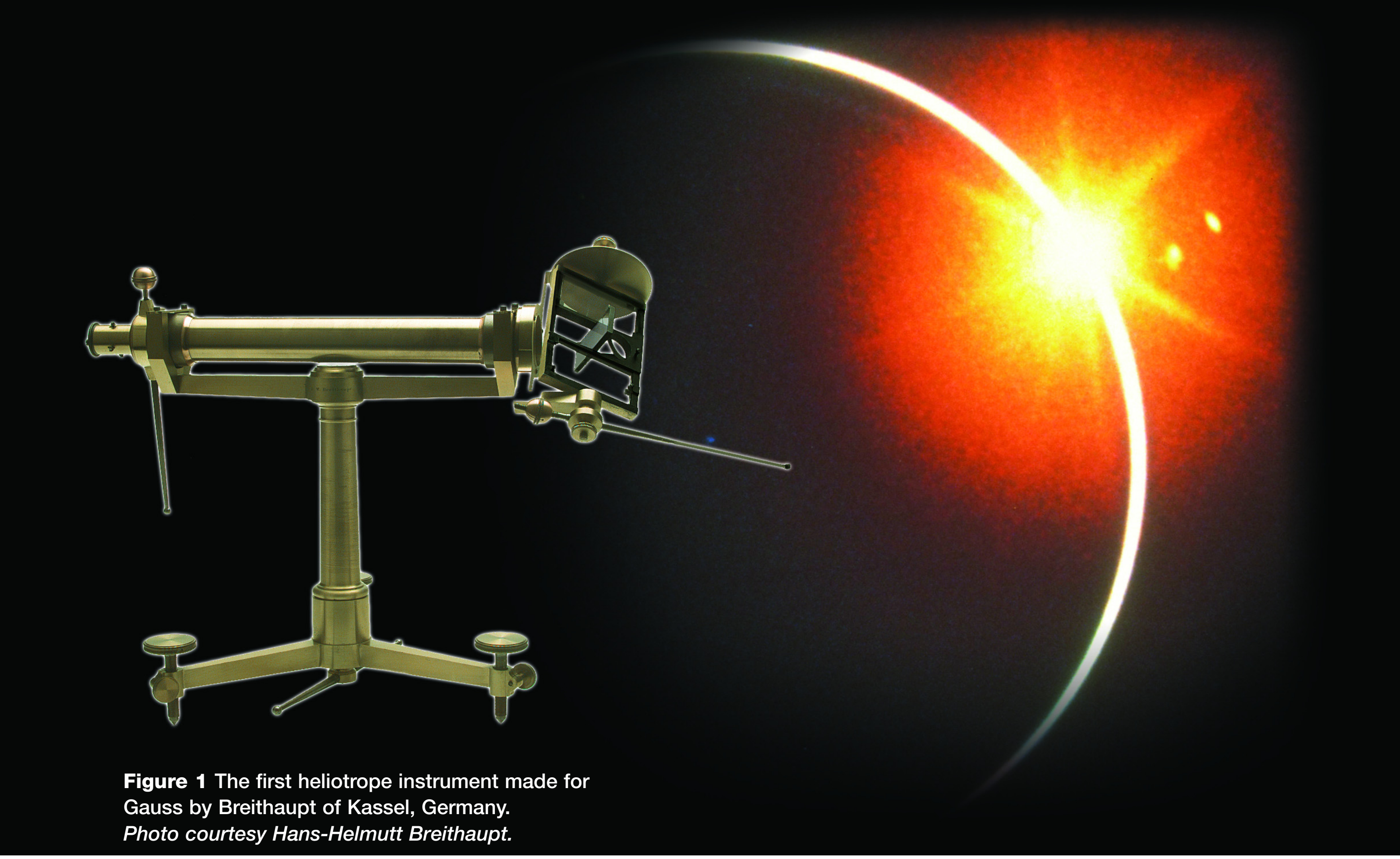

Figure 1 The first heliotrope instrument made for Gauss by Breithaupt of Kassel, Germany. *Photo courtesy Hans-Helmutt Breithaupt.*

The Surveyors' Heliotrope:

Its Rise and Demise

>> By Silvio A. Bedini

The name "heliotrope" in the English language is most frequently associated with a sweet scented flowering plant of the genus *heliotropium* [N.O. Ehretiaceae or Boraginaceae], in the sunflower and marigold family, the flowers and leaves of which turn and follow the sun. It is the name given also to a green semi-precious stone streaked with red known as bloodstone. According to *Webster's Dictionary*, it also is the name of "an instrument used in geodetic surveying for making long distance observations by means of the sun's rays thrown from a mirror." *The Oxford English Dictionary* provided additional detail, describing it as "an instrument used in surveying, an apparatus with a movable mirror for reflecting the rays of the sun, used for signaling and other purposes, especially in geodesic operations."

The heliotrope instrument, invented early in the nineteenth century, achieved importance in its time as a solution to a persistent annoying problem in surveying–dissatisfaction with existing methods for observing distant points. As a recourse, lamps or powder flares at night could be used. For example, Andrew Ellicott (1754-1820) in the course of surveying several of the national boundaries of the United States, utilized two copper lanterns for tracing meridians and obtaining the direction of lines when determined by celestial observations in the night. He had designed the lanterns and had them made to his

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Figure 2a (Top) Front of German 10 DM bank note honoring Gauss. Note Gauss bell curve.

Figure 2b (Bottom) Reverse of bank note shows a navigation sextant and a Gauss triangulation diagram in northern Germany.

Heliotrope *continued from page 38*
specifications, and described them in his published account of his boundary survey between the United States and the Spanish possessions. The lanterns were four-sided and made of copper, each side about 4-1/2 inches wide and 8 inches high, and made to accommodate a candle. The front side of each lantern had a vertical slit or aperture about 5 inches in length, and 3/10ths of an inch in width, through which the light from a lighted candle would be visible at night. Sometimes a slip of white paper was placed behind the lantern to render the aperture more distinct when the door on the opposite side was opened.

As late as 1879 C. O. Boutelle, when working with the U. S. Coast and Geodetic Survey, used Argand and coal oil lamps as targets for night signals. Although heliotrope instruments were readily available at that time, the lamps were less costly than a heliotrope of good quality and proved to be a bit more accurate than observations made in daylight.

Even with nighttime methods in place, it had been universally realized for a long time that some means was needed that would substitute the sun's reflected rays for a surveyor's target. It had to be capable of reflecting the sun's rays between surveying stations when the distance between the stations was so great that a conventional target would not be sufficiently large to be visible on a hazy day.

Carl Friedrich Gauss

The solution proved to be the heliotrope instrument, an invention that was conceived early in the nineteenth century by the celebrated German mathematician and astronomer Carl Friedrich Gauss (1777-1855). A native of the Duchy of Braunschweig (Brunswick), now part of Germany, he was born of a poor family with limited means. He proved to be a precocious child having remarkable mathematical abilities that became apparent from the age of three. His achievements as he grew attracted the attention of Ferdinand, Duke of Brunswick, who financed his education and became his permanent patron and friend. Gauss attended the University of Göttingen and received his doctorate in mathematics from the University of Helmstedt. In 1807 he was appointed the director of the astronomical observatory in Göttingen, a position he retained until his death, and it was about ten years later, in 1817, that he began his studies in geodesy.

In the period of the lifetime of Gauss, the kingdom of Hannover in northern Germany, situated between the Elbe River and the Netherlands, belonged to England. In 1817 King George IV of England commissioned Gauss to triangulate the entire kingdom of Hannover. The survey required thirty years before it finally was completed in 1847. Although the map of the region that resulted was not very accurate, Gauss compensated by the use of curvilinear coordinates which he developed.

An Annoying Problem

It was in 1820, while he was engaged in making trigonometrical observations at Lüneberg for the purpose of extending the Danish triangles into Hannover, that Gauss first became aware of an unusual phenomena that ultimately inspired his invention. Every time that he directed his telescope toward the steeple of St. Michael's Church at Hamburg, a distance of seven German miles (thirty-two English miles), the little round window in the upper part of the church reflected the image of the sun toward him. This was interfering with his observations and consequently repeatedly impeded the progress of his operations, to his increasing annoyance.

This distracting problem led Gauss to pause and meditate upon the need for a beacon that was sufficiently bright so that it could be observed even in the daytime. It occurred to him that it might be possible to utilize the sun's rays for signals, and he developed the concept of capturing the rays with a mirror and reflecting them to the place to which the signal was to be given. He estimated the strength of the sun's light as well as the amount of diminution it suffered in the atmosphere. From these calculations he concluded that a small mirror of not more than two or three inches in diameter would be adequate to reflect the sun's image to the distance of ten or more German miles.

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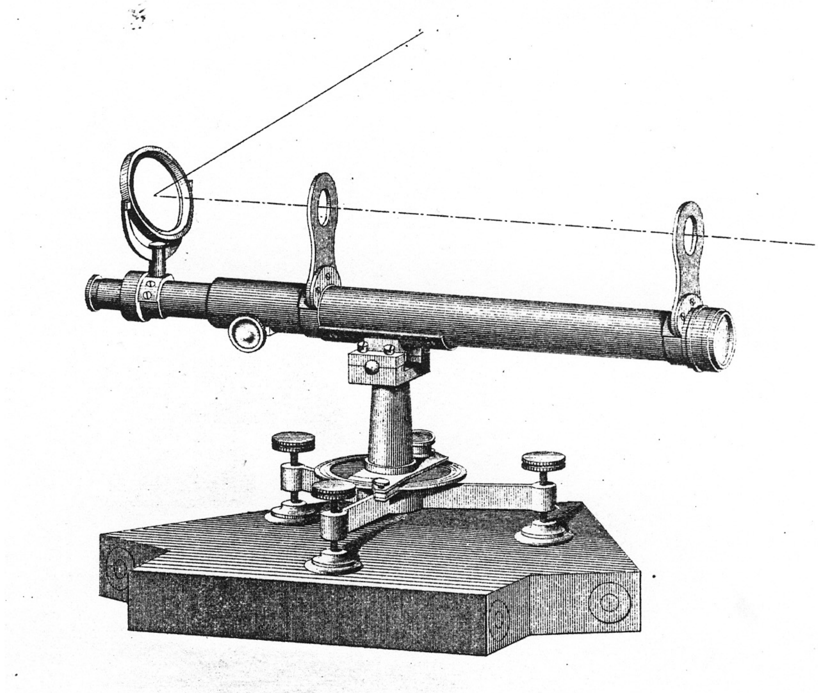

Figure 3 "The Heliotrope" from *Report of the Superintendent of the U. S. Coast Survey . . . During the Year 1866*, plate 27.

Thus was born the first heliotrope instrument for surveying, appropriately named after the sun-loving plant. In its time the new instrument was considered to be of great importance in the measurement of large triangles. It was believed likely that it would supersede nighttime methods.

After having resolved the optical theory, Gauss designed an instrument to fulfill his purpose, and in 1821 he commissioned the firm of Breithaupt in Kassel to construct the first model for him (**Figure 1**). It exceeded his expectations, proving to be extremely useful in practice, having the brightness of a first magnitude star at a distance of fifteen miles. Gauss gained full proof of the advantage to be derived from the heliotrope when he used it on the summit of Brocken Mountain, to determine the three corners of the triangle for measuring the meridian of the North of Germany. On this occasion he sent signals with his heliotrope to his assistants who were stationed upon the Inselbergh, in the forest of Thuringia, some fourteen German miles from his position.

Among the earliest published descriptions of the instrument was a brief account of Professor Gauss and his invention that appeared in *The Gentleman's Magazine: and Historical Chronicle* by Sylvanus Urban, published in London in 1822. After describing the circumstances that had led Gauss to develop the instrument with a small mirror, it went on to describe how it would replace methods hitherto employed:

These consisted in placing or fastening by night several Argand lamps, with reflectors, at those places which it was intended to observe from a great distance. This measuring by night is very inconvenient, and by day the light of the lamps is much too faint to be always seen at the distance of several miles through a telescope. The inventor of the Heliotrope, on the other hand, had full proof of the great advantage to be derived from it, when he was last year on the summit of the Brocken Mountain, to determine the three corners of the triangle for measuring the meridian of the North of Germany; on which occasion Professor Gauss gave signals with this instrument to his assistants, stationed at 14 German miles from him, upon the Inselbergh, in the forest of Thuringia. But the great use of the Heliotrope is not confined to such operations. It will be found greatly to excel the telegraph for giving signals, and in time probably will supersede it [provided the Professor could insure the perpetual appearance of the sun]. As the reflected image of the sun is visible at so great a distance, the signal stations may be much fewer. The mode of using it is likewise more simple, it being merely necessary alternately to shew and to hide the mirror; the intervals, measured by a stop watch, are the signals.

In recent years, shortly before its adoption of the European euro currency, the Federal Government of the German Republic issued a 10-mark banknote commemorating Gauss. (**Figures 2a and 2b**)

According to the *Oxford English Dictionary*, the one who operated a heliotrope was designated as a "heliotroper" or "flasher." Heliotropes also figured in the work of Ferdinand Rudolph Hassler (1770-1843), the Swiss born engineer who helped established the U. S. Coast Survey and became its first superintendent in 1816. Apparently after having learned about the invention of the heliotrope, Hassler contacted Gauss directly and with the inventor's assistance, obtained from Breithaupt a number of the instruments made to Gauss's design. In a report to the Secretary of the Treasury, dated November 17, 1837, Hassler wrote:

"Heliotropes, of which I had begun the use of last fall, have this year been used for most of the station points, and for the base points exclusively. I caused one to be constructed in our shop last winter, after the two received from Gottingen, by the kind assistance of Professor Gauss, the inventor of this instrument, and during my work this summer, I received four more; all seven are now in activity. The aim of the instrument is: to reflect the sun's image from the station point, at which they are placed, to the observer at his station. The new instruments require a man of some intelligence to attend them, and to replace them about every four minutes, according to the motion of the sun. . . . They will show a precise luminous point, even though haze, so frequent on the eastern seashore, when the outline of the hill itself, upon which they stand, cannot be traced."

In the course of the ensuing years, the heliotrope instrument went through a number of modifications, and various forms were devised to improve its convenience in use. Some included the use of clockwork to keep their flat mirrors at the correct angle as the sun crossed the sky during the day. Even greater precision was achieved by combining mirrors with a small telescope. One form of the heliotrope consisted of a telescope mounted with a vertical and horizontal motion. This was turned upon the station that the observer occupied. Mounted on the telescope was a mirror and two disks having a circular opening. The mirror had two motions so that it could be put in any position. Its center was coincident with the axis of the disks, in all positions. The mirror could be turned so as to throw a beam of light symmetrically through the forward disk, in which position the reflected rays would be parallel to the axis of the telescope, and thus fall upon the distant point.

The heliotrope in its various forms became standard equipment for large scale triangulation until about 1840, when more sophisticated models became available. Other types featured flat mirrors attached atop small refracting telescopes. An attendant would aim the telescope directly toward the surveyors on the neighboring mountaintop. The mirror attached above the telescope would then be positioned to reflect the sunlight through two circular rings attached in front of one another at the front of the telescope. When these were aligned with the optical axis of the telescope, the attendant was then assured that the sun's rays were correctly positioned and directed toward the instruments on the neighboring mountain. The disadvantage of both systems, however, was that an attendant was required to set up the device each day.

In 1866 the U.S. Coast Survey issued a report on the subject, proposing to dispense with the use of clockwork in heliotropes because it required too much careful handling, and furthermore, the use of clockwork would not dispense with the need for the services of an attendant, who could equally well be employed in directing the heliotrope. On that account the use of the heliotrope was considered to be expensive, and in remote localities, such as on the tops of high mountains, it was often difficult to subsist the attendant, and the employment of an additional hand if necessary. On the mountains of California, for example, this difficulty was often a very serious obstacle to the use of an otherwise desirable point (**Figure 3**).

In the catalogue issued in 1883 by Fauth and Company, makers of surveying instruments in Washington, D.C., two different types of heliotropes were offered. One was a heliotrope produced by the instrument maker William Wurdemann which had a telescope with two sights and two signal mirrors. It was offered with or without graduated horizontal and vertical axes. In the same catalogue Fauth introduced a "Pocket Heliotrope . . . a beautiful instrument that requires no adjustment" that had been introduced in 1844 by Carl August Steinheil (1801-1870), a Swiss physicist best known for his inventions ranging from an electric clock, telegraphic device and optical instruments. This instrument was sold also by the Washington-based instrument maker and dealer George N. Sagemuller for $20, and examples of which were purchased by the U. S. Coast and Geological Survey.

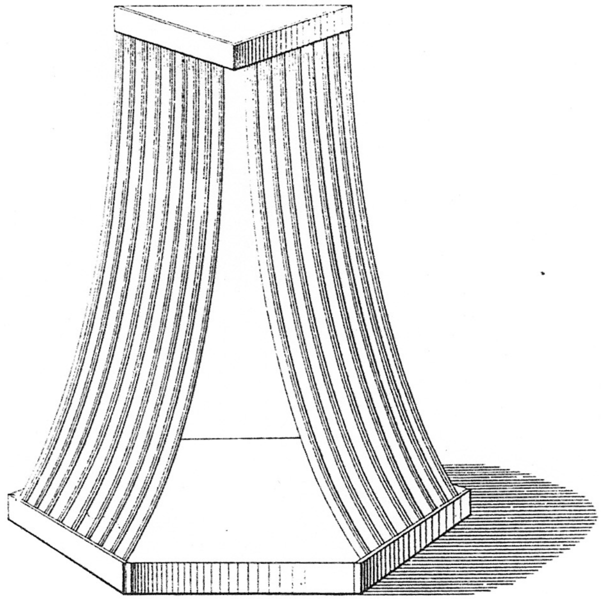

Figure 4 Hilgard's Reflector. From *Report of the Department of the United States Coast Survey Showing the Progress of the Survey For the Year 1867*.

Mirrored Globes

Eventually a solution seemed to have been found that would eliminate the need for an attendant. The problem was solved by means of heliotropes in the form of mirrored glass globes silvered on the inside; these were substituted in situations in which an attendant could not be spared for this task. The heliotrope was also found to excel the telegraph for giving signals, and at one time it was estimated that it might supersede it.

The brilliant reflection from the glass globes silvered on the inside by a method invented by the German chemist, Baron Justus von Leibig (1803-1873) favored their employment, the report continued, since such a hemisphere would, for all positions of the sun, throw a reflection to nearly every point in the horizon. There was a difficulty, however, because subsequently it was found that the image, although very brilliant, was too small in diameter to be readily seen in some situations, and in fact in some it was lost, just as the light of the stars was lost in the daytime. Owing to the perfect figure of the globe, the reflected image of the sun occupied not much more than half a degree of its surface, and it was estimated that it would require a hemisphere of six or eight feet diameter to provide a sufficiently large image. Nonetheless, there were many opportunities for the successful use of silvered globes.

Two heliotropes in the form of silvered globes in fact played a significant role in the surveying for the five-mile long Hoosac Railroad Tunnel through the talcose slate rock of the Hoosac Mountains in Massachusetts. The tunnel, which was to connect Greenfield, Massachusetts and Troy, New York, was under construction for twenty-five years, from 1851 until its completion in 1876.

In charge of the project from 1863 until its completion was Thomas Doane (1821-1897), civil engineer of the Burlington Missouri River Railroad, known for his association with railroads. Doane was largely responsible for the development in the United States of tunneling with machinery and high explosives, and he also was a pioneer in the use of compressed air machinery. In 1863, upon being appointed chief engineer of the Hoosac Tunnel, he immediately introduced new engineering methods, relocated the line of the tunnel, and achieved great accuracy in the meeting of the borings.

Figure 5 Silvered globe heliotrope, patented by E. Varnish Cox, London. This heliotrope is housed in Boswell Observatory, Doane College, Crete, Nebraska. *Photo by Janet Jeffries, Doane College, September 2001.*

When he undertook the project, Doane ordered a pair of heliotropes in the form of two matching mirrored glass globes especially designed to his specifications. The globes were in the form of spheres twelve inches in diameter made of very thin glass and silvered from within for reflection as a mirror. These globes had been patented and manufactured by the London firm of E. Varnish Cox, from which he purchased them (**Figure 5**).

Doane used the two heliotropes for alignment and to ensure precision in drilling in conjunction with two meridian transits made by John Hapgood Temple of Boston. During the course of the tunnel excavation from 1863 to 1874, the transits were mounted upon and operated from brick piers situated at each end of the tunnel site. Using the two meridian transits with the twin heliotropes, Doane and his crew were able to bore from each end of the tunnel to its center, with an alignment error at the meeting of the headings of just 9/16 of an inch! Both of the silvered globes have been preserved, one at Doane College in Crete, Nebraska with some of his other instruments, and the other globe was owned by a namesake descendant.

During the same period, the heliotrope was used to a great extent in India for the great trigonometrical survey. Colonel H. Thuillier stated from experience, "A heliotrope of 9 inches diameter answers for 90 to 100 miles. For nearer distances it is much too bright to be observed through a telescope, and the light must be diminished in the following proportion . . ." Also during the same period, the geodesist Julius Erasmus Hilgard (1825-1891), then Assistant of the Coast and Geodetic Survey and later its Superintendent, recommended the use of the heliotrope for making stations visible at long distances because it penetrated the haze whenever the outlines of the distant hills have disappeared. He did not approve of the clockwork-motivated heliotropes or heliostats, however, because they required the services of an attendant, which could be better employed in directing the heliotrope.

Silvered Glass Tubes

Instead of the use of a silvered globe, Hilgard proposed the use of a series of glass tubes silvered on the inside, arranged in parallel rows, bent in an arc of a circle of large diameter, to produce a curvature of about 24 degrees. These were placed with the upper part in a vertical position so that each tube sent to the horizon in every direction within a range of 120 degrees a line of light about one inch in length which appears near the top when the sun is in the horizon, and gradually travels downward as the sun rises, and at the same time moving across the tube as it changed its azimuth, until the reflection was lost at the bottom when the sun reached the altitude of twice the curvature of the tube, or about 44 degrees, at which time the heat of the day generally renders observing impracticable. The joint effect of nine of these brilliant lines, distributed over a breadth of six inches, was much the same as if a less intense reflection were evenly diffused over the same surface, and was readily seen over a great distance (**Figure 4**).

> **"The new instruments require a man of some intelligence to attend them, and to replace them about every four minutes . . ."**
>
> **—Ferdinand Hassler, 1837**

In using these reflectors, two or more faces as described might be set up on a common base, arranged in regular polygonal order or so disposed as to provide the most advantageous reflections in the directions from which it was to be observed. Hilgard reported that several of these reflectors had been used in the field and found to be quite satisfactory. The tubes were bent into the required form by being curved around a wooden disk eight feet in diameter, and they were relatively inexpensive to construct. The silvering was accomplished by known methods; he cautioned that the tubes should not have bores too small for facility of filling them with silvering fluids. The tubes then were arranged in simple wooden frames and secured in position with putty or plaster. Eventually the heliotrope in its various forms was made obsolete during the twentieth century with the advent of aerial surveying.

A Resourceful Solution

On occasion the principle of the silvered globe was duplicated by surveyors in the field even when the instrument itself was not available. A group of engineers of the Topographical Division of the U.S. Geological Survey, upon finding themselves without a heliotrope instrument and being stranded from a source of supply, as often happened, found a ready solution–by using their discarded beverage containers. G.S. Druhot, a topographical engineer with the U.S. Geological Survey, reported such an incident some years later. He described how it happened in 1925, while he was engaged in mapping in western Colorado as one of a party of the Survey's Topographical Division. Under the charge of H.H. Hodgson, they were extending a net of triangulation to control the mapping.

The surveyors experienced difficulty in seeing some of the signals of the extended net, and discussed the practicability of using some reflective surface, but realized that they had neither a heliotrope nor any other suitable means to solve the problem. Then one of the rod men, who was fresh from a chemistry course in college, suggested a solution. Between them they had several empty spherical flasks that were eight or ten inches in diameter, and the rod man tried his hand at silvering them, with success. These flasks were then raised by the surveyors on several mountain peaks and found that they served their purpose admirably. Until, that is, some roving hunters out after game in the region had spotted them and used the glittering globes for target practice!

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