

An astronaut examines the ATM preparatory to changing the coronagraph camera.

The Sun From Space

Solar astronomers have long sought a means of obtaining continuous high-resolution images of the solar corona without interference from the earth's atmosphere. Lyot's coronagraph, invented in 1930, allowed systematic studies of the structure of the solar corona and its changes over short periods of time. However, light scattered by the atmosphere and within Lyot's instrument (and subsequent coronagraphs) has limited ground-based observations to the innermost corona—less than two solar radii from the sun's center. Therefore, despite eclipse and coronagraph data, the detailed three-dimensional structure of the solar corona remains largely unknown.

Artificial satellites and spacecraft now offer a means of eliminating atmospheric scattering from long-term coronal observations. For several years staff members of NCAR's High Altitude Observatory have been working with Ball Brothers Research Corporation (BBRC) of Boulder, Colorado, on a coronagraph to be carried on an earth-orbiting NASA spacecraft. The instrument is a natural development of the HAO solar astronomy program and a direct descendant of HAO's balloon-borne Coronascope II, developed in the mid-1960s by Gordon Newkirk, John Eddy, and John Bohlin.

The orbiting coronagraph will be carried on the manned NASA satellite laboratory,

“Skylab,” scheduled for launch in the spring of 1973. Designs for Skylab include a workshop section with living and working space for three astronauts, smaller specialized docking and airlock sections, and the Apollo Telescope Mount (ATM). The ATM will provide a central spar on which several instruments can be mounted, an instrument temperature control system, four windmill-like panels of solar power cells, and a gyroscope system that controls instrument orientation. The six ATM instruments are:

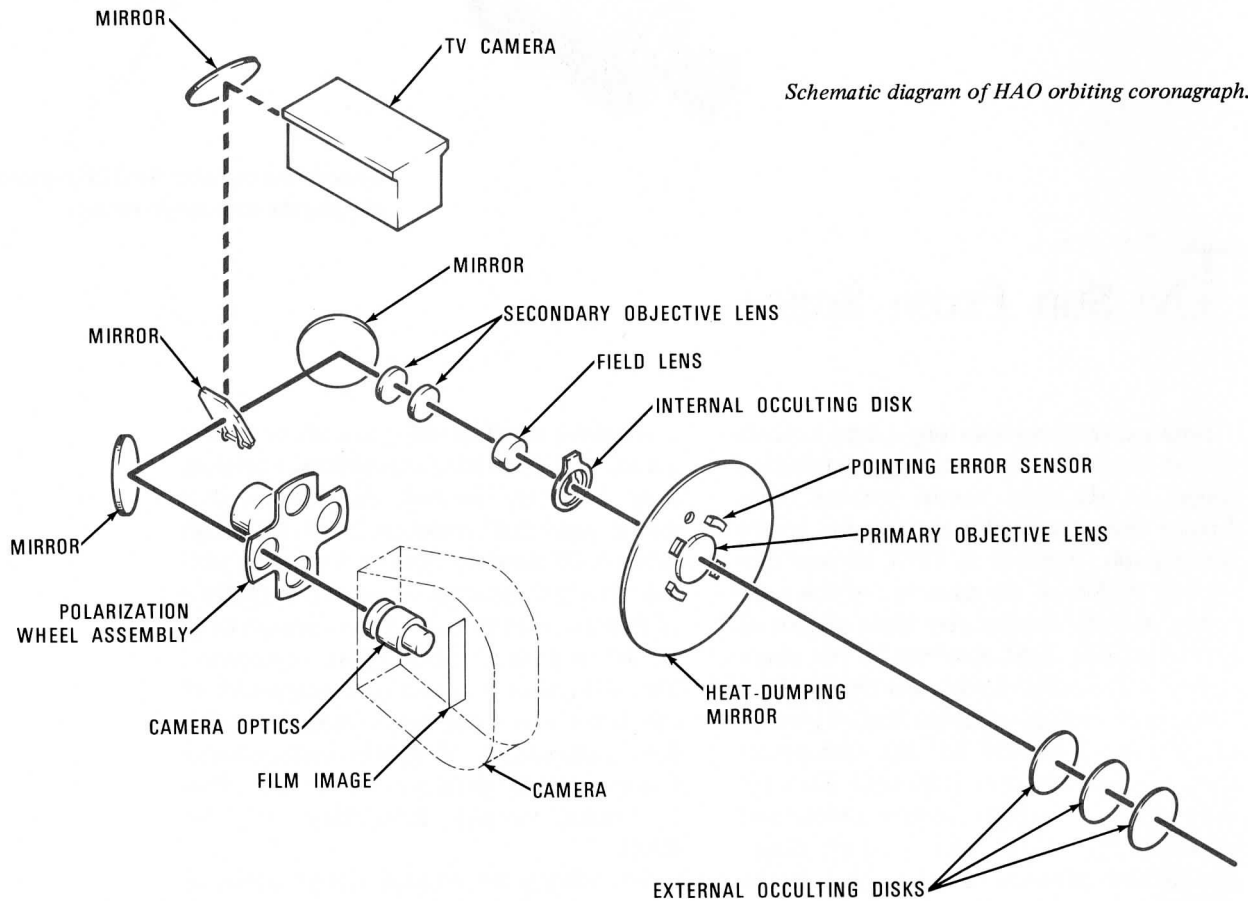
- White-light coronagraph (HAO)
- X-ray spectrograph (American Science and Engineering, Inc.)
- UV scanning polychromator/spectroheliometer (Harvard College Observatory)
- Dual x-ray telescope (NASA Goddard Space Flight Center)

- Extreme UV coronal spectroheliograph (Naval Research Laboratory)
- Extreme UV spectrograph (Naval Research Laboratory)

Coronagraph Development

In 1966 HAO contracted with BBRC for the engineering design, fabrication, and testing of the ATM coronagraph. HAO staff members, including Newkirk, Eddy, John Gosling, Charles Ross, and Robert MacQueen, have worked closely with BBRC on the project, and HAO has retained responsibility for the design and testing of the optical system.

The final ATM coronagraph design incorporates several features developed for the Coronascope II instrument. The optical



Schematic diagram of HAO orbiting coronagraph.

The National Center for Atmospheric Research (NCAR) is operated by the nonprofit University Corporation for Atmospheric Research (UCAR), and is principally funded by the National Science Foundation. Contracts, grants, and gifts are also provided by other government agencies, and by individuals, corporations, and foundations. NCAR participates in national and international research programs, as well as in joint research with universities and government agencies. All joint-use facilities of NCAR are available to scientists from UCAR member and non-member institutions (including private and government laboratories in the United States and abroad) on an equal basis.

Editor: William Dryer
Managing Editor: Halka Chronic
Contributing Editors: Robert Masterson
Halka Chronic

Art Direction: Bob L. Wyatt

National Center
for Atmospheric Research
Box 1470
Boulder, Colorado 80302

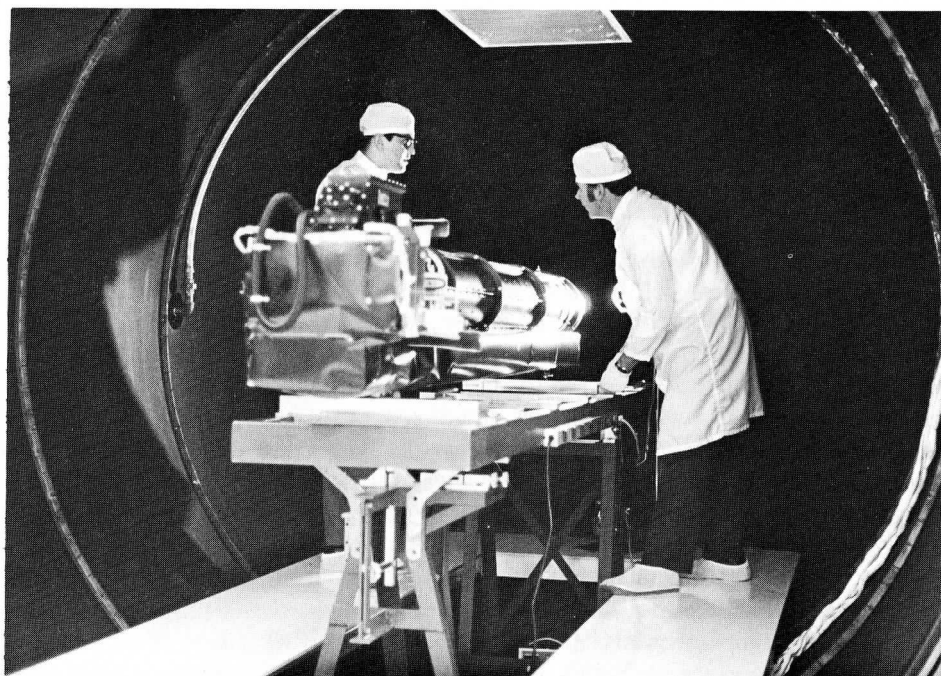
Published quarterly in February,
May, August, and November

Second class postage
paid at Boulder, Colorado

Sent without charge
on request

UCAR Member Universities

University of Alaska
University of Arizona
University of California
The Catholic University of
America
University of Chicago
Colorado State University
University of Colorado
Cornell University
University of Denver
Florida State University
Harvard University
University of Hawaii
University of Illinois
at Urbana-Champaign
The Johns Hopkins University
University of Maryland
Massachusetts Institute of
Technology
University of Miami
University of Michigan
University of Minnesota
University of Missouri
New York University
State University of New York
at Albany
University of Oklahoma
Pennsylvania State University
Saint Louis University
Texas A&M University
University of Texas
University of Toronto
University of Utah
University of Washington
University of Wisconsin



The flight coronagraph is positioned in the HAO vacuum tunnel in preparation for final photometric testing.

system, basically a 3.2-cm coronagraph, includes both external and internal occulting disks and two alignment sensors to keep it aimed at the sun. A heat-dumping mirror prevents overheating of the coronagraph, a 35-mm camera records coronal images, and a television camera provides an image for monitoring instrument operation. The entire unit weighs approximately 130 kg.

Because of the new and complex problems involved in designing a sophisticated astronomical instrument that can survive the stresses of a rocket launch and operate in the harsh environment of space, four models of the coronagraph were constructed: a thermal-mechanical model (an assembly of components closely approximating the mechanical structure, thermal capacity, mass distribution, and electrical power consumption of the coronagraph); a flight verification unit (a full-scale working coronagraph not qualified for extended operation in space); a fully tested and flight-qualified prototype to be used as a backup unit for the flight instrument; and the flight unit itself. The prototype was delivered to the NASA Marshall Space Flight Center in Huntsville, Alabama, in May 1970; the flight unit was delivered in February 1971.

Coronagraph Testing

Extensive tests carried out with the thermal-mechanical model and the flight verification unit were an important part of the coronagraph design and development program. The thermal-mechanical model was subjected by BBRC to nearly a year of tests simulating the radiation, vacuum, and vibration to which the coronagraph will be exposed in operation.

The flight verification unit was tested at the BBRC laboratory and was used in two photometric tests. In the first of these tests, carried out by HAO, the light-scattering characteristics of the instrument were evaluated in a 30-m-long vacuum tunnel constructed at HAO. The test revealed sources of stray light within the instrument and enabled reduction of the scattered light to a level significantly below that of previous coronagraphs.

For the second test, performed jointly by HAO and BBRC, the flight verification coronagraph was flown on a balloon gondola to an altitude of 36 km. At this altitude, above 99% of the atmosphere, the environment is almost identical to that at satellite altitude. During the 6-hr flight, photographs

of the solar corona were obtained that showed streamers out to six solar radii— unquestionably among the best photographs ever obtained with any coronagraph. In addition, coronal photographs were made with the external occulting disks intentionally misaligned and the instrument intentionally mispointed. During Skylab operations the astronauts will use these photographs to diagnose the causes of poor coronal images as seen on the coronagraph television monitor.

The Skylab Program

Until the time of the Skylab launch in 1973 the flight unit will undergo further testing. NASA, with the close cooperation of MacQueen, Ross, and other HAO staff members, will plan the coronagraph experiment down to the last detail. HAO is also participating in preparations for film processing and analysis and in training the astronauts who will operate the orbiting coronagraph. During the winter of 1970-71, Frank Orrall (an HAO visitor from the University of Hawaii) presented a ten-week course in solar physics to the Skylab astronauts at the NASA Manned Spacecraft Center in Houston, and MacQueen presented detailed briefings on the coronagraph operation.

The present Skylab schedule calls for three low-earth-orbit missions at an altitude of about 435 km. The workshop cluster will be placed in orbit by a Saturn V rocket; an Apollo Command and Service Module (CSM) carrying a crew of three astronauts will then be orbited by a Saturn IB rocket and will rendezvous with the workshop cluster to complete the Skylab.

For the first mission, the crew will spend 28 days in orbit, performing scientific experiments and engineering studies in space technology, biomedicine, physics, and astronomy. They will then return to earth in their CSM. During the second and third missions, new CSMs will dock with the Skylab and new crews will spend 56 days each in the Skylab.

The ATM Coronagraph Experiment

The objective of the ATM coronagraph experiment will be to monitor (in the 4000- to 6000-Å range) the brightness, form, and polarization of the solar corona in the region between 1.5 and 6 solar radii from the sun's center. To accomplish this, the Skylab astronauts will carry out patrol observations twice daily to obtain synoptic coronal data and will film rapid sequences of fast-moving coronal phenomena as opportunities arise. To facilitate their observations of rapidly changing coronal features such as solar flares, ground-based observatories (including NCAR's solar observatory at Mauna Loa) will inform the astronauts whenever such features appear on the sun.

The motorized 35-mm cameras that will be used with the ATM coronagraph were developed and built by BBRC under a separate NASA contract with HAO. Four pre-loaded cameras, sealed to prevent contamination, will be used during each Skylab mission. As each magazine of film is completely exposed the entire camera assembly will be changed by an astronaut, and at the end of each mission, the four cameras and their exposed film will be brought to earth by the Skylab crews and delivered to HAO personnel for examination and analysis.

If the present NASA schedule is followed, the HAO coronagraph should be in orbit by May 1973. In the first 28-day mission the coronagraph will produce more photographs of the solar corona than have been taken during all the natural eclipses since eclipse photography began in 1851. These photographs should contribute significantly to our understanding of the relationship between coronal features, solar magnetic fields, and solar activity and should provide a new source of information about the evolution of coronal features and the connection between the corona and the solar wind. These questions in turn relate to the mechanisms by which bursts of solar activity influence the structure of the earth's magnetic field and the general circulation of the earth's atmosphere.

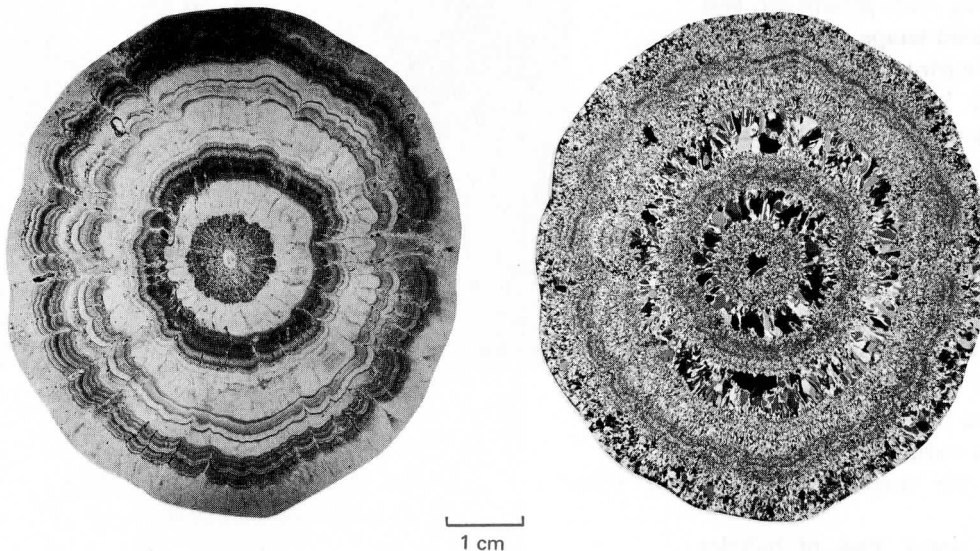
Deciphering Hailstones

“... and if, besides the nucleus, which is often snowy in large hailstones, there exist several snowy layers separated by compact layers, this would seem to indicate several oscillations and a see-saw battle between the force of gravity and the contrary push of the ascending current.”

Thus did P. H. Maille, an otherwise obscure Frenchman, propose a theory of hail formation which was to permeate hail literature for more than a century. The origin of hailstones by accretion of supercooled cloud droplets, alternately lifted by violent updrafts and dropped again through the freezing level,

seemed to solve the problem posed by the concentric layering of clear and opaque ice in hailstones.

During the last 25 years many long-range hailstone studies directed toward techniques to suppress damaging hail have revealed that Maille's up-and-down theory is not necessarily true; the layering in hailstones may develop from inhomogeneities in the clouds through which they fall. But there is no doubt that hailstones do record their own histories, chronicling for those who can decipher their code the atmospheric conditions in which they form and grow.



Hailstone sections are photographed under transmitted light and polarized light. Transmitted light shows the opaque, bubbly layers as dark bands (left); polarized light reveals that opaque layers are formed of multitudes of tiny crystals, while clear layers consist of fewer, larger crystals.

The Growth of Ice

Fundamentally, hailstones form by falling through clouds of supercooled water droplets, collecting droplets on their downward surfaces. Hail forms when cloud temperatures are between 0 and -40°C —the temperatures at which supercooled water droplets exist. Although in a violent updraft the hailstones may have a net upward motion relative to the earth, their motion is always downward relative to that of the water droplets in the cloud, so in effect they always “fall” through the droplets.

Wind tunnel experiments show that the nature of ice grown from accreted droplets depends on environmental temperature, ice temperature, and the amount of supercooled moisture available. Recent work by Levi and Aufdermaur at the Swiss Federal Institute for Snow and Avalanche Research suggests that large crystals (over 2 mm in diameter) normally form at environmental temperatures above -15 to -24°C , while at lower temperatures much smaller crystals develop.

The mode of growth is further indicated by the clearness or opaqueness of the ice. Opaque ice forms by riming, the rapid dry accumulation of discrete droplets in a lattice loose enough to enclose air. Such growth can best take place in low cloud temperatures (below about -20°C) in an environment of very fine supercooled droplets, but the important factor controlling dry growth is the temperature of the ice surface. Droplets must freeze almost on impact despite the release of latent heat of fusion.

Clear ice, on the other hand, forms by wet growth, with thin surface films of liquid water, when the temperature of the surface of the growing ice is not far below 0°C . This surface temperature can occur when liquid water is so abundant that the release of the latent heat of fusion warms the surface of the ice to well above the temperature of the environment.

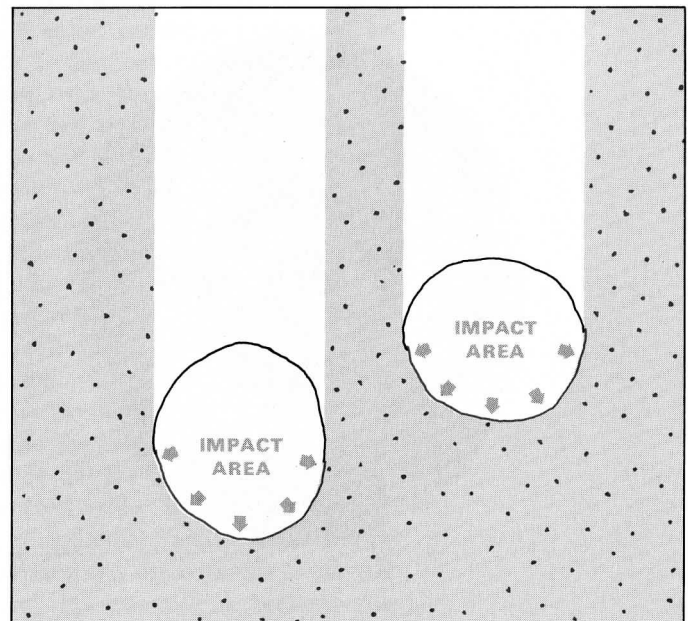
Many hailstones reveal lines of bubbles suggesting the previous existence of cracks, indicating that they formed from spongy ice containing internal water. When the liquid water froze, expansion caused the surrounding ice to crack. Spongy ice forms when the ice surface temperature is right at 0°C .

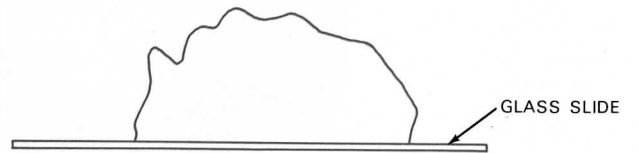
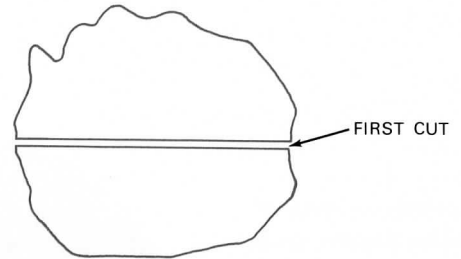
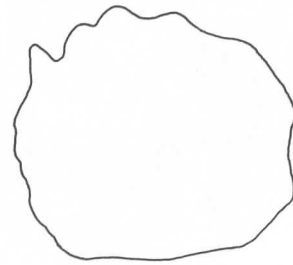
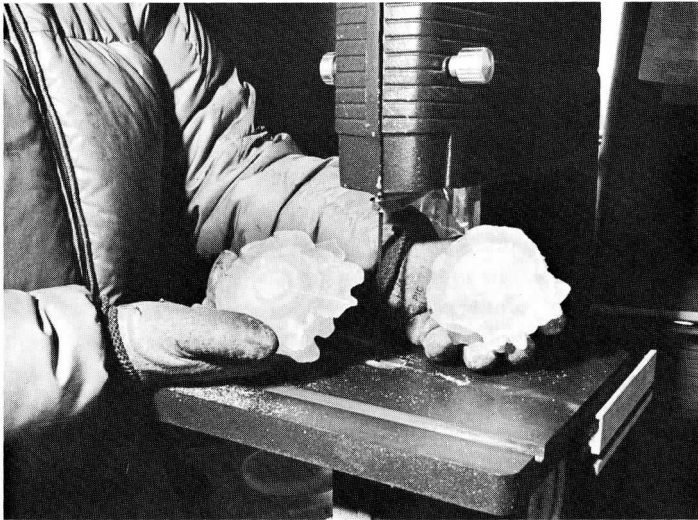
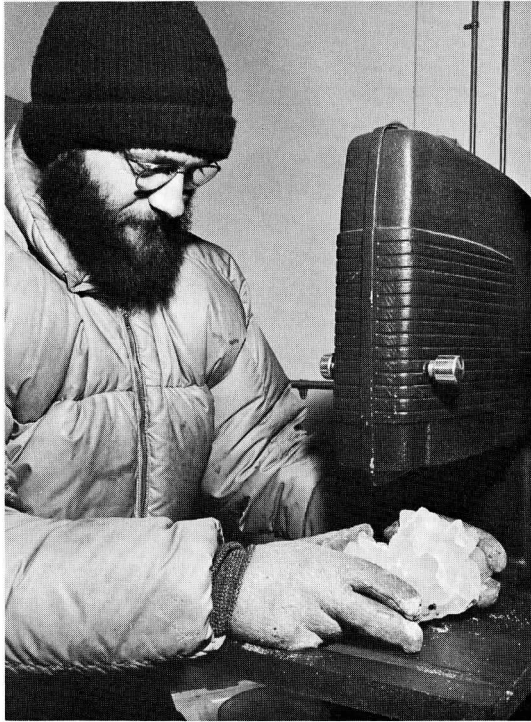
Hailstone Research at NCAR

At NCAR, Charles and Nancy Knight have examined more than 400 hailstones from 40 storms in the United States and elsewhere; many of the stones are large (2 - 15 cm in diameter) and lend themselves well to detailed investigations relevant to the search for ways to modify damaging storms. Applying crystallographic techniques to analyses of hailstone structure, they have been able to describe many features of the hailstones' histories.

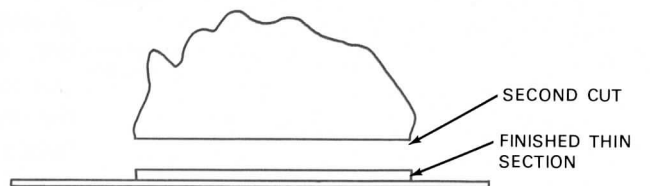
At the heart of almost every hailstone the Knights have found a distinct growth unit 5 - 10 mm in diameter and conical or spherical in shape, which they refer to as the hailstone embryo. (The word embryo has also been

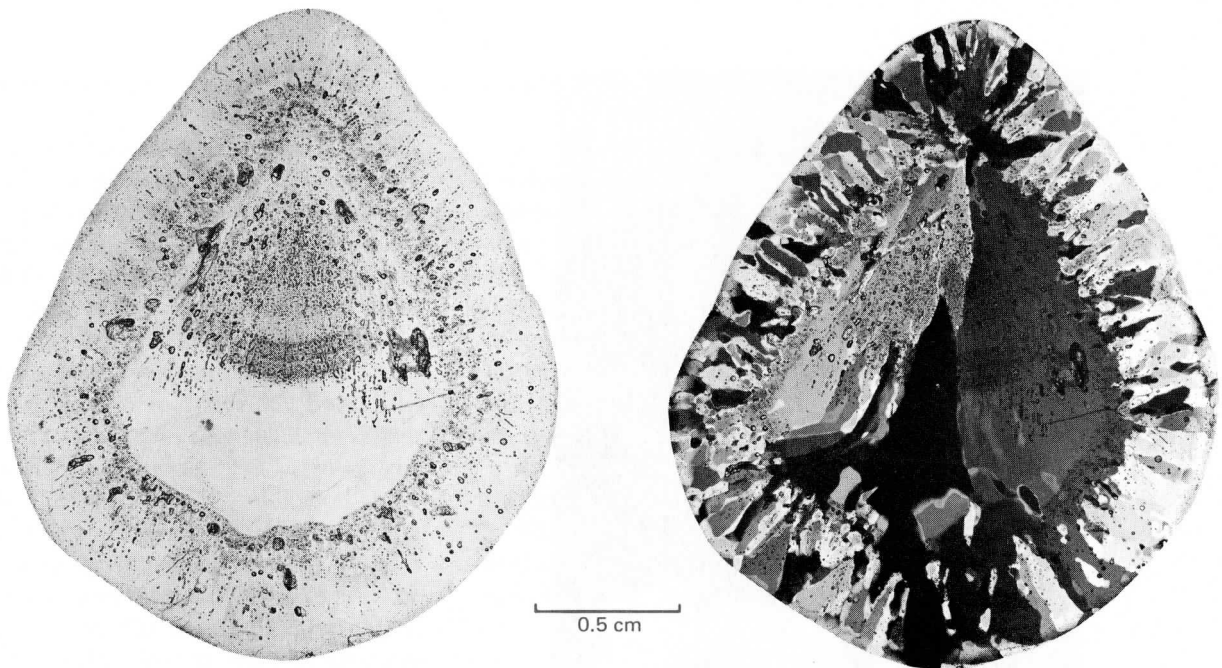
Hailstones falling through supercooled cloud droplets gather ice primarily on their lower surface. In an updraft, both hailstones and droplets may actually have a net upward motion.





Thin sections of hailstones are prepared at below freezing temperatures in NCAR's cold room.



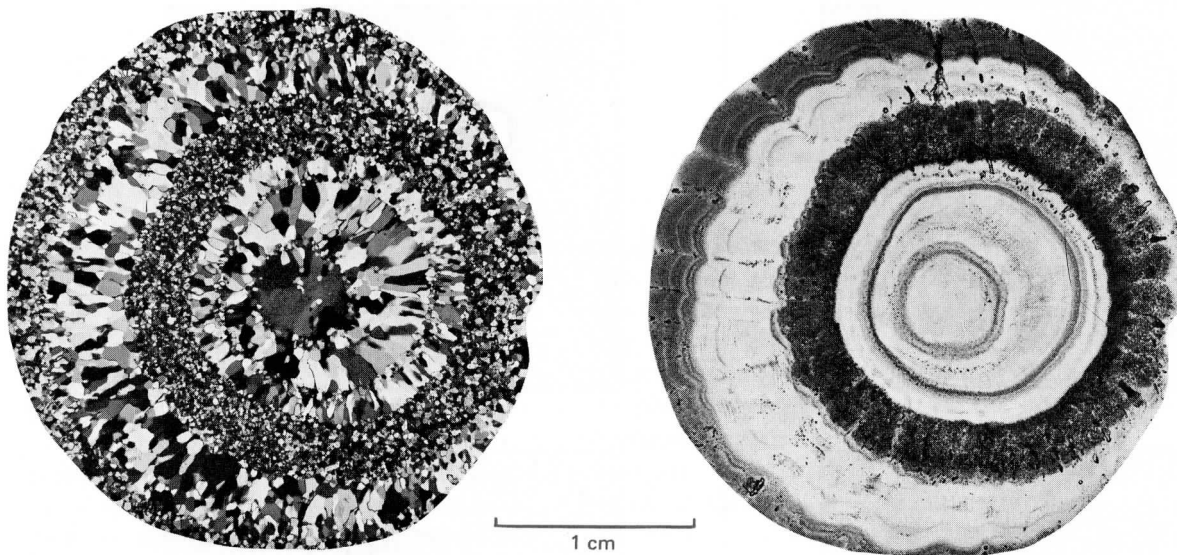


*The conical embryo of this hailstone is formed of a few very large crystals.
Crystals of a later growth layer are somewhat smaller.*

applied by some authors to the tiny first-frozen crystal of a hailstone.) It used to be thought that hailstone embryos were frozen raindrops, but the Knights have evidence that they probably are not: the embryos are consistently larger than raindrops and the ice within them usually shows crystal patterns that derive from accretion rather than from sudden freezing. Three types of embryos are common:

- *Conical embryos* (in 60% of the hailstones studied by the Knights). These embryos usually consist of crystals larger than 2 mm in diameter, or even of a single crystal, and so they must have formed at environmental temperatures above about -20°C . But they are formed of opaque ice, which results from dry growth, so the surface of the growing embryo must have been well below 0°C . Some conical embryos show alternate arcs of clear and bubbly layers, as if at times the surface temperature of the hailstone fluctuated.

- *Spherical embryos of clear ice* (in 25% of

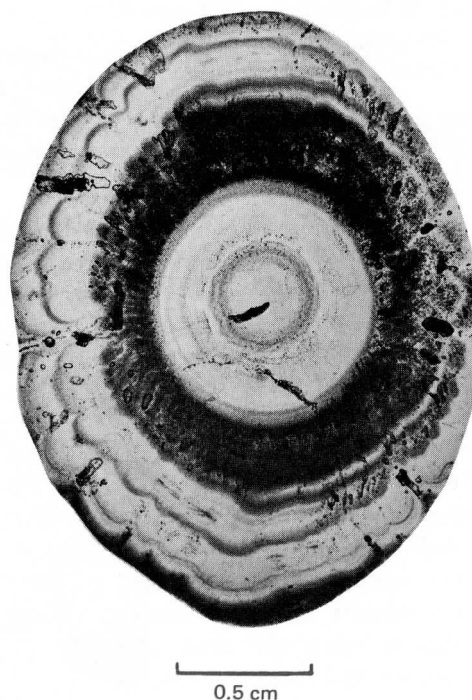


A hailstone with spherical embryo shows especially well the correlation between crystal size and bubble content. Note the lobate structure of the outermost growth layers.

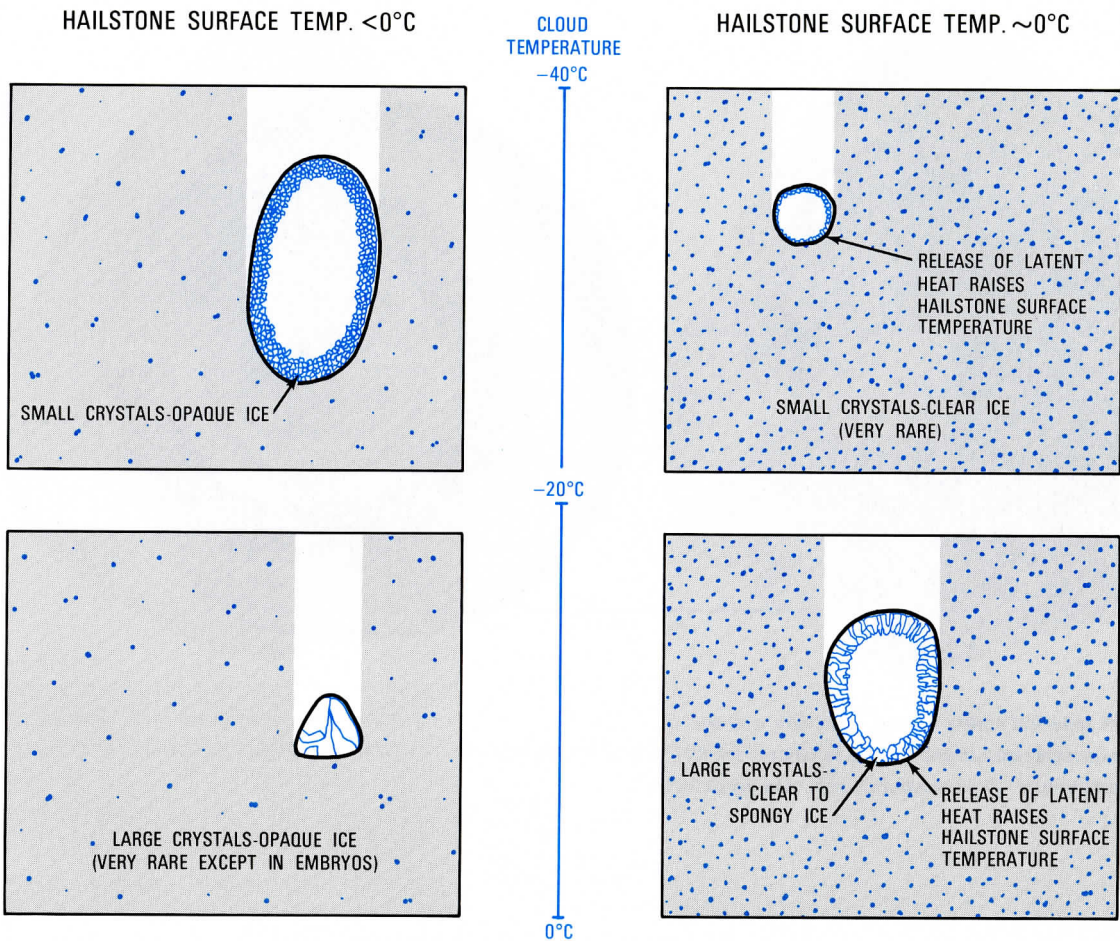
the hailstones studied). Like many of the conical embryos, these may consist of large crystals or of a single crystal, indicating growth in clouds with temperatures above about -20°C . Many clear spherical embryos show distinct cracks, indicated by lines of bubbles, resulting from freezing of spongy ice formed when the hailstone surface temperature was 0°C .

- *Spherical embryos of opaque ice* (in 10% of hailstones studied). Crystal size in these embryos is usually intermediate and the bubbles do not show any particular arrangement. They may have had a more complicated origin than other types of embryos, possibly involving partial melting and refreezing or even collection of snow crystals.

The difference in shape between conical and spherical embryos seems to result from their mode of fall: conical embryos fall in a stabilized position, blunt end downward, collecting droplets primarily on one surface, while spherical embryos tumble as they fall and so collect droplets equally on all surfaces.

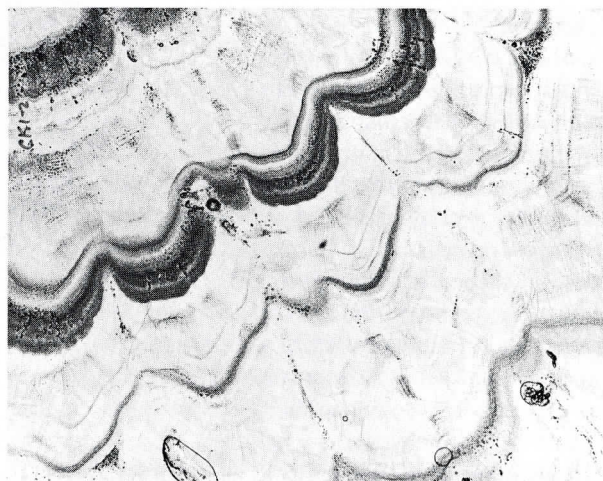


The embryo of this hailstone is almost perfectly spherical. Formed of clear ice, it reveals several cracks caused by the freezing of internal liquid water.



One of the problems in hailstone research is the relationship between crystal size and bubble content. Laboratory experiments show that cloud temperature controls crystal size, while hailstone surface temperature (largely a function of the rate of accretion) determines whether clear, bubbly (opaque), or spongy ice is formed. However, examination of natural hail shows that small crystals rarely occur in clear ice, or large crystals in opaque ice.

Well defined lobes are emphasized by accretion of droplets approaching a hailstone at varied angles. Cusps between the lobes are sheltered from low-angle approaches, so the lobes grow faster and become more pronounced. During the later wetter growth this pattern is lost and the lobes tend to become icicle-like.



Growth of Hailstones

In hailstones, embryos always appear to be distinct from subsequent growth. Just why this is we don't yet know. Possibly the embryos, once formed, are injected into a different part of the cloud system, where later growth takes place.

Even though the conditions for embryo development may not be identical with those for accretion of subsequent layers, the clues used to decipher the origin of hailstone embryos can be applied to studies of further hailstone growth:

- Clear ice indicates wet growth (about 0°C hailstone temperature).
- Opaque ice indicates dry growth or riming (cold hailstone temperature).
- Large crystals indicate cloud temperature above about -20°C.
- Small crystals indicate cloud temperature below about -20°C.
- Cracking occurs when wet, spongy ice formed at a hailstone surface temperature of 0°C subsequently freezes.

Simplified interpretations of hailstones suggest that opaque layers form in cold portions of a cloud and that clear layers form in lower, warmer cloud areas. But experimental evidence and observations of layered ice deposits on aircraft show that layering may result from variation in the moisture content of a cloud, for as accretion occurs, the heat of fusion is released at the hailstone surface. Therefore, increased liquid water concentration in the cloud, which speeds up accretion, may bring about a clear ice or spongy ice layer, while decreased liquid water may produce an opaque layer.

Tumbling

The Knights have found ample evidence that most large hailstones (those over 2.5 cm in diameter) tumble as they fall. The growth layers in these hailstones are more or less

concentric, showing that all sides of the stone were exposed to accretion. Completely random tumbling would produce perfect, spherically symmetric hailstones, but growth layers in the hailstones studied by the Knights are *not* perfectly symmetrical, nor are the stones themselves spherical (they tend to be slightly elongate and flattened), so tumbling in stones of this size is apparently somewhat systematic.

The Knights have also observed that growth layers in hailstones frequently show a sharply cusped lobate pattern. Minor surface irregularities have been emphasized by accretion. This could happen only if the accreting droplets approached the hailstone surface at varied low angles, as they would during tumbling fall. (A few hailstones develop long lobes resembling icicles. These derive from wet and often spongy growth with mobile liquid layers forced to flow toward lobe tips during fall. The two types are readily distinguished in thin sections.)

The Knights feel that rapid, somewhat systematic tumbling, spinning, and wobbling with the short axis predominantly horizontal could explain all the growth features they have observed. This tumbling may be particularly sensitive to minor changes in surface roughness, density distribution, and overall shape of the hailstones. Hailstone terminal velocities are also sensitive to these factors and so have important implications for hailstone and hailstorm interpretation.

The Knights' work points up the importance of studying individual hailstones in the search for significant information about their development, about their fall velocities and falling behavior, and about heat transfer and droplet collection rates. The shape of hailstones, their symmetry, growth features, and crystal fabric may hold the answers to many of the unsolved riddles posed by hailstorms, and perhaps will be the key to man's ultimate control of damaging storms.

Notes

New Computer Installed

NCAR's new Control Data 7600 computer is now being installed in the computing area of the NCAR Mesa Laboratory. The 7600 will offer NCAR and university users several new features, and will multiply NCAR's computing power by a factor of about six. Since the data input-output systems of the new computer are not significantly faster than those of the present 6600, the 7600 will be used primarily for problems which require large amounts of computing and comparatively little data input or output. Such problems include simulation and real data experiments with the General Circulation Model (GCM), testing of global observation systems for GARP with the GCM, problems in atmospheric turbulence and convection, and development of a hydro-magnetic model of the sun. Both the 7600 and 6600 computers use the same computer language and control cards and the two computers will ultimately be interconnected with a single data input system.

The Computing Facility plans eventually to install several remote terminals connecting with the 7600/6600 system, enabling frequent users to communicate with the computers directly. The first of these terminals, at NCAR's 30th Street laboratory in Boulder, should be in operation early in 1972.

HAO Summer Colloquium

This summer, NCAR's High Altitude Observatory will host a colloquium on Spectral Line Formation in Magnetic Fields. The program for the colloquium is being planned cooperatively with the Joint Institute for Laboratory

Astrophysics. About 40 invited participants specializing in radiative transfer or in magnetic field measurements will meet at HAO from 28 August to 1 September for discussions. As in previous colloquia in this series (held in 1968 and 1969), emphasis will be placed on discussion and review papers rather than on a collection of many short contributions. The intent of these colloquia is to provide a forum for thorough discussion of recent developments of fundamental interest in the subject area.

Members of the organizing committee for the colloquium are Grant Athay, Lewis House, and Gordon Newkirk of HAO, and Richard Thomas, John Jeffries, and Jean-Claude Pecker from JILA.

Summer Institute on Planetary Physics

A summer institute on planetary magnetospheres and auroras is being sponsored jointly by NCAR's Advanced Study Program, the Astro-Geophysics Department of the University of Colorado, and the National Oceanic and Atmospheric Administration. Morning lectures and afternoon discussions will cover such topics as basic magnetospheric and auroral processes, wave-particle interactions, diffusion of trapped particles, magnetospheric models, and auroral aeronomy. W. I. Axford of the University of California, San Diego, C. F. Kennel of the University of California, Los Angeles, and A. Vallance-Jones of the National Research Council of Canada are the principal speakers. Other participants will be graduate students and postdoctoral scientists with interests in space physics, auroral physics, and plasma physics.