Dr. H. Kamerlingh Onnes. "The liquefaction of helium."

§ 1. Method. As a first step on the road towards the liquefaction of helium the theory of van der Waals indicated the determination of its isotherms, particularly for the temperatures which are to be attained by means of liquid hydrogen. From the isotherms the critical quantities may be calculated, as van der Waals did in his Thesis for the Doctorate among others for the permanent gases of Faraday, which had not yet been made liquid then, either by first determining $a$ and $b$, or by applying the law of the corresponding states. Led by the considerations of Comm. No. 23 (Jan. 1896)¹ and by the aid of the critical quantities the conditions for the liquefaction of the examined gas may be found by starting from another gas with the same number of atoms in the molecule, which has been made liquid in a certain apparatus. By a corresponding process in an apparatus of the same form and of corresponding dimensions the examined gas may be made liquid.

The Joule-Kelvin effect, which plays such an important part in the liquefaction of gases whose critical temperature lies below the lowest temperature down to which we can permanently cool down by the aid of evaporating liquefied gases, may be calculated from the isotherms, at least if the specific heat in the gas state is not unknown, and its determination, though more lengthy than that of the isotherms, may be an important test of our measurements. If there is to be question of statical liquefaction of the gas by means of the Joule-Kelvin effect, this must at all events give a decrease of temperature at the lowest temperature already reached, which, as was

¹) Developed in view of the statical liquefaction of hydrogen and the obtaining of a permanent bath of liquid hydrogen (Comm. No. 94f) at which I was working then.
demonstrated in the above communication, will be the case to a corresponding amount for gases with the same number of atoms \(^1\) in the molecule at corresponding states, while a monatomic gas compared with a di-atomic one will be in more favourable circumstances for liquefaction (comp. also Comm. No. 66, 1900).

But the sign of the Joule-Kelvin effect under certain circumstances does not decide the question whether an experiment on the statical liquefaction of a gas will succeed. Speaking theoretically, when by the Joule-Kelvin effect at a certain temperature a decrease of temperature however slight can be effected, liquid may be obtained by an adiabatic process with a regenerator coil and expansion cock with preliminary cooling down of the gas to that temperature. But as long as we remain too near the point of inversion the Joule-Kelvin effect will have a slight value; accordingly the processes by which really gas was liquefied in a statical state with an apparatus of this kind, as those which were applied to air by Linde and Hampson, and to hydrogen by Dewar, start from a much lower reduced temperature, viz. from about half the reduced temperature at which the sign of the Joule-Kelvin effect at small densities is reversed, or more accurately from somewhat below the Boyle-point, i.e. that temperature at which the minimum of \(pv\) is found at very small densities. Experiments from which could be derived at how much higher reduced temperature the process still succeeds with monatomic gases are lacking. So according to the above theorem it is practically the question whether the lowest temperature at our disposal lies below this Boyle-point \(^2\) which is to be calculated.

\(^1\) The inversion points of the effect having reference to the amount 0 and therefore being independent of the number of atoms in the molecule, are at corresponding states, and the inversion point for small densities is at corresponding temperature for all gases as far as they obey the law of corresponding states. This is easily deduced from the considerations of Comm. No. 23.

\(^2\) The Boyle-point, as well as the Joule-Kelvin-inversion-point for small densities is a corresponding temperature and both are therefore theoretically proportional. In the present question it is better to refer to the Boyle-point than to the Joule-Kelvin-inversion-point, as between these two points association or any other deviation of the law of corresponding states occurring at lower temperatures can begin.