Fluff balls of fire

Graham K. Hubler

The most mysterious sort of lightning is ball lightning — glowing spheres of light that float in air. A new theory claims to explain nearly all the properties of these unusual balls of fire.

Ball lightning has been well documented since the Middle Ages as a natural phenomenon associated with thunderstorms. It is relatively rare — only about 1% of the population ever reports seeing it (Fig. 1). It remains an enigma to modern science. Experiments to reproduce ball lightning in the laboratory have not been successful, and a theoretical explanation has eluded scientists since the first attempts 150 years ago[1]. On page 519 of this issue, Abrahamson and Dinniss[2] offer a straightforward explanation of ball lightning, in which they suggest that fluffy balls of silicon burn and emit light. The balls of silicon are created when ordinary fork lightning strikes the earth, by the same chemical reaction that the semiconductor industry uses to form pure silicon from sand.

Because ball lightning has not been produced in the laboratory, observational data consist of several thousand accounts from eyewitnesses (see Box 1). An 'average' ball lightning[1,2] has a diameter somewhere between a golf ball and a large beach ball, and lasts on average 15 seconds (ranging from 2 to 50 seconds) before suddenly fading out or exploding. It can be any colour but is normally white to yellowish and less bright than a 100-watt lightbulb. Ball lightning usually appears out of thin air during thundery weather; its motion is not dictated by the wind and is described as floating in the air not far from the ground. It often bounces when it hits the ground and is influenced by electric fields. It will scorch wooden objects it strikes, and so is a considerable source of energy.

Previous models of ball lightning have mostly centred on electromagnetically confined plasmas of various kinds, nuclear processes and the chemical burning of gases. In the most recent review of ball lightning[3], David Turner observed that "a remarkably consistent picture emerges from the thousands of detailed descriptions which are now available. There is, however, no such consistency in the various hypotheses which have been put forward to explain ball lightning. The only thing most of them share is an ability to explain a few aspects of the phenomenon at the expense of physically impossible requirements in other areas".

The model proposed by Abrahamson and Dinniss[2] breaks the above trend because it can explain most aspects of ball lightning. The model has three important parts. First, the authors realized that the same chemistry used by the integrated-circuit industry to extract pure silicon from silica–carbon mixtures (SiO_2/C) could be at work in nature, provided that there is one to two times more carbon than silica and a temperature of 3,000 K is reached. Such temperatures are not unusual at the point where lightning strikes. The authors checked the composition of various soils and found that some have the appropriate SiO_2/C ratios. Eureka! So this idea can explain the association of ball lightning with thunderstorms, and provide a power source for ball lightning — the chemical energy stored in pure silicon, which is unstable to oxidation at high temperature.

Figure 1 **A rare photograph of ball lightning taken by Sankt Gallenkirch in Vorarlberg, Austria, in 1978. This particular example has a whitish centre with a blue surround, and a luminous tail. Such spectacular ball lightning is less frequently seen than the ordinary spherical sort, for which Abrahamson and Dinniss provide a new explanation[2]. There are extremely few photographs of ball lightning, and as yet no video tapes. It is possible that video evidence exists, but that people are unaware of what they have recorded. If anyone reading this has seen, or knows, of such a video tape or photographs, please write or e-mail me.**

The second part is that the free silicon cools rapidly and condenses into nanoparticles, which can form chains and perhaps even a spherical network of nanostrings, or a 'fluff' ball (my terminology). The authors managed to recreate the conditions of a lightning discharge on soil in the laboratory and produce chains of nanoparticles. But they did not ever see ball lightning. The formation of a ball of nanostrings is the weakest part of this model, but if it can be achieved in future experiments, then we have the remarkable result that most of the properties of ball lightning can be modelled by a fluff ball of silicon. This model can easily explain the floating motions of ball lightning because the silicon networks have very low density, similar to that of air, and it can also explain the range of ball lightning sizes because the initial conditions are quite variable. It is also easy to imagine a small net charge on the ball that would cause it to be influenced by electric fields.

In the third part of their model, the authors calculate the thermal properties of a 30-cm ball of silicon nanostrings. This gives

Box 1: A personal experience

I saw ball lightning during a thunderstorm in the summer of 1960. I was 16 years old. It was about 9 p.m., very dark, and I was sitting with my girlfriend at a picnic table in a pavilion at a public park in upstate New York. The structure was open on three sides and we were sitting with our backs to the closed side. It was raining quite hard. A whitish-yellowish ball, about the size of a tennis ball, appeared on our left, 30 yards away, and its appearance was not directly associated with a lightning strike. The wind was light. The ball was eight feet off the ground and drifting slowly towards the pavilion. As it entered, it dropped abruptly to the wet wood plank floor, passing within three feet of our heads on the way down. It skittered along the floor with a jerky motion (stick-slip), passed out of the structure on the right, rose to a height of six feet, drifted ten yards further, dropped to the ground and extinguished non-explosively. As it passed my head, I felt no heat. Its acoustic emission I liken to that of a freshly struck match. As it skittered on the floor it displayed elastic properties (a physicist would call them resonant vibrating modes). Its luminosity was such that it was not blinding. I estimate it was like staring at a less than 10-watt light bulb. The whole encounter lasted for about 15 seconds. I remember it vividly even today, as all eyewitnesses do, because it was so extraordinary. Not until ten years later, at a seminar on ball lightning, did I realize what I had witnessed. **G.K.H.**

100 YEARS AGO

The old East Anglian proverb, "As blue as wad," occurs to one visiting the Woad Mill described by Mr. [Francis] Darwin in Nature, in 1896 (vol. v. p. 36) as evidence that woad once yielded a blue dye. As a natural sequence one wonders what sort of blue it was and how it was obtained. A somewhat extended series of inquiries amongst those engaged in the woad industry, amongst those who have written on woad, and amongst botanical, archaeological and chemical friends, failed for a long time to elicit the desired information. Curious as it may appear, an appeal to botanical and chemical works, to dictionaries and encyclopaedias was equally unsuccessful. The last-named were pretty uniform in their statements about woad, in that it "was formerly used for dyeing blue, but is now superseded by indigo." Many of the books give an account of the woad-vat in which the manufactured woad is used with bran and lime as a ferment to change the insoluble indigo-blue onto the soluble indigo-white; but they give no clue as to how woad may be used as a blue dye alone. It has been said that the blueness of woad was more or less a myth, and even if it ever possessed this quality it has long since been lost by continued cultivation.

From *Nature* 1 February 1900.

50 YEARS AGO

Eighty years ago, Jevons, then professor of logic at Owens College (now the University of Manchester), built a machine which could perform logical inference by mechanical means. Other similar machines have been built since then. With the present interest in electrical and electronic computing machines, it seemed worth while to construct a logical machine using modern electrical methods, at the same time basing it on the present-day logical technique of truth tables rather more explicitly than had been done by Jevons… It is not to be expected that a machine of this small size will be able to solve logical problems which could not be done with pencil and paper, but it is hoped that this machine may prove to be of value in the teaching of symbolic logic, and that it will stimulate the interest of students in what otherwise tends to become a rather dull subject, and impress on them the mechanical nature of logical operations.

From *Nature* 4 February 1950.

simple explanations for the three most important aspects of ball lightning — lifetime, luminosity and extinction. The lifetime is related to the central starting temperature of the ball after its formation by rapid cooling and condensation, and just before its reheating by oxidation. A lower starting temperature leads to longer lifetimes, calculated to be 2 to 30 seconds. Light emission can last this long because the burn rate is limited by the slow diffusion of oxygen through the developing oxide layer on the surface to the unoxidized silicon underneath.

Abrahamson and Dinniss estimate a luminosity of 1.2 to 14 watts for the silicon ball over the visible range, and the range of blackbody temperatures in the ball's interior can explain most of the colour variation. Their model predicts that heating above a given starting temperature will lead to melting and an explosive end, whereas below a certain starting temperature the ball will completely oxidize before melting and just fade away. Finally, the model predicts that for lower starting temperatures, the ball will become visible only over the latter part of its lifetime, so the appearance of the ball will not be directly associated with the lightning strike, as is usually observed.

The attractiveness of this model is that it offers a rationale for the duration (very important), delayed time of appearance after lightning strike, luminosity, size, motion and extinction of ball lightning, all of which fit in with my personal experience (Box 1). Ball lightning is such an enigma that new ideas that bear on the problem, such as we find here, are badly needed. Such ideas must then be tested until a definitive result narrows the search. Happily, many of the physical processes in this model are experimentally accessible. We can look forward to observations that will prove or disprove these ideas, which are an unusual but welcome development in research on ball lightning.

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2. Abrahamson, J. & Dinniss, J. *Nature* **403,** 519–521 (2000).
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Animal behaviour

Survey flights in honeybees

Thomas Collett

Foraging honeybees may range as far as 10 km from their hive to reach a foraging site and must then find their way home. Before a bee begins its foraging career in earnest, it performs orientation flights that seem to be designed to help it learn landmarks that can guide subsequent returns to the hive. Detailed analysis of these special-purpose flights is helping to clarify the strategies that bees use for learning and navigation. Segments of orientation flights in which the insect is near to the hive can be recorded on videotape — this phase of the flight has been closely studied in ground-nesting wasps when they emerge from their nest holes[1]. Later phases, when the bee is far from the hive, are much harder to monitor. Capaldi and her colleagues describe on page 537 of this issue[2] the first examples of a bee's path during the later phases of the flight. They have used harmonic radar[3] to follow the bee from when it leaves the immediate vicinity of the hive to its return.

Individual bees are fitted with a small antenna incorporating a transponder, which, when activated by a radar pulse, emits the first harmonic of the radar signal. The bee can then be picked out from surrounding clutter over a range of 700 m. However, the technique has limitations. It can be used only over open ground, otherwise the bee is masked by vegetation. Positional fixes are given no more frequently than once every 3 seconds, and even so some fixes are missing. Height is not recorded. Nonetheless, radar tracking is a great advance over earlier methods of investigating long-range navigation. Bees can be tracked by eye for at best 30 m, so earlier studies were limited to measuring journey times and the bearings at which a departing bee vanished from view.

Capaldi *et al.*[2] find that a typical orientation flight starts with a relatively straight outward path from the hive. After flying between about 10 and 300 m, the bee loops round and returns directly home along a route that is often close to the outward one. Bees make a variable number of these flights (with a mean of about six) before beginning to collect food, with later flights tending to be longer and faster than earlier ones. As individuals have not yet been tracked over multiple flights, it is not known whether a sequence of flights is limited to a narrow sector around the hive. Nor is it known whether orienting bees choose their own flight direction or are directed by the dances of experienced foragers. The relationship between orientation flights and subsequent foraging behaviour will be fascinating to explore.

What do these results reveal about navigational strategies? An important finding is that the longer an orientation flight, the faster the bee flies. This correlation between