United States Patent

Carroll

[15] 3,664,143

[45] May 23, 1972

[54] LOW TEMPERATURE HEAT TRANSFER DEVICE

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[22] Filed: **May 8, 1970**

[21] Appl. No.: **35,821**

[52] **U.S. Cl.**.....**62/3,** 136/203

[51] **Int. Cl.**.....**F25b 21/02**

[58] **Field of Search**.....62/3

[56] **References Cited**

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2,800,772	7/1957	Carroll	62/3
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Primary Examiner—William J. Wye

Attorney—Ernest B. Lipscomb

[57] **ABSTRACT**

A heat transfer device for obtaining extremely low temperatures which transfers heat by electrical means through a series of transfer units of differing size thereby allowing for the successive lowering of temperature through each unit. Each transfer unit is constructed with filaments of superconducting material through an insulated block.

7 Claims, 5 Drawing Figures

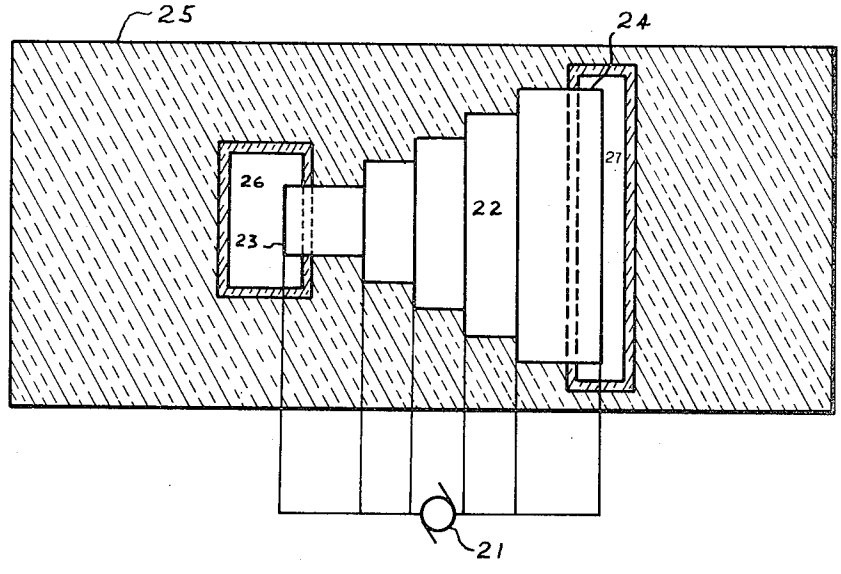

FIG. 1

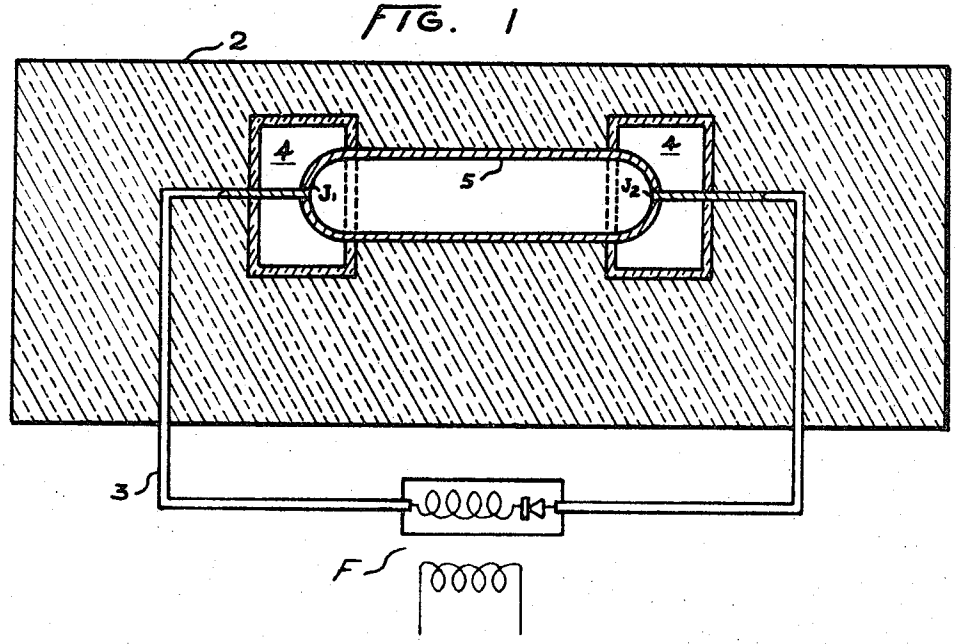

FIG. 2

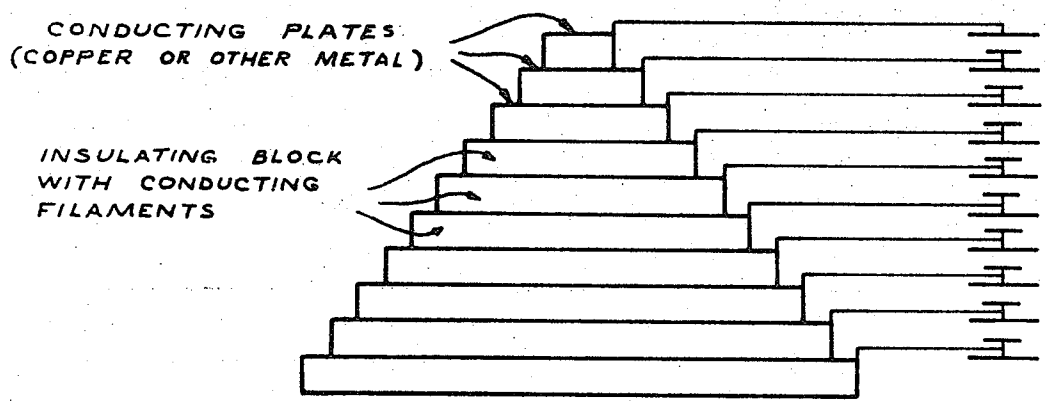

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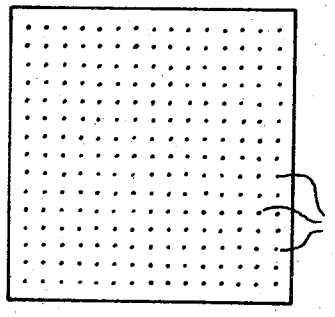
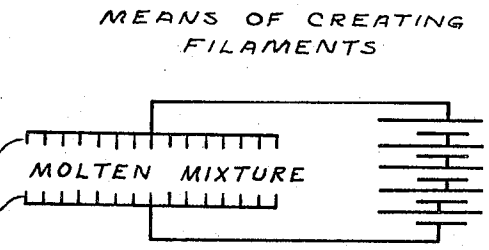
FIG. 3A



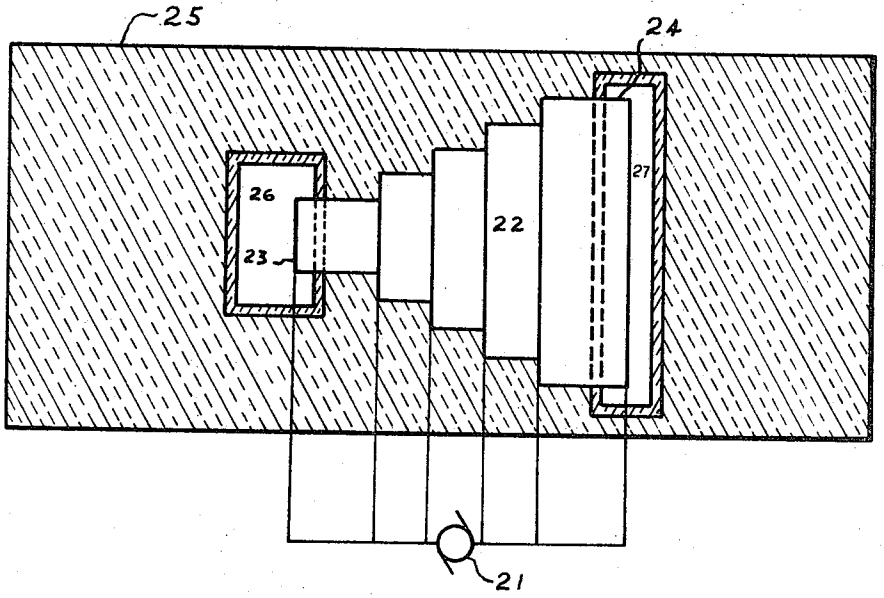
FLAT VIEW

FIG. 3B



EDGE VIEW

FIG. 4



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LOW TEMPERATURE HEAT TRANSFER DEVICE

BACKGROUND OF THE INVENTION

This invention relates to a novel device used for refrigeration. More particularly this invention relates to a device for producing extremely low temperatures, i.e., near 0° K., with an electric current cycle employing materials that are made superconductive at ambient temperature.

The practical attainment of extremely low temperatures is a difficult problem. Temperatures below 1° K. can be attained by helium evaporation, but the reduced pressures required introduce difficulties which make this process undesirable. Another application, that of adiabatic demagnetization has been used to reduce the temperature below 1° K. and the claim is made that a temperature of 10^{-6} °K. has been attained with this process.

Refrigeration as it is conventionally accomplished uses a molecular gas cycle in a portion of which the gas is compressed and over another portion of which the molecular gas is allowed to expand absorbing large amounts of heat. The conventional refrigerating systems such as, for instance, air conditioners require substantial mechanical apparatus for compressing the molecular gas and allowing for the expansion that is cumbersome and expensive. Furthermore, the use of conventional refrigerating apparatus is impractical at the very low temperatures obtainable with the device of this invention. It appears that all molecular gas refrigeration systems are limited in the temperatures obtainable and are unsuitable for low temperature applications. Therefore, a more sophisticated means of lowering temperature was investigated—that of heat transfer by electrical means. Prior attempts have been made to produce heat transfer by means of electrical cycles but these have met with little success because of losses due to ohmic resistance and the fact that the Peltier effect disappears when a conductor becomes superconducting.

Peltier heat transfer depends upon the existance of different work functions and different conduction electron densities applying to different metals. When contact is made to form a junction, electron diffusion occurs to remove the potential difference. Creation of another junction to form a loop provides an equal and opposing effect. In this case no current flows. However, if the two junctions are maintained at different temperatures, a current is found to flow around the loop in a direction which will transfer heat to increase the temperature of the cooler junction. The flow of current is dependent upon the differential change in the work functions of the two metals at the heated junction. When the junction is heated, a net EMF is introduced which exists as long as the temperature difference between the junctions is maintained. The effect described is termed the Seebeck effect and is the basis of the thermocouple. The Peltier effect is the reverse of this phenomenon. When a current is forced to flow around the loop, a transfer of heat from one junction to the other occurs. The limitation of the Peltier loop as a heat transfer mechanism depends upon the limitation on the differences which can be introduced in the work functions. By measurement, using ordinary metals, a few calories per hour per ampere of current is the order of magnitude to be expected.

This small amount can be multiplied by use of many such units. The basic difficulty is the existence of electrical resistance and the generation of heat in the resistance by the flow of the current. Since the resistance heating is proportional to the square of the current, and the Peltier heat transfer is proportional to the first power of the current, the practical application of the loop to the transfer of heat depends upon the reduction of electrical resistance to tolerable levels. It is well known that electrical resistance in metals is reduced by a temperature reduction. It then appears that the cooling of the Peltier loop by means of refrigeration mechanism may be desirable.

The phenomenon of superconductivity is a well established fact. In the event that the entire Peltier loop is in the superconducting state, no resistance heating is experienced. Such a

condition is quite desirable in the elimination of the resistance heating, but in this case the Peltier heat transfer mechanism no longer exists. If both conductors are in the superconducting state, the current is confined to the surface so that work function differentials have no meaning. Thus it would appear that the removal of the resistance heating mechanism has also removed the Peltier heat transfer mechanism.

The superconducting current is a surface phenomenon. For this reason it appears that only a small number of the valence electrons are involved in the conduction process. Considering the relative magnitude of the superconduction current, the electron transfer velocity is quite large in relation to that applying to ordinary metallic conduction. Since a step function of less than 1 volt will accelerate electrons to velocities of the order of 10^7 cm. per second, it is assumed that electron velocities of this magnitude exist in the superconduction current.

A heat transfer device utilizing the effects of differing electron velocity through superconducting materials has resulted in U. S. Pat. No. 2,800,772 issued July 30, 1957 to the applicant. This heat transfer device is limited by the fact that it must be cooled to the superconducting state by auxiliary refrigeration means before it becomes operative. In other words, to achieve the desired low temperatures a two-step cooling must be effected.

The present invention depends upon extending the range of operation of superconducting materials to include normal ambient temperatures so that a much greater simplicity of design can be achieved. The objects of this invention may be achieved by using a series or cascade of heat transfer units of increasing capacity, much like the form of a pyramid to regulate the velocity of electrons.

It is therefore the general object of this invention to provide a heat transfer device for cooling molecular substances to near 0° K. Another object is to provide a device for attaining extremely low temperature using a one-step cooling device. A further object is to provide a heat transfer device for cooling by regulating the velocity of electrons. A still further object of this invention is to provide a simple design for a cooling device by providing a series of superconducting heat transfer units. Other objects and advantages of this invention will become apparent from the following description taken in connection with the accompanying drawings.

SUMMARY OF THE INVENTION

It has been found that the range of conduction of superconducting materials can be extended into the normal temperature range to provide a series of heat transfer units. Each unit is constructed with conducting filaments formed within an insulating block. Each unit is constructed to have a larger heat transfer capacity than the one before it. Any sequence that transfers more heat per unit than it receives results in cooling the intermediate stages to establish the necessary gradient across the system.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the consequences of the present invention, reference should be had to the attached drawings in which:

FIG. 1 is a general diagram of circuit of a heat transfer device based upon changes in electron velocity;

FIG. 2 illustrates a cascade of heat transfer units;

FIGS. 3A and 3B illustrate the details of each heat transfer unit; and

FIG. 4 shows an embodiment of this invention.

DETAIL DESCRIPTION OF THE INVENTION

Shown in FIG. 1 is a heat transfer device based upon changes in electron velocity. Electrons driven around the loop by the transformer F flow at a high velocity on a conductor of small radius 3 which is composed of a material which exhibits the property of superconductivity or zero resistance at very low temperatures. When the high velocity electrons reach "-

cold" junction J_1, they are "retarded" by a second conductor 5 also of superconductive material but of large cross-sectional circumference having a "cold" junction J_1, and a "hot" junction J_2.

The heat transfer is accomplished in the following manner. At the junction J_1, the electron is retarded and energy is absorbed. This absorbed energy which may be, for instance, radiation energy is supplied at the expense of the field, which must make an adjustment reacting on the atomic systems in the neighborhood to provide a cooling effect. The absorbed thermal energy is carried internally by the electron to the junction J_2. At this junction the electron is accelerated by the conservation of flow momentum to the velocity which originally applied. The heat absorbed at junction J_1 is then expelled at junction J_2. This process will continue as long as electron mobility can be maintained.

Since the superconducting state is assumed, an auxiliary cooling mechanism is required. Thus, the loop is maintained in the superconducting state, and the heat radiated at the hot junction J_2 is removed by the auxiliary mechanism. Since the current is confined to the surface, the large cylindrical conductor 5 may be hollow. In fact, it may be formed by deposition on a thermal insulator. This adds to the insulation tending to prevent the conduction of heat back into the region of the cold junction.

As the superconducting state does not normally apply at ambient temperatures, the basic problem is that of transferring heat by the device at a rate which is greater than its rate of formation by the current flow. It has been found that these electron velocity changes can be imposed by the use of very thin filaments of a semi-metal such as bismuth. The choice presented is not meant to imply the exclusion of other possible materials. The limiting factor in such a device is the product PN. where P represents the resistivity of the material and N is the conduction electron density. Assuming one conduction electron in 10^6 atoms, which is the accepted value for bismuth, and a resistivity of 1.6×10^{-6} ohm meters, the PN product is 4×10^{16}. Thus, conducting filaments of 0.5 cm. length require a minimum voltage of 400V.

The value required for the conduction cross-section area may be derived by the following consideration. Assuming a cascade of ten heat (electron) transfer units as shown in FIG. 2 of increasing capacity in the form of a pyramid, the base of the largest unit is stabilized near room temperature by a water flow or other means. In operation, the temperature difference between faces of each unit is approximately 30° C. To prevent the need for electrical isolation of each unit a voltage divider arrangement is suggested. The power source may be composed of units in series as shown, or a single high voltage source such as a direct current generator may be used to activate a voltage divider circuit. The number of units connected in this manner is a matter of convenience. Ten was chosen as a representative number only.

Each unit must be constructed to have a larger heat transfer capacity than the one before it according to its number in the sequence. A possible choice, although not the only one, is that of doubling the capacity of the top unit for the next lower, adding the two for the third, adding three for the next, and so on. Any sequence that transfers more heat per unit than it receives will result in cooling the intermediate stagees to establish the necessary gradient across the system.

The conduction filaments are formed within the insulating blocks. Since these carry current, they can be considered to act as a single conductor in any one block. There is no mechanical means by which the filaments can be structured into the block. Therefore, it is proposed that any reasonable mixture of insulator and conductor in the molten state should be placed between the metal plates, as shown in FIG. 3B. The plates may be constructed so that any number of sharp points in any desired manner of grouping protrude beyond the general surface level. A voltage applied across the plates with the molten mixture in place will then establish conduction paths which will become permanent as the mixture hardens. Considering the high electrical field generated at the points by the applied voltage, these form termination points for the conduction paths. Since the number of points provided can be controlled, the number of conduction filaments is known.

The size of a filament can be controlled at least in principle by the magnitude of the current that is permitted to flow. Since this is a function of the applied voltage, it appears that the lower limit of the diameter of the filament is the diameter of the atom of the conducting material. As a practical matter, filaments of the diameter 10^{-7} cm. should be quite easy to attain. The size of the total conducting area then may be easily obtained.

The conductor as well as the insulator in the mixture is preferable in the molten state and allowed to harden. A possible combination is bismuth and sulfur since melting points are low for both. Other combinations are not excluded. The only point to consider is the permanent creation of conduction filaments as the mixture hardens, shown in FIG. 3A.

It is well known in the art that at temperatures below 10° absolute, many metals exhibit the property of superconductivity or zero resistance so that the resistance heating is at least negligible if not entirely absent. The metals of which the conductors are constructed should be superconductive at reasonably low temperatures.

Several superconductive elements and alloys as taken from "Phenomena at the Temperature of Liquid Helium" (Burton, Grayson, Smith, Wihelm), published by Reinhold, 1940, are given below:

Element	Transition temperature, °K.
Mercury	4.12
Tin	3.69
Lead	7.26
Thallium	2.38
Indium	3.37
Tantalum	4.38
Vanadium	4.3
Cadmium	0.54
Zirconium	0.70
Gallium	1.07
Thorium	1.32
Titanium	1.81
Columbium	9.22
Aluminum	1.14
Zinc	0.79
Hafnium	0.35
Lanthanum	4.71

In accordance with other embodiments of this invention, superconductive alloys may be used in place of superconductive elements. There are a number of such alloys composed of lead, with one other element such as silver, gold, bismuth, copper, mercury, indium or thallium. There are several alloys composed of tin with one of the series, thallium, silver, gold, copper and columbium. Also there are indium-thallium, mercury-cadmium, gold-bismuth, molybdenum-carbon alloys. In general, the superconducting alloy will have at least one superconducting element included. There are other superconducting alloys, which are compositions of bismuth, tin, lead, or these with cadmium. The combination with arsenic instead of cadmium is an operable alloy also.

Turning now to the preferred embodiment of this invention shown in FIG. 4, a cascade of heat transfer units like those shown in FIG. 2 has been incorporated into an electron gas system similar to that shown in FIG. 1. Generator 21 is connected to each end of the cascade unit 22 so as to cause a flow of electrons toward the "cold" junction 23 through that junction and each succeeding heat transfer unit to the "warm" junction 24. The direct current generator may be a rotational electric generator, a transformer or any convenient power source capable of providing satisfactory electron movement. Surrounding the entire cooling circuit is a heat insulated outer container 25. While it is understood that no perfect insulator

is obtainable in practice and that some heat will be conveyed along the conductors themselves, it is meant that the insulating means are provided for discouraging heat flow from one junction to another. Located inside outer container **25** are two heat insulated chambers **26, 27** one of which surrounds each of the junctions between the conductors. The chamber surrounding the "hot" junction, contains a coolant such as liquid helium and the other chamber, which surrounds the cold junction contains the material to be cooled. The coolant is not necessary for the mechanism which is superconducting at ambient temperature.

The operation of this embodiment of this invention is in some respects analogous to that of the ordinary gas refrigeration cycle. In the case of the gas refrigeration cycle compression is produced and circulation is maintained by a mechanical compressor pump. The compressed gas is allowed to expand in the system at the point where cooling is desired. The expansion is a cooling process. For this reason the expanding gas absorbs heat from the immediate surroundings and the surroundings are thereby cooled. The gas then continues carrying the absorbed heat with it until it reaches the region where it is again compressed by action of a pump. In the region of the pump, heat is given up and dissipated by radiation or conduction. In the operation of a device in accordance with this invention an electron "gas" is employed instead of a molecular gas.

In the metals forming the heat transfer units of conductor, there is a distribution of free electrons that may be caused to form an electron gas which is free to move in the interstices of the metallic atoms or along the surface of the conductor. These electrons move through the interior of a metal at room temperatures being distributed rather evenly throughout the conductor due to resistance of the metal. However, at temperatures below a certain level, depending on the material of the conductor, the conductor becomes superconducting. At this point, the conductor has zero resistance. The electrons therefore travel in a sheath around the surface of the metal rather than through the metal. As the electrons pass from the surface of a small heat transfer unit to the surface of a larger heat transfer unit they spread out and, due to a larger number of free electrons on the surface to constitute the current, they slow down. Thus, a situation of a few electrons moving rapidly on the surface of the small wire and a large number of electrons moving slowly through a heat transfer unit is presented.

It has been found that electron resistance is a function of the thermal velocity only. There are two possible implications of this fact. The first is that drift velocities in metallic conduction are negligible in comparison with thermal velocities at room temperature. The other implication is that superconductivity can never be achieved unless the drift velocity is sufficiently greater than the thermal velocity that the effect of thermal agitation on the moving electron is small. The implication is certainly confirmed in the soft superconductors. The thickness of the conducting sheath is so small that relatively few of the total number of valence electrons enter into the conduction process. In this case, each superconduction electron has a relatively high velocity in the flow. Thus, it is believed no material can be considered a superconductor until the flow is established. It then follows that the material is rendered superconducting by electrical means. The conclusion is that the extension of superconductivity into the room temperature range depends upon means of achieving and maintaining high electron velocity in the flow. Considering the nature of conducting materials, it appears that the only reasonable approach is that of generation of thin filaments.

While the invention has been described and illustrated herein by references to various specific materials, procedures and examples, it is understood that the invention is not restricted to the particular materials, combinations of materials, and procedures selected for that purpose. Numerous variations of such details can be employed, as will be appreciated by those skilled in the art. In particular, semiconductors exhibit the required property of low conduction electron density so that their use is not excluded.

What is claimed is:

1. A heat transfer device which comprises in combination, an electrical conductor and a heat transfer unit, said heat transfer unit having a plurality of filaments extending through an insulated block, the cross-sectional area of said electrical conductor being at least ten times smaller than the cross-sectional area of said heat transfer unit, the ends of said conductor being joined to the corresponding ends of said transfer unit heat insulating chambers surrounding each of the junctions between the conductor and the heat transfer unit, said device forming a heat pump when current is passed therethrough.

2. A device according to claim **1** wherein said plurality of filaments forming said heat transfer unit are superconducting materials.

3. A device according to claim **1** wherein, said heat transfer unit comprises a plurality of insulated blocks arranged in series with succeedingly larger heat transfer capacity.

4. A heat transfer device which comprises, an electrical conductor and at least one heat transfer unit comprising a block of insulating material having a plurality of material capable of being superconducting extending through said insulating material, said electrical conductor having a cross-sectional area at least ten times as great as the cross-sectional area of the filaments in said transfer unit, the ends of said conductor being joined to the corresponding ends of said filaments to form junctions, and a current generating means connected intermediate the ends of said conductor in series therewith when current is passed through the conductor-transfer unit an electron change is effected at said junctions causing an energy radiation at one of said junctions and an energy adsorption at the other junction.

5. A device according to claim **4** wherein, said heat transfer unit comprises in series a plurality of insulated blocks containing filaments extending therethrough, each block having a succeedingly larger heat capacity.

6. A device according to claim **5** wherein, said electrical conductor and said filaments are a superconducting member of the group consisting essentially of vanadium, zinc, gallium and bismuth.

7. A device according to claim **4** wherein, one junction is thermally insulated from the other and a chamber is provided in the region of one of the junctions for holding a liquefied gas in the region of that junction.

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