Name: .... Date: ....

Star chemistry

Scientists know that hydrogen molecules form in space. Hydrogen molecules are also always being destroyed by cosmic rays. Here is an equation to represent this:
$H_2(g) \rightleftharpoons 2H(g)$

Overall, the amount of hydrogen molecules stays roughly the same – this means that new molecules are always being made at the same rate as they are being destroyed.

To make a molecule, the atoms need to get close enough to share electrons – but space is huge, and the gaps between atoms are 1000 times bigger than those in air. There must be way for the atoms to meet to keep making hydrogen molecules, but how? This is the 'hydrogen problem'.

Chemical reactions in the Interstellar Medium

Here is a description of experiments to find out how hydrogen molecules might form in the Interstellar Medium (ISM). The experiments were carried out by two teams of researchers, one in Italy and the other in America. Scientists write their results up as research papers published in specialised magazines called journals. This allows other people working in the same area to read about the latest developments. These experiments were published in *The Astrophysical Journal* in February 2001.

Laboratory measurements of molecular hydrogen formation on water ice by G. Manico, G.Raguni, V. Pirronello, J.E.Roser and G. Vidali

Abstract

We report an experimental study of the formation of hydrogen molecules on the surface of water ice layers under conditions like those in the Interstellar Medium (ISM). Our results explain how hydrogen forms in dense cloud environments.

Introduction

Hydrogen molecules, H_2, are the most important molecules in the ISM. Several researchers have tried to explain in theory how hydrogen molecules might form. One aspect of this problem is to find out how hydrogen molecules form at a rate which compensates for the large quantities which are destroyed. When two neutral hydrogen atoms collide as gases, they bounce away, rather than forming a molecule. So collision can't explain the rate of formation – the molecules must form in another way. We study the formation of hydrogen molecules on solid surfaces which act as catalysts for making molecules. Until recently it has been hard to carry out practical experiments because of the difficulty of using conditions similar to the ISM. The aim of this study is to form hydrogen molecules on the surface of water ice to simulate the process that takes place on the icy mantles present on grains in dense clouds.

Experimental procedures

The experiments were done in an ultra-high vacuum apparatus consisting of a scattering chamber and two pumped beam lines (Figure 1).

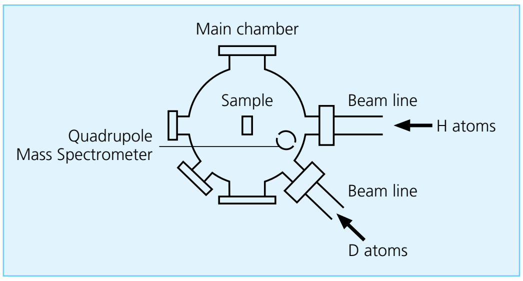

Figure 1 Apparatus used to make molecular HD on ice grains

continued on next page

continued from previous page

Radio waves are used to split apart molecular hydrogen and deuterium. This makes beams of H and D atoms. Using beams of H and D atoms means that the combined product can be formed only on the surface of the ice, and not in the beam by atoms joining together again after splitting. The beams, cooled to 200 K, are passed through collimators and then enter the scattering chamber reaching the ice layer.

The ice sample was made by depositing water vapour on a copper disc attached to a copper holder in contact with a 'cold finger'. The sample was kept at 10 K while about 1200 molecular layers of water were built up. When the experiments were running the temperature was kept below 38 K.

In the first experiment, we looked for the amount of HD produced in reactions between H and D atoms on the surface of the ice. HD molecules form when H and D atoms landing on the ice layer stick on it. If they are mobile and can meet, they will react and form HD. The amount of HD forming is recorded as 'recombination efficiency'. We exposed the ice grains to the beams for 2 minutes. The temperature inside the scattering chamber was increased slowly from 6 to 20 K. The amount of HD forming on the ice surface was measured several times within this range. We changed the temperature of the H and D beams as shown in Figure 2, but kept the exposure time at 2 minutes.

In the second experiment we measured the HD released from the ice grain surface. We exposed the ice to the H and D beams for five different amounts of time – 2, 4, 6, 8 and 18 minutes. Then the temperature inside the chamber was ramped up and we measured the HD released. The results are shown in Figure 3.

Results

Figure 2 shows the amount of hydrogen and deuterium recombination as the temperature inside the chamber was increased from about 6–20 K. In this figure, all data were obtained after 2 minutes adsorption.

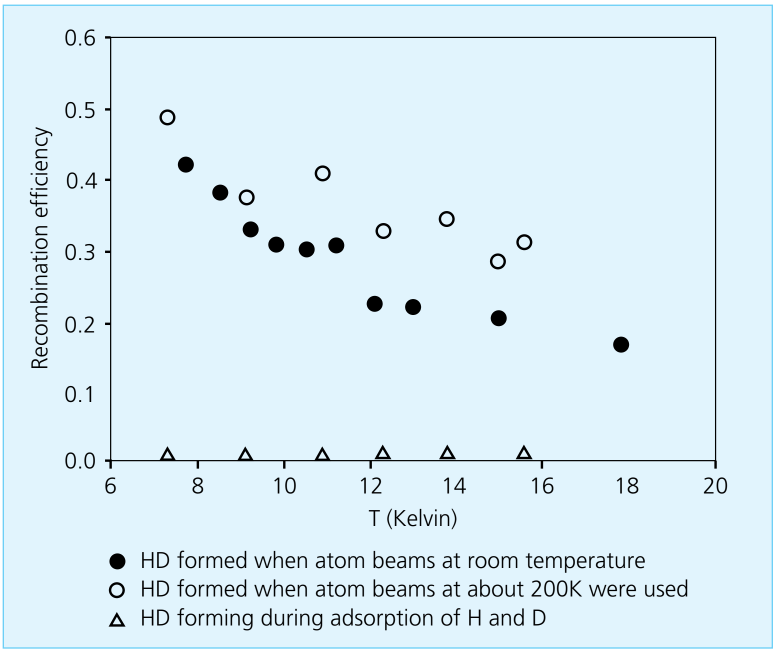

Figure 2 Formation of HD molecules on ice grains from H and D beams at different temperatures.
Based on Manico et al, 2001.

continued on next page

continued from previous page

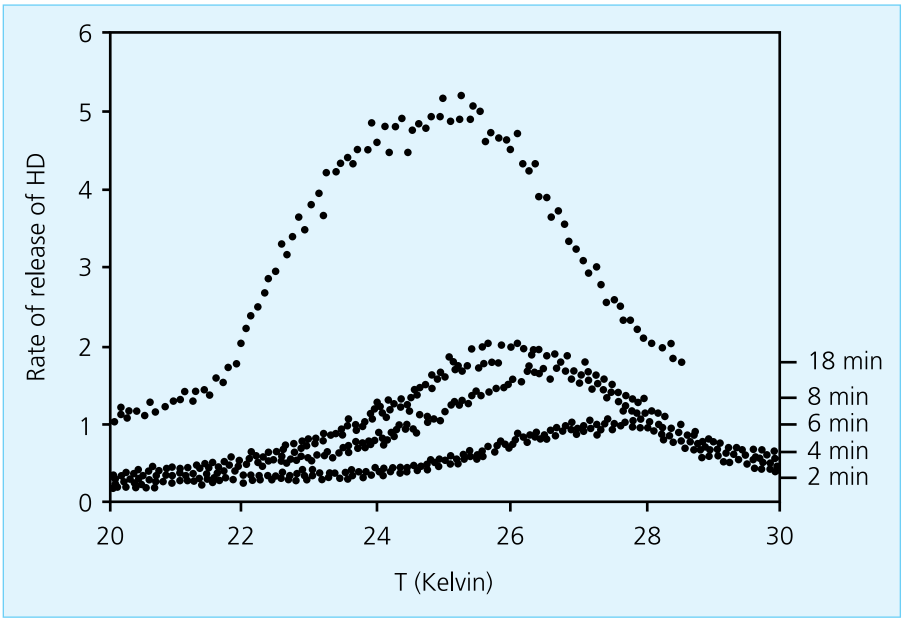

Figure 3 Rates of HD release at different temperatures after different exposure times.
Based on Manico et al, 2001.

The five curves correspond to (from top to bottom) 18, 8, 6, 4 and 2 minutes exposure times.

Conclusions

Our results apply in gas clouds where there is little UV radiation and where the density of hydrogen molecules is 10^4 cm^{-3} or higher. In these clouds, hydrogen molecules can be ionised by cosmic rays and then destroyed. The experiments described show that hydrogen molecules can be produced on water ice grains in the clouds. The efficiency at which molecules are formed on the icy surface of dust grains is high enough to compensate for those that are destroyed. This means the amount of hydrogen molecules in dense clouds can be in a steady state.

The hydrogen molecules may form by either of two mechanisms. These are called the 'Eley-Rideal' and 'Langmuir-Hinshelwood' mechanisms.

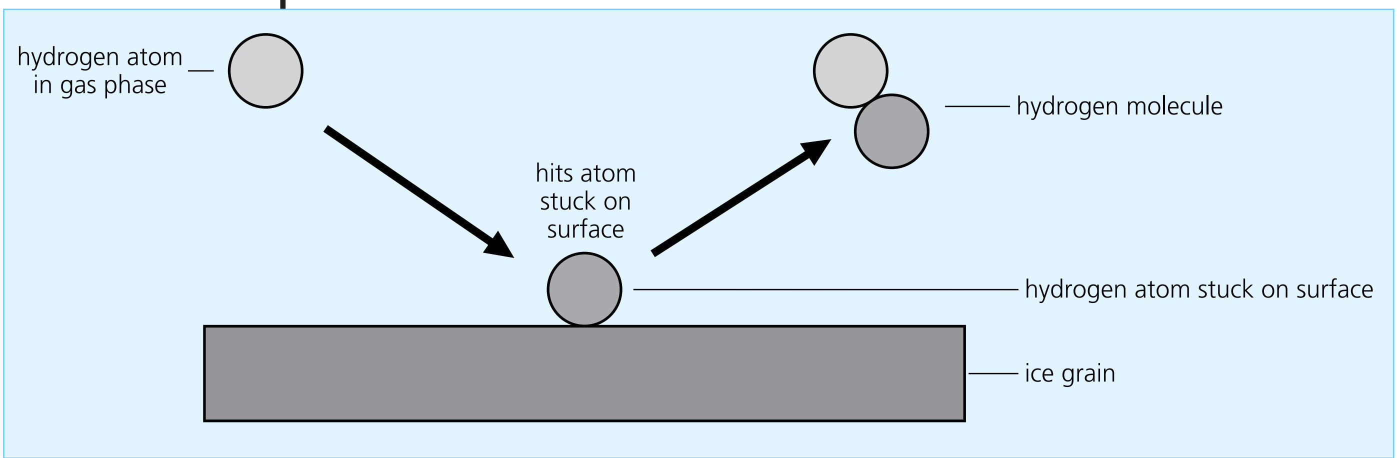

Figure 4 How molecules of hydrogen could form
Reproduced with permission from Valerio Pironello, University of Catania.

continued on next page

Star chemistry

continued from previous page

We believe that the structure of the water ice grain is also important. Micropores on the ice surface allow hydrogen atoms to have a larger surface to stick on to, leading to a better chance of meeting a second atom and forming a molecule.

In conclusion, our results show that hydrogen atoms can recombine on water ice grains at a rate matching molecular hydrogen destruction. This result agrees with the calculations made by other researchers.

Acknowledgements

We acknowledge financial support from NASA and the Italian Ministry for University and Scientific Research.

We thank other colleagues for helpful discussions and our technician for his assistance in the laboratory.

Questions

1. Find and underline these words and phrases in the text. Use the language guide below to understand what they mean.
   explain in theory, ultra-high vacuum, scattering chamber, beam lines, deuterium, collimators, 'cold finger', 38 K, HD, ionised, micropore, steady state

2. The report begins with an Abstract. Why is this the first section? Explain why the abstract is useful for other scientists.

3. Why did the scientists want to study hydrogen molecule formation?

4. Explain why the experimental apparatus needed:
   a) ultra-high vacuum;
   b) atomic beams of hydrogen and deuterium, not hydrogen alone; and
   c) cold temperatures, *eg* from the cold finger.

5. Now look at the results in Figure 2. At which temperature inside the chamber was the most HD formed?
   Does the temperature of the atom beams that are sent into the chamber make a difference to the amount of HD?
   Why might this be?

6. Look at the results in Figure 3. The graph shows five different exposure times.
   a) At which temperature and exposure was the highest amount of HD released?
   b) Explain why the most HD was formed after this exposure time.

7. Explain why the scientists conclude that hydrogen molecules can form in the ISM.

8. The experiment was done by a team of five scientists based in two countries and a technician. Why do scientists work in teams?

9. How is this scientific paper similar to how you write up investigations?

continued on next page

continued from previous page

Language guide

Explain in theory So far scientists have only done calculations, not practical experiments

Ultra-high vacuum All the air has been taken out of the apparatus so air molecules do not interfere. There is no air in the ISM.

Scattering chamber Part where the water ice grain is made. The atoms will be sent through the chamber to hit the grain. After hitting, they scatter around.

Beam lines Atoms of hydrogen and deuterium will be made into fine lines called beams. The atoms are made by splitting up molecules.

Deuterium An isotope of hydrogen with an extra neutron, so its atomic mass is 2 instead of 1. They make molecules in exactly the same way as hydrogen atoms, so it is possible to have D_2 and HD molecules.

Collimator A narrow slit through which the atoms pass to make a fine beam.

'Cold finger' A piece of glass shaped like a finger with has a stream of a cold liquid passing through it in fine tubes. The cold outside surface is used for low temperature experiments.

38K 'K' means degrees in Kelvin. 0 °C is 273 K. To work out the temperature in degrees centigrade, take away 273 from 38, making -235 °C. The coldest possible temperature is -273 °C, 'absolute zero', when all movement of atoms stops.

HD Molecule with one hydrogen atom and one deuterium atom. It is identical to a hydrogen molecule, but has an extra neutron.

Ionised Taking or adding an electron to atom or molecule so the number of positive and negative charges is not equal.

Micropore An atom-sized hole in the surface of a substance.

Steady state When two opposite events happen at the same rate, there is no overall change. This is called a steady state.