GENERAL PHYSICS

I. MOLECULAR BEAMS*

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A. SEARCH FOR CONTINUOUSLY CREATED HYDROGEN

1. Introduction

It is now twenty years since Bondi and Gold introduced the steady-state theory of the universe and the attendant continuous creation principle. Although this theory was considerably elaborated by Hoyle and co-workers it is no longer popular as increasing observational evidence favors the so-called big bang hypothesis. In the original form of the steady-state theory the creation rate was proportional to the proper volume and took place at such a rate that the average density of matter in the universe should not undergo secular change, despite the expansion determined from the red-shift. This rate is easily shown to be $3\rho_o/T$ where ρ_o is the mean density of matter in the universe and $1/T$ is Hubble's constant, 2.4×10^{-18} sec^{-1}. Taking $\rho_o = 2 \times 10^{-29}$ grams/cc this rate works out to be 1.4×10^{-46} grams/cm^3/sec, or approximately 1 hydrogen atom mass/cm^3 created every 5×10^{14} years. As Bondi has pointed out this is "utterly impossible to observe directly." If one makes the assumption, however, that the rate of creation is proportional to the amount of matter present, then the above rate becomes 7.2×10^{-18} grams/gram/sec. The rate of creation in intergalactic space where most of the mass of the universe may be would proceed about as before even with this matter proportional creation, but in dense regions such as stars, the creation process would lead to a doubling of the stellar mass every 3×10^9 years in disagreement with other deductions concerning the nature of the universe. A further difficulty is that the creation process must not generate a significant amount of electromagnetic radiation in violation of present observational limits. This seems to rule out charged particle creation or even excited atoms. Most of the matter in the universe (90%) is neutral hydrogen.

Let us assume that the matter created is atomic hydrogen in its ground state, and that the rate of creation is proportional to the number of nucleons (or nuclei) present. Let us inquire what the consequences of these assumptions are, first, locally, and then

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for increasingly remote and less well-known systems. Outgassing rates being as they are, it does not seem likely that high-vacuum experts would have had any trouble, especially considering how soluble hydrogen is in solid matter. Large distilling systems such as mercury cycle turbines have too much contamination to make it possible to draw any conclusion. The hydrogen generated within the earth would probably react before it emerged and, in any case, the amount of hydrogen is not much larger than the amount of helium that is known to be generated as a result of radioactive decay. The sun would supply its own fusion fuel by such a continuation creation process. There does not seem to be a situation that unambiguously rules out the consequences of these two assumptions. We therefore planned and carried out an experiment and obtained a null result, as might have been expected.

2. Experiment

If hydrogen were to be created in matter, proportional to the bulk mass of that matter, the problem of how to trap and separate the hydrogen from the matter would arise. This problem can be solved by the simple process of boiling and freezing.

Mercury was chosen as the matter to watch for the creation of hydrogen. It can be easily frozen to trap any gases formed within; subsequently, it can be boiled to expel the trapped gas. It also has a high density, and thus only moderate amounts need be handled.

To test the expelled gases, we decided to use a mass spectrometer. The amount of hydrogen expected was 4×10^{-11} Torr/sec. This is on the basis of 0.6 liter volume, 1 mole Hg, and complete liberation in boiling.

3. Apparatus

The apparatus is shown in Fig. I-1. Mercury was placed in one leg of an inverted vycor y-tube (2). A removable nichrome coil (1) was placed around that leg. A dewar (C) with dry ice and acetone was placed on the other leg to condense the mercury during boiling. After a boil-over the coil and dewar could be exchanged so that the mercury could again be boiled. The stem of the y-tube had 3 ball valves and a liquid nitrogen trap. These ball valves were moderately effective seals during boiling. Any Hg or H_2O vapor that passed them was trapped by the liquid N_2 trap. It was necessary in the operation of the mass spectrometer to keep the amount of extraneous gases minimum. During the boiling only hydrogen, oxygen, nitrogen, and helium could pass from the y-tube to the T joint (6). With this arrangement the total pressure at the omegatron mass spectrometer was always below 4×10^{-6} Torr, even during boiling. One side of the T-joint led to a Sylvania omegatron mass spectrometer tube (7). The other side led to both the sample gas inlet system (8) and the main vacuum system.

The sample gas inlet system was separated from the T-joint by two vacuum valves (9) and (10) which allowed small amounts of different pure gases to be leaked in. This

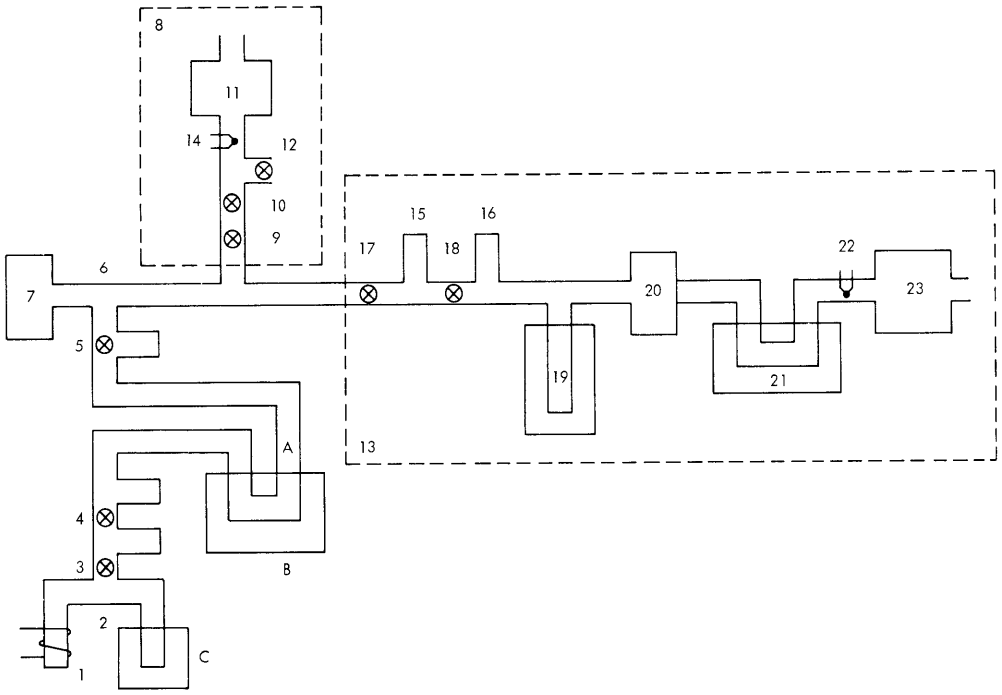

Fig. I-1. Vacuum system.

was for calibration purposes. There were also a forepump (11), a thermocouple vacuum gauge (14) and an inlet valve (12) in the sample gas inlet system. The pressure in this system was usually 30-35 μ.

The main vacuum system had 2 ion gauges (15) and (16), 2 valves (17) and (18), liquid nitrogen trap (19), diffusion pump (20), dry-ice trap (21), thermocouple vacuum gauge (22), and forepump (23). The main vacuum system could keep the entire system at 1×10^{-8} Torr.

4. Measurements

The ion gauge was calibrated by leaking known volumes of nitrogen gas into the apparatus and the omegatron was calibrated in two ways: First, by correlating the principal peaks of the mass spectrum, N_2^+ and O_2^+, with the total pressure, and second, by admitting known amounts of H_2 into the apparatus and observing the response of the omegatron. These calibrations were found to agree with the calculated sensitivity within a factor of two. The conclusion is that 5×10^{-10} Torr of H_2 produces 0.02 V input to the Moseley recorder. Because the omegatron dissociates H_2 into H^+ ions, 2 peaks should be observed, but since the ratio of these peaks was reliably found to be $H_2^+/H^+ = 1.39$, it was sufficient and more convenient to observe only the H_2 peak. Since the calibration was carried out in terms of the H_2^+ peak, no correction was necessary. The ion pump action of the omegatron was entirely negligible for the amount of gas observed.

5. Amount of Hydrogen Expected

As we have stated, we expect 1 hydrogen atom/1.4×10^{17} nucleons or per 1.4×10^{17} nuclei. There is 1 mole of Hg (±5%) in the apparatus. This would create 4×10^{8} H_2 molecules/sec. In the volume of the apparatus, 558 cm^3, this hydrogen, if completely liberated from the Hg, would cause a pressure rise of 2×10^{-11} Torr/sec.

6. Hydrogen Accumulation Attributable to Processes Other than Continuous Creation

There are numerous ways that hydrogen can get into the y-tube assembly, but while valves (17) and (18) are open the accumulation (i.e., hydrogen influx versus pumping speed) is negligible. Once the valves are closed, the hydrogen accumulation becomes noticeable (even when nothing is being heated). The processes that could account for this are diffusion, leakage, and outgassing of walls.

The system was leak-tested with helium at room temperature. After the leaks were sealed the maximum leakage rate was approximately 5×10^{3} He atoms/sec. This would account for a pressure rise of 7×10^{-13} Torr in 1 hour. Since the maximum time during which the valves were closed in a run was 1 hr, this effect was negligible. Similarly, diffusion through the vycor at room temperature can be ignored.

But we noted that if the valves were closed for 1 hr, a pressure of 4×10^{-10} Torr did build up which must have been due to outgassing. When the mercuryless side was heated by the nichrome coil, or the entire glass y-tube structure was heated by heating tape, the hydrogen accumulation was greater. It varied as a function of temperature. For heating-tape temperature of 150°C and coil temperature of approximately 540°C the hydrogen accumulation was around 10^{-9}. A figure of 0.4×10^{-9} Torr was used as a reasonable correction for outgassing.

7. Hydrogen Accumulation during Boil-overs

During most of the runs the hydrogen observed was at least 2000 (10) times less than theory predicted. This amount in the later runs was just that to be expected from outgassing of the apparatus.

8. Solubility of Hydrogen in Mercury

To test the ease with which H_2 could be got out of mercury, it was decided to dissolve some and try to distill it out. The Hg was boiled in 1 atm of H_2. It was subsequently boiled 6 times. The amount of H_2 that came out during the first three runs gave a pressure greater than 3×10^{-7} Torr. This saturated the integrator amplifier. The walls of the y-tube were heated for 6 hr, at 200°C to outgas them, and then 3 more runs were made. The pressure from the last run was 4×10^{-10} Torr. Thus we arrived at the same situation as before the hydrogen was dissolved.

9. Results

The results of 13 runs are tabulated in Table I-1. Δt is the time to the nearest hour since the mercury was last distilled. The pressure in Torr observed after distilling is

Table I-1. Data on mercury distillation.

Run No.	Date (1968)	Δt (hours)	Pressure H_2 Observed (Torr)	Corrected Pressure	Pressure Predicted	Comments
1	4/25	–	3×10^{-9}	3.5×10^{-9}	–	Hg boiled a week before this
2	4/26	23	3×10^{-9}	3.5×10^{-9}	1.7×10^{-6}	
3	4/26	1	1×10^{-9}	0.8×10^{-9}	0.07×10^{-6}	
4	4/27	18	2×10^{-9}	2.2×10^{-9}	1.3×10^{-6}	
5	4/27	8	1×10^{-9}	0.8×10^{-9}	0.6×10^{-6}	
6	4/29	40	1.5×10^{-9}	1.7×10^{-9}	2.9×10^{-6}	
7	5/2	72	$16. \times 10^{-9}$	$22. \times 10^{-9}$	5.2×10^{-6}	Leak
8	5/6	105	4×10^{-9}	5.0×10^{-9}	7.6×10^{-6}	Hg getting cleaner
9	5/8	40	1.2×10^{-9}	1.0×10^{-9}	2.9×10^{-6}	
10	5/9	30	$.4 \times 10^{-9}$	0	2.2×10^{-6}	
11	5/10	24	$.6 \times 10^{-9}$	0.2×10^{-9}	1.7×10^{-6}	
12	5/11	25	$.3 \times 10^{-9}$	0	1.8×10^{-6}	
13	5/12	24	$.5 \times 10^{-10}$	0.1×10^{-9}	1.7×10^{-6}	

tabulated in column 3 from which we subtract a constant 0.4×10^{-9} Torr as a measure of outgassing, to get the corrected pressure that is to be compared with the predicted pressure calculated from the creation rate as discussed above. We take the average of the last four runs during which the mercury was becoming continually purified. The average ratio of predicted-to-observed pressure is 2×10^{4} or less. We conclude, therefore, that under the conditions of this experiment we have not observed any hydrogen

that could not be accounted for by outgassing of the apparatus, and which in absolute amount is approximately 10,000 times less than that predicted by the hypothesis based on the assumptions stated above. If the creation rate were proportional to the number of nuclei rather than nucleons, the ratios quoted above would be approximately 10^2.

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B. THEORY OF METALLIC ADSORPTION ON REAL METAL SURFACES

[This report summarizes a paper that was presented at the Fourth International Symposium on "The Structure and Chemistry of Solid Surfaces," University of California, Berkeley, June 19-21, 1968.]

The theory of an ionic impurity at a metal surface has been developed. As the virtual impurity level associated with the unperturbed atomic state overlaps the occupied portion of the metal conduction band, screening of the impurity occurs by the formation of virtual bound states, and a metallic bond is formed. If, on the other hand, a net effective charge exists at the impurity center, there is screening of the impurity through polarization effects, and an effective ionic bond is formed. In the limit of large ion-metal separations, these polarization effects reduce to classical image charges. In both types of screening, the net charge configuration can be expressed in a multipole expansion. The dipole moments of such configurations, with all types of screening considered, have been calculated as a function of impurity-surface separation, conduction-band electron density, impurity parameters, and crystal work function. Numerical results for sodium, potassium, and cesium impurities on various crystallographic faces of several metals have been calculated and compared with existing experimentally determined values obtained from work-function data.

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