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ABSTRACT

The pressure rise in a vacuum chamber caused by the sudden release of liquid hydrogen into it was studied. Ten trials were made in which different quantities of hydrogen and different relief ports were used. The liquid, which was expanded from equilibrium conditions at 115 psia into a chamber 10 to 50 times the liquid volume, vaporized and caused a pressure rise of from 5 to 2 atmospheres absolute pressure. The exhaust from one test exploded spontaneously, and another was intentionally burned. The explosion was violent, but the intentional burn was just a big torch 40 feet long for 1.25 seconds.

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INTRODUCTION

The possibility of the sudden release of liquid hydrogen from a pressurized bubble chamber into its surrounding vacuum space, in the event of window fracture or other mechanical failure, raises questions concerning the safety of personnel and equipment in the area. Field tests were made to try to partially determine the possibility and probability of fire or explosion after the rapid release of hydrogen. The tests were also devised to concurrently test existing vent systems and provide design data for vents for the 10-inch and 72-inch liquid hydrogen bubble chambers.

APPARATUS

A sketch of the apparatus is shown in Fig. 1. The hydrogen container was a brass tank 7 inches in diameter and 13 inches long. It was suspended inside the evacuated tank by its fill tube. The hydrogen container was surrounded by a copper nitrogen-cooled heat shield which was also inside the vacuum tank. A copper-constantan thermocouple was used for measuring the heat-shield temperature. The bottom of the brass tank was closed with an aluminum foil window 4 inches in diameter and 0.0035 inch thick. A lead gasket sealed the aluminum foil to the brass.

The pressure in the vacuum tank was measured with a thermocouple vacuum gauge and a variable-capacitance-type pressure gauge. (The capacitance pressure gauge was designed by William Linlor of University of California, Radiation Laboratory, so it will be referred to as a "Linlor" gauge.) The output from the Linlor gauge was recorded with a Brush model BL202 oscillograph during the pressurizing and bursting of the foil. Several different vents were used, which will be described later.

The liquid-level indicator utilizes the phenomenon that carbon resistors increase considerably in resistance with decreasing temperature below 100°K. Since liquid is a much more effective coolant than gas at the same temperature, a pronounced step in current flow could be observed when the resistors were immersed. Ten resistors were mounted on a rod at evenly spaced distances inside the brass tank. They were connected as in the circuit schematic of Fig. 2.

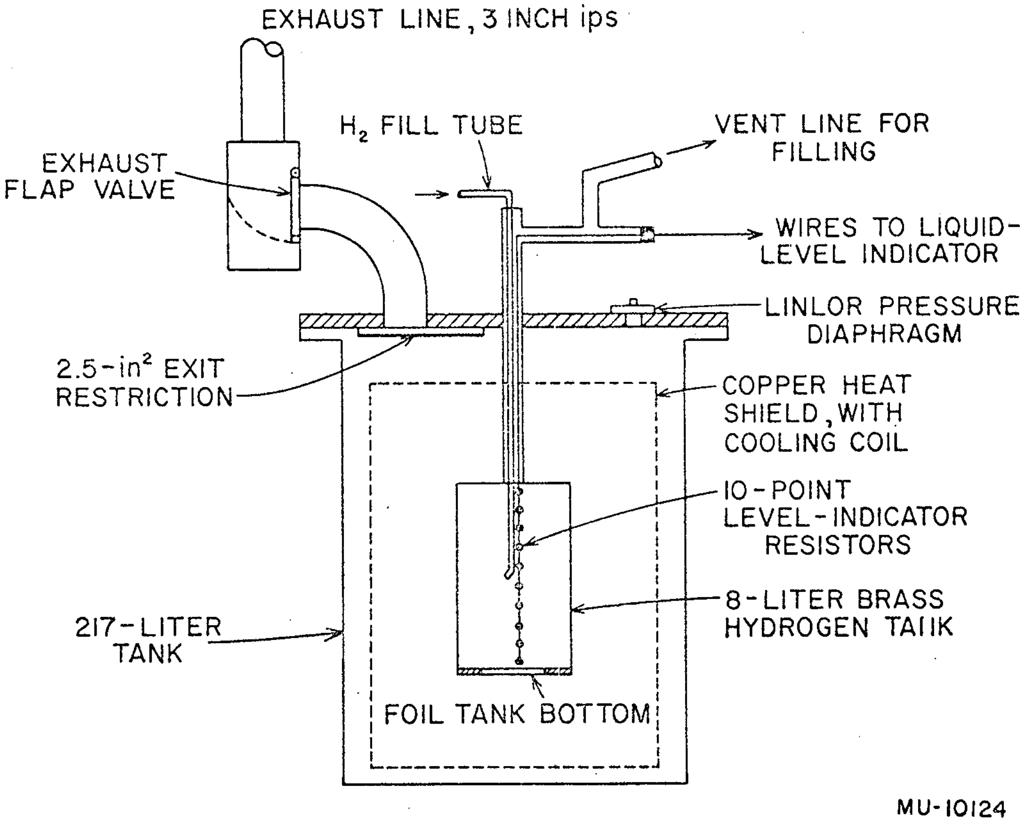

Fig. 1. Schematic section view of apparatus for testing 10 inch bubble chamber exhaust systems.

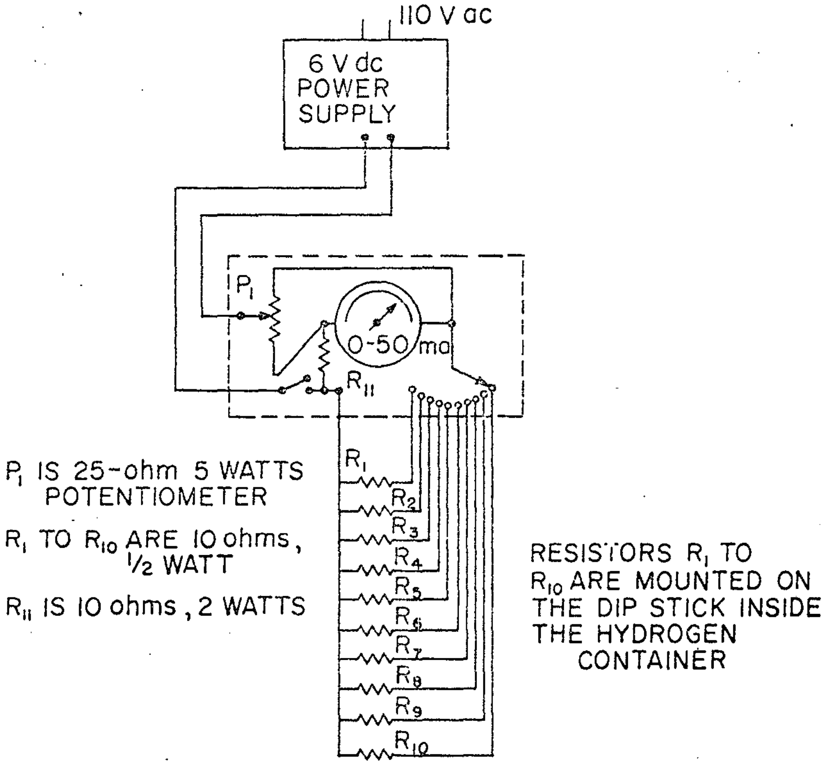

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Fig. 2. Schematic diagram for hydrogen liquid-level indicator.

RESULTS

The results are presented in Figs. 3, 4, 5, and 6, and Table I. The numbers of the curves correspond to run numbers listed in Table I. Eight trial runs with liquid nitrogen, and hydrogen runs Nos. 1 through 4 were made with the same exhaust stack arrangement. It was a 4-inch-diameter hole restricted to 2.5 square inches to approximate the actual 10-inch bubble chamber tank. The restriction was made by covering the underside of the hole with a plate, leaving an open area 5/16 inch high, and 8 inches wide. The hole was sealed with a 5-inch blowoff disk, which was inside a 6-inch-diameter pipe, 7 feet long. Figures 3 and 4 are typical pressure-rise curves obtained while using the first vent arrangement.

For the remaining six tests, an exact duplicate of the 10-inch bubble chamber vent was used. It has a swing check valve covering a 3-inch-diameter hole. Figure 1 shows the vent schematically. Tests Nos. 5 through 8 were made with six 3-foot lengths of 3-inch i.d. Airtron tubing attached to the exhaust stack to see if the tubing would withstand the pressure. After run No. 6, the heat shield was removed, and the tank was filled with material WOOD 2x4 4x4 to restrict the effective volume to 80 liters. The volume restrictions were for simulating the 10-inch bubble chamber assembly.

Tests 5 and 6 gave identical pressure-time curves even though one had twice as much hydrogen as the other. Curve (6) of Fig. 5 shows the pressure-time history of these runs.

EXPERIMENTAL PROCEDURE

The tank was assembled as shown in Fig. 1, and evacuated. When the pressure in the tank was about 100 microns, liquid nitrogen was circulated in the heat-shield cooling coils. After the shield had reached the desired temperature, the brass tank was first flushed with helium, and then filled with liquid hydrogen. When the proper quantity of hydrogen was in the brass tank, filling was stopped and the fill tube removed. All vents except a remotely operated solenoid valve were closed. When everything was secured and ready for a test, all personnel left the barricade in which the apparatus was set up, and the solenoid valve was closed. A 500-watt heater soldered to the brass tank caused the pressure of the hydrogen to rise rapidly. Before the foil bursting pressure was reached, the oscillograph was turned on for recording the

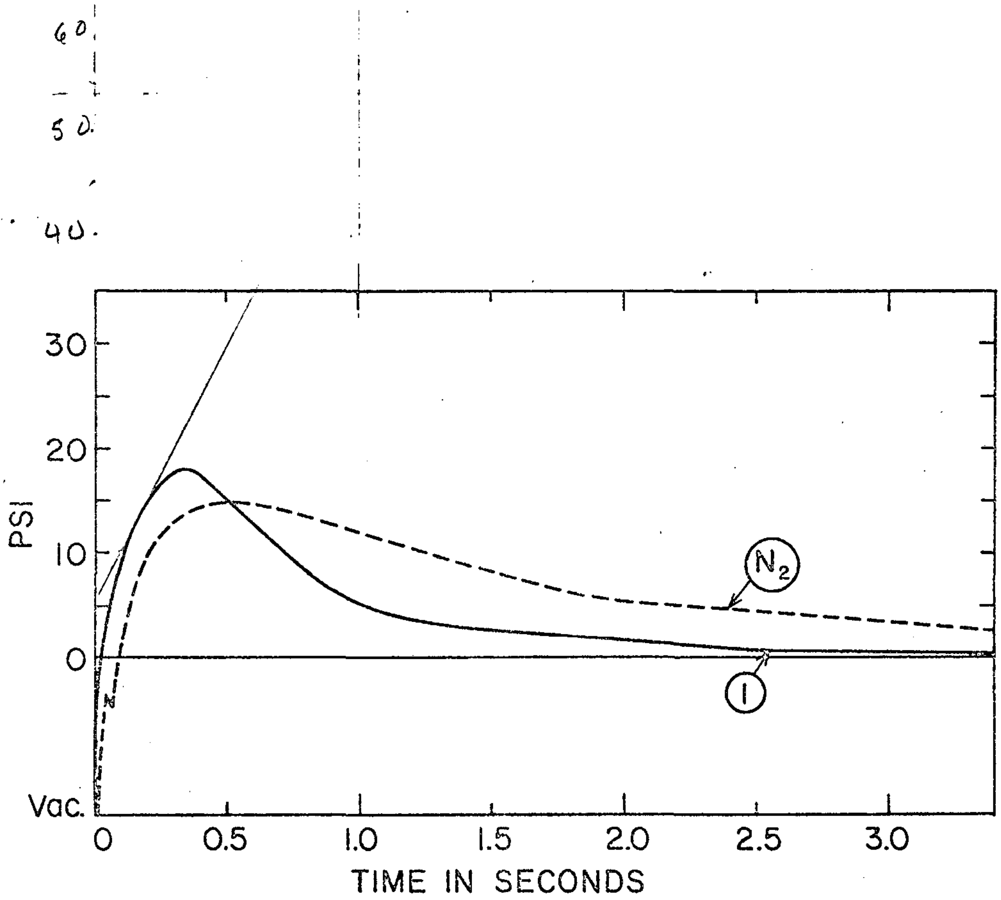

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Fig. 3. (1) Eight liters liquid hydrogen, saturated at 45 psig, blown into 217-liter tank.

(N_2) Eight liters liquid nitrogen, saturated at 45 psig, blown into 217-liter tank.

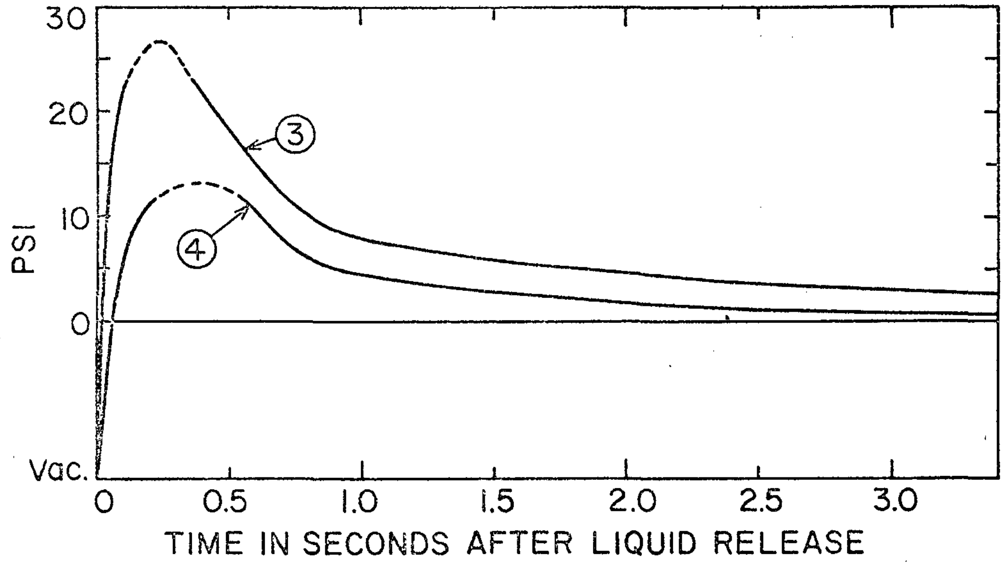

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Fig.4 (3) 7.5 liters hydrogen, saturated at 88 psig, blown into warm heat shield. Tank volume is 217 liters. 29 nv

(4) 4.2 liters hydrogen, saturated at 50 psig, blown into -125°C heat shield. Tank volume is 217 liters. 52 rv

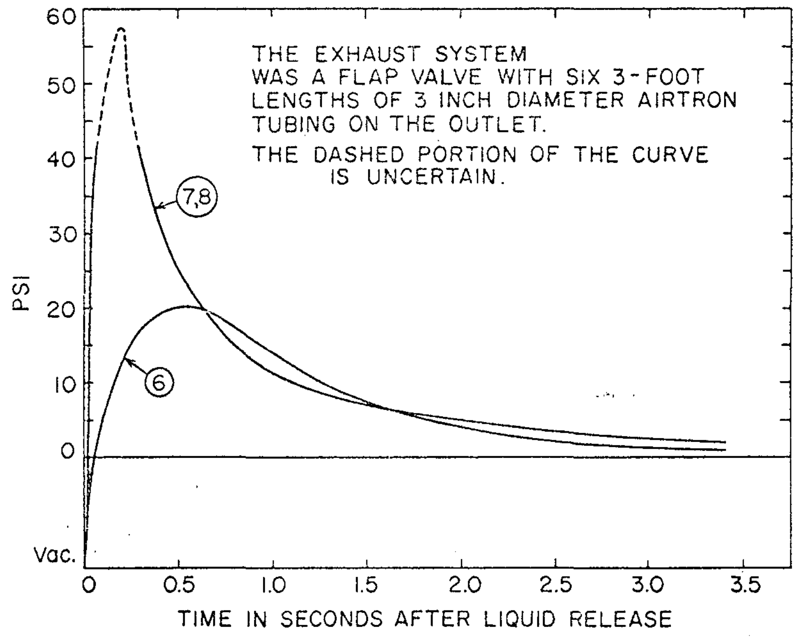

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Fig. 5. (7, 8) 5.5 liters liquid hydrogen, saturated at 100 psig, blown into 80-liter tank. No heat shield was used.

14.rv

(6) 8 liters liquid hydrogen, saturated at 110 psig, blown into 217-liter tank. Heat shield was at -195°C.

The exhaust system was a flap valve with six 3-foot lengths of 3 inch-diameter airtron tubing on the outlet. The dashed protion of the curve is uncertain.

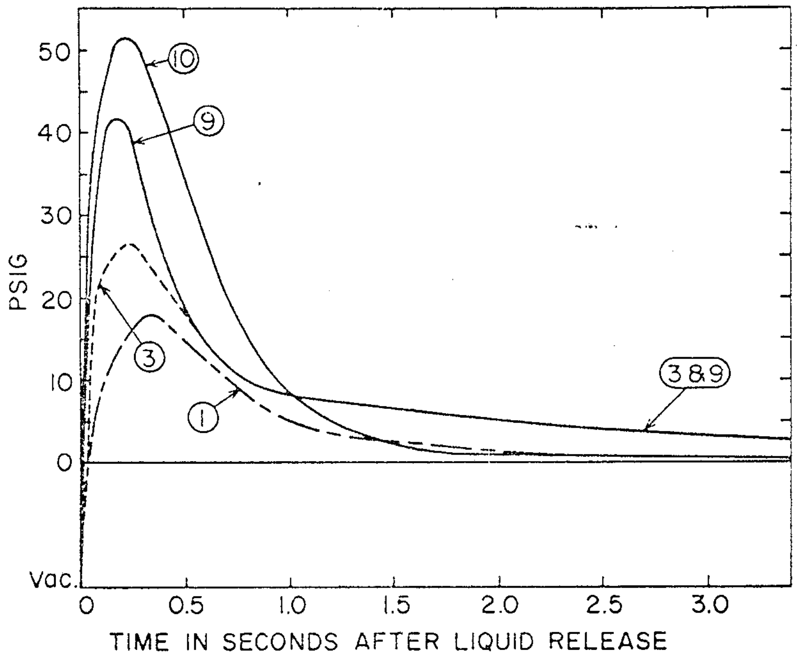

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Fig. 6. (10) 5 liters liquid hydrogen, saturated at 100 psig, released in 80-liter tank. Forty-three feet of 2-inch iron pipe formed the vent. No heat shield was used.

(9) Same as (10) except 7 liters of hydrogen were used, and the tank had a 3-foot vent line.

(3) 7.5 liters liquid hydrogen, saturated at 88 psig, released in 217-liter tank. A short, large-diameter vent line was used. The heat shield was 20°C.

Table I

Run No.	Tank volume (liters)	Heat shield. °C	Exhaust condition	Foil burst (psig.)	Liters of liquid hydrogen	Tank Vol. / H_2 vol.	Rate of rise (psi/sec)	Maximum Pressure	Decay time const.(second)	Remarks
1	217	-100	6" dia x 7' pipe	45	8	27	110	18	0.5	Very much like nitrogen
2	217	-195	6" dia x 7'	100	7	31	110	18	0.7	Very much like nitrogen
3	217	20	6" dia x 7'	88	7.5	29	350	est. 26	est. 0.4	Amplifier saturated at 22 psi so exact pressure is not known.
4	217	-125	6" dia x 7' pipe	50	4.2	51	140	est. 13	est. 0.4	Amplifier saturated at 12 psi.
5	217	-195	Vent used on 10' Bub. Chamb. 3' Flap valve.	110	4	54	90	21	1.0	No Explosion. Support blown over by exhaust.
6	217	-195	Six 3' lengths 3' -diam. Airtron flexible hose.	110	8	27	72	21	0.9	The Airtron hose knotted as it cooled from the liquid hydrogen.
7	80	20	Same as 5 and 6	100	5.3	15	1100	est. 57	est. 0.4	Amplifier saturated at 30 psi. 2 Airtron joints blew apart, followed by an explosion.
8	80	20	Same as 5 and 6	100	6	13	1000	est. 57	est. 0.5	Amplifier saturated at 45 psi. Airtron joints blew apart. No. explosion.
9	80	20	3" Flap vent + 3' of 3" pipe with elbow.	90	7	$11\frac{1}{2}$	370	41	0.4	A 15-kv spark at exhaust lighted the gas, which burned in a 30-foot flash torch.
10	80	20	Same as No. 9 with 43' of 2" pipe added	100	5	16	450	52	0.5	The exhaust stream missed the spark and gas didn't burn. It blew 50 feet straight up.

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pressure rise from the burst of expanding hydrogen.

After the burst, the tank was flushed with helium, and then disassembled.

Runs Nos. 7 and 8 were identical in every respect except one. About a second after the venting of run No. 7, there was an explosion. There was no explosion after run No. 8. The pressure curves are plotted as curve (7, 8) on Fig. 5. The peak pressure is unknown because the recorder was set for 42 psig maximum at the time.

Tests Nos. 9 and 10 were made to compare vent-line restrictions, and to observe the fire from an intentionally ignited exhaust. Figure 6 shows how 43 feet of 2-inch pipe increases the tank pressure over that in a short 3-inch pipe. Curve (3) can be compared to curve (9) to give an idea about changes in vacuum-to-liquid ratios.

DISCUSSION

Little needs to be added to Table I except that the tests were conducted primarily to determine whether the 10-inch bubble chamber vent design was satisfactory, and if the possibility of an explosion during venting was certain or remote. A little additional information was obtained about vent lines, but not enough for extrapolating to much different sizes of containers. It is also important to keep in mind that the conditions of the test do not exactly duplicate those that would be found around a bubble chamber. In many of the runs, it was impossible to provide a cold radiation shield, so the tests were run with the tank interior warm. We believe that a warm tank interior increases the maximum pressure about 30% above the maximum pressure that would result if a shield at liquid nitrogen temperature were used.

When a quantity of saturated liquid under pressure is released into an evacuated tank, larger in volume than the original liquid volume, some or all of the liquid "flashes" into vapor at a new equilibrium pressure. The pressures due to flash alone were calculated. The process is one of constant internal energy, which has been approximated by assuming constant enthalpy. The assumption overlooks the pv/J heat, which in this case would tend to raise the pressures a maximum of 0.1 atmosphere above those obtained by assuming constant enthalpy. Figure 7 shows the constant enthalpy lines for the cases starting with saturated liquid at 4, 6, 8, and 10 atmospheres and expanding up to 15 times. As an example, consider starting at a volume of 1 with 8 atmospheres pressure, and expanding to a volume of 12.5 The

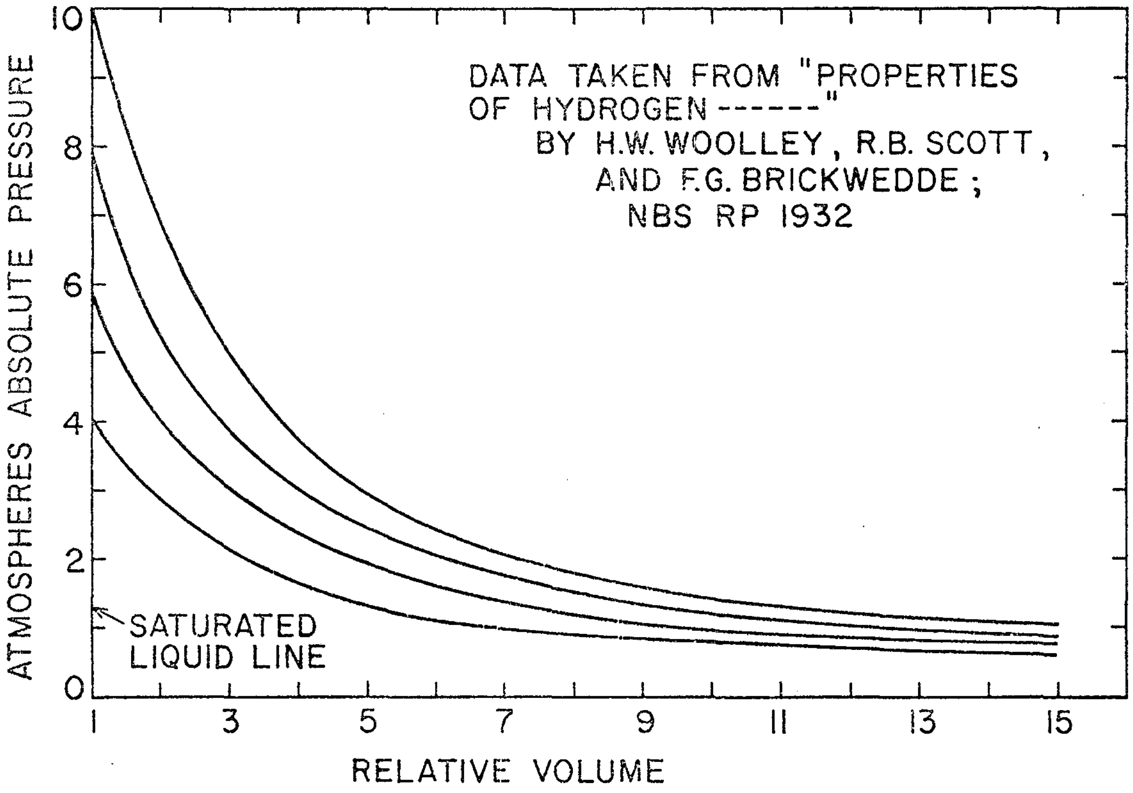

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Fig. 7. Relative volume.

final pressure would be about 1 atmosphere because of the internal energy of the liquid. It is evident, then, that the 4- or 5-atmosphere peak pressures observed had to be caused mostly by heat transfer to the liquid and gas. It is also apparent that heat transfer takes place so rapidly in hydrogen that no difference is noticeable in the slope of the curves for distinguishing between pressure rise caused by flash and subsequent heat transfer.

The one spontaneous explosion is difficult if not impossible to explain. Everything in the area, including the vent line, was securely grounded with heavy copper braid. The explosion occurred shortly after a distinct "whoosh" was heard from the venting. A guess as to the cause is a static discharge, or less likely, a spark caused by the flailing, broken, vent tube. Observers 250 feet away and not behind any obstructions felt the shock wave. The only damage done by the explosion was the melting of the insulation on some wiring, and the burning of some rags in the immediate area of the explosion.

The intentional ignition of the discharged gas was very impressive. A motion picture was taken of the fire. The flame came out about forty feet from the vent, and lasted only 1.25 seconds from start to finish. The heat was felt by the photographer 100 feet away. Impressive as the flame was, the noise was very small compared to the blast that ignited spontaneously. Some frames from the movie are shown in Fig. 8.

CONCLUSIONS AND RECOMMENDATIONS

From the foregoing tests it can be concluded that in the event of the sudden release of liquid hydrogen into a vacuum chamber, the resulting rate of pressure rise and the maximum pressure depend on the ratio of the vacuum space to liquid volume, the temperature of the vacuum tank and heat shield, the size of the vent, and the restrictions in the vent line. When liquid is released, as in all the tests, the temperature of the heat shield has a relatively small effect on the maximum pressure and rate of rise. The larger the ratio of the vacuum space to the liquid volume, the slower the rate of rise well be, and the lower the maximum pressure will be.

The largest practical blowoff disk and vent line should be used with liquid hydrogen bubble-chamber vacuum systems. In addition to being large and unrestricted, the vents should be located as near the bottom of the chamber as possible in order that liquid can blow out the vent before it has time to vaporize inside the vessel. From the results of the tests just completed, it

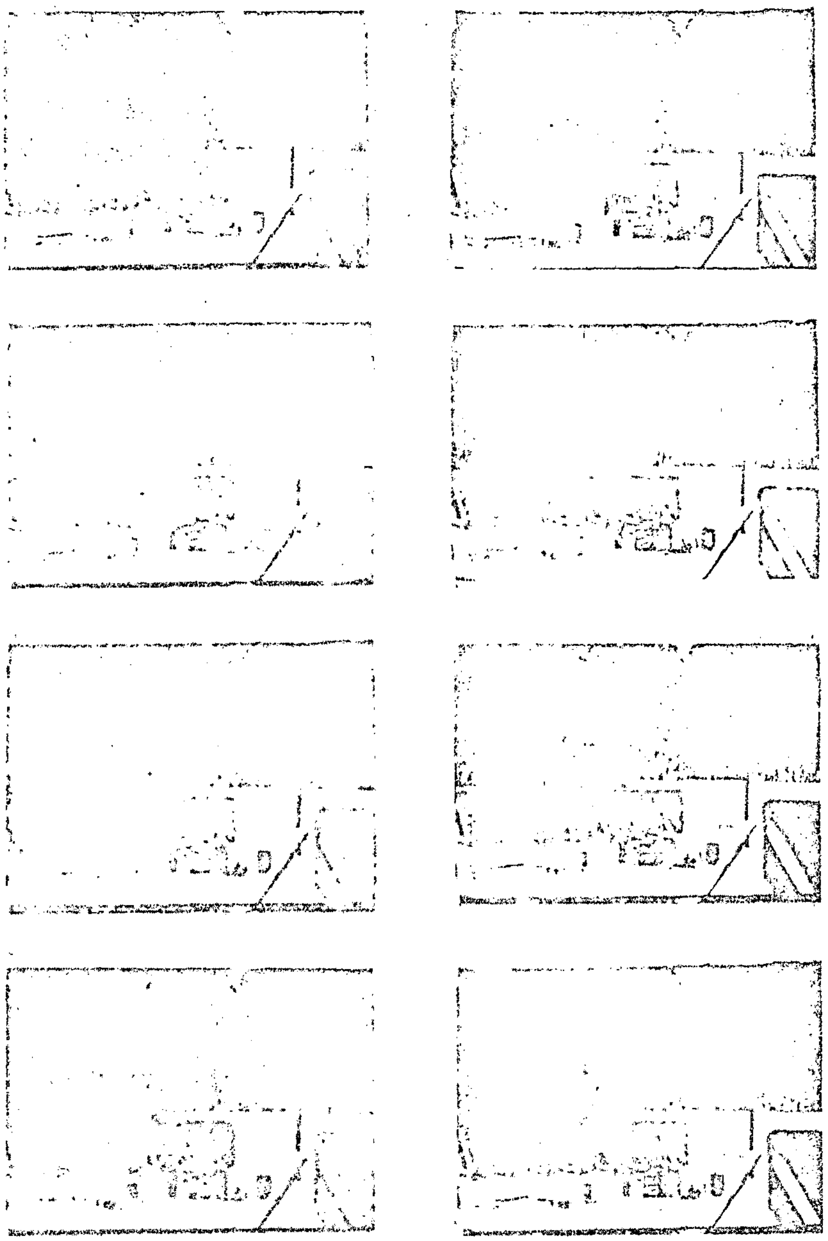

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Fig. 8. Burning of hydrogen during sudden venting.

appears that a pressure rise of about 4 to 5 atmospheres absolute pressure is possible for the 10-inch bubble chamber as now designed if a 3-inch ips vent line is used. The whole system, including every section of the vent line, has to be able to withstand pressures of this magnitude.

In the 72-inch-bubble chamber the vacuum-to-liquid ratio is about 13 as compared to 11 for the 10-inch chamber. Since these are of the same order of magnitude, pressures of the same order might be expected with comparable vents. Scaling up the 2-inch vent used in our tests (assuming equal stack velocities) gives a vent line about 13 inches in diameter for the 72-inch bubble chamber. Since the 72-inch chamber has much liquid hydrogen temperature shielding around it, the expected pressures are lower than we have observed. In spite of these considerations, a large vent such as one 12-inch-diameter line or two 9-inch-diameter vents is recommended.

Although too few tests were run to get statistics on the probability of an explosion under given weather conditions, the only way of being certain that an explosion cannot occur is to burn the hydrogen while it is venting, before it can form an explosive mixture. A hydrogen vent line should not be aimed at anything flammable, and it should be kept free of moisture that might freeze and plug it.

ACKNOWLEDGMENTS

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