Hydrogen permeation through a stainless steel membrane at small pressures

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Stainless steel is by far the most important constructional material for UHV systems. It is aligned into a group of metals with positive heat of solution as its pure constituents: iron, nickel and chromium. Hydrogen interaction with these metals was studied in the past extensively from the fundamental point of view by several experimental methods. Among these, hydrogen permeation through a metal membrane at low upstream pressure is still a good method to verify many theoretical models. The kinetics is supposed to be limited primarily by the diffusion process and further suppressed by surface reactions. In both cases, a very low concentration of dissolved hydrogen is assumed to persist in the bulk at steady conditions.

In a twelve month experiment, we obtained interesting data that allow us to present a substantially different picture of the permeation process at the atomic level at a very low upstream pressure. A stainless steel membrane was designed as a small cell (V=125 cm^3, A=460 cm^2) with the ability to measure the pressure by a spinning rotor gauge at stable temperatures: 25°C, 32°C, 42°C and 55°C. The initial pressure p(25°C)=2.6x10^{-4} mbar in the cell decreased slowly and asymptotically approached a value, determined by the set temperature. At a temperature change, the sorption and de-sorption kinetics near the equilibrium could be observed in a time frame of one day. On a month scale, a transient always led to a linear pressure decrease corresponding to a flow of the order of 10^4 molecules H_2 cm^{-2} out of the cell, recognized to be the permeation flow to the air. Finally, the cell was melted in vacuum and the released hydrogen greatly exceeded the value that was expected following the classical picture of hydrogen transport in metals. The permeation flow at low pressure is thus governed by a tiny fraction of all hydrogen presented in the bulk.