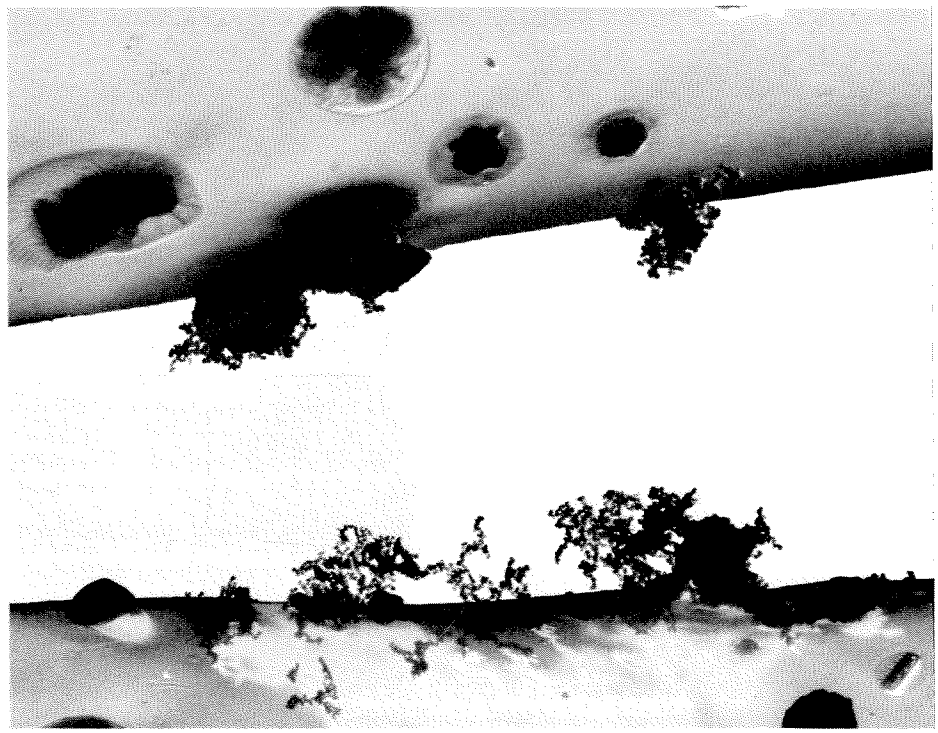
Research Notes

Clearing the Air for Pollution Standards

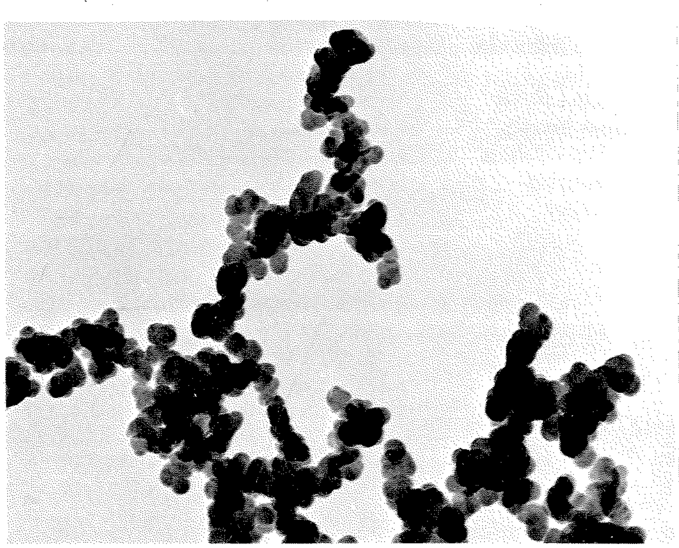
A key factor in government efforts to control pollution is the setting of standards for pollutant concentrations both in the environment and in emissions. The levels at which standards are set are usually imprecise because of difficulties in measuring environmental concentrations and effects.

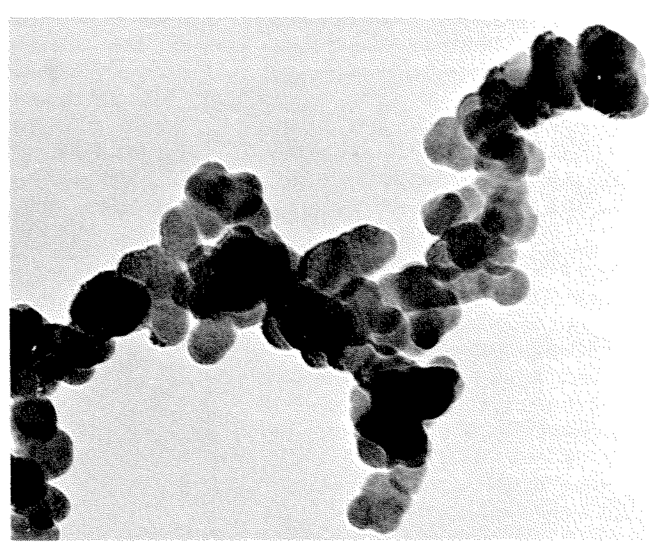
Nevertheless, decisions on standards have important implications for public health and the ecology; small changes in standards—an alteration of just a few percentage points in the amount of emissions, for example—may also mean millions of dollars spent on the purchase and development of new technology. With the costs of imprecise standards so great, it is essential to have as much information as possible before the standards are set.

The way to get this kind of information is to conduct long-term studies of the quality of the environment in the areas that will be affected by such standards. Obtaining this kind of comprehensive information about Los Angeles, the San Francisco Bay area, and the San Joaquin



Agglomerates of complex chains of lead halide particles are caught between two massive bars (which are really parts of a thin copper wire grid about a tenth of an inch in diameter). Solid particles like these make up 10 to 30 percent of the airborne particle mass that makes up smog; these samples were captured on the roof of Keck Laboratory on a thin transparent foil stretched across an electron microscope grid.



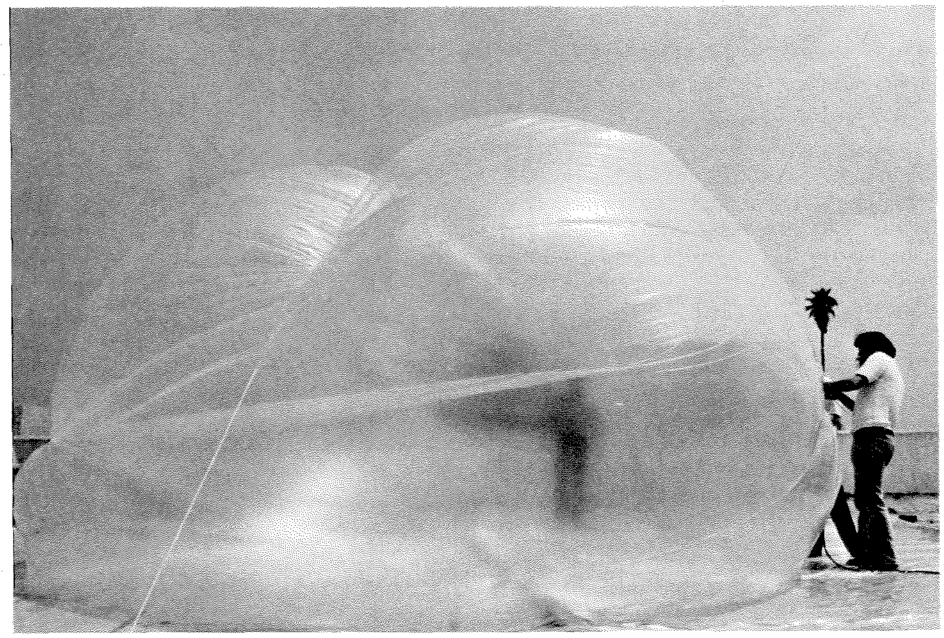


Closer (above) and still closer (right) views of the lead particles reveal what some of the particulates in the air we breathe really look like. The chains are formed when lead halides produced by automobile engines condense into spherical masses during combustion and link together in the tail pipe. Each sphere is about 150 Angstroms (six ten-millionths of an inch) in diameter.

Valley—California's three major air pollution basins, or areas of consistent and regular air circulation patterns —will occupy the time of at least 12 Caltech scientists over the next several years. Their research will be funded through two grants, one from the Rockefeller Foundation of New York for $150,000 and the other a portion of a $1,679,384 contract from the California Air Resources Board (ARB) to North American Rockwell Corporation (NAR).

The Rockefeller grant, which is for a one- to two-year period, will be used to start a study of the flow of pollutants, including lead and other metals, through the southern California environment. Principal investigators are Sheldon Friedlander, professor of chemical engineering and environmental health engineering; Norman Brooks, professor of environmental science and civil engineering; and James Morgan, professor of environmental engineering science. Other Caltech specialists engaged in the project include Sam Epstein, isotope geochemistry; R. B. Husar, aerosol physics; E. J. List, environmental fluid mechanics; Jack McKee, water supplies and wastes, and nuclear wastes; Wheeler North, marine biology; Clair Patterson, trace metals in the environment; and John Seinfeld, air pollution simulation and control.

Friedlander, Seinfeld, and Husar are also involved in the ARB-funded study, which is aimed at collecting, identifying, analyzing, and tracing aerosols in the state's three major smog basins. Aerosols



Rudolf Husar, research fellow in environmental engineering science, and his co-workers struggle with a 400-cubic-foot plastic balloon on the roof of Keck Laboratory. The balloon is used to capture samples of smog for analysis of how, where, and how fast particulates are produced in the Los Angeles Basin.

—particles suspended in the atmosphere—are the cause of the visible haze that hangs over most pollution-plagued cities. Aerosols are also the major transport mechanisms for heavy metals and non-volatile organic compounds through the air.

George Hidy, senior research fellow in environmental health engineering at Caltech and senior scientist at the NAR Science Center, is the principal investigator. Other Caltech researchers include Robert Lamb, chemical engineering research fellow; James Huntzicker, research fellow in environmental engineering science; and Steven Heisler, a graduate student in environmental engineering science.

The Rockefeller study is designed to serve as a pilot project for future large-scale environmental programs. It will provide an integrated picture of the pollutants through the total environment of the Los Angeles Basin—air, water, plants, animals, and man. It complements the ARB study as well as a southern California counties-sponsored study—the Southern California Coastal Water Research Project (SCCWRP). Headed by Morgan, SCCWRP will determine the trace-metal content of rivers during their winter-storm flow and how much of this they contribute to the ocean trace-metal content. The Rockefeller study will look at the contribution of sewage outfall and atmospheric pollution to the ocean trace-metal content.

Traditionally, such studies have been limited to one sector of the environment, such as the atmosphere. However, many persistent pollutants become widely dispersed through the total environment. Two types of substances have been selected for study—trace metals and their associated organic compounds. The metals include those with health and ecological significance—lead, zinc, barium, mercury, chromium, arsenic, and vanadium. Such pollutants are not biodegradable although they may change chemical form. The flow of associated organic compounds will also be investigated because of the potential biological importance of metal-organic compounds. It is hoped that data from the study will be used to help various governmental agencies set standards to control emissions of these metals.

The ARB study includes about 40 other scientists in addition to the Caltech investigators. They are associated with the California State Department of Health, the University of California at Riverside, the universities of Minnesota and Washington, the ARB, and Meteorology Research, Incorporated. The study has five major objectives: to determine the physical and chemical nature of the aerosols in the three basins; to determine what percentage comes from man-made sources and how much from natural sources and from processes taking place in the atmosphere; to identify the origins of the aerosols geographically; to estimate how better air quality standards can be achieved; and to improve instruments for monitoring stations.

Pollutants fed into the air from a wide variety of sources tend to fuse into aerosols, which grow and change constantly, becoming very complex chemically. They are composed of man-made pollutants, nature-made particles, and those produced by photochemical reactions in the atmosphere. Chemical analysis of the aerosols will help reveal their origins. Friedlander's laboratory will provide one of the two permanent monitoring stations in the Los Angeles Basin. The other will be at UC, Riverside. A mobile station in a large trailer will sample air in downtown Los Angeles, El Segundo, and Downey.

In some instances the atmosphere will be sampled continuously for 24 hours so that the evolution of aerosols can be mapped. Sampling will be done on the most and least smoggy days. Wind patterns, temperatures, and humidity will be monitored and compared with smog patterns. The sampling phase of the comprehensive project will continue for the rest of the year.

Checkup on Einstein

The studies of two Caltech researchers working independently—Cliff Will, instructor in physics, and Andrew Ingersoll, associate professor of planetary science—have recently produced evidence that favors Einstein's General Theory of Relativity over its many competing theories.

In 1915 Albert Einstein published his theory, which offered an entirely new view of gravitation (and, indirectly, of the universe), and scientists have been disputing it ever since. Einstein saw gravity as a property of space rather than as a force between bodies: As a result of the presence of matter, space became curved, and bodies followed the line of least resistance among the curves. Strange as this idea seemed, it explained things that the Newtonian law of gravity could not.

Nevertheless, there are now about 50 other serious theories—and literally hundreds of crackpot ones—that attempt to "improve" on Einstein's theory of gravity in various ways.

Working with Kenneth Nordvedt of Montana State University, Will has developed a kind of supertheory that tests various cosmological and gravitational theories for completeness, consistency, and accuracy. There is only one group of theories that meets the criteria set up by Nordvedt and Will—those theories which predict that gravity will bend light waves and produce the light shifts that appear to cause the planet Mercury's perihelion (its point of nearest approach to the sun) to change.

It is from this group of theories that the strongest competitor to Einstein's theory has arisen. It was proposed by physicist Robert Dicke of Princeton University in 1967. But if the calculations of Ingersoll and Gary Chapman, a solar astronomer at Aerospace Corporation, are correct, Dicke's theory is in error because it is based on a misinterpretation of data.

The cornerstone of Dicke's case against Einstein's theory is the mathematical prediction of the perihelion shift of Mercury. Long ago astronomers determined that the gravitational effects of the sun and planets accounted for all but a tiny fraction of the amount of the shift.

Einstein attributed the difference to relativistic effects and predicted that the value of this difference should be 43 seconds of arc every 100 years, which agrees with the observed value to the nearest second. In 1967 Dicke published a report claiming that about 3½ seconds of the 43-second shift comes, not from relativistic effects, but from the effect of the sun's equatorial bulge (oblateness)—which, according to Dicke, is five times greater than had been supposed.

Such a bulge would indicate that the sun's gravitational field is distorted, and such a distortion would have an observable effect on Mercury's orbit. If Dicke's conclusions are correct, then Einstein's prediction of Mercury's perihelion shift is wrong, and the basic assumptions underlying Einstein's theory must be re-examined.

In a recent issue of the *Astrophysical Journal,* Ingersoll and Chapman challenged the validity of the observations on which Dicke made his predictions. In their 1966 observations Dicke and his co-worker, H. Mark Goldenberg, had used a spinning disk on a telescope to mask out all but the sun's outer rim. They observed more light at the outer edges of the sun at the equator than at the poles, and attributed this to bulging at the sun's equator, due to a rapidly rotating inner core.

To check these observations, Chapman and Ingersoll examined photographs of the sun taken at Aerospace Corporation's San Fernando Observatory on the same days in 1966 on which Dicke had observed. They found that there was indeed more light being emitted from the equatorial regions, but they considered it evidence not of bulging but of large numbers of faculae—bright clouds that often appear near sunspots and that seem to be more concentrated at the sun's equator.

Dicke had discarded the data on faculae, but Ingersoll and Chapman fed their observations of faculae into a computer and compared them to the original measurements of brightness by Dicke and Goldenberg. It was found that there was a close correlation between the two signals.

This is evidence, Chapman and Ingersoll believe, that Dicke had simply observed more faculae at the equator and not an excess bulge. If they are right, Einstein's theory has survived another challenge.

However, there are large uncertainties in both the original and computer-simulated signals, and the possibility that the sun is really oblate still remains. But it must be oblate by a much smaller amount than Dicke originally claimed.

A Revised View of Mars

After a summer of analyzing thousands of feet of computer print-outs and thousands of photographs, Mariner 9 scientists at the Jet Propulsion Laboratory are busy revising their views of Mars—again.

The early unmanned probes of Mars by Mariners 4, 6, and 7 seemed to deflate the beliefs of many who believed life was possible on that planet. Investigators concluded that Mars was an ancient planet, a product of the accumulation of cosmic debris; that it was cold and dead; that there was no water on it; and that there was no possibility of an atmosphere suitable for life.

But the data from Mariner 9 indicate that Mars is, on the contrary, a young planet with considerable variation in topography and climate; that it has had recent tectonic activity, evidence that it is not cold and dead geologically; that there is water vapor in the atmosphere and signs of water erosion in the past on the surface; and that there are faint traces of ozone, a molecular form of oxygen, in the atmosphere, an indication that in the past it may have been more hospitable to life.

As a result, some scientists are a little more optimistic about the chances of life—no matter how primitive—being found on Mars when two unmanned Viking spacecraft land on the surface in 1976 and 1977.

The 7,200 photographs returned by Mariner 9 have been used to piece together a map of the planet's surface. From these photographs, JPL scientists have identified four major types of terrain on Mars.

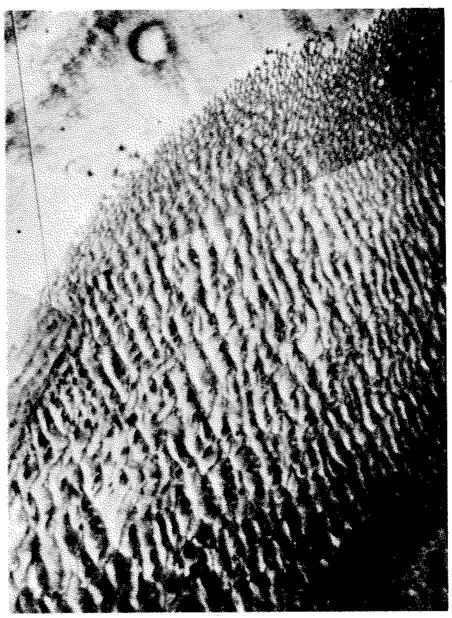
The first of these types is volcanic. These areas include the most prominent of the volcanic peaks, Nix Olympica. The caldera, or crater, formed by the collapse of the central part of this volcano is 315 miles wide at its summit, twice as wide as that of the volcano that formed the Hawaiian Islands. One of the measures used to determine planetary age, the frequency and number of meteorite impacts, indicates that the region is a rather young feature. But scientists have been unable to determine how young because Mariner 9's sensing devices have detected no clear-cut indications of heat sources such as from geologically recent active volcanoes.

The second type is an equatorial plateau area marked by deep canyons and great cracks, or faults, in the crust—evidence of significant tectonic activity during the recent history of Mars. The features of the Martian Grand Canyon, ten times the length of our own and three times deeper, include a network of tributaries to the canyon and a delta-like region extending from its eastern end—evidence of possible water erosion.

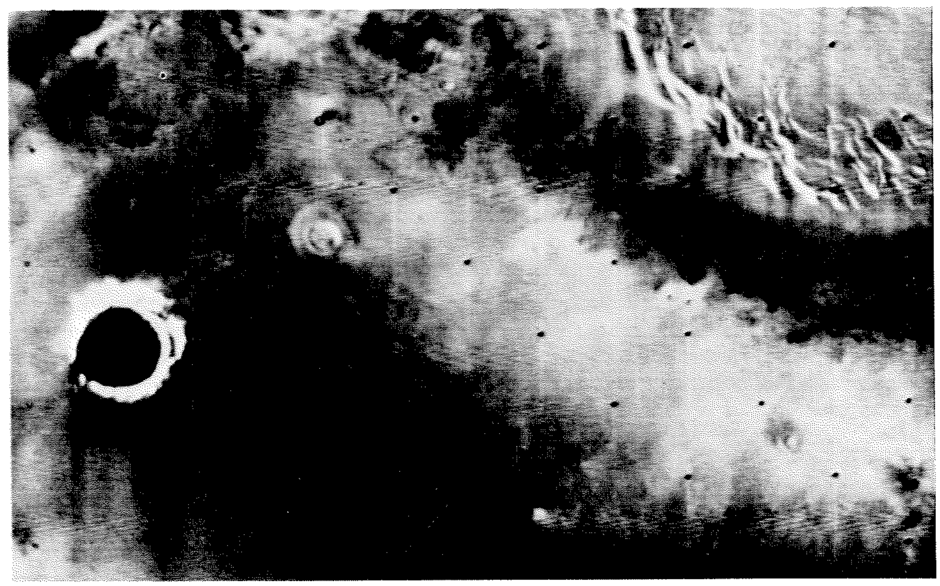
The third type of terrain, which seems to extend over half the planet, is a heavily cratered region that looks much like the broad plains of the moon. One of its many impact basins, Hellas, is larger than any similar basin on the moon. Great expanses of sand dunes are also seen in the area. This cratered terrain is thought to be the most ancient on Mars, because its many craters appear to have been eroded by wind, water, rain, subsequent meteorite impacts, and other as yet unidentified forces.

The fourth type is a spectacular expanse of stair-step terraces and deep grooves radiating from the south polar region. Scientists suspect that glaciers moving out from the polar ice cap gouged out the grooves and piled up rocky debris to form the terraces. Such terrain is an indication

This Mariner 9 photograph of the Martian atmosphere, taken along the rim of the planet, shows a double-layered haze that was at first thought to be dust. But scientists now think both layers may consist of water ice crystals. The lower layer rises about 9 miles above the surface; the upper layer is 28 miles high.



Dark spots observed in some of the bigger craters on Mars were a mystery until Mariner 9 cameras zeroed in on one and discovered it was a sand dune field reminiscent of the Mojave Desert. This one is roughly 40 miles wide and 80 miles long.



The first sign of spring in the northern hemisphere of Mars is the retreat of the northern polar ice cap (the curved swath through the center of the photograph). The crater on the left may possibly be rimmed with a deposit of water ice.

that Mars, like Earth, has had its ice ages and is now in a warmer period.

Other Mariner 9 findings include:

—Clouds containing water crystals which appear to form around large volcanoes. The source of the water could be the volcanoes themselves; on Earth volcanoes spew forth copious quantities of water and may have been the source of the oceans. However, it seems more likely to most investigators that the water vapor is from the polar regions.

—Ozone, which appears on a seasonal basis in the polar regions in amounts of about one part in a million. None has been detected in the warmer equatorial regions.

—A multi-layered haze structure over the north polar region that could consist of carbon dioxide and water moved by winds with velocities up to 300 miles an hour.

—Surface temperatures ranging from about 81 degrees Fahrenheit near the equator to –189 degrees at the poles. Although evidence of internal activity is growing, the infrared radiometer aboard Mariner 9 has not detected any internal heat.

Also, an increasing number of signs indicate that Mars has had considerable seismic activity. To check out the possibilities of both tectonic and volcanic activity, a set of miniature seismometers built at Caltech's Seismological Laboratory will be among the instruments aboard the Viking Lander probes. Designed by a multi-institutional research team headed by Don L. Anderson, professor of geophysics and director of the Seismological Laboratory, the devices are cube-shaped, five inches on a side, and weigh three and a half pounds.

Though the primary purpose of the seismometers is to record local quakes, they also can pick up average-size temblors originating anywhere on Mars. They can record ground motions as small as one twenty-five millionth of an inch. Each seismometer is, in effect, an electric generator driven by ground motion. When the ground moves, a weight in the instrument, supported by a string, tries to remain stationary while the rest of the instrument moves with the ground. This causes a coil to be pumped in and out of a magnet, generating an electric current. The greater the quake, the greater the current. Each cube contains about 54,000 transistors which will amplify the signal, digitize it, store it, and then transmit it from the Viking Lander to the orbiting portion of the spacecraft, which in turn relays the signal to earth.

In addition to measuring seismological activity, the instruments will register winds and meteorite impact. They will also provide valuable information about the planet's crust, as well as data about the composition and evolution of the interior and the evolution of the atmosphere.

In fact, the answer to whether Mars ever had an atmosphere suitable for life may depend on whether Mars has quakes. A geologically active Mars means life is more likely. Quakes would indicate that it has an unstable interior similar to Earth's which—eons ago—produced the hot gases that escaped to the surface to form oceans and an atmosphere.

How It All Began?

It has generally been assumed that the earth and moon were formed over a period of several million years by the coalescence of cold meteorite material long after the formation of the sun.

Satisfying as this theory is in many ways, it leaves many questions unanswered. For example, why does the earth have a solid inner core and a molten outer one, when common sense indicates that it should be just the reverse? And why are there so many chemical differences among the different classes of meteorites, among the planets, and in the surface geochemistry of the moon?

These enigmas could be explained if the earth-moon system was born very quickly—the earth in about 10,000 years and the moon in 2,000 years—from hot material that had just condensed from the solar nebula. This concept has now been proposed by Don L. Anderson, professor of geophysics and director of Caltech's Seismological Laboratory, and Thomas Hanks, research fellow in geology, in an article in the British scientific journal *Nature*. The theory is an elaboration of one proposed by Fred Hoyle of Cambridge, England, and its development by a group at Yale headed by Sydney Clark, Jr.

The Anderson-Hanks theory makes use of the temperatures at which different materials solidify from a gas to a solid. The two investigators assume that the minerals united into solid aggregates in the order that they solidified from the very hot whirling cloud of gas from which the solar system is believed to have been born some five billion years ago.

As the hot gas gradually cooled beyond the embryo sun, the first compounds to condense out of the cloud were those that were rich in calcium, aluminum, titanium, and the radioactive elements of uranium and thorium. They were converted from a gas to a solid when the cloud cooled to about 2,800 degrees Fahrenheit.

These compounds came together to form the nucleus of the earth, the moon, and the other planets. As all these newly formed objects orbited the embryo sun, they tended to attract and sweep up dust composed of these elements. The earth at that time was probably about 2,500 miles in diameter (roughly the size of the moon today) rather than its present 7,909 miles.

As the gas continued to cool, iron condensed out at about 2,500 degrees and was swept into the earth. Eventually the cloud cooled to about 2,000 degrees, and normal mantle silicates condensed to form the earth's mantle. The earth was fully assembled in the very short time—geologically speaking—of 10,000 years. At that time the deep interior of the earth was entirely solid. Then the radioactive materials in the nucleus heated up and melted the layer of iron and nickel outside the nucleus, a process that took about 300,000 years. When the iron melted, the material in the inner nucleus, because it was lighter in weight, rose to the top of the melted nickel-iron core, and the nickel-iron sank to the center of the earth, where it solidified because of the greater pressure there. This explains why the inner core is solid and the outer core molten. Some radioactive material may still be in the outer core, but most of it was plastered into the base of the mantle. A little may have melted its way up through the mantle in certain locations to start forming continents.

The Anderson-Hanks model of the earth's formation helps explain the chemical differences among the meteorites and among the planets by supposing that they accreted from material that condensed at different temperatures. Mercury, for example, has a different mix of elements and is smaller than the earth because solar radiation "blew away" the lighter elements before they had a chance to accrete to that planet.

The theory attributes the differences in size and composition of the moon and the earth to the fact that the moon formed at a later date and was in an orbit almost perpendicular to the plane of the ecliptic, where most of the planet-forming was taking place. The moon started accreting when the earth was about 50 percent assembled.

By this time the earth had swept up most of the iron. Even after the moon began developing, the earth still got most of the remaining iron and the silicates, because its orbit was largely in the high-density areas of the still-forming solar system, and the moon crossed those areas only twice a year. In the regions out of the plane of the ecliptic—where the developing moon was most of the time—there was only a hot gas of aluminum, titanium, and similar high-temperature condensates from which the moon could form. That process, calculated by Hitoshi Mizutani, a research fellow at the Seismological Laboratory, took about 2,000 years. Later, the effects of drag and collisions slowly reduced the moon's inclination from the perpendicular to its present orbit.