United States Patent

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[33] **Netherlands**
[31] **6807902**

[54] **LIQUID HELIUM REFRIGERATION APPARATUS AND METHOD**
15 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** **62/56,** 62/467, 62/514
[51] **Int. Cl.** **F25d**
[50] **Field of Search** 62/467, 514, 56

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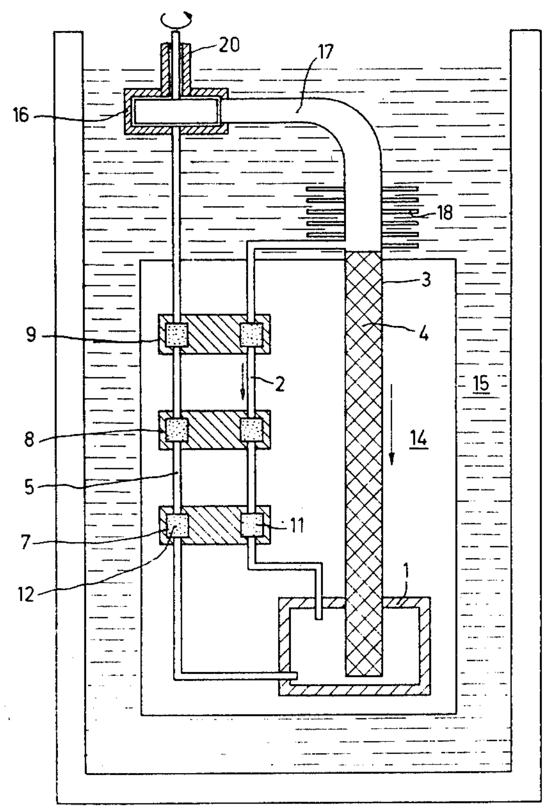
ABSTRACT: A refrigerator operating below the λ-point of ^4He in which a mixture of ^3He and ^4He is circulated by means of a liquid pump first to a cooler having a temperature lower than that of the λ-point of the mixture producing superfluid ^4He in addition to a mixture of normal ^4He and liquid ^3He. The superfluid ^4He is passed through a superleak and combined with said mixture to dilute same in a mixing chamber, thus producing cold to cool an object disposable in the chamber. An exhaust duct from the mixing chamber is proportioned so that the medium discharged therethrough exceeds its critical speed and thus flows turbulently.



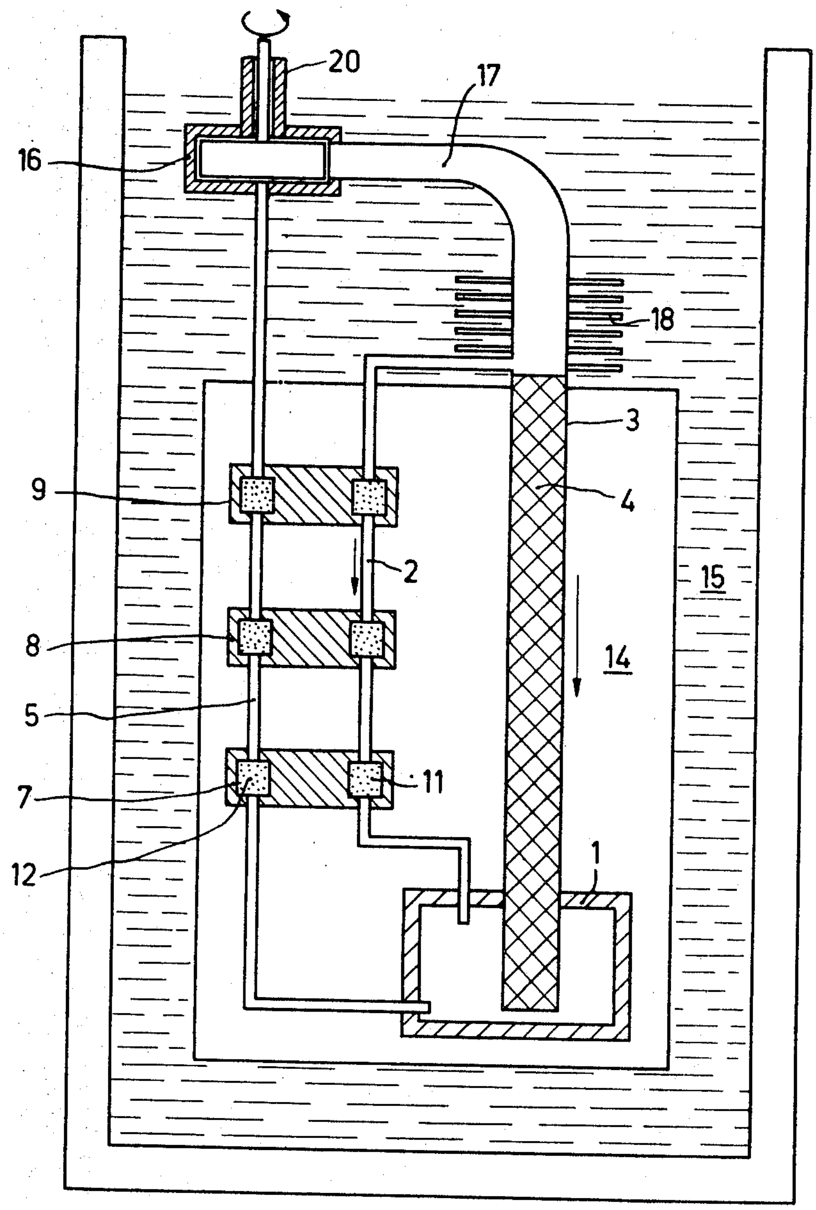


fig.1

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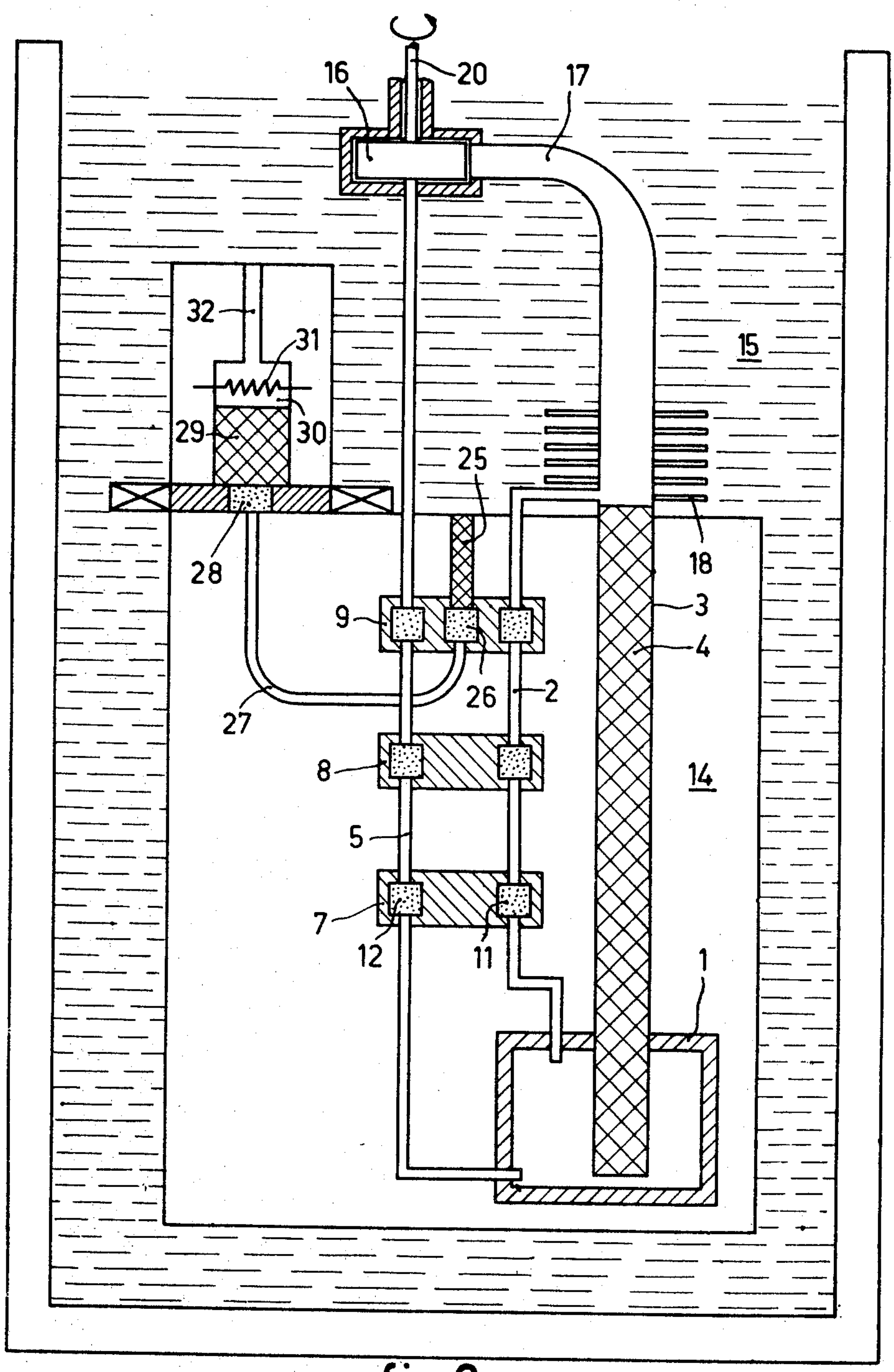

fig.2

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LIQUID HELIUM REFRIGERATION APPARATUS AND METHOD

The invention relates to a device for transporting thermal energy from a lower to a higher temperature level, which two temperature levels lie below the temperature of the λ-point of ^{4}He. A known device of the type to which the present invention relates is described in "Cryogenics," Apr. 1966, pp. 80—88. This device is filled with a ^{3}He—^{4}He-mixture and comprises a mixing chamber which is at a very low temperature, for example, 0.1° K. and which communicates, through a communication duct, with an evaporation reservoir which has a temperature of, for example, 0.8° K. The vapor space of said reservoir communicates, through one or more counter-flow heat-exchangers, with the suction side of a diffusion pump operating at room temperature which sucks away vapor. As a result of its larger volatility, said vapor will mainly consist of ^{3}He. From the compression side of the pump, the vapor is then supplied, through the heat exchangers in which it cools in counter current with the vapor flowing towards the pump and one or more coolers in which it is further cooled to below its condensation temperature, to a further heat exchanger which is in thermal contact with the communication duct and the exhaust side of which communicates with the mixing chamber. Since the device is filled initially with a mixture of ^{4}He and ^{3}He and substantially only ^{3}He-Vapor is circulated, a substantially stationary quantity of ^{4}He will be situated in the mixing chamber and in the communication duct, which quantity, dependent upon the temperature, consists partly of superfluid and partly of normal ^{4}He. In liquid ^{3}He—^{4} He mixtures, a phase separation takes place below 0.8° K, namely to a ^{3} He rich phase which behaves like a liquid and a phase which is poor in ^{3}He which behaves like a gas. This phase separation manifests itself in the mixing chamber. In the transition from the supplied ^{3}He rich phase (liquid) to the ^{3}He poor phase (gas) evaporation takes place as it were and the transition heat required for this purpose (heat of evaporation) provides a cooling effect. The ^{3}He will then expand in the quantity of superfluid ^{4}He present in the communication duct during which a much larger quantity of cold is produced which, however, is substantially entirely required for cooling the ^{3}He-stream towards the mixing chamber.

A drawback of this known device is that the ^{3}He vapor from the evaporation reservoir is heated to room temperature and is then cooled again to the temperature of liquid helium. Of course, this is associated with losses, while the device structurally is very complicated. A further important drawback is that the diffusion pump operates at room temperature so that at the very low pressure prevailing of, for example, 10^{14}mm. Hg, only small quantities can be circulated so that the cold production will also be only small.

In another proposed device for transporting thermal energy from a lower to a higher temperature level, which two levels lie below the λ-temperature of ^{4}He, pure ^{4}He is pumped in a circulation duct which comprises a superleak.

A superleak is to be understood to mean in the present application a mass of a material having the property that normal ^{4}He cannot pass said mass and superfluid ^{4}He can pass said mass without turbulence occurring during the flowing.

The rest of the circulation duct is constructed so that the medium therein exceeds its critical speed and turbulence occurs. A driving force is exerted on the helium in the circulation duct by means of the pump, which force upon starting while the temperature is still the same everywhere, results in a pressure difference across the part of the circulation duct in which no superleak is situated. No pressure difference will occur across the superleak as long as the temperature is the same on both sides. Due to the pressure difference across the other part of the circulation duct, the helium, both superfluid and normal helium, will start flowing therein. This means that with the normal helium, thermal energy will be conducted namely from one side of the superleak to the pump and the cooler present there. This results in a temperature difference occurring across the superleak which results in a corresponding pressure difference. In this manner and when the temperature difference across the superleak decreases, the pressure difference across the superleak will increase and at the same time the pressure difference across the further part of the circulation duct will decrease until an equilibrium situation is reached, in which a very low temperature prevails on one side of the superleak and thermal energy is then transported to the cooler. In this case the device can cool an object at the said low temperature.

It is the object of the invention to provide a combination of the known device operating with a mixture of ^{3}He and ^{4}He and the proposed device operating with pure ^{4}He in which the cold production is obtained partly by cyclic unmixing of ^{3}He and ^{4}He and subsequent expansion of ^{3}He in superfluid ^{4}He, and partly by applying a pressure difference across a superleak and cold transport by a flow of superfluid ^{4}He exceeding its critical speed.

The device according to the invention is characterized in that the device comprises a liquid pump the exhaust of which communicates, through one or more coolers, both with a first and a second supply duct. The first supply duct communicates on its other side with the upper side of a mixing chamber, and the second supply duct comprises a superleak and empties on its other side in the lower part of the mixing chamber. An exhaust duct communicates with the mixing chamber and is in heat-exchanging contact with the first supply duct and communicates on its other side with the suction side of the liquid pump. The mixing chamber, the first and the second supply duct and the exhaust duct are insulated thermally; and the device is filled during operation with a mixture of ^{3}He and ^{4}He, a temperature prevailing during operation in the said cooler(s) which lies below the λ-point of the ^{3}He —^{4}He mixture on the entrance side of the first and second supply duct, so that inmixing of ^{4}He and ^{3}He occurs there. The concentration of ^{3}He in the first supply duct is higher than in the exhaust duct and the pump, the dimensions of the exhaust duct being so that the medium therein exceeds its critical speed and turbulence occurs.

In the device according to the invention, the medium remains constantly in the liquid phase, so that no losses will occur due to heating to room temperature and subsequent cooling to the temperature of liquid helium as is the case in the known device. Furthermore, liquid is circulated by pumping in the device according to the invention, so that a large quantity can easily be transported.

In the device according to the invention unmixing of ^{3}He and ^{4}He is obtained by conveying the mixture compressed by the pump to a cooled place where the exhaust duct of the pump communicates with the first supply duct and the second supply duct in which the superleak is situated. The cooled place is kept at a temperature which lies below the λ-point of the mixture at that location. The superfluid ^{4}He can pass the superleak substantially unhindered, while the superleak has a great resistance to flow for ^{3}He. As a result of this the ^{3}He will flow to the first supply duct. This first supply duct has a great impedance for the superfluid. The thermal energy released upon unmixing is given off to the cooler. The ^{3}He in the first supply duct is further cooled by heat-exchange with medium in the exhaust duct. In the mixing chamber the ^{3}He is then added to the ^{4}He, a large quantity of cold being produced at a very low temperature. This cold may be used for cooling some object or others, thus termal energy being supplied to the medium. The transfer of said thermal energy occurs by means of the ^{3}He flowing to the exhaust duct and normal ^{4}He. The ^{3}He concentration in the exhaust duct will be lower than in the first supply duct. This is possible since the exhaust duct is proportioned so that turbulence occurs therein in the superfluid which gives rise to a pressure difference across the exhaust duct. As a result of this both ^{3}He and normal ^{4}He and superfluid ^{4}He will flow through the exhaust duct. In this manner a device is obtained which structurally in simple and in which a large quantity of cold can be produced at a very low temperature with a comparatively good efficiency.

In a further favourable embodiment the liquid pump is a centrifugal pump. In another embodiment the first and the second supply duct, the mixing chamber and the exhaust duct are arranged in a vacuum-insulated space, and the assembly is immersed in a reservoir containing liquid helium at a temperature which is lower than that of the λ-point of ^{4}He.

In a further favourable embodiment of the device according to the invention, a further device for transporting thermal energy from a lower to a higher temperature level is present, which two levels also lie below the temperature of the λ-point of ^{4}He, the coldest part of which device is in heat exchanging relationship with the first supply duct. As a result of this the medium in the first supply duct is cooled so that a lower temperature can be reached in the mixing chamber.

In order that the invention may be readily carried into effect two embodiments of devices for transporting thermal energy between two levels lying below the λ-point of ^{4}He will now be described in greater detail, with reference to the accompanying drawings, wherein FIGS. 1 and 2 are elevation views partially in cross section of two embodiments of the invention.

In the drawings, reference numeral 1 in FIG. 1 denotes a mixing chamber. A first supply duct 2 and a second supply duct 3 comprising a superleak 4 communicate with the mixing chamber 1; whereas the first supply duct opens into the upper part of the mixing chamber, the second supply duct opens into the lower part of the mixing chamber. Furthermore, an exhaust duct 5 communicates with the lower part of the mixing chamber. The first supply duct 2 and the exhaust duct 5 are in heat exchanging contact with each other by means of heat exchangers 7, 8 and 9 (of course the number of said heat exchangers may be increased or decreased, as is desired). Each of these heat exchangers is constituted by a housing of a material which readily conducts heat, for example, copper, while said housing comprises two separate chambers 11 and 12, filled with balls of sintered copper which chambers form a part of the first supply duct 2 and the exhaust duct 5, respectively. The mixing chamber 1, the first supply duct 2, and the exhaust duct 5, in which the heat exchangers 7, 8 and 9 are provided and the part of the second supply duct 3, in which the superleak 4 is situated are incorporated in a vacuum-insulated chamber 14. The chamber 14 is surrounded by a bath 15 of liquid helium at a temperature of, for example, 1.3° K.

On its side remote from the mixing chamber the exhaust duct 5 communicates with a liquid pump 16. The exhaust duct 17 of said liquid pump 16 communicates through a cooler 18 with both the first supply duct 2 and the second supply duct 3. With the suction side of the liquid pump 16 a duct 20 also communicates through which the mixture of ^{3}He and ^{4}He can be supplied.

The operation of this device is as follows: A mixture of ^{3}He and ^{4}He under pressure is supplied to the exhaust 17 by pump 16. Since the exhaust 17 is in heat exchanging relationship with the helium bath 15, the mixture will have a temperature of approximately 1.3° K. Since the superleak 4 has a great resistance to the ^{3}He, only superfluid ^{4}He will flow through it. The supply duct 2 is constructed so that it has a great resistance to the superfluid as compared with the superleak. So mainly ^{3}He will flow through the duct 2, with only a few percent of ^{4}He. In this manner, unmixing of the ^{3}He and the ^{4}He is obtained prior to the entrance in the supply ducts 2 and 3. Thermal energy is liberated which is conducted away to the liquid helium bath 15. As a result of the pressure difference applied across the superleak 4 by means of the pump 16, a temperature difference will adjust, namely so that the temperature in the mixing chamber is lower than 1.3° K. and may be, for example, 0.6° K. The ^{3}He which flows through the supply duct 2 to the mixing chamber, is cooled in the heat exchangers 9, 8 and 7. The ^{3}He is again mixed with the ^{4}He in the mixing chamber 1. A quantity of cold is produced (transition heat plus expansion of ^{3}He in ^{4}He). This cold may be used effectively for cooling an object. The thermal energy supplied is then transported, through the medium flowing through the exhaust duct 5 to the suction side of the pump, to a higher temperature level (1.3° K.). Cooling is obtained on the one hand by the transition from the ^{3}He rich phase to the ^{3}He poor phase and expansion of ^{3}He in ^{4}He, and on the other hand in that turbulence occurs in the exhaust duct in the superfluid, which results in a pressure difference across said duct and consequently normal ^{4}He and ^{3}He flow through the exhaust duct in addition to the superfluid, so that a heat current is obtained from the mixing chamber to the helium bath. The ^{3}He may expand slightly further in the exhaust duct, in which cold is produced which can be used effectively for cooling the ^{3}He in the supply duct 2.

In this manner a device is obtained having a large cooling power which operates entirely in the liquid phase and in which nevertheless cyclic unmixing and mixing of ^{3}He and ^{4}He take place.

FIG. 2 shows a device for transporting thermal energy between two temperature levels lying below the λ-point of helium. This device in part the same device as shown in FIG. 1. The components of said device are denoted by the same reference numerals as in FIG. 1. The device furthermore comprises a second cooling device which also supplies cold at a temperature which lies below the λ-point of helium. This cooling device comprises a first superleak 25 which at its one side is in open communication with the liquid ^{4}He bath 15 and at its other end communicates with a space 26 in the heat exchanger 9. The space 26 communicates, through a duct 27 and a cooler 28, with a second superleak 29. The superleak 29 is bounded at its upper side by a space 30 which comprises a heating device 31. The space 30 furthermore communicates with the ^{4}He bath through a duct 32. This device is entirely incorporated in the vacuum space 14.

The operation is as follows: By supplying current to the heating device 31, a higher temperature will prevail in the space 30 than in the cooler 28. As a result of this, a fountain pump effect occurs across the superleak 29 and superfluid helium will flow through the superleak 29 to the space 30, and then through the duct 32 to the helium bath. As a result of this a lower pressure will prevail in the cooler 28, so that the medium will flow from the space 26 through the duct 27 to the cooler 28. The duct 27 is proportioned so that the medium therein exceeds its critical speed and turbulence occurs. This means that both superfluid and normal helium, flows through the duct 27. With the normal helium thermal energy is transported from the space 26 to the cooler 28, so that a temperature will prevail in the space 26 which is lower than that of the helium bath 15. So a temperature difference exists across the superleak 25. The cooling power obtained in the space 26 is used to cool the flow of ^{3}He in the supply duct 2. This means that in the heat exchanger 9, the ^{3}He will show a lower temperature than is the case in the device shown in FIG. 1. As a result of this the temperature in the mixing chamber 1 will also be lower so that the device shown in FIG. 2 supplies its cold at a lower temperature than the device shown in FIG. 1. It will be obvious that instead of the cooling device 25—32, a different cooling device may be used, if desirable, to cool the ^{3}He in the supply duct 2.

What we claim is:

1. A device for transporting thermal energy from a lower temperature level to a higher temperature level, which two temperature levels lie below the temperature of the λ-point of ^{4}He, wherein the device comprises a liquid pump, at least one cooler receiving liquid from the pump, a first supply duct communicating between the cooler and a mixing chamber, and a second supply duct comprising a superleak and, communicating between said cooler and emptying on its other side in the mixing chamber, an exhaust duct communicating between the mixing chamber and the suction side of the liquid pump, the mixing chamber, the first and the second supply duct and the exhaust duct being thermally insulated, and the device when being filled during operation with a mixture of ^{3}He and ^{4}He, having a temperature prevailing during operation in the said cooler which lies below the λ-point of the ^{3}He—^{4}He mixture on the entrance side of the first and the second supply duct, so

that unmixing of ^4He and ^3He occurs there, the concentration of ^3He in the first supply duct being higher than in the exhaust duct and the pump, the dimensions of the exhaust duct being such that the medium therein exceeds its critical speed and turbulence occurs.

2. A device according to claim 1 wherein the liquid pump is a centrifugal pump.

3. A device according to claim 1, further comprising a reservoir containing liquid helium at a temperature which is lower than that of the λ-point of ^4He the mixing chamber, the first and second supply duct and the exhaust duct being arranged in a vacuum-insulated space which is immersed in said reservoir.

4. A device according to claim 1, further comprising an additional device for transporting thermal energy from a lower to a higher temperature level, which two levels also lie below the temperature of the λ-point of ^4He, and the coldest part of which device is in heat exchanging relationship with the first supply duct.

5. Apparatus operating with a supply mixture of liquid helium for producing cold or cool an object, comprising:

a. pump means for applying a pressure to flow the supply mixture of liquid helium,
b. cooler means for cooling the flowing helium to a temperature below its λ-point, with a resulting mixture of superfluid ^4He, normal ^4He, and liquid ^3He components,
c. a superleak through which flows only superfluid ^4He from the cooler,
d. a supply duct through which flows liquid ^4He and liquid ^3He from said cooler,
e. a mixing chamber in which an object to be cooled is disposable, and into which flows said mixture of liquid ^3He and liquid ^4He from the supply duct which mixture is diluted in the chamber by superfluid ^4He which flows into the chamber from the superleak, with a production of cold resulting in the chamber for cooling the object therein, and
f. exhaust duct means for discharge of the diluted fluid mixture from the mixing chamber.

6. Apparatus according to claim 5 wherein said exhaust duct has an outlet to said pump means, and said exhaust duct is dimensioned internally such that fluid flow therethrough will be turbulent.

7 Apparatus according to claim 5 further comprising a chamber containing a cooling bath of liquid ^4He maintained below the λ-point thereof.

8. Apparatus according to claim 5 further comprising a vacuum-insulated housing containing said mixing chamber, the superleak, the supply duct and exhaust duct.

9. Apparatus according to claim 5 wherein the fluid in the supply duct is a mixture of liquid ^3He and ^4He at a temperature below the λ-point of said ^3He—^4He mixture.

10. Apparatus according to claim 8 further comprising a reservoir for containing liquid ^4He at a temperature below the λ-point thereof in said vacuum-insulated housing immersed in the liquid ^4He of said reservoir.

11. A method for cooling an object, comprising the steps:

a. cooling a mixture of liquid ^3He and ^4He to below the λ-point, thus forming a quantity of superfluid ^4He within the mixture,
b. separating at least some of the superfluid ^4He from the $^3He-^4He$ mixture by flowing (i) the superfluid ^4He through a superleak, and (ii) the remaining $^3He-^4He$ mixture through a supply duct,
c. flowing both (*i*) the ^3He—^4He mixture and (*ii*) the superfluid ^4He into a mixing chamber, thereby diluting the ^3He—^4He mixture with the superfluid ^4He, and producing cold in said chamber for cooling an object therein, and
d. flowing the diluted mixture out of the chamber.

12. A method according to claim 11 wherein flowing said liquid helium ^4He and ^3He comprises pumping same with a pump means.

13. A method according to claim 11 wherein flowing the diluted mixture of liquid helium out of the mixing chamber comprises flowing same turbulently.

14. A method according to claim 11 further comprising insulating from heat transfer by using a vacuum chamber, said steps of (*i*) separating and flowing the superfluid ^4He through a superleak, (*ii*) flowing the remaining mixture through a supply duct, (*iii*) mixing said flows from the superleak and the supply duct, and (*iv*) discharging the mixed helium from the mixing chamber.

15. A method according to claim 11 further comprising maintaining a quantity of liquid ^4He about said vacuum chamber at below the λ-point temperature thereof.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,581,512 Dated June 1, 1971

Inventor(s) Frans Adrianus Staas et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 21, after "producing cold" delete "or" and insert -- to --.

Signed and sealed this 27th day of February 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents