The Notebooks of Kamerlingh Onnes and the Discovery of Superconductivity

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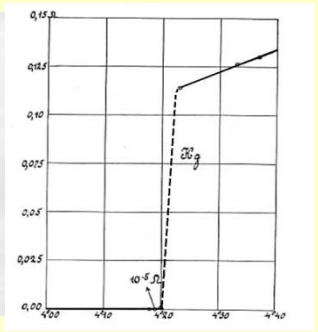
8 April 2011, Centennial Symposium Lecture


HKO

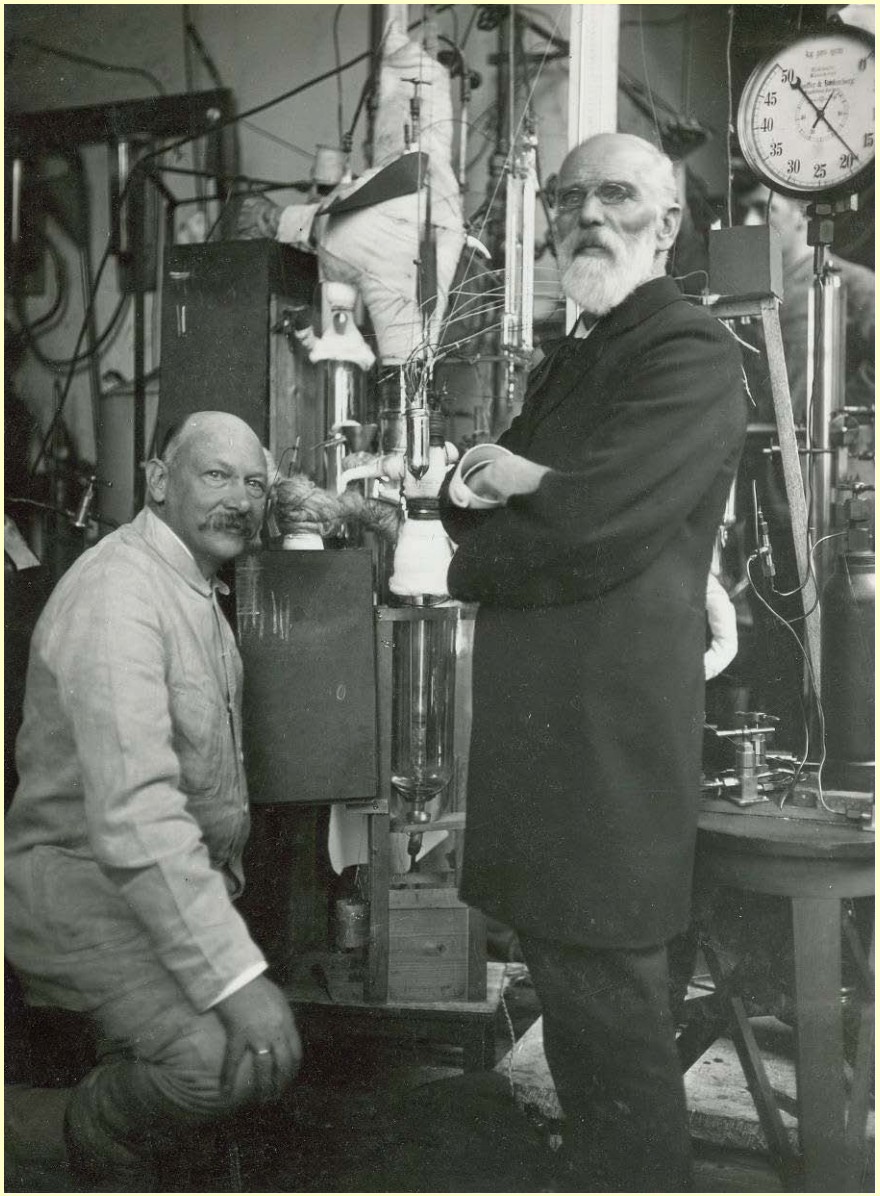

FLIM


KESSELRING




DORSMAN

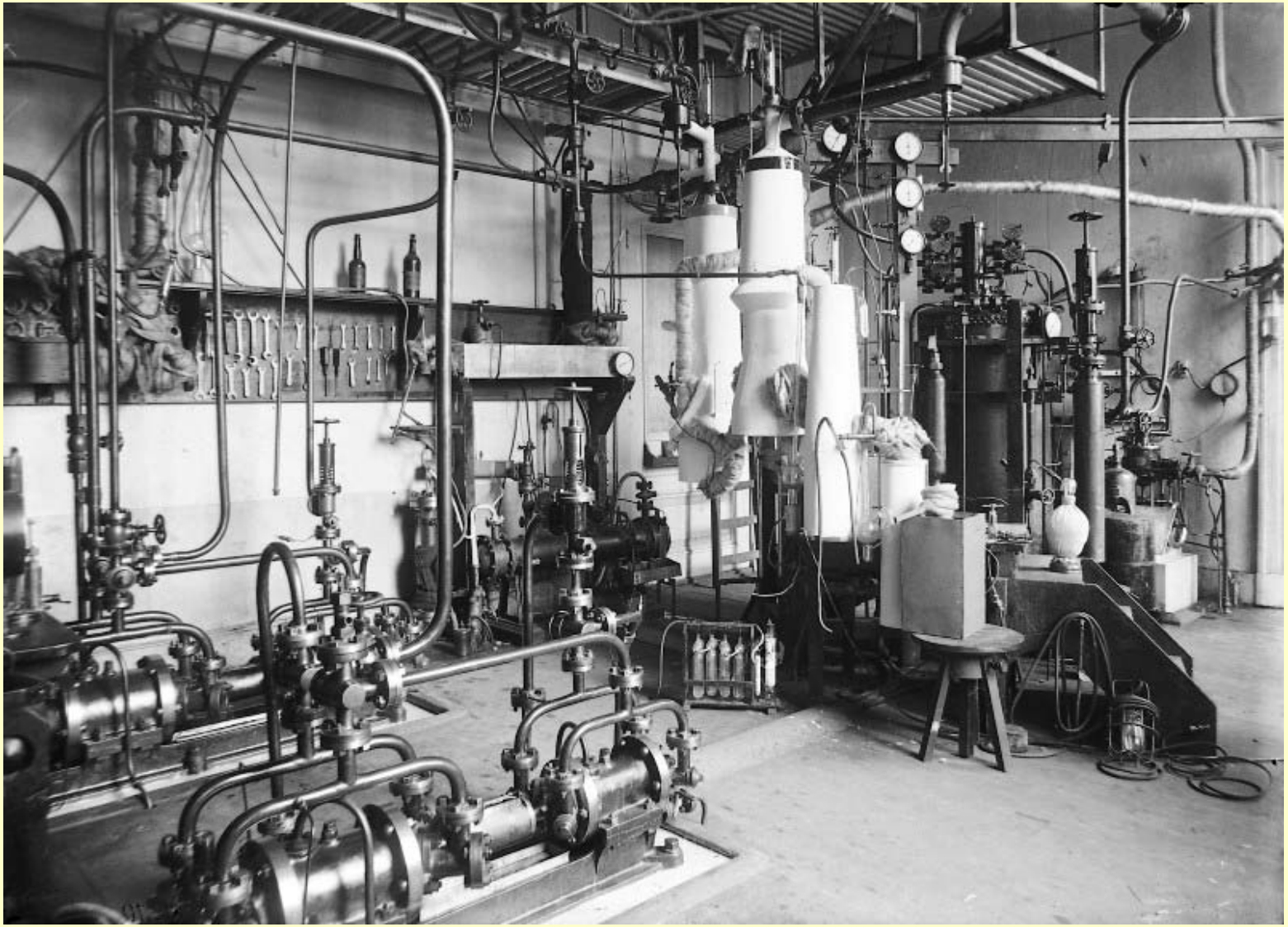

HOLST



Heike Kamerlingh Onnes and Johannes Diderik van der Waals (1913)

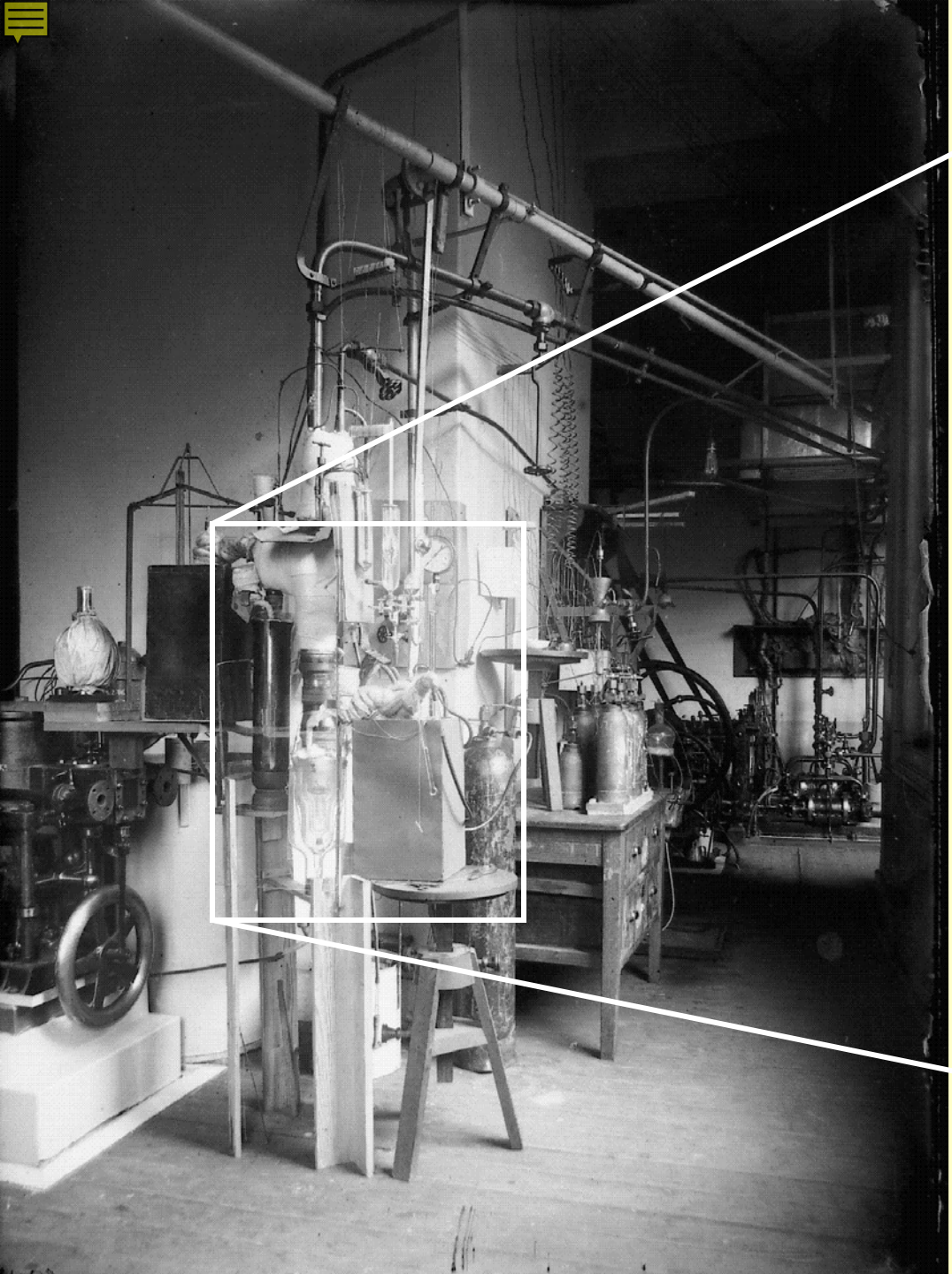
Laboratory for physics, chemistry, anatomy en physiology (~1880)

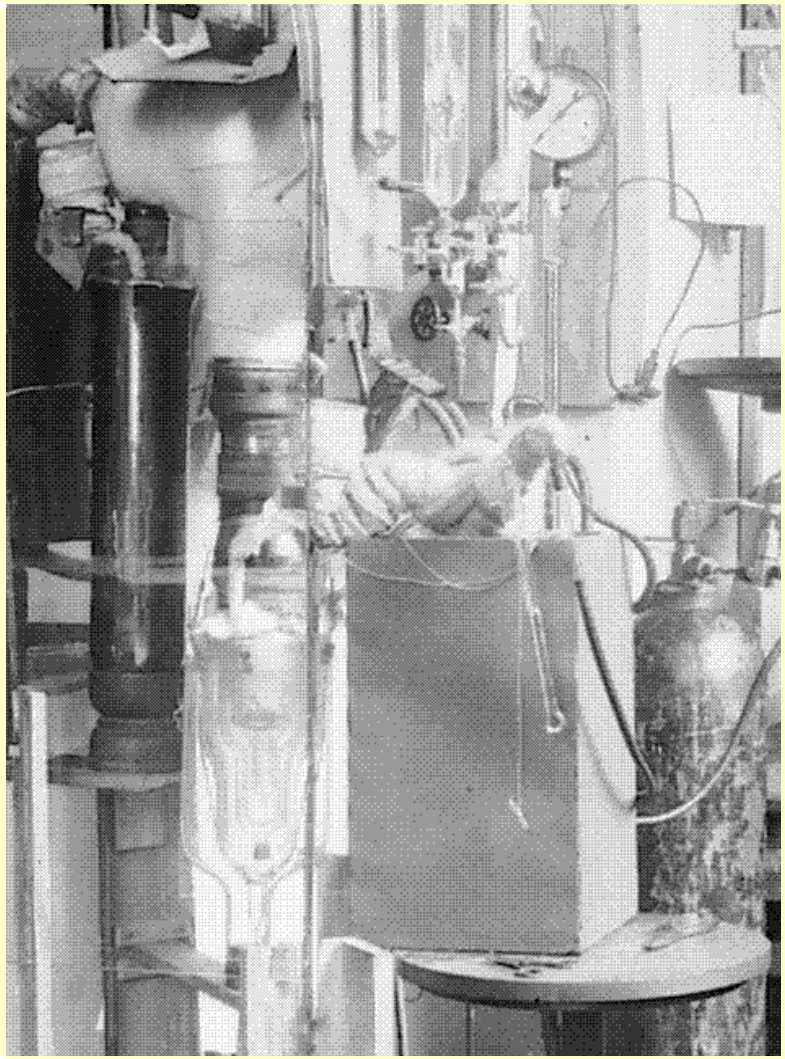
Fig. 17. — Plan du laboratoire cryogène de Leyde. (1908)



Production facility for liquid air (1892)

Hydrogen liquefier (1905)





He liquefier (1908)

Premier Congres International du Froid, Paris, Octobre 1908

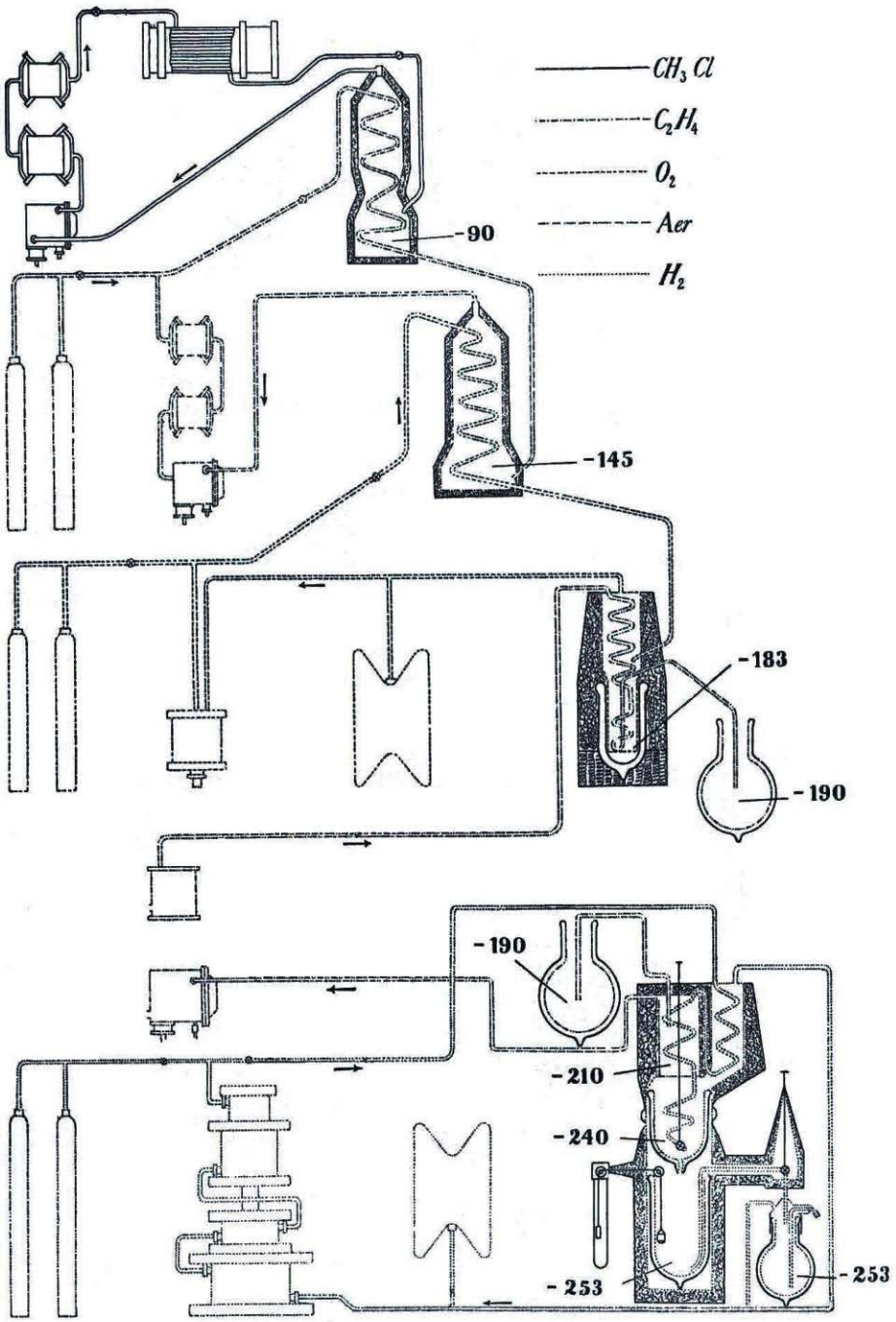
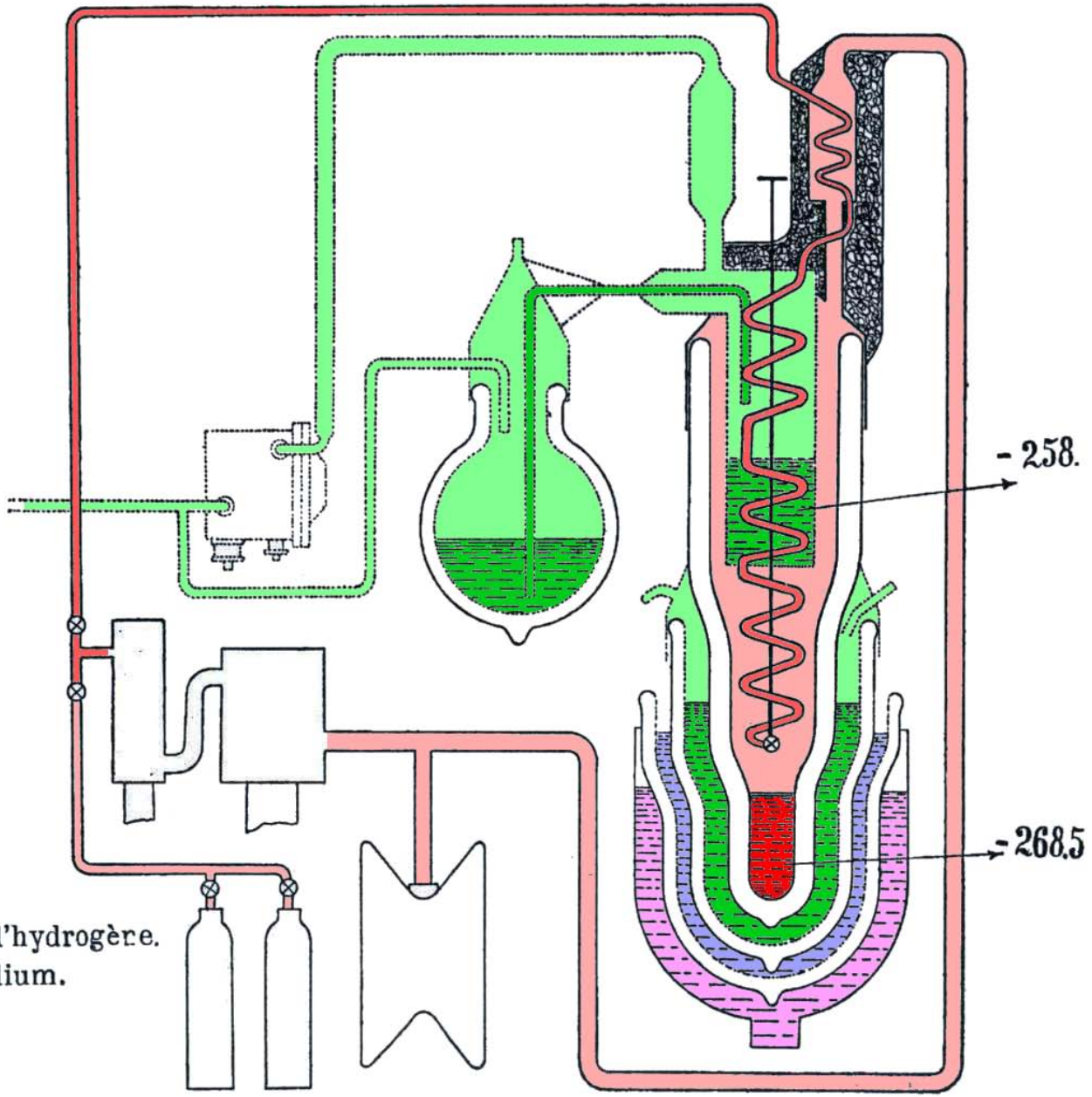


Fig. 1. — Cycles de la cascade du laboratoire cryogène de Leyde.

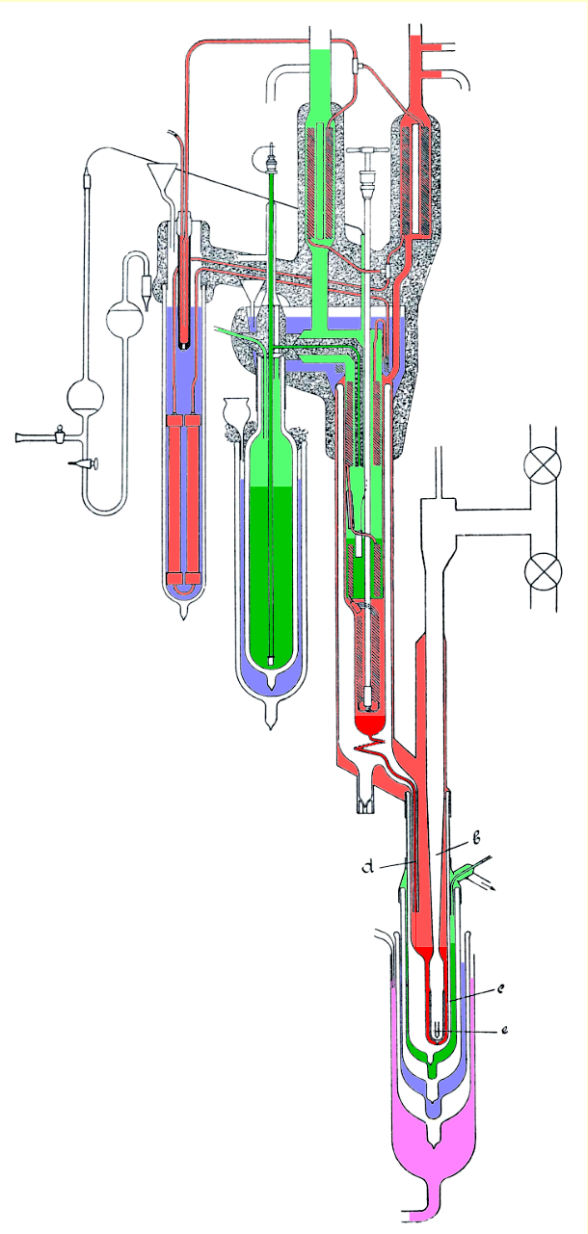
degrees C (°C)	(degrees) K(elvin)
0 °C	+273 K
	1892
-190	+83 (liquid air at 1 atmosphere)
	1905
-253	+20 (liquid H_2)
-273 °C	0 K

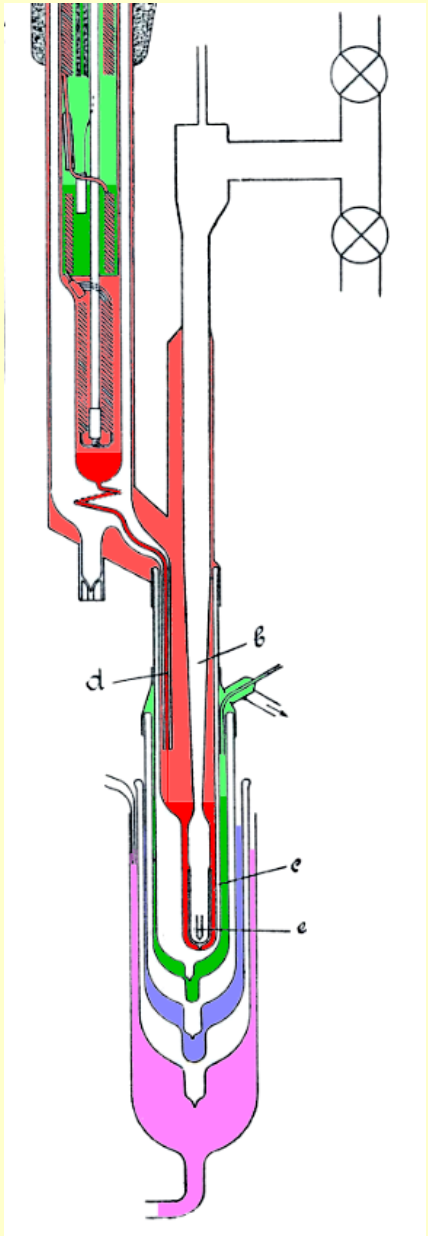


Trait pointillé : cycle d'hydrogène.
Trait plein : cycle d'hélium.

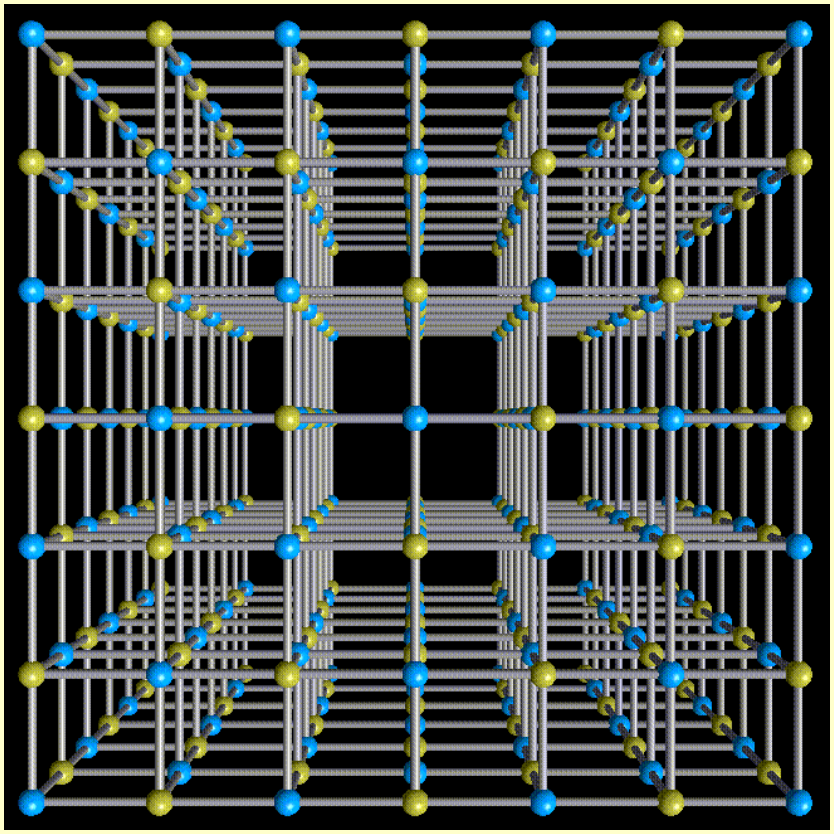
Fig. 4. — Schema de l'appareil de liquéfaction de l'hélium.

10 July 1908





First attempt to transfer liquid helium from the liquefier to a separate cryostat (12 March 1910)



For the experts

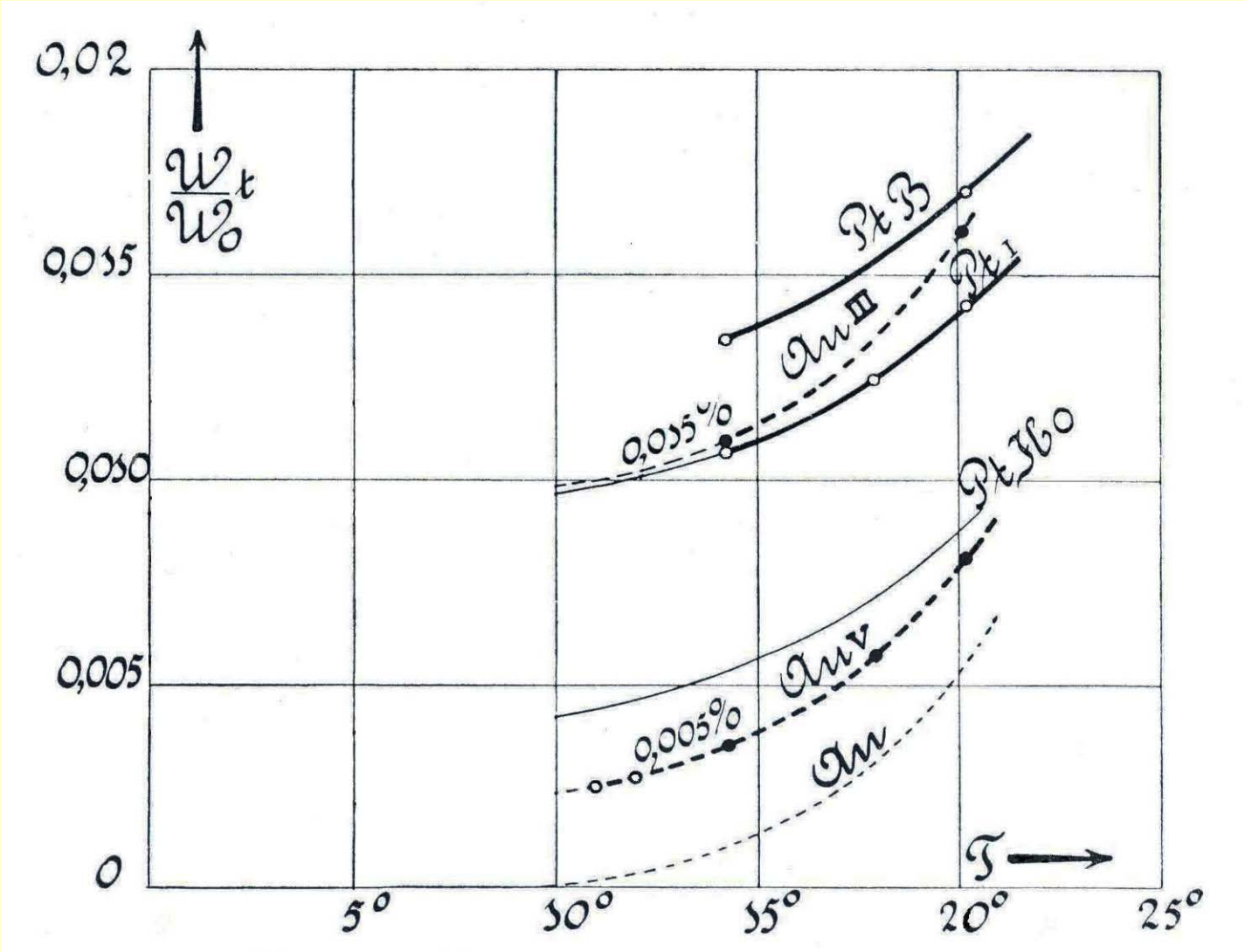
Kamerlingh Onnes's model

$R(T)/R_0 = \sqrt{(TE_T/T_0E_0)}$
with
$E_T = 3R\beta\nu[\exp(\beta\nu/T - 1)]^{-1}$

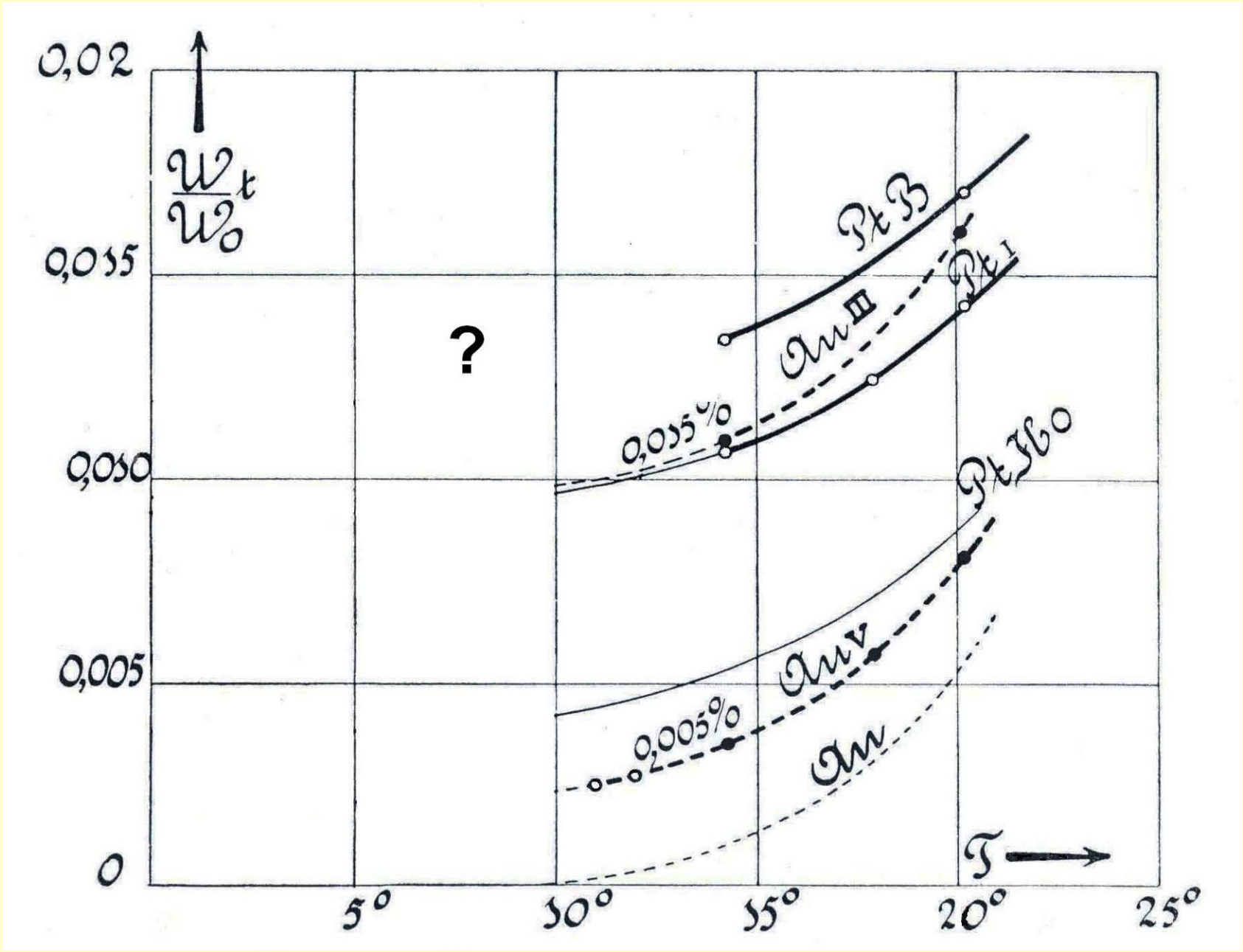
$\beta\nu = h\nu/k_B$

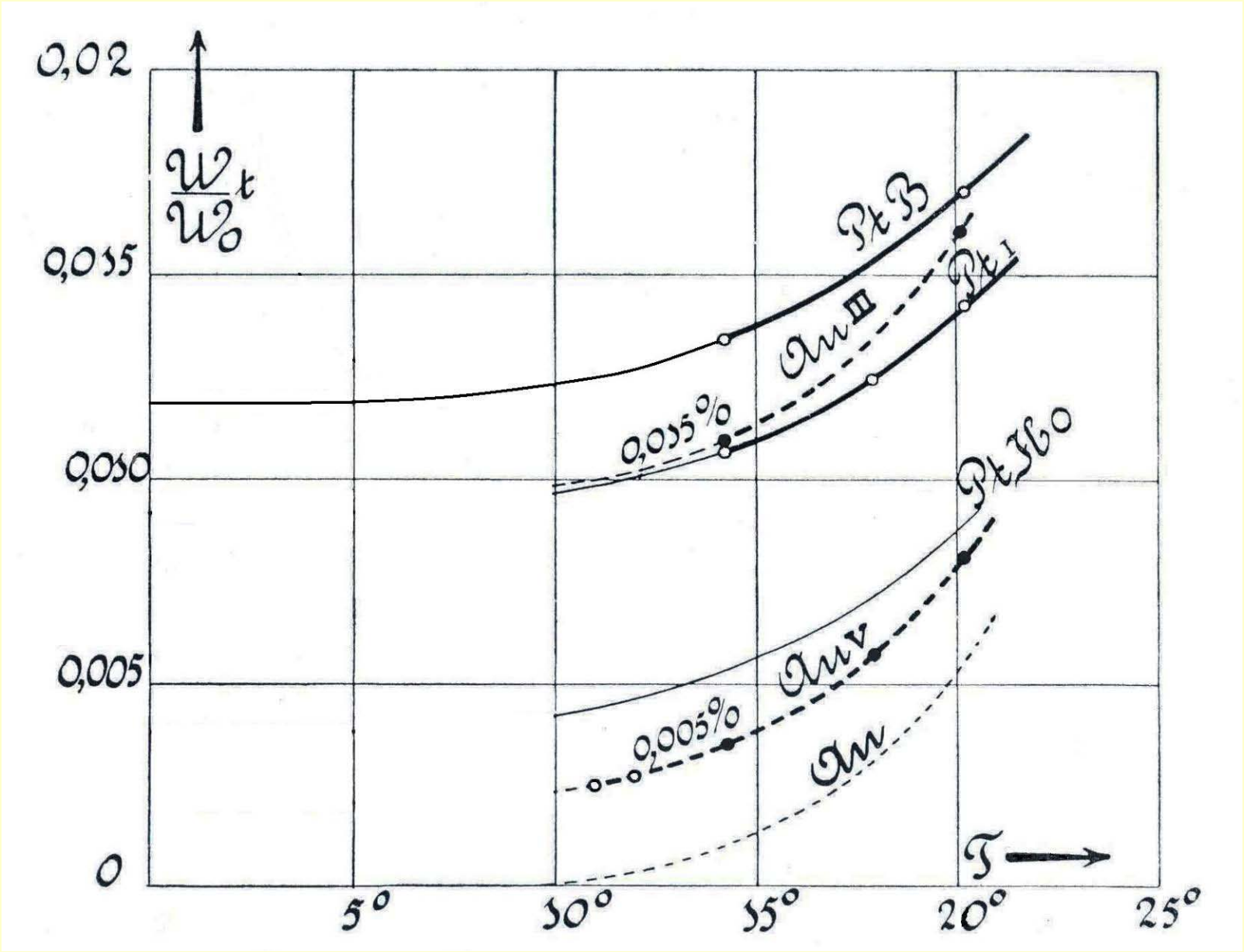
ν frequency of Planck vibrator

Crystal lattice
The conduction electrons in a metal will be scattered by
the thermal vibrations of the lattice atoms and by static impurities

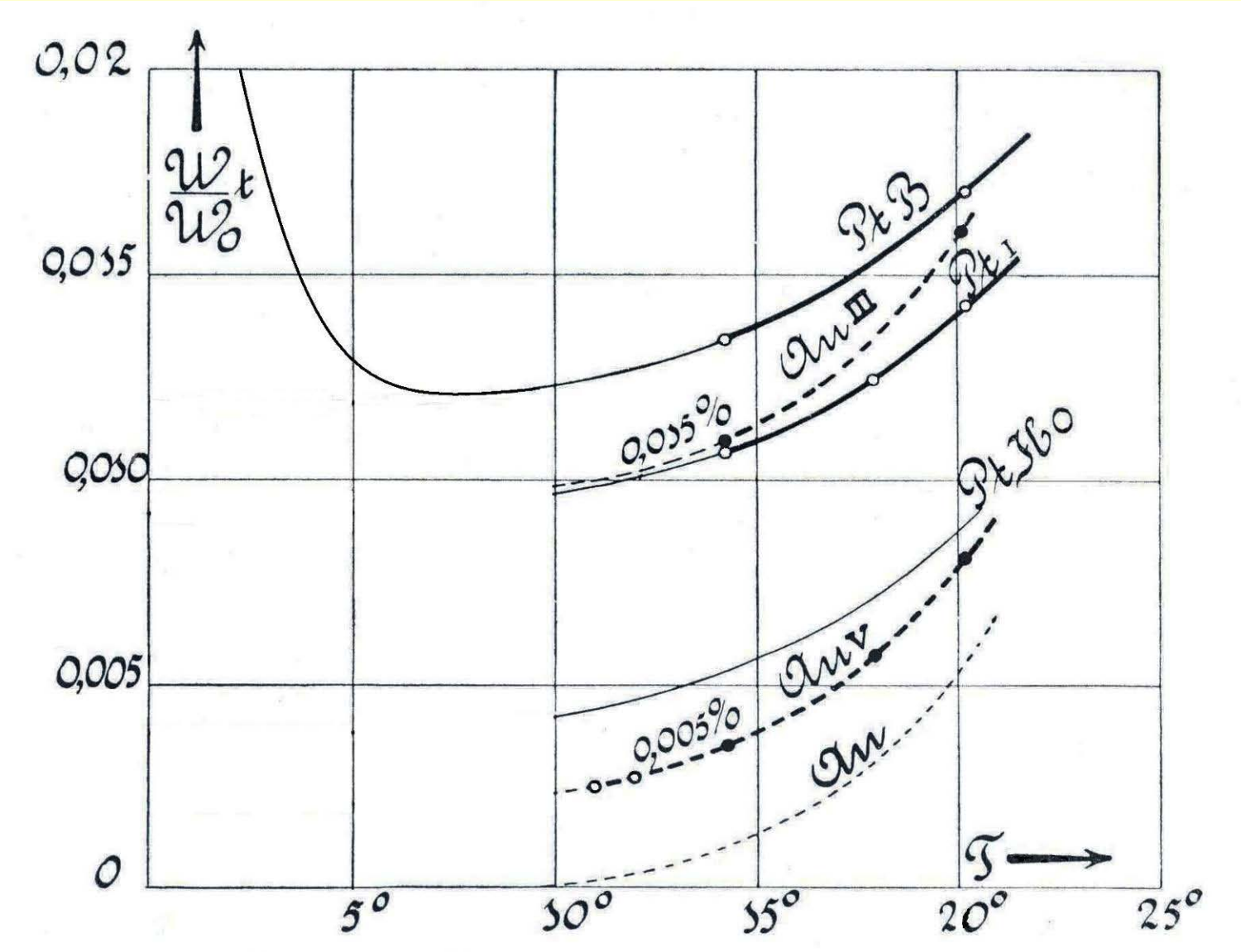


Resistance versus temperature of Platinum and Gold resistors (1907)

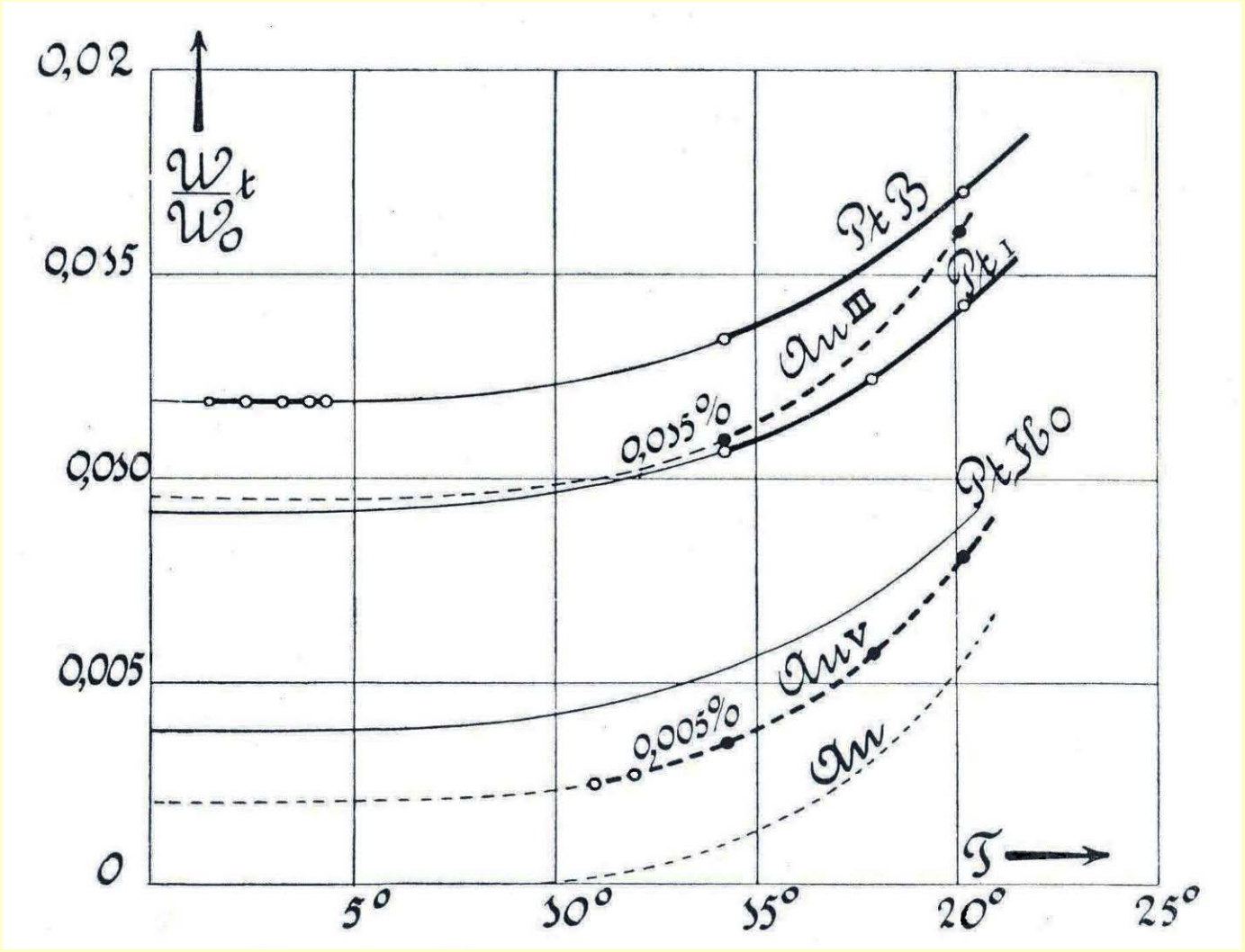

0,02
0,015
0,010
0,005
0
$\frac{w}{w_0}t$
?
Pt B
Pt I
Au III
0,015%
Pt Ko
Au V
0,005%
Au
T
5°
10°
15°
20°
25°

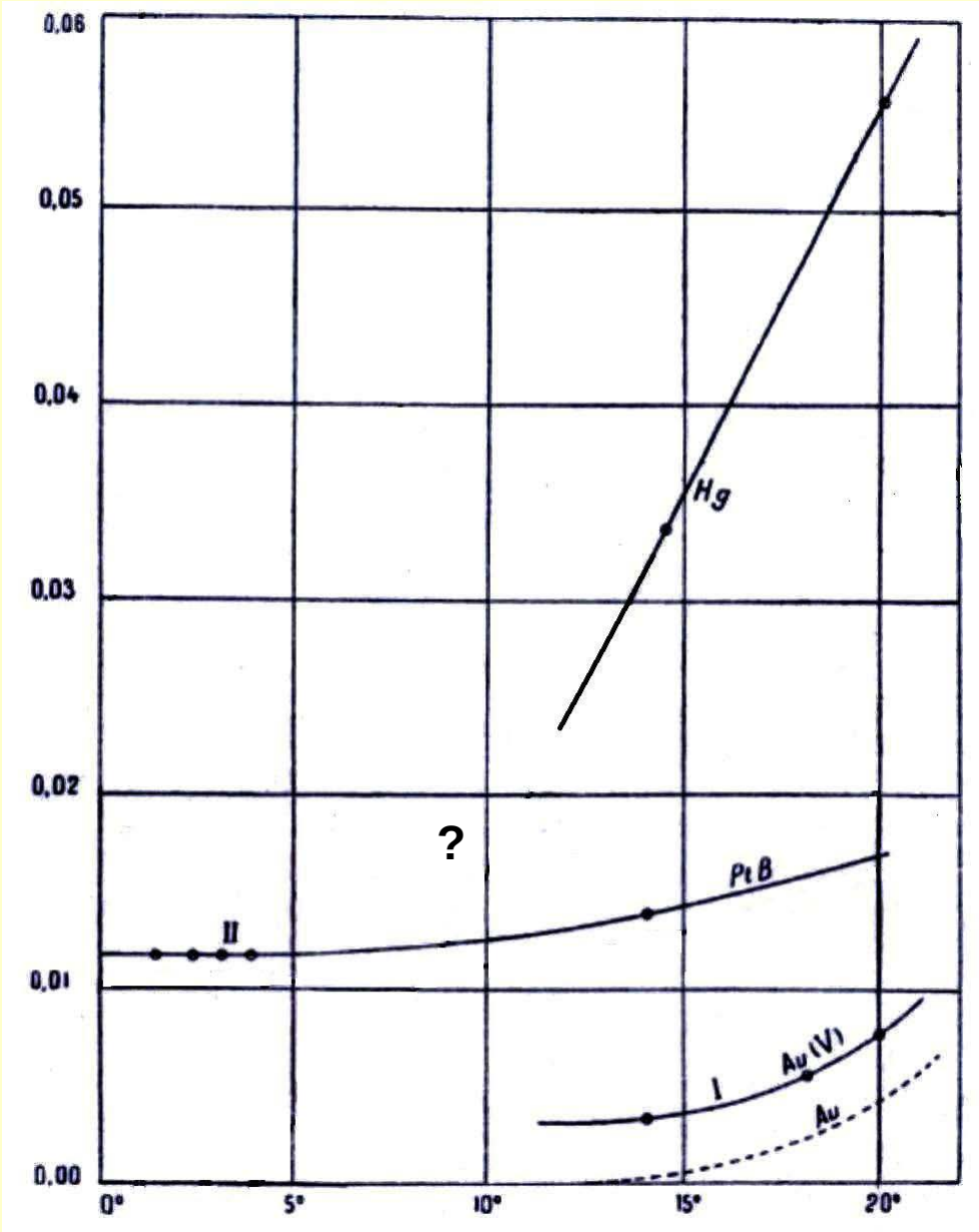


Scattering by Planck vibrators and lattice impurities

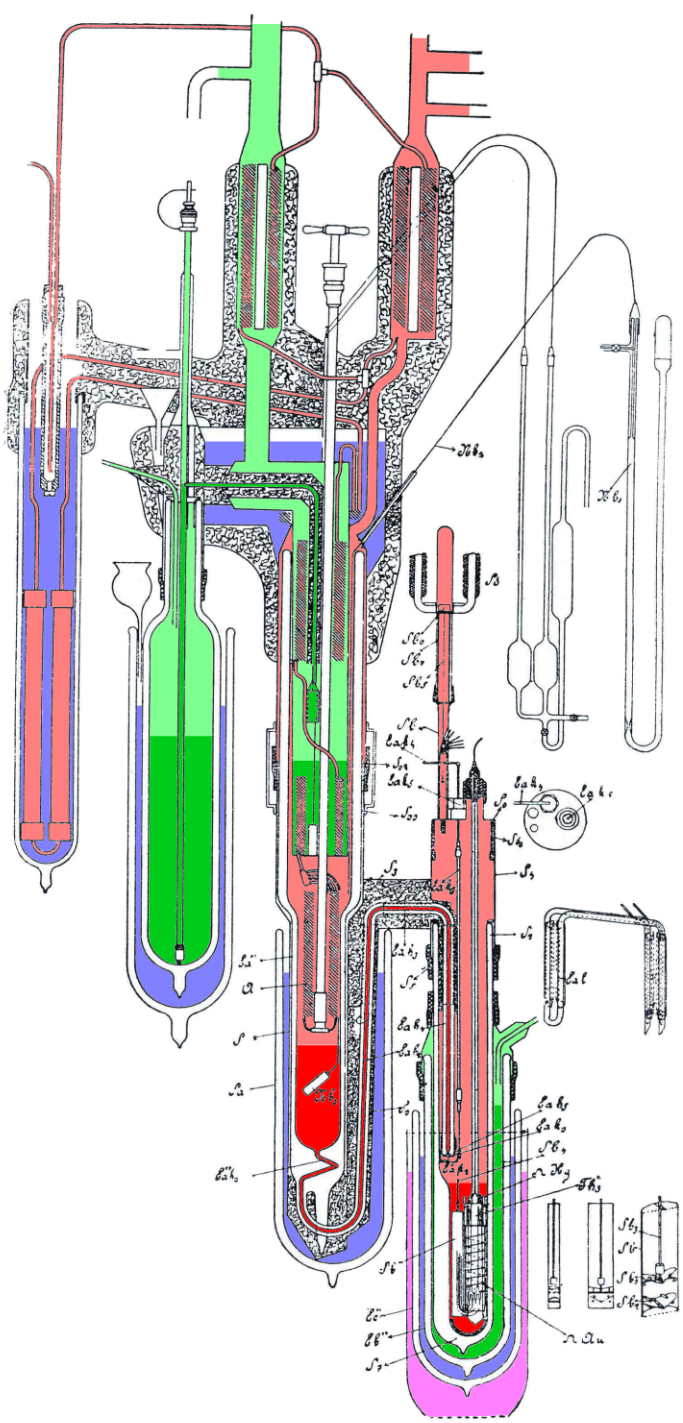


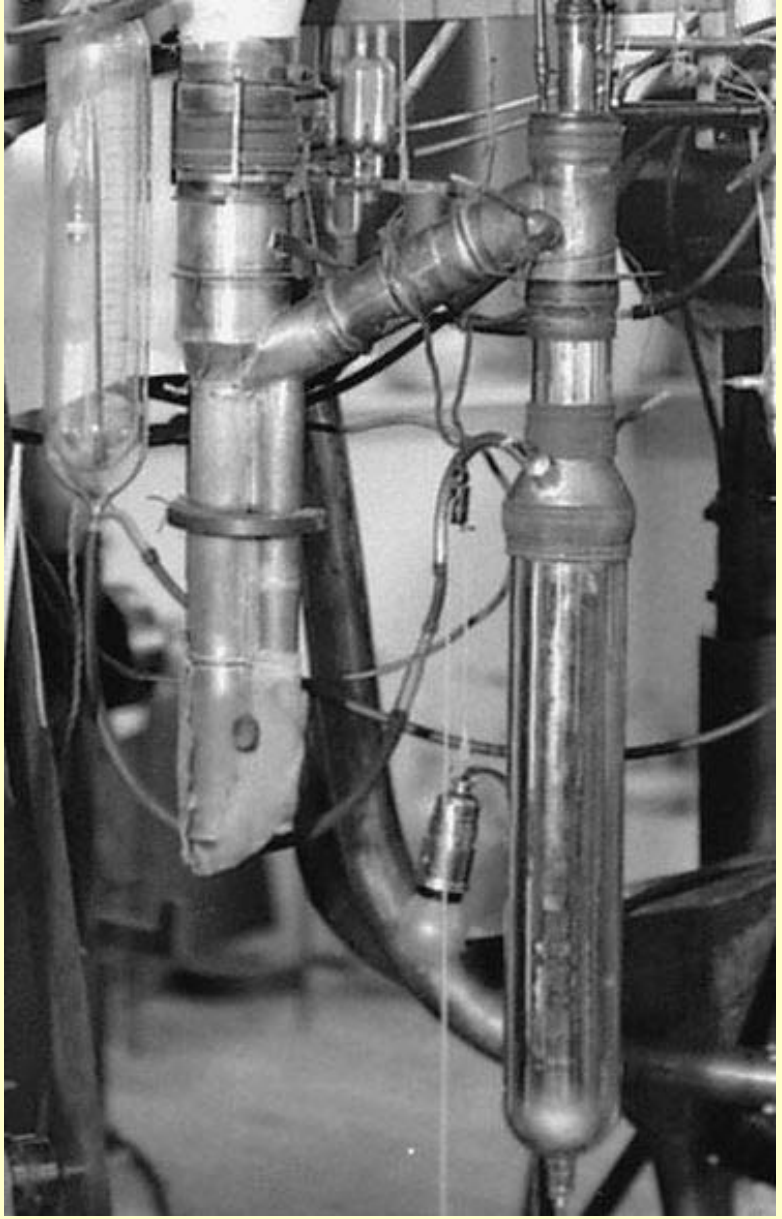
Freezing out of mobility of conduction electrons, Lord Kelvin (1902)


0,02
0,015
0,010
0,005
0
$\frac{W_t}{W_0}$
Pt 3
Au III
Pt 1
0,015%
Pt 10
Au V
0,005%
Au
T
5°
10°
15°
20°
25°

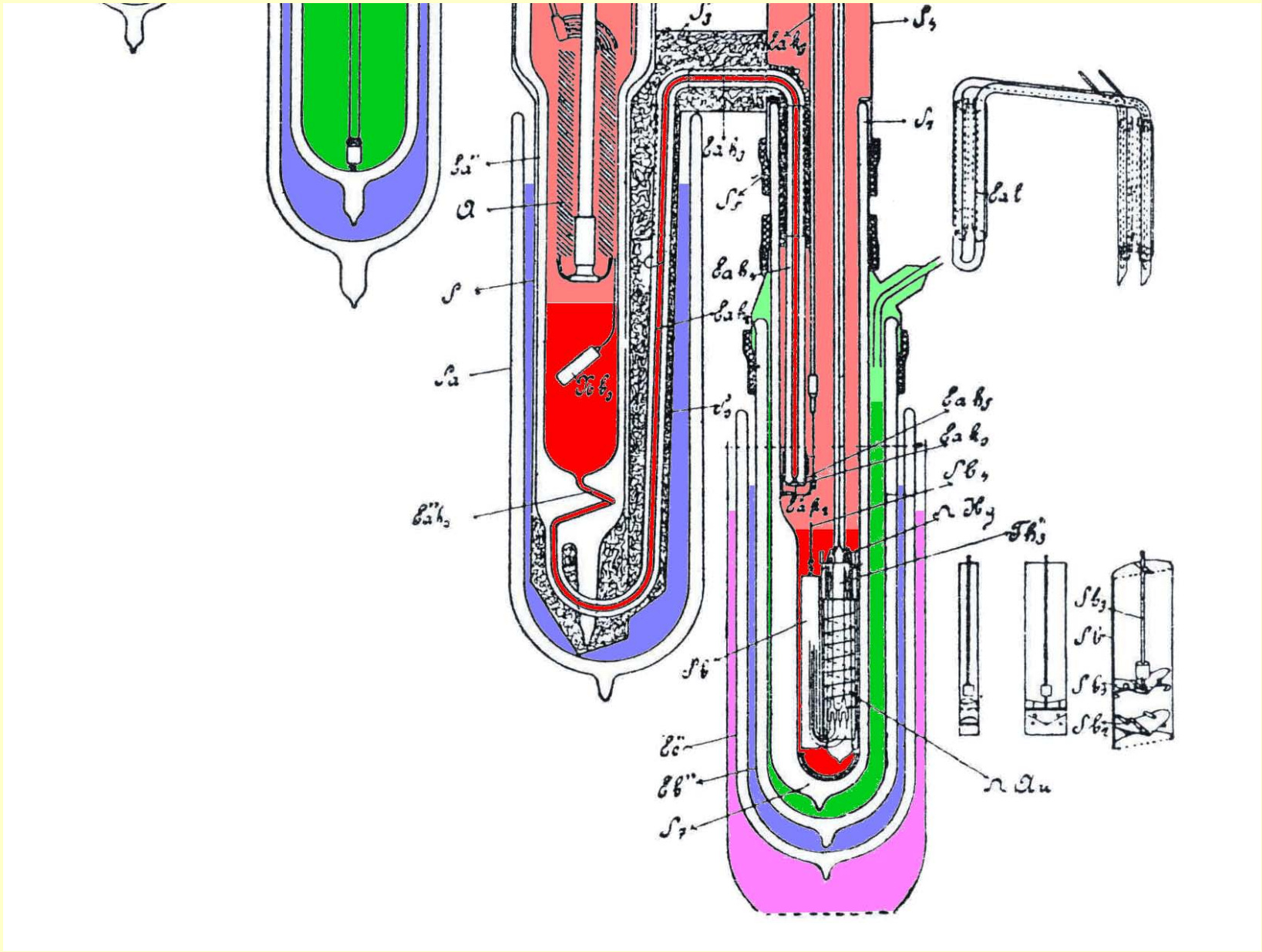


R vs *T* of mercury resistor in comparison to platinum and gold

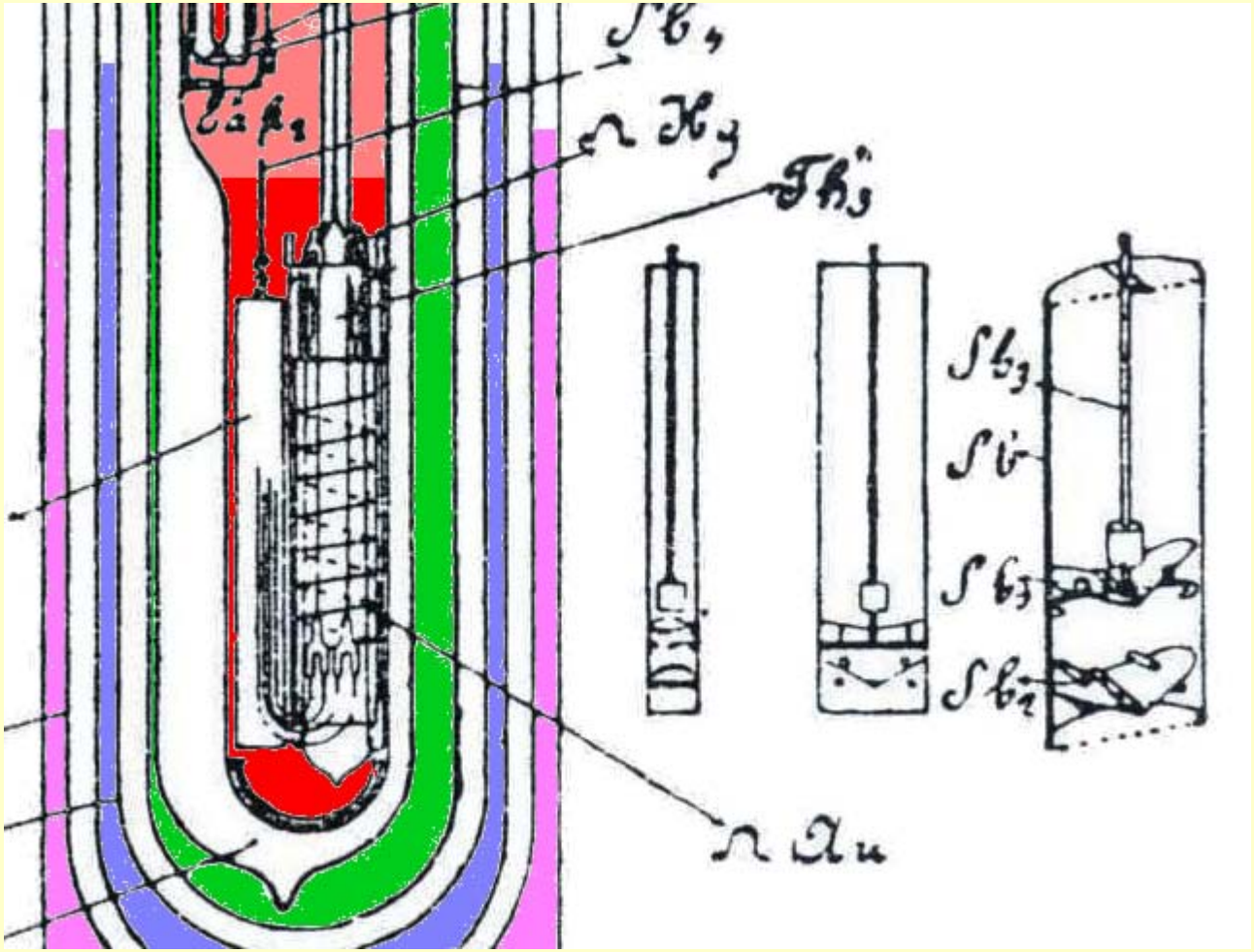




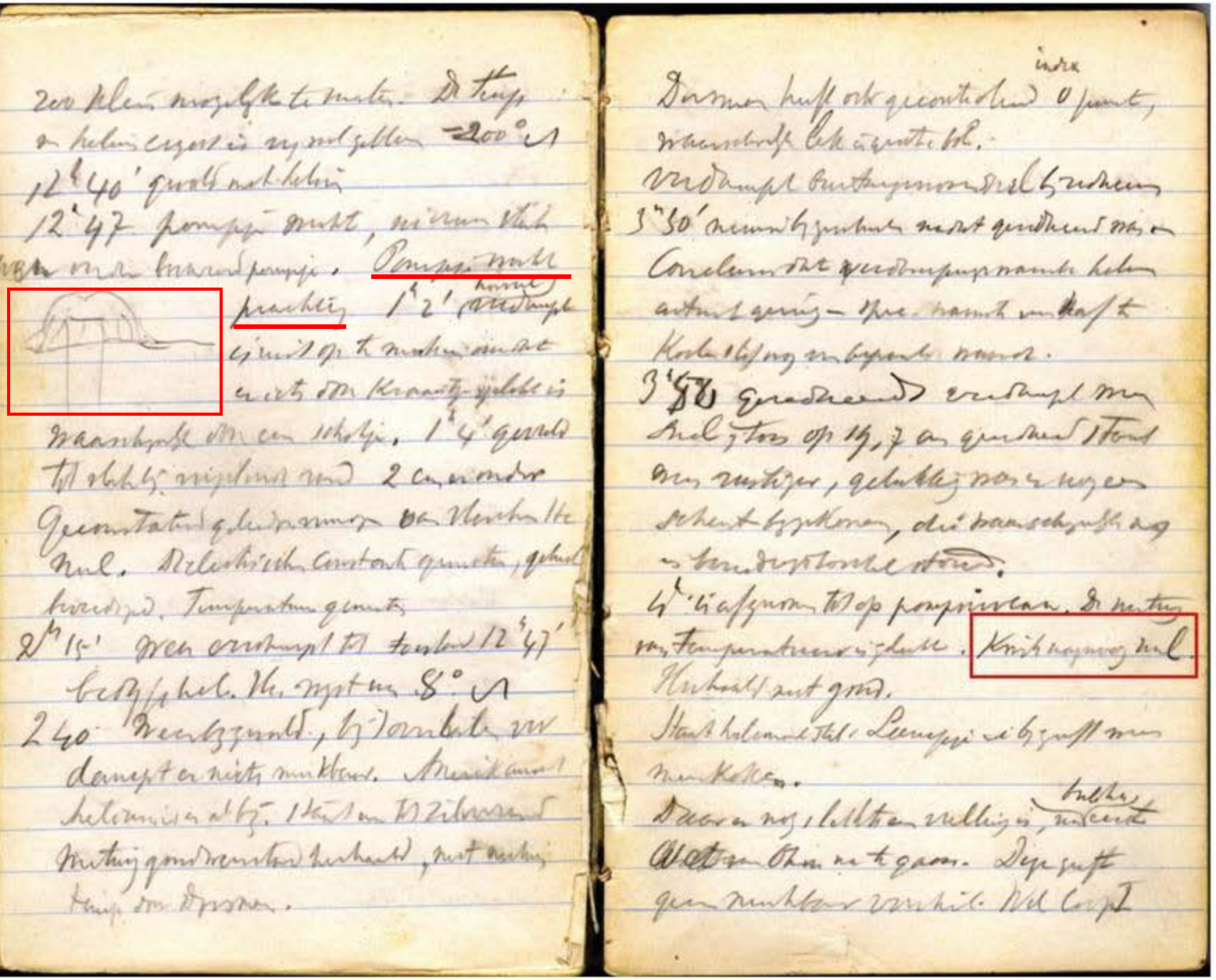
Set up of 8 April experiment



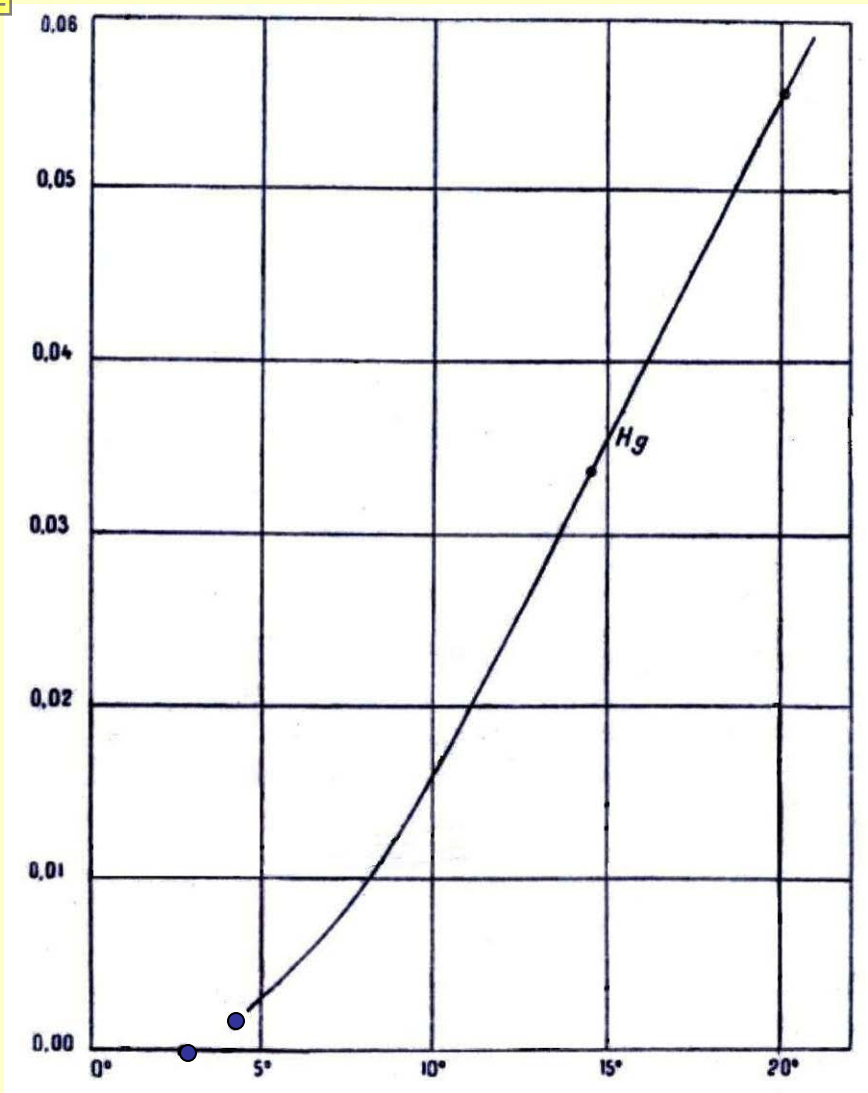
Transfer tube with valve controlled from outside the cryostat



What was placed inside the cryostat?
The stirrer (“het pompje”) electromagnetically driven.
It functioned well.
“Pompje werkt prachtig”, HKO writes in his notebook.



THE page from HKO's notebook



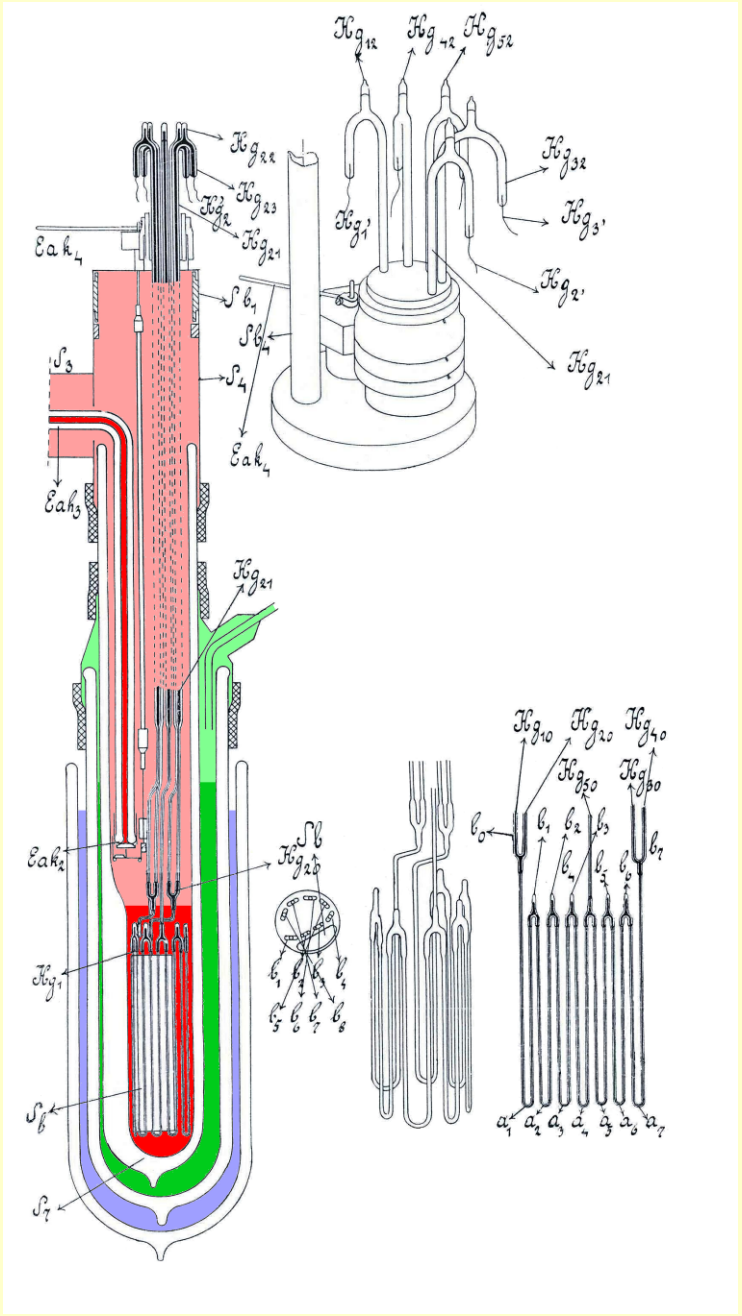
Only two points were measured.
HKO: my model works indeed!
The superfluid transition of He was not mentioned in the publications.

Experiment of 23 May 1911

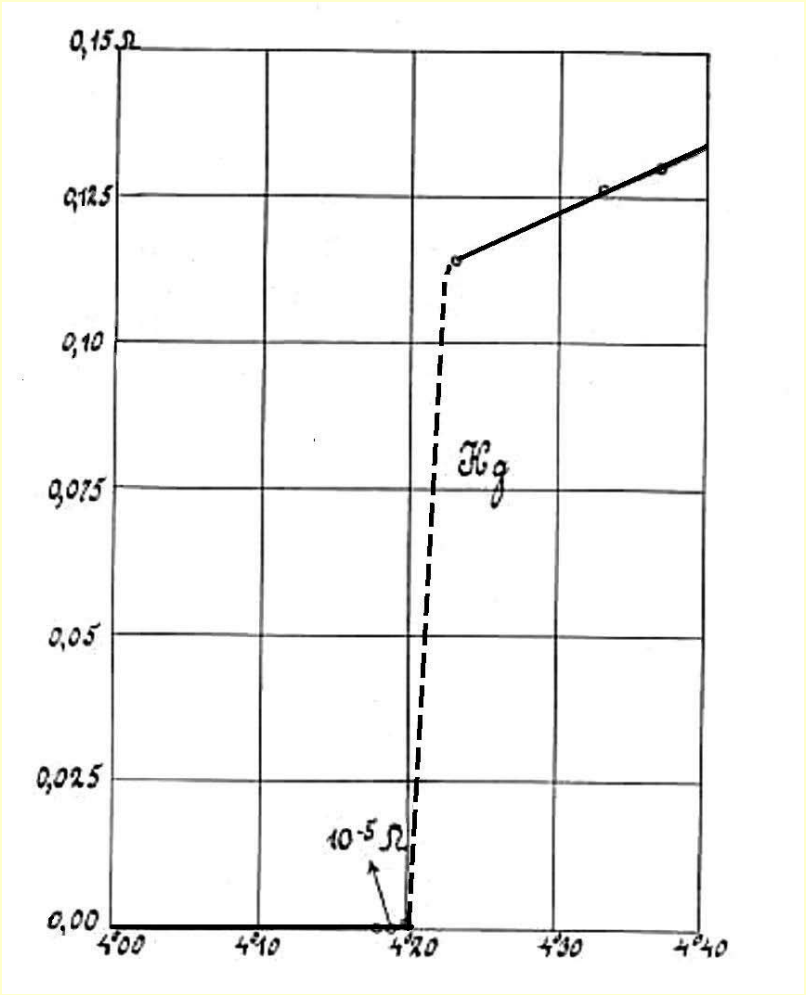
They increased the temperature from 3.0 K

HKO's notebook says:
At 4.00 [K] not yet anything to notice of rising resistance.
At 4.05 [K] not yet either.
At 4.12 [K] resistance begins to appear.

Notebook entry of May 26: no short circuit!



Experiment of 26 October 1911 with the historic plot showing the resistance jump at 4.20 K.

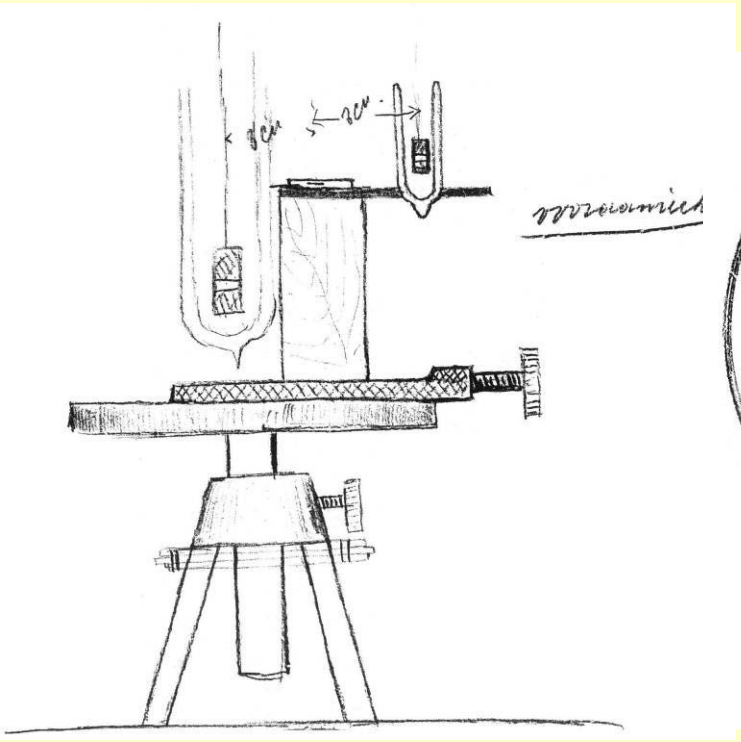


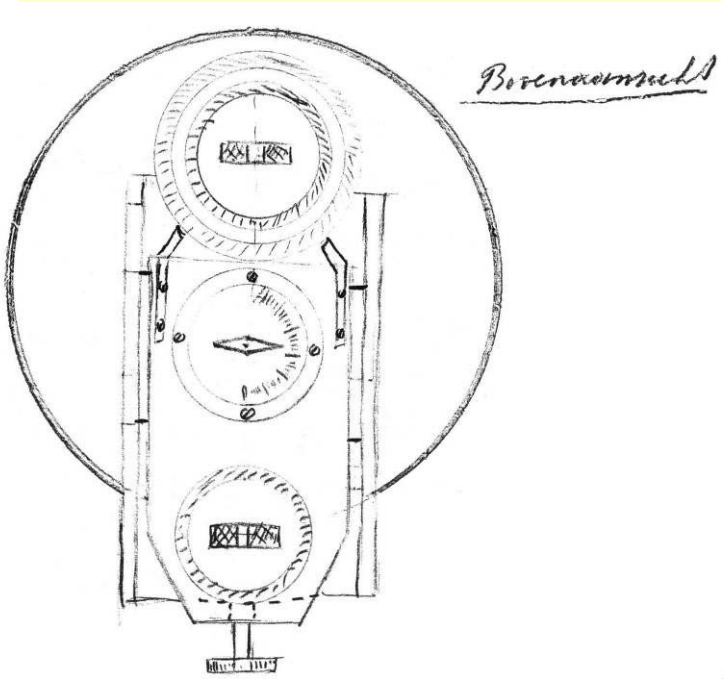
Subsequent developments

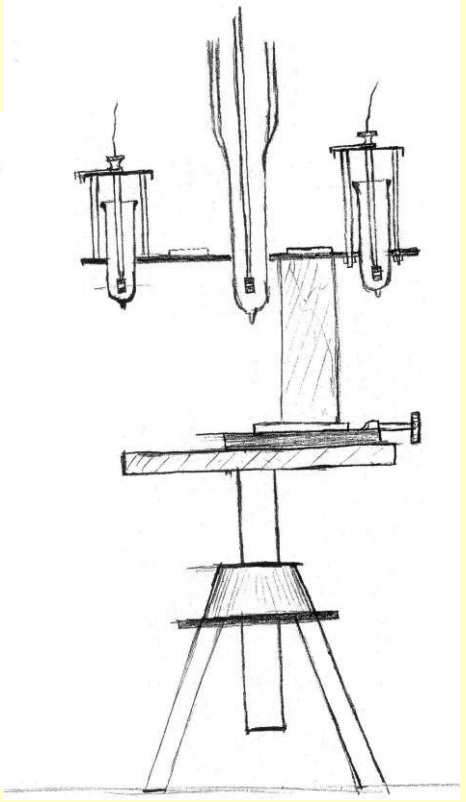
Holst was actively involved.
Was it a phase transition? Specific heat experiments failed.
22 June 1912: Mercury with gold or cadmium turned out to be superconducting as well. Even with amalgam for backing of mirrors the resistance disappeared with a jump and at a higher T_c!
Autumn 1912: also tin (3.8 K) and lead (~ 6 K) were superconducting.
Dreams of big magnets (almost) without losses. December 1913: a big disappointment, the resistance came back in a few tens of mT (a few 100 Gauss).
Were the Planck vibrators responsible? No measurable isotope effect of Pb.

Spring and early summer 1914: persistent current experiments.
This exciting result spread quickly and convinced even the theoreticians .

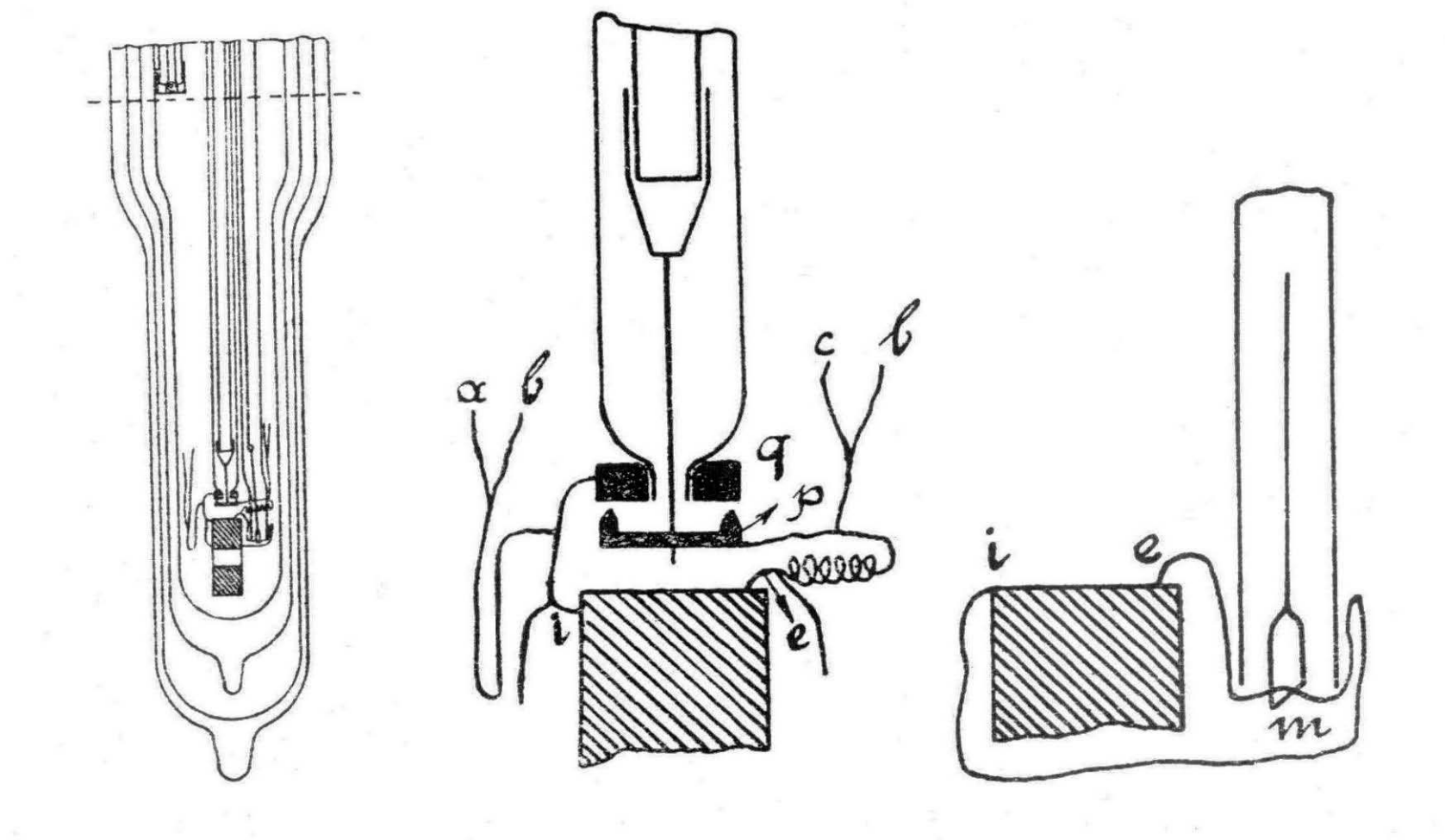
Then Wold War 1 broke out and experiments were discontinued until the early 1920's.







The persistent current experiments of 1914 finally convinced the theoretical



The first (mechanical) persistent mode switch and

a cutting device (1914)