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were pretty uniform in their statements about woad, in that it "was formerly used for dyeing blue, but is now superseded by indigo."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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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 distance and speed suggests that bees fly higher on longer orientation flights. Bees adjust their flight speed to keep images moving at a constant speed across the retina[4]. And to maintain a constant image speed, they will need to fly faster if they gain height. A strategy of increasing height with distance from the hive has interesting consequences. It means that bees learn small features of the landscape close to the ground when they are near the hive, and larger features when they are further away. Their geographical knowledge would be fine-grained close to home and coarse-grained further away, making it ideal for homing in on the hive. Another significant characteristic of orientation flights is the simple hairpin shape of the flight paths. On the straight homeward leg, the bee faces mostly towards the hive, so any views captured en route would be especially helpful in guiding subsequent journeys home. Straight flights towards the hive also allow bees to associate the views they learn with the action of flying along a particular homeward compass bearing.

A bee does learn something about its way home, even from a single orientation flight, as shown first by Becker[5] and later by Capaldi and Dyer[6]. In the latter study, bees were caught after their first orientation flight and moved to one of several release sites. On release, the bees flew directly towards the hive from those release sites that gave an unobstructed view of the landscape around the hive. Enough landmark information had been acquired during the orientation flight to guide a short homeward trip. The landscape away from the hive is presumably unfamiliar on the orientation flight itself, so the bee's homeward leg is likely to be steered by vector information rather than by landmarks. On the outward leg, the bee records the net distance and direction flown from the hive and then reverses this vector for its return. Straight paths in and out allow the bees to minimize errors in dead reckoning.

That the prime function of these orientation flights is to ensure a safe journey home is so far only a plausible assumption. We can expect this and other issues to be resolved as radar tracking reveals more of the story. An intriguing observation of Capaldi *et al.*[2] is that bees seem to land during some orientation flights. Why bees land, and whether this behaviour reflects a continuum between orientation and foraging flights, rather than discrete categories, is still uncertain. ■

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Condensed-matter physics

Electrons in the looking glass

Eric Heller

The scanning tunnelling microscope (STM) is a marvel to scientists and the interested public. Twenty years ago, who would have thought that we would 'see' individual atoms so directly? New science has flowed from this technology like water from a fire hose. After atoms, electrons were next to be imaged, although they are too light to stay put and be 'photographed'. At best the images are blurred, but not just any old blur: the electrons are seen moving in atomic and molecular orbitals, in textbook fashion.

Electrons next made a surprising appearance on the condensed-matter physicist's turf, in the form of conduction electrons freely moving around on the surface of metals such as copper[1,2]. Not only that, but at low temperatures they showed off their true quantum nature by creating dramatic interference patterns that can only happen when waves come together, adding crest to crest (constructive interference), or crest to trough (destructive interference). The STM images that emerged from Donald Eigler's laboratory are now well known, earning the cover-page 'triple crown': the covers of *Nature*, *Science* and *Physics Today*[1–3]. Not surprisingly, the latest STM images from Eigler's group, reported on page 512 of this issue[4], can again be found on the cover.

It is easier to understand what is going on in these images if we use an acoustic analogy. Suppose you have a mobile omnidirectional speaker, which you place at some point in a room. The speaker plays a sine wave of a given frequency, while you measure power radiated into the room. You would notice a variation in power output by changing either the frequency of the sound or the position of the speaker. The reason is simple: sound reflected off walls and furniture comes back and combines at the speaker to make a returning wave with a given amplitude and phase. This wave makes the speaker do more or less work as it oscillates in and out, depending on the relative phase of the speaker and the returning sound. If you keep the frequency fixed, you could make a plot of power output against speaker position; it would have a definite wavy appearance.

If you have followed this acoustic example so far, you are almost there. Now, replace

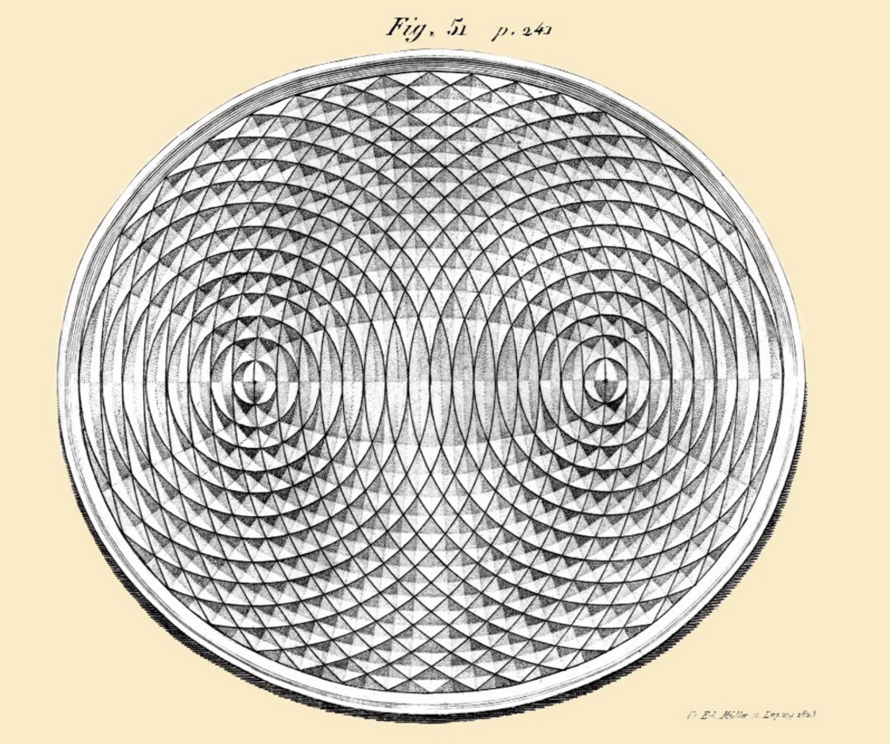

Figure 1 **Waves in an elliptical dish of mercury. This drawing by the Weber brothers[8] in 1825 may be one of the most remarkable hand-drawn scientific illustrations ever. It shows what happens when you put droplets of liquid mercury into one focus of an elliptical dish filled with mercury. The experiment clearly reveals the other focus. In their experiment, Manoharan *et al.*[4] create an elliptical quantum corral (see cover) in which the signature of an atom at one focus of the ellipse is clearly sensed at the other 'empty' focus.**