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The interrelationship of hydrogen energy and superconductivity is a new area research

Davron Rahmonovich Djurayev
Abdullo Amrullojon o’g’li Ahadov
abdulloahadov7@gmail.com
Bukhara State University

Abstract: In this article,the information about interrelationship of hydrogen energy and superconductivity, which is new research theme of modern physics, is given. Advantages and causes of restrict using hydrogen energy is emphasized and developing hydrogen energy plans of world community is briefly stated. Physical nature and theories of superconductivity and types of superconductors are also explained. Experimental results of hybrid energy transfer with hydrogen energy and superconductivity are given for revealing the essence of the article. Then some important conclusions about interrelationship of hydrogen energy and superconductivity are mentioned.

Keywords: green energy, ferromagnetizm, Meissner effect, high-temperature superconductors, BCS theory, hybrid transfer.

It is no secret that humanity has achieved a prosperous life today by discovering and skillfully using its vast energy reserves. As a result of the development of science, new types of energy are being discovered. Many scientists are now focusing on hydrogen energy. The use of hydrogen energy is recognized as the most optimal energy due to a number of its advantages.

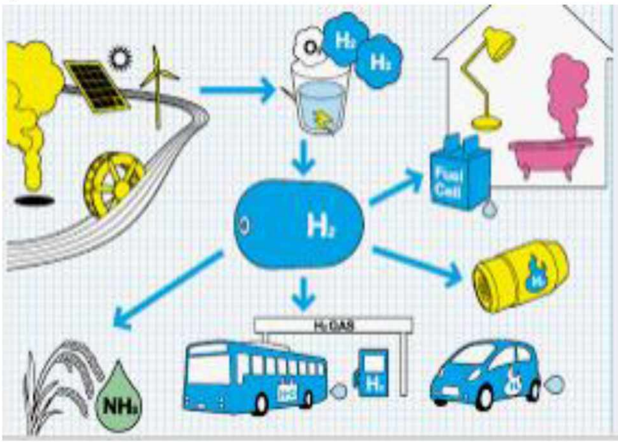
Main task for the next decades is to create a completely new industry and market for hydrogen technology. This requires the production of environmentally friendly "green" hydrogen, large-scale storage and transportation of thousands of miles by pipeline and tanker, as well as the creation of energy, transport, industrial and household applications.

At present, hydrogen gas is produced at a rate of 55-65 million tons. Hydrogen is mainly used in oil refining and in the chemical industry for the production of ammonia and methanol. Currently, only 1-2% of the total hydrogen is used in energy.

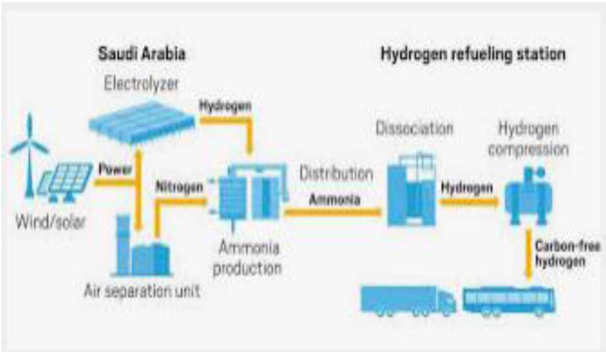
The International Energy Agency forecasts that by 2040, solar and wind power will account for 20-35 percent of the world's electricity generation. In this development, the demand for energy storage and rapid compensation technologies will increase. Hydrogen energy is an effective tool that creates long-term energy storage opportunities. In this case, the technology of hydrogen production from water can be used, using excess energy from solar and wind sources. More than 20 countries and more than 50 corporations have adopted long-term strategies for the development of hydrogen technology, and these programs are being implemented rapidly through various incentives. For example, Japan has set itself the goal of building a "hydrogen-based society" and has begun to implement hydrogen projects in households by importing hydrogen from countries such as Australia and Norway. Japan also plans to spend $ 10 million a year by 2050 on its project named as Strategic Roadmap for Hydrogen and Fuel Cells.

The USA Hydrogen Program has been running under various names since the 1970s. In the 21st century, the program is in a period of awakening - the USA Hydrogen and Fuel Cells Program receives $ 120 million annually.

The Fuel Cells and Hydrogen Joint Undertaking program was launched in the EU in 2017. According to this program 1.8 billion will be allocated for the development of hydrogen technology by 2023.



Picture-1. Using hydrogen energy.



Picture-2. Hydrogen refueling system in Saudia Arabia.

Solar and wind energy in Uzbekistan have great potential, but one of the main obstacles to their development is the dependence of these energy routes on climate change and day and night shifts. Wind generators operate only at wind speeds above 5-6 m/s and provide an average of 3200-4300 hours of power per year in areas of Uzbekistan with high wind potential, with an annual duration of 8760 hours. Solar photovoltaic plants operate only during the day, in cloudless and low-cloud conditions, and provide an average of 1,500 to 2,200 hours of energy per year in areas of Uzbekistan with high solar potential.

Hydrogen can be used in our country in the following ways:

a) As an environmental friendly fuel. During the combustion of hydrogen, only water vapor is released, and heat and electricity can be produced during combustion.

b) As fuel cells. This produces electricity directly from hydrogen without combustion, resulting in only pure water. These elements are also used in hydrogen cars.

From the point of view of "green" energy, the efficiency of hydrogen fuel cells is very high: 70-90%. For comparison: the efficiency of the best internal combustion engines 35-40%, for solar photovoltaic plants is only 15-20%, depending on weather conditions. The efficiency of the best wind power plants is up to 40%, but wind farms also require favorable weather conditions and costly maintenance.

In order to develop the hydrogen energy sector in the country, the Ministry of Innovative Development has developed a proposal to establish "Scientific and Practical Innovation Center for Hydrogen Energy Technology." The center will conduct research on the extraction, storage and use of hydrogen.

On July 10, 2020, the Decree of the President of the Republic of Uzbekistan, named as PQ-4779 "On additional measures to reduce the dependence of the economy on fuel and energy products by increasing energy efficiency and attracting available resources",which is the roadmap for improving efficiency and saving fuel and energy resources was approved. Paragraph 15 of the Roadmap sets the task of "developing a long-term national strategy for the development of hydrogen energy."

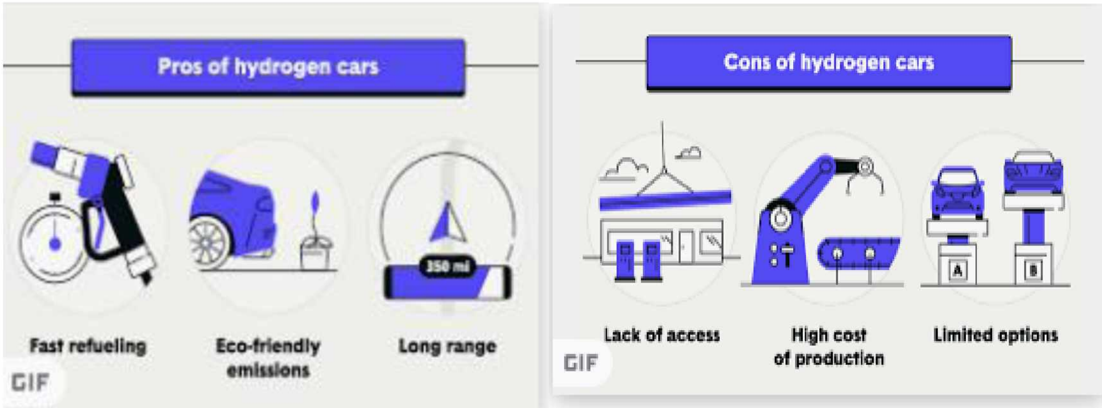
Solar and wind energy in Uzbekistan have great prospects. However, one of the reasons hindering the development of this sector is the dependence of alternative energy sources on climate change and day and night changes.

The attractiveness of hydrogen energy is characterized by the following features:

- There are huge reserves of hydrogen in nature, and they are inexhaustible reserves;
- Its use does not release large amounts of heat, and the use of hydrogen does not adversely affect the water supply of the planet like the use of other fuels;
- The use of hydrogen from spacecraft as an energy source avoids large costs;
- The most efficient element in nuclear reactors is hydrogen, and hydrogen is one of the best energy carriers in chemical, metallurgical, and technological production;
- Eco-friendly fuel for transport;
- It can be a cheap heat supply source in the domestic service sector.

However, there are a number of disadvantages to using hydrogen energy, which is why hydrogen energy cannot be the first digital energy type. The following are the facts:

- The consumption price of hydrogen is expensive (e.g., the price of 1 kg of hydrogen is about 18 m^3 times the price of natural gas);
- Not all methods of obtaining hydrogen energy produce environmentally friendly energy;
- Hydrogen energy has less energy than other types of energy;
- Organizing the use of hydrogen energy requires additional costs (for example, if we want to use hydrogen energy for heating, we have to produce hydrogen pipes at a higher price than other pipes).
- 95% of the hydrogen produced is used as fuel in manufacturing plants, with only the rest being commercialized;
- In order to use hydrogen as a transportation fuel, it will be necessary to build a large number of hydrogen filling stations;
- In general, the cost-effectiveness of hydrogen energy is much lower;
- Losses in long-distance delivery are large;
- The physics of hydrogen energy has not yet been perfectly developed;
- Since hydrogen has no taste, color, or flavor, it is difficult to feel it coming out of the tube.



Picture-3. Pros and cons of hydrogen energy in cars.

At present, the world's leading scientists are conducting a lot of research to achieve the development of hydrogen energy using various physical processes. One of the innovative ideas for increasing the efficiency of hydrogen energy is to identify and study its aspects related to superconductivity. Before we talk about the interrelationship between hydrogen energy and the superconductivity phenomenon, let's look at general information about superconductivity.

The phenomenon of superconductivity is defined as the sudden loss of electrical resistance of a substance at temperatures close to absolute zero. Substances with this property are called superconductors. When the temperature is lowered to almost absolute zero, the resistance of the ordinary metal conductor gradually decreases, while the resistance of the superconductor disappears suddenly at a temperature called the critical temperature. Superconductivity gives us a number of interesting results: a very large electric current is generated when the resistance is lost. The current achieved in the superconducting state of the superconducting wire flows for a long time without any additional work.

In this article, we learn connections between hydrogen energy and superconductivity.

The superconductivity phenomenon was discovered in 1911 by the German physicist Kamerling Onnes. Only quantum mechanics was able to explain physic characters of superconductivity, such as ferromagnetizm, atomic spectral lines and the Meissner effect. The occurrence of the Meissner effect means that the ideal interpretation of a superconductor as a good conductor, as in classical physics, is incorrect.

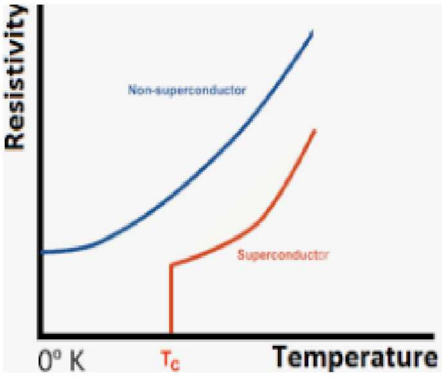
In 1986, some cuprate-perovskite ceramic materials were found to have a critical temperature below 90 K (C). It is theoretically impossible for traditional superconductors to have such large critical temperatures of materials called high-temperature superconductors. Liquid nitrogen, which is suitable and inexpensive in refrigerant quality, boils at 77 K, which makes it easy to determine the presence of a superconductor at high temperatures through many experiments and observations.

Superconductors are classified into several types according to certain characteristics. The most basic of them are given below.

According to the magnit field, superconductors may be Type I, meaning it has a single critical field, above which all superconductivity is lost and below which the magnetic field is completely expelled from the superconductor; or Type II, meaning it has two critical fields, between which it allows partial penetration of the magnetic field through isolated points. These points are called vortices. Furthermore, in multicomponent superconductors it is possible to have a combination of the two behaviours. In that case the superconductor is of Type-1.5.

According to the theory, it is divided into conventional superconductors and non-conventional superconductors. While the superconductors explained by the BCS theory are called conventional superconductors, the superconductors that deviate from this theory are called nonconventional superconductors.

They are also classified according to the critical temperatures of the superconductors. Typically, superconductors with a critical temperature above 30 K ($-243{,}15^0$C) are called high temperature superconductors, and superconductors with a temperature below 30 K are called low temperature superconductors.



Picture-4. Connection between resistivity

Material	T	Bc,
Aluminum	1.2 K	0.01 T
Indium	3.4 K	0.03 T
Lead	7.2 K	0.08 T
60Sn-40Pb	7.8 K	0.2 T
97Sn-3Ag	3.7 K	0.02 T
26Sn-34Bi-20Cd	3.7 K	0.06 T

Picture-5. Critical tempurature and tempurature of superconductor. magnetic field of some materials

There are also chemical, alloy, ceramic, pniktid and organic superconductors depending on their composition and what they are made of. Superconducting materials differ from each other in physical parameters such as critical temperature, properties in the superconducting state, critical magnetic field, and density in the superconducting state. On the other hand, such properties have almost no depend on what material they are made of. The Meissner effect, quantized magnetic flux, zero resistance, etc. are important arguments for this claim. Such "universal" physical properties justify the violation of symmetry in the superconductor. Superconductivity is a thermodynamic process consisting of independent microscopic properties.

One of the most basic properties of superconductivity is that the resistance is zero. In terms of superconductivity, Garter and Kazimir's superconducting model of "super-fluid" and "normal" electrons, which successfully implemented the properties of superconducting electrodynamics, London theory, quantum theory, Ginzburg-Landau theory, and the Ginzburg-Landau equation not only developed the field theoretically but also paved the way for its practical application.

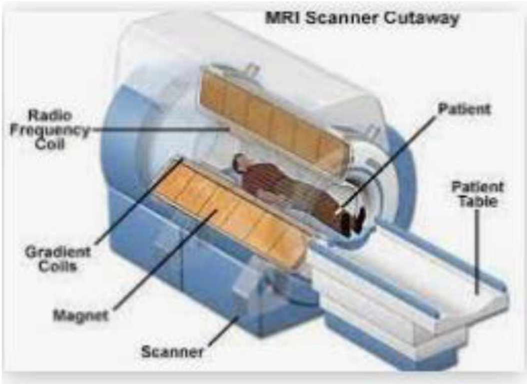
Here are some examples of the practical significance of the superconductivity phenomenon:

► Uninterruptible current flow in the superconducting mode can provide a constant power supply. Success in this direction is very important to meet the needs of the population.The implementation of thermonuclear reactions will require the creation of a strong magnetic field. This can only be formed from packages made of superconducting substances.

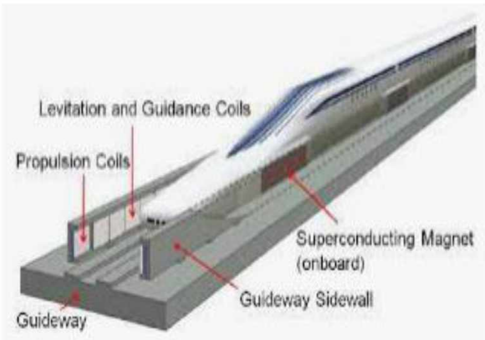
► Wires and tapes made of several kilometers of superconductors are widely used in industry. Such wires and tapes have good efficiency.

► Superconductors have a place in medicine. As an example, we can say that the magnetic coils (MRT) used in modern tomography are made of superconductors.

► High-speed computing devices in electronics, magnesium field detectors, radiation detectors, communication devices in the microwave range are made of superconductors. In transport, superconductors drive Maglev trains. Such trains move on the railway using an electromagnetic field and do not touch the rails.



Picture-6. MRT device.



Picture-7. Suporconductivity in railway.

There are many examples of this increasing humanity's need for superconducting physics. A pertinent question arises: is there a relationship between hydrogen and superconductivity? First of all, it should be noted that the connection of the chemical element hydrogen with the phenomenon of superconductivity is in the observation of superconductivity in the production of liquid hydrogen. Hydrogen-containing compounds are also used in the preparation of high tempurature superconductors in substances such as hydrogen sulfide (H_3S).

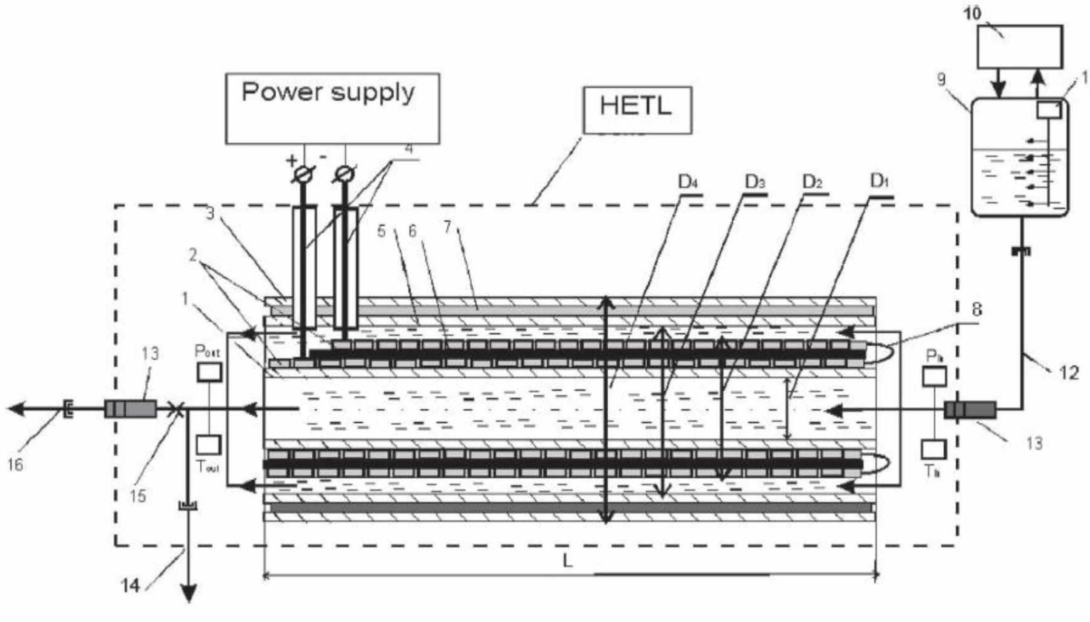
Let's explain why superconductors are needed for hydrogen energy. Since 92% of all atoms in the universe are hydrogen atoms, it is used in many technical and energy matters. In particular, one of the reasons to believe that hydrogen energy is now promising is that there are huge reserves of hydrogen in nature. Currently, 60 million tons of hydrogen are produced worldwide, and this figure is growing by 18% every year. For example, in the European Union, by 2040, the use of hydrogen fuel quality will be introduced for the majority of cars. Hydrogen costs from $ 3 to $ 20 per kilogram, depending on how it is produced. The development of technologies to produce hydrogen at a lower cost is one of the most difficult issues facing scientists today. It is the cost of producing hydrogen that deprives it of its widespread use. In addition to the problem of cost of using hydrogen as a source of energy, there is also the problem of low efficiency in energy production. To get 1 kg of hydrogen you need 2-3 kg of gas or oil. This will drastically reduce the already depleted oil and gas reserves. Similar disadvantages are hampering the popularity of hydrogen energy. However, the use of hydrogen as an energy source is undoubtedly the basis of future energy, as it is environmentally friendly, has the potential to generate large amounts of water and is the most suitable fuel for the transport sector. Therefore, the development of hydrogen energy now requires a great deal of attention by scientists. In this case, it is impossible to achieve without the achievements of physics in improving the application of hydrogen energy. Of course, many physic laws processes are used in the field of hydrogen energy, from the production of hydrogen to its delivery to consumers. It is known that superconductors are widely used in energy. Superconductors are also used in hydrogen power.

In recent years, a great deal of research has been conducted on the hybrid transfer of hydrogen and electricity in superconducting cables. Below we provide information on the role of superconductivity in the transmission of hydrogen energy.

Superconductors are used to store and transport liquid hydrogen. This is considered beneficial to the economy. The transportation and delivery of hydrogen in superconducting pipes has been introduced into practice. It is known that the problem of energy transmission is a topical problem of its production. Methods of using superconductors have been studied to solve this problem. Some of the successes achieved in high-capacity liquid helium superconducting cables in the late 1970s made it impossible to take advantage of the high cost of helium cooling. With the discovery of high-temperature superconductors, new research in this area was opened. One of the ideas that has been put forward for a long time as a hypothesis is that cryogenic for a liquid hydrogen superconducting cable and a very high energy flux is used as an additional fuel to provide. This is called as hybrid transfer line or super-grid. The idea has become even more attractive due to the growing need to use hydrogen energy in the energy sector and for other purposes. This is also determined by the effective physical parameters of hydrogen use. For example, hydrogen has the highest fuel efficiency among other chemical elements - 120 MJ / kg. Hydrogen is the best refrigerant, i.e. the best cryogen. For example, if the cooling capacity of liquid nitrate $(LN_2)$is 199 kJ / kg, the cooling capacity of hydrogen is about 2.3 times greater than that of 446 kJ / kg. Parallel connection of the conductor to the cable was accepted as a feasible project. Of course, this idea had to be tested in practice.

Two experiments in the world test of the hybrid energy transfer line has been performed by Russian scinetists at the KB "Khimavtomatika" (Voronezh City) in 2011 and 2013. In these experiments, both electrical and chemical power over are transferred by two parallel cables. The team of experementers with using Italian-produced superconductor (MgB_2) wire has made and successfully tested two hybrid energy transfer lines with liquid hydrogen as a chemical source of power and superconducting cable as a source of electricity. Researchers performed successful tests of two prototypes of hybrid energy transfers lines: 10 m in 2011 and 30 m in 2013.

Picture-8. General view of the control monitor during tests.



Ficture-9. Sketch of The Hybrid Energy Transmission Line (HETL) experimental test facility: (1) former; (2) current carrying superconductors; (3) outer tube of cryostat; (4) current leads; (5) inner tube of the cryostat; (6) polyimide insulation; (7) layered super-insulation; (8) current jumpers; (9) liquid hydrogen storage tank; (10) filling, pressure busting and drainage systems; (11) level meter and temperature sensors; (12) liquid hydrogen 12 m transfer line; (13) bayonet connectors ∅ = 32 mm; (14) drainage 4 m, flexible line ∅ = 32 mm; (15) jet nozzle ∅ = 4 mm; (16) drainage flexible line ∅ = 32 mm; $L \sim 12$ m, is the total length of the cryostat with current leads, the length of the cable is 10 m.

In conclusion, we can say that all of this suggests that hydrogen energy and superconductivity have many dependencies that are not yet known to us, and that researching them could lead to solutions to problems in both areas. In the future, we can achieve new reults with scientific or experimental ways.

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