THE LUMINESCENCE OF METEORITES.

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ABSTRACT. A number of stone meteorites are found to be luminescent in an electrical discharge in a vacuum, but not in ultra-violet or X-rays. Olivine contributes little or nothing to the luminescence, enstatite being the most active mineral. However, not all enstatite is active. The usual color of the glow is bluish, but two howardites give a yellow glow and two other stones contain particles giving a red luminescence. Roasting in air changed the glow of one stone to green.

This phenomenon may be of value in distinguishing separate falls of similar meteorites in nearby localities. It may also have some bearing on the violet type, continuous spectra of comets.

THE first report of the luminescence of a meteorite appears to be that of Flight,[1] who found that when the oldhamite in the Bustee, United Provinces, India stone is slightly warmed and exposed to the light of burning magnesium, it gives an orange phosphorescence. Wirt Tassin found 9.12 per cent calcium and 7.30 per cent sulphur in a fine powder derived from the Allegan, Michigan stone, but neither the powder nor the solid meteorite luminesced after exposure to either burning magnesium or sunlight.[2]

Maria Kalaczowska[3] has reported a greenish phosphorescence on part of a polished surface of the Łowicz, Warszawa district, Poland stone after exposure to X-rays.

I have mentioned elsewhere[4] that a number of stone meteorites do not luminesce after exposure to ultra-violet light, and that the powder of the Holbrook, Arizona and Washougal, Washington stones is luminescent in a spectrum tube. The meteorites tested with ultra-violet light (a variety of sources were used) have since been tested with X-rays.* Exposures up to one minute produced no visible luminescence. The meteorites are: Admire, Kansas; Allegan, Michigan; Llano del Inca, Chile; Holbrook, Arizona; Covert, Kansas; Estacado, Texas; Brenham, Kansas; Winona, Arizona; Ness City, Kansas; Lake Labyrinth, South Australia; Molong, New South Wales; Richardton, North Dakota; Esterville, Iowa; Mincy, Missouri; Springwater, Saskatchewan, Canada; and Plainview, Texas. In addition tektites from Habří, Bohemia, and Kwang Chow Wan, South China, and polished nodules of josephinite and the

* A dental machine with a tungsten target was used at 40 killovolts and 10 milliamperes.

native iron of Bühl, Germany, were tested and found to be inactive.

Since the spectrum tube luminescence of the Holbrook and Washougal stones appears to be an hitherto unreported phenomenon, further work has been done upon it. It is found that both cathode rays and the miscellaneous ions present in a spectrum tube have the same effect on the meteorites except *that in* cathode rays the luminescence appears to be brighter and is easier to observe. For this reason I will call this phenomenon ionoluminescence rather than cathodoluminescence, since the latter term might imply that only cathode rays are effective in exciting it.

The apparatus used consisted of glass tubes about one inch in diameter and six inches long. Small pieces of the meteorites were sealed up inside and the tubes evacuated. The electrodes in each end were connected at times to a Ford coil and at other times to a sign transformer rated at 9,000 volts and 30 milliamperes.

The Washougal meteorite has not been very thoroughly investigated, but according to H. H. Nininger it is probably a howardite.[5] It has previously been found to luminesce with a yellow glow whose spectrum extends from the orange to the middle of the green, but is brightest in the yellow. This glow is very short lived. The only other meteorite with a yellow phosphorescence is Sioux County, Nebraska. Unfortunately, anything like an adequate description of this stone is lacking, but it is also classed as a howardite. In this case the phosphorescence is much whiter and lasts about one minute. The Farmington, Kansas stone (Cs or Csa) contains numerous specks giving a yellowish fluorescence. The bulk of the meteorite is inactive.

Other inactive substances are: Olivine from the Brenham and Admire, Kansas pallasites; the La Lande, New Mexico stone; and a stone labeled Adrian, Texas II which will be referred to again. The Roy, New Mexico stone has only a very weak phosphorescence.

The Tabory (Ochansk), Russia meteorite (Ccb) has a very bright, long-lived, bluish phosphorescence. Under a 10X lens three parts can be distinguished. One is inactive and relatively small in amount, although there are some large inactive chondri. The other two parts are both phosphorescent, one being brighter than the other. These two are present in the ratio of about 2:1. The most brilliant of the two is the least abundant and in white light is, in part at least, somewhat lighter in color.

Searsmont, Maine (Cc) resembles Tabory in general, except that there are only two parts, the darker colored one being nearly inactive.

Richardton, North Dakota (Cca) is less luminescent than Searsmont, possibly on account of its rusted condition. All the chondri look gray and are inactive.

Tyron, Nebraska has a weak phosphorescence. There are two parts, one more active than the other and the least active is the most abundant. The same is true of Ness City, Kansas (Ck or Cib).

Allegan, Michigan (Cc or Cco) has a strong, long-lived, bluish phosphorescence. As in Tabory there are three parts, one of them inactive, one slightly active, and one brightly active. The second is the most abundant and the last is the rarest part. The chondri are said to be chiefly enstatite, and most of them are almost inactive. No luminescence that could be ascribed to oldhamite was observed, although Tassin[2] has reported 0.064 per cent oldhamite in the stone as a whole.

Plainview, Texas (Cc + Cia breccia) contains nearly equal parts of very weak and moderately active material plus a very small amount of a very brightly phosphorescent substance. This was the lightest colored.

Graetna, Kansas is composed of active and inactive parts, the former being the most abundant. A 1 mm. chondrus consists of an active core enclosed in inactive material. The part in which it is imbedded is active.

The powder of Holbrook, Arizona (Cck) was previously reported to have a weak, but long-lived phosphorescence. The unpowdered stone is among the most brightly ionoluminescent meteorites found. When the sign transformer was used, a number of small particles were found to have a brilliant scarlet glow. This, however, rapidly faded and disappeared. If the tube was allowed to cool, however, they reappeared with their former brilliance. If the Ford coil was used, they did not disappear. This would seem to indicate that the active substance is ionoluminescent at room temperature, but not at some undetermined higher temperature. A specimen of Holbrook that had been roasted for some time in air, at a low red heat luminesced somewhat less brightly than an unaltered specimen and parts of it gave a green instead of a blue light. This also contains red luminescing particles. This meteorite is said to consist of 50-60 per cent enstatite and 40-50 per cent olivine and diallage. The inactive part amounts to less than half of the visible surface, thus suggesting that the enstatite is the luminescent part.

In order to test this hypothesis a piece of Holbrook was soaked for 24 hours in concentrated hydrochloric acid, and then in two changes of plain water. After drying, it was introduced into a tube and examined. The result was that the residue (which should consist mainly of the enstatite) gave a bright, long-lived, bluish glow with almost no inactive material. The acid had altered a small amount of some constituent, so that it gave a dull olive-green light. Since the acid removed most of the inactive material, and since olivine is soluble in acid while enstatite is not, it follows that the luminescence of this meteorite must be due almost entirely to the enstatite. It is not unreasonable to apply this conclusion to other stones.

In order further to test the theory that the ionoluminescent constituent of meteorites is enstatite and not olivine, a sample of the Bishopville, South Carolina stone (Chla) was secured. This stone is supposed to be composed almost entirely of enstatite. It has a bright, bluish phosphorescence which decays rather slowly, but there are parts that are inactive, and these seem to be more extensive than can be accounted for by the feldspar and other supposedly inactive minerals. It is evident therefore that not all of the enstatite in meteorites is necessarily ionoluminescent. That the olivine is inactive is shown by the effect of acid on the Holbrook stone, and the fact that pieces of olivine from the Admire and Brenham, Kansas pallasites were virtually inactive.

Several terrestrial minerals were also tested. Olivines were bound to be either inactive or inconclusive owing to the presence of impurities, and diopside, bronzite, diallage, and hedenbergite were all more or less active. Only the bronzite, however, luminesced blue, the others being red or orange.

A substance present in minute particles in the Bishopville stone had a bright, red-orange fluorescence closely resembling the scarlet fluorescent particles in Holbrook. It could not be identified, but it is possibly diallage. This mineral has been reported to occur in the Holbrook meteorite in small quantity, and a terrestrial specimen gave an apricot-colored fluorescence. Terrestrial diopside gave a strong, partly yellow and partly orange, rather long-lived phosphorescence. The spectrum of the latter consists of a rather sharp band including the yellow and two-thirds of the red.

A number of the above specimens of meteorites were purchased from Dr. H. H. Nininger, and some of them have not yet been described. Among them are two from Texas labeled Adrian I and Adrian II and carrying the notation that although they were found rather close together and are similar in appearance, they are not certainly parts of the same fall. The ionoluminescence of Adrian I is a weak, short-lived, white or bluish glow, whereas Adrian II is inactive. If these specimens are representative, it follows that they are probably not parts of the same fall.

When this result was communicated to Doctor Nininger, he sent four more specimens with the request that they be tested in the same way. Two of these from Kansas are labeled Hugoton and Rolla. The former has rather large inactive areas, the remainder being weakly active with bright, short-lived particles. Rolla is almost inactive. Doctor Nininger states that this implication of two falls is in accord with other differences between the two stones. The other pair are labeled La Lande, New Mexico, and No. 174. The former is inactive, while the latter contains about 50 per cent of moderately active, but short-lived mineral. There is also a small amount of brighter material which still glows after the rest is dark. This is lighter in color than the rest when viewed in daylight. This indicates that these two also represent two falls.

Since there is good evidence that comets consist, in part at least, of a swarm of meteorites, and since the sun continually emits electrons, i.e. cathode rays, it may be that there is a luminescence of the meteorites that contributes to the continuous spectrum of the comet. Unless otherwise described, all of the meteorites that luminesced emitted a bluish or bluish-white light. Therefore if this effect exists, it is probably the violet type of continuous spectrum that is produced by it.

Of the 22 meteorites so far tested for ionoluminescence the distribution of brightness is as follows:

Very active	6	27.2%
Moderately active	4	18.2
Weakly active	8	36.4
Inactive	4	18.2
	22	100.0

Except for the two howardites, the color of the active meteorites is bluish; the howardites are yellow. Some of the most active ones phosphoresced for more than a minute. Most of the active meteorites consist of two or three parts. As far as the evidence goes, the inactive part is largely olivine. The other one, or two, are largely enstatite of differing degrees of activity. The inactive meteorites are all dark brown or black, and weakly active ones are dark colored. The most active ones are all light colored, and the most active parts of the others are generally the lightest colored.

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Bibliography.

1. Flight: 1887, "A Chapter in the History of Meteorites," p. 119.
2. Tassin, Wirt: 1908, Proc. U. S. Nat. Mus., 34, 433-4.
3. Kalaczowska, Maria: 1938, Arch. Min. Soc. Sci. Varsovie, 14, 47-56, Min. Abs. 7, 174-5.
4. Buddhue, J. D.: 1940, Mineralogist, 8, 49. 1940, Amer. Jour. Sci. 238, 572.
5. Nininger, H. H.: 1939, Popular Astronomy, 47, 504.

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