AMORPHOUS ICE IN ASTROPHYSICS
J. Klinger

To cite this version:
J. Klinger. AMORPHOUS ICE IN ASTROPHYSICS. Journal de Physique Colloques, 1985, 46 (C8), pp.C8-657-C8-660. <10.1051/jphyscol:19858106>. <jpa-00225148>

HAL Id: jpa-00225148
https://hal.archives-ouvertes.fr/jpa-00225148
Submitted on 1 Jan 1985

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
AMORPHOUS ICE IN ASTROPHYSICS

J. Klinger

Laboratoire de Glaciologie et Géophysique de l'Environnement, B.P. 96, 38402 Saint Martin d'Hères Cedex, France

I - INTRODUCTION

Condensation of matter under extreme conditions like that of astrophysical environments often occur far from equilibrium. This evidently favours the formation of amorphous solids. This is true for refractory materials like silicates as well as for moderately volatile substances.

With the improvement of spectroscopic data due to modern observational techniques a fascinating subject is opening to physicists interested in amorphous substances.

The field of amorphous solids in space is wide; thus it is not possible to cover the whole subject by a single paper. So the author decided to limit this review to the amorphous forms of a substance that since the first half of this century is thought to be rather common in space: $\text{H}_2\text{O}$. This supposition is justified by the high cosmic abundance of $\text{H}$ and $\text{O}$.

It is well known that $\text{H}_2\text{O}$ forms an amorphous solid by vapor deposition at temperatures lower than 100°K. Since recent times we have some evidence that the evolution of some outer solar system bodies seems in fact influenced by the physical properties of amorphous solid water.

II - THE INTERSTELLAR MEDIUM

Interstellar clouds can be investigated using the absorption features detected in the light of stars laying behind the cloud. If the type of the star is sufficiently well known, the compounds responsible for the absorptions can be identified.

In 1968 an absorption in the 3 $\mu$m band has been reported in NML Cygnus /1, 2/. In the meantime a great number of very similar absorption features have been found in molecular clouds (molecular clouds are interstellar clouds with $10^7$ molecules/cm$^3$).
These absorption features were thought to be due to solid H$_2$O. But this interpretation left several problems open:

- The weakness of the absorption feature suggested that only about 7% of the absorbing matter was ice. This was less than predicted /3/.
- Mie calculations for grains of 0.1 and 1 μm in size using the spectral parameters of crystalline ice gave line shapes very different from that of the interstellar absorptions /4/.
- The liberation band that occurs for crystalline ice near 12 μm was not found in the interstellar absorptions.

The question of the nature of the stuff producing the 3 μm absorption was at least partially answered by Leger et al. /5/. These authors compared the infrared spectrum near 3 μm of amorphous solid water obtained by vapor deposition at liquid nitrogen temperature to the absorption feature of the Becklin-Neugebauer point source which is situated in the Orion nebula. It turned out that the low wavelength wing of the interstellar absorption could be fitted quite satisfactorily by the laboratory data. As the absorption feature for amorphous ice areas was flatter than that of crystalline ice the proportion of interstellar ice is probably a factor of 1.5 higher than estimated previously.

As it is the case for the O - H stretching band, the 12 μm liberation band is weaker for amorphous ice than for crystalline ice. Further this band is shifted to longer wavelengths for the amorphous solid /5, 6/. These facts probably explain that the 12 μm band is difficult to find in interstellar absorptions.

Thus it seems established that solid H$_2$O in interstellar clouds is amorphous. The shape of the long wavelength wing that cannot be fitted by laboratory spectra of pure amorphous ice most likely is due to the CH stretching vibration of other "ices" that are present on the interstellar grains /7/. An alternative explanation could be that the long wavelength wing is due to water ice grains containing some NH$_3$ with grain size distribution as N α a$^{-3/2}$ the maximum grain radius being ≈ 1.2 μm /8/. The main difficulty of this explanation is that interstellar grains probably are much smaller than the maximum grain radius required in order to fit the 3 μm absorption line.

III - COMETS.

Comets probably are the most primitive bodies in the solar system. They formed in the outer part of the premodern solar nebula and they probably always remained at a temperature lower than 100 K since 4.6 billion years; thus they may be witnesses of the interstellar matter that formed the planets. Some 10$^3$ comets are thought to be contained in the so called "Oort cloud". The Oort cloud is a sphere around the sun with a radius of about 150 000 Astronomical Units (1 AU = mean distance sun - earth = 150 million km). The comets in the outer shell of the Oort cloud are subject to gravitational perturbations by nearly stars. In this way some of them are injected into the inner solar system. Here the cometary ices are evaporated thus forming a gas and dust halo ("coma") and tails of dust and ionized gas. There is indirect evidence that H$_2$O is a major constituent of comets:

- Molecular fragments like H$_3$O$^+$ and OH are currently detected in cometary comae.
- The light curve of most comets as a function of heliocenter distance fits well with H$_2$O evaporation.

It is well known that amorphous solid water crystallizes in an irreversible manner at temperatures between 130 and 153 K depending on the conditions of formation /9, 10/. During this phase transition some heat is released. The crystallization of amorphous ice may be the key to some unexplained behavior of comets:

- comets sometimes show unpredictable outbursts that increase the optical brightness by several magnitudes,
the light curves of some comets show an asymmetry with respect to perihelion, the comet being often less bright after perihelion than before.

In order to explain the outbursts Patashnick et al. /11/ suggested that the heat freed during crystallization may be the energy source for outbursts, the outburst being triggered when fresh amorphous layers reach the transition temperature. Due to the coupling between the rotation and the revolution of the comet nucleus the outburst occurs in an apparently random manner.

On the other hand the heat conduction coefficient of the ice increases in an important manner during crystallization and the temperature dependence of the heat conduction coefficient is reversed /11/. Thus the thermal inertia of comets that have a thick crystalline crust should be higher than that of comets which have not. The development of such a crust depends on the orbital parameters. When the thermal inertia of the comet is high, the post-perihelion activity should be lower than the pre-perihelion activity. The present statements seem in good agreement with observation /12, 13/.

IV - PLANETARY RINGS AND Icy SATELLITES

Most of the satellites of Jupiter and Saturn and the particles of Saturn's rings contain high amounts of solid H\textsubscript{2}O.

The particles of the ring system of Saturn are continuously broken up due to particle-particle collisions and are eroded due to sputtering by energetic particles of Saturn's magnetosphere. The permanent redistribution of H\textsubscript{2}O at temperatures lower than 100 K probably produces amorphous ice. This is compatible with the low thermal inertia found when the ring particles are eclipsed by Saturn /14, 15/.

On the icy satellites of Jupiter and Saturn volatile surface material is removed by sputtering of energetic particles and by meteoritic bombardment. Some of these satellites have a sufficient gravitational field to be able to retain an important fraction of the ejected molecules. These molecules can recondense in cold regions of the body where they form an amorphous deposit. Polar caps have indeed been found on Ganymede, one of the Galilean Satellites of Jupiter /16, 17/. The conditions under which these deposits have formed strongly suggest that they are amorphous.

V - CONCLUSION

It seems now established that amorphous H\textsubscript{2}O occurs in molecular clouds in the interstellar medium. It is almost certain that amorphous silicates are present in interstellar grains too. But very few is known until now on the occurrence of amorphous forms of other moderately volatile substances. Some more knowledge could help us to better understand the mechanism of deposit of interstellar gas on grains and on recycling of grain material.

Comets seem to be very primitive bodies and thus could be much influenced by the physical behavior of premordial amorphous substances. Amorphous deposits could further be present on ring particles on Saturn and in polar caps of icy satellite.

In summary we can say that improved knowledge of amorphous substances can help us to understand the evolution of interstellar matter, the early stage of the solar system and the particular evolution of some outer solar system bodies.

ACKNOWLEDGEMENTS

Financial support from the French "Institut des Sciences de l'Univers" ATP grant N°4789 is gratefully acknowledged.

REFERENCES

/16/ Lyot, B., L'Astronomie 67 (1953) 1.