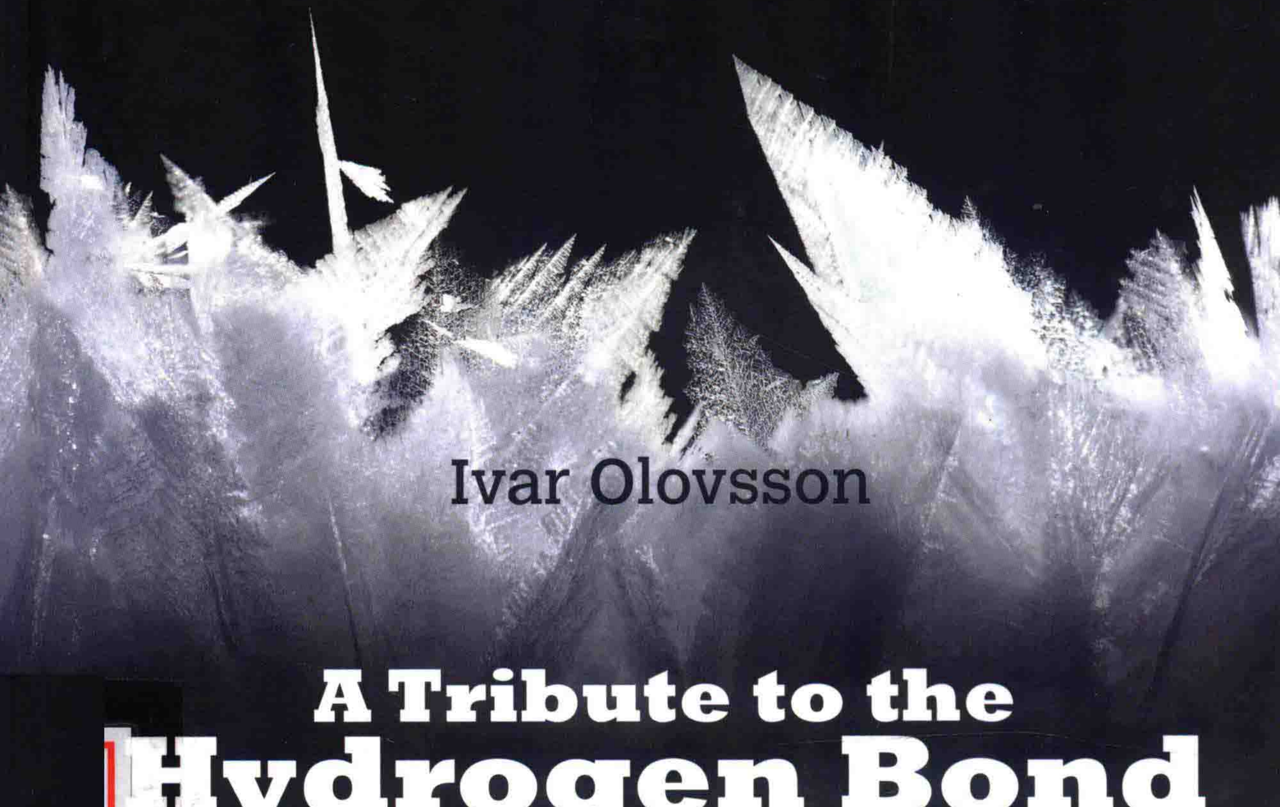
Snow, Ice and Other Wonders of Water



Ivar Olovsson

A Tribute to the Hydrogen Bond

World Scientific

Snow, Ice and Other Wonders of Water

A Tribute to the Hydrogen Bond

Ivar Olovsson
University of Uppsala, Sweden

World Scientific

NEW JERSEY • LONDON • SINGAPORE • BEIJING • SHANGHAI • HONG KONG • TAIPEI • CHENNAI • TOKYO

Published by

World Scientific Publishing Co. Pte. Ltd.
5 Toh Tuck Link, Singapore 596224
USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601
UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

SNOW, ICE AND OTHER WONDERS OF WATER
A Tribute to the Hydrogen Bond

ISBN 978-981-4749-35-0
ISBN 978-981-4749-36-7 (pbk)

Printed in Singapore by Mainland Press Pte Ltd.

Snow, Ice and Other Wonders of
Water
A Tribute to the Hydrogen Bond

Preface

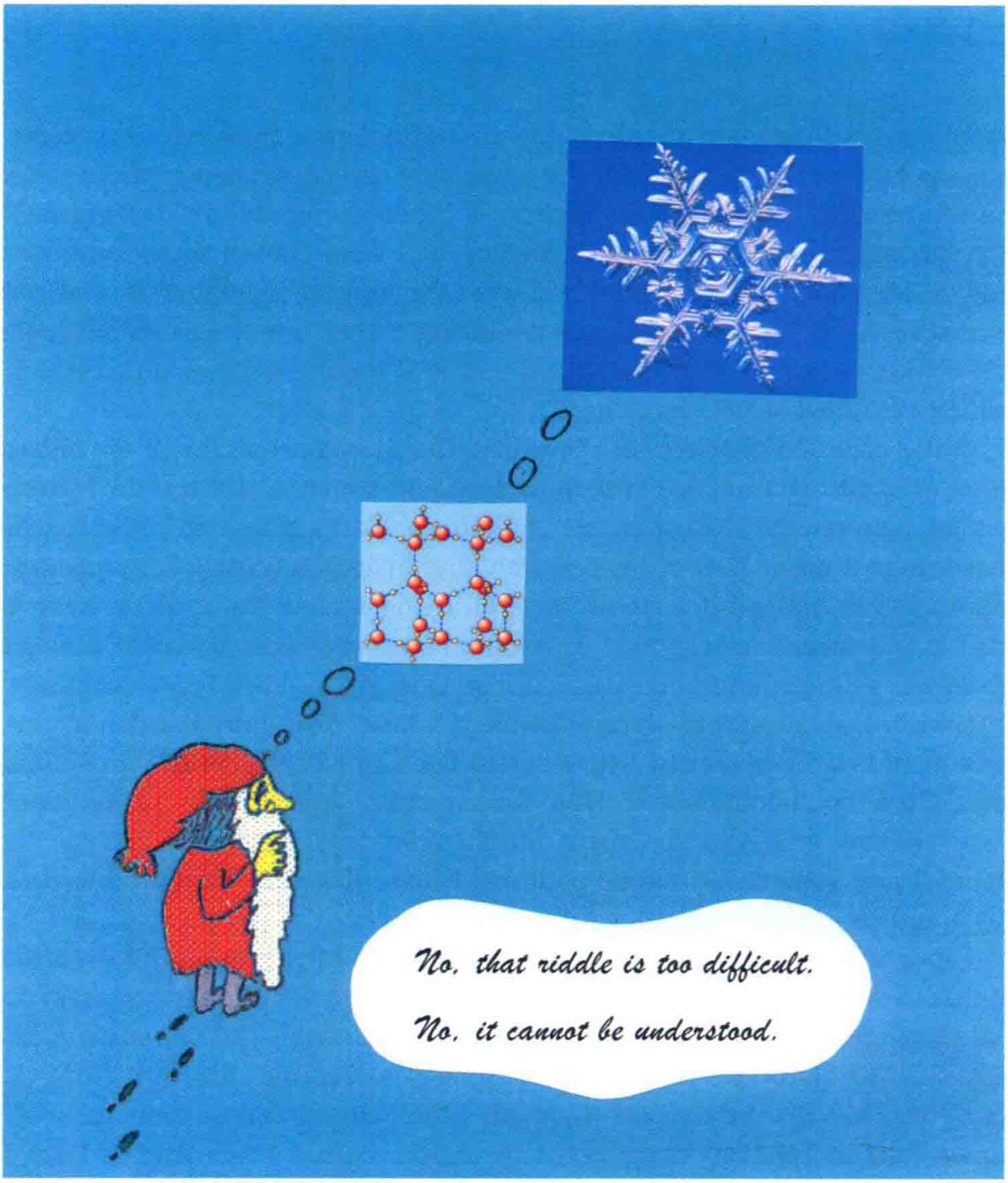
Water plays a fundamental role in life and, although a tremendous amount of research has been performed on this seemingly simple substance, there are still many unresolved questions. The literature is virtually unlimited and it is impossible to cover more than a few topics in this book. I have chosen to concentrate on snow and ice, and I hope the book will whet the appetite to learn more about this fascinating field. The selected topics are mostly rather briefly treated but further information is easily available on the Internet. It therefore seems unnecessary to include a long list of references here.

Water plays a unique role in chemistry. The special properties of the different forms of water — from ice and snow to liquid water — are due to hydrogen bonding between the H_2O molecules, and this book is a tribute to a field to which I have spent a major part of my research. The hydrogen bond is of fundamental importance in biological systems since all living matter has evolved from and exists in an aqueous environment. Hydrogen bonds are involved in most biological processes as little energy is needed in forming as well as breaking these bonds.

I wish to express my sincere thanks to Prof. Yoshinori Furukawa of the Institute of Low Temperature Science (Hokkaido University), British artist Simon Beck, Canadian photographer Don Komarechka, and Russian photographers Alexey Kljatov and Andrei Osokin for their kind permission to include their beautiful and sometimes unique pictures. I hope the pictures reproduced here will stimulate further studies regarding their books.

I am grateful for permission from publisher De Gruyter to reprint my articles from *Zeitschrift für Physikalische Chemie*, from publisher VCH Verlagsgesellschaft GmbH to reprint a paper from *Angewandte Chemie, International Edition* and from the Harbourcreek Historical Society to reprint an article from their newsletter. My thanks to Prof. Kenneth Libbrecht for permission to use his snow crystal morphology diagram. Many thanks to Prof. Emer. Anders Liljas for checking the manuscript and for his valuable suggestions. I welcome suggestions for improvements and the alerting of errors.

Ivar Olovsson
Uppsala, 15 October 2015
Ivar.Olovsson@gmail.com

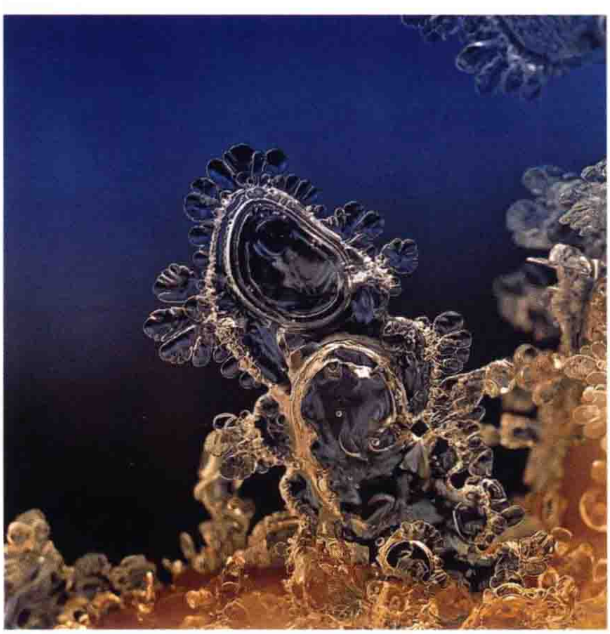

No, that riddle is too difficult.
No, it cannot be understood.

Contents

1 There Are Many Different Types of Snow

Frozen water — snow and ice — appears in a myriad of different shapes and with properties which can be quite different. Detailed knowledge of the properties of snow is of great importance for the Sami people (Laplanders) involved in reindeer herding. A large number of names are used by the Laplanders to characterize the different types, and snow may still be a daily topic of conversation. In Yngve Ryd's book (in Swedish) *Snö: En Renskötare Berättar* (*Snow: A Laplander Narrates*), more than 300 words for "snow" are documented with explanations and photos. The words describe for instance the amount of snow, consistency, gliding, buoyancy or melting.

In this book I will mostly use the term "snow crystal" for a single crystal, i.e. a sample which is continuous and has no boundaries (all parts of the crystal are extinguished simultaneously in polarized light). A fully developed dendritic snow crystal is, for example, a single crystal. All snow crystals (in my terminology) are transparent. As a snow crystal falls toward the earth, it will often hook onto other crystals in a random way and a *snowflake* is formed. A layer of snow looks white owing to repeated reflection of the light toward the randomly oriented snowflakes. In the literature the word "snowflake" seems to be used for all types — a single crystal as well as a random collection of snow crystals. A snow crystal is just ordinary ice, but ice with a special, mostly rather open structure. A large, more compact and irregular crystal is better named *ice crystal* (see photo on the left by Andrei Osokin).



2 Early Snow Crystal Observations

Snow has always fascinated mankind and is mentioned in a dozen places in the Bible. In Job 38:22–23 is written: "Hast thou entered into the treasure house of the snow, or hast thou seen the treasure house of the hail, which I have reserved against the time of trouble, against the day of battle and war?" Hail is often considered to be punishment from God — in Revelation 16:21 is written: "And there fell upon men a great hail out of heaven, every stone about the weight of a talent: and men blasphemed God because of the plague of the hail; for the plague thereof was exceeding great." (One talent was about 50 kg.)

To my knowledge, the first pictures of snow crystals were published in 1555 by Olaus Magnus in his famous *Historia de Gentibus Septentrionalibus* (*History of the Nordic People*, an assembly of essays in 22 volumes; Fig. 2.1). Owing to the Reformation in Sweden, he lived at that time in Rome together with his brother, Catholic archbishop Johannes Magnus. In exile he seems to have largely forgotten how snow crystals look and applied his fantasy.

It is commonly considered that it was the astronomer Johannes Kepler who, in his essay *De Nive Hexangula*, first established that snow crystals have a six-fold symmetry (Figs. 2.2 and 2.3). This conclusion appears to be based on his studies of the closest packing of spheres. In this context he had also been asked to solve a practical problem: how best to stack cannonballs on ships.

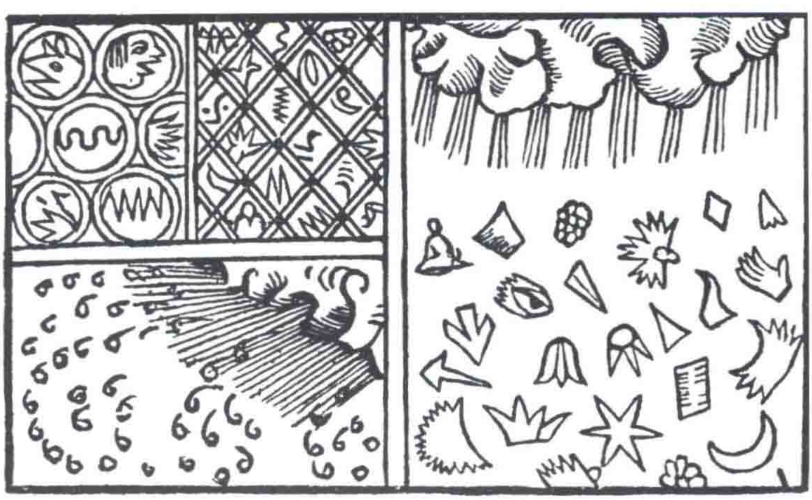


Fig. 2.1. Snow crystals drawn by Olaus Magnus.

Fig. 2.2. Johannes Kepler (1571–1630).

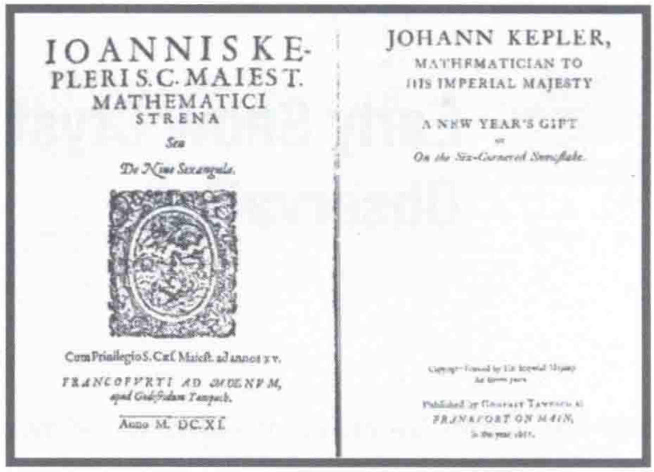


Fig. 2.3. Kepler's book *De Nive Sexangula* (*On the Six-Cornered Snowflake*), published in 1611.

The French philosopher and mathematician René Descartes (Fig. 2.4) made, during the unusually cold winter in Amsterdam in 1635, the first detailed observations of snow crystals, which were published in 1637 in his famous work *Discours de la Methode* (Fig. 2.5). The pictures in Fig. 2.6 are found in the chapter *"Les Meteores."* This may seem strange in a treatise dealing with snow, but *Meteorology* deals with all atmospheric phenomena, such as wind, storms, cyclones, rain, snow and hail.

Descartes was born at La Haye in Touraine, France. The village is nowadays named "Descartes," in his honor. In 1649 he was invited to Stockholm by Queen Kristina to be her teacher and adviser, and to organize a new scientific academy

Fig. 2.4. René Descartes (1596–1650).

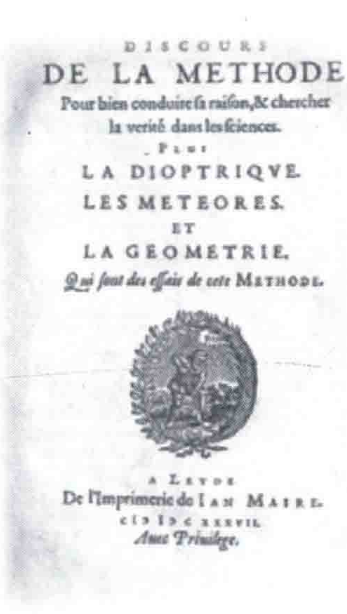


Fig. 2.5. *Discours de la Methode* (1637).

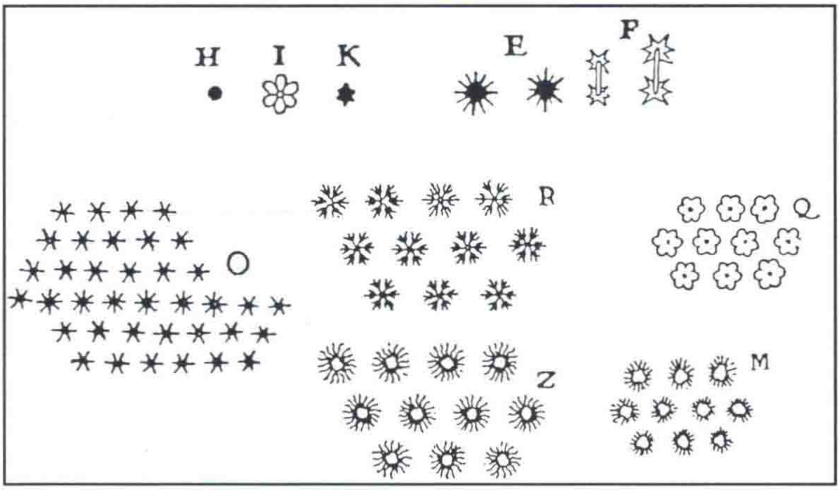
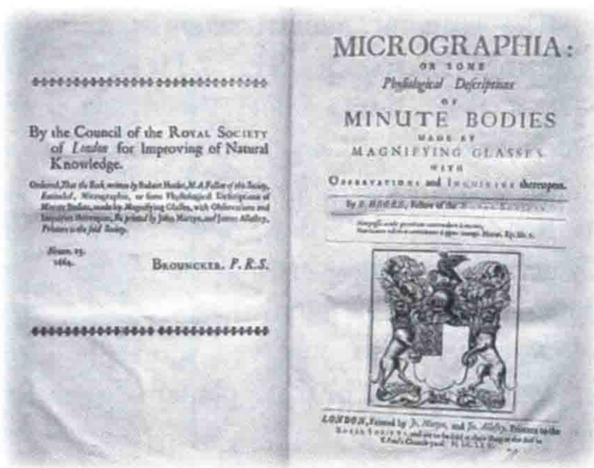


Fig. 2.6. Snow crystals observed by Descartes.

Fig. 2.7. Descartes and Queen Kristina.



By the Council of the ROYAL SOCIETY of *London* for Improving of Natural Knowledge.

BROUNCKER. P.R.S.

MICROGRAPHIA:

OR SOME

Physiological Descriptions

OF

MINUTE BODIES

MADE BY

MAGNIFYING GLASSES.

WITH

OBSERVATIONS and INQUIRIES thereupon.

Fig. 2.8. Robert Hooke's *Micrographia*, published in 1665.

(Fig. 2.7). It has been said that Descartes considered Sweden a country where both people and thoughts froze to ice. The meetings were held early in the morning (at 5 a.m.) in the castle which was hardly heated and very cold and draughty. Descartes caught a cold and died of pneumonia on February 11, 1650, after only a few months in Sweden.

Many other scientists have also pondered on the mysteries of snow crystals. When the microscope was invented in the later part of 1600, the possibilities of studying snow crystals became much better. In 1665 the multidimensional scientist and polymath Robert Hooke published *Micrographia: Or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses with Observations and Inquiries Thereupon* (Fig. 2.8). An imagined picture of Hooke at his desk is shown in Fig. 2.9 (no contemporary portrait has been preserved). A few of his drawings of snow crystals are shown in Fig. 2.10. Hooke remarked that the angle between the side branches is always 60°.

Fig. 2.9. Robert Hooke (1635–1703).

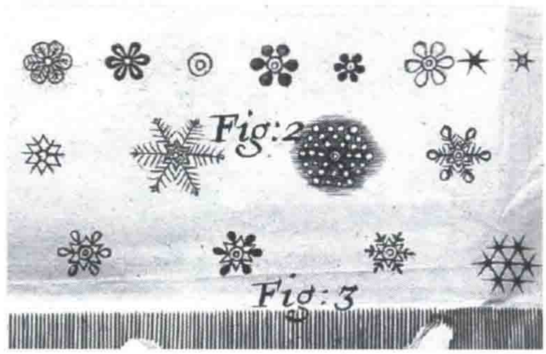


Fig. 2.10. Snow crystals drawn by Robert Hooke.

The eminent natural scientist and whaler William Scoresby, Jr. (Fig. 2.11) published in 1820 a two-volume book, *An Account of the Arctic Regions with a History and Description of the Northern Whale Fishery* (Fig. 2.12). In this famous work he also made accurate observations of snow crystals, some of which are shown in Fig. 2.13. Note that Scoresby (as well as Descartes) also observed three-dimensional snow crystals: two or three planar crystals joined by an axis.

Fig. 2.11. William Scoresby, Jr. (1789–1857).

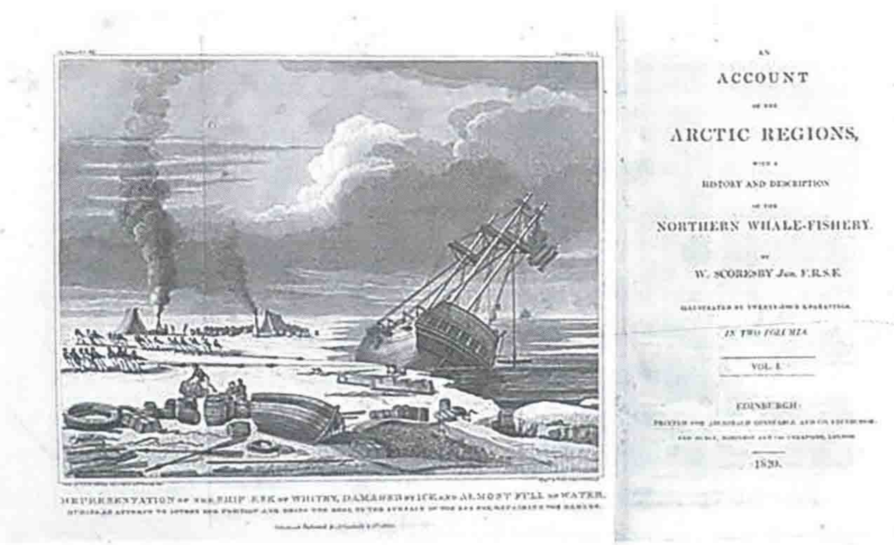


Fig. 2.12. An Account of the Arctic Regions with a History and Description of the Northern Whale Fishery.

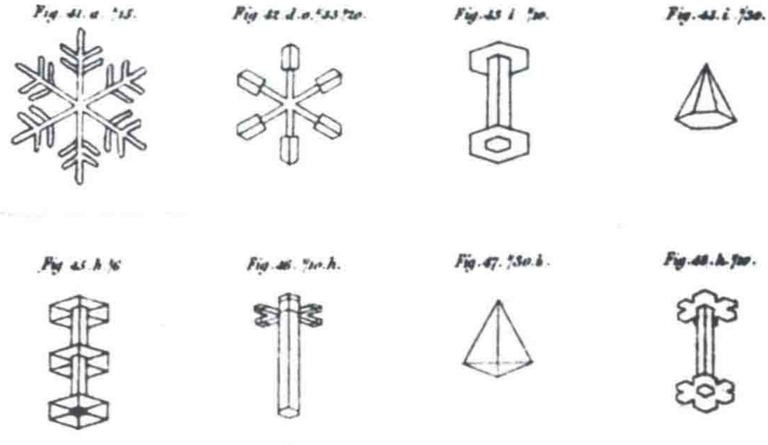


Fig. 2.13. Snow crystals observed by William Scoresby, Jr.

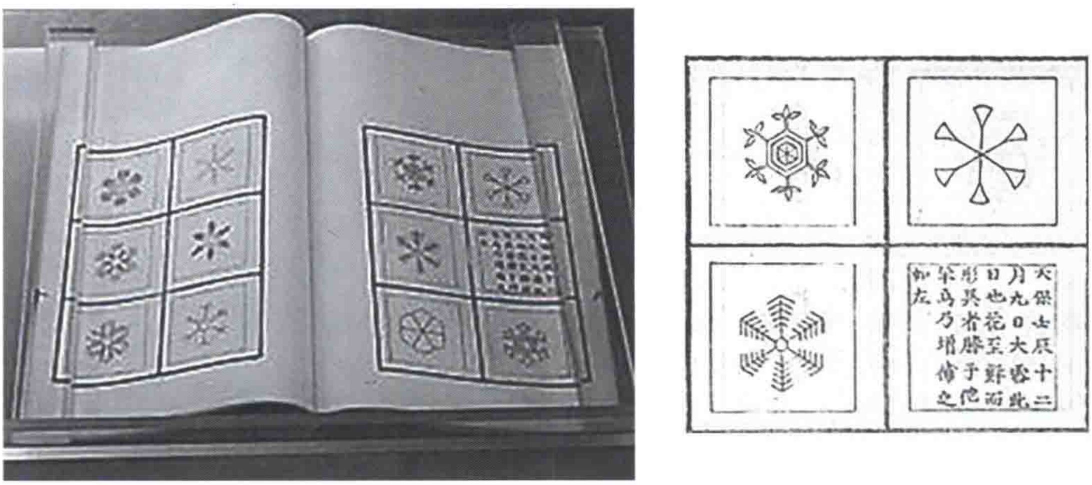


Fig. 2.14. Snow crystals from the book *Sekka Zusetsu* by Doi Toshitsura. (From an exhibit in the National Museum of Nature and Science, Tokyo, Japan.)

The *daimyo* (Japanese feudal lord) Doi Toshitsura wrote in 1832 the book *Sekka Zusetsu,* on snow crystals (Fig. 2.14). Note that in one of the pictures the branches are directed inward — a most unlikely situation, and probably never observed.

The English meteorologist and aeronaut James Glaisher (Fig. 2.15) published in 1855 a collection of snow crystals: *Photogenic Drawings of Snow Crystals, as Seen in January 1854.* The

Fig. 2.15. James Glaisher (1809–1903).

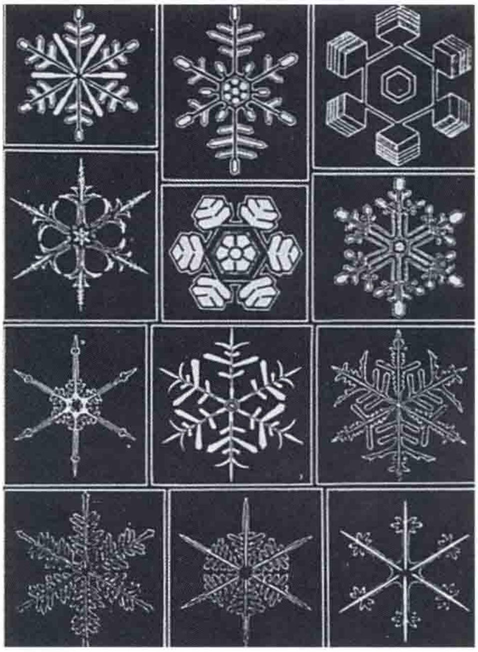


Fig. 2.16. Glaisher's drawings of snow crystals.

Fig. 2.17. Wilson A. Bentley (1865–1931).

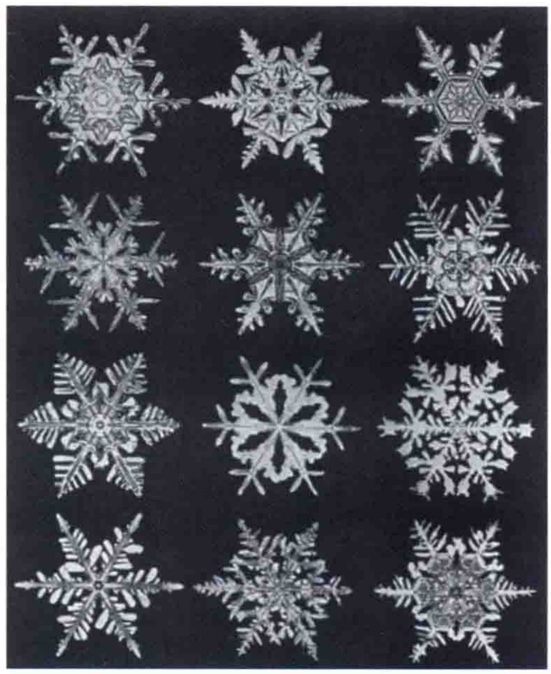


Fig. 2.18. Snow crystals by Bentley.

snow crystals shown in Fig. 2.16 were sketched by Glaisher and drawn properly by his wife, artist Cecilia Louisa Glaisher. These drawings of snow crystals are considered to be among the best ever published.

Wilson "Snowflake" Bentley from Jericho, Vermont, USA, was one the first known photographers of snowflakes (Fig. 2.17). He was a farmer without a scientific background. He attached a bellows camera to a compound microscope and, after much experimentation, photographed his first snowflake on January 15, 1885. For almost half a century Bentley captured and photographed more than 5,000 snowflakes. He poetically described snowflakes as "tiny miracles of beauty." He wanted them to appear "like diamonds on velvet," so he carefully cut the photographs and mounted them on black paper. His pictures were spread all over the world and published in many leading magazines. In 1931 the American Meteorological Society gathered the best of his pictures in a monograph illustrated with 2,500 pictures; a few are shown in Fig. 2.18. Bentley died of pneumonia at his farm on December 23, 1931, after walking home six miles in a blizzard. His book *Snow Crystals* was published shortly before his death.

3 Artificial Snow Crystals

Wilson A. Bentley's beautiful snow pictures inspired many scientists and artists, among them the Japanese nuclear physicist Ukichiro Nakaya (Fig. 3.1). In 1932 Nakaya got a position in the newly established science faculty at the university in Sapporo on the island of Hokkaido in northern Japan. No apparatus for research in nuclear physics was available there, so he directed his interest toward research material which was unlimited around Sapporo — *snow*. During a series of winters he made careful studies of snow crystals in the mountains around Sapporo and found that regular hexagonal crystals were not as common as more irregular ones. His findings and classification are summarized in Fig. 3.2. (New classification schemes have later been introduced. The widely used Mogano–Lee scheme from 1966 contains 80 types. K. Kikuchi, T. Kameda, K. Higushi and A. Yamashita have in 2013 suggested a global classification scheme with 121 types.)

Fig. 3.1. Ukichiro Nakaya (1900–1962).

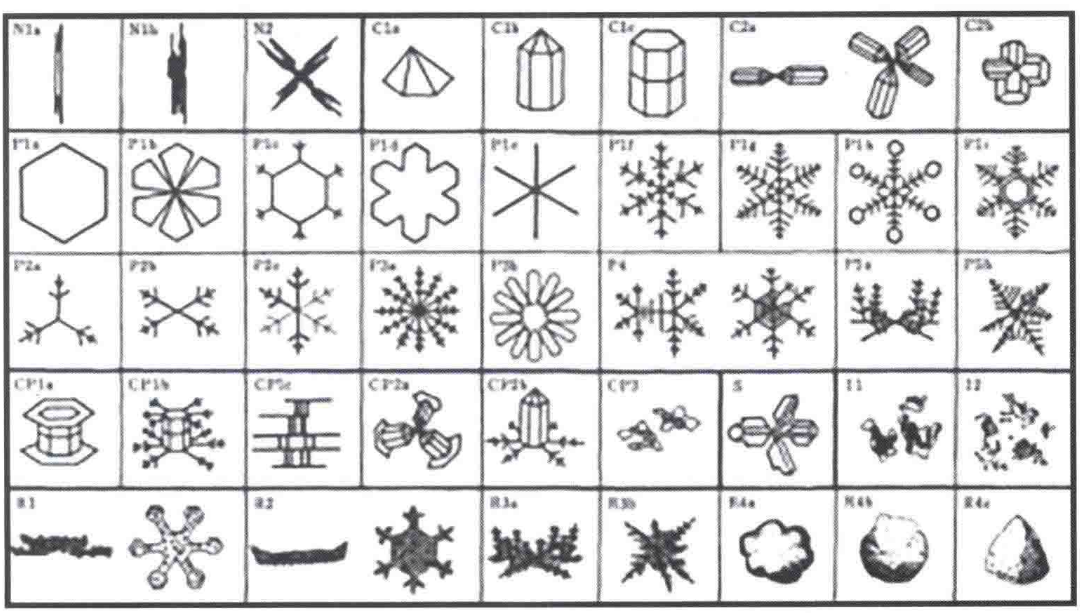


Fig. 3.2. Different snow crystal forms found by Nakaya.