A REACTIVE MODIFICATION OF HYDROGEN PRODUCED BY ALPHA–RADIATION.

By WILLIAM DUANE AND GERALD L. WENDT.

IT is well known that the rays from radio-active substances produce chemical reactions. They decompose water, whether the water is in the liquid, solid or gaseous phase; they transform oxygen into ozone; they split up hydrogen sulphide and ammonia into their elements; they form hydrochloric and hydrobromic acid and ammonia from their elements, etc.

The investigations described in the following pages were undertaken in order to find out whether the rays produce an appreciable chemical change in the purest hydrogen obtainable.

SOURCES OF RADIATION.

The most suitable source of radiation for the purpose appeared to be a small "alpha-ray bulb" consisting of a glass sphere .5 mm. in diameter, filled with radium emanation. If the walls of the sphere are thin enough a large fraction of the alpha-ray energy passes through them, producing an intense radiation in its immediate neighborhood. Such a source also has the advantage that the radioactive substance does not come into contact with the chemical reagents under investigation.

The bulbs used in our experiments were filled in the laboratories of the Harvard Cancer Commission by a method previously described.[1] They usually contained about 35 millicuries of emanation.

PURIFICATION OF THE HYDROGEN.

The hydrogen was prepared in the familiar zinc amalgam-platinum cell with eight per cent. hydrochloric acid as the electrolyte. This type of cell has been found to deliver very pure hydrogen in numerous atomic weight determinations in the Harvard laboratories. Merck's purest zinc bars were etched with hydrochloric acid, washed and immersed in mercury, which had been washed in mercurous nitrate and redistilled in air and in hydrogen. The amalgam formed the bottom

[1] PHYS. REV., 5, 311, 1915.

layer in a two-liter ground-glass stoppered Wolff bottle (*A*, Fig. 1)
electrical connection being made through a tube extending to the bottom
of the generator. The cathode was a sheet of carefully cleaned platinum
about 100 square centimeters in a r e a
which had been coated with a deposit
of platinum black by the electrolysis
of a solution of chlor-p l a t i n i c acid.
The hydrochloric acid was prepared by
distillation of a twenty per cent. solu-
tion of the purest commercial acid and
subsequent dilution of the purer frac-
tions of the d i s t i l l a t e with distilled
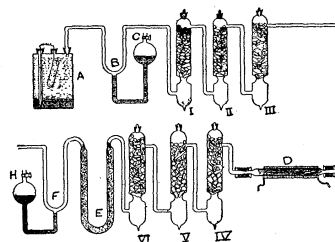water.

Fig. 1.

In order to prevent contamination of the hydrogen by organic ma-
terials, we avoided the use of stop-cock grease throughout. The stoppers
of the generator and of the purifying towers were surrounded by short
lengths of wide rubber tubing, which permitted the entire stopper to
be covered with mercury. This arrangement proved to be sufficiently
gas-tight. In place of stop-cocks, we substituted the U-tubes *B* and *F*
(Fig. 1) filled with mercury, which could be opened by applying suction
at *C* and *H*. The hydrogen from the generator passed first through
three Emmerling towers filled with lumps of potassium hydroxide which
had been fused with a little potassium permangate to remove organic
matter. This freed the gas from acid spray, chlorine, carbon dioxide
and a large part of its water vapor. Air, which had been dissolved in
the acid solution, was next removed by passing the hydrogen through a
hard glass tube filled with clean asbestos fibres which had been soaked
in chlorplatinic acid solution and ignited to impregnate them with
platinum black. The tube was wound with nichrome ribbon covered
with asbestos and maintained at a red heat by an electric current. The
joints between the hard glass and the soft glass of the rest of the system
were ground to a close fit and surrounded by a jacket of glass filled with
mercury. This again gave a gas-tight joint without the use of grease.
(See *D* in Fig. 1.) The gas was again dried in three towers of potassium
hydroxide lumps and passed finally through the U-tube *E*, about eighteen
inches in length and filled with phosphorus pentoxide, which removed
the remaining water vapor.

The hydrogen after this treatment could have been contaminated
only with nitrogen and the rare gases which might have been dissolved
in the acid of the generator. To remove even these as far as possible,
we exhausted the whole system by means of a water aspirator to very

close to the vapor pressure of the acid solution. Hydrogen was then generated until the pressure reached atmospheric value. After three repetitions of this exhaustion, the entire system was swept out by its own hydrogen for forty hours before the commencement of the actual experiment.

As a further precaution against some unknown impurity in this hydrogen, we made a few experiments with hydrogen derived from the electrolysis of a weak solution of potassium hydroxide containing a little barium hydroxide to remove carbonate. The solution was in a cylindrical vessel and a wide ring of heavy platinum wire formed the anode. Within this hung a smaller glass cylinder tapering at the top and sealed to a glass tube which in turn was sealed to the U-tube in place of the Wolff bottle, A. A strip of platinum gauze sealed into the inner cylinder formed the cathode. The cylinder extended ten inches below the level of the cathode and anode in order to prevent contamination by the oxygen liberated at the anode. This hydrogen was purified exactly as in the first case, except that the system could not be exhausted.

We used still another variety of hydrogen, namely the electrolytic hydrogen as supplied compressed in tanks by the International Oxygen Company. A short piece of rubber tubing connected the tank to the purifying system used before. The accumulation of water in the fourth Emmerling tower in this case revealed some impurity of oxygen.

The Chemical Activity Imparted by the Rays.

In the first experiments undertaken we attempted to measure the contraction in volume which should ensue, if H_2 is converted into H_3. A definite though small contraction appeared. On account of the size of the effect a study of the chemical properties of the gas by some dynamic method seemed more promising. In point of fact, the chemical properties as revealed by the dynamic method are important in their bearing on the observed volume change, so that the latter will be described after the reactions.

In the first experiment a bulb of about 4 cm. diameter was coated on the interior with a thin layer of sulphur by distilling flowers of sulphur into it in a vacuum. The bulb was similar to the bulb B of Fig. 2, and the bulb A, containing the radium emanation, was similarly placed at the center of B. Pure hydrogen entered through a side tube and after passing slowly through the field of radiation passed out through a glass tube, which dipped into a weak solution of lead acetate, and which held in its mouth a strip of filter paper kept moistened by the solution. A block of lead was so placed that only a minute quantity of gamma

radiation from the emanation could reach the test paper or the acetate solution. Wourtzel has reported the decomposition of hydrogen sulphide by the rays, and inasmuch as ammonia, water and hydrobromic acid have been seen to be both decomposed and synthesized by the rays, it is perhaps not surprising that the lead acetate paper showed a decided blackening after the hydrogen had passed over it during one night.

This is the only reaction of a heterogeneous nature that has been reported as produced by the rays. The question arises as to whether the reaction is a consequence of the activation of the sulphur surface, or of the hydrogen, or is an effect of the actual firing of the hydrogen molecules into the sulphur by the bombardment of the alpha particles. The last mechanism is not very probable because the rays penetrate readily through hydrogen and comparatively few hydrogen molecules are given high velocities. The question is capable of ready answer. In the following experiment the bulb in which the hydrogen was radiated did not contain sulphur, and the hydrogen after emerging from it passed through a short tube containing redistilled flowers of sulphur and thence over a lead acetate paper (see Fig. 2). A block of lead protected the sulphur from the direct action of the rays. The paper was blackened even more rapidly than in the preceding experiment. Repetition of both these experiments with no change except the withdrawal of the emanation produced no blackening. Without the sulphur there is also no effect on the acetate paper.

Since the black coloration of the test paper can be due only to sulfide the evidence is conclusive that the sulphur is being reduced by some more or less stable compound, which is a stronger reducing agent than ordinary hydrogen, and which becomes active after having been intensely bombarded by alpha rays. If this compound is an impurity in the hydrogen it is difficult to imagine its nature. The reduction effect was obtained equally well with the three quite different sources of hydrogen. A number of tests were made in which the hydrogen, in addition to the above described rigorous purification, passed through a glass spiral two feet in length immersed in liquid air. Precisely the same results followed. The only gases which could have survived this purification are helium, neon, argon and nitrogen, and the acquirement of reducing properties by any of these is harder to understand than the activation of hydrogen itself. Finally whatever impurity may have been present was so very dilute that the minute fraction of it that could have been acted upon by the rays would be unable to produce effects of the magnitude observed. The evidence points unmistakably to an abnormal activity on the part of the hydrogen itself.

This does not necessarily mean that a reactive molecule is being formed. The hydrogen is subjected to a very intense ionization by the alpha rays, and though the mobility of the gaseous hydrogen ion is high, large numbers of ions undoubtedly are not yet recombined when they reach the sulphur. It is entirely possible that the observed reactivity may be due to these charged particles in the same manner that chemical activity is the distinguishing mark of the hydrogen ion in solution. To test this point we inserted a plug of glass wool between the ionization bulb and the sulphur tube. Glass wool is exceedingly efficient in filtering out ions, but in this case it had no effect on the result. This experiment indicated the presence of a real modification of hydrogen, which is chemically active. It cannot, however, be the same as Langmuir's hydrogen because the latter not only cannot exist in the presence of any considerable number of other hydrogen molecules but it is condensed completely by glass, especially in the form of wool.

To eliminate further the possibility that ions produce the observed effects a tube was inserted between the ionization bulb and the sulphur tube into which were sealed two platinum rods about four centimeters in length and a centimeter apart on opposite sides of the tube (see *F* in Fig. 2). These were connected respectively to the terminals of a battery
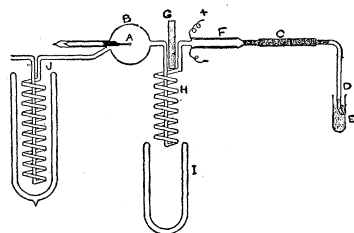

Fig. 2.

composed of two hundred very small cadmium cells, and were therefore at a difference of potential somewhat over two hundred volts. The mobility of the hydrogen ion in hydrogen is nine cms. per sec. per volt per cm., and during the time allowed for the hydrogen to pass through this tube all the ions must have been swept out of the stream of gas. Nevertheless the paper was blackened precisely as before. Later some tests were made using the large storage battery in the Jefferson Physical Laboratory, but even the application of two thousand volts produced no diminution in the chemical activity. The chemical activity, therefore, cannot be due to the presence of ions.

We are dealing, then, with a more or less stable, reactive molecule. Judging from the properties of Langmuir's hydrogen, which certainly consists of free atoms, this new form cannot be monatomic. In Langmuir's experiments the free atoms as they were liberated from solution in the tungsten or platinum filament deposited at once on the glass wall of the evacuated bulb and formed there a thin layer. It was not possible for him to obtain large quantities because the formation of

more free atoms resulted only in their recombination with others on the glass to form diatomic molecules. He did not obtain the atomic form at all unless the pressure was so low that the atoms were able to pass from the filament to the wall without encountering other molecules. On the other hand, the modification we observed is fairly stable at atmospheric pressure and it passes readily through a long plug of closely packed glass wool—facts which exclude the possibility of its being monatomic. The molecule is therefore polyatomic and larger than H_2. It will be seen that all subsequent experimental data bears out this interpretation.

An instance in point is the stability of this modification. Ozone reverts spontaneously to oxygen at the rate of about 0.6 per cent. per minute, and a polyatomic form of hydrogen would be expected to have a similar, though perhaps somewhat greater, instability. We noted early in the research that reducing the velocity of the stream of hydrogen diminished the effect on the sulphur. If more than one minute elapsed between the exposure of the hydrogen to the rays and its contact with the sulphur, results were unsatisfactory. A few special experiments established the fact that doubling this interval reduced by much more than one half the chemical action.

The fact that this modification of hydrogen has a much higher boiling point than that of ordinary hydrogen, being condensed even at the temperature of liquid air, accords with the conception of a polyatomic molecule. Fig. 2 illustrates the apparatus designed to investigate this point. The hydrogen on emerging from the purifying system as pictured in Fig. 1 passed through the glass spiral J, two feet in length, which was kept completely immersed in liquid air throughout the experiment in order to remove any condensible impurity. Passing into the bulb B, the hydrogen was exposed to the alpha rays from the emanation contained in the small bulb A. It passed then through the spiral H, through an electrostatic field of four hundred volts per centimeter in F, through a short plug of glass wool, then over the flowers of sulphur in the tube C, and finally over the strip of filter paper, D, moistened with lead acetate in E. Natural size photographs of the test papers resulting in this experiment are shown in Fig. 3. Since it is not possible to reproduce test papers from all the experiments carried out, those here presented may be taken as typical. A coloration as feeble as that in (b) was never accepted as positive evidence. (a) and (c) however are very typical tests. The parabolic trace near the center of the strips corresponds with the mouth of the glass tube where the hydrogen formed bubbles and had a longer time to react with the lead salt. The test

(*a*) was obtained by passing the hydrogen through the apparatus just as indicated in Fig. 2, for six hours. At the end of that time another paper was inserted and the Dewar bulb, *I*, filled with liquid air, was raised to cover the spiral, *H*, through which the hydrogen passed after exposure
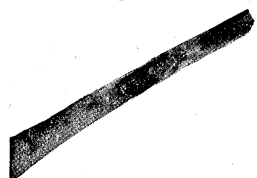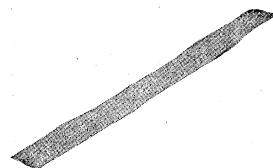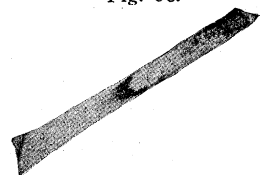
Fig. 3a.

Fig. 3b.

Fig. 3c.

Fig. 3.

to the rays but before contact with the sulphur. Nothing else was altered. In six hours the test appeared as shown in (*b*). With the Dewar bulb, *I*, lowered again a six hours' run produced the test (*c*). Especial care was taken to maintain the velocity of the hydrogen stream at twenty cubic centimeters per minute throughout the eighteen h o u r s of the experiment. Although there is a barely perceptible blackening of the second paper, the active constituent of the hydrogen has evidently been removed by the low temperature. If this is a true condensation the boiling points of H_2 and of this hydrogen are at least seventy degrees apart, and probably more. It must be noted, however, that adsorption of gases is much increased at low temperatures and that consequently the effect observed may be due to an increased selective adsorption of the active gas by the glass walls of the spiral, though this is hardly probable in view of the great excess of H_2 always present. One other interpretation of the disappearance of the activity is that the low temperature hastens the decomposition of the larger molecule into H_2, but this is inconsistent with the conceptions of kinetics.

In this test — as in every other—a blank run made without the emanation produced no blackening. *G* is a block of lead five millimeters in thickness which prevented the beta and most of the gamma radiation from reaching the sulphur or the test paper.

An attempt was made to obtain further information about the stability of the active gas by interposing between the ionization bulb and the sulphur tube a device for heating the gas to about 500° C. This consisted of 40 cm. of fine platinum wire wound spirally on a quartz rod supported by little quartz feet within a tube of soft glass sealed to the rest of the apparatus. The terminals of the platinum wire were sealed into this outer tube and connected through a rheostat with a 110-volt circuit, and thus heated to dull redness. No information could be obtained from this apparatus, however, because it was not found possible

within the available period of one minute to heat the hydrogen to the temperature of the platinum wire and thereafter cool it again to a temperature at which the ordinary hydrogen, unaided by the rays, no longer attacked the sulphur. No blank tests could be obtained that did not show some slight action of the ordinary heated hydrogen on the sulphur.

A number of other reactions, besides the formation of hydrogen sulphide, were studied.

On substituting a tube of red phosphorus for the sulphur tube phosphine was formed even more readily than the sulphide had been. A test paper moistened with silver nitrate solution (and kept in the dark) blackened considerably in the course of three hours. Here again a blank test showed no action without the rays. It is interesting to note that Langmuir's active hydrogen is completely destroyed when a little phosphorus vapor is admitted into the evacuated bulb.

Powdered arsenic was also readily reduced to arsine, but this reaction is slower than the two preceding, an exposure of about twelve hours being necessary for a good test. The Gutzeit test was employed. The filter paper strips were moistened with nearly saturated mercuric chloride solution. The coloration obtained was the usual brown shading into yellow, both turning deep black when dipped into a solution of ammonia.

An interesting criterion of the reactivity of this hydrogen lies in the possibility of its attacking metallic bismuth to form the hydride. The formation of BiH_3 by this new hydrogen would have indicated a greater reducing power than that possessed by nascent hydrogen. When pulverized bismuth was placed in the contact tube a test lasting twenty-four hours produced no mirror in a glass capillary tube kept at about $250°$ by a luminous gas flame. No deposit of any kind was noted, so that the bismuth does not appear to be reduced. This form, then, is not more active than nascent hydrogen.

The new hydrogen attacks mercury.[1] This was discovered quite by accident, when, in an experiment on the volume effect, a few droplets of mercury were spattered against the interior wall of the ionization bulb. After a day of radiation we noticed that the droplets were covered with a crust of minute yellow crystals. Their form could not be determined with accuracy even under a magnification of 900 diameters. Thereupon a wide glass tube which served as a sort of trough for about six cubic centimeters of mercury was sealed in place of the contact tube so that the hydrogen passed directly over the surface of the mercury. In the course of two hours a faint yellowish scum appeared that on allowing the hydrogen to pass over night, increased to a golden-yellow,

[1] As does Sir J. J. Thomson's X_3.

wrinkled film which, as it became progressively thinner on the side re-moved from the ionization bulb, showed two distinct series of interference spectra. Not enough of the yellow substance could be obtained from the deposit for an analysis. This is regrettable, because the result of the test, unlike the others that have been mentioned, might have been due to the presence of oxygen in the hydrogen and the formation of ozone. In view of the preparation and purification of the hydrogen the presence of oxygen is extremely improbable, and such as was present should,—on the basis of Scheuer's work,—have combined rapidly with the hydrogen to form water. That so notable a quantity of oxide should have been formed is hardly possible. The yellow substance was insoluble in water and resisted attack by weak alkalis, but dissolved in HCl and HNO_3. On standing for a week it decomposed, leaving a dirty grey deposit wh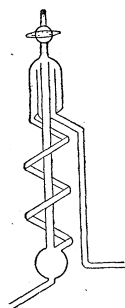ich on heating collected into droplets and distilled off, *i. e.*, mercury. The experiment was repeated several times, but in the course of two weeks all the yellow color regularly disappeared. This is excellent evidence that the crystals are a hydride of mercury, since such conduct would be expected of that substance while the oxide is very stable in air. Two similar fractions of the yellow substance were sealed in glass tubes, one in an atmosphere of oxygen, the other in hydrogen, but no difference could be noted in their rates of decomposition, except that both changed rather more slowly than samples kept in the open air. When gently warmed the yellow crystals broke up rapidly to give tiny drops of mercury.

Fig. 4.

This hydrogen reduced neutral potassium permangate solution to manganese dioxide. The absorption tube (Fig. 4) was used for this test and for all other tests involving the reduction of substances in solution. It is designed for the absorption in a minimal quantity of reagent of a small quantity of a gas which is diluted with a large excess of an inert gas. The gas enters through the tube at the left and bubbles up through the reagent passing through the spiral also, in the form of bubbles. It escapes at the top while the reagent which has been driven up returns through the vertical tube. This gives very efficient absorption by small quantities of solution. The device, however, was not necessary in the case of potassium permangate reduction because the reaction is so rapid that the manganese dioxide deposited as a brown ring around the bottom of the tube through which the gas entered the absorber. Here, as above, a blank test without the emanation gave a negative result.

The same absorption tube was used in an attempt to reduce two organic dyestuffs in water solution. Neither methyl violet nor indigo carmine, however, were bleached by several days' passage of the hydrogen. The one, indigo carmine, involves the reduction of a ketone group to a carbinol, the other, methyl violet, the reduction of a quinone grouping. Both of these can be effected with nascent hydrogen, so that this form of the gas would seem to be less active than the nascent. The fact that the substances are in solution, however, may interfere with the reaction. In a separate test the hydrogen bubbled through water between the radiation and its contact with the sulphur. This reduced the amount of sulphide only slightly, and water itself, therefore, seems not to affect the active gas.

Mention may here be made of an experiment (to be described later) in which a mixture of nitrogen and hydrogen was exposed to the rays. Although a contraction in volume resulted, a test of the gases with Nessler's reagent revealed only a small amount of ammonia. The reaction between nitrogen and the active hydrogen thus seems to be very slow.

A review of the facts thus far established shows that we are dealing with a modification of hydrogen which is more active than the ordinary form but less active than the nascent or Langmuir's monatomic states, —properties which demand a polyatomic molecule larger than H_2. In accord with this also are the physical instability and the boiling point. In many respects the new gas is related to hydrogen as ozone is to oxygen, but no method could be devised for determining its molecular weight.

CHANGE OF VOLUME EXPERIMENTS.

Fig. 5 represents the arrangement of the apparatus to detect the change in volume due to the rays. Before the experiment the water-bath, C, was not in place and the bulb A was connected by glass tubing with the hydrogen generator and purifier while the bulb B was connected through a small mercury trap with the open air. The mercury in the U-tube was drawn into E by applying suction at G and the two bulbs thereby connected. Pure hydrogen was swept through at a rate of about fifteen cubic centimeters a minute for over twenty-four hours. The tube leading from B dipped into a beaker of mercury through which the hydrogen bubbled before reaching the open air. This was to prevent the diffusion of air into the bulbs. When thoroughly swept out and filled with pure hydrogen the bulbs were sealed off as shown in the diagram. The water bath was then put in place and filled in order to equalize the temperature in the two bulbs. This bath was constructed

of a shallow crystallizing dish through the bottom of which three holes were drilled for the passage of the three tubes. The dish was partly filled with mercury and into this was set a tall cylindrical bottomless beaker. Water was poured into this to completely cover the two bulbs. Stirring was effected by a stream of air' bubbles rising through the bath.

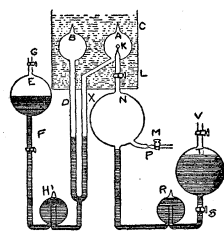After standing at a fairly constant temperature for four or five hours the mercury was allowed to rise in the U-tube, D–X, by opening the stopcock F. H is a trap to prevent access of air into the U-tube from the bulb, E. Since the bulbs B and A have nearly the same volume the levels of the mercury in D and X are nearly the same. Both positions are marked on scales attached to the outside of the tubes. The tubes D and X are capillary tubes with a bore of half a millimeter, so that violent tapping is needed to determine the true level of the mercury in each arm. Once the level was thus determined the mercury could be raised or lowered and accurately reset on the marks.

Fig. 5.

The emanation is then introduced into the small bulb, K. For this purpose the emanation is compressed at the radium laboratory into a fine capillary tube about two centimeters in length. This is inserted into the bore of the stopcock, M, in such a way that it projects on both sides. A sealed connection is then made at M with a Gaede rotary mercury pump. The stopcocks L and M are open and the bulbs N and K are exhausted until no difference in level was exhibited by a Mac-Leod gauge with a magnification of one thousand. The pump is then sealed off from the apparatus shown in the diagram, leaving the bulbs evacuated. The stopcock, M, is then turned and the fine tube containing the emanation breaks, allowing the emanation to enter the bulb N. The stopcock, M, is then sealed off at the constriction, P, and by opening the cock, S, the mercury rises in N driving the emanation into K. When the mercury has reached the neck of the bulb K the stopcock L is closed. This is necessary to avoid changes in level of the mercury due to the large thermal expansion and contraction of the mercury in the bulb N. With L closed these are applied to the air space in the trap, R.

In every case, the introduction of the emanation into K produced a contraction in volume A, indicated by a rise of the mercury in the capillary tube, X. The change in volume opposes and overbalances the expansion due to the heating effect of the emanation.

The contraction in volume did not appear immediately. The pressure change seldom amounted to a millimeter at the end of an hour. At

the end of three hours the pressure usually had fallen three millimeters, and did not exceed this limit even after fifteen hours. Such a pressure change involves a loss of 3/760 or 1/250 in volume, *i. e.*, 0.4 per cent. The bulb, *A*, contained about five cubic centimeters so that the actual contraction amounted to 0.02 cubic centimeter.

The interpretation of the observed contraction is not quite clear, and the phenomenon will be the object of further experimentation. The change in volume appears to be rather larger than one would expect from the number of ions produced by the alpha rays. On the other hand, the effect may be due to some chemical reaction such as that between the hydrogen and the mercury in the tube *DX*.

An interesting point now remains to be investigated, namely, whether the active hydrogen is produced directly by the actual bombardment of the atoms, or whether it may not be due to a breaking down of the clusters of atoms which form around the charged ions.

In an attempt to decide this question, we performed the following experiment. Hoping to be able to remove a large fraction of the ions before the clusters could form around them, we ionized the hydrogen in a very strong electrostatic field. Fig. 6 represents the ionizing chamber in the apparatus. The purified hydrogen entered at *D*. *CC* represents a cylinder of sheet platinum 15 cm. long and 4 cm. in diameter. The platinum rod *B* lies along the axis of the cylinder and close to the emanation bulb *A*. A large storage battery was attached to *B* and *C*, and pro-

Fig. 6.

duced a difference of potential of 2,000 volts between them. After passing between *B* and *C*, the hydrogen flowed through *E* into the sulphur tube.
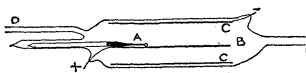
The electric field had no appreciable effect on the result. The sulphide paper appeared as black with as without the field.

If the field had destroyed or diminished the action perceptibly, it would have been possible to draw some definite conclusions as to the rôle played by the clusters. As no effect was observed, however, the experiment must be regarded as negative and no conclusions can be drawn from it, either one way or the other. Thus the mechanism of the formation of the active molecules needs further investigation.

CONCLUSIONS.

It appears from the above described experiments that intense bombardment by alpha rays produces in the purest hydrogen we could obtain a certain capacity for entering into chemical reactions, which ordinary

hydrogen at ordinary temperatures does not possess. For instance, the radiated hydrogen combines directly with sulphur to form hydrogen sulfide, with phosphorus to form phosphine, with arsenic to form arsine, etc. It also reacts with mercury, and reduces neutral potassium permanganate solution to manganese dioxide, etc.

This acquired chemical reactivity cannot be ascribed to the direct action of the hydrogen ions, for the passage of the hydrogen through glass wool and a strong electrostatic field (either of which would remove the ions) does not destroy the acquired property of the gas.

The chemical activity may be due to the formation of H_3 by the alpha rays. Certain characteristics of the active gas seem to point in this direction. We have not obtained, however, conclusive proof of the existence of H_3.

Experiments designed to discover whether the formation of the active gas takes place during the actual bombardment by the alpha particles, or subsequently, during the formation or disintegration of ionic clusters turned out inconclusive.

The active modification can be removed from the hydrogen by passing it through a tube immersed in liquid air.

A diminution of volume takes place in the hydrogen when it is bombarded by the rays. Experiments are in progress designed to discover whether this is a primary action, or is due to some secondary chemical reaction.

The active modification of hydrogen is not very stable, its life being measured in minutes.

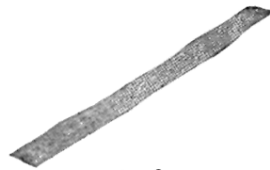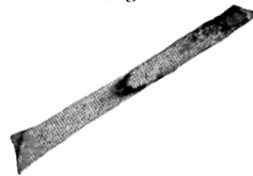HARVARD UNIVERSITY.

Fig. 3a.

Fig. 3b.

Fig. 3c.

Fig. 3.