Rocks that glow in the dark

The light released when meteorites are heated artificially — "thermoluminescence" — can reveal much of their history before they fell to Earth

Dr Derek Sears
and
Dr Stephen McKeever
are research fellows at the University of Birmingham

"Some fine dust and grains obtained from the inner portion of the mass of the Middlesborough aerolite, when the meteorite was first being chemically and microscopically examined, were found, to my considerable surprise, to glow quite distinctly, though not very brightly, with yellowish-white light, when sprinkled in the usual way for these experiments on a piece of nearly red-heated iron in the dark."

So wrote Professor Alexander Herschel, grandson of the great British astronomer William Herschel, after he had first observed the phenomenon of thermoluminescence in meteorites in 1889. Herschel had unwittingly opened the door on what is now proving to be a useful and, in many ways, unique tool in meteorite research.

Thermoluminescence is not restricted to meteorites. Indeed many terrestrial rocks and ceramics are similar in this respect, but the phenomenon is probably best known for its value in dating pottery of archaeological interest. Thermoluminescence does, however, have a particular significance for meteorites because it appears to be related to several diverse events: for example, the orbit that the meteorites had been on during the past million years or so before collision with Earth; the break-up of the original body in which they had formed; and the time since they fell to Earth. Such matters are of importance to modern meteorite research and it may seem strange that they should all tie up with this same, curious phenomenon. How does the thermoluminescence process work, and how can it be related to such diverse questions?

Alexander Herschel

Most crystalline substances are thermoluminescent to some extent: the light is produced in several stages. First, the lattice of atoms in the crystal absorbs some sort of radiation. The radiation given out by the small amount of radioactive elements present in most substances is sufficient to produce measurable thermoluminescent effects. Meteorites, however, also receive an enormous dose of cosmic radiation. The meteorite crystal absorbs radiation energy via the excitation of electrons which, once excited, move freely through the crystal lattice until they become "trapped" at a defect of some kind. In this way, the crystal stores the energy of the radiation. When the specimen is heated, the electrons are "shaken out" of their traps and, as they return to their normal lower energy, or ground state, some of the electrons give out their excess energy in the form of visible light. Because heat stimulates this light emission (luminescence), the phenomenon takes the name *thermoluminescence.*

The number of thermoluminescent centres builds up steadily under exposure to radiation as more and more electrons are trapped, and falls off at high temperatures as electrons are freed from their traps. The intensity of the thermoluminescence reflects the number of electrons which remain trapped after the irradiation had stopped. So great is the efficiency of meteorites at trapping electrons that the light emission from these materials is intense enough to be just detectable with the dark-adapted naked eye. If the meteoritic sample is given a high dose of radiation in the laboratory, the thermoluminescent emission can even be photographed. The photographs show that only a small proportion of the grains in the meteorite are actually thermoluminescent, and that they are very unevenly spread throughout the specimen.

Usually the colour of the light emission is blue-green, but sometimes it is red, or blue, depending on the type of meteorite under study. Occasionally, the light changes colour as the temperature of the samples increases and different traps are freed of their electrons (Figure 1).

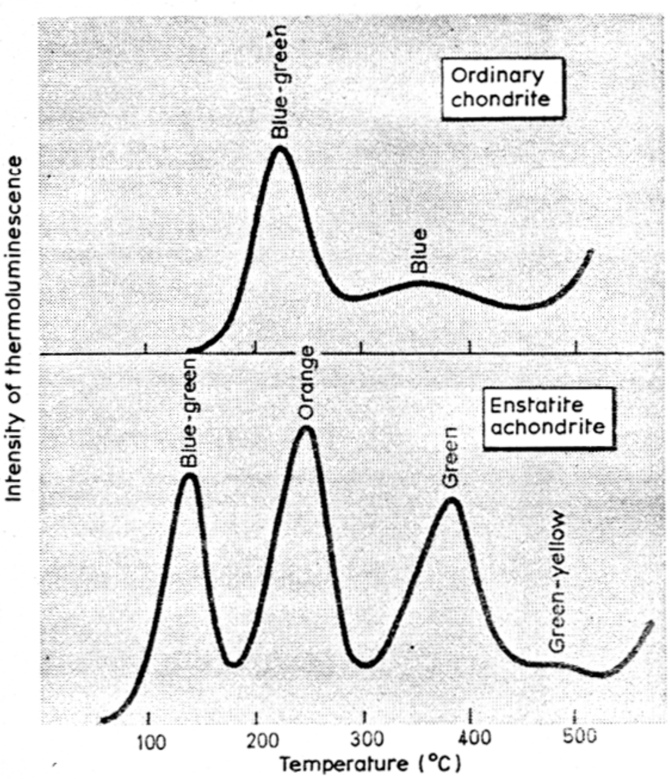
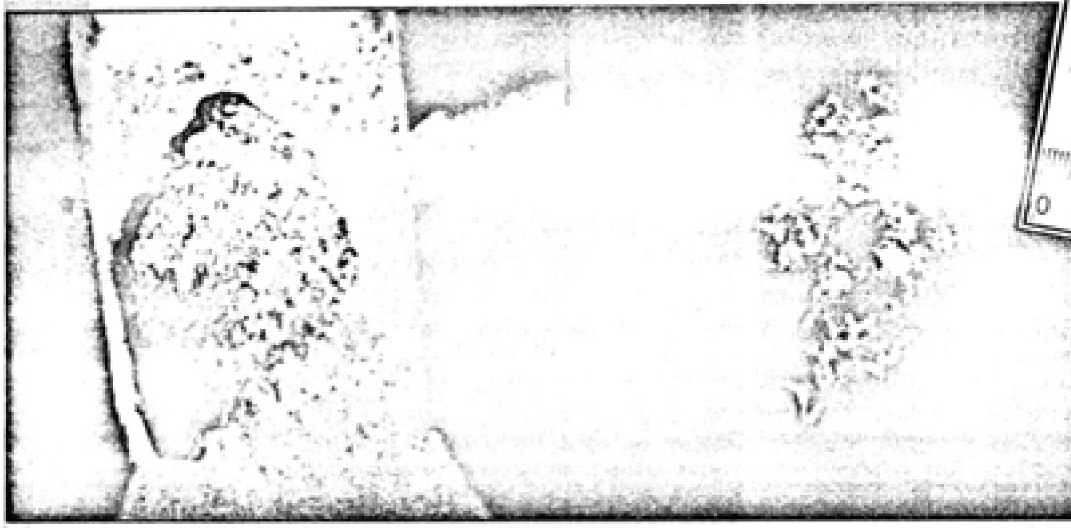
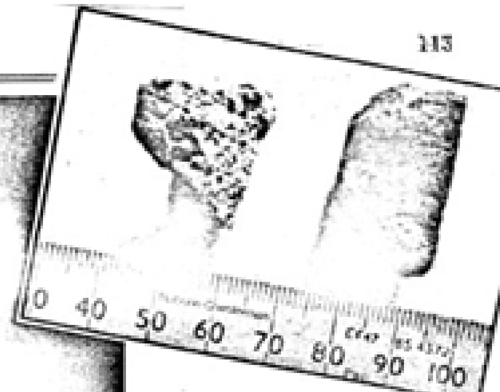


Figure 1 The colour of thermoluminescent emission depends on the meteorite type and the temperature to which it is heated, and reflects the particular mineral contents

Meteorite history

Thermoluminescence is sensitive to two quantities of great value to us in our attempts to decipher meteorite history at Birmingham University—namely, the amount of radiation the meteorites have received and the temperatures to which they have been subjected. Surprisingly, the thermoluminescence within a meteorite is little affected by the heat generated during its passage through the atmosphere. Only the outer 2 or 3 mm of a meteorite have generally been affected by temperatures high enough to disturb the thermoluminescent levels. The reason is that the hot surface of the sample is worn away during its atmospheric descent. The Colby (Wisconsin) meteorite was covered with frost when found shortly after its fall,





Slices of the Holbrook meteorite on the heating strip (far left) and emitting thermoluminescence when heated (left). Shown above are a sample of a black meteorite, that has been "shocked", and a "normal" white specimen

which illustrates this lack of heat penetration. This meteorite fractured on impact so that its cold (below zero) interior was exposed to the air and frost formed over it.

A great many newly fallen meteorites do not show the same levels of thermoluminescence, but rather the intensity of the light emission varies from meteorite to meteorite, over a range of about a factor of five. This is mainly because the fragments that we examine come from inside larger specimens. These larger meteorites were shielded inside, to varying degrees, from external cosmic radiation. The result is that different specimens have stored different amounts of energy and therefore they give rise to varying levels of thermoluminescence. However, a few specimens have levels which are much lower than can be accounted for in this way. Some have had their thermoluminescence at about 200°C completely removed, while in the region of 400°C it remains essentially unaffected. It is as if the specimens have already been heated to, say, 250°C before we examined them. They show no signs of having been reheated by violent means, such as in the collision between two meteorites in space, so the inference is that a close passage to the Sun caused the heating. If this were so, then we have, in thermoluminescence, a potential indicator of a meteorite's orbit. From the temperatures that appear necessary to cause the level of luminescence drainage observed in these meteorites over the time scales involved—about one million years—they probably passed within about 0·75 astronomical units (AU) of the Sun (one AU is the average distance between the Sun and the Earth). We know accurately the orbits of only three meteorites—namely Innisfree, Lost City and Pribram (Figure 2); any technique which can provide data relevant to meteorite orbits is a crucial aid to meteorite research.

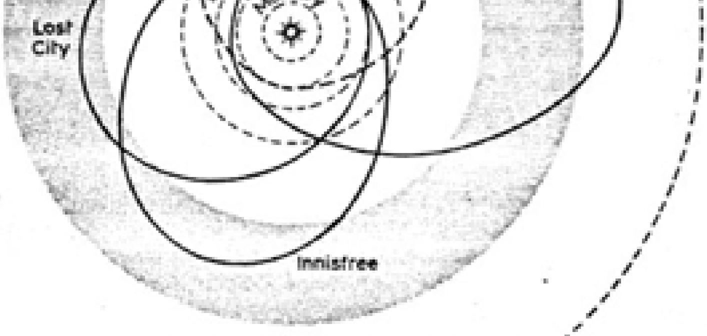


Figure 2 Lost City, Pribram and Innisfree are the only

Black meteorites

Some meteorites have very low thermoluminescence but for entirely different reasons. In these, unlike those we have just described, the thermoluminescence level is low, even after exposure to large doses of radiation in the laboratory. In other words, it is not just that the level of emission is low, but also that the ability of these specimens to store thermoluminescence is low. These meteorites have a number of curious properties. Unlike most meteorites, which are a pale grey (or even white), these specimens are black. Such blackening occurs in the laboratory when meteorite fragments are subjected to high shock pressures, for example by placing the fragments close to an explosion produced by plastic explosive. Most meteorites contain metal, but in the black ones this has been heated and, as a result, their characteristic appearance has been completely changed. When dated by the normal radiometric methods, such as potassium/argon dating, they give unusually "young" ages of 500 million years. Most meteorites have ages of around 4600 million years, in line with the ages of the oldest lunar rocks. This is probably the age of the Solar System, and meteorites presumably formed as a by-product of the process which produced the Sun and planets. But the black meteorites had their radiometric "clock" reset 500 million years ago by an event which severely heated and shocked them and which caused them virtually to lose their ability to thermoluminesce. The blackened meteorites are nearly all from one class—the so-called *L* chondrites—and the catastrophic event which caused the blackening could have been the break-up of the parent body of this meteorite class. We do not know for sure, but it seems likely that this body was an asteroid on the inner fringes of the asteroid belt.

The event which caused the shock and heating of the *L*-chondrites was probably a collision between two meteorite parent bodies. Maybe the other object was the parent body of one of the iron meteorite groups—the III AB irons—which also show evidence of a catastrophic event 500 to 600 million years ago. Apart from altering the physical properties of the meteorites involved (including reducing their ability to produce thermoluminescence), this event also caused the meteorite orbit to change into one which intercepted that of the Earth.

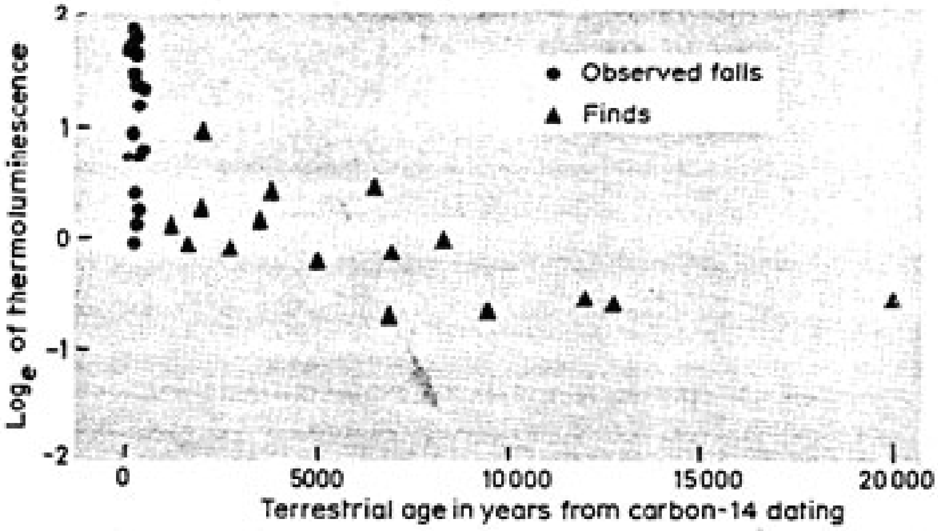


Figure 3 Relationship between thermoluminescence and terrestrial age—the time spent on Earth—of meteorites, determined from carbon-14 measurements

is quite high, even allowing for the lower storage ability of the blackened meteorites. This is due to the high level of cosmic ray bombardment in space which keeps the thermoluminescence high before the meteorites fall (setting aside for a moment the few that passed close to the Sun). Once on Earth, this important source of radiation is denied the meteorite and the amount of thermoluminescence starts to decay to a new level appropriate to its new radiation and thermal environment. Theoretically, this gives a means of estimating the terrestrial residence time of meteorites which have been found, but which were not seen to fall; an important example of such finds are the enormous number of meteorites now being found in Antarctica (*New Scientist*, 22 March, p 959). By measuring the thermoluminescence level ‹
with those of newly fallen m‹
how long it would take for t‹
decay from one level to the othe‹
of the meteorite's time on Ear‹
need to know the rate at which ‹
from its level in space to its te‹
we not know this rate, but the‹
decay does not occur in a simple‹

We have attempted to circum‹
paring the thermoluminescence‹
with their terrestrial residence‹
carbon-14 method (Figure 3). ‹
isotope produced by cosmic-ra‹
much carbon-14 in space, but ‹
a well-known and predictable r‹
in a meteorite depends on the ‹
the meteorite fell to Earth. Des‹
carbon-14 ages—errors are usua‹
because of the difficulties in acc‹
during carbon-14 production in‹
thermoluminescence of three ‹
the curve in Figure 3, we estim‹
mens fell within the past 100 ye‹
fell some 5000 to 10 000 years ‹

We have described three wa‹
and thermal histories of meteori‹
luminescence. There are others,‹
of minor significance. Thermolu‹
new technique and its applicat‹
is in its infancy, but at this stag‹
Herschel had discovered much m‹
have imagined.