# Historic methods for capturing magnetic field images

Alistair Kwan
Centre for Learning & Research in Higher Education, University of Auckland

Preprint. Accepted for publication in *The Physics Teacher*

**Abstract**

Two late nineteenth-century methods for capturing magnetic field images from iron filings are investigated for historical insight into the pedagogy of hands-on physics education methods, and to flesh out teaching and learning practicalities tacit in the historical record. Both methods offer opportunities for close sensory engagement in data-collection processes.

## 1 Magnetic blueprints

Inspired by the rich blue magnetic field prints that I found in students' physics notes from the early twentieth century (Fig. 1), I decided to try the method myself to explore how the process differed pedagogically from the plotting compass method commonly used today. Instructions can be found in many period laboratory manuals. Wauchope, for example, instructs:[1]

> Place on the table a bar magnet, and over this a plate of glass. Sift fine iron filings evenly on the plate, being careful not to use too many filings. Holding one corner of the plate, tap it gently with a pencil until the magnetic lines of force are well defined. Lift up the plate vertically from the magnet and place beneath it a piece of blue-print paper. Expose this to the sunlight about 20 seconds, then quickly place it in the sink and rinse thoroughly. When dry, bind it in your notebook.

Millikan gives fuller details about the printing process: for the exposure, "wait until the uncovered parts of the paper have turned pale blue." He quantifies the rinse as a "soak in water for about five minutes." Finally, "Place the paper flat against a pane of glass to dry" so that, held by the water's surface tension, the product will be smooth and flat.[2]

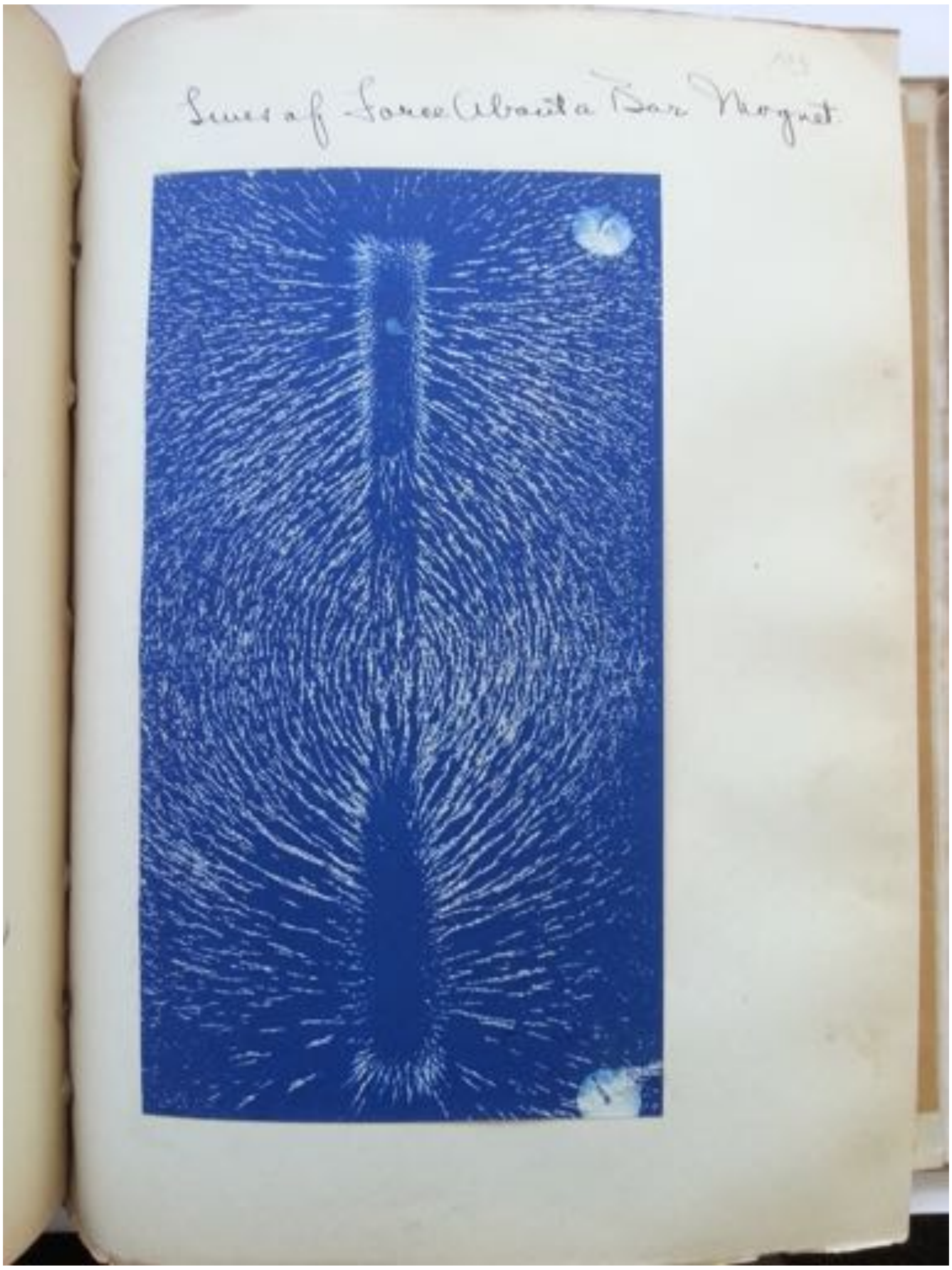
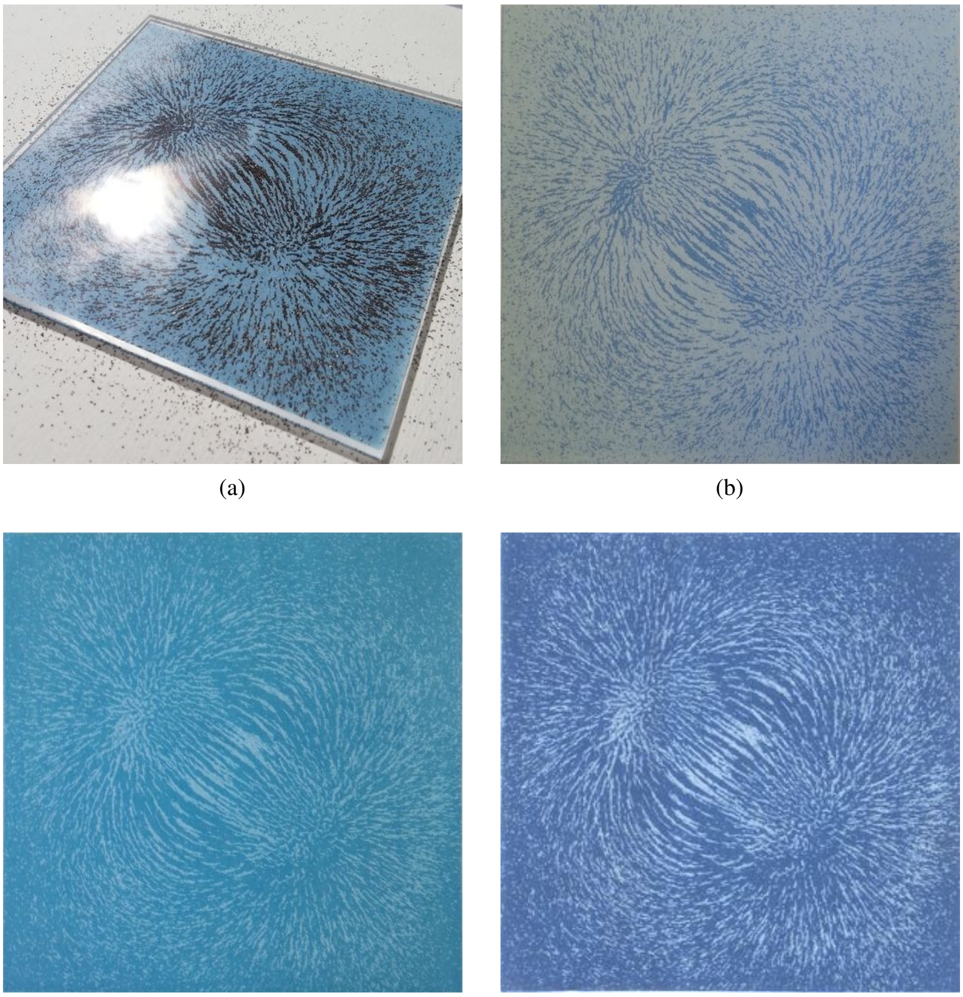



Figure 1: A magnetic field cyanotype pasted into the laboratory notebook of Clara Weiss, a student at the Ethical Culture School in New York, 1915–16. Cyanotype dimensions 10 cm × 18 cm. Author's collection.

Wauchope's phrasing suggests that cyanotype (blueprint) paper is either easy to make or was at least easy to obtain. At the time, it was mass-produced for engineers and architects.[3] While that market has given way to other duplication processes, blueprinting paper is still easy to make, and in fact still commercially available, for example in the Sunprint Kits produced by the Lawrence Hall of Science.[4] I placed a Sunprint Kit sheet on a plastic box lid, with a magnet in the cavity underneath, scattered filings over, and placed the Sunprint Kit's acrylic sheet on top to hold the filings securely while I carried the sandwich outdoors, and to protect them from the breeze. After approximately a minute in Auckland's early-afternoon sunlight, the visible paper was pale yellow. Back indoors, I poured the filings back into their jar. I smoothed the wet paper onto a glass window to dry flat. Drying took about fifteen minutes; the time required is of course affected by local humidity, temperature and airflow — and easily sped up with a radiator or hairdryer. The image was immediately serviceable, but the blue did darken over the coming day, producing the cyanotype shown in figure 2.

How does blueprinting work? The process was discovered in 1842 by Sir John Herschel (1792–1871). Herschel's recipe is "a mixture of the solutions of ammonio-citrate of iron [ferric ammonium citrate] and ferrosesquicyanate of potash [potassium ferricyanide], so as to contain the two salts in about equal proportions".[5] The liquid is brushed onto paper and left to dry. Exposure to ultraviolet light energises production of the pigment known as Prussian Blue (or, in German, Berliner Blau) — hence the print being called a 'cyanotype', whose Greek etymology means 'struck in blue'. The exposed print is washed in water to remove the unexposed reagents, leaving a white negative trace. The exposed reagents remain and oxidise over a day or so to produce the final rich color.

Herschel saw potential for rapid, large-scale reproduction of handwritten texts, and developed techniques that ultimately became the well-known blueprinting used for reproducing architects' and engineers' drawings. Such blueprints are made by drawing in ink on tracing paper, then laying blueprint paper behind the drawing. A glass- or celluloid-fronted frame holds the two sheets closely together so that the inked drawing accurately masks sunlight otherwise reaching the blueprint paper underneath. Finally, the print is removed for washing, leaving the frame and drawing free for another blueprint to be exposed. By 1910, numerous patents had been lodged for frame designs incorporating electric lighting to replace the sun, curved surfaces for easier loading and unloading of the drawings, and machinery to move the paper between exposure, washing and drying for continuous copying. Washing and drying



(a) (b)

(c) (d)

Figure 2: Four steps in cyanotyping a magnetic field photogram: (a) paper under filings and acrylic in the sun, (b) exposed but not yet washed, (c) washed and still wet, (d) after a day's drying.

inevitably distorts the paper, hence the rule to explicitly specify dimensions on diagrams, and never to measure directly from a blueprint. The distortion was sufficiently small, however, that cyanotyping was applied almost immediately to scientific representation, notably in the first photographically illustrated book, a study of algae, scans of which can be viewed at the British Library's website.[6]

Artists continue to use Herschel's basic idea, sometimes with adaptations for shorter exposure times, preservation against mold, better adhesion to paper and color variations, and toning to other hues.[7] The blueprint process was also taught in introductory chemistry courses. Brownlee et al.'s *Laboratory exercises*, for example, uses it as the context for experiments in which students determine which of the two ingredients is photosensitive, supported by practical hints about the paper and technique:[8]

> Dip a piece of absorbent cotton in the [solution]. Squeeze the cotton nearly dry and coat very lightly one side of a piece of Parchment Bond paper. If an unsuitable paper is used, the ferric chloride solution will soak into it and will not wash out, but will leave yellow where white ought to appear on the print.
>
> ...
>
> A good blue-print paper can be prepared by coating a non-porous paper with a 10% solution of ferric ammonium citrate and drying in a dark place. After the exposure, the print is developed with a solution of potassium ferricyanide and fixed by washing with water.
>
> Practically, the solutions of ferric ammonium citrate and potassium ferricyanide are mixed and a suitable paper is coated with the mixture, then dried and kept ready for use. After printing, the print is developed and fixed by washing with water.

## 2 Iron gall printing

Another method, also described in textbooks around 1900, uses a chemical trace left by the iron filings themselves:[9]

> *Make a map of the field of a magnet showing the direction of the lines of magnetic force.*
>
> Place the glass over the magnet lying on a table so that the magnet will be at the center of the glass, and support the glass at its opposite

> ends on the strips of wood. Sift iron-turnings (previously broken fine in a mortar) through the sieve very sparsely over the glass plate. Tap the glass at different points near its edges with the end of a lead-pencil. When the filings in the vicinity of the magnet have arranged themselves satisfactorily, wet one side of a sheet of white paper with the solution of tannin; commencing at one end, lay the wet side carefully on the turnings, place the blotting-paper over this paper, and press gently upon them with the hand. Now raise the white paper from the glass carefully, so as not to disturb the adhering turnings; put it aside to dry, and, when dry, brush off the turnings. Marks will be made by chemical action between the tannin and iron wherever the latter touches the paper.

This process is a variation on the manufacture of iron gall ink, created directly on the paper wherever the iron filings happen to lie — similar to the variation described by the Alexandrine scholar Philo of Byzantium (280–220 BC), who wrote that invisible messages written in oak gall infusion (the tannin solution) will be revealed by dabbing with a solution of copper or ferrous sulfate.[10] More usually, though, iron gall ink was made in already-visible form by mixing ferrous sulfate or iron and an acid (such as vinegar) with the liquid produced by boiling, macerating or fermenting crushed oak galls in water or wine. A binder — traditionally gum arabic, the dried sap of acacia trees — was then added to suspend insoluble precipate and stick it to the paper. Powdered eggshell or seashell could also be added to reduce the acidity that otherwise eats away the paper or parchment on which the ink is applied.

Oak galls can be hard to find, but laboratory suppliers sell tannic acid, and suitable tannins can be extracted also from many plant materials. I prepared an infusion from acorns fallen from English oaks (Quercus robur), chosen partly for the convenience of having so many on and near my university campus, and partly to test the robustness of this ink-making method. A kitchen blender quickly reduced a cup of acorn cotyledons and a cup of water to a coarse slurry which, after an overnight soak, I strained through a paper coffee filter. I brushed the infusion onto photocopying paper and laid it on iron filings as Gage instructs, pressing lightly with the side of my hand to effect good contact.

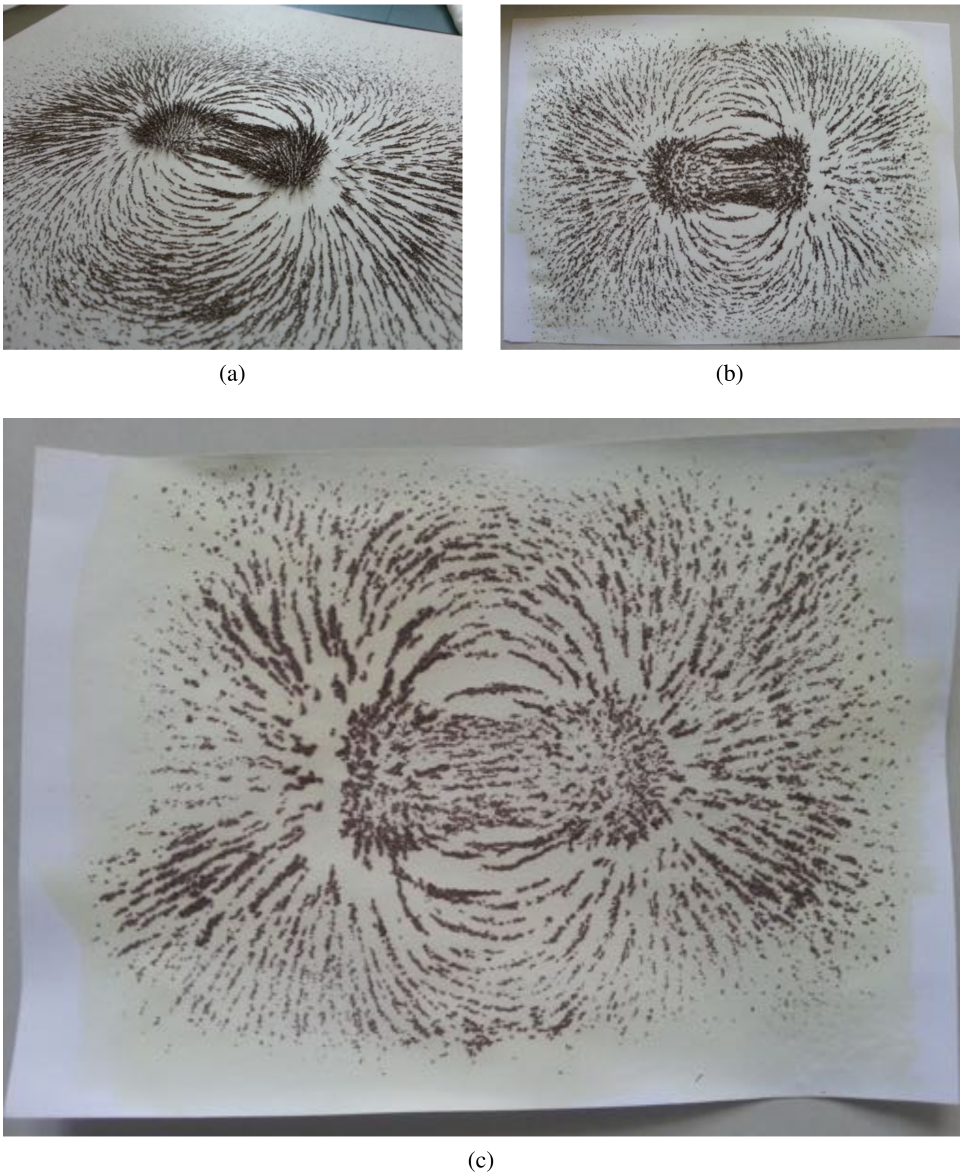
I laid the wet sheets, with adherent filings, on a flat surface to dry. By the time I turned the gall-infused sheets over, dark purple spots had already formed where the iron touched the wet paper. I soon learned why Gage recommended that the filings be "broken fine" and spread "very sparsely". Too many filings make for an illegible mottling rather than the field pattern expected, and the patterns are far better when made with fine filings than with the coarse granules that educational suppliers sometimes sell as “filings”. (Fine filings are often listed under reagents, rather than with the magnetic demonstration apparatus.) A sample print is shown in Figure 3.

## 3 What can we learn from old methods?

While the plotting compass provides opportunities to learn about interpolation and to measure locally generated magnetic fields relative to the earth’s, using it requires a raft of skills and conceptualizations that introductory students do not always have. Moving the compass, marking positions and fitting the curve require manual drawing skills distinct from the book-reading and algorithmic mastery that dominate today’s curriculum. Placing the compass requires either a prior conceptualization of the field or the deep cognitive engagement to develop and refine measurement strategy based on points already observed. When the plots are complete, students turn out to have produced all sorts of field lines, and not all have yet understood enough to tell whether they have done a good job. In my search of historical archives, I have found only one case of the compass plot done well. The student was Ernest Walton, whose freshman laboratory notes left me in no doubt that he entered university already on-track for research in experimental physics, leading eventually to his Nobel Prize — the skill requirement seems mismatched with the vast majority whom we teach.

Iron filings allow more direct and dynamic engagement with field geometry. The filings respond instantly to changes in magnet position or the insertion of magnetic materials, providing immediate learner-accessible scope to participate in controlling data quality. All three of Wauchope, Millikan and Gage caution the reader not to put too many filings on, and say to tap the glass plate until the filings produce an image worth collecting. What counts as a satisfactory image? It takes some experimenting with the filings to learn what is possible, some experimenting with the printing process to learn what can be captured, and some serious but feasible consideration to decide what constitutes a faithful representation. It even takes some skill to tap usefully, but not so much skill as to be beyond school or university learners. Such subjective judgement is important in experimental science, and these old methods offer opportunities for students to participate meaningfully in making them.

Iron filings do not show polarity, which requires a compass or multiple magnets. The value of using a cyanotype or iron gall image is in separating the concepts so



(a) (b) (c)

Figure 3: Iron gall ink impressions of a magnetic field: (a) filings on dry paper, (b) filings adhering on photocopying paper wet with acorn infusion, (c) dried print.

they, and their associated manual skills, can be addressed in smaller bites. There is scope for integration, however: Millikan's laboratory manual introduces polarity by having students "hold a short compass needle in a number of positions over the board, and observe whether or not there is any connection between the direction of the curved lines and the direction taken by the needle." He introduces the "lines of force" concept at this point, directly from the iron filing pattern and compass needle. Millikan hence eliminates the need to draw lines before the student has had a chance to conceptualize them. Once that is done, he sends them outside to expose their blueprints.

From a conceptual standpoint, imaging the fields by cyanotype or the iron gall process offers a reasonably literal record of what was seen: the image is formed by the very iron filings that reveal the field shape, unfiltered by a novice or biased observer, and not distanced by an intermediary technology such as a digital camera. While we cannot look at the magnetic field, we can at least look at its immediate indicators — the iron filings — with less conceptual overlay or distraction than if we focus on a higher technology such as a camera viewfinder. Photography is itself a skilled task — it may not require the pencil control needed for drawing, but composing a good shot does require adequately seeing the scene before opening the shutter. To see the scene well requires the very conceptualization of a magnetic field that we are trying to teach.

The apparition of the printed image, aside from being memorably impressive, offers another moment for students to engage critically in the measurement process: they must judge for themselves how long to expose the image for. Wauchope specified "about 20 seconds," but the actual time depends on the paper and sky conditions or light source. My cyanotypes, for example, took approximately a minute under thinly clouded sky, on a late summer afternoon in Auckland, New Zealand. Millikan's instructions have students monitor the print to actively evaluate and control the quality of data gathered. Photographing with a mobile telephone might be more convenient, but complicates this opportunity for critical engagement with the image capture process. The cyanotype exposure process is sufficiently convenient that students can easily investigate what it is about some light sources (like the sun) that activates the paper, while others (like candle flames and dim tungsten filaments) do not, which explains why no darkroom is needed. Exposing blueprint paper to sunlight dispersed by a prism will demonstrate which parts of the solar spectrum energize the reaction for Prussian blue — in fact Herschel, in the article cited above, shows the results of doing so using a flint-glass prism made by

Fraunhofer.

## Notes

[1]J.A. Wauchope, *Laboratory manual in physics* (Scott, Foresman and Company, Chicago, 1912), p. 52.

[2]R.A. Millikan, H.G. Gale and E.S. Bishop, *A First Course in Laboratory Physics for Secondary Schools* (Ginn and Company, Boston, 1914), p. 63.

[3]F.B. Hays, "Blueprint paper: its manufacture and some of its characteristics", *Scientific American Supplement* 75, 45–46 (18 January 1913).

[4]Lawrence Hall of Science, "Sunprint," `http://sunprints.org/` (2010).

[5]J.F.W. Herschel, "On the action of the rays of the solar spectrum on vegetable colours, and on some new photographic processes," *Phil. Trans. Roy. Soc. Lond.* 132, 181–215 (1842).

[6]A. Atkins, *Photographs of British Algae: Cyanotype Impressions* (Anna Atkins, London, 1843–1853).

[7]M. Ware, *Cyanotype: the History, Science and Art of Photographic Printing in Prussian Blue* (Science Museum, London, 1999).

[8]R.B. Brownlee, R.W. Fuller, W.J. Hancock, M.D. Sohon, J.E. Whitsit, *Laboratory Exercises to Accompany First Principles of Chemistry* (Allyn and Bacon, Boston, 1908), pp. 102–104.

[9]A.P. Gage, *Physical Laboratory Manual and Note Book* (Ginn and Company, Boston, 1895).

[10]K. Mackrakis, "Ancient imprints: fear and the origins of secret writing," *Endeavour* 33, 24–28 (2009).