MONTCLAIR STATE UNIVERSITY

LASER Journal

Volume 2 | Issue 1 Article 2

2024

`The very beautiful principles of natural philosophy': Michael Faraday, Paper Marbling and the Physics of Natural Forms

Robert Pepperell
Cardiff Metropolitan University, rpepperell@cardiffmet.ac.uk

LASER Journal Volume 2, Issue 1 (2024)

'The very beautiful principles of natural philosophy': Michael Faraday, Paper Marbling and the Physics of Natural Forms

Robert Pepperell[1]

Abstract

In 1854, Michael Faraday wrote to thank the author who had sent him a book on the art of paper marbling. In the letter, Faraday referred to 'the very beautiful principles of natural philosophy' involved in the process of dropping ink on thickened water. What are the 'beautiful principles' that Faraday referred to, and how are they involved in the art of paper marbling? Here I consider some of the physical processes that occur in paper marbling and how the patterns that emerge represent 'dissipative structures' that are governed by fundamental principles of nature, in particular the tendency for physical systems to minimize their free energy. Similar principles informed the theories of perception and aesthetic appreciation developed by the founders of the Gestalt school of psychology in the early twentieth century, which were inspired by Faraday's work on magnetic fields. I suggest that combining these theories with the insights from thermodynamics offers a fertile approach for understanding the relationship between fundamental principles of nature and art.

1 Introduction

Michael Faraday, born in London in 1791, was one of the leading experimental scientists — or natural philosophers — of the nineteenth century. He made many important contributions to the fields we now call physics and chemistry, including discovering the principles of electromagnetic induction. He was also a great populariser of scientific knowledge through his many writings and public lectures.

In 1854, at the height of his prestige, he wrote to thank the author Charles Woolnough who had sent him a copy of his recently published manual on the art of paper marbling, the first of its kind in the English language [1]. In the letter, Faraday referred to 'the very beautiful principles of natural philosophy' involved in the technique of marbling, which Woolnough's book had catalogued and exemplified in detail

[1]rpepperell@cardiffmet.ac.uk, Professor, Cardiff Metropolitan University, Cardiff CF5 2YB, UK

[2]. Faraday was familiar with the art of marbling as it was widely used in bookbinding, the trade in which he had apprenticed before becoming a laboratory assistant to Sir Humphry Davy in 1813.

The marbling technique frequently produces patterns that resemble organic structures like stones, animal markings, eyes, shells, veins and cells (see Figure 1). The readiness with which these patterns appear through this technique suggests there is some common — perhaps deep — organisational principle at work in the formation of certain organic structures and the physical processes involved in marbling.

Many people are struck by the naturalistic beauty of marbled papers, as indeed was Michael Faraday. What are the 'beautiful principles' that Faraday referred to in his letter to Woolnough? How are they expressed in physical processes like marbling and in the formation of natural structures, and why are they thought to be beautiful? In this paper, I suggest that by addressing these questions we may reveal connections between the appreciation of art and the scientific principles that guide the formation of natural structures.

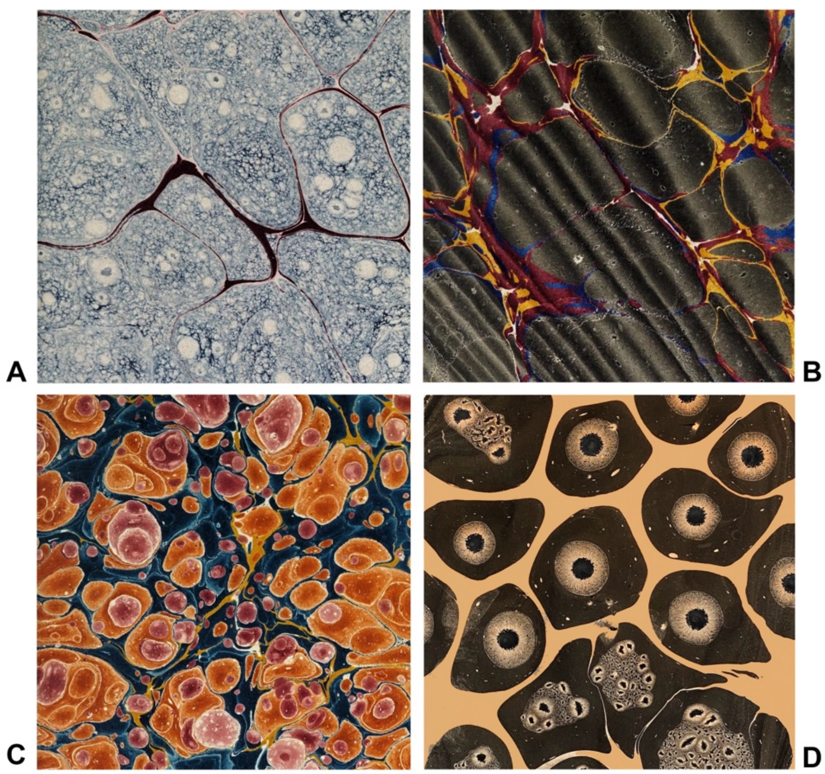

Figure 1: Examples of traditional paper marbling patterns that evoke natural forms. The designs shown are: panel **A**, stone; **B**, vein; **C**, shell and **D**, tiger eye. These designs were used widely in book binding in the nineteenth century and would have been familiar to Michael Faraday (Panels A-C from Charles Woolnough's marbling manual of 1853 [1]; panel D by the author).

2 The Paper Marbling Process

Paper marbling is an ancient visual artform that is thought to have originated in China and Japan around 800 years ago, spreading to Europe via India and Turkey in the 1500s, and becoming an integral part of the bookbinding trade in Europe and the Americas by the 1700s [3, 4]. The process involves dropping coloured media — which can include various inks, pigments bound in oil, acrylic polymers or Gum Arabic, and chemicals that modify the behaviour of the media — onto a bath of water thickened with an agent such as carrageenan, which is extracted from red seaweed. Due to the surface tension of the bath and effect of the thickening agent, the coloured media float rather than sinking or diffusing when applied. Depending on their density, weight, chemical composition and on the method of their application the media spread across the surface of the bath at varying rates and distances. Typically, they form circular shapes that are deformed when other drops are applied nearby. By applying multiple drops of different colour, complex patterns can be built up on the surface of the bath that are then transferred to specially prepared paper to make a permanent print (Figure 2).

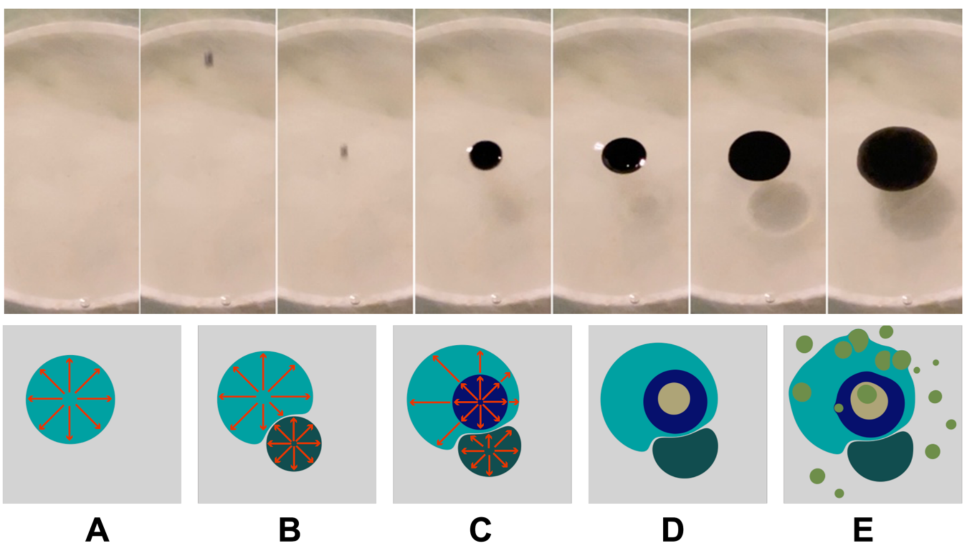

Figure 2: *Upper image*: A sequence of frames from a video made by the author showing a drop of ink media falling onto the surface of a marbling bath. Note that the drop spreads out into a circular disc shape on contact with the bath. It is by repeated application of drops of ink, and subsequent manipulation of the patterns they produce, that the overall designs of marbled papers are produced. *Lower image*: A schematic model of the marbling process, adapted from [5], in which drops of media are added next to or on top of each other. (Reproduced by permission of IEEE). Red arrows in panels **A-C** indicate directions of forces acting on drops of coloured media floating on the horizontal plane surface of the marbling bath (in grey). Panels **D** and **E** show the build-up of more complex cell-like patterns as more drops of media are added and interact with each other and the bath.

3 The Physics of Paper Marbling

The technique of paper marbling exploits several basic principles of classical mechanics and thermodynamics. In simple terms, the marbling process can be treated as a dynamical material system in which portions of matter (drops of coloured media) containing certain quantities of thermal and chemical energy have further kinetic energy transferred to them during the process of application, all of which is then dissipated as the matter makes contact with the surface of the bath.

Forces acting on the media during application are directed downward due to gravity and outward from the centre of application due to the bath's surface tension, causing the media to expand into a thin disc (Figure 2). The disc of media reaches its lowest energy state and largest size when its cohesive forces prevent further expansion. More energy and matter are added to the system as new drops of media are applied, which do mechanical work on existing discs and move their boundaries.

Forces of repulsion, adhesion and cohesion in different portions of media act on each other such that the pattern on the surface of the bath becomes a dynamic system that seeks to accommodate all its opposing forces. Once the addition of new media stops, the sum effect of all the forces that have been exerted in the system produces a static equilibrated pattern that constitutes the lowest free energy, or highest entropy, state of the system as a whole.

Finally, a print is taken from this pattern by carefully laying paper on the surface of the bath such that the floating media transfer to the paper, thus permanently capturing the equilibrium state of the system in a design (Figure 3). Modelling the behaviour of a marbling-bath system using physics-based methods is extremely difficult due to the complexity of the dynamical interactions involved. However, progress has been made in mathematically modelling them [5] and is being further explored [6].

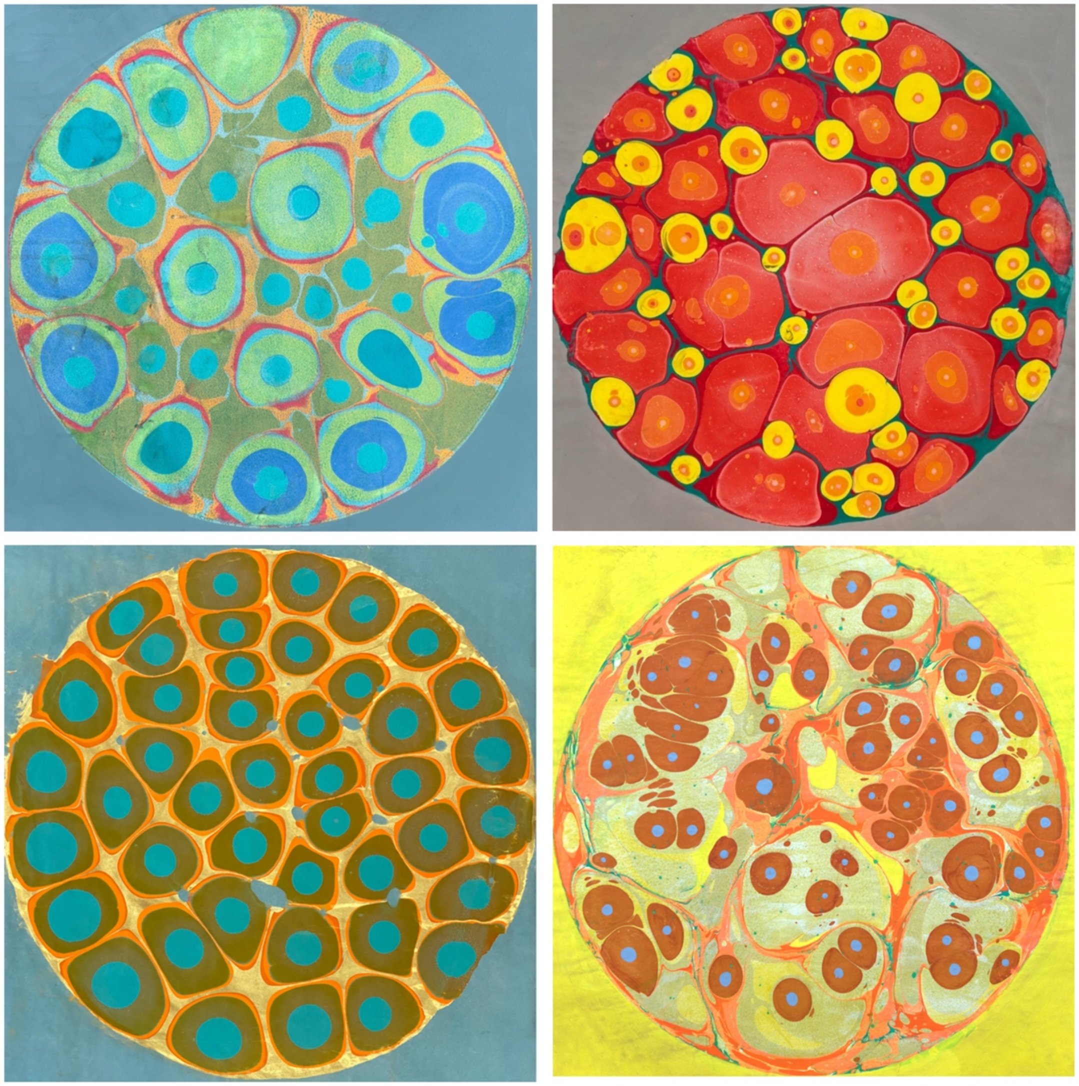

Figure 3: Examples of paper marbling patterns created by the author (2024). Each is 60 x 60 cm in size and made using various ink and paint media on paper. Note the organic forms that strongly resemble cellular shapes. These patterns appear to emerge spontaneously when the ink is applied to the surface but are the product of many interacting forces that tend towards a state of near-stable equilibrium (low free energy and maximum entropy) during the marbling process, and which is captured in the final image as a static print.

4 The Biophysics of Organic Structures

As with the cell-like designs produced by paper marbling, biological cells are products of dissipative processes involving the transfer of (biochemical) energy between portions of (organic) matter that actuates (biophysical) work in which forces displace matter against resistance ([7, 8]; see Figure 4, A), although there are some important differences in the way marbling systems and biological systems function.

Forces act in numerous ways on organic matter during processes of cell formation, growth and operation, from the random Brownian motion of intracellular molecules due to thermal energy to the highly organised flows of ions that regulate membrane potentials and intercellular communication. The free energy required for most of this cellular work is sourced from hydrolysis of adenosine triphosphate [9].

One of the most important ways that work is carried out by cells to regulate development and behaviour is through cytoskeletal filaments, including actin filaments [10] (Figure 4, B). These dense meshes of polymers provide structural support for the cell and enable motility by exerting microscopically small forces within the cell that can be measured with precision [11]. Cytoskeletal structures also respond mechanically to externally applied forces. Acting alongside other forces, such as those exerted by cortical tension, adhesion-driven tension and pressure, the forces exerted by cytoskeletal structures allow the cell to adapt its shape and maintain its integrity under environmental stresses [12] (Figure 4, D).

Biological cells are one example of a general class of natural phenomena that have been described as 'dissipative structures' [13, 14, 15]. These structures tend to emerge when a system absorbs matter and/or energy from an external source and, if it has enough degrees of freedom to reconfigure itself, takes on a form that efficiently minimizes its free energy for as long as the source of matter and/or energy is maintained. Applying these principles to the case of cellular systems, and their intricate internal structures and processes, a recent author writes:

> The molecular constituents of the cell... have a tendency to spontaneously self-organize into morphologically and functionally distinct organizations through inherently stochastic interactions. These transient meta-stable systems are sustained by the incessant flow of energy and matter passing through them, with their respective components displaying different recruitment probabilities, residence times, and turnover rates[16].

These self-organizing processes, which have also been called 'self-maintenant' in that they take on a form that contributes to their own stability [17], tend to settle into a state that is far from thermodynamic equilibrium locally, and therefore relatively highly ordered, i.e., low in entropy, but having a relatively high rate of entropy production, i.e., heat dissipation into the environment. A well-known non-biological example is the Rayleigh-Bénard convection process in which cell-like patterns self-organize in a liquid medium that lies between a temperature gradient that is maintained by a continual influx of free energy (Figure 4, C). Throughout nature we find examples of such systems in which organic shapes or patterns recur at different scales and under quite different physical conditions [18].

The visual similarity between marbling patterns of the kind seen in Figure 3 and the living and non-living dissipative structures also discussed can be accounted for, to some extent, by certain commonalities in the principles underlying the physical processes that produce them. Both require an influx of energy and matter into a system that can reconfigure itself, within certain constraints, to accommodate the competing forces and pressures produced by the energy–matter flow and both tend to minimize their free energy to reach a state of stability by maximizing the rate of entropy production. To this extent, they are both examples of dissipative structures.

A major difference exists, however, between the marbled images and the other kinds of dissipative structures discussed here. In the case of the marbling images, by the time the print is taken the energy–matter flow has ceased, and the system has reached a state of static equilibrium. In the case of the other structures discussed, meanwhile, a constant influx of free energy, and sometimes matter, from the system's environment is required to do the work of maintaining it locally at a far from thermodynamic equilibrium state, and therefore keeping it in a state of relatively low entropy. This dynamic equilibrium state, however, generally entails an increase in the rate of entropy production, usually in the form of heat expelled to the environment.

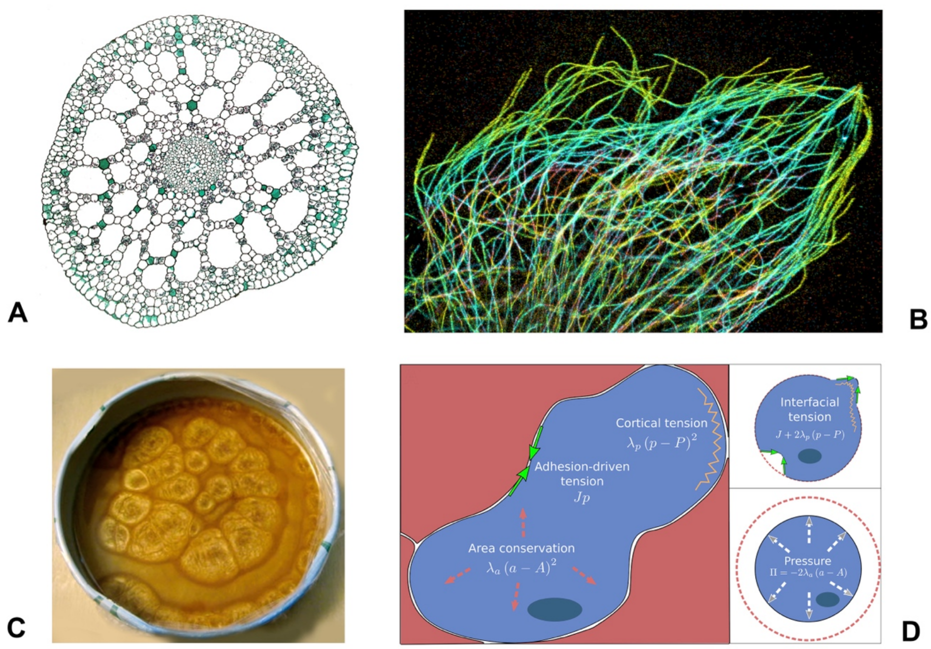

Figure 4: *Cellular patterns in natural structures*. Image **A** shows the structure of a cross section of a aquatic monocot stem with a typical interlocking cellular pattern (Photo credit: Fayette A. Reynolds M.S.); image **B** shows a high-resolution microscopy image of strands of tubulin in a human cell (Photo credit: Pakorn Kanchanaong and Clare Waterman); image **C** shows a typical formation of cell-like dissipative structures in a Rayleigh-Bénard convection system (Credit: Wikicommons); image **D** is a figure from [7] showing the different kinds of forces that act within a cell to regulate cell surface mechanics (Credit: Creative Commons).

5 Faraday's Beautiful Principles of Nature

What of Faraday's 'beautiful principles'? Throughout his scientific notes and lectures, Faraday frequently mentions the beauty he perceives in chemical reactions and other natural phenomena. He was particularly fascinated by, what he called, the 'lines of force' that he observed during his experiments on electricity and magnetism, and which he captured in drawings made by sprinkling iron filings on paper overlaid on magnets (see Figure 5). He said:

> When there are several magnets in presence and in restrained conditions, the lines of force, which they present by filings, are most varied and beautiful [19].

The forms that appear in these drawings are produced by similar principles to those that generate the designs in paper marbling, and to some extent are similar to those that drive the formation of dissipative structures such as biological cells.

In Faraday's drawings, particles of matter (the iron filings) are given an initial influx of kinetic energy as they are sprinkled onto the paper in a random arrangement. On contact with the paper, the particles are affected by the fields of force that surround the magnets. These forces do work on the particles of matter, moving them from their randomised state into organised patterns that reflect the relative strength of the fields across the surface of the paper as the energy transferred to the iron filings is minimized. The visible forms are produced by lawful interactions between matter and otherwise invisible forces, and the final drawings are a further example of statically equilibrated dissipative structure that we find in marbled images.

These iron filing drawings, and the interactions between matter and energy due to the actions of forces they make visible were, as Faraday told the audience at one of his Christmas lectures, expressions of…

> ...beautiful laws… by which we grow, and exist, and enjoy ourselves…

… all of which are…

> … effected in consequence of the existence of certain forces, or abilities to do things, or powers, that are so common that nothing can be more so.

Nature, for Faraday, consisted in…

> ...the universal correlation of the physical forces of matter, and their mutual conversion into one another [20]

Statements of this kind, which appear throughout his writings, show that Faraday understood there to be a deep connection between the physics underlying the appearance of natural phenomena and our sense of aesthetic value. Faraday was devoutly Christian and even though he meticulously insulated his spiritual and scientific views the deep intuition that drove his experimental research was of the inherent unity of nature and interconnected between visible and invisible forces. It is clear that one of his main motivations in his scientific work was to uncover this deeper unity. [21]

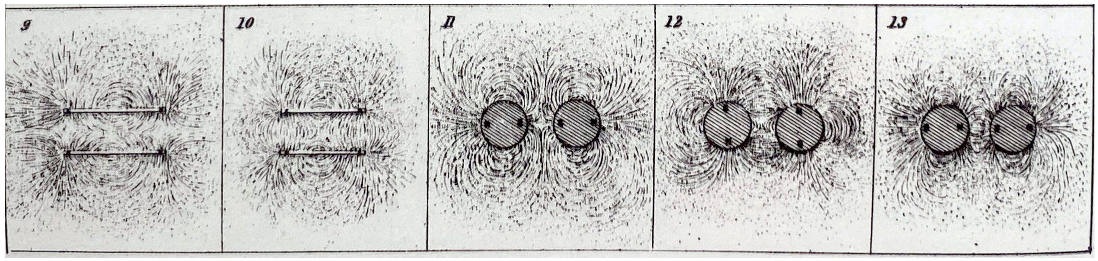

Figure 5: Faraday's 'lines of force'. Some examples of Michael Faraday's drawings from *Experimental Researches in Electricity* [22] show the pattern produced when iron filings were sprinkled over paper coated in wax which was then placed on top of magnets of various shapes and orientations. The 'lines of force' due to the magnetic fields surrounding the magnets caused the filings to form into these distinctive patterns, which were fixed on the paper by warming the wax.

6 Gestalt Theory, Forces and Aesthetics

I have suggested so far that the shapes that frequently occur in marbling images and drawings of the lines of force in magnetic fields reflect general organizational principles of nature that, to some extent, are also at work in the processes that produce biological cells and other complex organic and non-organic phenomena. This is probably what Michael Faraday was referring to when he used the phrase 'beautiful principles of natural philosophy' and what led to make his remarks about the aesthetic value of these principles when he found them expressed in nature.

But this begs the question of why he — and we — find these forms and patterns beautiful; that is, why do they elicit a positive emotional response in us rather than an emotionally neutral or even negative response? Do they speak to something in our own psychological makeup that makes them intrinsically attractive to behold? While acknowledging that not all aesthetic value is derived from visual forms (art can be a multisensory experience that entails contextual as well as sensory factors) I will sketch out one potential approach to addressing these questions in the visual aesthetics domain using ideas developed by the fertile tradition of Gestalt psychology, which emerged mainly in Germany in the late nineteenth century.

It was to Michael Faraday, and particularly his work on fields of force, that the founders of the Gestalt school of psychology turned in the first half of the twentieth century when seeking to explain the 'psychophysical' nature of our perceptual and aesthetic experiences and, in doing so, explicitly tried to establish the physical basis of psychological phenomena. They proposed two key principles to account for these experiences: the psychophysical isomorphism principle, which is that there is a direct correspondence between psychological states and physical states of the brain, and the stability principle, which is that the tendency of physical systems to move towards a state of maximum stability, or equilibrium, is inherently good, positive or pleasurable. To take each principle in turn.

In his book Dynamics in Psychology [23], Wolfgang Köhler, who had studied physics under the physicist Max Planck, argued that a neurobiological theory of perception must be a *'field theory'* (his emphasis) like that which evolved from Faraday's experimental work on electromagnetism and was later was mathematically formalized by James Clerk Maxwell [24]. As Köhler put it: '…in the theory of perception we are now in precisely the situation in which Faraday found himself when he investigated electrostatic, electromagnetic, and electrodynamic interactions'. According to this field theory, the association between 'neural functions' and 'perceptual facts' (to use his terminology) was due to an 'psychophysical isomorphism' between experience A and brain state α such that for any variation in A there is a corresponding variation in α. On this view, psychological states are manifestations of physical fields of force at work in the brain.

In Principles of Gestalt Psychology [25], Köhler's colleague Kurt Koffka, further developed this physically based conception of psychology, which Köhler had originally proposed in the 1920s. Physics, Koffka noted, teaches us that the world can be considered as a system of interactions between fields of force — where forces are understood as distributed 'strains and stresses'. The behaviour of objects in the world, including that of our nervous systems, is governed by laws that depend on the properties of these fields.

According to Köhler and Koffka, the organization of objects in the world is bound to take certain forms because all processes must follow the same physical laws, as already discussed, that compel systems towards a state of stability (whether that is static or dynamic equilibrium) and the minimization of energy; in any system where the forces exerted in the relevant fields are imbalanced the system will act in a way that achieves the greatest balance most quickly, thus reducing the strains and stresses acting on it to the greatest extent possible. Koffka, gives the example of a soap bubble, which is the simplest and most stable form given all the opposing forces that act on its matter. In this sense, their understanding of natural systems as expressions of the 'stability principle' is broadly compatible with the principles of self-organization outlined above.

The application of these principles to the psychological domain was termed the 'Law of Prägnanz' by another founder of the Gestalt school, Max Wertheimer, who proposed that the 'psychological organization will always be as 'good' as the prevailing conditions allow.' In defining this principle, Wertheimer was building on the principle of isomorphism by drawing a direct link between the physical behavior of material systems — i.e. how they are governed by a tendency towards stability — and experiences that are perceived as either good or bad by our nervous systems, and hence our minds. For it was also implicit in the Law of Prägnanz that systems being displaced from stability result in a 'bad' psychological organisation.

For the Gestaltists, this 'good form' principle establishes a direct relationship between (i) the organisation of physical processes in the world that tend towards stability, (ii) the organisation of the fields of force acting in the brains of those who perceive the physical processes, and (iii) the aesthetic value of the act of perception. This direct relationship was elevated into a 'fundamental law of aesthetics' by another proponent of Gestalt psychology, Hans Eysenck [26], according to whom: 'The pleasure derived from a percept as such is directly proportional to the decrease of energy capable of doing work in the total nervous system, as compared with the original state of the whole system.' Although he did not state it, the inverse of this aesthetic law — that displeasure is directly proportional to the increase of energy — would be equally true. By applying these Gestalt principles of good form to the operation of the nervous system itself, Eysenck was advancing a neurobiological theory of aesthetic value and pleasure.

These ideas were further developed in the early 1970s through the work of Rudolf Arnheim, a Gestalt theory-trained art historian, in his essay Entropy and Art [27]. He drew on ideas from a range of nineteenth and early-twentieth century scientists—such as Johannes Zöllner, Sigmund Freud, Herbert Spencer, Gustav Fechner as well as the Gestaltist figures already mentioned—to formulate a theory of aesthetics grounded in the psychophysical economy of energy minimization and entropy production. For Arnheim, one of the ways in which pleasure is gained through art is by perceiving physical forms that optimally reduce the competing forces acting in them because this leads to a corresponding reduction of tension (strain and stress) in the brain and so in the mind of the beholder, according to the principle of isomorphism.

Arnheim uses this principle to analyse the visual compositions of works of art in different historical periods and media. Despite paintings and sculptures being 'frozen' arrangements of matter, like the marbling pieces and iron filing drawings discussed above, he asks us to consider them not as static patterns—that is, as fixed blocks of colour distributed over canvas or shapes carved into stone—but as dynamic structures composed of the 'antagonistic play of forces' in fields which are tending towards the simplest and most stable configuration they can adopt under the circumstances. The dynamic processes of energy flow and entropy production that lead to the production of a finished artwork, and which are embodied in its stabilized state, are 'replayed' in our minds when we behold it. Concerning the sense of beauty evoked by the sculpture of the Madonna of Würzburg, he says:

> Each element has its appropriate form in relation to all others, thus establishing a definitive order, in which all component forces hold one another in such a way that none of them can press for any change of the interrelation. The play of forces is at a standstill, the maximum of entropy attainable for the given system of constraints has been reached. Although the tension invested in the work is at a high absolute level, it is reduced to the lowest level the constraints will let it assume.

According to Arnheim, it is because the sculptor has so exquisitely managed the balance of competing forces represented in the sculpture that the competing forces acting in the fields in our brains, and so in our minds, are likewise exquisitely balanced as we perceive it. The accompanying experience is intrinsically pleasurable because it affords the forces acting in our minds an opportunity for tension reduction as the equilibrated state of balance is reached. It is to this pleasurable emotion, and the object that evokes it, that we attribute the value of 'beauty'. We could apply this same analysis to account for the beauty of the patterns we see in marbled papers.

7 Conclusion

The patterns produced by paper marbling and by sprinkling iron filings over magnetic fields are both broadly expressions of the same 'beautiful principles' that govern interactions between energy and matter to create structures such as biological cells and other complex forms in nature. Generally, the influx of energy and matter into a system, and the competition between the unbalanced forces doing work in the system, cause it to reconfigure itself into a form that minimises its free energy as it tends towards stability or equilibrium. In paper marbling and lines of force patterns, these are states of static equilibrium, where all the forces at work have reached a balance. In the case of cells and other complex natural forms, these are states of dynamic equilibrium where the structure is kept from static equilibrium (or death) by a continual influx of energy and matter and where entropy is locally minimal while the rate of entropy production, normally expelled as heat, is maximal.

Gestalt theorists of the twentieth century, recognising the fundamental role of certain physical principles like these in ordering natural forms, sought to marry some of these general principles to the psychological mechanisms underlying perceptual experience in general and aesthetic experience in particular. Moreover, they sought to do by supposing a direct isomorphism between these experiences and physical states of the brain, which were for them also structured by these same principles. This was a bold and ambitious attempt to identity unifying laws governing the nature, perception, neurobiology and art and — as we saw in the case of Rudolf Arnheim — led to a rich and insightful explanatory framework with which to account for the visual aesthetics of certain artworks.

While none of this yet provides a conclusive account of the relationship between natural forms, perception and aesthetic judgments, it does suggest that the 'beautiful principles' of which Faraday spoke, and which seem to play a role in many natural phenomena, are scientifically and artistically significant. This points to potentially deep connections between these two, often disconnected, domains and suggests how they might be more fully integrated in future research. It suggests, for example, that there may be value in integrating knowledge from physics, biophysics, non-equilibrium thermodynamics and foundational theories of perception such as those offered by the Gestalt School with aesthetically oriented work in the visual arts. Given what has been outlined here, it is probable that such wide-ranging cooperation would have value for all contributing fields.

References

[1] Woolnough, C W (1853). The art of marbling, as applied to book-edges and paper, London: Alexander Heylin.

[2] Faraday, M. (1854). Correspondence 2773, in Epsilon: The Michael Faraday Collection, accessed on 20 February 2023, https://epsilon.ac.uk/view/faraday/letters/Faraday2773.

[3] Maurer-Mathison, D. (1999), The Ultimate Marbling Handbook, New York: Watson-Guptill.

[4] Wolfe, R. (2018). Marbled Paper: Its History, Techniques and Patterns. Delaware, US: Oak Knoll Press.

[5] Lu, S., Jaffer, A., Jin, X., Zhao, H., Mao, X. (2012). Mathematical marbling. IEEE computer graphics and applications, 32(6), 26–35.

[6] Ghassaei, A. (2022). https://blog.amandaghassaei.com/2022/10/25/digital-marbling/#marbling-simulation, Accessed 6th June 2024.

[7] Magno, R., Grieneisen, V.A., Marée, A.F. (2015). The biophysical nature of cells: potential cell behaviours revealed by analytical and computational studies of cell surface mechanics. BMC Biophys 8, 8.

[8] Horwitz R. (2016). Cellular Biophysics. Biophysical journal, 110(5), 993–996.

[9] Gómez-Puyou, M. T., Martins, O. B., Gómez-Puyou, A. (1988). Synthesis and hydrolysis of ATP by the mitochondrial ATP synthase. Biochemistry and cell biology, 66(7), 677–682.

[10] Hohmann, T., Dehghani, F. (2019). The Cytoskeleton-A Complex Interacting Meshwork. Cells, 8(4), 362.

[11] Parekh, S. H., Chaudhuri, O., Theriot, J. A., Fletcher, D. A. (2005). Loading history determines the velocity of actin-network growth. Nature cell biology, 7(12), 1219–1223.

[12] Fletcher, D. A., Mullins, R. D. (2010). Cell mechanics and the cytoskeleton. Nature, 463(7280), 485–492.

[13] Turing, A. M. (1953). The chemical basis of morphogenesis. Phil. Trans. R. Soc. B 237, 5537–5572.

[14] Kondepudi DK, Prigogine I. 2015 Modern thermodynamics: from heat engines to dissipative structures, 2nd edn. New York, NY: John Wiley.

[15] De Bari, B., Dixon, J., Kondepudi, D., Vaidya, A. (2023). Thermodynamics, organisms and behaviour. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences, 381(2252), 20220278.

[16] Nicholson D. J. (2019). Is the cell really a machine?. Journal of theoretical biology, 477, 108–126.

[17] Bickhard, M. (2009). The interactivist model. Synthese, 166, pp. 547-591.

[18] Pandey, A., Scheel, J. D., Schumacher, J. (2018). Turbulent superstructures in Rayleigh-Bénard convection. Nature communications, 9(1), 2118.

[19] Faraday, M. (1852). On the Physical Character of The Lines of Magnetic Force. Philosophical Magazine, 403, pp. 401-28.

[20] Faraday, M. (1859). A Course of Six Lectures on the Various Forces of Matter and Their Relations to Each Other, London: Griffin and Co.

[21] Morris, I. R. (2004). Michael Faraday and the Electrical Century, London: Icon Books.

[22] Faraday, M. (1855). Experimental Researches in Electricity, Vol. III., London: Bernard Quaritch.

[23] Köhler, W. (1940), Dynamics in Psychology, New York: Grove Press.

[24] Maxwell, J. C. (1877). Matter and Motion. London: Society for Promoting Christian Knowledge.

[25] Koffka, K. (1935). Principles of Gestalt Psychology, London: Routledge and Kegan Paul.

[26] Eysenck, H. (1942). The Experimental Study of the 'Good Gestalt' — A New Approach. Psychological Review, 49(4), 344–364.

[27] Arnheim, R. (1971). Entropy and Art. Berkeley, California: University of California Press.