Most of the present theories on the a-c losses are based on the model of Bean (*10*) and London (*11*) or a modification of it (*12*). The theories state that the losses are hysteretic and depend on the peak magnetic field as $H^n$ where $3 < n < 4$, depending on the model for the critical current density, $J_c(H)$. Our measurements of the frequency dependence of the losses (30 to 60 hertz) suggest that the observed losses are, in fact, hysteretic. However, the magnetic field dependence is much greater than predicted by the theories. In fact, $n$ in most cases is larger than 4, and it is as large as 6 in some of the composite processed $Nb_3Sn$. The smaller values of $n$ are observed only for those specimens with high losses, for example, $Nb_3Sn$ with added impurities (curve c in Fig. 1). The effect of surface roughness also tends to decrease $n$. The present theories on a-c losses do not account for some of the observations reported here. A more detailed comparison of the theories and the present loss data will be given elsewhere (*13*).

After these encouraging results with rod specimens we decided to make several tape geometry $Nb_3Sn$ conductors in lengths of 9.2 to 12.2 m by the composite process. Measurements performed on these tapes confirm that the losses in the composite processed tape are substantially lower than the best tapes produced by commercial suppliers. This result demonstrates that the losses in the improved conductors will not be significantly higher than other heat loads for a complete cable system, thus producing an optimized design. In addition, the composite process for making $Nb_3Sn$ conductors does not require any new and relatively complex developments in technology such as vacuum evaporation techniques. In fact, it is possibly simpler than the two commercial methods commonly used to produce $Nb_3Sn$ conductors, gas decomposition and tin dipping. Development of the low-loss $Nb_3Sn$ described here makes its application to practical cables in the gigawatt range very attractive (*1, 5*). Such cables would have marked advantages with respect to higher operating temperature and fault current capability than cables employing a niobium conductor, and with the same or lower a-c loss.

M. SUENAGA
M. GARBER
*Division of Metallurgy and Materials Science, Brookhaven National Laboratory, Upton, New York 11973*

**References and Notes**

1. E. B. Forsyth, M. Garber, J. E. Jensen, G. H. Morgan, R. B. Britton, J. R. Powell, J. P. Blewett, D. H. Gurinsky, J. M. Hendrie, *Proceedings of the 1972 Applied Superconductivity Conference* (Institute of Electrical and Electronics Engineers, New York, 1972), p. 202 (this reference describes a conceptual coaxial transmission line made from $Nb_3Sn$ ribbon conductor similar to that discussed in this report or made commercially).
2. M. Garber and W. B. Sampson, *Proc. 13th Int. Congr. Refrig.* (Paris) (1971), p. 393; M. J. Chant, M. R. Halse, H. O. Lorch, *Proc. Inst. Elec. Eng.* **117**, 1441 (1970).
3. C. H. Meyer, Jr., D. P. Snowden, S. A. Sterling, *Rev. Sci. Instrum.* **42**, 1584 (1971); D. P. Snowden, *Gulf Gen. At. Rep. No. 10281* (1962).
4. A. R. Kaufmann and J. J. Pickett, *Bull. Am. Phys. Soc.* **15**, 838 (1970); M. Suenaga and W. B. Sampson, *Appl. Phys. Lett.* **18**, 584 (1971).
5. E. B. Forsyth, Ed., *Brookhaven Natl. Lab. Rep. No. 50325* (1972).
6. R. M. Easson and P. Hlawiczka, *Br. J. Appl. Phys.* **18**, 1237 (1967).
7. H. M. Long, W. T. Beall, Jr., L. K. Eigenrod, R. W. Meyerhoff, J. Notaro, "Superconducting Cable System, EEI Project RP 78-7" (final report, Edison Electric Institute, New York, October 1969); R. W. Meyerhoff and W. T. Beall, Jr., *J. Appl. Phys.* **42**, 147 (1971).
8. H. H. Farrell, G. H. Gilmar, M. Suenaga, unpublished data.
9. R. Scanlan, personal communication; B. Park and M. Suenaga, unpublished data.
10. C. P. Bean, *Rev. Mod. Phys.* **36**, 31 (1964).
11. H. London, *Phys. Lett.* **6**, 162 (1963).
12. For a summary, see P. H. Melville, *Phil. Mag.* **27**, 647 (1973).
13. M. Suenaga, M. Garber, J. Bussiére, in preparation.
14. We thank D. H. Gurinsky, E. B. Forsyth, and W. B. Sampson for helpful discussions and guidance. We also thank S. Shen for measurements and C. Klamut, A. Cendrowski, D. Horne, F. Iseli, R. Mitchell, and S. Pollack for expert technical assistance. This work was carried out under the auspices of the National Science Foundation and the Divisions of Physical Research and Applied Technology of the U.S. Atomic Energy Commission.

15 October 1973; revised 17 December 1973

## Melting Relations of the Allende Meteorite

Abstract. *The proportions of major oxides in the Allende carbonaceous chondrite after partial reduction are remarkably similar to those in possible mantle material of the earth. When heated, the Allende meteorite generates a sulfide melt (47 percent iron, 25 percent nickel, and 24 percent sulfur by weight), a ferrobasaltic melt, and olivine with or without pyroxene, over a wide pressure range (5 to 25 kilobars). The silicate melt contains more sodium and less titanium than lunar ferrobasalts. An aggregate of the Allende chondrite rich in calcium and aluminum produces silica-undersaturated, calcium-rich melt and spinel over a wide pressure and temperature range. From these studies, it is suggested that the earth's core contains significant amounts of both nickel and sulfur and that a 3 : 2 mixture of Allende bulk sample and calcium- and aluminum-rich aggregates is closer in major element abundances than either of these components to the average composition of the moon.*

The carbonaceous chondrites are believed to be the most undifferentiated condensed material in the solar system (*1*). If planets formed by accretion of material having solar proportions of the condensed elements, heating and melting experiments with a carbonaceous chondrite should reproduce the events that would have taken place in the early evolution of these planets.

Many considerations have been advanced to support the premise that the earth has a composition similar to that of some chondritic meteorites (*2*). Further evidence that the proportions of major elements of at least the silicate fraction of the earth are similar to those of one group of carbonaceous chondrites is presented in Table 1. The composition of the silicate portion of the Allende type 3 carbonaceous chondrite (*3*) after reduction of 19.7 percent of the iron oxide to metallic iron is given in Table 1. For comparison, the composition of a peridotite inclusion from a tuff of the Salt Lake Crater, Hawaii, is also presented. On being heated, this rock produces tholeiite and alkali basaltic melts at pressures from 10 to 20 kbar (*4*) and is believed to be representative of the oceanic upper mantle (*5*). The composition of the partially reduced silicate phase of the Allende

Table 1. Chemical composition of the Allende meteorite after partial loss of oxygen and extraction of the metallic phase compared with that of possible mantle material. The Allende material was analyzed by Clarke *et al.* (*3*) after subtracting 4.73 percent oxygen, 19.2 percent iron, 1.45 percent nickel, and 2.21 percent sulfur. Peridotite analysis is by Kuno and Aoki (*5*).

| Oxide | Percentage in | |
|---|---|---|
| | Allende meteorite | Salt Lake peridotite |
| $SiO_2$ | 46.50 | 48.3 |
| $TiO_2$ | 0.22 | 0.22 |
| $Al_2O_3$ | 4.56 | 4.91 |
| $Cr_2O_3$ | 0.70 | 0.25 |
| FeO | 9.91 | 9.95 |
| MnO | 0.24 | 0.14 |
| MgO | 33.31 | 32.5 |
| CaO | 3.59 | 2.99 |
| $Na_2O$ | 0.60 | 0.66 |
| $K_2O$ | 0.04 | 0.07 |
| $P_2O_5$ | 0.32 | |

meteorite is very close to that of the peridotite inclusion. The amount of the metallic phase in the partially reduced Allende chondrite is about 23 percent by weight, which is smaller than the 31 percent of the earth believed to comprise its core. However, the agreement in major element abundances of the oxide fractions is remarkable, suggesting that the melting relations of this chondrite may also give clues to understanding the early evolution of the earth.

In addition to the groundmass and chondrules, the Allende carbonaceous chondrite contains white aggregates rich in calcium and aluminum. These aggregates are believed to be high-temperature condensates that separated from the cooling solar nebula (*6, 7*), and their origin and evolution have received considerable attention. It has been proposed, on the basis of lunar heat flow models, that the moon and protoplanetary nuclei are similar in composition to these aggregates (*8*).

In an effort to establish the initial evolutionary sequence of a planet of chondritic composition, we have studied the melting relations of a bulk sample of the Allende type 3 carbonaceous chondrite at pressures from 5 to 27 kbar under both hydrous and anhydrous conditions. In addition we have performed melting experiments on a Ca-, Al-rich aggregate separated from the Allende meteorite and on a mixture of three parts of the bulk meteorite to two parts of the aggregate at pressures from 1 atm to 18 kbar. These experiments provide a petrologic basis for testing certain proposed lunar compositions (*9*). Chemical analyses of the bulk sample and Ca-, Al-rich aggregate are given by Clarke *et al.* (*3*).

All high-pressure experiments were made with a solid-media, high-pressure apparatus. Anhydrous experiments were made in graphite capsules after the sample was heated to 1000°C for about 1 minute to remove water. Hydrous experiments were made in Ag (50 percent)–Pd (50 percent) capsules, with $H_2O$ contents ranging from 10 to 22 percent by weight. The experiments at 1 atm on the Ca-, Al-rich aggregate were made in platinum containers. This aggregate contains only a small amount (about 2 percent) of FeO, and loss of iron to the platinum container was not detected with the electron microprobe.

The compositions of the coexisting phases formed at 20 kbar and 1350°C have been analyzed with the electron microprobe (Table 2) (Fig. 1). The silicate melt formed by about 25 percent partial melting is rich in iron and similar to lunar ferrobasalts. The olivine composition is 71 mole percent forsterite ($Fo_{71}$), which is close to the composition of olivine crystallized from some lunar ferrobasalts. However, titanium in the melt is much lower and sodium is higher than in the lunar ferrobasalts, indicating that the composition of the Allende meteorite may not be representative of undifferentiated lunar material. The sulfide phase contains significant amounts of nickel and sulfur but no detectable potassium (*10*). Oxygen may constitute the unanalyzed portion of the sulfide melt, as inferred from the presence of oxygen in natural sulfide melts (*11*) and from experimental results in the system Fe-S-O (*12*). The iron contents of the silicate melt, the olivine, and the sulfide phase depend strongly on the oxygen fugacity, which in the present experiments was probably close to but higher than that given by the iron-wüstite buffer (*13*). If the oxygen fugacity is lowered, both the silicate melt and the olivine should become more magnesian and the sulfide phase should contain less nickel and sulfur.

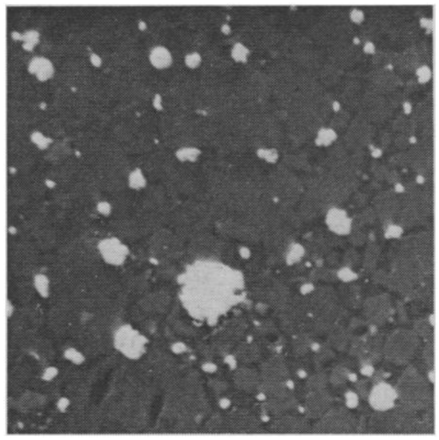

Fig. 1. Photomicrograph of a sample of the Allende carbonaceous chondrite which has been partially melted at 1350°C and 20 kbar. The fractionation giving a bright iron-nickel sulfide, gray iron-magnesium crystals, and a dark melt of ferrobasaltic composition is believed to be similar to processes which occurred in the early stages of evolution of the earth. The section shown is 125 $\mu$m wide.

Table 2. Compositions of phases of a bulk sample of the Allende meteorite and a Ca-, Al-rich aggregate after a partial melting. Abbreviations for the phases: Px, pyroxene; Si, silicate; Sp, spinel. The pressures and temperatures are: (bulk sample) 20 kbar, 1350°C; (Px) 7 kbar, 1250°C; (Sp) 1 atm, 1310°C; (aggregate Si melt) 1 atm, 1350°C. The olivine in the bulk sample is 71 mole percent forsterite.

| | Percentage in | | | | |
|---|---|---|---|---|---|
| | Bulk sample | | Aggregate | | |
| | Sulfide | Si melt | Px | Sp | Si melt |
| Fe | 46.6 | | | | |
| Ni | 25.2 | | | | |
| S | 24.3 | | | | |
| Co | 0.5 | | | | |
| K | <0.01 | | | | |
| $SiO_2$ | | 40.8 | 44.0 | 0.2 | 40.5 |
| $TiO_2$ | | 0.7 | 4.3 | 0.4 | 1.6 |
| $Al_2O_3$ | | 13.2 | 15.1 | 66.5 | 18.1 |
| FeO | | 24.4 | 0.1 | 2.1 | 2.2 |
| MgO | | 6.2 | 12.9 | 29.9 | 10.9 |
| CaO | | 13.0 | 24.7 | 0.1 | 26.1 |
| $Na_2O$ | | 1.6 | 0.1 | 0.05 | 0.6 |
| $K_2O$ | | 0.1 | | | |

The melting relations of the bulk sample of the Allende chondrite are shown in Fig. 2a. The solidus of the silicate, that is, the temperature at which the silicate begins to melt, is shown by a solid line for anhydrous conditions. It increases from 1225°C near 1 atm to 1375°C at 24 kbar, giving an increase in temperature with pressure of about 6° per kilobar. Above the silicate solidus, olivine and the liquid sulfide phase are dominant. Minor phases are a pale green spinel and pyroxene. Plagioclase is expected to crystallize only very near the solidus at pressures lower than 10 kbar in the presence of magnesian olivine (*14*).

Garnet was found to be stable at pressures of 24 and 27.5 kbar. Under hydrous conditions, the solidus of the silicate phase is lowered to about 1000°C for pressures greater than 15 kbar. From the composition of the sulfide phase, its solidus, that is, the temperature at which it begins to melt, is expected to be below 1000°C (*15*).

The melting experiments on the Allende chondrite producing crystalline silicates (olivine and pyroxene), Fe-Ni-S melt, and a silicate melt (ferrobasaltic compositions under anhydrous conditions) may be similar to processes that occurred in the early stage of the evolution of terrestrial planets. The anhydrous solidus determined in the experiments gives the beginning of melting of planets formed by accretion of essentially anhydrous type 3 carbonaceous chondrite. The hydrous solidus gives the melting temperature of the planets formed by accretion of carbonaceous chondrites with appreciable amounts of water (for example, type 1). The experiments also suggest

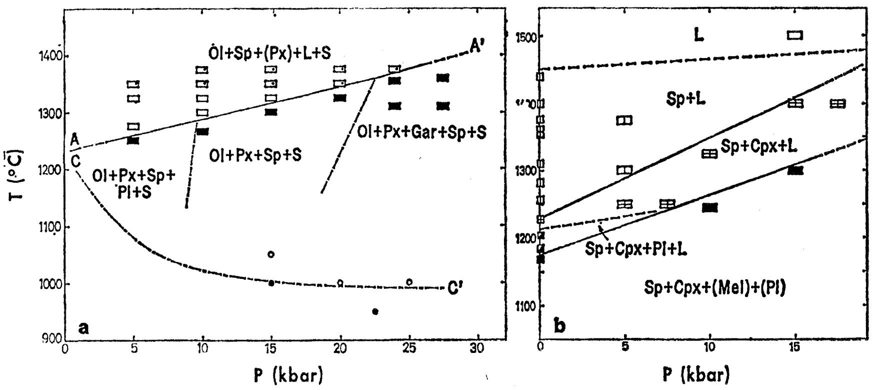


Fig. 2. Melting relations of (a) the Allende bulk sample and (b) a Ca-, Al-rich aggregate. Solid rectangles indicate subsolidus conditions. Lines separate stability fields for different phase assemblages. Abbreviations: Ol, olivine; Sp, spinel; Px, pyroxene; L, silicate liquid; S, sulfide; Pl, plagioclase; Gar, garnet; Cpx, clinopyroxene; Mel, melilite. (a) The pressures and temperatures of the experiments are indicated by rectangles for anhydrous conditions and by circles for hydrous conditions. The beginning of melting is given by the solid line for anhydrous conditions and by the dot-dash line for hydrous conditions. Dots indicate agglomeration of the sulfide melt into spherical globules. Parentheses indicate that Px is stable only near the liquidus. (b) Parentheses indicate that Mel and Pl are stable only below 10 kbar. Differently marked rectangles are used for different fields.

that ferrobasaltic liquid can be generated by partial melting of materials similar in bulk composition to the Allende meteorite under anhydrous conditions and in the presence of less than 10 percent metal. Under more reducing conditions, however, more metallic phase would precipitate, making the silicate melt more magnesian. The latter case would be expected in planets with a large metal core (that is, the earth). If the core formed after accretion, as commonly suggested for the earth, it would be expected, from these experiments, to contain a large proportion of the nickel and sulfur and very little of the potassium (*10*) of the system.

The melting relations of the Ca-, Al-rich aggregate show wide fields of spinel plus melt and spinel plus Al-rich clinopyroxene and melt (Fig. 2b). Plagioclase and melilite crystallize at relatively low temperatures. Analyses of the major minerals and melt are given in Table 2. The melt formed at 1 atm and 1350°C is rich in calcium and also enriched in magnesium relative to iron, as compared to known terrestrial and lunar magmas. The composition of the melt is similar to one of the analyses of glass coexisting with spinel obtained from an Allende chondrule by Marvin *et al.* (*6*), which suggests that the chondrule was quenched from a temperature between 1225° and 1450°C. Although it is likely that these spinel-glass assemblages in the Allende meteorite were formed by reheating of solid condensates, the possibility that they were formed from primary liquid condensates cannot be ruled out solely on the basis of the presence of spinel, because in this temperature interval spinel is believed to exist as an equilibrium condensate at pressures below $10^{-3}$ atm (*7*). The melt is unlike those of any known terrestrial and lunar igneous rocks. In addition, the residue of partial melting, which is enriched in clinopyroxene, is very low in iron and, therefore, cannot be a source of ferrobasalts such as those found on the moon.

From these experimental results, it appears unlikely that either the Allende bulk sample or the Ca-, Al-rich aggregates represents the original materials of the moon. Krähenbühl *et al.* (*16*) and Wänke *et al.* (*17*) have estimated model compositions of the moon from the alkali, uranium, and iron contents of lunar materials. By one estimate (*16*) 42 percent Ca-, Al-rich, high-temperature condensates are combined with 58 percent "chondritic" material that has undergone an Fe-Si fractionation and partial melting. The other model combines 69 percent high-temperature condensates similar to the white Ca-, Al-rich inclusions of Allende with 31 percent unfractionated type 1 carbonaceous chondrite material (*17*). We have examined these models by using a mixture of three parts Allende bulk sample and two parts Ca-, Al-rich aggregate. This mixture contains about 2 percent more iron and 2 percent less silica but is otherwise very similar to the composition proposed by Krähenbühl *et al.* (*16*).

From experiments in carbon capsules at 5 kbar, the 3 : 2 mixture was found to have the crystallization order olivine, spinel, clinopyroxene, and calcic plagioclase. Under fractional crystallization, this order could yield a layered succession of rocks of the following sequence: dunite with a small amount of spinel, olivine clinopyroxenite with minor plagioclase, and olivine gabbro consisting of plagioclase with subordinate olivine and clinopyroxene. This sequence is consistent with the lunar differentiation model outlined by Wood *et al.* (*18*). Melting and differentiation of the outer 160 km of a moon of this composition would produce dunite at depths below 65 km, as suggested on the basis of seismic data (*19*). However, if the olivine clinopyroxenite layer is the source of mare basalts, the observed crystallization sequence would not produce highland anorthositic rocks with Fe/Mg ratios lower than that observed in the mare basalts. Thus, in detail, the 3 : 2 mixture cannot account for present chemical observations of lunar material.

A mixture in which plagioclase crystallizes before pyroxene would not present this difficulty. From the crystallization sequences obtained on the Allende sample and the Ca-, Al-rich aggregate, any mixture of these two components would crystallize pyroxene before plagioclase. Early crystallization of plagioclase, however, is expected from material enriched in silica relative to the 3 : 2 mixture. Thus, the composition proposed by Krähenbühl *et al.* (*16*), containing 2 percent more silica than the 3 : 2 mixture, may be more representative of lunar material than either the 3 : 2 mixture or the composition proposed by Wänke *et al.* (*17*).


M. G. Seitz, I. Kushiro

*Geophysical Laboratory,*
*Carnegie Institution of Washington,*
*Washington, D.C. 20008*


#### References and Notes


1. H. C. Urey, *Q. J. R. Astron. Soc.* **8**, 23 (1967); B. H. Mason, *Space Sci. Rev.* **1**, 621 (19[illegible] J. W. Larimer and E. Anders, *Geochim. Cosmochim. Acta* **31**, 1239 (1967).
2. A. E. Ringwood, in *Researches in Meteorites*, C. B. Moore, Ed. (Wiley, New York, 1962), p. 198; P. M. Hurley, *Geochim. Cosmochim. Acta* **32**, 273 (1968).
3. R. S. Clarke, Jr., E. Jarosewich, B. Mason, J. Nelen, M. Goméz, J. R. Hyde, *Smithson. Contrib. Earth Sci. No. 5* (1970).
4. I. Kushiro, *Tectonophysics* **17**, 211 (1973).
5. H. Kuno and K. Aoki, *Phys. Earth Planet. Interiors* **3**, 273 (1970).
6. U. B. Marvin, J. A. Wood, J. S. Dickey, Jr., *Earth Planet. Sci. Lett.* **1**, 346 (1970).
7. L. Grossman and S. P. Clark, Jr., *Geochim. Cosmochim. Acta* **37**, 635 (1973).
8. T. C. Hanks and D. L. Anderson, *Phys. Earth Planet. Interiors* **5**, 409 (1972).

9. The samples of the Allende meteorite were provided from the Smithsonian Institution by B. H. Mason.
10. It is suggested that the alkalies potassium, rubidium, and cesium were fractionated into the earth's core, producing marked deficiencies of these elements in the crust. See, for example, J. S. Lewis, *Earth Planet. Sci. Lett.* **15**, 286 (1972). In experiments with carbon crucibles no potassium was detected in the sulfide phase (detectability limit 0.01 percent) compared with 0.1 percent found in the silicate melt at 20 kbar. To provide a reducing environment more conducive to a potassium-metal association we experimented with Allende bulk meteorite plus silicon metal in carbon crucibles at 20 kbar. Similarly, no potassium was detected in the sulfide-silicon melt (detectability limit 0.01 percent) compared with 0.1 percent in the silicate melt, indicating that potassium would not separate with the sulfide phase, at least in the upper 65 km of the earth's surface.
11. B. J. Skinner and D. L. Peck, *Econ. Geol. Monogr.* **4**, 310 (1969).
12. A. J. Naldrett, *J. Petrology* **10**, 171 (1969).
13. R. N. Thompson and I. Kushiro, *Carnegie Inst. Wash. Yearb.* **71**, 615 (1972).
14. I. Kushiro and H. S. Yoder, Jr., *J. Petrology* **7**, 337 (1966).
15. G. Kullerud, *Carnegie Inst. Wash. Yearb.* **62**, 175 (1963).
16. U. Krähenbühl, R. Ganapathy, J. W. Morgan, E. Anders, in "Proceedings of the Fourth Lunar Science Conference," *Geochim. Cosmochim. Acta* **2** (Suppl. 4), 1325 (1973).
17. H. Wänke, H. Baddenhausen, G. Dreibus, E. Jagoutz, H. Kruse, H. Palme, B. Spettel, F. Teschke, in *ibid.*, p. 1461.
18. J. A. Wood, J. S. Dickey, Jr., U. B. Marvin, B. S. Powell, in "Proceedings of the Apollo 11 Lunar Science Conference," *Geochim. Cosmochim. Acta* **1** (Suppl. 1), 965 (1970).
19. M. N. Toksöz *et al.*, in "Proceedings of the Third Lunar Science Conference," *Geochim. Cosmochim. Acta* **3** (Suppl. 3), 2527 (1972).
20. We thank E. Anders for discussions and P. M. Bell, S. R. Hart, T. Irvine, Y. Nakamura, and H. S. Yoder, Jr., for critical reviews. Supported by NASA grant NGR 09-140-017.

19 November 1973

## Light Flashes Observed by Astronauts on Apollo 11 through Apollo 17

*Abstract.* *The crew members on the last seven Apollo flights observed light flashes that are tentatively attributed to cosmic ray nuclei (atomic number $\geqq 6$) penetrating the head and eyes of the observers. Analyses of the event rates for all missions has revealed an anomalously low rate for transearth coast observations with respect to translunar coast observations.*

The observation of visual phenomena described generically as light flashes was reported by Apollo 11 Lunar Module pilot Edwin Aldrin during one of his postmission debriefings. Subsequently, the crews of Apollo 12 and Apollo 13 were briefed on the phenomena and asked to report their observations. All of them reported the ability to "see" the flashes with relative ease when the spacecraft was dark, and with their eyes either open or shut. Apollo 12 commander Charles Conrad stated that "there were big bright ones all over," and added that he had not noticed anything like it on his two previous Gemini missions orbiting the earth (*1*). Apollo 13 commander James Lovell observed the flashes during Apollo 13, but did not remember seeing them during his Apollo 8 lunar mission.

Because of these reports, a 1-hour session on Apollo 14 was dedicated to observe light flashes (*2*). Subsequently, there were three separate 1-hour sessions on Apollo 15 and two 1-hour sessions on Apollo 16 (*3*) and Apollo 17 (*4*). Simple blindfolds (designed to avoid pressure on the eyeballs) were used on the last three missions. The crew's comments and descriptions of each event were radioed to the earth and simultaneously recorded on tape in the spacecraft. To explore the most widely accepted hypothesis of the origin of the flashes (*5*)—that they are caused by cosmic ray nuclei traversing the head or eyes—a device known as the Apollo Light Flash Moving Emulsion Detector (ALFMED) was used on Apollo 16 and Apollo 17. The ALFMED is a masklike apparatus containing two sets of nuclear emulsion plates. One set of plates is fixed with respect to the head, and the second set can be translated parallel to the fixed set at a uniform rate during a 1-hour observing session. When the ALFMED data have been analyzed they should tell whether there are coincidences between reported flashes and cosmic rays (atomic number $Z \geqq 6$) passing through the head or eyes. This report is concerned with the subjective data obtained during the dedicated sessions described above.

The flashes are generally described as white or colorless (the only exception is the report by Apollo 14 Lunar Module pilot Edgar Mitchell of a flash that appeared "blue with a white cast, like a blue diamond"). Three basic types of flashes have been reported. The most prevalent type (occurring about 66 percent of the time) is the "spot" or "starlike" flash, which has also been referred to as a "supernova." David Scott, the Apollo 15 commander, described it as resembling a photographic flashbulb that has been flashed across a dark arena, several hundred feet from the observer. Mitchell stated that the phenomenon was not as clear as he thought it would be. "There still seemed to be at least two flashes, maybe a bright flash followed an instant later by a more subdued flash, or perhaps a halolike effect—there does not seem to be a set pattern in each case. Sometimes it is a very clear single flash; at times it seems followed by a halo. Sometimes it seems followed by an adjacent flash." On several occasions stars have been reported in pairs, either both in the same eye or one star in each eye.

The second most abundant type of flash (occurring about 25 percent of the time) is described as a "streak." Some observers reported that the streaks were sharp lines, and to others they appeared more (laterally) diffuse. Some of the streaks were like dashed lines, the most common version consisting of two principal segments with a gap in the middle. The most interesting characteristic of the streaks is that they all appeared to have a definite sense of propagation (typical descriptions were "going from left to right" or "coming straight at me"). Most observers agreed that the "motion" was exceedingly fast, and may in fact have been due to shape cues rather than actual motion. Light flash experiments with accelerators have apparently duplicated this sense of propagation feature of the streaks (*6*). The streaks are probably caused by particles with trajectories approximately tangent to the retina.

The third type of flash (occurring in the remaining 8 percent of the cases) is referred to as a "cloud." Clouds were always seen in the periphery, and do not seem to have any distinct shape. Apollo 14 Command Module pilot Stuart Roosa described the clouds as resembling a lightning discharge when viewed from behind terrestrial clouds in the distance. Some of these cloudlike events have appeared to fill the entire periphery, while leaving the central visual field dark.

Analyses of the elapsed time between events for a particular observer, and between events for any observer, both indicate that the events seen during each 1-hour session fit an interval distribution (that is, the events were randomly distributed in time). Further, there does not appear to be a significant preference for one eye over the other, either for a single type of event or for all the events taken together.