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A CRYOSTAT OPERATING ON THE HEAD OF TRANSITION OF He^3 *FROM A SOLUTION RICH IN* He^3 *TO A SOLUTION RICH IN* He^4

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Calculations referring to an apparatus operating on the heat of transition of He^3 from one liquid phase of helium to another are presented. It is shown that at temperatures of the order of millidegrees the cooling effect is proportional to the heat of transition $q = 100T^2$ J/mole. When the He^3 circulation rate is 1.6×10^{-4} mole/sec a temperature of 0.001°K can be attained and 5 erg/min can be absorbed at this temperature.

A proposal to utilize the process of solution of liquid He^3 in He^4 to obtain low temperatures was made by London and Mendoza[1] and has been realized with the greatest degree of success by Neganov et al.[2] using an apparatus whose schematic diagram is similar to the one shown in Fig. 1. Using their apparatus they obtained a temperature of approximately 0.03°K.

In accordance with the most recent data[3,4] He^3 at $T = 0.01°K$ dissolves in liquid He^4 up to concentrations $\nu = N_3/(N_3 + N_4) = 0.05$ (N_3 and N_4 are respectively the numbers of He^3 and He^4 atoms). In all probability this solubility holds right down to 0°K. This affords the possibility of obtaining very low temperatures if one utilizes the heat of transition of He^3 from a phase consisting of almost pure liquid He^3 into a phase with $\nu = 0.05$ of He^3 in He^4, and the removal of He^3 by means of diffusion from the zone of solution into a region of lower concentrations and higher temperatures.

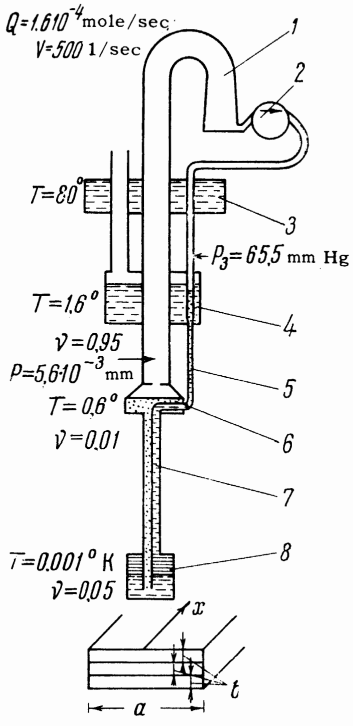

FIG. 1.

Taking the curve of stratification of solutions of He^3 in He^4 obtained in [3-5] and taking into account on the basis of [6] that the vapor pressure over weak solutions of He^3 in He^4 at low temperatures is equal to $p = p_{He^3}\nu + p_{He^4}(1-\nu)$ we obtain the diagram for the state of He^4-He^3 shown in Fig. 2. The domelike curve corresponds to equilibrium of the two liquid phases, while curves labelled by values of pressure correspond to liquid-vapor equilibrium at the pressures indicated. An investigation of the diagram of the state of He^4-He^3 enables one to discuss the possibility of obtaining very low temperatures in a relatively simple ap-

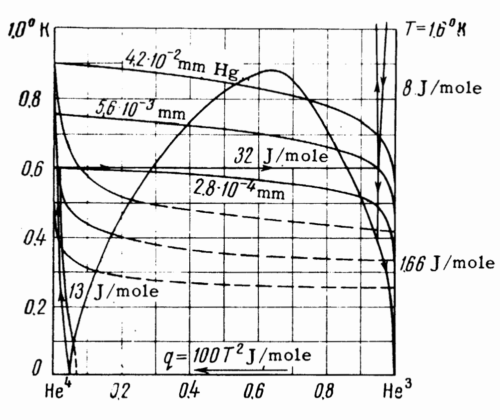

FIG. 2.

paratus which is schematically shown in Fig. 1.

The principle of operation of the apparatus is the following. He^3 of concentration close to 100% is pumped off and compressed by means of a diffusion pump 1 and of a rotary pump 2. It is then cooled in the bath 3 by liquid nitrogen and is condensed in the capillary by means of heat exchange with bath 4 of liquid He^4. It then flows along the thin capillary 5, attains a pressure close to zero, is cooled in the evaporation bath 6 and the heat exchanger 7 and enters the upper part of the solution bath 8. In the solution bath He^3 behaves as if it "evaporates" into the lower phase and from there, acted upon by the difference in concentrations, the "gaseous" He^3 proceeds by viscous flow into the evaporation bath 6 where it evaporates and is pumped off by the pumps thus completing the cycle. The transition of He^3 in the bath 8 from the upper phase into the lower phase is analogous to evaporation, and the heat of transition determines the cooling efficiency of the apparatus.

The heat of transition can be evaluated by means of the formula $q = T(S_1 - S_2)$ where T is the temperature of transition, S_1 is the entropy of one mole of He^3 in the lower phase, and S_2 is the entropy of the upper phase which is practically equal to the entropy of liquid He^3. At low temperatures the upper phase consists of practically pure He^3, while the entropy of He^4 in the lower phase is negligible in comparison with the entropy of the dissolved He^3 and plays no role in the process. According to the data of Anderson et al[4] the heat capacity of a solution of concentration $\nu = 0.05$ He^3 at temperatures below 0.04°K calculated per mole of He^3 is equal to

$$C = \left(\frac{\pi}{3n\nu}\right)^{2/3} \frac{m^* k^2 N}{\hbar^2} T = 124T \left[\frac{\text{J}}{\text{mole-deg}}\right],$$

where m^* is the effective mass equal to 2.4 times the mass of a He^3 atom, k is Boltzmann's constant, $\hbar$ is Planck's constant, N is Avogadro's number, n_i is the number of atoms of helium per cm^3. Without taking into account the small corrections associated with the transition at very low temperatures into the superfluid phase, with $C \sim T$ the entropy is numerically equal to the heat capacity and, therefore, the entropy of the lower phase is equal to $S_1 = 124T$ [J/mole deg]. The entropy of liquid He^3 in the upper phase for $T < 0.1°$ is equal to $S_2 = 24T$ [J/mole deg] and, therefore, the heat of transition of He^3 from the upper phase into the lower will be given by

$$q = T(S_1 - S_2) = 100T^2 \text{ [J/mole]}.$$

The cooling efficiency of the apparatus without taking into account parasitic heat leaks and imperfections of the heat exchanger will be given by

$$W = qQ \text{ [W]},$$

where Q is the rate of circulation of He^3 (in moles per second). In order to provide circulation it is necessary to remove the He^3 by means of diffusion from the solution bath 8 into the evaporation bath 6 in the presence of a temperature gradient. Calculations involving such a process are very complex, and are associated with taking into account the properties of solutions of He^3 in the degenerate region which at present have not been investigated experimentally. However, certain specific properties of weak solutions of He^3 in He^4 at low temperatures give us the possibility of making a fairly accurate estimate of the operation of such an installation.

Ptukha[7] has shown that at 0.5°K the mean free path in liquid helium of a phonon with respect to collisions with He^3 atoms attains in a one per cent solution the value of 0.27 mm, while the mean free path for a roton with respect to collisions with He^3 atoms attains the value of 0.3 mm. At the same time atoms of He^3 in solution behave as a free gas. According to the measurements of Ouboter et al.[6] the heat capacity of weak solutions of He^3 in liquid helium in the temperature range in the neighborhood of 0.5°K is equal to $C_v = 3R/2$ where R is the gas constant. Treating the He^3 atoms in solution as a gas and assuming that the cross section for collisions of the atoms with each other may be taken equal to $\sigma_i = \pi(m_{He^3}/\rho)^{2/3} = 5 \times 10^{-15}$ cm^2 (where $\rho = 0.08$ g/cm^3 is the density of liquid He^3) we obtain the mean free path for He^3 atoms for a solution of concentration $\nu = 0.01$ equal to $l_{ii} = 1/n_i\sigma_i = 10^{-6}$ cm (n_i is the number of He^3 atoms per cm^3). Therefore, if in the heat exchanger the thickness of the film along which helium flows is of the order of 0.2–0.3 mm, one can regard the motion of He^3 atoms as viscous flow of gas governed by the kinetic theory of gases, and the flow of heat associated with phonons as the molecular motion of a phonon "gas" through a slit.

Such a discussion will be valid up to the temperature of degeneracy which for a weak solution of He^3 in He^4 is determined by the formula

$$T_d = (3\pi^2 n_i)^{2/3} \hbar^2 / 2m^* k.$$

For $\nu = 0.05$ we shall have $T_d = 0.34°$. For temperatures $T \ll T_d$ one can regard the motion of He^3 atoms in solution as the motion of a degenerate Fermi-gas and utilize the appropriate formulas[8] 1). For mean free path l_{ii}, viscosity η_d, and heat conductivity κ_d of the solution in the domain $T \ll T_d$ on the basis of theoretical considerations[9,10] one should expect functional dependences of the form $l_{ii} \sim T^{-2}$, $\eta_d \sim T^{-2}$, $\kappa_d \sim T^{-1}$.

Since experimental data are not available for all the required parameters of solutions of He^3 in He^4 we shall for our calculations utilize the following values,

$$m^* = 2.4 m_{He^3} = 1.2 \cdot 10^{-23}\ \text{g}$$

$$n_i = 2.19 \cdot 10^{22} \nu, \qquad \sigma_i = 5 \cdot 10^{-15}\ \text{cm}_2$$

The phonon heat conductivity

$$\varkappa_{ph} = {}^1/_3 C_{ph} u_s l_{ph} = 24 T^3 l_{ph},$$

where C_{ph} is the phonon heat capacity, u_s is the sound velocity, l_{ph} is the mean free path for a phonon; in our case $l_{ph} = 0.03$ cm and $\kappa_{ph} = 0.72T^3$ [W/cm deg].

1. In the gas kinetic domain $T > T_d$ we have: average velocity of the motion of He^3 atoms in solution

$$v_{av} = \sqrt{8kT / \pi m^*} = 5.4 \cdot 10^3 \sqrt{T}\ [\text{cm/sec}];$$

the heat capacity, the heat conductivity and the viscosity of the "gas" of He^3 atoms are respectively equal to

$$C_i = {}^3/_2 k n_i = 0.45\nu\ [\partial\text{J/cm}^3\text{deg}],$$

$$\varkappa_i = {}^1/_3 C_i v_{av} l_{ii} = 7.5 \cdot 10^{-6} \sqrt{T}\ [\text{W/cm deg}],$$

$$\eta_i = {}^1/_3 m^* n_i v_{av} l_{ii} = 4.3 \cdot 10^{-6} \sqrt{T}\ [\text{g/cm sec}];$$

the osmotic compressure is given by

$$p_i = {}^1/_3 m^* n_i v_{av}^2 = 2.6 \cdot 10^6 \nu T\ [\text{dyne/cm}^2].$$

2. In the domain of the degenerate state $T \ll T_d$ where $T_d = 2.5\nu^{2/3} = 0.34°K$ is the temperature of degeneracy for $\nu = 0.05$ we obtain

$$v_{ph} = 7.6 \cdot 10^3 \nu^{1/3} = 28\ \text{m/sec},$$

the heat capacity of 1 cm^3 of solution is

$$C_d = 15\ k n_i T = 4.5 \nu T\ [\text{J/cm}^3\text{deg}],$$

the viscosity of the "gas" is

$$\eta_d = {}^1/_3 m^* n_i v_{ph} l_d = 1.4 \cdot 10^{-8} T^{-2}\ [\text{g/cm-sec}],$$

where $l_d = 2.1 \times 10^{-11} \nu^{-4/3} T^{-2}$ [cm] is the mean free path for the particles, the heat conductivity is

$$\varkappa_d = {}^1/_3 C_d v_{ph} l_d = 2.4 \cdot 10^{-7} T^{-1}\ [\text{W/cm-deg}],$$

the osmotic pressure is

$$p_d = \frac{(3\pi^2)^{2/3}}{5} \frac{\hbar^2}{m^*} \left(n_i^{5/3} + 0.18 \left(\frac{m^* kT}{\hbar^2} \right)^2 n_i^{1/3} \right)$$

$$= 3 \cdot 10^6 (\nu^{5/3} + 0.65 \nu^{1/3} T^2) \left[\frac{\text{dyne}}{\text{cm}^2} \right].$$

The values of l_d, η_d and κ_d are obtained by equating at $T = 0.1°$ the quantities $\eta_d = \eta_i$ and $\kappa_d = \kappa_i$. The basis for this is the fact that at this temperature

$$\frac{\varkappa_d}{\eta_d} = \frac{C_d}{m^* n_i} = \frac{C_i}{m^* n_i} = \frac{\varkappa_i}{\eta_i}.$$

If we choose the heat exchanger 7 in the form shown schematically at the botton of Fig. 1 with the height of the channels b = 0.02—0.03 mm and of width $a \gg b$, and if we send along the central channel the condensed He^3 and along the outer channels the atoms of He^3 diffusing through the superfluid helium from the solution bath 8 into the evaporation bath 6, then, taking into account the fact that the mean free path for He^3 atoms colliding with one another in a solution with $\nu = 0.05$ even at $T = 0.001°$ is equal to $\sim 1.1 \times 10^{-3}$ cm, while for collisions with thermal excitations it greatly exceeds b, the motion in the channels can be regarded as viscous motion determined by the osmotic pressure.

As is well known the flow through a slit in the case of viscous flow is equal to

$$u = \frac{ab^3}{12\eta} \frac{dp}{dx} \left[\frac{\text{cm}^3}{\text{sec}} \right],$$

i.e., the number of He^3 atoms passing through the channel per second is given by Q

$$Q = n_i u = \frac{ab^3 n_i}{12\eta} \frac{dp}{dx} = \text{const.} \tag{1}$$

We substitute into this equation the quantities p_i and η_i from the first variant ($T > T_d$). We obtain

$$Q = 1.1 \cdot 10^{33} \frac{ab^3 \nu}{\sqrt{T}} \frac{d(\nu T)}{dx} \left[\frac{1}{\text{sec}} \right]. \tag{2}$$

Taking $Q = 1.6 \times 10^{-4}$ mole/sec $= 9.6 \times 10^{19}\ \text{sec}^{-1}$, a = 2 cm and b = 0.03 cm we obtain

$$d(\nu T) / dx = 1.6 \cdot 10^{-9} \sqrt{T} / \nu \quad [\text{deg/cm}],$$

i.e., the product νT remains constant. Thus, for a heat exchanger length L = 200 cm we have $\Delta(\nu T)/\nu T \sim 5 \times 10^{-3}$. For the degenerate gas we obtain

$$Q = 4 \cdot 10^{35} ab^3 \nu T^2 \frac{d}{dx} (\nu^{5/3} + 0.65 \nu^{1/3} T^2)\ [\text{sec}^{-1}] \tag{3}$$

or for the conditions chosen above

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1)It should be noted that the heat capacity of a He^3 solution calculated on the basis of theoretical data with $m^* = 2.4 m_{He^3}$ agrees well with the measurements of Anderson et al. [4] and for $T \ll T_d$ is equal to $C = (3R/2)(\pi^2 T/3T_d)$.

$$\frac{d}{dx}(\nu^{5/3}+0.65\nu^{1/3}T^2)=4.5\cdot10^{-12}/\nu T^2,$$

i.e., in this case also the expression in brackets must remain constant.

Thus, in both cases, and, consequently, along the whole heat exchanger the osmotic pressure must remain constant. And since we have (cf., for example, [8]) a general relation valid for the whole range $pV = 2E/3$ or $p = 2n\nu E/3N$ where E is the energy, then along the thermal osmotic line the product νE must remain constant.

Stoner[10] has evaluated the values of E for a Fermi gas, and using them one can determine the dependence of ν on T. Stoner has given data for $\mathscr{E} = E/RT_d$ as functions of $\tau = T/T_d$. Since in our case $T_d = 2.5\nu^{2/3}$, we have

$$E\nu = 2.5R\mathscr{E}\nu^{5/3} = \text{const} \tag{4}$$

and correspondingly the temperature is given by

$$T = 2.5\tau\nu^{2/3}. \tag{5}$$

In the table are given values of ν —the concentrations along the thermal osmotic line for two different initial (at T = 0°K) concentrations, S_{He^3} — the entropy of liquid He^3, S_{sol} —the entropy of He^3 in a solution of concentration determined by the stratification curve, and q —the heat of transition of He^3 from one phase into the other. The values for the entropy of solution, and, consequently, for the heat of transition, are only estimates since there are no reliable data on the shape of the stratification curve for solutions of He^3 in He^4 at temperatures below 0.4°K. Since Stoner gives data only to $\tau = 2$ the values for concentrations along the thermal osmotic line were determined from equations (4) and (5) to T = 0.35°K for $\nu_0 = 0.05$, and to T = 0.45°K for $\nu_0 = 0.07$, and at higher temperatures from the condition νT = const.

T, °K	ν_1	ν_2	S_{He^3}, $\frac{J}{\text{mole-deg}}$	S_{sol}, $\frac{J}{\text{mole deg}}$	q, J/mole
0	5.00	7.00	0	0	0
0,025	4,93	6.96	0,60	3.07	0,062
0.050	4.73	6.83	1.18	5,65	0.224
0.075	4,48	6,63	1.70	8.06	0.477
0,100	4.13	6.40	2.23	10,21	0,80
0.125	3.80	6,14	2.71	11,55	1.11
0,150	3.47	5,79	3.18	12,70	1.43
0,175	3.18	5.47	3.58	13.37	1.72
0.20	2.92	5,10	3.93	13.95	2.0
0,25	2,48	4,55	4,60	14.9	2.6
0.30	2,13	4,07	5.17	15.45	3.1
0.35	1,85	3.67			
0.40	1.62	3.30			
0.45	1.44	2,99			
0,50	1,30	2.72			
0.55	1,19	2,48			
0,60	1.08	2.26			

Using Stoner's table[10] one can determine how much heat $\mathcal{Q}_1$ is absorbed by He^3 atoms moving from the solution bath to the evaporation bath at T = 0.6°K. This heat is equal to

$$\mathcal{Q}_1 = E - E_0 + p(V - V_0).$$

Since Stoner gives data only to the value $\tau = 2$ corresponding to T = 0.35°K we determine

$$\mathcal{Q}_1 = E(0{,}35) - E_0 + 1.5R(0.6 - 0.35) + pNn^{-1}(\nu^{-1} - \nu_0^{-1}) = 4.01 + 3.1 + 5.72 = 13 \text{ J/mole}.$$

If we take the thermal capacity of liquid He^3 to be equal to $C_3 = 2.4C$ [J/mole • deg] and $T = 0.5\tau$, and we take the values of τ and $C = C_V/R$ from Stoner's table, then within experimental error the heat capacity of liquid He^3 agrees with the values obtained in this manner. Therefore

$$\mathcal{Q}_3 = \int_0^{0,6} C_3 dT = 2{,}4\cdot 0.5\int_0^{1,2} C d\tau = 1{,}66\partial \text{ J/mole}.$$

It should be noted that in order to provide the required circulation of He^3 it is necessary to introduce heat into the evaporation bath in order to compensate for 13 J/mole of cold brought from the solution bath and for 32 J/mole of the heat of evaporation of He^3. Taking into account the fact that 8 J/mole is brought by the liquid He^3 from the helium bath at T = 1.6°K, for $Q = 1.6 \times 10^{-4}$ mole/sec this will give the value $W = 37 \times 1.6 \times 10^{-4} = 6 \times 10^{-3}$ W.

The large store of cold in solution ($\mathcal{Q}$ = 13 J/mole) compared to the heat brought by the liquid He^3 ($\mathcal{Q}_3$ = 1.66 J/mole) and also the low heat conductivity along the heat exchanger leads to a peculiar temperature distribution. If there were not heat exchange then for He^3 diffusing along the channels the heat balance could be written in the form

$$QC_p\frac{dT}{dx} = 2ab\frac{d}{dx}\left(\varkappa_{ph}\frac{dT}{dx}\right). \tag{6}$$

For $T > T_d$ the heat capacity is $C_p = 5R/2$ and we can immediately obtain the first integral

$$\varkappa_{ph}\frac{dT}{dx} = \frac{5QR}{4ab}(T - T_0),$$

or, substituting the appropriate values ($a = 2$ cm, $b = 0.03$ cm, $Q = 0.6 \times 10^{-4}$ mole/sec and $l_{ph} = 0.03$ cm) we obtain the value

$$T^3 dT/dx = 0.039(T - T_0).$$

We can neglect the heat conductivity κ_i through the "gas," since in this temperature range κ_i

$\ll \kappa_{ph}$. In the last equation we should interpret T_0 as the temperature of the solution bath, i.e., $T_0 \approx 0.001$, and this term can also be neglected, then $T^2 dT/dx = 0.039$ or

$$(0.6)^3 - T^3 = 0.117\Delta x.$$

Thus, at a distance $\Delta x = 2$ cm from the evaporation bath the temperature will be close to T_0. Heat exchange with liquid He^3 leads to the fact that the diffusing stream will remove from the helium 1.66 J/mole and will be heated by this to a temperature $T \approx \sqrt{1.66/7.5}\,R \approx 0.16$°K. This means that in the heat exchanger in the outer channels the temperature falls abruptly from the evaporation bath over a distance of several centimeters to 0.1° and then slowly decreases to the solution bath.

The exact solution of the problem of the regime in the heat exchanger presents great difficulties; moreover, there are no data on the heat exchange between liquid helium and a solid at temperatures of the order of millidegrees, which is the determining factor in the present problem. Therefore, we shall carry out an approximate calculation of the regime for the central channel assuming that at the boundary between liquid helium and a solid there exists a thermal discontinuity ΔT with a resistance $r = 70T^{-3}$ [deg cm^2/W] and that heat transfer takes place in accordance with

$$\frac{2a\Delta T dx}{2r} = abn_3C_3T dx = abn_3C_3\frac{dT}{dx}u dx.$$

But $abn_3u = Q$ and therefore

$$a\Delta T / r = QC_3 dT / dx. \qquad (7)$$

The value $2r$ is taken because we must take into account the discontinuities at the boundary between the helium and the wall and at the boundary between the wall and the solution.

Taking into account the peculiarities in the temperature distribution along the outer channels of the heat exchanger we shall take $\Delta T = T/2$. In this case equation (7) takes the form

$$C_3 dT / dx = aT / 2rQ.$$

In the interval $0.6° > T > 0.15°$ we have $C_3 \approx 3$ J/mole·deg and $dT/dx = 30T^4$. Integrating we obtain $(0.15)^{-3} - (0.6)^{-3} = 90\Delta x_1$, i.e., $\Delta x_1 = 3.2$ cm. Below the temperature of 0.15°K the heat capacity of liquid He^3 can be taken equal to $C_3 = 24T$ [J/mole·deg], then we have $dT/dx = 3.7T^3$ or after integration $T_2^{-2} - (0.15)^{-2} = 7.4\Delta x_2$. The limiting temperature which can be attained with this installation will be determined from the condition $q = \mathcal{Q}_3$ or $100T_0^2 = 12(T_2^2 - T_0^2)$, i.e., $T_2 = 3T_0$.

Neglecting the value $(0.15)^{-2}$ compared with T_2^{-2} we obtain for the limiting temperature

$$T_0 = 14(Q[\text{mole/sec}] / S[\text{cm}^2])^{1/2}, \qquad (8)$$

where $S = 2a\Delta x_2$ is the total area of the lower part of the heat exchanger. If we wish to retain one half of the cooling power $q = 2\mathcal{Q}_3$, then $T_2 = 2.3T_{0.5}$. The temperature which will become established in this case will be equal to

$$T_0 = 14(Q[\text{mole/sec}] / S[\text{cm}^2])^{1/2}, \qquad (9)$$

while the cooling power will be given by

$$W_{0,5} = 50T_{0,5}^2 Q \ [\text{W}]. \qquad (10)$$

If we choose $\Delta x_2 = 2$m, then $S = 4 \times 10^2$ cm^2 and for $Q = 1.6 \times 10^{-4}$ mole/sec we shall have

$$T_0 = 0.009°\,\text{K}, \quad T_{0,5} = 0.011°\,\text{K}, \quad W_{0,5} = 10 \ \text{erg/sec}$$

In order that $T_{0.5} = 0.001$°K it is necessary for a circulation $Q = 1.6 \times 10^{-4}$ mole/sec to have the area of the lower part of the heat exchanger equal to $S = 5 \times 10^4$ cm^2. The cooling power in this case will be equal to

$$W_{0,5} = 8\cdot 10^{-9}\ \text{вт} = 5 \ \text{erg/min}$$

If the thickness of the walls of the heat exchanger is δ it is desirable to impose on the heat conductivity of the material of the heat exchanger κ the requirements

$$(\varkappa_{\text{ph}} + \varkappa_{\text{d}})\, b / \delta > \varkappa > \delta / r.$$

For alloys at low temperatures $\kappa = \kappa_0 T$ and, therefore, for $\delta = 0.01$ cm

$$3(0.72T^3 + 2.4\cdot 10^{-7}T^{-1}) > \varkappa_0 T > 1.4\cdot 10^{-4}T^3.$$

The inequality on the right hand side is satisfied for all alloys, while on the left it has the most stringent conditions at $T \sim 2 \times 10^{-2}$ and reduces to $\kappa_0 < 2 \times 10^{-3}$ W/cm deg^2 and is also satisfied for a number of alloys.

We have not given here a discussion of the time required for the establishment of thermal equilibrium inside the channels, but it is of order $\tau = C_3b^2/\kappa_3\pi^2 = 1$ sec at $T = 0.1°$, while at other temperatures it is even lower. It is also not essential that the evaporating, and consequently also the condensing helium has a concentration $\nu = 0.95$, for during the process of cooling it will separate into two phases and 95% of it will act as described above. Difficulties could arise in the transition of He^3 into the superfluid phase, but in this case the entropy of the superfluid helium must fall with the temperature even faster and the apparatus must work even more effectively. But if initially the solution of He^3 in He^4 should go over into the superfluid state, then the efficiency of the apparatus would be reduced sharply, however such an occurrence is not very probable. It should also be noted that in order to reduce the quantity of He^4 coming from the evaporation bath along the film and evaporating in the warmer part of the apparatus it is necessary in the upper portion of the evaporation bath to insert a diaphragm of such small diameter that it would only slightly reduce the rate of pumping out of the helium vapor.

In this paper calculations are given for one variant of operation of the apparatus, but a recalculation to any other arbitrary concrete case with other parameters presents no great difficulties.

There is no doubt that in the nearest future installations of this type will appear in practically all the cryogenic laboratories having He^3.

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