4 F at 220pm
CrF_2	4 F at 200pm 2 F at 243pm
$KCrF_3$	4 F at 214pm 2 F at 200pm
MnF_3	2 F at 209pm 2 F at 191pm 2 F at 179pm

Fig.13, Some examples of Jahn-Teller distorted complexes. This proves the potential of Jahn Teller Metals as a high temperature superconductors which can be used in Maglev or other advanced technologies. High-temperature superconductors (abbreviated high-Tc or HTS) are materials that have a superconducting transition temperature (Tc) above 30K.

As human beings we always crave for attention and reality, and the crux of the whole ball game is our earnest desire to obtain superconductivity at higher temperature. Thus, making things simpler and attainable.

Tabular representation of advancement in Maglev Trains:

Speed	Date	Line	Country
603 km/h	2015-04-21	Yamanashi Test Track	Japan
590 km/h	2015-04-16	Yamanashi Test Track	Japan
581 km/h	2003-12-02	Yamanashi Test Track	Japan
552 km/h	1999-04-14	Yamanashi Test Track	Japan
550 km/h	1997-12-24	Yamanashi Test Track	Japan
501 km/h	2003-11-12	Shanghai Maglev Train	China
411.5 km/h	1974-08-14	High Speed Ground Test Center	USA
164 km/h	1971-10	Krauss-Maffei's plant inMunich - Allach	West Germany
90 km/h	1971-05-06	MBB's Ottobrunnfactory	West Germany

We can see that maximum recorded speed is 603 km/hr achieved in Japan at Yamanashi Test Track and this SCMaglev system uses an electrodynamic suspension (EDS) system in which there are conductors which are exposed to time-varying magnetic fields. This induces eddy currents in the conductors that creates a repulsive magnetic field which holds the two objects apart.

Installed in these trains' bogies are superconducting magnets. And now this superconductivity can be obtained in a more efficient manner via Jahn Teller Metal which displays an unusual combination of properties—insulator, metal, superconductor, magnet. Moreover, one may try new transition elements which by doping in C60 may provide better results (i.e. more high temperature Superconductors).

4 CONCLUSION

In this dynamic era, we actually need maglev vehicles to be deployed in every nation. Maglev vehicles are the fastest vehicle ever invented on earth, crossing all the limitations of time and distance which even airlines could not overcome. And further this introduction of the new state of matter, ”THE JAHN TELLER METAL” provides an eccentric edge which could lead to the NEXT GENERATION MAGLEV VEHCILES. Augmentation of these new transition elements with C60 may provide better observations (i.e. more high temperature Superconductors).Further, keeping in mind the future scope, the concept of this NEXT GENERATION maglev should be brought in every field of science and technology, as without the audience there is no theatre so we need that the populace should get acquainted with these new findings. It's time to take MAGLEV to the next generation with JAHN TELLER metal. So, bend the rules and let's go invent tomorrow.

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Written by, MICHAEL BYRNE EDITOR 9 May 2015 // 11:30 AM CET.
[18] 8 Ways Magnetic Levitation Could Shape the Future(from net)