PL1-INV

Real space imaging of the superconducting vortex lattice: Recent results and prospects

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I will review vortex lattice imaging using scanning probe microscopes and discuss recent prospects. First, I will discuss the behavior of vortex lattices in tilted magnetic fields. Many practical applications of high Tc superconductors involve anisotropic materials and magnetic fields applied on an arbitrary direction. The shape and properties of vortices in titled magnetic fields is largely unknown and I will discuss the insight won about vortex properties and manipulation by imaging experiments in several anisotropic superconductors [1,2]. I will also review vortex distributions at very high magnetic fields and make a comparative discussion of results in the new 1144 family of pnictide superconductors[3]. I will finally make the point about new techniques in achieving atomic scales measurements of the Josephson effect using superconducting tips and recent (and rather serendipitous) insight into the shape of the superconducting transition[4,5].

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PL2-INV

Superconducting Magnet Development for Next-Generation Accelerator Capabilities

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The physics needs of particle accelerators have pushed the boundaries of superconducting magnet technology from their initial implementation in the Tevatron through the current High Luminosity Upgrade project for the LHC. Potential future machines like the FCC, ILC, or the CEPC will require the development of even more advanced magnet technology. Current state of the art Nb_3Sn magnets are unable to meet the needs of future colliders both from a cost and performance standpoint, so teams around the world are working to define the needs and develop the technologies needed to meet the aggressive requirements of future accelerators. Everything from the conductor through the design and construction of magnets will need to be re-thought to ensure that future accelerators will be feasible. Current roadmaps on how this development may play out, along with the magnet needs for future accelerators and technologies under development to meet these needs will be presented.

Keywords: Accelerators, Superconducting Magnets, High temperature superconductors, Nb3Sn

PL3-INV

Advanced SQUID instruments for mineral exploration

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Quantum magnetometers, say magnetic field sensors with quantum limited resolution, have the potential to develop significant impact on applications in geo- and environmental science such as mineral exploration, geo-engineering and geo-technical tasks like pipe line detection or unexploded ordnance detection and archaeometry. Especially, mineral exploration has a high social priority to enable a sustainable and affordable supply of the high technology industry with the required materials.

Within this talk, we will give a short and limited introduction on the geophysical methods which make use of highly sensitive magnetometers, herein Superconducting Quantum Interference Devices (SQUIDs), and the according specific demands on them. In order to make use of their extreme resolution in mineral exploration, the magnetometers themselves have to overcome two main challenges – they must be operable at Earth's magnetic field without degradation of their performance especially in terms of signal resolution and, often for active methods, have to be able to track fast changing signals with large amplitude.

The two main methods in geophysics for SQUID magnetometers, namely magnetics and electromagnetics will be discussed in more detail. We will introduce instruments which are able to map magnetic field anomalies with utmost resolution in order to derive 3D distributions of magnetization or conductivity of sub-surface geological structures. We will provide examples form mineral exploration and archaeology.

Within the second method, a secondary magnetic field induced from currents in the sub-surface has to be recorded with high resolution and bandwidth for determining the conductivity and polarization effects of the according geological structures under investigation. We will provide examples of ground based transient electromagnetics and will discuss the future prospects of SQUIDs in this context.

Finally, we will discuss which research topics have to be addressed to widen the range of applications for SQUIDs in geophysics.

Keywords: Quantum magnetometers, SQUID, Magnetometry, Magnetics, Electromagnetics, Gradiometry, Transient electromagnetics

PL4-INV

Development of (Ba,K)Fe_2As_2 tapes and wires in Japan

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Among various iron-based superconductors, (Ba,K)Fe_2As_2(Ba-122) are potentially useful for high field applications due to their high upper critical fields of over 50T and small anisotropy. However, enhancements of superconducting properties are still needed to boost the successful use of Ba-122 in such applications. In this presentation I will review recent progress of Ba-122 conductors in Japan.

Ba-122 tapes and wires are prepared by *ex situ* PIT method using Ag as a sheath material. The application of uniaxial pressing at the final stage of deformation significantly enhances J_c values. However, the uniaxial pressing is not a practical method for long tape fabrications. Furthermore, the Ag sheath is completely annealed and becomes very soft after the heat treatment. In order to solve these problems a combination of new sheath structure of stainless steel(SS) and Ag-Sn alloy double sheath are used. The highest J_c value of SS/(Ag-Sn) double sheathed tapes reaches 1.4×10^5A/cm^2 in 10 T, 4.2K for cold pressed tape. Even for rolled tapes, the J_c reaches to the practical level of 10^5A/cm^2 in 10T. More interestingly, the heat treatment temperature can be greatly reduced for these double sheathed tapes.

Recently ~1m long Ba-122/SS/(Ag-Sn) double sheath tape with fairly uniform J_c distribution was fabricated. Bending tests of the double sheath tapes were also carried out. J_c started to decrease at the bending diameter of 30mm which corresponds to bending strain of ~0.17% in Ba-122 layer. These results demonstrate that the double sheath is promising for making long Ba-122 tapes for high magnetic field applications.

Superconducting joints for Ag sheathed mono-filamentary Ba-122 tapes were fabricated. Two wires were inserted into Ag-Sn alloy tube from both ends, uniaxial pressure was applied to the joint and the joint was heat treated. J_c at the joint was 1.7×10^4A/cm^2 at 4.2K and 10T.

Generally, round wire superconductors are more useful than tape conductors. However, Ba-122 round wires show much lower J_c values than the tape conductors due to lower Ba-122 mass density. Application of hot isostatic pressing(HIP) is effective in improving mass density and J_c values. However, the J_c of HIP processed wires still remains low level compared to the tape conductors. Further improvement of J_c capacity is required for Ba-122 wires.

Keywords: mass density, sheath material, critical current density, superconducting joint

PL5-INV

Frontiers of Nb_3Sn wire technology

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65 years after its discovery, Nb_3Sn still defends its leading place against HTS in high field applications, like high-resolution NMR spectrometers, fusion magnets and laboratory magnets, and has even regained interest over the past decades pulled by the next Big Science experiments. In particular, the Future Circular Collider at CERN represents the next big potential application as well as a grand challenge for Nb_3Sn superconductors. The goal of a 100 TeV proton-proton collider set by the high-energy physics community has led to a baseline configuration requiring dipoles generating 16 T in a 100 km tunnel. This translates into a requirement of a minimum critical current density of more than 1'500 A/mm^2 at 16 T and 4.2 K, which is substantially beyond state-of-the-art for commercial Nb_3Sn wires. Apart from high critical current density, the stress sensitivity of Nb_3Sn is a parameter of the highest importance for the design of the next generation accelerator magnets, whose large sizes and intense fields will result in unparalleled electromagnetic forces. The aim of this talk is to illustrate the directions in which these technology needs are driving the properties evolution of Nb_3Sn. First, I will introduce the main parameters controlling the achievable transport current density in Nb_3Sn. Emphasis will be given to some recent innovations showing that the potential of the material for future performance upgrades is not yet exhausted. I will also report on what we learned regarding the mechanisms of the wires' irreversible critical current degradation upon mechanical loading and discuss possible strategies towards high-performance Nb_3Sn wires with enhanced stress tolerance.

PL6-INV

ISEULT, a Whole Body 11.7 T MRI magnet

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The Iseult project is a French-German initiative focused on very high magnetic-field molecular imaging. That project includes a Whole Body 11.7 T MRI magnet that will equip Neurospin, a neuroscience research center operating at CEA Saclay since November 2006. After 7 years of fabrication at Belfort by GE Power, the Iseult magnet was delivered to CEA in June 2017 and its connection with the cryoplant and with all the ancillary equipment was completed in October 2018. After 4 months of cooldown and 4 months of tests, the Iseult magnet has reached its nominal field of 11.72T for the first time, on July 18th.

OR-1-INV

Status of global supply and demand of helium and outlook for the future

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Helium is indispensable as coolant in cryogenic technology research and development. The gas is tight in supply and demand globally, making it difficult to obtain. Gas Review has been reporting the latest situation of helium for almost 40 years as the magazine specialized in industrial gas industry. In the lecture we will describe the current tight situation of helium and estimate how long this would continue.

Helium has been expanding in use in the USA, Japan, and Europe as an indispensable gas for cryogenic technology, MRI, and semiconductor as well as optical fiber manufacturing since around 1980, due to its physical property such as inert, high thermal conductivity, and low boiling point. The demand has rapidly been increasing in the East Asia including China, and India in these years.

Helium is also extremely rare natural resource, of which production area is very limited in the world. The gas is present in minute amounts in atmosphere, but the gas for industrial use is mostly produced as LNG by-product from natural gas field. Therefore, helium production depends on LNG plant operation and demand and supply balance of energy in the world. In addition, helium cannot be produced from any natural gas field. Only the USA, Qatar, Africa and Australia have natural gas field which can extract and purify helium at economically viable cost.

Tightness this time is the result of supply capacity not keeping up with globally growing demand. Regarding supply capacity, there has been no investment for new capacity in the world since Qatal II project in 2013. And the US helium operations will completely stop in 2020.

In spite of growth in demand, supply capacity has not been expanded. Limited supply capacity in the market leaded to limited supply to the users in the world.

This trend seems to continue over a coming few years. Sales price of helium will also hover at a high price. There is another point of view that the price might be down due to temporally mitigated demand and supply situation after 2021 when the new plant will start operation. But Gas Review expect that producers and suppliers will keep current price or move to additional price increase to maintain profitability in unstable helium business.

In the lecture, we would like to find out the future trend in helium supply and demand in the future.

Keywords: helium, natural resource, cryogenic

OR-2-INV

Development of High-Resolution HTS-SQUID Magnetometer for Observation of Magnetic Signals from Earthquake-Piezomagnetic Effects

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Electromagnetic changes associated with earthquakes have been investigated previously. For decades, researchers have studied the seismomagnetic effects[1,2]. From continuous observations, our research group reported a successful result which is "co-faulting" Earth's magnetic field variation due to piezomagnetic effects caused by earthquake rupturing (i.e., earthquake(EQ)-piezomagnetic effects)[3]. This is an important finding: observation of EQ-piezomagnetic effect may lead us to a new system for super-early warning of earthquake detection.

However, additionally the observed result also suggested that the geomagnetic field accompanying fault movement are very small variations of some hundreds pT. Therefore, to develop an extremely high-resolution magnetometer system is so important, that our research group has developed a new geomagnetic observation system with low running cost and higher resolution at Iwaki observation site in Fukushima, Japan: we introduce high-temperature-superconductor based superconducting-quantum-interference-device (HTS-SQUID) as a magnetometer for a long-term geomagnetic observation.

The sampling-frequency of our magnetometer system is 50 Hz (0.02 s) which are higher sampling frequency than our conventional observation system using a flux-gate. Our system observed the orthogonal three-vectors of geomagnetic field vibration. The clock of this system is synchronized with a GPS signal. These observed data are uploaded to the web server through the mobile network.

Through our evaluation, it is clarified that the resolution of our HTS-SQUID magnetometer systems is about a few or several pico-tesla. We obtained the observation results of geomagnetic field changes associated with the earthquake generated near our observation point using our high-resolution magnetometer system.

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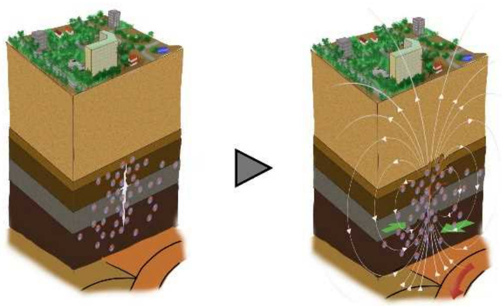

Fig. Aspect of Earthquake (EQ)-piezomagnetic effect: Earth's magnetic field variation due to piezomagnetic effects caused by earthquake rupturing

Keywords: magnetometer, HTS-SQUID, earthquake-piezomagnetic effects, observation

LN-1-INV

Accessing critical currents in large pulsed fields: challenges and opportunities

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Expanding non-linear transport (I-V) studies to magnetic fields above those accessible by DC magnets can bring valuable information on vortex pinning and phase diagram of superconductors. Very-high field all-superconducting and hybrid magnets make it technologically relevant to study vortex matter in this regime. However, pulsed magnetic fields reaching 100T in milliseconds impose technical and fundamental challenges that have prevented the realization of these studies. Here, we present a fast I-V DC technique that enables determination of the superconducting critical current in pulsed magnetic fields, beyond the reach of DC magnets.[1] We demonstrated this technique on standard and pinning enhanced $RE\mathrm{Ba_2Cu_3O_7}$ (RE = rare earth) on single crystal and metallic substrates with excellent agreement with DC field measurements.[1,2] The I-V characteristics change with the magnetic field rate. We capture this unexplored vortex physics through a model based on the broken symmetry of the vortex velocity profile produced by the applied current.[1] By measuring J_c at 65T, 4K, we are able to observe the end of the power-law regime with important implications to applications and fundaments of the change of pinning regime.[2]

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Keywords: pulsed magnetic fields, current voltage curves, critical current, REBCO

LNP-1

DESIGN AND MANUFACTURING STATUS OF SUPERCONDUCTING MAGNET FOR MULTI-PURPOSE DETECTOR AT NICA COLLIDER

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The main scientific project being created at the Joint Institute for Nuclear Research is Nuclotron-based Ion Collider fAcility (NICA). One of the main elements of this complex is a multi-purpose detector, created on the basis of a large superconducting solenoidal magnet with a diameter of 5.2 m. The magnet will operate at a temperature of 4.5 K and a nominal magnetic field of 0.5 T. This publication describes the parameters of the magnet, a description of its subsystems, as well as manufacturing status.

LNP-2

Complex Research of the Unclosed HTS Shield for Improving Homogeneity of the Magnetic Field

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Homogeneous magnetic fields are required in different applications. The resolution of MRI techniques depends on the quality of the magnetic field, as well as the efficiency of electron cooling systems used at particle accelerators. Unclosed magnetic shield made of superconducting tapes is able to nullify the radial component of a solenoidal magnetic field, forming the long region of the homogeneous magnetic field.
The shield is a lengthwise winding made from (Y)BCO tapes are wound along a carcass generatrix. Then it is positioned coaxially inside an electromagnet. The measurements were carried out under quasistationary conditions, magnetic fields up to 1 kG at 77K.
This poster discusses the design of the superconducting shield and presents experimental and numerical studies into the homogeneity of the magnetic field in solenoids with the superconducting shield.

LNP-3

First-cut Design of a No-Insulation All-REBCO 7 T Whole-body MRI Magnet

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As high temperature superconductor (HTS) magnets exhibit noble current-carrying abilities under high magnetic field while being capable of operations at cryogen free conditions, they could be possible candidates for the future use for main magnets of ultra-high field magnetic resonance imaging scanners (UHF-MRIs). With employment of the well-known no-insulation (NI) technique, strong magnetic fields may be achieved within relatively small volumes, which is an attractive trait for commercial MRI. In this paper, we present a first-cut design of a no-insulation HTS magnet that generates a center field of 7 T in a 800-mm room-temperature bore. The magnet consists of a stack of double-pancake coils wound with multi-width REBCO tapes. The so-called "inside-notch" winding configuration is adopted to generate a target field homogeneity of <10 ppm in 40 cm diameter spherical volume (DSV). This paper presents: (1) detailed design parameters of the magnet; (2) performance analyses with the intrinsic "NI-behaviors" considered; and (3) discussion on the options for active shielding.

Acknowledgement: This work was supported by Samsung Research Funding & Incubation Center of Samsung Electronics under Project Number SRFC-IT1801-09. It was also supported by the BK21 Plus Project in 2019.

Keywords: HTS magnet, multi-width, no-insulation, ultra-high field MRI

LNP-4

Opportunities and Challenges of No-insulation Winding Technique for Stability Enhancement of Low Temperature Superconductor Magnet

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The no-insulation (NI) winding technique for low temperature superconductor (LTS) magnet was proposed a few decades ago. In early days, mainly due to the low stability margin of LTS, the NI technique was regarded to be unacceptable to LTS magnets. Recently, multiple variations of the NI technique such as partial-insulation, metal-clad insulation, metal-co-wound and electrically-conductive epoxy resin were proposed, which led to an expectation to use those innovative winding methods to substantially improve stability margin of LTS magnets. This paper presents an analytic study on applying the NI (or its variations) technique to various LTS magnets. Stability margin and minimum quench energies are compared in various types of LTS coils with and without the *insulation*. Discussions on new opportunities and potential pitfalls are also provided in details.

Acknowledgement: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249). It was also supported by the BK21 Plus Project in 2019.

Keywords: Insulation, low temperature superconductor magnet, No-insulation, stability margin

LNP-5

Fabrication and Performance Evaluation of a 400-MHz 66-mm Bore All-REBCO Conduction-Cooled NMR Magnet

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In 2014, a project to develop a 400 MHz 66 mm high temperature superconductor Nuclear Magnetic Resonance (NMR) magnet was embarked with a team led by Korea Basic Science Institute in close international collaboration among the National High Magnetic Field Laboratory, Korea Institute of Machinery and Materials, Kunsan National University, Seoul National University, and SuNAM Co., Ltd. The magnet consists of a stack of 48 Double Pancake coils wound with the multi-width no-insulation winding technique. It operates under conduction-cooled environment at 20 K or lower to generate the target center field of 9.4 T at a nominal operating current of 187 A. To reduce temporal field drift and spatial field error due to screening current, the current sweep reversal method is adopted as a charging protocol. This paper presents design, construction, and operation results including passive and active shimming with the respective ferro and copper-coil shim sets.

Acknowledgement: This work was supported by the Korea Basic Science Institute (KBSI) grant D39611.

Keywords: Conduction-cooled, no-insulation, multi-width, REBCO

LNP-6

Simulation of Superconducting Coplanar Waveguides for Quantum Computing

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Superconducting circuit plays an important role in realization of a scalable quantum computer. Anomalous characteristics of superconductor such as extremely low surface losses and a single quantum state at the macroscopic level have been able to realize a scalable and programmable quantum computer. Unlike the ion trap architecture – another type of candidate for the realization of a quantum computer, Josephson junctions are mainly used as superconducting quantum bits (qubits) in superconducting quantum computing. Since the control and readout of multiple superconducting qubits are one of the most challenging issues to address, precise design and simulations of quantum IO systems are required. In particular, 3D cavities and 2D coplanar waveguides (CPW) are mainly employed to manipulate superconducting qubits using electromagnetic waves. In this paper, we present the performance simulation results of superconducting CPW and theoretical approaches for calculating anomalous characteristics of a superconductor.

Acknowledgement: This research was supported by Samsung Electronics. It was also supported by the BK21 Plus Project in 2019

Keywords: Coplanar Waveguide, RF Resonator, Q-factor, Quantum Computing

LNP-7

Comparative Analysis of Superconducting Bulk-type magnet and Wire-type electromagnet Applicable to Mechanical DC Circuit Breakers

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The core technology of the DC grid system is to protect the system in the event of a transient and to cut-off the faults current in a trouble line, quickly.

We sat down to analyze to implement the DC breaking technology of mechanical DC circuit breaker on the faster and more safely. However, the mechanical DC circuit breakers have limitations on the opening speed and the components of the break contact. To solve this problem, we applied a superconducting electromagnet to a mechanical DC circuit breaker and proposed a method to reduce the DC Arc energy generated during the breaking operation.

In this paper, we proposed the application of superconducting bulk-type magnet and superconducting wire-type electromagnet to the conventional mechanical DC circuit breaker and analyzed the breaking characteristic. We designed a mechanical DC blocking contact, a superconducting bulk-type magnet, and a superconducting wire-type electromagnet through the Maxwell 3D program.

As a result, the Lorentz force was generated between the mechanical DC blocking contacts each applied the superconducting bulk-type magnet and wire-type electromagnets. The superconducting bulk-type magnets produced about 43.8 percent faster and the superconducting wire-type electromagnets produced about 87.2 percent faster DC Arc breaking speed.

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Keywords: Superconductivity, bulk-type magnet, Wire-type electromagnet, circuit breaker

LNP-8

Analysis of the Operating Characteristics of fault Current limited DC Circuit Breaker According to Superconducting Winding Type

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We proposed a current-limiting DC blocking technology with superconductors. In the case of the fault current, the fault current in the DC system is primarily limited by the superconductor. After that, the limited current is stably cut off by the DC circuit breaker.

In this paper, we analyzed the operating characteristics of DC circuit breaker according to the winding type of superconducting wire in the current-limiting part. The current-limit windings were selected as helical wire and spiral wire types. In the same length, spiral wires generate higher heat and magnetic fields than helical wires. However, spiral wire have higher inductance than helical wire rods, which delays the current limit. Therefore, in this paper, we analyzed the fault current limit rate, quench speed, and the DC breaker's breaking characteristics while changing the inductance according to the wire winding method. In addition, the power burden of each superconductor and DC circuit breaker was compared and analyzed. For simulation analysis, HFSS program was used to analyze the electromagnetic field analysis according to the winding type of the current-limit. Also, after the fault current is simulated using the EMTDC / PSCAD simulation, the breakdown behavior of the superconducting DC circuit breaker is analyzed.

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LNP-9

The Search of New Superconducting Materials in Ni – N and Ni –H Systems

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Fe–H and Fe–N systems are well known for their superconducting compounds with transition temperatures up to 50 K. Based on the affinity of iron and nickel atoms we suggested the existence of similar superconductors in Ni–N and Ni–H systems and undertook their theoretical search. The calculations on crystal structure prediction have been performed with evolutionary algorithms (USPEX package) and density functional theory (VASP) package at 100, 200, 300, and 400 GPa. As a result, several new candidates for superconducting materials have been revealed in the Ni-N system. During our investigation, the results on the Ni-H system have been published by Xi and co-authors [1]. The transition temperatures nickel hydrides do not exceed 1 K. In addition to Ni-H and Ni-N systems, we have also performed the search in Fe–H and Fe–N systems. Although no new perspective structures have been found in these systems, we will use them for comparison.

In the system Ni-N, which has not been investigated before, seven new stable structures have been found. The convex-hulls and corresponding sequences of phase transitions for this system are shown in Figure1. In nitrogen-reach part of the system which is more perspective for superconductors, the new structure NiN_2-*Pnnm* has been revealed. Found NiN_2-*Pnnm* is isostructural to FeN_2-*Pnnm*, which has a transition temperature of 4-8 K [2]. Our calculations of transition temperatures for NiN_2 are in progress, the results will be presented in Conference and in Proceedings.

Despite at ambient conditions nickel shows 2+, 3+, and 4+ valences, while iron only 2+ and 3+, at pressures above 100 GPa, both iron hydrides and iron nitrides are more reache in the number of phases in comparison with their nickel counterparts. However, this can be the consequence of a less thorough search in nickel compounds. In cases, when nickel hydrides or nitrides have the same stoichiometry they are usually isostructural.

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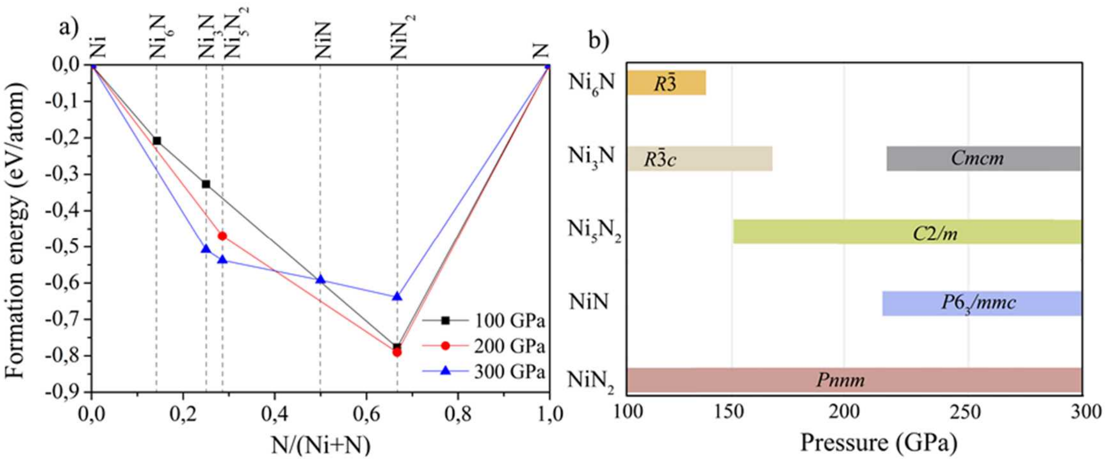

Figure 1. Convex hulls (a) and phase transitions (b) of Ni-N compounds.

Keywords: high-pressure, nitrides, crystal structure prediction, density dunctional theory